# Multi-Sensor High Accuracy Digital Temperature Measurement System with EEPROM

## FEATURES

- Directly Digitizes 2-, 3- or 4-Wire RTDs, Thermocouples, Thermistors, and Diodes
- On-Chip EEPROM (LTC2986-1) Stores Channel Configuration Data and Custom Coefficients
- Single 2.85V to 5.25V Supply
- 10 Flexible Inputs Allow Interchanging Sensors
- Automatic Thermocouple Cold Junction Compensation
- Built-In Standard and User-Programmable Coefficients for Thermocouples, RTDs and Thermistors
- Measures Negative Thermocouple Voltages
- Automatic Burn Out, Short-Circuit and Fault Detection
- Buffered Inputs Allow External Protection
- Simultaneous 50Hz/60Hz Rejection
- Includes 15ppm/°C (Max) Reference
- Includes Special Protection Modes

## APPLICATIONS

- Direct Thermocouple Measurements
- Direct RTD Measurements
- Direct Thermistor Measurements
- Custom Sensor Applications

## DESCRIPTION

The LTC®2986 measures a wide variety of temperature sensors and digitally outputs the result, in °C or °F, with 0.1°C accuracy and 0.001°C resolution. The LTC2986 can measure the temperature of virtually all standard (Type B, E, J, K, N, S, R, T) or custom thermocouples, automatically compensate for cold junction temperatures and linearize the results. The device can also measure temperature with standard 2-, 3- or 4-wire RTDs, thermistors, and diodes. The LTC2986 includes excitation current sources and fault detection circuitry appropriate for each type of temperature sensor.

The LTC2986/LTC2986-1 are 10-channel software and pin-compatible versions of the 20-channel LTC2983/LTC2984. Additional features include special modes that enable easy protection in universal multi-sensor applications, custom tables for generic ADC readings, and direct temperature readout from active analog temperature sensors. The LTC2986-1 is the EEPROM version of the LTC2986.

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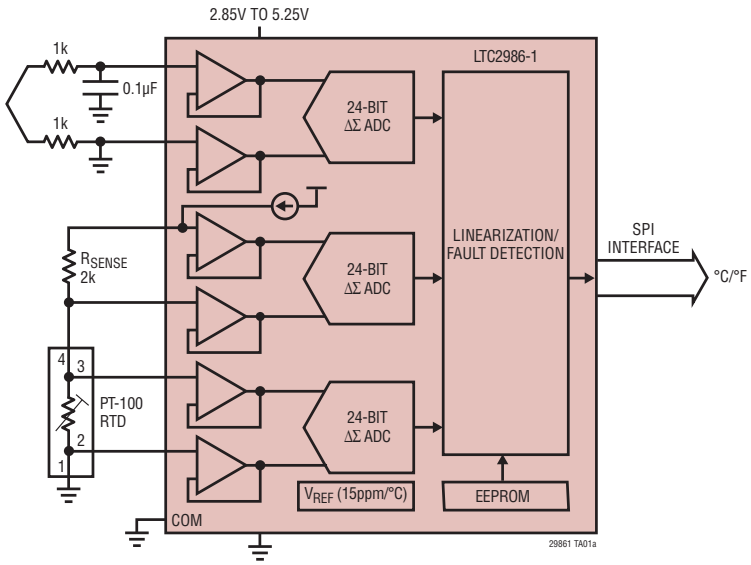
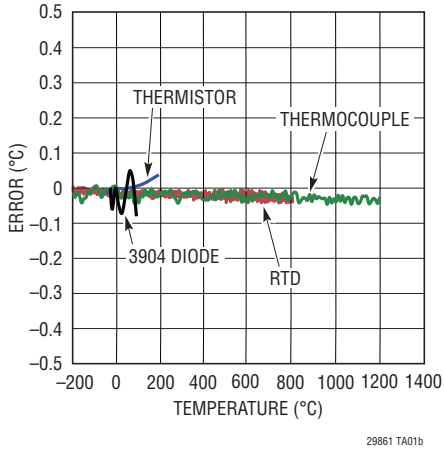
## TYPICAL APPLICATION

**Thermocouple Measurement with Automatic Cold Junction Compensation**




**Typical Temperature Error Contribution**



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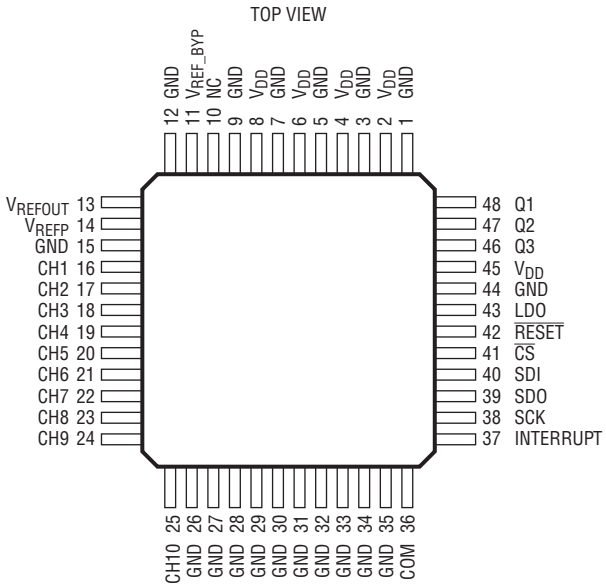
## ABSOLUTE MAXIMUM RATINGS

**(Notes 1, 2)**

Supply Voltage ($V_{DD}$) ..... –0.3V to 6V
Analog Input Pins (CH1 to CH10, COM) ..... –0.3V to ($V_{DD}$ + 0.3V)
Input Current (CH1 to CH10, COM) ..... ±15mA
Digital Inputs ($\overline{CS}$, SDI, SCK, $\overline{RESET}$) ..... –0.3V to ($V_{DD}$ + 0.3V)
Digital Outputs (SDO, INTERRUPT) –0.3V to ($V_{DD}$ + 0.3V)
$V_{REFP}$ ..... –0.3V to 2.8V
Q1, Q2, Q3, LDO, $V_{REFOUT}$, $V_{REF_BYP}$ (Note 18)
Reference Short-Circuit Duration ..... Indefinite
Operating Temperature Range
LTC2986C ..... 0°C to 70°C
LTC2986I ..... –40°C to 85°C
LTC2986H ..... –40°C to 125°C

## PIN CONFIGURATION




LX PACKAGE
48-LEAD (7mm × 7mm) PLASTIC LQFP

$T_{JMAX}$ = 150°C, $\theta_{JA}$ = 57°C/W

## ORDER INFORMATION

http://www.linear.com/product/LTC2986#orderinfo

| LEAD FREE FINISH | TRAY | PART MARKING* | PACKAGE DESCRIPTION | TEMPERATURE RANGE |
|---|---|---|---|---|
| LTC2986CLX#PBF | LTC2986CLX#PBF | LTC2986LX | 48-Lead (7mm × 7mm) LQFP | 0°C to 70°C |
| LTC2986ILX#PBF | LTC2986ILX#PBF | LTC2986LX | 48-Lead (7mm × 7mm) LQFP | –40°C to 85°C |
| LTC2986HLX#PBF | LTC2986HLX#PBF | LTC2986LX | 48-Lead (7mm × 7mm) LQFP | –40°C to 125°C |
| LTC2986CLX-1#PBF | LTC2986CLX-1#PBF | LTC2986LX-1 | 48-Lead (7mm × 7mm) LQFP | 0°C to 70°C |
| LTC2986ILX-1#PBF | LTC2986ILX-1#PBF | LTC2986LX-1 | 48-Lead (7mm × 7mm) LQFP | –40°C to 85°C |
| LTC2986HLX-1#PBF | LTC2986HLX-1#PBF | LTC2986LX-1 | 48-Lead (7mm × 7mm) LQFP | –40°C to 125°C |

Consult LTC Marketing for parts specified with wider operating temperature ranges. *The temperature grade is identified by a label on the shipping container.
For more information on lead free part marking, go to: http://www.linear.com/leadfree/

## COMPLETE SYSTEM ELECTRICAL CHARACTERISTICS

**The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A$ = 25°C.**

| PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| Supply Voltage | | ● | 2.85 | | 5.25 | V |
| Supply Current | | ● | | 15 | 20 | mA |
| Sleep Current | | ● | | 25 | 60 | µA |
| Input Range | All Analog Input Channels | ● | –0.05 | | $V_{DD}$ – 0.3 | V |
| Output Rate | Two Conversion Cycle Mode (Notes 6, 9) | ● | 150 | 164 | 170 | ms |
| Output Rate | Three Conversion Cycle Mode (Notes 6, 9) | ● | 225 | 246 | 255 | ms |
| Input Common Mode Rejection | 50Hz/60Hz (Note 4) | ● | 120 | | | dB |
| Input Normal Mode Rejection | 60Hz (Notes 4, 7) | ● | 120 | | | dB |
| Input Normal Mode Rejection | 50Hz (Notes 4, 8) | ● | 120 | | | dB |
| Input Normal Mode Rejection | 50Hz/60Hz (Notes 4, 6, 9) | ● | 75 | | | dB |
| Power-On Reset Threshold | | | | 2.25 | | V |
| Analog Power-Up | (Note 11) | ● | | | 100 | ms |
| Digital Initialization | (Note 12) | ● | | | 100 | ms |

## ADC ELECTRICAL CHARACTERISTICS

**The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A$ = 25°C.**

| PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| Resolution (No Missing Codes) | $-V_{REFOUT/2} \le V_{IN} \le +V_{REFOUT/2}$ | ● | 24 | | | Bits |
| Integral Nonlinearity | $V_{IN(CM)}$ = 1.25V (Note 15) | ● | | 2 | 30 | ppm of $V_{REF}$ |
| Offset Error | | ● | | 0.5 | 2 | µV |
| Offset Error Drift | (Note 4) | ● | | 10 | 20 | nV/°C |
| Positive Full-Scale Error | (Notes 3, 15) | ● | | | 100 | ppm of $V_{REF}$ |
| Positive Full-Scale Drift | (Notes 3, 15) | ● | | 0.1 | 0.5 | ppm of $V_{REF}$/°C |
| Input Leakage | (Note 19)<br>H-Grade | ●<br>● | | | 1<br>10 | nA<br>nA |
| Negative Full-Scale Error | (Notes 3, 15) | ● | | | 100 | ppm of $V_{REF}$ |
| Negative Full-Scale Drift | (Notes 3, 15) | ● | | 0.1 | 0.5 | ppm of $V_{REF}$/°C |
| Input Referred Noise | (Note 5)<br>H-Grade | ●<br>● | | 0.8 | 1.5<br>2.0 | $\mu V_{RMS}$<br>$\mu V_{RMS}$ |
| Common Mode Input Range | | ● | –0.05 | | $V_{DD}$ – 0.3 | V |
| RTD Excitation Current | (Note 16) | ● | –25 | Table 33 | 25 | % |
| RTD Excitation Current Matching | Continuously Calibrated | ● | Error within Noise Level of ADC | | | |
| Thermistor Excitation Current | (Note 16) | ● | –37.5 | Table 57 | 37.5 | % |

## REFERENCE ELECTRICAL CHARACTERISTICS

**The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A$ = 25°C.**

| PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| Output Voltage | $V_{REFOUT}$ (Note 10) | | 2.49 | | 2.51 | V |
| Output Voltage Temperature Coefficient | I-Grade, H-Grade | ● | | 3 | 15 | ppm/°C |
| Output Voltage Temperature Coefficient | C-Grade | ● | | 3 | 20 | ppm/°C |
| Line Regulation | | ● | | | 10 | ppm/V |
| Load Regulation | $I_{OUT(SOURCE)}$ = 100µA | ● | | | 5 | mV/mA |
| | $I_{OUT(SINK)}$ = 100µA | ● | | | 5 | mV/mA |
| Output Voltage Noise | 0.1Hz ≤ f ≤ 10Hz | | | 4 | | $\mu V_{P-P}$ |
| | 10Hz ≤ f ≤ 1kHz | | | 4.5 | | $\mu V_{P-P}$ |
| Output Short-Circuit Current | Short $V_{REFOUT}$ to GND | | | 40 | | mA |
| | Short $V_{REFOUT}$ to $V_{DD}$ | | | 30 | | mA |
| Turn-On Time | 0.1% Setting, $C_{LOAD}$ = 1µF | | | 115 | | µs |
| Long Term Drift of Output Voltage (Note 13) | | | | 60 | | ppm/$\sqrt{kHr}$ |
| Hysteresis (Note 14) | ΔT = 0°C to 70°C<br>ΔT = –40°C to 85°C | | | 30<br>70 | | ppm<br>ppm |

## DIGITAL INPUTS AND DIGITAL OUTPUTS

**The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A$ = 25°C.**

| SYMBOL | PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| | External SCK Frequency Range | | ● | 0 | | 2 | MHz |
| | External SCK LOW Period | | ● | 250 | | | ns |
| | External SCK HIGH Period | | ● | 250 | | | ns |
| $t_1$ | $\overline{CS}$↓ to SDO Valid | | ● | 0 | | 200 | ns |
| $t_2$ | $\overline{CS}$↑ to SDO Hi-Z | | ● | 0 | | 200 | ns |
| $t_3$ | $\overline{CS}$↓ to SCK↑ | | ● | 100 | | | ns |
| $t_4$ | SCK↓ to SDO Valid | | ● | | | 225 | ns |
| $t_5$ | SDO Hold After SCK↓ | | ● | 10 | | | ns |
| $t_6$ | SDI Setup Before SCK↑ | | ● | 100 | | | ns |
| $t_7$ | SDI HOLD After SCK↑ | | ● | 100 | | | ns |
| | High Level Input Voltage | $\overline{CS}$, SDI, SCK, $\overline{RESET}$ | ● | $V_{DD}$ – 0.5 | | | V |
| | Low Level Input Voltage | $\overline{CS}$, SDI, SCK, $\overline{RESET}$ | ● | | | 0.5 | V |
| | Digital Input Current | $\overline{CS}$, SDI, SCK, $\overline{RESET}$ | ● | –10 | | 10 | µA |
| | Digital Input Capacitance | $\overline{CS}$, SDI, SCK, $\overline{RESET}$ | | | 10 | | pF |
| | LOW Level Output Voltage (SDO, INTERRUPT) | $I_O$ = –800µA | ● | | | 0.4 | V |
| | High Level Output Voltage (SDO, INTERRUPT) | $I_O$ = 1.6mA | ● | $V_{DD}$ – 0.5 | | | V |
| | Hi-Z Output Leakage (SDO) | | ● | –10 | | 10 | µA |

## LTC2986-1 EEPROM CHARACTERISTICS

**The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A$ = 25°C. These specifications apply only to LTC2986-1, LTC2986 does not include EEPROM.**

| SYMBOL | PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| | Retention | Notes 4 and 17 | ● | 10 | | | Years |
| | Endurance | Note 4 | ● | 10000 | | | Cycles |
| | Programming Time | Complete Transfer from RAM to EEPROM | ● | | | 2600 | ms |
| | Read Time | Complete Transfer EEPROM to RAM | ● | | | 20 | ms |

**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 voltage values are with respect to GND.

**Note 3:** Full scale ADC error. Measurements do not include reference error.

**Note 4:** Guaranteed by design, not subject to test.

**Note 5:** The input referred noise includes the contribution of internal calibration operations.

**Note 6:** MUX configuration delay = default 1ms.

**Note 7:** Global configuration set to 60Hz rejection.

**Note 8:** Global configuration set to 50Hz rejection.

**Note 9:** Global configuration default 50Hz/60Hz rejection.

**Note 10:** The exact value of $V_{REF}$ is stored in the LTC2986 and used for all measurement calculations. Temperature coefficient is measured by dividing the maximum change in output voltage by the specified temperature range.

**Note 11:** Analog power-up. Command status register inaccessible during this time.

**Note 12:** Digital initialization. Begins at the conclusion of Analog Power-Up. Command status register is 0×80 at the beginning of digital initialization and 0×40 at the conclusion.

**Note 13:** Long-term stability typically has a logarithmic characteristic and therefore, changes after 1000 hours tend to be much smaller than before that time. Total drift in the second thousand hours is normally less than one third that of the first thousand hours with a continuing trend toward reduced drift with time. Long-term stability will also be affected by differential stresses between the IC and the board material created during board assembly.

**Note 14:** Hysteresis in output voltage is created by package stress that differs depending on whether the IC was previously at a higher or lower temperature. Output voltage is always measured at 25°C, but the IC is cycled to the hot or cold temperature limit before successive measurements. Hysteresis measures the maximum output change for the averages of three hot or cold temperature cycles. For instruments that are stored at well controlled temperatures (within 20 or 30 degrees of operational temperature), it is usually not a dominant error source. Typical hysteresis is the worst-case of 25°C to cold to 25°C or 25°C to hot to 25°C, preconditioned by one thermal cycle.

**Note 15:** Differential Input Range is $\pm V_{REF}/2$.

**Note 16:** RTD and thermistor measurements are made ratiometrically. As a result, current source excitation variation does not affect absolute accuracy. Choose an excitation current such that largest sensor or $R_{SENSE}$ resistance value, when driven by the nominal excitation current, will drop 1V or less. The extended ADC input range will accommodate variation in excitation current and the ratiometric calculation will negate the absolute value of the excitation current.

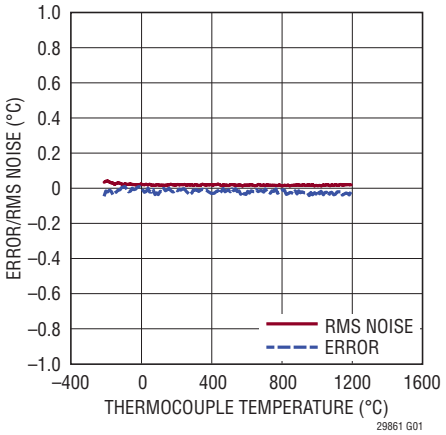
**Note 17:** 10-year data retention guaranteed for up to 1000 program cycles.

**Note 18:** Do not apply voltage or current sources to these pins. They must be connected to capacitive loads only. Otherwise, permanent damage may occur.

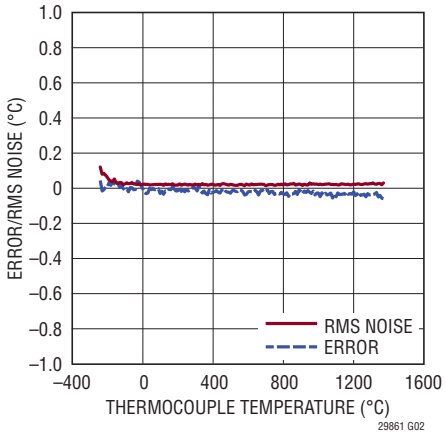
**Note 19:** Input leakage measured with $V_{IN}$ = –10mV and $V_{IN}$ = 2.5V.

# TYPICAL PERFORMANCE CHARACTERISTICS

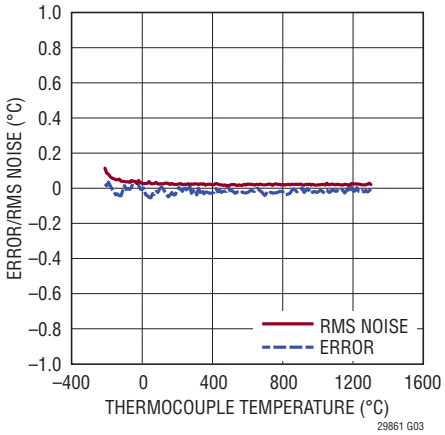
### Type J Thermocouple Error and RMS Noise vs Temperature



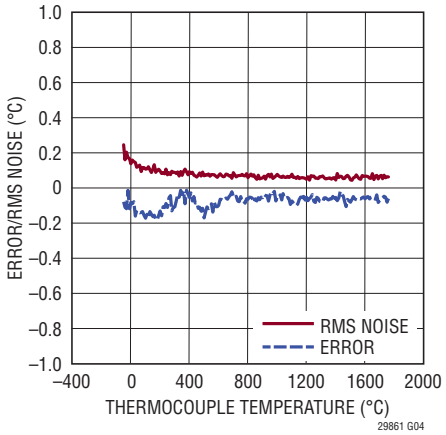

### Type K Thermocouple Error and RMS Noise vs Temperature



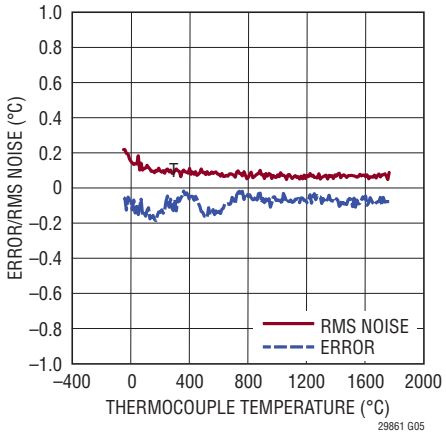

### Type N Thermocouple Error and RMS Noise vs Temperature



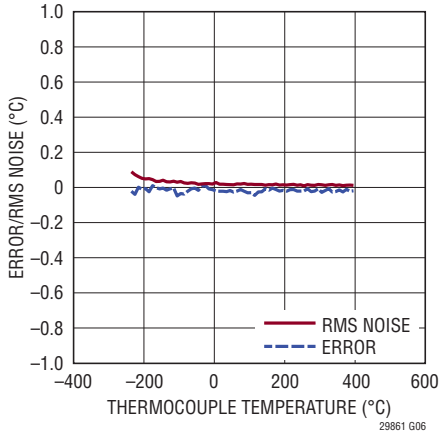

### Type R Thermocouple Error and RMS Noise vs Temperature



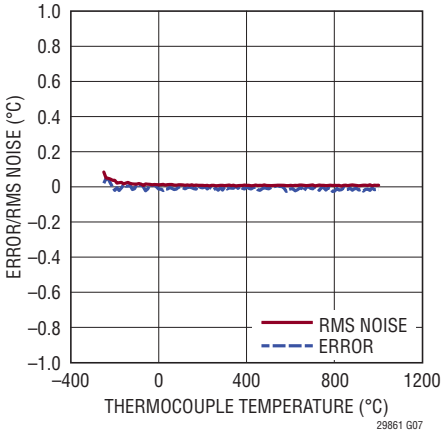

### Type S Thermocouple Error and RMS Noise vs Temperature



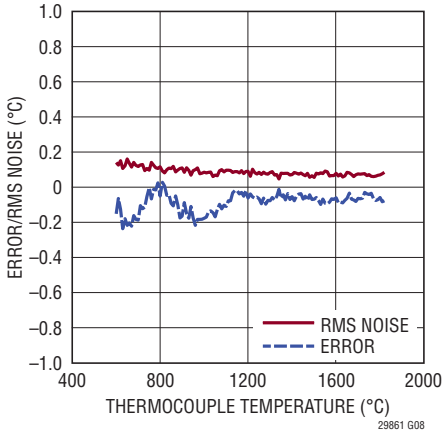

### Type T Thermocouple Error and RMS Noise vs Temperature



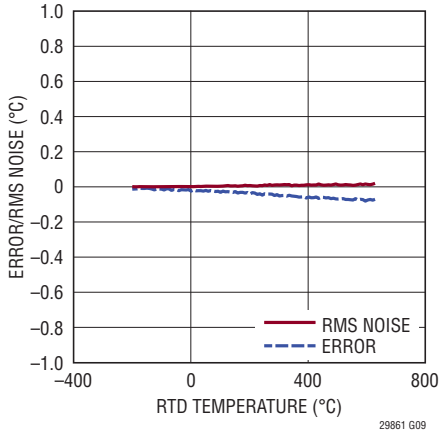

### Type E Thermocouple Error and RMS Noise vs Temperature




### Type B Thermocouple Error and RMS Noise vs Temperature

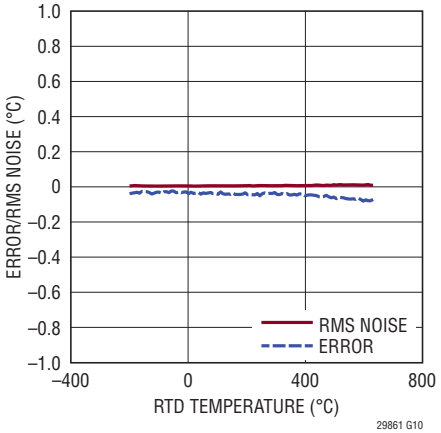



### RTD PT-1000 Error and RMS Noise vs Temperature

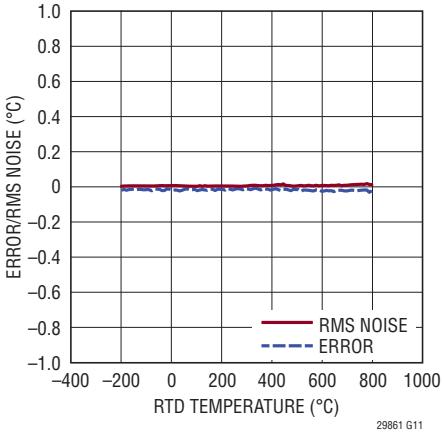


## TYPICAL PERFORMANCE CHARACTERISTICS

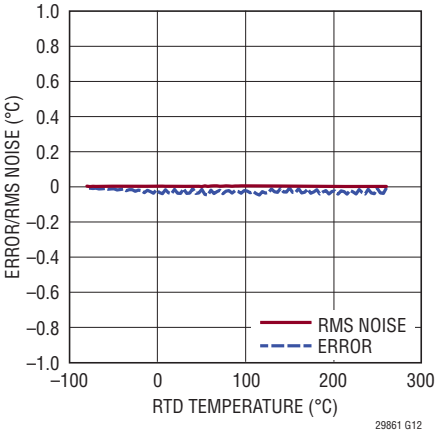
**RTD PT-200 Error and RMS Noise vs Temperature**



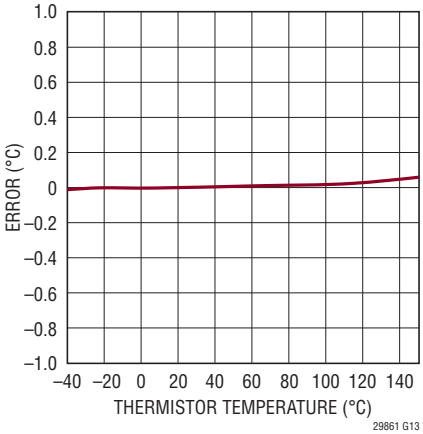

**RTD PT-100 Error and RMS Noise vs Temperature**



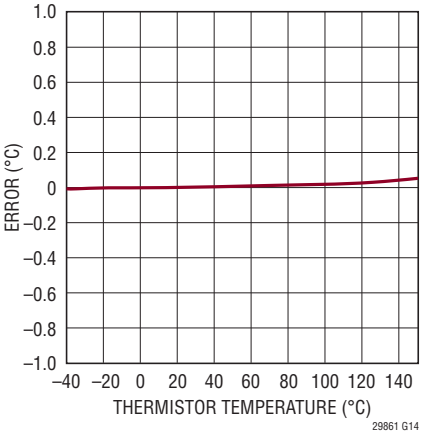

**RTD NI-120 RTD Error and RMS Noise vs Temperature**



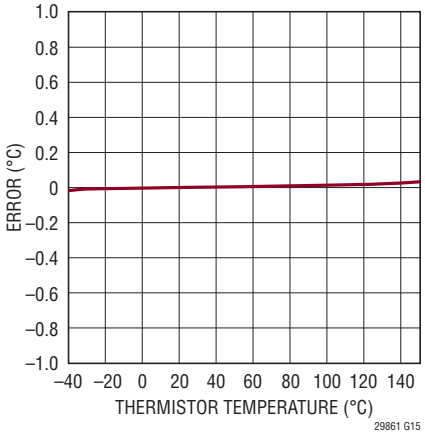

**2.252k Thermistor Error vs Temperature**



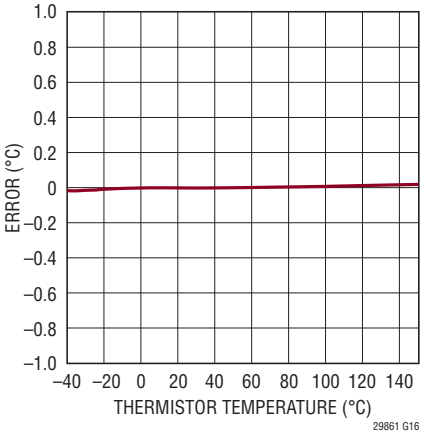

**3k Thermistor Error vs Temperature**



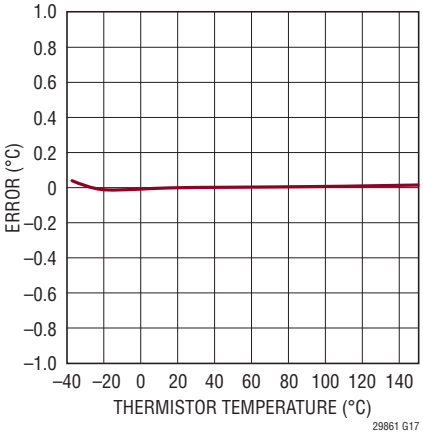

**5k Thermistor Error vs Temperature**



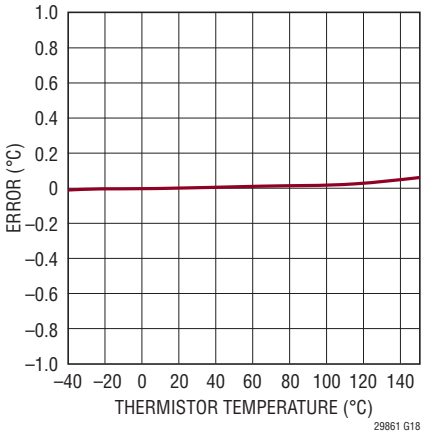

**10k Thermistor Error vs Temperature**




**30k Thermistor Error vs Temperature**

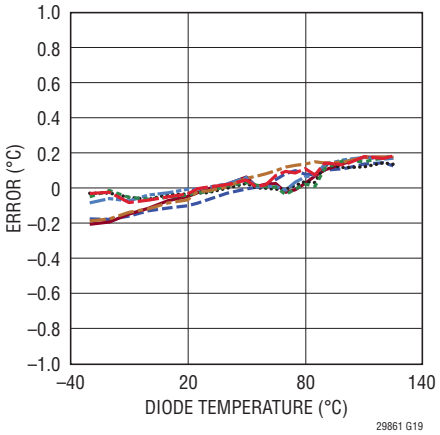



**YSI-400 Thermistor Error vs Temperature**

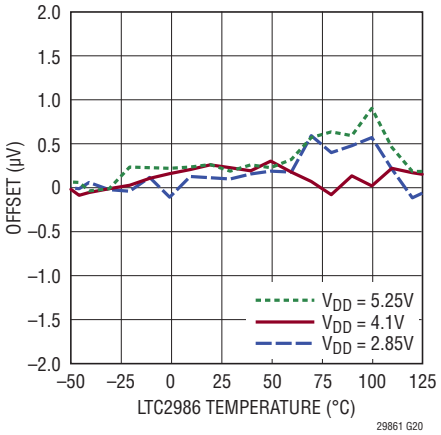


# TYPICAL PERFORMANCE CHARACTERISTICS

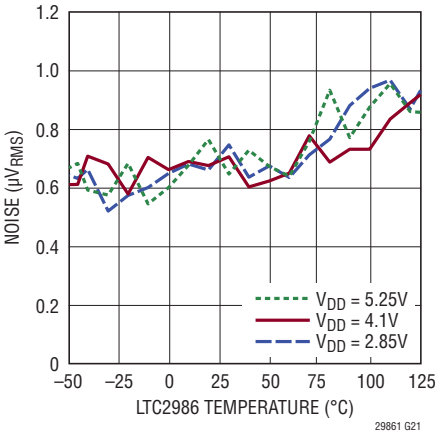
### Diode Error and Repeatability vs Temperature



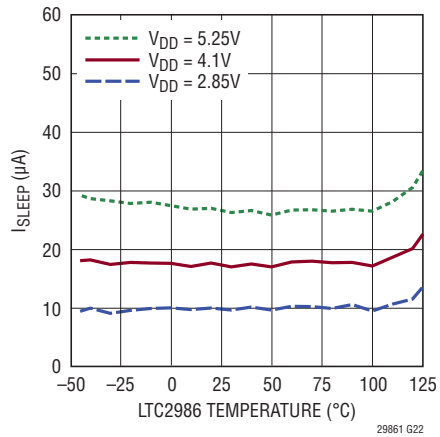

### Offset vs Temperature



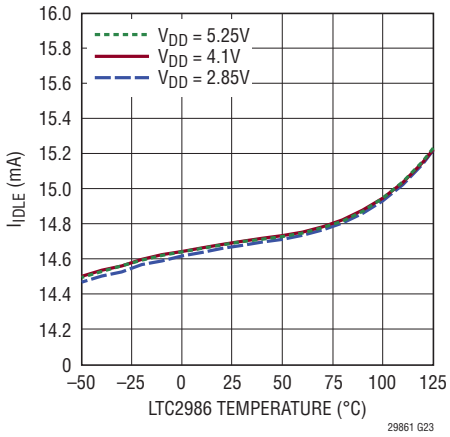

### Noise vs Temperature



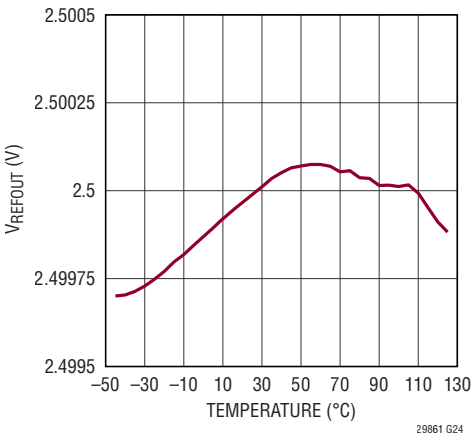

### $I_{SLEEP}$ vs Temperature



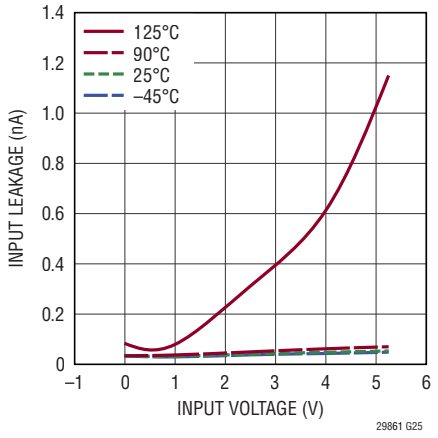

### One Shot Conversion Current vs Temperature



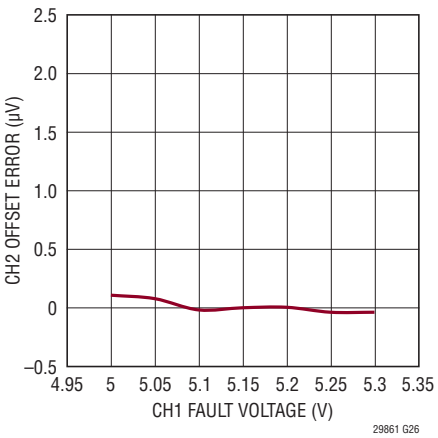

### $V_{REFOUT}$ vs Temperature



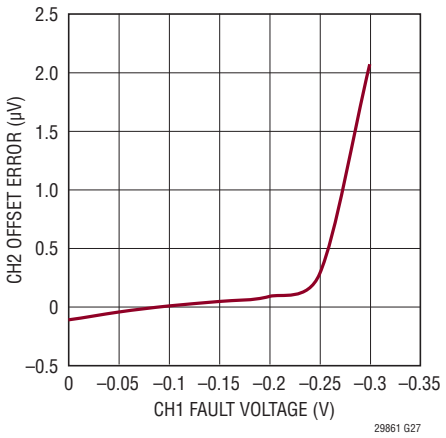

### Channel Input Leakage Current vs Temperature




### Adjacent Channel Offset Error vs Input Fault Voltage ($V_{DD}$ = 5V)




### Adjacent Channel Offset Error vs Input Fault Voltage



## PIN FUNCTIONS

**GND (Pins 1, 3, 5, 7, 9, 12, 15, 26-35, 44):** Ground. Connect each of these pins to a common ground plane through a low impedance connection. All 18 pins must be grounded for proper operation.

**$V_{DD}$ (Pins 2, 4, 6, 8, 45):** Analog Power Supply. Tie all five pins together and bypass as close as possible to the device, to ground with 0.1µF and 10µF capacitors.

**$V_{REF_BYP}$( Pin 11):** Internal Reference Power. This is an internal supply pin, do not load this pin with external circuitry. Decouple with a 0.1µF capacitor to GND.

**$V_{REFOUT}$ (Pin 13):** Reference Output Voltage. Short to $V_{REFP}$. A minimum 1µF capacitor to ground is required. Do not load this pin with external circuitry.

**$V_{REFP}$ (Pin 14):** Positive Reference Input. Tie to $V_{REFOUT}$.

**CH1 to CH10 (Pin 16 to Pin 25):** Analog Inputs. May be programmed for single-ended, differential, or ratiometric operation. The voltage on these pins can have any value between GND – 50mV and $V_{DD}$ – 0.3V. Unused pins can be grounded or left floating.

**COM (Pin 36):** Analog Input. The common negative input for all single-ended configurations. The voltage on this pin can have any value between GND – 50mV and $V_{DD}$ – 0.3V. This pin is typically tied to ground for temperature measurements.

**INTERRUPT (Pin 37):** This pin outputs a LOW when the device is busy either during start-up or while a conversion cycle is in progress. This pin goes HIGH at the conclusion of the start-up state or conversion cycle.

**SCK (Pin 38):** Serial Clock Pin. Data is shifted out of the device on the falling edge of SCK and latched by the device on the rising edge.

**SDO (Pin 39):** Serial Data Out. During the data output state, this pin is used as the serial data output. When the chip select pin is HIGH, the SDO pin is in a high impedance state.

**SDI (Pin 40):** Serial Data Input. Used to program the device. Data is latched on the rising edge of SCK.

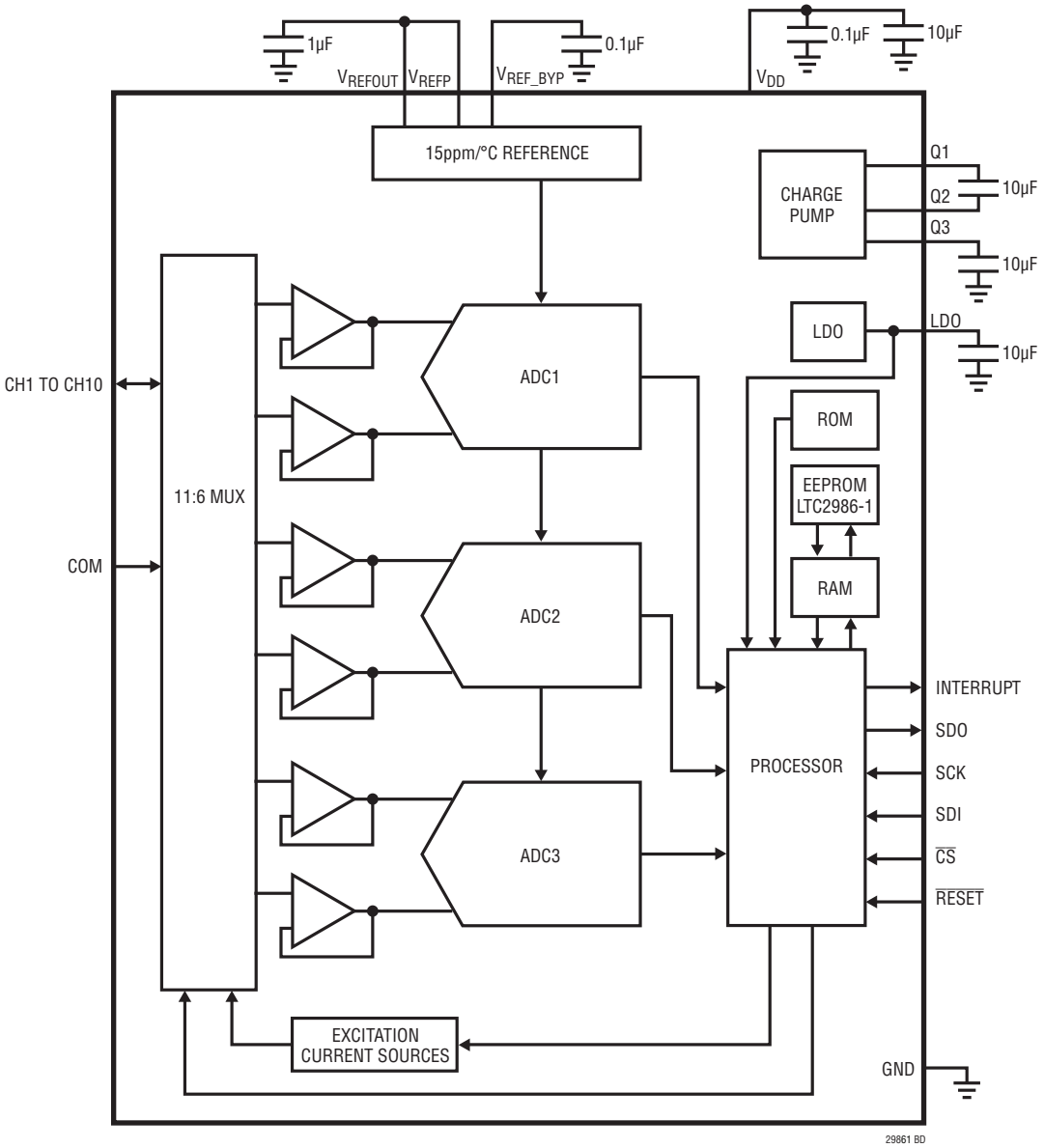
**$\overline{CS}$ (Pin 41):** Active Low Chip Select. A low on this pin enables the digital input/output. A HIGH on this pin places SDO in a high impedance state. A falling edge on $\overline{CS}$ marks the beginning of a SPI transaction and a rising edge marks the end.

**$\overline{RESET}$ (Pin 42):** Active Low Reset. While this pin is LOW, the device is forced into the reset state. Once this pin is returned HIGH, the device initiates its start-up sequence.

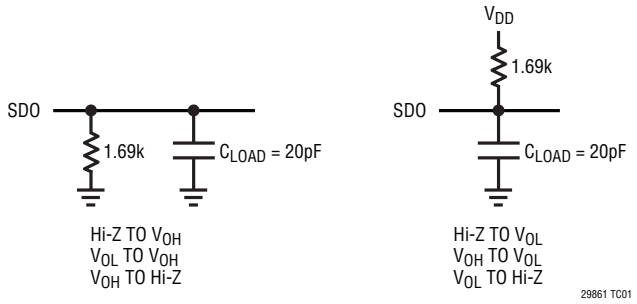
**LDO (Pin 43):** 2.5V LDO Output. Bypass with a 10µF capacitor to GND. This is an internal supply pin, do not load this pin with external circuitry.

**Q3, Q2, Q1 (Pins 46, 47, 48):** External Bypass Pins for –200mV Integrated Charge Pump. Tie a 10µF X7R capacitor between Q1 and Q2 close to each pin. Tie a 10µF X7R capacitor from Q3 to Ground. These are internal supply pins, do not make additional connections.

## BLOCK DIAGRAM

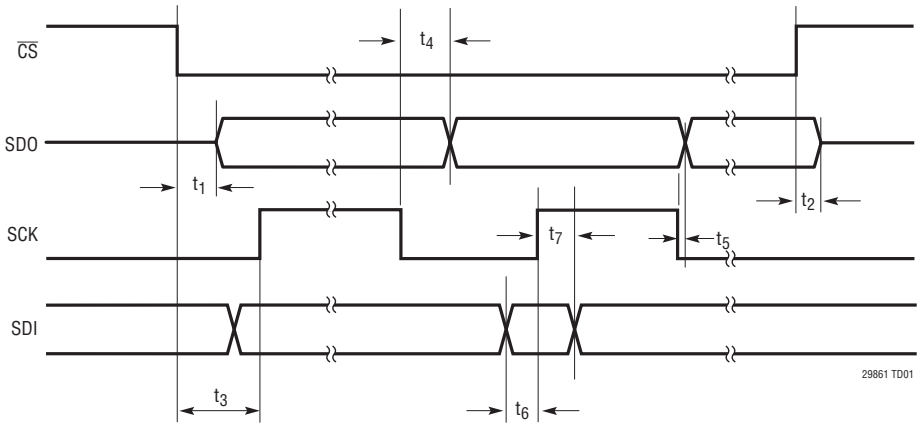


## TEST CIRCUITS




## TIMING DIAGRAM

**SPI Timing Diagram**



## OVERVIEW

The LTC2986 measures the temperature of the most common sensors (thermocouples, RTDs, thermistors, active analog temperature sensors, and diodes). It includes all necessary active circuitry, switches, measurement algorithms, and mathematical conversions to determine the temperature for each sensor type.

Thermocouples can measure temperatures from as low as –265°C to over 1800°C. Thermocouples generate a voltage as a function of the temperature difference between the tip (thermocouple temperature) and the electrical connection on the circuit board (cold junction temperature). In order to determine the thermocouple temperature, an accurate measurement of the cold junction temperature is required; this is known as cold junction compensation. The cold junction temperature is usually determined by placing a separate (non-thermocouple) temperature sensor at the cold junction. The LTC2986 allows diodes, active analog temperature sensors, RTDs, and thermistors to be used as cold junction sensors. In order to convert the voltage output from the thermocouple into a temperature result, a high order polynomial equation (up to 14th order) must be solved. The LTC2986 has these polynomials built in for virtually all standard thermocouples (J, K, N, E, R, S, T, and B). Additionally, inverse polynomials must be solved for the cold junction temperature. The LTC2986 simultaneously measures the thermocouple output and the cold junction temperature and performs all required calculations to report the thermocouple temperature in °C or °F. It directly digitizes both positive and negative voltages (down to 50mV below ground) from a single ground referenced supply, includes sensor burn-out detection, and allows external protection/anti-aliasing circuits without the need of buffer circuits.

Diodes are convenient low cost sensor elements and are often used to measure cold junction temperatures in thermocouple applications. Diodes are typically used to measure temperatures from –60°C to 130°C, which is suitable for most cold junction applications. Diodes generate an output voltage that is a function of temperature and excitation current. When the difference of two diode output voltages are taken at two different excitation current levels, the result ($\Delta V_{BE}$) is proportional to temperature. The LTC2986 accurately generates excitation currents, measures the diode voltages, and calculates the temperature in °C or °F.

RTDs and thermistors are resistors that change value as a function of temperature. RTDs can measure temperatures over a wide temperature range, from as low as –200°C to 850°C while thermistors typically operate from –40°C to 150°C. In order to measure one of these devices a precision sense resistor is tied in series with the sensor. An excitation current is applied to the network and a ratiometric measurement is made. The value, in Ω, of the RTD/thermistor can be determined from this ratio. This resistance is used to determine the temperature of the sensor element using a table lookup (RTDs) or solving Steinhart-Hart equations (thermistors). The LTC2986 automatically generates the excitation current, simultaneously measures the sense resistor and thermistor/RTD voltage, calculates the sensor resistance and reports the result in °C. The LTC2986 can digitize most RTD types (PT-10, PT-50, PT-100, PT-200, PT-500, PT-1000, and NI-120), has built in coefficients for many curves (American, European, Japanese, and ITS-90), and accommodates 2-wire, 3-wire, and 4-wire configurations. It also includes coefficients for calculating the temperature of standard 2.252k, 3k, 5k, 10k , and 30k thermistors. It can be configured to share one sense resistor among multiple RTDs/thermistors and to rotate excitation current sources to remove parasitic thermal effects. In addition to built-in linearization coefficients, the LTC2986 provides the means of inserting custom coefficients for both RTDs and thermistors.

The LTC2986 includes the capability to measure active analog output temperature sensors. These sensors output voltage as a function of temperature. The relationship between voltage and temperature can be stored in the LTC2986. These sensors can be used as a stand alone temperature sensor or as the cold junction compensation for thermocouple measurements.

## OVERVIEW

Table 1 shows the estimated system accuracy and noise associated with specific temperature sensing devices. System accuracy and peak-to-peak noise include the effects of the ADC, internal amplifiers, excitation current sources, and integrated reference. Accuracy and noise are the worst-case errors calculated from the guaranteed maximum ADC and reference specifications. Peak-to-peak noise values are calculated at 0°C (except Type B was calculated at 400°C) and diode measurements use AVG = ON mode.

Thermocouple errors do not include the errors associated with the cold junction measurement. Errors associated with a specific cold junction sensor within the operating temperature range can be combined with the errors for a given thermocouple for total temperature measurement accuracy.

**Table 1. LTC2986 Error Contribution and Peak Noise Errors**

| SENSOR TYPE | TEMPERATURE RANGE | ERROR CONTRIBUTION | PEAK-TO-PEAK NOISE |
|---|---|---|---|
| Type K Thermocouple | –200°C to 0°C<br>0°C to 1372°C | ±(Temperature • 0.23% + 0.05)°C<br>±(Temperature • 0.12% + 0.05)°C | ±0.08°C |
| Type J Thermocouple | –210°C to 0°C<br>0°C to 1200°C | ±(Temperature • 0.23% + 0.05)°C<br>±(Temperature • 0.12% + 0.05)°C | ±0.07°C |
| Type E Thermocouple | –200°C to 0°C<br>0°C to 1000°C | ±(Temperature • 0.18% + 0.05)°C<br>±(Temperature • 0.10% + 0.05)°C | ±0.06°C |
| Type N Thermocouple | –200°C to 0°C<br>0°C to 1300°C | ±(Temperature • 0.27% + 0.08)°C<br>±(Temperature • 0.10% + 0.08)°C | ±0.13°C |
| Type R Thermocouple | 0°C to 1768°C | ±(Temperature • 0.10% + 0.4)°C | ±0.62°C |
| Type S Thermocouple | 0°C to 1768°C | ±(Temperature • 0.10% + 0.4)°C | ±0.62°C |
| Type B Thermocouple | 400°C to 1820°C | ±(Temperature • 0.10%)°C | ±0.83°C |
| Type T Thermocouple | –250°C to 0°C<br>0°C to 400°C | ±(Temperature • 0.15% + 0.05)°C<br>±(Temperature • 0.10% + 0.05)°C | ±0.09°C |
| External Diode (2 Reading) | –40°C to 85°C | ±0.25°C | ±0.05°C |
| External Diode (3 Reading) | –40°C to 85°C | ±0.25°C | ±0.2°C |
| Platinum RTD – PT-10, $R_{SENSE}$ = 1kΩ<br>Platinum RTD – PT-100, $R_{SENSE}$ = 2kΩ<br>Platinum RTD – PT-500, $R_{SENSE}$ = 2kΩ<br>Platinum RTD – PT-1000, $R_{SENSE}$ = 2kΩ | –200°C to 800°C<br>–200°C to 800°C<br>–200°C to 800°C<br>–200°C to 800°C | ±0.1°C<br>±0.1°C<br>±0.1°C<br>±0.1°C | ±0.05°C<br>±0.05°C<br>±0.02°C<br>±0.01°C |
| Thermistor, $R_{SENSE}$ = 10kΩ | –40°C to 85°C | ±0.1°C | ±0.01°C |

# OVERVIEW

## Memory Map

The LTC2986 channel assignment, configuration, conversion start, and results are all accessible via the RAM (see Table 2A). Table 2B details the valid SPI instruction bytes for accessing memory. The channel conversion results are mapped into memory locations 0x010 to 0x037 and can be read using the SPI interface as shown in Figure 1. A read is initiated by sending the read instruction byte = 0x03 followed by the address and then data. Channel assignment data resides in memory locations 0x200 to 0x227 and can be programmed via the SPI interface as shown in Figure 2. A write is initiated by sending the write instruction byte = 0x02 followed by the address and then data. Conversions are initiated by writing the conversion control byte (see Table 6) into memory location 0x000 (command status register).

**Table 2A. Memory Map**

| LTC2986 MEMORY MAP | | | | |
|---|---|---|---|---|
| **SEGMENT** | **START ADDRESS** | **END ADDRESS** | **SIZE (BYTES)** | **DESCRIPTION** |
| Command Status Register | 0x000 | 0x0000 | 1 | See Table 6 and 12, Initiate Conversion, Sleep Command, EEPROM Command |
| Reserved | 0x001 | 0x000F | 15 | |
| Temperature Result Memory 10 Words – 40 Bytes | 0x010 | 0x037 | 40 | See Tables 8 to 10, Read Result |
| Reserved | 0x038 | 0x0AF | 120 | |
| EEPROM Key | 0x0B0 | 0x0B3 | 4 | See Table 11 (LTC2986-1 Only, Otherwise Reserved) |
| Reserved | 0x0B4 | 0x0CF | 44 | |
| EEPROM Read Result Code | 0x0D0 | 0x0D0 | 1 | See Table 11 (LTC2986-1 Only, Otherwise Reserved) |
| Reserved | 0x0D1 | 0x0EF | 15 | |
| Global Configuration Register | 0x0F0 | 0x0F0 | 1 | See Table 67 for Global Configuration |
| Reserved | 0x0F1 | 0x0F3 | 3 | |
| Measure Multiple Channels Bit Mask | 0x0F4 | 0x0F7 | 4 | See Tables 84, 85, Run Multiple Conversions |
| Reserved | 0x0F8 | 0x0F8 | 1 | |
| EEPROM Status Register | 0x0F9 | 0x0F9 | 1 | See Table 13 (LTC2986-1 Only, Otherwise Reserved) |
| Reserved | 0x0FA | 0x0FE | 5 | |
| MUX Configuration Delay | 0x0FF | 0x0FF | 1 | See MUX Configuration Delay Section of Data Sheet |
| Reserved | 0x100 | 0x1FF | 256 | |
| Channel Assignment Data | 0x200 | 0x227 | 40 | See Tables 3, 4, Channel Assignment |
| Reserved | 0x228 | 0x24F | 40 | |
| Custom Sensor Table Data | 0x250 | 0x3CF | 384 | |
| Reserved | 0x3D0 | 0x3FF | 48 | |

**Table 2B. SPI Instruction Byte**

| INSTRUCTION | SPI INSTRUCTION BYTE | DESCRIPTION |
|---|---|---|
| Read | 0b00000011 | See Figure 1 |
| Write | 0b00000010 | See Figure 2 |
| Invalid | 0bxxxxxx0x | |

## OVERVIEW

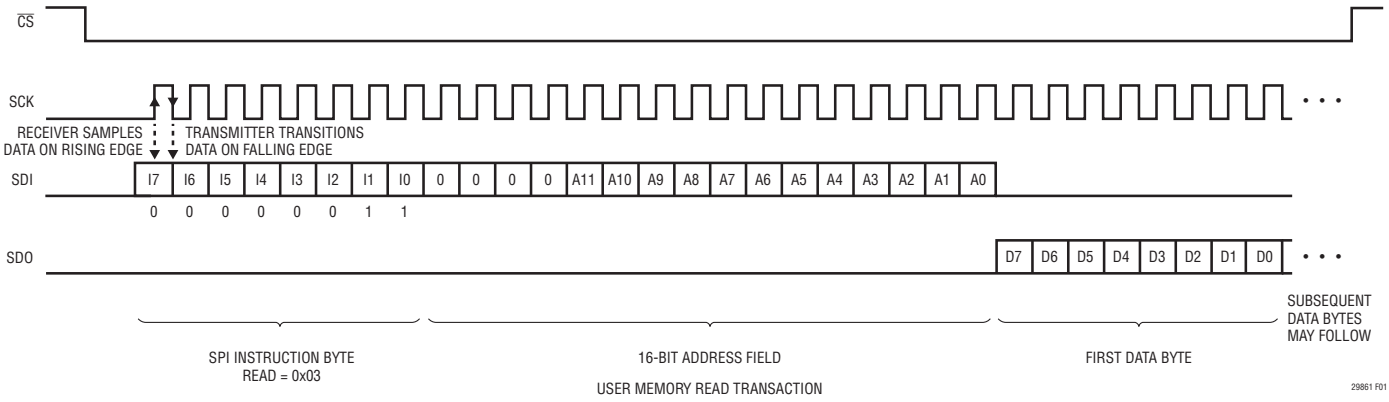



**Figure 1. Memory Read Operation**

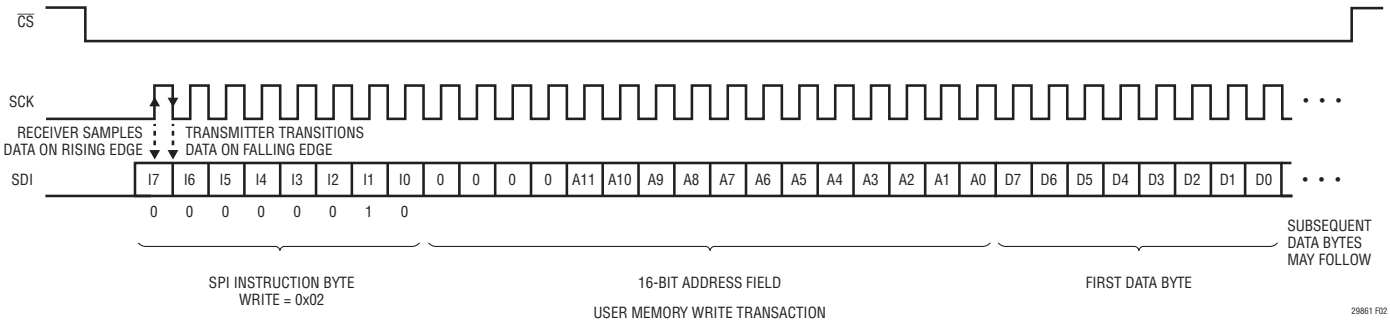



**Figure 2. Memory Write Operation**

## APPLICATIONS INFORMATION

The LTC2986 combines high accuracy with ease of use. The basic operation is simple and is composed of five states (see Figure 3).

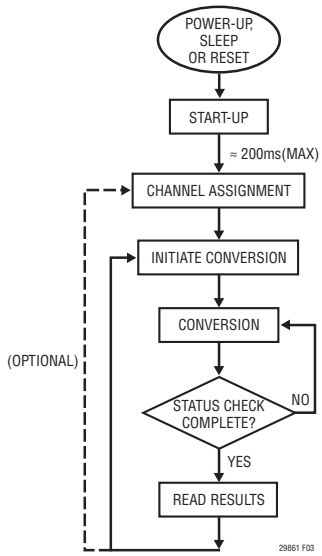



**Figure 3. Basic Operation**

### Conversion States Overview

1. **Start-Up.** After power is applied to the LTC2986 ($V_{DD}$ > 2.6V), there is a 200ms wake up period. During this time, the LDO, charge pump, ADCs, and reference are powered up and the internal RAM is initialized. Once start-up is complete, the INTERRUPT pin goes HIGH and the command status register will return a value of 0x40 (Start bit = 0, Done bit = 1) when read.
2. **Channel Assignment.** The device automatically enters the channel assignment state after start-up is complete. While in this state, the user writes sensor specific data for each input channel into RAM. For the LTC2986-1, the user can also load it from the EEPROM (see the EEPROM section for more details). The assignment data contains information about the sensor type, pointers to cold junction sensors or sense resistors, and sensor specific parameters.
3. **Initiate Conversion.** A conversion is initiated by writing a measurement command into RAM memory location 0x000. This command is a pointer to the channel in which the conversion will be performed.
4. **Conversion.** A new conversion begins automatically following an Initiate Conversion command. In this state, the ADC is running a conversion on the specified channel and associated cold junction or $R_{SENSE}$ channel (if applicable). The user is locked out of RAM access while in the state (except for reading status location 0x000). The end of conversion is indicated by both the INTERRUPT pin going HIGH and a status register START bit going LOW and DONE bit going HIGH.
5. **Read Results.** In this state, the user has access to RAM and can read the completed conversion results and fault status bits. It is also possible for the user to modify/append the channel assignment data during the read results state.

### Conversion State Details

### State 1: Start-Up

The start-up state automatically occurs when power is applied to the LTC2986. If the power drops below a threshold of ≈2.6V and then returns to the normal operating voltage (2.85V to 5.25V), the LTC2986 resets and enters the power-up state. Note that the LTC2986 also enters the start-up state at the conclusion of the sleep state. The start-up state can also be entered at any time during normal operation by pulsing the $\overline{\text{RESET}}$ pin low.

In the first phase of the start-up state all critical analog circuits are powered up. This includes the LDO, reference, charge pump and ADCs. During this first phase, the command status register will be inaccessible to the user. This phase takes a maximum of 100ms to complete. Once this phase completes, the command status register will be accessible and return a value of 0x80 until the LTC2986 is completely initialized. Once the LTC2986 is initialized and ready to use, the INTERRUPT pin will go high and the command status register will return a read value of 0x40 (Start bit = 0, Done bit = 1). At this point the LTC2986 is fully initialized and is ready to perform a conversion.

### State 2: Channel Assignment

The LTC2986 RAM can be programmed with up to 10 sets of 32-bit (4-byte) channel assignment data. These reside sequentially in RAM with a one-to-one correspondence

## APPLICATIONS INFORMATION

**Table 3. Channel Assignment Memory Map**

| CHANNEL ASSIGNMENT NUMBER | CONFIGURATION DATA START ADDRESS | CONFIGURATION DATA ADDRESS + 1 | CONFIGURATION DATA ADDRESS + 2 | CONFIGURATION DATA END ADDRESS + 3 | SIZE (BYTES) |
|---|---|---|---|---|---|
| CH1 | 0x200 | 0x201 | 0x202 | 0x203 | 4 |
| CH2 | 0x204 | 0x205 | 0x206 | 0x207 | 4 |
| CH3 | 0x208 | 0x209 | 0x20A | 0x20B | 4 |
| CH4 | 0x20C | 0x20D | 0x20E | 0x20F | 4 |
| CH5 | 0x210 | 0x211 | 0x212 | 0x213 | 4 |
| CH6 | 0x214 | 0x215 | 0x216 | 0x217 | 4 |
| CH7 | 0x218 | 0x219 | 0x21A | 0x21B | 4 |
| CH8 | 0x21C | 0x21D | 0x21E | 0x21F | 4 |
| CH9 | 0x220 | 0x221 | 0x222 | 0x223 | 4 |
| CH10 | 0x224 | 0x225 | 0x226 | 0x227 | 4 |

## APPLICATIONS INFORMATION

to each of the 10 analog input channels (see Table 3). Channels that are not used should have their channel assignment data set to all zeros (default at START-UP).

The channel assignment data contains all the necessary information associated with the specific sensor tied to that channel (see Table 4). The first five bits determine the sensor type (see Table 5). Associated with each sensor are sensor specific configurations. These include pointers to cold junction or sense resistor channels, pointers to memory locations of custom linearization data, sense resistor values and diode ideality factors. Also included in this data are, if applicable, the excitation current level, single-ended/differential input mode, as well as sensor specific controls. Separate detailed operation sections for thermocouples, RTDs, diodes, thermistors, analog temperature sensors, and sense resistors describe the assignment data associated with each sensor type in more detail. The LTC2986 demonstration software includes a utility for checking configuration data and generating annotated C-code for programming the channel assignment data.

**Table 4. Channel Assignment Data**

| | SENSOR TYPE | SENSOR SPECIFIC CONFIGURATION | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Channel Assignment Memory Location | Configuration Data Start Address | | | | | | | | Configuration Data Start Address + 1 | | | | | | | | Configuration Data Start Address + 2 | | | | | | | | Configuration Data Start Address + 3 | | | | | | | |
| | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Unassigned (Default) | Type = 0 | | | | | Channel Disabled | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Thermocouple | Type = 1 to 9 | | | | | Cold Junction Channel Assignment [4:0] | | | | | SGL=1 DIFF=0 | OC Check | OC Current [1:0] | | | | 0 | 0 | 0 | 0 | 0 | 0 | Custom Address [5:0] | | | | | | Custom Length – 1 [5:0] | | | | | |
| RTD | Type = 10 to 18 | | | | | $R_{SENSE}$ Channel Assignment [4:0] | | | | | 2, 3, 4 Wire | | Excitation Mode | | Excitation Current [3:0] | | | | Curve [1:0] | | Custom Address [5:0] | | | | | | Custom Length – 1 [5:0] | | | | | |
| Thermistor | Type = 19 to 27 | | | | | $R_{SENSE}$ Channel Assignment [4:0] | | | | | SGL=1 DIFF=0 | Excitation Mode | | | Excitation Current [3:0] | | 0 | 0 | 0 | | Custom Address [5:0] | | | | | | Custom Length – 1 [5:0] | | | | | |
| Diode | Type = 28 | | | | | SGL=1 DIFF=0 | 2 to 3 Reading | Avg on | Current [1:0] | | Ideality Factor (2, 20) Value from 0 to 4 with 1/1048576 Resolution All Zeros Use Factory Set Default in ROM | | | | | | | | | | | | | | | | | | | | | | | |
| Sense Resistor | Type = 29 | | | | | Sense Resistor Value (17, 10) Up to 131,072Ω with 1/1024Ω Resolution | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Direct ADC | Type = 30 | | | | | SGL=1 DIFF=0 | Table Mode | | | | Not Used | | | | | | | | | | | | Custom Address [5:0] | | | | | | Custom Length – 1 [5:0] | | | | | |
| Active Analog Temperature Sensor | Type = 31 | | | | | SGL=1 DIFF=0 | | | | | Not Used | | | | | | | | | | | | Custom Address [5:0] | | | | | | Custom Length – 1 [5:0] | | | | | |

## APPLICATIONS INFORMATION

**Table 5. Sensor Type Selection**

| 31 | 30 | 29 | 28 | 27 | SENSOR TYPE |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | Unassigned |
| 0 | 0 | 0 | 0 | 1 | Type J Thermocouple |
| 0 | 0 | 0 | 1 | 0 | Type K Thermocouple |
| 0 | 0 | 0 | 1 | 1 | Type E Thermocouple |
| 0 | 0 | 1 | 0 | 0 | Type N Thermocouple |
| 0 | 0 | 1 | 0 | 1 | Type R Thermocouple |
| 0 | 0 | 1 | 1 | 0 | Type S Thermocouple |
| 0 | 0 | 1 | 1 | 1 | Type T Thermocouple |
| 0 | 1 | 0 | 0 | 0 | Type B Thermocouple |
| 0 | 1 | 0 | 0 | 1 | Custom Thermocouple |
| 0 | 1 | 0 | 1 | 0 | RTD PT-10 |
| 0 | 1 | 0 | 1 | 1 | RTD PT-50 |
| 0 | 1 | 1 | 0 | 0 | RTD PT-100 |
| 0 | 1 | 1 | 0 | 1 | RTD PT-200 |
| 0 | 1 | 1 | 1 | 0 | RTD PT-500 |
| 0 | 1 | 1 | 1 | 1 | RTD PT-1000 |
| 1 | 0 | 0 | 0 | 0 | RTD 1000 (0.00375) |
| 1 | 0 | 0 | 0 | 1 | RTD NI-120 |
| 1 | 0 | 0 | 1 | 0 | RTD Custom |
| 1 | 0 | 0 | 1 | 1 | Thermistor 44004/44033 2.252kΩ at 25°C |
| 1 | 0 | 1 | 0 | 0 | Thermistor 44005/44030 3kΩ at 25°C |
| 1 | 0 | 1 | 0 | 1 | Thermistor 44007/44034 5kΩ at 25°C |
| 1 | 0 | 1 | 1 | 0 | Thermistor 44006/44031 10kΩ at 25°C |
| 1 | 0 | 1 | 1 | 1 | Thermistor 44008/44032 30kΩ at 25°C |
| 1 | 1 | 0 | 0 | 0 | Thermistor YSI 400 2.252kΩ at 25°C |
| 1 | 1 | 0 | 0 | 1 | Thermistor Spectrum 1003k 1kΩ |
| 1 | 1 | 0 | 1 | 0 | Thermistor Custom Steinhart-Hart |
| 1 | 1 | 0 | 1 | 1 | Thermistor Custom Table |
| 1 | 1 | 1 | 0 | 0 | Diode |
| 1 | 1 | 1 | 0 | 1 | Sense Resistor |
| 1 | 1 | 1 | 1 | 0 | Direct ADC |
| 1 | 1 | 1 | 1 | 1 | Analog Temperature Sensor |

### State 3: Initiate Conversion

Once the channel assignment is complete, the device is ready to begin a conversion. A conversion is initiated by writing Start (B7 = 1) and Done (B6 = 0) followed by the desired input channel (B4 – B0) into RAM memory location 0x000 (see Tables 6 and 7). It is possible to initiate a measurement cycle on multiple channels by setting the channel selection bits (B4 to B0) to 00000; see the Running Conversions Consecutively on Multiple Channels section of the data sheet.

**Table 6. Command Status Register**

| B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 | |
|---|---|---|---|---|---|---|---|---|
| Start = 1 | Done = 0 | 0 | EEPROM Command and Channel Selection 1 to 10 | | | | | Start Conversion |
| 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | Initiate Sleep |

**Table 7. Input Channel Mapping**

| B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 | CHANNEL SELECTED |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Multiple Channels |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | CH1 |
| 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | CH2 |
| 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | CH3 |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | CH4 |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | CH5 |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | CH6 |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | CH7 |
| 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | CH8 |
| 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | CH9 |
| 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | CH10 |
| 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | Sleep |
| All Other Combinations | | | | | | | | Reserved |

## APPLICATIONS INFORMATION

Bits B4 to B0 determine which input channel the conversion is performed upon and are simply the binary equivalent of the channel number (see Table 7). These bits are also used for EEPROM read and write operations (LTC2986-1, see Table 12).

Bit B5 should be set to 0.

Bits B7 and B6 serve as start/done bits. In order to start a conversion, these bits must be set to "10" (B7=1 and B6=0). When the conversion begins, the INTERRUPT pin goes LOW. Once the conversion is complete, bits B7 and B6 will toggle to "01" (B7=0 and B6=1) (Address = 0x000) and the INTERRUPT pin will go HIGH, indicating the conversion is complete and the result is available.

### State 4: Conversion

The measurement cycle starts after the Initiate Conversion command is written into RAM location 0x000 (Table 6). The LTC2986 simultaneously measures the selected input sensor, sense resistors (RTDs and thermistors), and cold junction temperatures if applicable (thermocouples).

Once the conversion is started, the user is locked out of the RAM, with the exception of reading status data stored in RAM memory location 0x000.

Once the conversion is started the INTERRUPT pin goes low. Depending on the sensor configuration, two or three 82ms cycles are required per temperature result. These correspond to conversion rates of 167ms and 251ms, respectively (assuming a filter frequency setting of 55Hz). Details describing these modes are described in the 2- and 3-cycle Conversion Modes section of the data sheet.

The end of conversion can be monitored either through the INTERRUPT pin (LOW to HIGH transition), or by reading the command status register in RAM memory location 0x000 (start bit, B7, toggles from 1 to 0 and DONE bit, B6, toggles from 0 to 1).

### State 5: Read Results

Once the conversion is complete, the conversion results can be read from RAM memory locations corresponding to the input channel (see Table 8).

The conversion result is 32 bits long and contains both the sensor temperature (D23 to D0) and sensor fault data (D31 to D24) (see Tables 9A and 9B).

The result is reported in °C for all temperature sensors with a range of –273.15°C to 8192°C and 1/1024°C resolution or in °F with a range of –459.67°F to 8192°F with 1/1024°F resolution. Included with the conversion result are seven sensor fault bits and a valid bit. These sensor fault bits are set to a 1 if there was a problem associated with the corresponding conversion result (see Table 10). Two types of errors are reported: hard errors and soft errors. Hard errors indicate the reading is invalid and the resulting temperature reported is –999°C or °F. Soft errors indicate operation beyond the normal temperature range of the sensor or the input range of the ADC. In this case, the calculated temperature is reported but the accuracy may be compromised. Details relating to each fault type are sensor specific and are described in detail in the sensor specific sections of this data sheet. Bit D24 is the valid bit and will be set to a 1 for valid data.

Once the data read is complete, the device is ready for a new Initiate Conversion command. In cases where new channel configuration data is required, the user has access to the RAM in order to modify existing channel assignment data.

**Table 8. Conversion Result Memory Map**

| CONVERSION CHANNEL | START ADDRESS | END ADDRESS | SIZE (BYTES) |
|---|---|---|---|
| CH1 | 0x010 | 0x013 | 4 |
| CH2 | 0x014 | 0x017 | 4 |
| CH3 | 0x018 | 0x01B | 4 |
| CH4 | 0x01C | 0x01F | 4 |
| CH5 | 0x020 | 0x023 | 4 |
| CH6 | 0x024 | 0x027 | 4 |
| CH7 | 0x028 | 0x02B | 4 |
| CH8 | 0x02C | 0x02F | 4 |
| CH9 | 0x030 | 0x033 | 4 |
| CH10 | 0x034 | 0x037 | 4 |

# APPLICATIONS INFORMATION

**Table 9A. Example Data Output Words (°C)**

| | START ADDRESS | | | | | | | | START ADDRESS + 1 | | | | | | | | START ADDRESS + 2 | | | | | | | | START ADDRESS + 3 (END ADDRESS) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D31 | D30 | D29 | D28 | D27 | D26 | D25 | D24 | D23 | D22 | D21 | D20 | D19 | D18 | D17 | D16 | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
| | Fault Data | | | | | | | | SIGN MSB | | | | | | | | | | | | | | | | | | | | | | | LSB |
| Temperature | Sensor Hard Fault | ADC Hard Fault | CJ Hard Fault | CJ Soft Fault | Sensor Over Range Fault | Sensor Under Range Fault | ADC Out of Range Fault | Valid If 1 | 4096°C | | | | | | | | | | | | | 1°C | | | | | | | | | | 1/1024°C |
| 8191.999°C | | | | | | | | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1024°C | | | | | | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1°C | | | | | | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1/1024°C | | | | | | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 0°C | | | | | | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| –1/1024°C | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| –1°C | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| –273.15°C | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 |

**Table 9B. Example Data Output Words (°F)**

| | START ADDRESS | | | | | | | | START ADDRESS + 1 | | | | | | | | START ADDRESS + 2 | | | | | | | | START ADDRESS + 3 (END ADDRESS) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D31 | D30 | D29 | D28 | D27 | D26 | D25 | D24 | D23 | D22 | D21 | D20 | D19 | D18 | D17 | D16 | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
| | Fault Data | | | | | | | | SIGN MSB | | | | | | | | | | | | | | | | | | | | | | | LSB |
| Temperature | Sensor Hard Fault | ADC Hard Fault | CJ Hard Fault | CJ Soft Fault | Sensor Over Range Fault | Sensor Under Range Fault | ADC Out of Range Fault | Valid If 1 | 4096°F | | | | | | | | | | | | | 1°F | | | | | | | | | | 1/1024°F |
| 8191.999°F | | | | | | | | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1024°F | | | | | | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1°F | | | | | | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1/1024°F | | | | | | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 0°F | | | | | | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| –1/1024°F | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| –1°F | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| –459.67°F | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 |

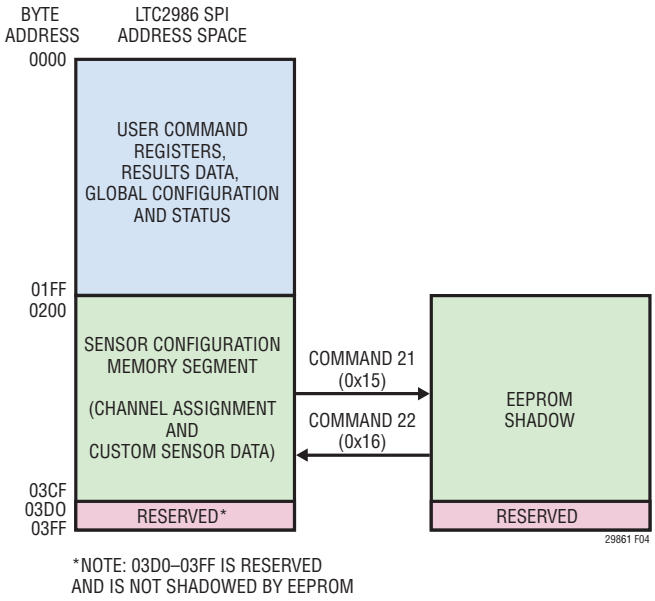
**Table 10. Sensor Fault Reporting**

| BIT | FAULT | ERROR TYPE | DESCRIPTION | OUTPUT RESULT |
|---|---|---|---|---|
| D31 | Sensor Hard Fault | Hard | Bad Sensor Reading | –999°C or °F |
| D30 | Hard ADC-Out-of-Range | Hard | Bad ADC Reading (Could Be Large External Noise Event) | –999°C or °F |
| D29 | CJ Hard Fault | Hard | Cold Junction Sensor Has a Hard Fault Error | –999°C or °F |
| D28 | CJ Soft Fault | Soft | Cold Junction Sensor Result Is Beyond Normal Range | Suspect Reading |
| D27 | Sensor Over Range | Soft | Sensor Reading Is Above Normal Range | Suspect Reading |
| D26 | Sensor Under Range | Soft | Sensor Reading Is Below Normal Range | Suspect Reading |
| D25 | ADC Out-of-Range | Soft | ADC Absolute Input Voltage Is Beyond ±1.125 • $V_{REF}$/2 | Suspect Reading |
| D24 | Valid | NA | Result Valid (Should Be 1) Discard Results if 0 | Suspect Reading |

# APPLICATIONS INFORMATION

## EEPROM OVERVIEW (LTC2986-1)

The LTC2986-1 contains 512 bytes of EEPROM, which shadows the upper sensor configuration segment of USER RAM (locations 0x200–0x3CF, see Figure 4). Prior to initial usage, the user programs the USER RAM with all channel assignment and custom sensor data. Once the USER RAM has been programmed, the user can save this segment of memory into the EEPROM. After subsequent power down or sleep cycles, the user can reload the USER RAM with this stored EEPROM data bypassing the channel assignment and customer sensor programming normally required.




*NOTE: 03D0–03FF IS RESERVED AND IS NOT SHADOWED BY EEPROM

**Figure 4. Shadow EEPROM Memory Map**

## EEPROM READ/WRITE VALIDATION

Access to the EEPROM is key-protected to prevent inadvertent access. The EEPROM also has two levels of data integrity protection. The first level is implemented using an error correcting code (ECC) on each 32-bit word of data in the EEPROM. The ECC is capable of correcting any single bit error per word and detecting 2-bit errors per word. The second level of protection is implemented using a 32-bit checksum, which covers the entire contents of user EEPROM. Status bits are available to the user for reporting ECC status and checksum error conditions.

## EEPROM WRITE OPERATION

The EEPROM write operation requires 5 states (see Figure 5).

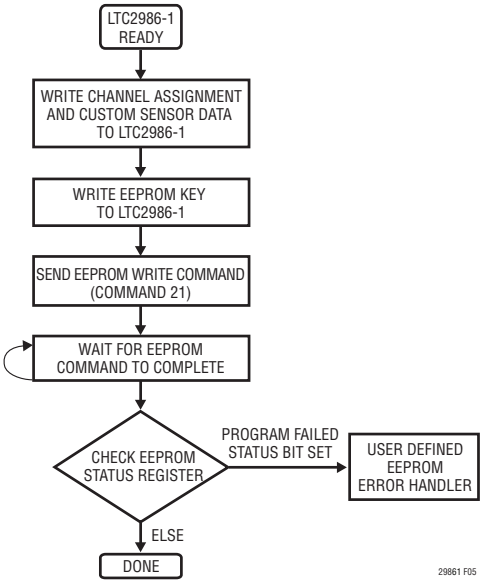



**Figure 5. EEPROM Write Operation**

1. **Sensor Configuration.** Write all desired channel assignment and custom sensor data to the LTC2986-1 USER RAM.
2. **Set EEPROM Key.** Write the EEPROM Key (0xA53C0F5A) to the key register space of the LTC2986-1 USER RAM (Address range 0x0B0–0x0B3, see Table 11). Note the key is written MSB first.
3. **Send EEPROM Write Command.** Write the EEPROM write command (0x15) and start bit (0x80) to the LTC2986-1 command register (Address 0x000). The command plus start bit is 0x80 + 0x15 = 0x95 (see Table 12).
4. **Wait for EEPROM Command to Complete.** Completion of the write operation is indicated by both the INTERRUPT pin going HIGH and the status register START bit going LOW and DONE bit going HIGH.
5. **Check EEPROM Status Register.** Read EEPROM Status register (Address 0x0F9) and checks the Program-Failed status bit (Bit 2) to determine whether the EEPROM write operation was successful (see Table 13). The Program-Failed status bit being set indicates that the write operation failed.

Upon successful completion of steps 1–5, the EEPROM will now contain the image that was present in USER RAM locations 0x200–0x3CF.

# APPLICATIONS INFORMATION

## EEPROM READ OPERATION (LTC2986-1)

The LTC2986-1 EEPROM read operation is comprised of 4 states (see Figure 6)

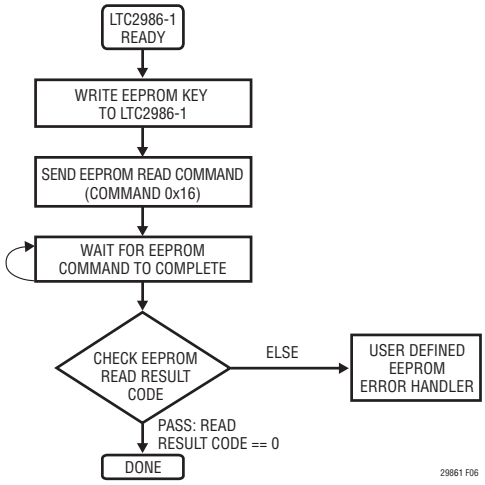



**Figure 6. Read Operation**

1. **Set EEPROM Key.** Write the EEPROM Key (0xA53C0F5A) to the key register space of the LTC2986-1 USER RAM (Address range 0x0B0–0x0B3, see Table 11). Note the key is written MSB first.
2. **Send EEPROM Read Command.** Write the EEPROM read command (0x16) and start bit (0x80) to the LTC2986-1 command register (Address 0x000). The command plus start bit would be 0x80 + 0x16 = 0x96 (see Table 12).
3. **Wait for EEPROM Command to Complete.** Completion of the read operation is indicated by both the INTERRUPT pin going HIGH and the status register START bit going LOW and DONE bit going HIGH.
4. **Check EEPROM Read Result Code.** Read the EEPROM read result code register address (0x0D0) to determine the pass/fail status of the read operation. A value of zero indicates that the command completed successfully and a non-zero value indicates that an error has occurred. Additional read operation status bits are also available in the EEPROM Status Register (see Tables 13 and 14).

Upon successful completion of steps 1–4, USER RAM locations 0x200–0x3CF will now contain the data that was stored in the LTC2986-1's shadow EEPROM.

**Table 11. LTC2986-1 EEPROM Related Registers**

| ADDRESS | REGISTER NAME | DESCRIPTION |
|---|---|---|
| 0x0B0 | EEPROM Key [3] (MSB) | EEPROM Key byte 3 – Set to 0xA5 |
| 0x0B1 | EEPROM Key [2] | EEPROM Key byte 2 – Set to 0x3C |
| 0x0B2 | EEPROM Key [1] | EEPROM Key byte 1 – Set to 0x0F |
| 0x0B3 | EEPROM Key [0] (LSB) | EEPROM Key byte 0 – Set to 0x5A |
| 0x0D0 | EEPROM Read Result Code | This register indicates the Pass/Fail status of the most recent EEPROM read operation<br>0x00 = PASS<br>0xFF = FAIL |
| 0x0F9 | EEPROM Status Register | See LTC2986-1 EPROM Status Register Tables 12 and 13 |

**Table 12. LTC2986-1 EEPROM Related Commands and Status**

| B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | **EEPROM Write Command** – Transfer the contents of user memory locations 0x200–0x3CF to the on-chip shadow EEPROM |
| 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | **EEPROM Read Command** – Transfer the contents of the on-chip shadow EEPROM to user memory locations 0x200–0x3CF |

**Table 13. EEPROM Status Bits**

| EEPROM STATUS BIT | DESCRIPTION |
|---|---|
| ECC Used | **Error Correcting Code Used** – This bit indicates that ECC was used to correct data on one or more locations during the EEPROM read process (Note 20) |
| ECC Failure | **Error Correcting Code Failure** – This bit indicates that ECC failed to correct data on one or more locations during the EEPROM read process. If this bit is set one or more locations has invalid data (Note 20) |
| Program Failure | **Program Failure** – This bit indicates that a write data error occurred on one or more locations during the EEPROM programming process (Note 20) |
| Checksum Error | **Checksum Error** – This bit indicates that a checksum error occurred during the EEPROM read process (Note 20) |

Note 20: Once bits in the EEPROM status register are set they will remain set until cleared by the user. The EEPROM status register bits are cleared by writing 0x00 to address 0x0F9. These bits are also cleared on reset and after exiting sleep mode.

**Table 14. LTC2986-1 EEPROM Status Register (Address 0x0F9)**

| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|
| – | – | – | – | Checksum Error | Program Failure | ECC Failure | ECC Used |

# APPLICATIONS INFORMATION

## THERMOCOUPLE MEASUREMENTS

### Channel Assignment – Thermocouples

For each thermocouple tied to the LTC2986, a 32-bit channel assignment word is programmed into a memory location corresponding to the channel the sensor is tied to (see Table 15). This word includes (1) thermocouple type, (2) cold junction channel pointer, (3) sensor configuration, and (4) custom thermocouple data pointer.

### (1) Thermocouple Type

The thermocouple type is determined by the first five input bits B31 to B27 as shown in Table 16. Standard NIST coefficients for types J, K, E, N, R, S, T and B thermocouples are stored in the device ROM. If custom thermocouples are used, the custom thermocouple sensor type can be selected. In this case, user-specific data can be stored in the on-chip RAM starting at the address defined in the custom thermocouple data pointer.

### (2) Cold Junction Channel Pointer

The cold junction compensation can be a diode, active analog temperature sensor, RTD, or thermistor. The cold junction channel pointer tells the LTC2986 which channel (1 to 10) the cold junction sensor is assigned to (see Table 17). When a conversion is performed on a channel tied to a thermocouple, the cold junction sensor is simultaneously and automatically measured. The final output data uses the embedded coefficients stored in ROM to automatically compensate the cold junction temperature and output the thermocouple sensor temperature.

### (3) Sensor Configuration

The sensor configuration field (see Table 18) is used to select single-ended (B21=1) or differential (B21=0) input and allows selection of open circuit current if internal open-circuit detect is enabled (bit B20). Single-ended readings are measured relative to the COM pin and differential are measured between the selected $CH_{TC}$ and adjacent $CH_{TC-1}$ (see Figure 7). If open-circuit detection is enabled, B20=1, then the user can select the pulsed current value applied during open-circuit detect using bits B18 and B19 . The user determines the value of the open circuit current based on the size of the external protection resistor and filter capacitor (typically 10µA). This network needs to settle within 50ms to 1µV or less. The duration of the current pulse is approximately 8ms and occurs 50ms before the normal conversion cycle.

Thermocouple channel assignments follow the general convention shown in Figure 7. The thermocouple positive terminal ties to $CH_{TC}$ (where TC is the selected channel number) for both the single-ended and differential modes of operation. For single-ended measurements the thermocouple negative terminal and the COM pin are grounded. The thermocouple negative terminal is tied to $CH_{TC-1}$ for differential measurements. This node can either be grounded or tied to a bias voltage.

**Table 15. Thermocouple Channel Assignment Word**

| | (1) THERMOCOUPLE TYPE | | | | | (2) COLD JUNCTION CHANNEL POINTER | | | | | (3) SENSOR CONFIGURATION | | | | | | | | | | (4) CUSTOM THERMOCOUPLE DATA POINTER | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TABLES 4, 16 | | | | | TABLE 17 | | | | | TABLE 18 | | | | | | | | | | TABLES 86 TO 88 | | | | | | | | | |
| Measurement Type | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Thermocouple | Types 1 to 9 | | | | | Cold Junction Channel Assignment [4:0] | | | | | SGL=1 DIFF=0 | OC Check | OC Current [1:0] | | 0 | 0 | 0 | 0 | 0 | 0 | Custom Address [5:0] | | | | | | Custom Length –1 [5:0] | | | | | |

# APPLICATIONS INFORMATION

**Table 16. Thermocouple Type**

| (1) THERMOCOUPLE TYPE | | | | | |
|---|---|---|---|---|---|
| B31 | B30 | B29 | B28 | B27 | THERMOCOUPLE TYPES |
| 0 | 0 | 0 | 0 | 1 | Type J Thermocouple |
| 0 | 0 | 0 | 1 | 0 | Type K Thermocouple |
| 0 | 0 | 0 | 1 | 1 | Type E Thermocouple |
| 0 | 0 | 1 | 0 | 0 | Type N Thermocouple |
| 0 | 0 | 1 | 0 | 1 | Type R Thermocouple |
| 0 | 0 | 1 | 1 | 0 | Type S Thermocouple |
| 0 | 0 | 1 | 1 | 1 | Type T Thermocouple |
| 0 | 1 | 0 | 0 | 0 | Type B Thermocouple |
| 0 | 1 | 0 | 0 | 1 | Custom Thermocouple |

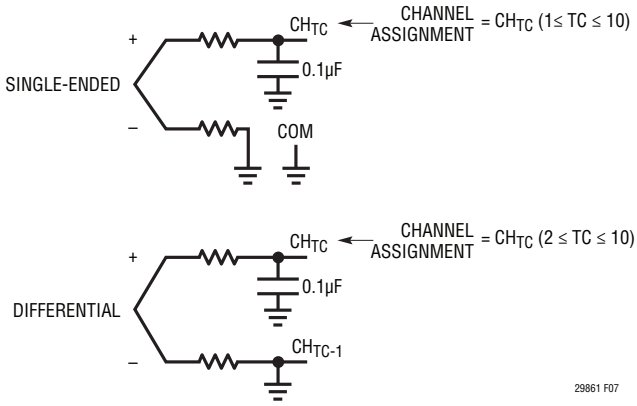



**Figure 7. Thermocouple Channel Assignment Convention**

**Table 17. Cold Junction Channel Pointer**

| (2) COLD JUNCTION CHANNEL POINTER | | | | | |
|---|---|---|---|---|---|
| B26 | B25 | B24 | B23 | B22 | COLD JUNCTION CHANNEL |
| 0 | 0 | 0 | 0 | 0 | No Cold Junction Compensation, 0°C Used for Calculations |
| 0 | 0 | 0 | 0 | 1 | CH1 |
| 0 | 0 | 0 | 1 | 0 | CH2 |
| 0 | 0 | 0 | 1 | 1 | CH3 |
| 0 | 0 | 1 | 0 | 0 | CH4 |
| 0 | 0 | 1 | 0 | 1 | CH5 |
| 0 | 0 | 1 | 1 | 0 | CH6 |
| 0 | 0 | 1 | 1 | 1 | CH7 |
| 0 | 1 | 0 | 0 | 0 | CH8 |
| 0 | 1 | 0 | 0 | 1 | CH9 |
| 0 | 1 | 0 | 1 | 0 | CH10 |
| All Other Combinations | | | | | Invalid |

**Table 18. Sensor Configuration**

| (3) SENSOR CONFIGURATION | | | | | |
|---|---|---|---|---|---|
| SGL | OC CHECK | OC CURRENT | | SINGLE-ENDED/ DIFFERENTIAL | OPEN-CIRCUIT CURRENT |
| B21 | B20 | B19 | B18 | | |
| 0 | 0 | X | X | Differential | External |
| 0 | 1 | 0 | 0 | Differential | 10µA |
| 0 | 1 | 0 | 1 | Differential | 100µA |
| 0 | 1 | 1 | 0 | Differential | 500µA |
| 0 | 1 | 1 | 1 | Differential | 1mA |
| 1 | 0 | X | X | Single-Ended | External |
| 1 | 1 | 0 | 0 | Single-Ended | 10µA |
| 1 | 1 | 0 | 1 | Single-Ended | 100µA |
| 1 | 1 | 1 | 0 | Single-Ended | 500µA |
| 1 | 1 | 1 | 1 | Single-Ended | 1mA |

## APPLICATIONS INFORMATION

### (4) Custom Thermocouple Data Pointer

See Custom Thermocouples section near the end of this data sheet for more information.

### Fault Reporting – Thermocouple

Each sensor type has a unique fault reporting mechanism indicated in the upper byte of the data output word. Table 19 shows faults reported in the measurement of thermocouples.

Bit D31 indicates the thermocouple sensor is open (broken or not plugged in), the cold junction sensor has a hard fault, or the ADC is out of range. This is indicated by a reading well beyond the normal operating range. Bit D30 indicates a bad ADC reading. This can be a result of either a broken (open) sensor or an excessive noise event (ESD or static discharge into the sensor path). Either of these are a hard error and –999°C or °F is reported. In the case of an excessive noise event, the device should recover and the following conversions will be valid if the noise event was a random, infrequent event. Bit D29 indicates a hard fault occurred at the cold junction sensor and –999°C or °F is reported. Refer to the specific sensor (diode, themistor, or RTD) used for cold junction compensation. Bit D28 indicates a soft fault occurred at the cold junction sensor. A valid temperature is reported, but the accuracy may be compromised since the cold junction sensor is operating outside its normal temperature range. Bits D27 and D26 indicate over or under temperature limits have been exceeded for specific thermocouple types, as defined in Table 20. Bit D25 indicates the absolute voltage measured by the ADC is beyond its normal operating range. This fault reflects a reading that is well beyond the normal range of a thermocouple.

**Table 19. Thermocouple Fault Reporting**

| BIT | FAULT | ERROR TYPE | DESCRIPTION | OUTPUT RESULT |
|---|---|---|---|---|
| D31 | Sensor Hard Fault | Hard | Open Circuit or Hard ADC or Hard CJ | –999°C or °F |
| D30 | Hard ADC-Out-of-Range | Hard | Bad ADC Reading (Could Be Large External Noise Event) | –999°C or °F |
| D29 | CJ Hard Fault | Hard | Cold Junction Sensor Has a Hard Fault Error | –999°C or °F |
| D28 | CJ Soft Fault | Soft | Cold Junction Sensor Result Is Beyond Normal Range | Suspect Reading |
| D27 | Sensor Over Range | Soft | Thermocouple Reading Greater Than High Limit | Suspect Reading |
| D26 | Sensor Under Range | Soft | Thermocouple Reading Less Than Low Limit | Suspect Reading |
| D25 | ADC Out-of-Range | Soft | ADC Absolute Input Voltage Is Beyond ±1.125 • $V_{REF}$/2 | Suspect Reading |
| D24 | Valid | NA | Result Valid (Should Be 1) Discard Results if 0 | Valid Reading |

**Table 20. Thermocouple Temperature Limits**

| THERMOCOUPLE TYPE | LOW TEMP LIMIT °C | HIGH TEMP LIMIT °C |
|---|---|---|
| J-Type | –210 | 1200 |
| K-Type | –265 | 1372 |
| E-Type | –265 | 1000 |
| N-Type | –265 | 1300 |
| R-type | –50 | 1768 |
| S-Type | –50 | 1768 |
| T-Type | –265 | 400 |
| B-Type | 40 | 1820 |
| Custom | Lowest Table Entry | Highest Table Entry |

# APPLICATIONS INFORMATION

## DIODE MEASUREMENTS

### Channel Assignment – Diode

For each diode tied to the LTC2986, a 32-bit channel assignment word is programmed into a memory location corresponding to the channel the sensor is tied to (see Table 21). This word includes (1) diode sensor selection, (2) sensor configuration, (3) excitation current, and (4) diode ideality factor.

### 1) Sensor Type

The diode is selected by the first five input bits B31 to B27 (see Table 22).

### (2) Sensor Configuration

The sensor configuration field (bits B26 to B24) is used to define various diode measurement properties. Configuration bit B26 is set high for single-ended (measurement relative to COM) and low for differential.

Bit B25 sets the measurement algorithm. If B25 is low, two conversion cycles (one at ***1I*** and one at ***8I*** current excitation) are used to measure the diode. This is used in applications where parasitic resistance between the LTC2986 and the diode is small. Parasitic resistance effects can be removed by setting bit B25 high, enabling three conversion cycles (one at ***1I***, one at ***4I*** and one at ***8I***).

Bit B24 enables a running average of the diode temperature reading. This reduces the noise when the diode is used as a cold junction temperature element on an isothermal block where temperatures change slowly.

The algorithm used for diode averaging is a simple recursive running average. The new value is equal to the average of the current reading plus the previous value.

$$\text{NEW VALUE} = \frac{\text{CURRENT READING}}{2} + \frac{\text{PREVIOUS VALUE}}{2}$$

If the current reading is 2°C above or below the previous value, the new value is reset to the current reading.

### (3) Excitation Current

The next field in the channel assignment word (B23 to B22) controls the magnitude of the excitation current applied to the diode (see Table 23). In the two conversion cycle mode, the device performs the first conversion at a current equal to 8x the excitation current ***1I***. The second conversion occurs at ***1I***. Alternatively, in the three conversion cycle mode the first conversion excitation current is ***8I***, the second is ***4I*** and the 3rd is ***1I***.

**Table 21. Diode Channel Assignment Word**

| | (1) SENSOR TYPE | | | | | (2) SENSOR CONFIGURATION | | | (3) EXCITATION CURRENT | | (4) DIODE IDEALITY FACTOR VALUE | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TABLE 22 | | | | | | | | TABLE 23 | | TABLE 24 | | | | | | | | | | | | | | | | | | | | | | | |
| Measurement Class | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Diode | Type = 28 | | | | | SGL=1 DIFF=0 | 2 or 3 Readings | Avg on | Current [1:0] | | Non-Ideality Factor (2, 20) Value from 0 to 4 with 1/1048576 Resolution All Zeros Uses a Factory Set Default of 1.003 | | | | | | | | | | | | | | | | | | | | | | | | | |

**Table 22. Diode Sensor Selection**

| (1) SENSOR TYPE | | | | | |
|---|---|---|---|---|---|
| B31 | B30 | B29 | B28 | B27 | SENSOR TYPE |
| 1 | 1 | 1 | 0 | 0 | Diode |

**Table 23. Diode Excitation Current Selection**

| (3) EXCITATION CURRENT | | | | |
|---|---|---|---|---|
| B23 | B22 | *1I* | *4I* | *8I* |
| 0 | 0 | 10µA | 40µA | 80µA |
| 0 | 1 | 20µA | 80µA | 160µA |
| 1 | 0 | 40µA | 160µA | 320µA |
| 1 | 1 | 80µA | 320µA | 640µA |

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### (4) Diode Ideality Factor

The last field in the channel assignment word (B21 to B0) sets the diode ideality factor within the range 0 to 4 with 1/1048576 ($2^{-20}$) resolution. The top two bits (B21 to B20) are the integer part and bits B19 to B0 are the fractional part of the ideality factor (see Table 24).

Diode channel assignments follow the general convention shown in Figure 8. The anode ties to $CH_D$ (where D is the selected channel number) for both the single-ended and differential modes of operation, and the cathode is grounded. For differential diode measurements, the cathode is also tied to $CH_{D-1}$.

### Fault Reporting – Diode

Each sensor type has unique fault reporting mechanism indicated in the upper byte of the data output word. Table 25 shows faults reported in the measurement of diodes.

Bit D31 indicates the diode is open, shorted, not plugged in, wired backwards, or the ADC reading is bad. Any of these are hard faults and –999°C or °F is reported. Bit D30 indicates a bad ADC reading. This can be a result of either a broken (open) sensor or an excessive noise event (ESD or static discharge into the sensor path). This is a hard error and –999°C or °F is reported. In the case of

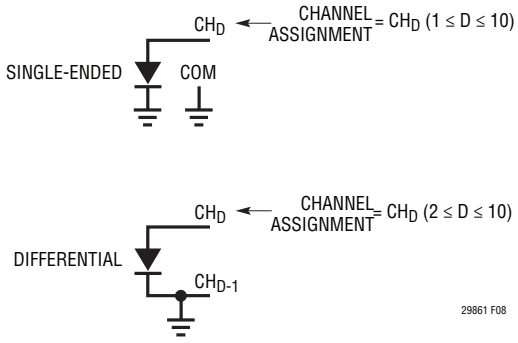


**Figure 8. Diode Channel Assignment Convention**

**Table 24. Programming Diode Ideality Factor**

| | (4) DIODE IDEALITY FACTOR VALUE | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| Example η | $2^1$ | $2^0$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ | $2^{-11}$ | $2^{-12}$ | $2^{-13}$ | $2^{-14}$ | $2^{-15}$ | $2^{-16}$ | $2^{-17}$ | $2^{-18}$ | $2^{-19}$ | $2^{-20}$ |
| 1.25 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.003 (Default) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.006 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |

**Table 25. Diode Fault Reporting**

| BIT | FAULT | ERROR TYPE | DESCRIPTION | OUTPUT RESULT |
|---|---|---|---|---|
| D31 | Sensor Hard Fault | Hard | Open, Short, Reversed, or Hard ADC | –999°C or °F |
| D30 | Hard ADC-Out-of-Range | Hard | Bad ADC Reading (Could Be Large External Noise Event) | –999°C or °F |
| D29 | Not Used for Diodes | N/A | Always 0 | |
| D28 | Not Used for Diodes | N/A | Always 0 | |
| D27 | Sensor Over Range | Soft | T > 130°C | Suspect Reading |
| D26 | Sensor Under Range | Soft | T < –60°C | Suspect Reading |
| D25 | ADC Out-of-Range | Soft | ADC Absolute Input Voltage Is Beyond ±1.125 • $V_{REF}$/2 | Suspect Reading |
| D24 | Valid | NA | Result Valid (Should Be 1) Discard Results if 0 | Valid Reading |

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an excessive noise event, the device should recover and the following conversions will be valid if the noise event was a random, infrequent event. Bits D29 and D28 are not used for diodes. Bits D27 and D26 indicate over or under temperature limits (defined as T > 130°C or T < –60°C). The calculated temperature is reported, but the accuracy may be compromised. Bit D25 indicates the absolute voltage measured by the ADC is beyond its normal operating range. If a diode is used as the cold junction element, any hard or soft error is flagged in the corresponding thermocouple result (bits D28 and D29 in Table 19).

### Example: Single-Ended Type K and Differential Type T Thermocouples with Shared Diode Cold Junction Compensation

Figure 9 shows a typical temperature measurement system where two thermocouples share a single cold junction diode. In this example, a Type K thermocouple is tied to CH1 and a Type T thermocouple is tied to CH3 and CH4. They both share a single cold junction diode with ideality factor of η=1.003 tied to CH2. Channel assignment data for both thermocouples and the diode are shown in Tables 26 to 28. Thermocouple #1 (Type K) sensor type and configuration data are assigned to CH1. 32-bits of binary configuration data are mapped directly into memory locations 0x200 to 0x203 (see Table 26). The cold junction diode sensor type and configuration data are assigned to CH2. 32-bits of binary configuration data are mapped directly into memory locations 0x204 to 0x207 (see Table 27). Thermocouple #2 (Type T) sensor type and configuration data are assigned to CH4. 32-bits of binary configuration data are mapped directly into memory locations 0x20C to 0x20F (see Table 28). A conversion is initiated on CH1 by writing 10000001 into memory location 0x000. Both the Type K thermocouple and the diode are measured simultaneously. The LTC2986 calculates the cold junction compensation and determines the temperature of the Type K thermocouple. Once the conversion is complete, the INTERRUPT pin goes HIGH and memory location 0x000 becomes 01000001. Similarly, a conversion can be initiated on CH4 by writing 10000100 into memory location 0x000. The results (in °C) can be read from memory locations 0x010 to 0x013 for CH1 and 0x01C to 0x01F for CH4.

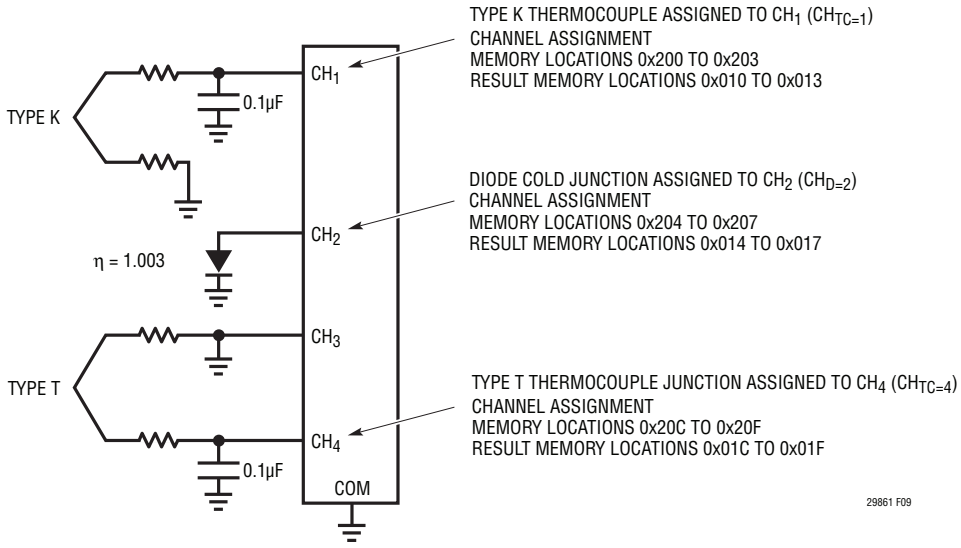


**Figure 9. Dual Thermocouple with Diode Cold Junction Example**

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**Table 26. Thermocouple #1 Channel Assignment (Type K, Cold Junction $CH_2$, Single-Ended, 10µA Open-Circuit Detect)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x200 | | | | | | | | MEMORY ADDRESS 0x201 | | | | | | | | MEMORY ADDRESS 0x202 | | | | | | | | MEMORY ADDRESS 0x203 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Thermocouple Type | Type K | 5 | 00010 | 0 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Cold Junction Channel Pointer | $CH_2$ | 5 | 00010 | | | | | | 0 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | Single-Ended, 10µA Open-Circuit | 4 | 1100 | | | | | | | | | | | 1 | 1 | 0 | 0 | | | | | | | | | | | | | | | | |
| Not Used | Set These Bits to 0 | 6 | 000000 | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | |
| (4) Custom Thermocouple Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 27. Diode Channel Assignment (Single-Ended 3-Reading, Averaging On, 20µA/80µA Excitation, Ideality Factor = 1.003))**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x204 | | | | | | | | MEMORY ADDRESS 0x205 | | | | | | | | MEMORY ADDRESS 0x206 | | | | | | | | MEMORY ADDRESS 0x207 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Sensor Type | Diode | 5 | 11100 | 1 | 1 | 1 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sensor Configuration | Single-Ended, 3-Reading, Average On | 3 | 111 | | | | | | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | |
| (3) Excitation Current | 20µA, 80µA, 160µA | 2 | 01 | | | | | | | | | 0 | 1 | | | | | | | | | | | | | | | | | | | | |
| (4) Ideality Factor | 1.003 | 22 | 0100000000110001001001 | | | | | | | | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |

**Table 28. Thermocouple #2 Channel Assignment (Type T, Cold Junction $CH_2$, Differential, 100µA Open-Circuit Detect)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x20C | | | | | | | | MEMORY ADDRESS 0x20D | | | | | | | | MEMORY ADDRESS 0x20E | | | | | | | | MEMORY ADDRESS 0x20F | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Thermocouple Type | Type T | 5 | 00111 | 0 | 0 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Cold Junction Channel Pointer | $CH_2$ | 5 | 00010 | | | | | | 0 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | Differential, 100µA Open-Circuit Current | 4 | 0101 | | | | | | | | | | | 0 | 1 | 0 | 1 | | | | | | | | | | | | | | | | |
| Not Used | Set These Bits to 0 | 6 | 000000 | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | |
| (4) Custom Thermocouple Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# APPLICATIONS INFORMATION

## RTD MEASUREMENTS

### Channel Assignment – RTD

For each RTD tied to the LTC2986, a 32-bit channel assignment word is programmed into a memory location corresponding to the channel the sensor is tied to (see Table 29). This word includes (1) RTD type, (2) sense resistor channel pointer, (3) sensor configuration, (4) excitation current, (5) RTD curve, and (6) custom RTD data pointer.

### (1) RTD Type

The RTD type is determined by the first five input bits B31 to B27 as shown in Table 30. Linearization coefficients for RTD types PT-10, PT-50, PT-100, PT-200, PT-500, PT-1000, and NI-120 with selectable common curves ($\alpha$ = 0.003850, $\alpha$ = 0.003911, $\alpha$ = 0.003916, and $\alpha$ = 0.003926) are built into the device. If custom RTDs are used, RTD Custom can be selected. In this case, user specific data can be stored in the on-chip RAM starting at the address defined by the custom RTD data pointers.

### (2) Sense Resistor Channel Pointer

RTD measurements are performed ratiometrically relative to a known $R_{SENSE}$ resistor. The sense resistor channel pointer field indicates the differential channel the sense resistor is tied to for the RTD (see Table 31). Sense resistors are always measured differentially.

### (3) Sensor Configuration

The sensor configuration field is used to define various RTD properties. Configuration bits B20 and B21 determine if the RTD is a 2-, 3-, or 4-wire type (see Table 32).

The simplest configuration is the 2-wire configuration. While this setup is simple, parasitic errors due to IR drops in the leads result in systematic temperature errors. The 3-wire configuration cancels RTD lead resistance errors (if the lines are equal resistance) by applying two matched current sources to the RTD, one per lead. Mismatches in the two current sources are removed through transparent background calibration. 4-wire RTDs remove unbalanced RTD lead resistance by measuring directly across the sensor using a high impedance Kelvin sensing. 4-wire measurements with Kelvin $R_{SENSE}$ are useful in applications where sense resistor wiring parasitics can lead to errors; this is especially useful for low resistance PT-10 type RTDs. In this case, both the RTD and sense resistor have Kelvin sensing connections.

The next sensor configuration bits (B18 and B19) determine the excitation current mode. These bits are used to enable $R_{SENSE}$ sharing, where one sense resistor is used for multiple 2-, 3-, and/or 4-wire RTDs. In this case, the RTD ground connection is internal and each RTD points to the same $R_{SENSE}$ channel.

Bits B18 and B19 are also used to enable excitation current rotation to automatically remove parasitic thermocouple effects. Parasitic thermocouple effects may arise from the physical connected between the RTD and the measurement instrument. This mode is available for all 4-wire configurations using internal current source excitation.

**Table 29. RTD Channel Assignment Word**

| | (1) RTD TYPE | | | | | (2) SENSE RESISTOR CHANNEL POINTER | | | | | (3) SENSOR CONFIGURATION | | | | (4) EXCITATION CURRENT | | | | (5) RTD CURVE | | (6) CUSTOM RTD DATA POINTER | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TABLE 30 | | | | | TABLE 31 | | | | | TABLE 32 | | | | TABLE 33 | | | | TABLE 34 | | TABLES 92 TO 94 | | | | | | | | | |
| Measurement Class | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| RTD | Type = 10 to 18 | | | | | $R_{SENSE}$ Channel Assignment [4:0] | | | | | 2, 3, 4 Wire | | Excitation Mode | | Excitation Current [3:0] | | | | Curve [1:0] | | Custom Address [5:0] | | | | | | Custom Length-1 [5:0] | | | | | |

## APPLICATIONS INFORMATION

**Table 30. RTD Type**

| (1) RTD TYPE | | | | | |
|---|---|---|---|---|---|
| B31 | B30 | B29 | B28 | B27 | RTD TYPE |
| 0 | 1 | 0 | 1 | 0 | RTD PT-10 |
| 0 | 1 | 0 | 1 | 1 | RTD PT-50 |
| 0 | 1 | 1 | 0 | 0 | RTD PT-100 |
| 0 | 1 | 1 | 0 | 1 | RTD PT-200 |
| 0 | 1 | 1 | 1 | 0 | RTD PT-500 |
| 0 | 1 | 1 | 1 | 1 | RTD PT-1000 |
| 1 | 0 | 0 | 0 | 0 | RTD 1000 ($\alpha$ = 0.00375) |
| 1 | 0 | 0 | 0 | 1 | RTD NI-120 |
| 1 | 0 | 0 | 1 | 0 | RTD Custom |

**Table 31. Sense Resistor Channel Pointer**

| (2) SENSE RESISTOR CHANNEL POINTER | | | | | |
|---|---|---|---|---|---|
| B26 | B25 | B24 | B23 | B22 | SENSE RESISTOR CHANNEL |
| 0 | 0 | 0 | 0 | 0 | Invalid |
| 0 | 0 | 0 | 0 | 1 | Invalid |
| 0 | 0 | 0 | 1 | 0 | CH2-CH1 |
| 0 | 0 | 0 | 1 | 1 | CH3-CH2 |
| 0 | 0 | 1 | 0 | 0 | CH4-CH3 |
| 0 | 0 | 1 | 0 | 1 | CH5-CH4 |
| 0 | 0 | 1 | 1 | 0 | CH6-CH5 |
| 0 | 0 | 1 | 1 | 1 | CH7-CH6 |
| 0 | 1 | 0 | 0 | 0 | CH8-CH7 |
| 0 | 1 | 0 | 0 | 1 | CH9-CH8 |
| 0 | 1 | 0 | 1 | 0 | CH10-CH9 |
| All Other Combinations | | | | | Invalid |

# APPLICATIONS INFORMATION

**Table 32. RTD Sensor Configuration Selection**

| (3) SENSE CONFIGURATION | | | | MEASUREMENT MODE | | | | | BENEFITS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NUMBER OF WIRES | | EXCITATION MODE | | NUMBER OF WIRES | GROUND CONNECTION | CURRENT SOURCE ROTATION | SENSE RESISTOR SHARING | RTDs POSSIBLE PER DEVICE | CANCELS RTD MATCHED LEAD RESISTANCE | CANCELS RTD MISMATCH LEAD RESISTANCE | CANCELS PARASITIC THERMOCOUPLE EFFECTS | CANCELS $R_{SENSE}$ LEAD RESISTANCE |
| B21 | B20 | B19 | B18 | | | | | | | | | |
| 0 | 0 | 0 | 0 | 2-Wire | External | No | No | 2 | | | | |
| 0 | 0 | 0 | 1 | 2-Wire | Internal | No | Yes | 4 | | | | |
| 0 | 1 | 0 | 0 | 3-Wire | External | No | No | 2 | • | | | |
| 0 | 1 | 0 | 1 | 3-Wire | Internal | No | Yes | 4 | • | | | |
| 0 | 1 | 1 | X | Reserved | | | | | | | | |
| 1 | 0 | 0 | 0 | 4-Wire | External | No | No | 2 | • | • | | |
| 1 | 0 | 0 | 1 | 4-Wire | Internal | No | Yes | 2 | • | • | | |
| 1 | 0 | 1 | 0 | 4-Wire | Internal | Yes | Yes | 2 | • | • | • | |
| 1 | 0 | 1 | 1 | Reserved | | | | | | | | |
| 1 | 1 | 0 | 0 | 4-Wire, Kelvin $R_{SENSE}$ | External | No | No | 2 | • | • | | • |
| 1 | 1 | 0 | 1 | 4-Wire, Kelvin $R_{SENSE}$ | Internal | No | Yes | 2 | • | • | | • |
| 1 | 1 | 1 | 0 | 4-Wire, Kelvin $R_{SENSE}$ | Internal | Yes | Yes | 2 | • | • | • | • |
| 1 | 1 | 1 | 1 | Reserved | | | | | | | | |

# APPLICATIONS INFORMATION

### (4) Excitation Current

The next field in the channel assignment word (B17 to B14) controls the magnitude of the excitation current applied to the RTD (see Table 33). The current selected is the total current flowing through the RTD independent of the wiring configuration. The $R_{SENSE}$ current is 2x the sensor excitation current for 3-wire RTDs.

**Table 33. Total Excitation Current for All RTD Wire Types**

| (4) EXCITATION CURRENT | | | | |
|---|---|---|---|---|
| **B17** | **B16** | **B15** | **B14** | **CURRENT** |
| 0 | 0 | 0 | 0 | External |
| 0 | 0 | 0 | 1 | 5µA |
| 0 | 0 | 1 | 0 | 10µA |
| 0 | 0 | 1 | 1 | 25µA |
| 0 | 1 | 0 | 0 | 50µA |
| 0 | 1 | 0 | 1 | 100µA |
| 0 | 1 | 1 | 0 | 250µA |
| 0 | 1 | 1 | 1 | 500µA |
| 1 | 0 | 0 | 0 | 1mA |

In order to prevent soft or hard faults, select a current such that the maximum voltage drop across the sensor or sense resistor is nominally 1.0V. For example, if $R_{SENSE}$ is 10kΩ and the RTD is a PT-100, select an excitation current of 100µA for 2-wire and 4-wire RTDs and select 50µA for a 3-wire RTD. Alternatively, using a 1kΩ sense resistor with a PT-100 RTD allows 500µA excitation for any wiring configuration.

### (5) RTD Curve

Bits B13 and B12 set the RTD curve used and the corresponding Callendar-Van Dusen constants (shown in Table 34).

### (6) Custom RTD Data Pointer

In the case where an RTD not listed in Table 34 is used, a custom RTD table may be entered into the LTC2986.

See Custom RTD section near the end of this data sheet for more information.

**Table 34. RTD Curves: $RT = R0 \bullet (1 + a \bullet T + b \bullet T^2 + (T - 100°C) \bullet c \bullet T^3)$ for $T < 0°C$, $RT = R0 \bullet (1 + a \bullet T + b \bullet T^2)$ for $T > 0°C$**

| (5) CURVE | | | | | | |
|---|---|---|---|---|---|---|
| **B13** | **B12** | **CURVE** | **ALPHA** | **a** | **b** | **c** |
| 0 | 0 | European Curve | 0.00385 | 3.908300E-03 | –5.775000E-07 | –4.183000E-12 |
| 0 | 1 | American | 0.003911 | 3.969200E-03 | –5.849500E-07 | –4.232500E-12 |
| 1 | 0 | Japanese | 0.003916 | 3.973900E-03 | –5.870000E-07 | –4.400000E-12 |
| 1 | 1 | ITS-90 | 0.003926 | 3.984800E-03 | –5.870000E-07 | –4.000000E-12 |
| X | X | RTD1000-375 | 0.00375 | 3.810200E-03 | –6.018880E-07 | –6.000000E-12 |
| X | X | *NI-120 | N/A | N/A | N/A | N/A |

*NI-120 uses table based data.

# APPLICATIONS INFORMATION

### Fault Reporting – RTD

Each sensor type has unique fault reporting mechanism indicated in the most significant byte of the data output word. Table 35 shows faults reported in the measurement of RTDs.

Bit D31 indicates the RTD or $R_{SENSE}$ is open, shorted, or not plugged in. This is a hard fault and –999°C or °F is reported. Bit D30 indicates a bad ADC reading. This can be a result of either a broken (open) sensor or an excessive noise event (ESD or static discharge into the sensor path). This is a hard error and –999°C or °F is reported. In the case of an excessive noise event, the device should recover and the following conversions will be valid if the noise was a random infrequent event. Bits D29 and D28 are not used for RTDs. Bits D27 and D26 indicate over or under temperature limits (see Table 36). The calculated temperature is reported, but the accuracy may be compromised. Bit D25 indicates the absolute voltage measured by the ADC is beyond its normal operating range. If an RTD is used as the cold junction element, any hard or soft error is also flagged in the thermocouple result.

### Sense Resistor Channel Assignment

For each sense resistor tied to the LTC2986, a 32-bit channel assignment word is programmed into a memory location corresponding to the channel the sensor is tied to (see Table 37). This word includes (1) sense resistor selection and (2) sense resistor value.

**Table 35. RTD Fault Reporting**

| BIT | FAULT | ERROR TYPE | DESCRIPTION | OUTPUT RESULT |
|---|---|---|---|---|
| D31 | Sensor Hard Fault | Hard | Open or Short RTD or $R_{SENSE}$ | –999°C or °F |
| D30 | Hard ADC-Out-of-Range | Hard | Bad ADC Reading (Could Be Large External Noise Event) | –999°C or °F |
| D29 | Not Used for RTDs | N/A | Always 0 | Valid Reading |
| D28 | Not Used for RTDs | N/A | Always 0 | Valid Reading |
| D27 | Sensor Over Range | Soft | T > High Temp Limit (See Table 36) | Suspect Reading |
| D26 | Sensor Under Range | Soft | T < Low Temp Limit (See Table 36) | Suspect Reading |
| D25 | ADC Out-of-Range | Soft | ADC Absolute Input Voltage Is Beyond ±1.125 • $V_{REF}$/2 | Suspect Reading |
| D24 | Valid | N/A | Result Valid (Should Be 1) Discard Results if 0 | Valid Reading |

**Table 36. Voltage and Resistance Ranges**

| RTD TYPE | MIN Ω | MAX Ω | LOW TEMP LIMIT °C | HIGH TEMP LIMIT °C |
|---|---|---|---|---|
| PT-10 | 1.95 | 34.5 | –200 | 850 |
| PT-50 | 9.75 | 172.5 | –200 | 850 |
| PT-100 | 19.5 | 345 | –200 | 850 |
| PT-200 | 39 | 690 | –200 | 850 |
| PT-500 | 97.5 | 1725 | –200 | 850 |
| PT-1000 | 195 | 3450 | –200 | 850 |
| NI-120 | 66.6 | 380.3 | –80 | 260 |
| Custom Table | Lowest Table Entry | Highest Table Entry | Lowest Table Entry | Highest Table Entry |

**Table 37. Sense Resistor Channel Assignment Word**

| | (1) SENSOR TYPE | | | | | (2) SENSE RESISTOR VALUE (Ω) | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Table 38 | | | | | Table 39 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Measurement Class | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Sense Resistor | Type = 29 | | | | | Sense Resistor Value (17, 10) Up to ≈ 131,072Ω with 1/1024Ω Resolution | | | | | | | | | | | | | | | | | | | | | | | | | | |

# APPLICATIONS INFORMATION

### (1) Sensor Type

The sense resistor is selected by setting the first 5 input bits, B31 to B27, to 11101 (see Table 38).

**Table 38. Sense Resistor Selection**

| (1) SENSOR TYPE | | | | | |
|---|---|---|---|---|---|
| B31 | B30 | B29 | B28 | B27 | SENSOR TYPE |
| 1 | 1 | 1 | 0 | 1 | Sense Resistor |

### (2) Sense Resistor Value

The last field in the channel assignment word (B26 to B0) sets the value of the sense resistor within the range 0 to 131,072Ω with 1/1024Ω precision (see Table 39). The top 17 bits (B26 to B10) create the integer and bits B9 to B0 create the fraction of the sense resistor value.

### Example: 2-Wire RTD

The simplest RTD configuration is the 2-wire configuration, 2-wire RTDs follow the general convention shown in Figure 10. They require only two connections per RTD and can be tied directly to 2-lead RTD elements. This topology, however, causes errors due to parasitic lead resistance. If sharing is not selected (1 $R_{SENSE}$ per RTD), then $CH_{RTD}$ should be grounded. The ground connection should be removed if sharing is enabled (1 $R_{SENSE}$ for multiple RTDs).

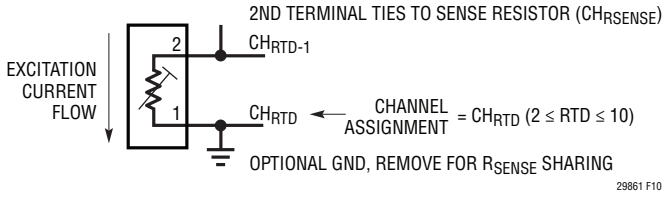


**Figure 10. 2-Wire RTD Channel Assignment Convention**

Sense resistor channel assignments follow the general convention shown in Figure 11. The sense resistor is tied between $CH_{RSENSE}$ and $CH_{RSENSE-1}$, where $CH_{RSENSE}$ is tied to the 2nd terminal of the RTD. Channel assignment data (see Table 37) is mapped into a memory location corresponding to $CH_{RSENSE}$.

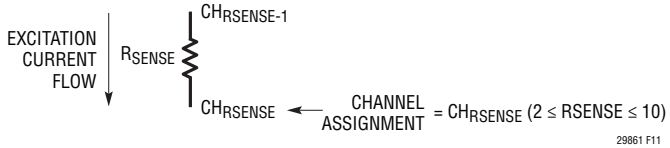


**Figure 11. Sense Resistor Channel Assignment Convention for 2-Wire RTDs**

### Example: 2-Wire RTDs with Shared $R_{SENSE}$

Figure 12 shows a typical temperature measurement system using multiple 2-wire RTDs. In this example, a PT-1000 RTD ties to CH7 and CH8 and an NI-120 RTD ties to CH9 and CH10. Using this configuration, the LTC2986 can digitize up to four 2-wire RTDs with a single sense resistor.

RTD #1 sensor type and configuration data are assigned to CH8. 32 bits of binary configuration data are mapped directly into memory locations 0x21C to 0x21F (see Table 40). RTD #2 sensor type and configuration data are assigned to CH10. 32-bits of binary configuration data are mapped directly into memory locations 0x224 to 0x227 (see Table 41). The sense resistor is assigned to CH6. The user-programmable value of this resistor is 5001.5Ω. 32 bits of binary configuration data are mapped directly into memory locations 0x214 to 0x217 (see Table 42).

A conversion is initiated on CH8 by writing 10001000 into memory location 0x000. Once the conversion is complete, the INTERRUPT pin goes HIGH and memory location 0x000 becomes 01001000. The resulting temperature in °C can be read from memory locations 0x02C to 0x02F (corresponding to CH8). A conversion can be initiated and read from CH10 in a similar fashion.

**Table 39. Example Sense Resistor Values**

| | (2) SENSE RESISTOR VALUE (Ω) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B26 | B25 | B24 | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| Example R | $2^{16}$ | $2^{15}$ | $2^{14}$ | $2^{13}$ | $2^{12}$ | $2^{11}$ | $2^{10}$ | $2^{9}$ | $2^{8}$ | $2^{7}$ | $2^{6}$ | $2^{5}$ | $2^{4}$ | $2^{3}$ | $2^{2}$ | $2^{1}$ | $2^{0}$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ |
| 10,000.2Ω | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 99.99521kΩ | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| 1.0023kΩ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |

## APPLICATIONS INFORMATION

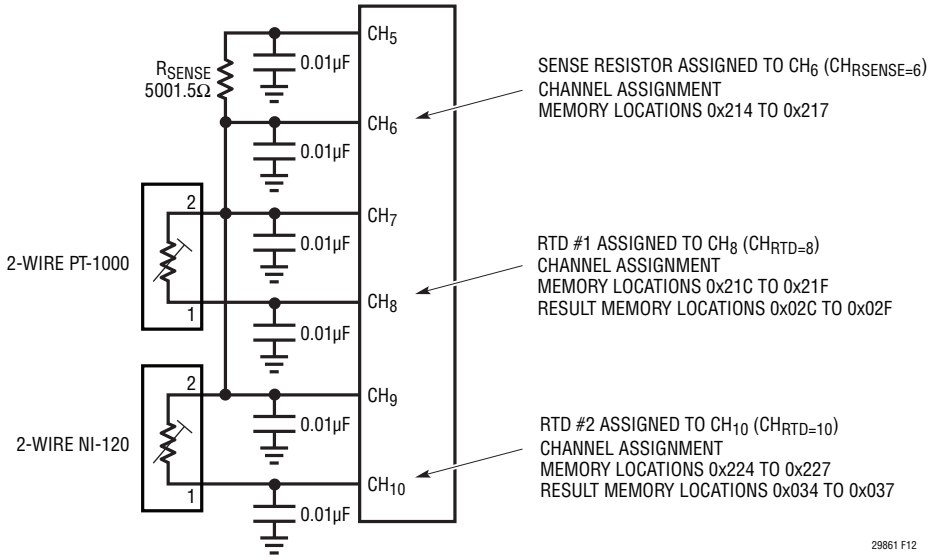


**Figure 12. Shared 2-Wire RTD Example**

**Table 40. Channel Assignment Data for 2-Wire RTD #1 (PT-1000, $R_{SENSE}$ on $CH_6$, 2-Wire, Shared $R_{SENSE}$, 10µA Excitation Current, $\alpha$ = 0.003916 Curve)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x21C | | | | | | | | MEMORY ADDRESS 0x21D | | | | | | | | MEMORY ADDRESS 0x21E | | | | | | | | MEMORY ADDRESS 0x21F | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) RTD TYPE | PT-1000 | 5 | 01111 | 0 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_6$ | 5 | 00110 | | | | | | 0 | 0 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | 2-Wire with Shared $R_{SENSE}$ | 4 | 0001 | | | | | | | | | | | 0 | 0 | 0 | 1 | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 10µA | 4 | 0010 | | | | | | | | | | | | | | | 0 | 0 | 1 | 0 | | | | | | | | | | | | |
| (5) Curve | Japanese, $\alpha$ = 0.003916 | 2 | 10 | | | | | | | | | | | | | | | | | | | 1 | 0 | | | | | | | | | | |
| (6) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# APPLICATIONS INFORMATION

**Table 41. Channel Assignment Data for 2-Wire RTD #2 (NI-120, $R_{SENSE}$ on $CH_6$, 2-Wire, Shared $R_{SENSE}$, 100µA Excitation Current)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x224 | | | | | | | | MEMORY ADDRESS 0x225 | | | | | | | | MEMORY ADDRESS 0x226 | | | | | | | | MEMORY ADDRESS 0x227 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) RTD TYPE | NI-120 | 5 | 10001 | 1 | 0 | 0 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_6$ | 5 | 00110 | | | | | | 0 | 0 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | 2-Wire with Shared $R_{SENSE}$ | 4 | 0001 | | | | | | | | | | | 0 | 0 | 0 | 1 | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 100µA | 4 | 0101 | | | | | | | | | | | | | | | 0 | 1 | 0 | 1 | | | | | | | | | | | | |
| (5) Curve | European $\alpha$ = 0.00385 | 2 | 00 | | | | | | | | | | | | | | | | | | | 0 | 0 | | | | | | | | | | |
| (6) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 42. Channel Assignment Data for Sense Resistor (Value = 5001.5Ω)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x214 | | | | | MEMORY ADDRESS 0x215 | | | | | | | | MEMORY ADDRESS 0x216 | | | | | | | | MEMORY ADDRESS 0x217 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Sensor Type | Sense Resistor | 5 | 11101 | 1 | 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Value | 5001.5Ω | 27 | 000010011100010011000000000 | | | | | | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPLICATIONS INFORMATION

### Example: 3-Wire RTD

3-wire RTD channel assignments follow the general convention shown in Figure 13. Terminals 1 and 2 tie to the input/excitation current sources and terminal 3 connects to the sense resistor. Channel assignment data is mapped to memory locations corresponding to $CH_{RTD}$.

Sense resistor channel assignments follow the general convention shown in Figure 14. The sense resistor is tied between $CH_{RSENSE}$ and $CH_{RSENSE-1}$, where $CH_{RSENSE}$ is tied to the 3rd terminal of the RTD and $CH_{RSENSE-1}$ is tied to ground (or left floating for $R_{SENSE}$ sharing). Channel assignment data (see Table 37) is mapped into the memory location corresponding to $CH_{RSENSE}$.

Figure 15 shows a typical temperature measurement system using a 3-wire RTD. In this example, a 3-wire RTD's terminals tie to CH9, CH8, and CH7. The sense resistor ties to CH7 and CH6. The sense resistor and RTD connect together at CH7.

The 3-wire RTD reduces the errors associated with parasitic lead resistance by applying excitation current to each RTD input. This first order cancellation removes matched lead resistance errors. This cancellation does not remove errors due to thermocouple effects or mismatched lead resistances. The RTD sensor type and configuration data are assigned to CH9. 32 bits of binary configuration data are mapped directly into memory locations 0x220 to 0x223 (see Table 43). The sense resistor is assigned to CH7. The user-programmable value of this resistor is 12150.39Ω. 32 bits of binary configuration data are mapped directly into memory locations 0x218 to 0x21B (see Table 44).

A conversion is initiated on CH9 by writing 10001001 into memory location 0x000 . Once the conversion is complete, the INTERRUPT pin goes HIGH and memory location 0x000 becomes 01001001. The resulting temperature in °C can be read from memory locations 0x030 to 0x033 (corresponding to CH9).

## APPLICATIONS INFORMATION

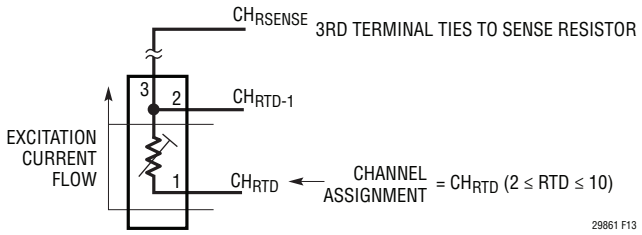


**Figure 13. 3-Wire RTD Channel Assignment Convention**

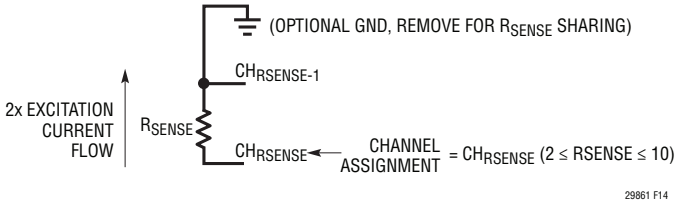


**Figure 14. 3-Wire Sense Resistor Channel Assignment Convention for 3-Wire RTDs**

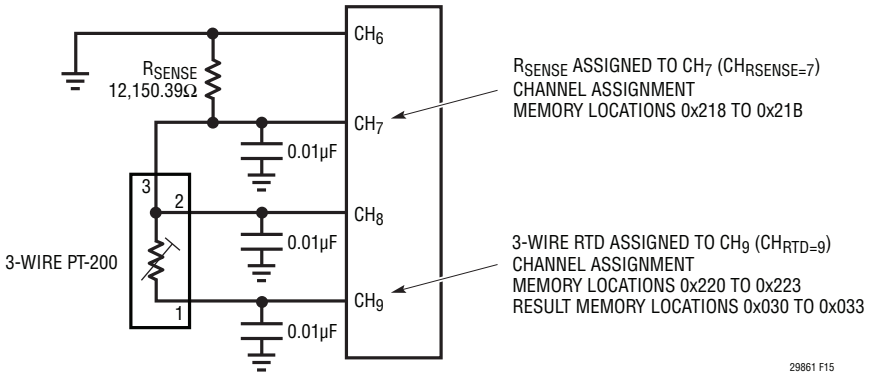


**Figure 15. 3-Wire RTD Example**

## APPLICATIONS INFORMATION

**Table 43. Channel Assignment Data for 3-Wire RTD (PT-200, $R_{SENSE}$ on $CH_7$, 3-Wire, 50µA Excitation Current, $\alpha$ = 0.003911 Curve)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x220 | | | | | | | | MEMORY ADDRESS 0x221 | | | | | | | | MEMORY ADDRESS 0x222 | | | | | | | | MEMORY ADDRESS 0x223 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) RTD TYPE | PT-200 | 5 | 01101 | 0 | 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_7$ | 5 | 00111 | | | | | | 0 | 0 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | 3-Wire | 4 | 0100 | | | | | | | | | | | 0 | 1 | 0 | 0 | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 50µA | 4 | 0100 | | | | | | | | | | | | | | | 0 | 1 | 0 | 0 | | | | | | | | | | | | |
| (5) Curve | American, $\alpha$ = 0.003911 | 2 | 01 | | | | | | | | | | | | | | | | | | | 0 | 1 | | | | | | | | | | |
| (6) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 44. Channel Assignment Data for Sense Resistor (Value = 12150.39Ω)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x218 | | | | | | | | MEMORY ADDRESS 0x219 | | | | | | | | MEMORY ADDRESS 0x21A | | | | | | | | MEMORY ADDRESS 0x21B | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Sensor Type | Sense Resistor | 5 | 11101 | 1 | 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Value | 12150.39Ω | 27 | 000101111011101100110001111 | | | | | | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |

## APPLICATIONS INFORMATION

### Example: Standard 4-Wire RTD (No Rotation or $R_{SENSE}$ Sharing)

Standard 4-wire RTD channel assignments follow the general convention shown in Figure 16. Terminal 1 is tied to ground, terminals 2 and 3 (Kelvin sensed signal) tie to $CH_{RTD}$ and $CH_{RTD-1}$, and the 4th terminal ties to the sense resistor. Channel assignment data (see Table 29) is mapped to memory locations corresponding to $CH_{RTD}$.

Sense resistor channel assignments follow the general convention shown in Figure 17. The sense resistor is tied between $CH_{RSENSE}$ and $CH_{RSENSE-1}$, where $CH_{RSENSE}$ is tied to the 4th terminal of the RTD. Channel assignment data (see Table 37) is mapped into a memory location corresponding to $CH_{RSENSE}$.

Figure 18 shows a typical temperature measurement system using a 4-wire RTD. In this example, a 4-wire RTD's terminals tie to GND, CH4, CH3, and CH2. The sense resistor ties to CH2 and CH1. The sense resistor and RTD share a common connection at CH2. The RTD sensor type and configuration data are assigned to CH4. 32 bits of binary configuration data are mapped directly into memory locations 0x20C to 0x20F (see Table 45). The sense resistor is assigned to CH2. The user-programmable value of this resistor is 5000.2Ω. 32 bits of binary configuration data are mapped directly into memory locations 0x204 to 0x207 (see Table 46).

A conversion is initiated on CH4 by writing 10000100 into the data byte at memory location 0x000. Once the conversion is complete, the INTERRUPT pin goes HIGH and memory location 0x000 becomes 01000100. The resulting temperature in °C can be read from memory locations 0x01C to 0x01F (corresponding to CH4).

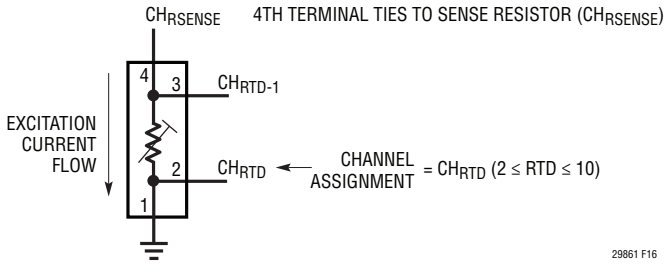


**Figure 16. 4-Wire RTD Channel Assignment Convention**

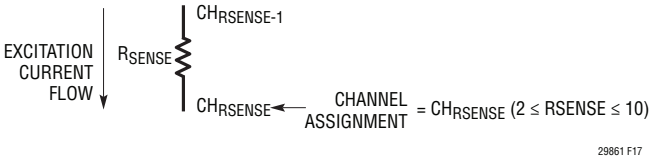


**Figure 17. Sense Resistor Channel Assignment Convention for 4-Wire RTDs**

## APPLICATIONS INFORMATION

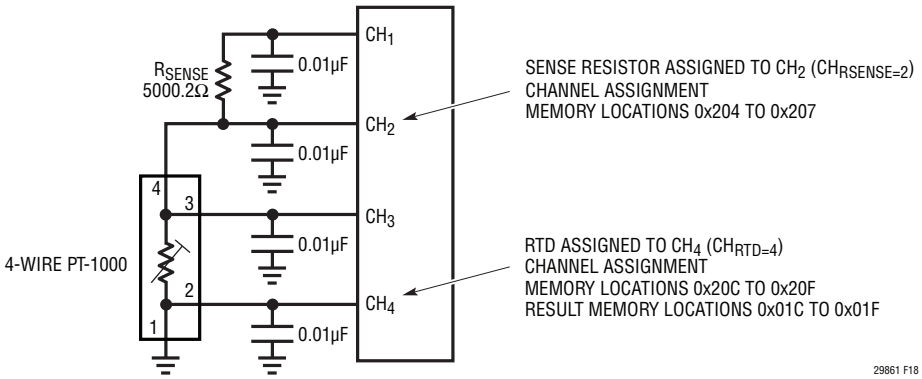


**Figure 18. Standard 4-Wire RTD Example**

**Table 45. Channel Assignment Data for 4-Wire RTD (PT-1000, $R_{SENSE}$ on $CH_2$, Standard 4-Wire, 25µA Excitation Current, $\alpha$ = 0.00385 Curve)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x20C | | | | | | | | MEMORY ADDRESS 0x20D | | | | | | | | MEMORY ADDRESS 0x20E | | | | | | | | MEMORY ADDRESS 0x20F | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) RTD TYPE | PT-1000 | 5 | 01111 | 0 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_2$ | 5 | 00010 | | | | | | 0 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | 4-Wire, No Rotate, No Share | 4 | 1000 | | | | | | | | | | | 1 | 0 | 0 | 0 | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 25µA | 4 | 0011 | | | | | | | | | | | | | | | 0 | 0 | 1 | 1 | | | | | | | | | | | | |
| (5) Curve | European, $\alpha$ = 0.00385 | 2 | 00 | | | | | | | | | | | | | | | | | | | 0 | 0 | | | | | | | | | | |
| (6) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 46. Channel Assignment Data for Sense Resistor (Value = 5000.2Ω)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x204 | | | | | | | | MEMORY ADDRESS 0x205 | | | | | | | | MEMORY ADDRESS 0x206 | | | | | | | | MEMORY ADDRESS 0x207 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Sensor Type | Sense Resistor | 5 | 11101 | 1 | 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Value | 5000.2Ω | 27 | 000010011100010000011001100 | | | | | | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |

## APPLICATIONS INFORMATION

### Example: 4-Wire RTD with Rotation

One method to improve the accuracy of an RTD over the standard 4-wire implementation is by rotating the excitation current source. Parasitic thermocouple effects are automatically removed through autorotation. In order to perform autorotation, the 1st terminal of the RTD ties to $CH_{RTD+1}$ instead of GND, as in the standard case. This allows the LTC2986 to automatically change the direction of the current source without the need for additional external components.

4-wire RTD with rotation channel assignments follow the general convention shown in Figure 19. Terminal 1 is tied to $CH_{RTD+1}$, terminals 2 and 3 (Kelvin sensed signal) tie to $CH_{RTD}$ and $CH_{RTD-1}$, and the 4th terminal ties to the sense resistor. Channel assignment data (see Table 29) is mapped to memory locations corresponding to $CH_{RTD}$.

Sense resistor channel assignments follow the general convention shown in Figure 20. The sense resistor is tied between $CH_{RSENSE}$ and $CH_{RSENSE-1}$, where $CH_{RSENSE}$ is tied to the 4th terminal of the RTD. Channel assignment data is mapped into a memory location corresponding to $CH_{RSENSE}$.

Figure 21 shows a typical temperature measurement system using a rotating 4-wire RTD. In this example a 4-wire RTD's terminals tie to CH10, CH9, CH8, and CH6. The sense resistor is tied to CH6 and CH5. The sense resistor and RTD connect together at CH6. The RTD sensor type and configuration data are assigned to CH9. 32 bits of binary configuration data are mapped directly into memory locations 0x220 to 0x223 (see Table 47). The sense resistor is assigned to CH6. The user programmable value of this resistor is 10.0102kΩ. 32 bits of binary configuration data are mapped directly into memory locations 0x214 to 0x217 (see Table 48).

A conversion is initiated on CH9 by writing 10001001 into memory location 0x000. Once the conversion is complete, the INTERRUPT pin goes HIGH and memory location 0x000 becomes 01001001. The resulting temperature in °C can be read from memory locations 0x030 to 0x033 (corresponding to CH9).

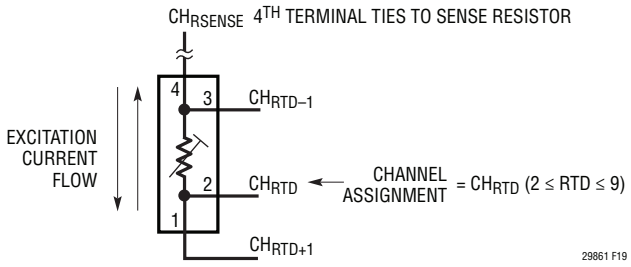


**Figure 19. 4-Wire RTD Channel Assignment Convention**

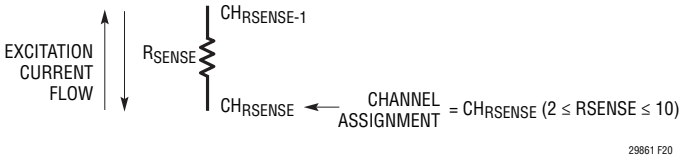


**Figure 20. Sense Resistor Channel Assignment Convention for 4-Wire RTDs with Rotation**

# APPLICATIONS INFORMATION

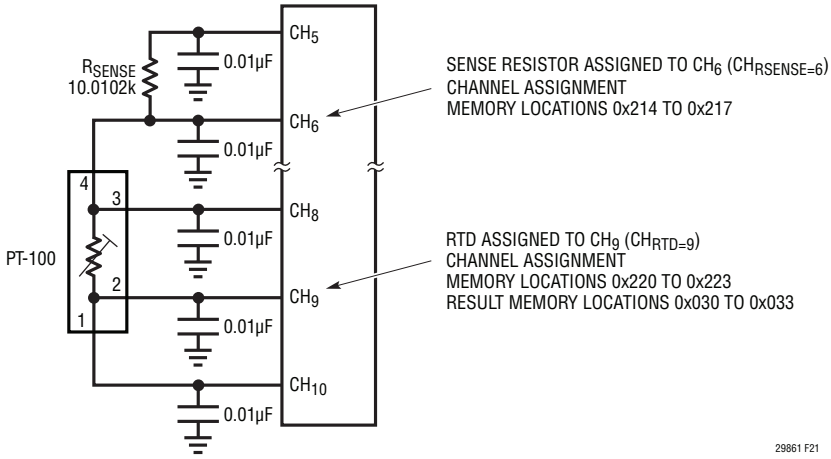


**Figure 21. Rotating 4-Wire RTD Example**

**Table 47. Channel Assignment Data for Rotating 4-Wire RTD (PT-100, $R_{SENSE}$ on $CH_6$, Rotating 4-Wire, 100µA Excitation Current, $\alpha$ = 0.003911 Curve)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x220 | | | | | | | | MEMORY ADDRESS 0x221 | | | | | | | | MEMORY ADDRESS 0x222 | | | | | | | | MEMORY ADDRESS 0x223 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) RTD TYPE | PT-100 | 5 | 01100 | 0 | 1 | 1 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_6$ | 5 | 00110 | | | | | | 0 | 0 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | 4-Wire with Rotation | 4 | 1010 | | | | | | | | | | 1 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 100µA | 4 | 0101 | | | | | | | | | | | | | | 0 | 1 | 0 | 1 | | | | | | | | | | | | | |
| (5) Curve | American, $\alpha$ = 0.003911 | 2 | 01 | | | | | | | | | | | | | | | | | | 0 | 1 | | | | | | | | | | | |
| (6) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 48. Channel Assignment Data for Sense Resistor (Value = 10.0102kΩ)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x214 | | | | | | | | MEMORY ADDRESS 0x215 | | | | | | | | MEMORY ADDRESS 0x216 | | | | | | | | MEMORY ADDRESS 0x217 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Sensor Type | Sense Resistor | 5 | 11101 | 1 | 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Value | 10.0102kΩ | 27 | 000100111000110100011001100 | | | | | | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |

# APPLICATIONS INFORMATION

### Example: Multiple 4-Wire RTDs with Shared $R_{SENSE}$

Figure 22 shows a typical temperature measurement system using two 4-wire RTDs with a shared $R_{SENSE}$. The LTC2986 can support up to two 4-wire RTDs with a single sense resistor. In this example, the first 4-wire RTD's terminals tie to CH5, CH4, CH3, and CH2 and the 2nd ties to CH8, CH7, CH6, and CH2. The sense resistor ties to CH1 and CH2. The sense resistor and both RTDs connect together at CH2. This channel assignment convention is identical to that of the rotating RTD. This topology supports both rotated and non-rotated RTD excitations. Channel assignment data for each sensor is shown in Tables 49 to 51.

A conversion is initiated on CH4 by writing 10000100 into memory location 0x000. Once the conversion is complete, the INTERRUPT pin goes HIGH and memory location 0x000 becomes 01000100. The resulting temperature in °C can be read from memory locations 0x01C to 0x01F (corresponding to CH4). A conversion can be initiated and read from CH7 in a similar fashion.

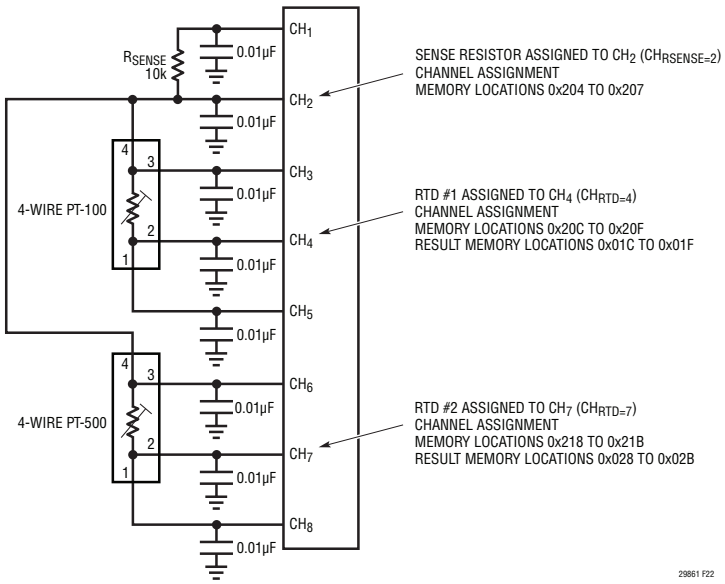


**Figure 22. Shared $R_{SENSE}$ 4-Wire RTD Example**

**Table 49. Channel Assignment Data for 4-Wire RTD #1 (PT-100, $R_{SENSE}$ on $CH_2$, 4-Wire, Shared $R_{SENSE}$, Rotated 100µA Excitation Current, $\alpha$ = 0.003926 Curve)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x20C | | | | | | | | MEMORY ADDRESS 0x20D | | | | | | | | MEMORY ADDRESS 0x20E | | | | | | | | MEMORY ADDRESS 0x20F | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) RTD TYPE | PT-100 | 5 | 01100 | 0 | 1 | 1 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_2$ | 5 | 00010 | | | | | | 0 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | 4-Wire Rotated | 4 | 1010 | | | | | | | | | | | 1 | 0 | 1 | 0 | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 100µA | 4 | 0101 | | | | | | | | | | | | | | | 0 | 1 | 0 | 1 | | | | | | | | | | | | |
| (5) Curve | ITS-90, $\alpha$ = 0.003926 | 2 | 11 | | | | | | | | | | | | | | | | | | | 1 | 1 | | | | | | | | | | |
| (6) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# APPLICATIONS INFORMATION

**Table 50. Channel Assignment Data for 4-Wire RTD #2 (PT-500, $R_{SENSE}$ on $CH_2$, 4-Wire, Rotated 50µA Excitation Current, $\alpha$ = 0.003911 Curve)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x218 | | | | | | | | MEMORY ADDRESS 0x219 | | | | | | | | MEMORY ADDRESS 0x21A | | | | | | | | MEMORY ADDRESS 0x21B | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) RTD TYPE | PT-500 | 5 | 01110 | 0 | 1 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_2$ | 5 | 00010 | | | | | | 0 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | 4-Wire Shared, No Rotation | 4 | 1001 | | | | | | | | | | | 1 | 0 | 0 | 1 | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 50µA | 4 | 0100 | | | | | | | | | | | | | | | 0 | 1 | 0 | 0 | | | | | | | | | | | | |
| (5) Curve | American, $\alpha$ = 0.003911 | 2 | 01 | | | | | | | | | | | | | | | | | | | 0 | 1 | | | | | | | | | | |
| (6) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 51. Channel Assignment Data for Sense Resistor (Value = 10.000kΩ)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x204 | | | | | | | | MEMORY ADDRESS 0x205 | | | | | | | | MEMORY ADDRESS 0x206 | | | | | | | | MEMORY ADDRESS 0x207 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Sensor Type | Sense Resistor | 5 | 11101 | 1 | 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Value | 10.000kΩ | 27 | 000100111000100000000000000 | | | | | | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPLICATIONS INFORMATION

### Example: 4-Wire RTD with Kelvin $R_{SENSE}$

It is possible to cancel the parasitic lead resistance in the sense resistors by configuring the 4-wire RTD with a 4-wire (Kelvin connected) sense resistor. This is useful when using a PT-10 or PT-50 with a small valued $R_{SENSE}$ or when the sense resistor is remotely located or in applications requiring extreme precision.

The 4-wire RTD channel assignments follow the general conventions previously defined (Figure 19) for a standard 4-wire RTD. The sense resistor follows the convention shown in Figure 23.

Figure 24 shows a typical temperature measurement system using a 4-wire RTD with a Kelvin connected $R_{SENSE}$. In this example, the 4-wire RTD's terminals tie to CH10, CH9, CH8, and CH6. The sense resistor ties to CH6, CH5, and CH4 and excitation current is applied to CH4 and CH10. The sense resistor's nominal value is 1kΩ in order to accommodate a 1mA excitation current. The sense resistor and RTD connect together at CH6. This topology supports rotated, shared and standard 4-wire RTD topologies. If rotated or shared configuration are not used then terminal 1 of the RTD is tied to ground instead of CH10, freeing up one input channel. Channel assignment data is shown in Tables 52 and 53.

A conversion is initiated on CH9 by writing 10001001 into memory location 0x000. Once the conversion is complete, the INTERRUPT pin goes HIGH and memory location 0x000 becomes 01001001 (see Table 6). The resulting temperature in °C can be read from memory locations 0x030 to 0x033 (corresponding to CH9).

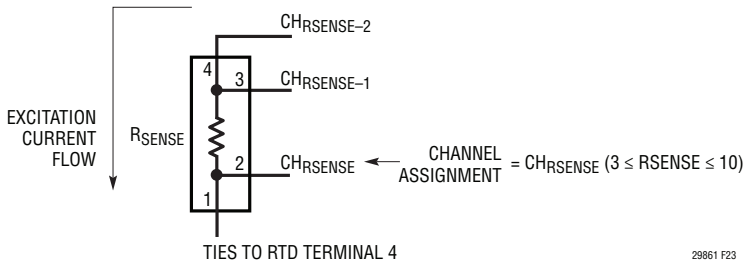


**Figure 23. Sense Resistor with Kelvin Connections Channel Assignment Convention**

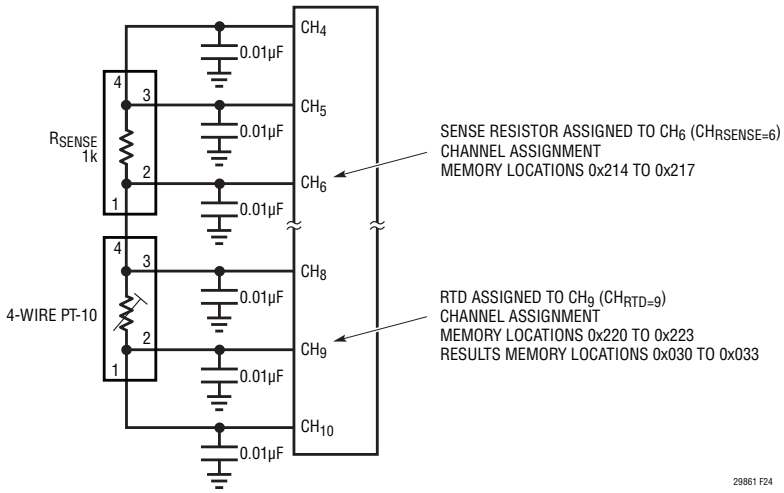


**Figure 24. Sense Resistor with Kelvin Connections Example**

# APPLICATIONS INFORMATION

**Table 52. Channel Assignment Data for 4-Wire RTD with Kelvin Connected $R_{SENSE}$ (PT-10, $R_{SENSE}$ on $CH_6$, 4-Wire, Kelvin $R_{SENSE}$ with Rotated 1mA Excitation Current, $\alpha$ = 0.003916 Curve)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x220 | | | | | | | | MEMORY ADDRESS 0x221 | | | | | | | | MEMORY ADDRESS 0x222 | | | | | | | | MEMORY ADDRESS 0x223 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) RTD TYPE | PT-10 | 5 | 01010 | 0 | 1 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_6$ | 5 | 00110 | | | | | | 0 | 0 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | 4-Wire Kelvin $R_{SENSE}$ and Rotation | 4 | 1110 | | | | | | | | | | | 1 | 1 | 1 | 0 | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 1mA | 4 | 1000 | | | | | | | | | | | | | | | 1 | 0 | 0 | 0 | | | | | | | | | | | | |
| (5) Curve | Japanese, $\alpha$ = 0.003916 | 2 | 10 | | | | | | | | | | | | | | | | | | | 1 | 0 | | | | | | | | | | |
| (6) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 53. Channel Assignment Data for Sense Resistor (Value = 1000Ω)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x214 | | | | | | | | MEMORY ADDRESS 0x215 | | | | | | | | MEMORY ADDRESS 0x216 | | | | | | | | MEMORY ADDRESS 0x217 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Sensor Type | Sense Resistor | 5 | 11101 | 1 | 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Value | 1000Ω | 27 | 00000001111101000000000000 | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# APPLICATIONS INFORMATION

## THERMISTOR MEASUREMENTS

### Channel Assignment – Thermistor

For each thermistor tied to the LTC2986, a 32-bit channel assignment word is programmed into a memory location corresponding to the channel the sensor is tied to (see Table 54). This data includes (1) thermistor type, (2) sense resistor channel pointer, (3) sensor configuration, (4) excitation current, (5) Steinhart-Hart address pointer or custom table address pointer.

### (1) Thermistor Type

The thermistor type is determined by the first five input bits (B31 to B27) as shown in Table 55. Linearization coefficients based on Steinhart-Hart equation for commonly used Thermistor types 44004/44033, 44005/44030, 44006/44031, 44007/44034, 44008/44032 and YSI-400 are built into the device. If other custom thermistors are used, Thermistor Custom Steinhart-Hart or Thermistor Custom Table (temperature vs resistance) can be selected. In this case, user specific data can be stored in the on-chip RAM starting at the address defined in Thermistor Custom Steinhart-Hart or Thermistor Custom Table address pointers.

### (2) Sense Resistor Channel Pointer

Thermistor measurements are performed ratiometrically relative to a known $R_{SENSE}$ resistor. The sense resistor channel pointer field indicates the differential channel the sense resistor is tied to for the current thermistor (see Table 31).

**Table 54. Thermistor Channel Assignment Word**

| | (1) THERMISTOR TYPE | | | | | (2) SENSE RESISTOR CHANNEL POINTER | | | | | (3) SENSOR CONFIGURATION | | | (4) EXCITATION CURRENT | | | | | | (5) CUSTOM THERMISTOR DATA POINTER | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TABLE 55 | | | | | TABLE 31 | | | | | TABLE 56 | | | TABLE 57 | | | | | | TABLES 96, 97, 98, 100, 101 | | | | | | | | | |
| Measurement Class | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Thermistor | Type = 19 to 27 | | | | | $R_{SENSE}$ Channel Pointer [4:0] | | | | | SGL = 1 DIFF = 0 | Excitation Mode | | Excitation Current [3:0] | | | | Not Used 0 0 0 | | | Custom Address [5:0] | | | | | | Custom Length –1 [5:0] | | | | | |

**Table 55. Thermistor Type: $1/T = A + B \bullet \ln(R) + C \bullet \ln(R)^2 + D \bullet \ln(R)^3 + E \bullet \ln(R)^4 + F \bullet \ln(R)^5$**

| B31 | B30 | B29 | B28 | B27 | THERMISTOR TYPE | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | Thermistor 44004/44033 2.252kΩ at 25°C | 1.46800E-03 | 2.38300E-04 | 0 | 1.00700E-07 | 0 | 0 |
| 1 | 0 | 1 | 0 | 0 | Thermistor 44005/44030 3kΩ at 25°C | 1.40300E-03 | 2.37300E-04 | 0 | 9.82700E-08 | 0 | 0 |
| 1 | 0 | 1 | 0 | 1 | Thermistor 44007/44034 5kΩ at 25°C | 1.28500E-03 | 2.36200E-04 | 0 | 9.28500E-08 | 0 | 0 |
| 1 | 0 | 1 | 1 | 0 | Thermistor 44006/44031 10kΩ at 25°C | 1.03200E-03 | 2.38700E-04 | 0 | 1.58000E-07 | 0 | 0 |
| 1 | 0 | 1 | 1 | 1 | Thermistor 44008/44032 30kΩ at 25°C | 9.37600E-04 | 2.20800E-04 | 0 | 1.27600E-07 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | Thermistor YSI-400 2.252kΩ at 25°C | 1.47134E-03 | 2.37624E-04 | 0 | 1.05034E-07 | 0 | 0 |
| 1 | 1 | 0 | 0 | 1 | Spectrum 1003k 1kΩ at 25°C | 1.445904E-3 | 2.68399E-04 | 0 | 1.64066E-07 | 0 | 0 |
| 1 | 1 | 0 | 1 | 0 | Thermistor Custom Steinhart-Hart | user input | user input | user input | user input | user input | user input |
| 1 | 1 | 0 | 1 | 1 | Thermistor Custom Table | not used | not used | not used | not used | not used | not used |

# APPLICATIONS INFORMATION

### (3) Sensor Configuration

The sensor configuration field is used to define various thermistor properties. Configuration bit B21 is set high for single-ended (measurement relative to COM) and low for differential (see Table 56).

**Table 56. Sensor Configuration Data**

| (3) SENSOR CONFIGURATION | | | | | |
|---|---|---|---|---|---|
| SGL | EXCITATION MODE | | SINGLE-ENDED/ DIFFERENTIAL | SHARE $R_{SENSE}$ | ROTATE |
| B21 | B20 | B19 | | | |
| 0 | 0 | 0 | Differential | No | No |
| 0 | 0 | 1 | Differential | Yes | Yes |
| 0 | 1 | 0 | Differential | Yes | No |
| 0 | 1 | 1 | | Reserved | |
| 1 | 0 | 0 | Single-Ended | No | No |
| 1 | 0 | 1 | | Reserved | |
| 1 | 1 | 0 | | Reserved | |
| 1 | 1 | 1 | | Reserved | |

The next sensor configuration bits (B19 and B20) determine the excitation current mode. These bits are used to enable $R_{SENSE}$ sharing, where one sense resistor is used for multiple thermistors. In this case, the thermistor ground connection is internal and each thermistor points to the same $R_{SENSE}$ channel.

Bits B19 and B20 are also used to enable excitation current rotation to automatically remove parasitic thermocouple effects. Parasitic thermocouple effects may arise from the physical connection between the thermistor and the measurement instrument. This mode is available for differential thermistor configurations using internal current source excitation.

### (4) Excitation Current

The next field in the channel assignment word (B18 to B15) controls the magnitude of the excitation current applied to the thermistor (see Table 57). In order to prevent hard or soft faults, select a current such that the maximum voltage drop across the sensor or sense resistor is nominally 1.0V. The LTC2986 has no special requirements related to the ratio between the voltage drop across the sense resistor and the sensor. Consequently, it is possible to have a sense resistor several orders of magnitude smaller than the maximum sensor value. For optimal performance over the full thermistor temperature range, auto ranged current can be selected. In this case, the LTC2986 conversion is performed in three cycles (instead of the standard two cycles) (see Table 83). The first cycle determines the optimal excitation current for the sensor resistance value and $R_{SENSE}$ value. The following two cycles use that current to measure the thermistor temperature.

### (5) Steinhart-Hart Address/Custom Table Address

See Custom Thermistors section near the end of this data sheet for more information.

**Table 57. Excitation Current for Thermistors**

| (4) EXCITATION CURRENT | | | | |
|---|---|---|---|---|
| B18 | B17 | B16 | B15 | CURRENT |
| 0 | 0 | 0 | 0 | Reserved |
| 0 | 0 | 0 | 1 | 250nA |
| 0 | 0 | 1 | 0 | 500nA |
| 0 | 0 | 1 | 1 | 1µA |
| 0 | 1 | 0 | 0 | 5µA |
| 0 | 1 | 0 | 1 | 10µA |
| 0 | 1 | 1 | 0 | 25µA |
| 0 | 1 | 1 | 1 | 50µA |
| 1 | 0 | 0 | 0 | 100µA |
| 1 | 0 | 0 | 1 | 250µA |
| 1 | 0 | 1 | 0 | 500µA |
| 1 | 0 | 1 | 1 | 1mA |
| 1 | 1 | 0 | 0 | Auto Range* |
| 1 | 1 | 0 | 1 | Invalid |
| 1 | 1 | 1 | 0 | Invalid |
| 1 | 1 | 1 | 1 | External |

*Auto Range not allowed for custom sensors.

# APPLICATIONS INFORMATION

### Fault Reporting – Thermistor

Each sensor type has unique fault reporting mechanism indicated in the upper byte of the data output word. Table 58 shows faults reported during the measurement of thermistors.

Bit D31 indicates the thermistor or $R_{SENSE}$ is open, shorted, or not plugged in. This is a hard fault and –999°C is reported. Bit D30 indicates a bad ADC reading. This could be a result of either a broken (open) sensor or an excessive noise event (ESD or static discharge into the sensor path). This is a hard error and –999°C is output. In the case of an excessive noise event, the device should recover and the following conversions will be valid if the noise event was a random infrequent event. Bits D29 and D28 are not used for thermistors. Bits D27 and D26 indicate the reading is over or under temperature limits (see Table 59). The calculated temperature is reported, but the accuracy may be compromised. Bit D25 indicates the absolute voltage measured by the ADC is beyond its normal operating range. If a thermistor is used as the cold junction element, any hard or soft error is flagged in the thermocouple result.

**Table 58. Thermistor Fault Reporting**

| BIT | FAULT | ERROR TYPE | DESCRIPTION | OUTPUT RESULT |
|---|---|---|---|---|
| D31 | Sensor Hard Fault | Hard | Open or Short Thermistor or $R_{SENSE}$ | –999°C |
| D30 | Hard ADC-Out-of-Range | Hard | Bad ADC Reading (Could Be Large External Noise Event) | –999°C |
| D29 | Not Used for Thermistors | N/A | Always 0 | Valid Reading |
| D28 | Not Used for Thermistors | N/A | Always 0 | Valid Reading |
| D27 | Sensor Over Range* | Soft | T > High Temp Limit | Suspect Reading |
| D26 | Sensor Under Range* | Soft | T < Low Temp Limit | Suspect Reading |
| D25 | ADC Out-of-Range | Soft | ADC Absolute Input Voltage Is Beyond ±1.125 • $V_{REF}$/2 | Suspect Reading |
| D24 | Valid | N/A | Result Valid (Should Be 1) Discard Results if 0 | Valid Reading |

*Do not apply to custom Steinhart-Hart sensor type. Custom table thermistor over/under range is determined by the resistor table values, see custom thermistor table example for details.

**Table 59. Thermistor Temperature/Resistance Range**

| THERMISTOR TYPE | MIN (Ω) | MAX (Ω) | LOW Temp Limit (°C) | HIGH Temp Limit (°C) |
|---|---|---|---|---|
| Thermistor 44004/44033 2.252kΩ at 25°C | 41.9 | 75.79k | –40 | 150 |
| Thermistor 44005/44030 3kΩ at 25°C | 55.6 | 101.0k | –40 | 150 |
| Thermistor 44007/44034 5kΩ at 25°C | 92.7 | 168.3k | –40 | 150 |
| Thermistor 44006/44031 10kΩ at 25°C | 237.0 | 239.8k | –40 | 150 |
| Thermistor 44008/44032 30kΩ at 25°C | 550.2 | 884.6k | –40 | 150 |
| Thermistor YSI 400 2.252kΩ at 25°C | 6.4 | 1.66M | –80 | 250 |
| Spectrum 1003K 1kΩ at 25°C | 51.1 | 39.51k | –50 | 125 |
| Thermistor Custom Steinhart-Hart | N/A | N/A | N/A | N/A |
| Thermistor Custom Table | Second Table Entry | Last Table Entry | | |

## APPLICATIONS INFORMATION

### Example: Single-Ended Thermistor

The simplest thermistor configuration is the single-ended configuration. Thermistors using this configuration share a common ground (COM) between all sensors and are each tied to a unique sense resistor ($R_{SENSE}$ sharing is not allowed for single-ended thermistors). Single-ended thermistors follow the convention shown in Figure 25. Terminal 1 ties to ground (COM) and terminal 2 ties to $CH_{THERM}$ and the sense resistor. Channel assignment data (see Table 54) is mapped to memory locations corresponding to $CH_{THERM}$.

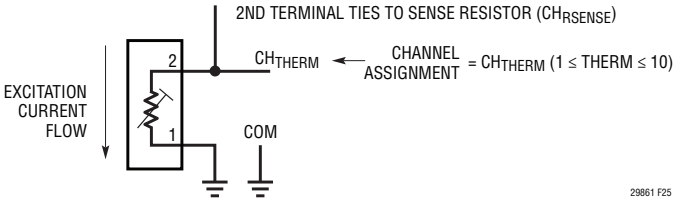


**Figure 25. Single-Ended Thermistor Channel Assignment Convention**

Sense resistor channel assignments follow the general convention shown in Figure 26. The sense resistor is tied between $CH_{RSENSE}$ and $CH_{RSENSE-1}$, where $CH_{RSENSE}$ is tied to the 2nd terminal of the thermistor. Channel assignment data (see Table 37) is mapped into the memory location corresponding to $CH_{RSENSE}$.

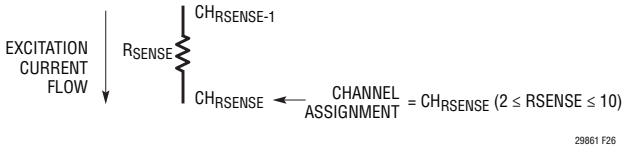


**Figure 26. Sense Resistor Channel Assignment Convention**

Figure 27 shows a typical temperature measurement system using a single-ended thermistor. In this example a 10kΩ (44031 type) thermistor is tied to a 10.1kΩ sense resistor. The thermistor is assigned channel CH5 (memory locations 0x210 to 0x213) and the sense resistor to CH4 (memory locations 0x20C to 0x20F). Channel assignment data are shown in Tables 60 and 61.

A conversion is initiated on CH5 by writing 10000101 into memory location 0x000. Once the conversion is complete, the INTERRUPT pin goes HIGH and memory location 0x000 becomes 01000101. The resulting temperature in °C can be read from memory locations 0x020 to 0x023 (corresponding to CH5).

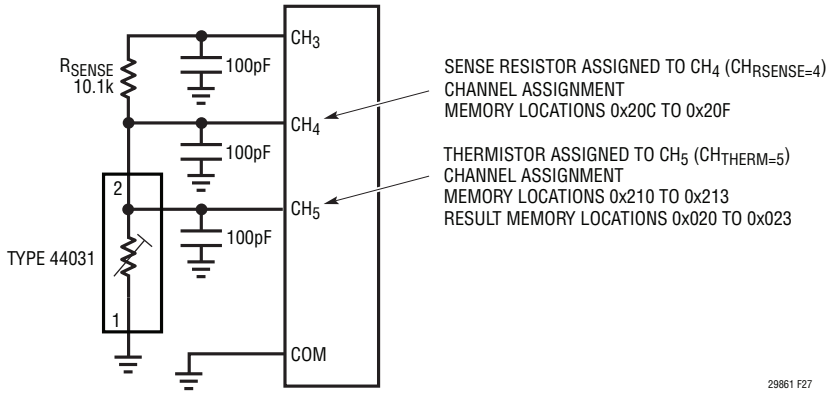


**Figure 27. Single-Ended Thermistor Example**

# APPLICATIONS INFORMATION

**Table 60. Channel Assignment Data for Single-Ended Thermistor (44006/44031 10kΩ at 25°C Type Thermistor, Single-Ended Configuration, $R_{SENSE}$ on $CH_4$, 1µA Excitation Current)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x210 | | | | | | | | MEMORY ADDRESS 0x211 | | | | | | | | MEMORY ADDRESS 0x212 | | | | | | | | MEMORY ADDRESS 0x213 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Thermistor Type | 44006/44031 10kΩ at 25°C | 5 | 10110 | 1 | 0 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_4$ | 5 | 00100 | | | | | | 0 | 0 | 1 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | Single-Ended | 3 | 100 | | | | | | | | | | | 1 | 0 | 0 | | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 1µA | 4 | 0011 | | | | | | | | | | | | | | 0 | 0 | 1 | 1 | | | | | | | | | | | | | |
| Not Used | Set These Bits to 0 | 3 | 000 | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | | | | | | | | | | |
| (5) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 61. Channel Assignment Data for Sense Resistor (Value = 10.1kΩ)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x20C | | | | | | | | MEMORY ADDRESS 0x20D | | | | | | | | MEMORY ADDRESS 0x20E | | | | | | | | MEMORY ADDRESS 0x20F | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Sensor Type | Sense Resistor | 5 | 11101 | 1 | 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Value | 10.1kΩ | 27 | 000100111011101000000000000 | | | | | | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPLICATIONS INFORMATION

### Example: Differential Thermistor

The differential thermistor configuration allows separate ground sensing for each sensor. In this standard differential configuration, one sense resistor is used for each thermistor. Differential thermistors follow the convention shown in Figure 28. Terminal 1 ties to $CH_{THERM}$ and is shorted to ground and terminal 2 ties $CH_{THERM-1}$ to and the sense resistor. Channel assignment data (see Table 54) is mapped to memory locations corresponding to $CH_{THERM}$.

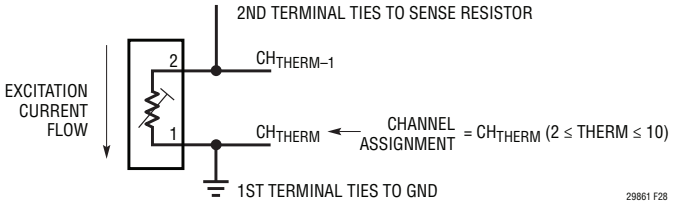


**Figure 28. Differential Thermistor Channel Assignment Convention**

Sense resistor channel assignments follow the general convention shown in Figure 29. The sense resistor is tied between $CH_{RSENSE}$ and $CH_{RSENSE-1}$, where $CH_{RSENSE}$ is tied to the 2nd terminal of the thermistor. Channel assignment data (see Table 37) is mapped into a memory location corresponding to $CH_{RSENSE}$.

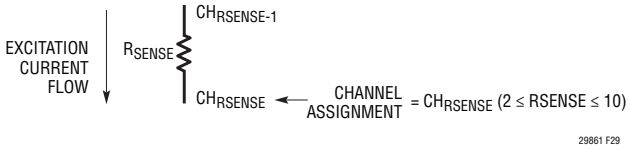


**Figure 29. Sense Resistor Channel Assignment Convention**

Figure 30 shows a typical temperature measurement system using a differential thermistor. In this example a 30kΩ (44032 type) thermistor is tied to a 9.99kΩ sense resistor. The thermistor is assigned channel CH9 (memory locations 0x220 to 0x223) and the sense resistor to CH7 (memory locations 0x218 to 0x21B). Channel assignment data is shown in Table 62 and Table 63).

A conversion is initiated on CH9 by writing 10001001 into memory location 0x000. Once the conversion is complete, the INTERRUPT pin goes HIGH and memory location 0x000 becomes 01001001. The resulting temperature in °C can be read from memory locations 0x030 to 0x033 (Corresponding to CH9).

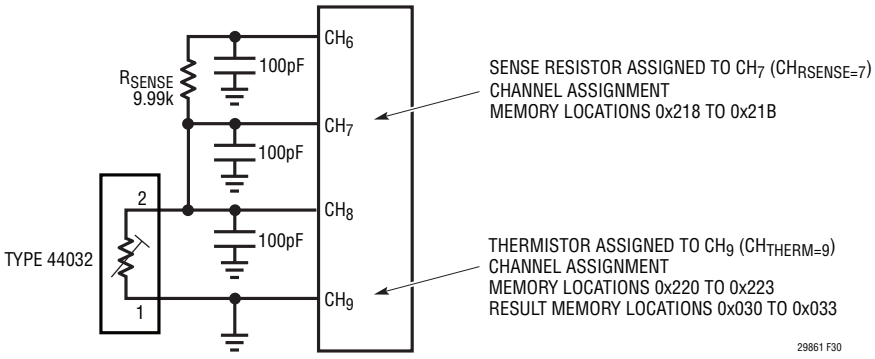


**Figure 30. Differential Thermistor Example**

# APPLICATIONS INFORMATION

**Table 62. Channel Assignment Data for Differential Thermistor (44008/44032 30kΩ at 25°C Type Thermistor, Differential Configuration, $R_{SENSE}$ on $CH_7$, Auto Range Excitation)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x220 | | | | | | | | MEMORY ADDRESS 0x221 | | | | | | | | MEMORY ADDRESS 0x222 | | | | | | | | MEMORY ADDRESS 0x223 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Thermistor Type | 44008/44032 30kΩ at 25°C | 5 | 10111 | 1 | 0 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_7$ | 5 | 00111 | | | | | | 0 | 0 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | Differential, No Share, No Rotate | 3 | 000 | | | | | | | | | | | 0 | 0 | 0 | | | | | | | | | | | | | | | | | |
| (4) Excitation Current | Auto Range | 4 | 1100 | | | | | | | | | | | | | | 1 | 1 | 0 | 0 | | | | | | | | | | | | | |
| Not Used | Set These Bits to 0 | 2 | 000 | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | | | | | | | | | | |
| (5) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 63. Channel Assignment Data for Sense Resistor (Value = 9.99kΩ)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x218 | | | | | | | | MEMORY ADDRESS 0x219 | | | | | | | | MEMORY ADDRESS 0x21A | | | | | | | | MEMORY ADDRESS 0x21B | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Sensor Type | Sense Resistor | 5 | 11101 | 1 | 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Value | 9.99kΩ | 27 | 000100111000001100000000000 | | | | | | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# APPLICATIONS INFORMATION

### Example: Shared/Rotated Differential Thermistor

The differential thermistor configuration allows separate internal ground sensing for each sensor. In this configuration, one sense resistor can be used for multiple thermistors. Differential thermistors follow the convention shown in Figure 31. Terminal 1 ties to $CH_{THERM}$ and terminal 2 ties to $CH_{THERM-1}$ and the sense resistor. Channel assignment data (see Table 54) is mapped to memory locations corresponding to $CH_{THERM}$.

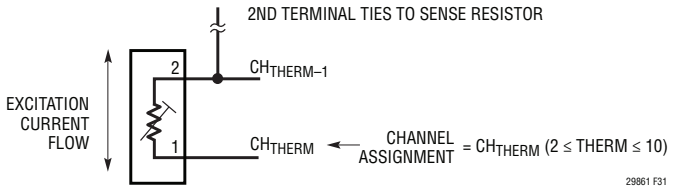


**Figure 31. Thermistor with Shared $R_{SENSE}$ Channel Assignment Convention**

Sense resistor channel assignments follow the general convention shown in Figure 32. The sense resistor is tied between $CH_{RSENSE}$ and $CH_{RSENSE-1}$, where $CH_{RSENSE}$ is tied to the 2nd terminal of the thermistor. Channel assignment data (see Table 37) is mapped into a memory location corresponding to $CH_{THERM}$.

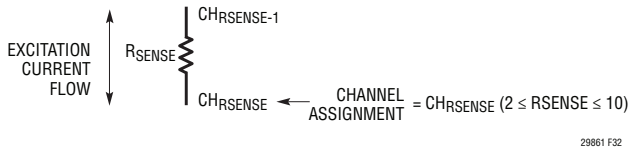


**Figure 32. Sense Resistor Channel Assignment Convention for Thermistors**

Figure 33 shows a typical temperature measurement system using a shared sense resistor and one rotated/non-rotated differential thermistors. In this example a 30kΩ (44032 Type) thermistor is tied to a 10.0kΩ sense resistor and configured as rotated/shared. The second thermistor a 2.25kΩ (44033 type) is configured as a non-rotated/shared. Channel assignment data are shown in Tables 64 to 66.

A conversion is initiated on CH8 by writing 10001000 into memory location 0x000. Once the conversion is complete, the INTERRUPT pin goes HIGH and memory location 0x000 becomes 01001000. The resulting temperature in °C can be read from memory locations 0x02C to 0x02F (corresponding to CH8). A conversion can be initiated and read from CH10 in a similar fashion.

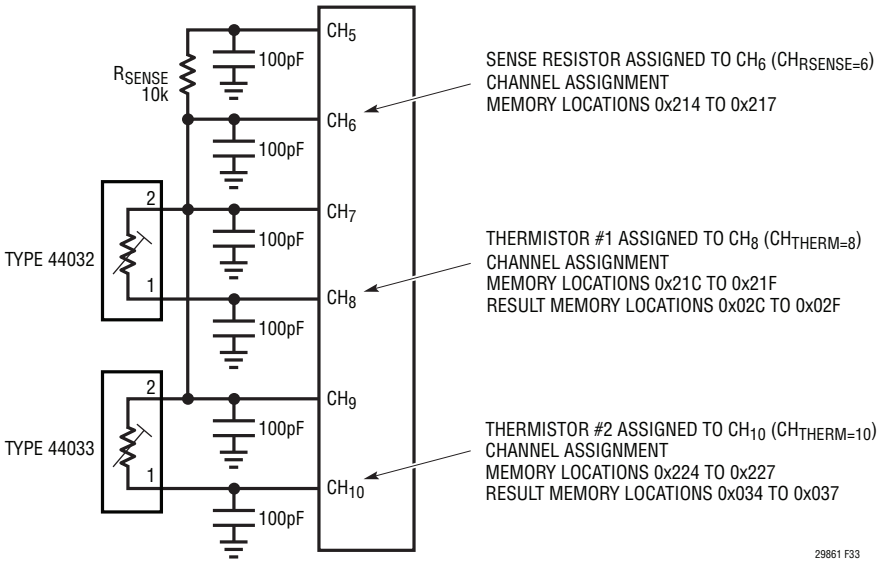


**Figure 33. Rotated and Shared Thermistor Example**

# APPLICATIONS INFORMATION

**Table 64. Channel Assignment Data Differential Thermistor (44008/44032 30kΩ at 25°C Type Thermistor, Differential Configuration with Sharing and Rotation, $R_{SENSE}$ on $CH_6$, 250nA Excitation Current)**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x21C | | | | | | | | MEMORY ADDRESS 0x21D | | | | | | | | MEMORY ADDRESS 0x21E | | | | | | | | MEMORY ADDRESS 0x21F | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Thermistor Type | 44008/44032 30kΩ at 25°C | 5 | 10111 | 1 | 0 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_6$ | 5 | 00110 | | | | | | 0 | 0 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | Differential, Rotate and Shared | 3 | 001 | | | | | | | | | | | 0 | 0 | 1 | | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 250nA Excitation Current | 4 | 0001 | | | | | | | | | | | | | | 0 | 0 | 0 | 1 | | | | | | | | | | | | | |
| Not Used | Set These Bits to 0 | 3 | 000 | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | | | | | | | | | | |
| (5) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 65. Channel Assignment Data Differential Thermistor (44004/44033 2.252kΩ at 25°C Type Thermistor, Differential Configuration with Sharing and No Rotation, $R_{SENSE}$ on $CH_6$, 10µA Excitation Current)**

| Configuration Field | Description | # Bits | Binary Data | MEMORY ADDRESS 0x224 | | | | | | | | MEMORY ADDRESS 0x225 | | | | | | | | MEMORY ADDRESS 0x226 | | | | | | | | MEMORY ADDRESS 0x227 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Thermistor Type | 44004/44033 2.252kΩ at 25°C | 5 | 10011 | 1 | 0 | 0 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_6$ | 5 | 00110 | | | | | | 0 | 0 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | Differential, No Rotate and Shared | 3 | 010 | | | | | | | | | | | 0 | 1 | 0 | | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 10µA Excitation Current | 4 | 0101 | | | | | | | | | | | | | | 0 | 1 | 0 | 1 | | | | | | | | | | | | | |
| Not Used | Set These Bits to 0 | 3 | 000 | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | | | | | | | | | | |
| (5) Custom RTD Data Pointer | Not Custom | 12 | 000000000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 66. Channel Assignment Data for Sense Resistor (Value = 10.0kΩ)**

| Configuration Field | Description | # Bits | Binary Data | MEMORY ADDRESS 0x214 | | | | | | | | MEMORY ADDRESS 0x215 | | | | | | | | MEMORY ADDRESS 0x216 | | | | | | | | MEMORY ADDRESS 0x217 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Sensor Type | Sense Resistor | 5 | 11101 | 1 | 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Value | 10.0kΩ | 27 | 000100111000100000000000000 | | | | | | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# APPLICATIONS INFORMATION

## GLOBAL CONFIGURATION REGISTER

Table 67 shows a summary of the global configuration register. The global configuration register is 1 byte long and is at memory location 0x0F0. Bits G0 – G1 set the notch frequency of the on chip digital filter, Bit G2 sets the temperature results unit (°C or °F), Bits G3 and G7 are reserved and should be set low, Bits G4 – G6 determine the Kelvin current excitation mode.

**Table 67. Global Configuration Register**

| Bit # | Field Name | Description |
|---|---|---|
| G0<br>G1 | Filter Frequency Select [1:0] | 00 = 55Hz<br>01 = 60Hz<br>10 = 50Hz |
| G2 | Temperature Result Format | 0 = Celsius<br>1 = Fahrenheit |
| G3 | Reserved | Set to 0 |
| G4 | 3-Wire RTD Kelvin Current Excitation Mode | Excitation Current on Adjacent Channels |
| G5 | 2-Wire RTD Kelvin Current Excitation Mode | Excitation Current on Adjacent Channels |
| G6 | Thermistor Kelvin Current Excitation Mode | Excitation Current on Adjacent Channels |
| G7 | Reserved | Set to 0 |

## INPUT OVERVOLTAGE PROTECTION – OVERVIEW

Temperature sensors are often used in harsh environments. The sensors or leads can short to high voltages or each other. Resistive circuits can protect the LTC2986 from these fault conditions. These external resistors can potentially introduce measurement errors; however, the LTC2986 includes special modes and features that reduce these effects

The tip of a thermocouple is often unshielded, creating a low impedance conductive path to the input of the measurement device. In order to protect the LTC2986 from damage due to overvoltage conditions, current-limiting resistors can be placed between the input channels and the thermocouple sensor. The value of this resistor is chosen such that at the maximum overvoltage, the current entering the LTC2986 is less than ±15mA. Errors due to these protection resistors are minimal during normal operation due to the very low input leakage (1nA) specifications of the LTC2986.

Most RTD sensor elements are electrically isolated from the sensor leads either through a non-conductive encapsulation or a separate grounding shield. While these types of sensors may not require input overvoltage protection, certain applications may require current limiting resistors between the RTD and the LTC2986. One such application is a universal input device where an input terminal can see either an RTD or a thermocouple. Other applications may require protection against erroneous connections, for example, connecting a voltage source accidentally to the RTD input terminals. The protection circuits implemented for RTDs should accommodate 2-wire, 3-wire, and 4-wire configurations.

Thermistors are 2-wire resistance to temperature sensors with a non-conductive encapsulation enclosing the sensor element. Similar to the RTD, overvoltage protection for thermistors may be required for both universal sensor input applications and inadvertent user applied overvoltage.

The LTC2986 offer several current excitation modes for eliminating errors due to resistive overvoltage protection circuits. The following sections describe overvoltage protection circuits for thermocouples, 2-, 3-, and 4-wire RTDs and thermistors with an emphasis on universality (sharing the same protection scheme for all sensor types).

### Input Overvoltage Protection – Resistor Value Selection

The maximum continuous current the LTC2986 can sustain without damage is ±15mA. In order to determine the value of the overvoltage protection resistor and its power rating, the maximum voltage is required. This voltage is application specific and depends on the maximum anticipated overvoltage. For example, a system with possible overvoltage of 40V would require a resistance R > 2.7kΩ and a power rating (see Figure 34 and Figure 35):

$$P > 600mW, \text{ where } R > \frac{V_{MAX} - V_{DD}}{15mA}$$

## APPLICATIONS INFORMATION

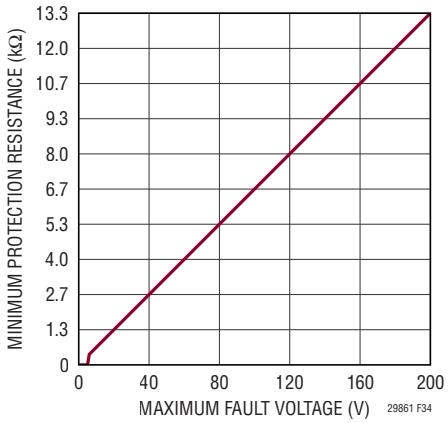


**Figure 34. Maximum Fault Voltage vs Minimum Protection Resistance**

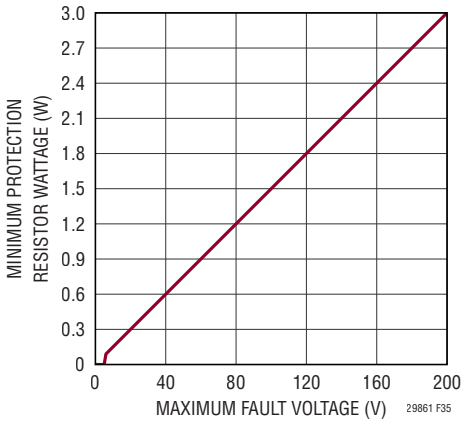


**Figure 35. Maximum Fault Voltage vs Minimum Protection Resistor Power Rating**

### Input Overvoltage Protection – Thermocouples

Thermocouples are low impedance devices that generate voltage as a function of temperature differences. Since the LTC2986 input impedance is very high (input leakage < 1nA) external overvoltage protection resistors have minimal effect on the temperature measurement accuracy. For example, a 2kΩ protection resistor results in a worst-case error of 4µV (see Figure 36). This corresponds to a 0.1°C error for a Type K thermocouple at 25°C.

In addition to the protection resistors, 100pF capacitors should be added to each input for anti-alias filtering; these are not shown in the following schematics for simplicity.

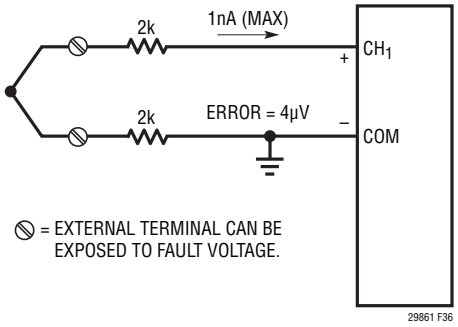


**Figure 36. Thermocouple with Protection Resistors**

### Input Overvoltage Protection – RTDs

RTDs are resistive devices that require excitation current in order to determine their temperature. The excitation is applied to the series network consisting of the RTD and a sense resistor in order to make a ratiometric measurement. Overvoltage protection is implemented by placing a resistor between each RTD terminal and the LTC2986 input channels.

### 4-Wire RTDs

The simplest RTD configuration to protect is the 4-wire RTD. A protection resistor is tied to each of the 4 RTD terminals (see Figure 37). Excitation current flows through the sense resistor ($R_{SENSE}$), the RTD, and protection resistors RP1 and RP4. The LTC2986 measures the voltage drop across the RTD using CH3 and CH4 through protection resistors RP2 and RP3. Since the excitation current does not flow through RP2 and RP3, errors due to the protection resistance are negligible. Measurement errors are dominated by input leakage current (I < 1nA). For example, errors due to leakage current for a PT-100 RTD with 1kΩ sense resistor and 1kΩ protection resistors are below 0.025°C.

## APPLICATIONS INFORMATION

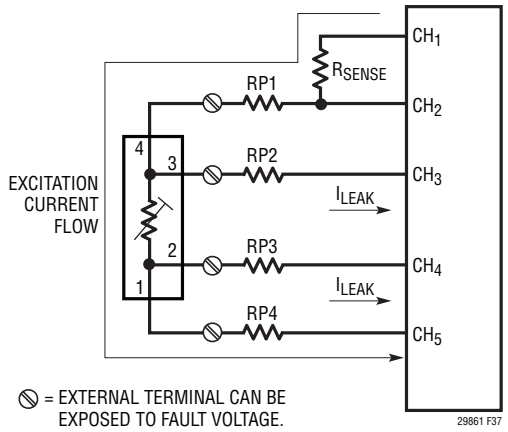


**Figure 37. 4-Wire RTD with Protection Resistors**

### 3-Wire RTDs

3-wire RTDs are more difficult to protect than 4-wire RTDs. Normally, protection resistors are tied to each of the 3 RTD terminals (see Figure 38). The LTC2986 provides two matched excitation currents, $I_1$ and $I_2$. These currents flow from CH3 and CH4 through RP2 and RP3 into the RTD. The resulting voltage is measured between CH3 and CH4. Assuming RP2 = RP3 and $I_1 = I_2$, the errors resulting from the protection resistors are cancelled. While the LTC2986 provides matched current source excitation, external protection resistors may be difficult to match. Every 1Ω mismatch in RP2 and RP3 translates to a 1Ω error in the RTD measurement.

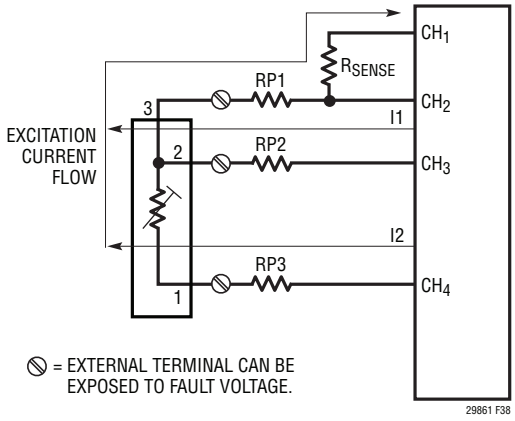


**Figure 38. 3-Wire RTD with Protection Resistors**

The LTC2986 offers a 3-wire RTD Kelvin current source mode in order to remove errors due to mismatched protection resistors. This feature is enabled by setting the global 3-wire RTD Kelvin current excitation mode bit (G4 = 1, see Table 67) prior to initiating a conversion start. This mode uses the adjacent channels (in this example CH5 and CH6) for the current source excitation and performs the measurement on CH3 and CH4 (see Figure 39). Two additional resistors are placed between the RTD and the channels tied to the excitation current sources, but the protection resistor matching constraint is removed for all resistors. The excitation current no longer flows through RP2 or RP3, removing the voltage drop across them. Figure 40 shows the channel assignment convention for this mode.

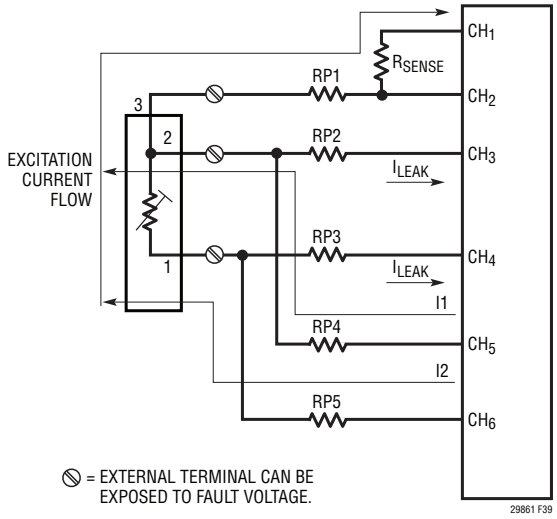


**Figure 39. 3-Wire RTD Kelvin Current Mode (G4 = 1)**

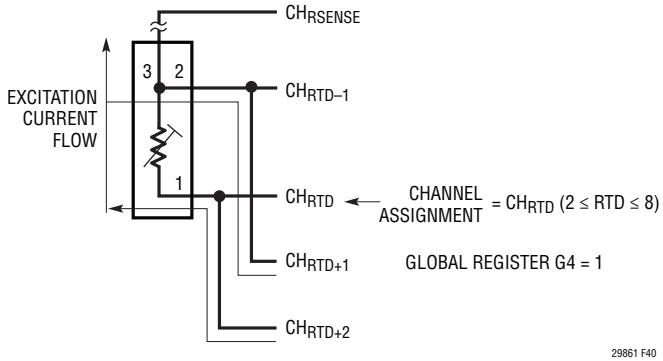


**Figure 40. 3-Wire RTD Kelvin Current Mode Channel Assignment Convention (G4 = 1)**

# APPLICATIONS INFORMATION

## 2-Wire RTDs

2-wire RTDs are difficult to protect because the protection resistor (RP3) is in series with the RTD (see Figure 41). Every 1Ω of protection resistance adds 1Ω measurement error to the RTD.

The LTC2986 offers a 2-wire Kelvin current source mode in order to remove the errors associated with protection resistors. This feature is enabled by setting the global 2-wire RTD Kelvin current excitation mode bit (G5 = 1, see Table 67) prior to initiating a conversion start. This current excitation mode uses the adjacent channel (CH5 for this example) for the internal ground connection (see Figure 42). One additional protection resistor is added between the RTD and CH5. The excitation current no longer flows through RP3, removing the voltage drop across it. Figure 43 shows the channel assignment convention for this mode.

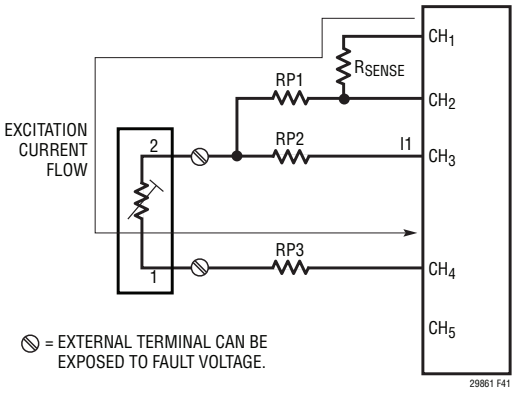


**Figure 41. 2-wire RTD with Protection Resistors**

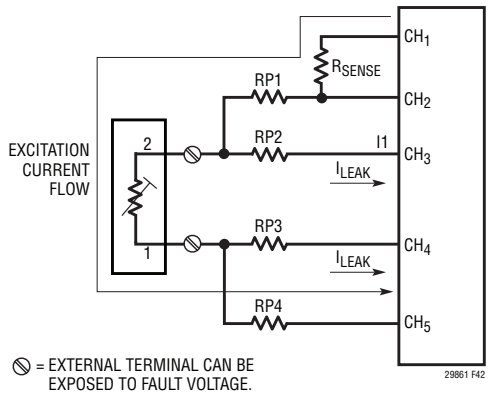


**Figure 42. 2-Wire RTD Kelvin Current Mode (G5 = 1)**

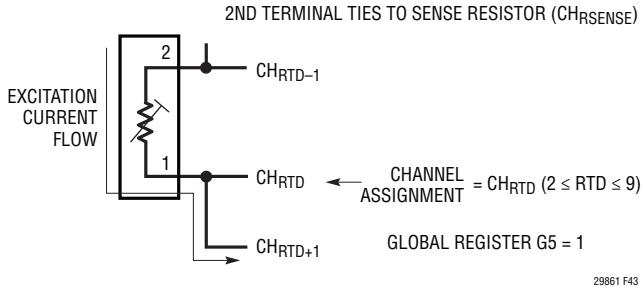


**Figure 43. 2-Wire Kelvin Current Mode Channel Assignment Convention (G5 = 1)**

## Thermistors

Similar to the 2-wire RTD, thermistors are difficult to protect because the protection resistor RP3 is in series with the sensor (see Figure 44). Every 1Ω of protection resistance adds 1Ω measurement error to the thermistor.

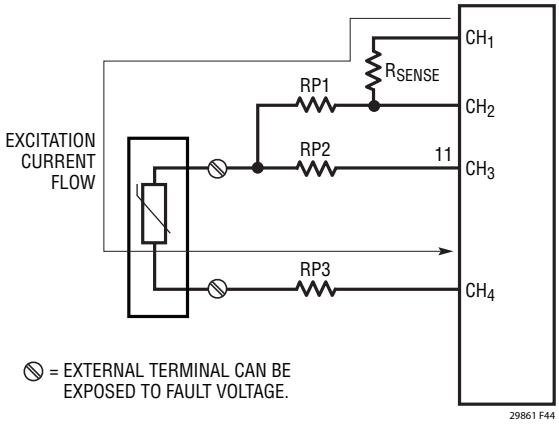


**Figure 44. Thermistor with Protection Resistors**

The LTC2986 offers a thermistor Kelvin current source mode in order to remove the errors associated with protection resistors. This feature is enabled by setting the global thermistor Kelvin current excitation mode bit (G6 = 1, see Table 67) prior to initiating a conversion start. This current excitation mode uses the adjacent channel (CH5 for this example) for the internal ground connection (see Figure 45). One additional protection resistor is added between the thermistor and CH5. The excitation current no longer flows through RP3, removing the voltage drop across it. Figure 46 shows the channel assignment convention for this mode.

## APPLICATIONS INFORMATION

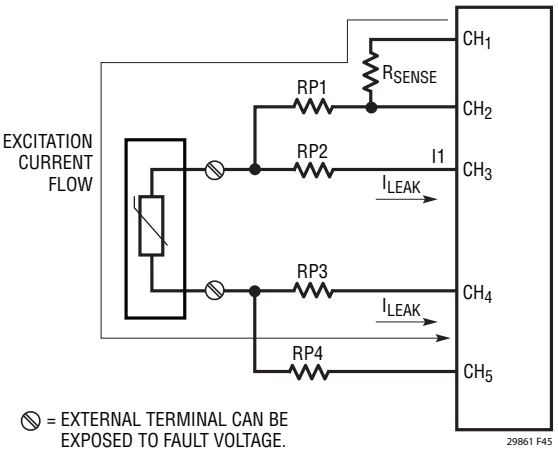


**Figure 45. Thermistor Kelvin Current Source Mode (G6 = 1)**

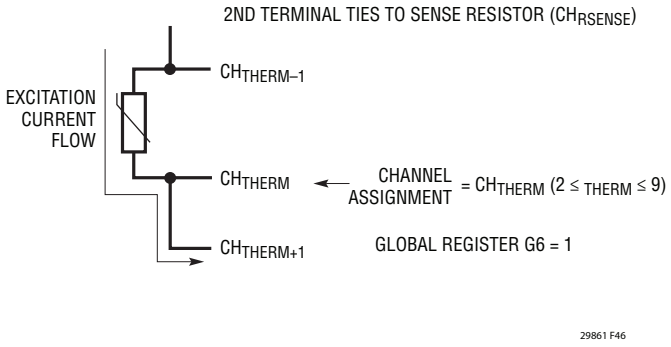


**Figure 46. Thermistor Kelvin Current Mode Channel Assignment Convention (G6 = 1)**

### Universal Example

The LTC2986 is capable of sharing one protected interface with multiple sensor types (see Figure 47). This includes all RTD configurations (2-, 3- and 4-wire), thermistors, and thermocouples. Switching between sensors only requires a new channel assignment word via software control. The multi-sensor circuit provides 4 input terminals, each protected against external overvoltage conditions. In order to enable Kelvin current excitation mode for all sensors set all 3 global configuration bits G4, G5, and G6 to 1 (see Table 67).

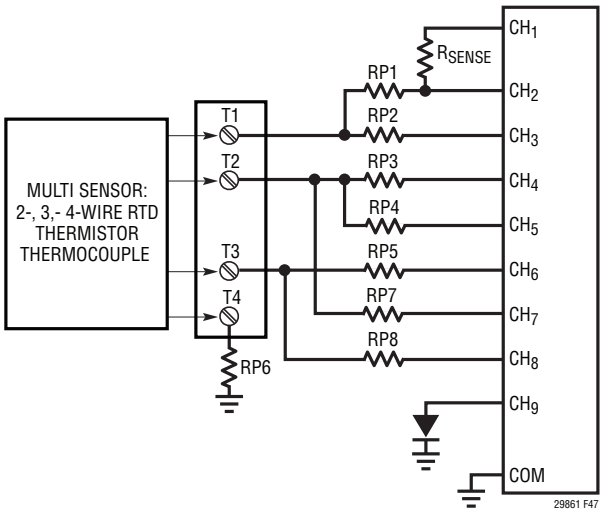


**Figure 47. Universal Multi-Sensor Schematic**

In Figure 48, a 4-wire RTD is tied directly to the 4 input terminals. In this case, the 4-wire RTD is assigned to CH6 and the sense resistor is tied to CH2. The excitation current flows through protection resisters RP1 and RP6. Since RP6 is grounded, $R_{SENSE}$ sharing and excitation current rotation are off.

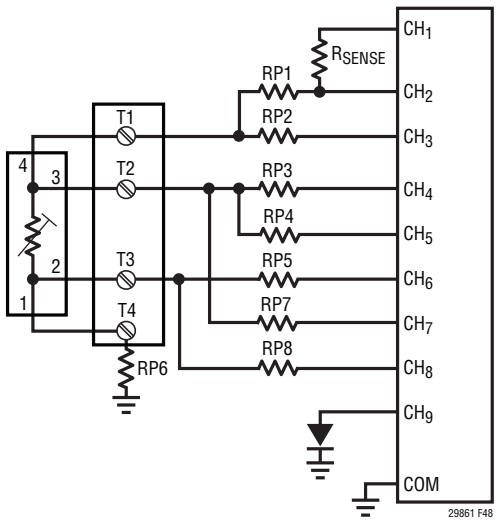


**Figure 48. Protected Multi-Sensor 4-Wire RTD Connection**

## APPLICATIONS INFORMATION

Figure 49 shows the interface to a 3-wire RTD using the multi-sensor circuit. In this case, the RTD ties directly to terminals T1 – T3 and terminal T4 is left floating. Matched excitation currents flow from CH7 and CH8 through protection resistors RP7 and RP8 while the RTD measurement occurs at CH5 and CH6. The 3-wire RTD is assigned to CH6 and $R_{SENSE}$ sharing is turned on.

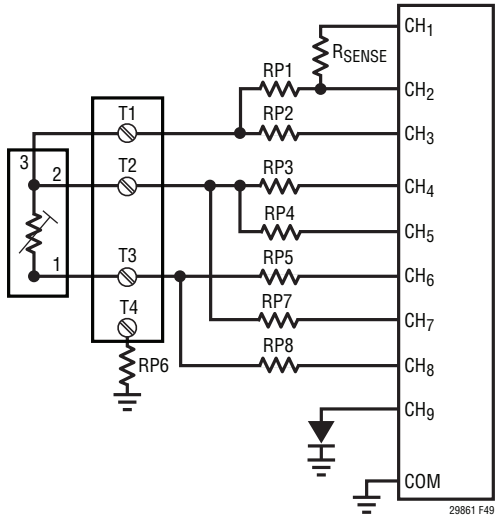


**Figure 49. Protected Multi-Sensor 3-Wire RTD Connection**

Figure 50 shows the interface to a 2-wire RTD using the LTC2986 multi-sensor circuit. In this case, the RTD ties directly to terminals T1 and T2 while terminals T3 and T4 are left floating. The excitation currents flows from CH1 through $R_{SENSE}$ and protection resistors RP1 and RP4 (CH5 is internally grounded) while the RTD measurement occurs at CH3 and CH4. The 2-wire RTD is assigned to CH4 and $R_{SENSE}$ sharing is turned on.

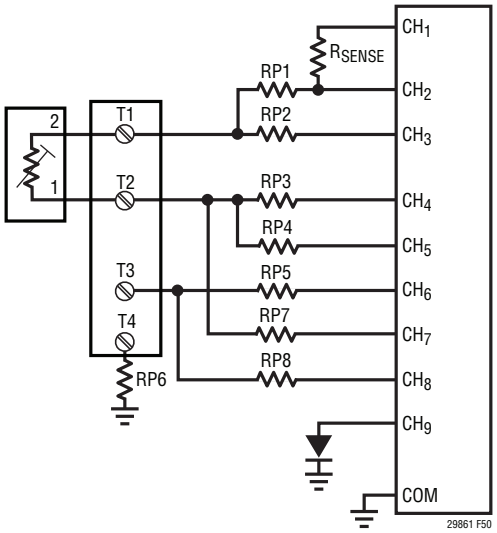


**Figure 50. Protected Multi-Sensor 2-Wire RTD Connection**

Figure 51 shows the interface to a thermistor using the LTC2986 multi-sensor circuit. In this case, the thermistor ties directly to terminals T1 and T2 while terminals T3 and T4 are left floating. The excitation current flows from CH1 through $R_{SENSE}$ and protection resistors RP1 and RP4 (CH5 is internally grounded) while the thermistor differential measurement occurs at CH3 and CH4. The thermistor is assigned to CH4 and $R_{SENSE}$ sharing is enabled in order to provide an internal ground connection.

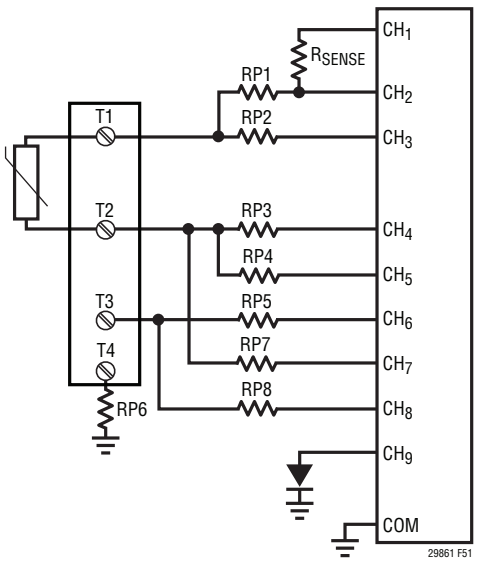


**Figure 51. Protected Multi-Sensor Thermistor Connection**

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Figure 52 shows the interface to a thermocouple using the LTC2986 multi-sensor circuit. In this case, the thermocouple ties directly to terminals T3 and T4 while terminals T1 and T2 can be left floating or tied to an RTD (Global Register G5 = 1) or thermistor (Global Register G6 = 1) for cold junction compensation. Alternatively, a diode (tied to CH9) can be used for cold junction compensation. The thermocouple is assigned to CH6 with single ended measurement mode.

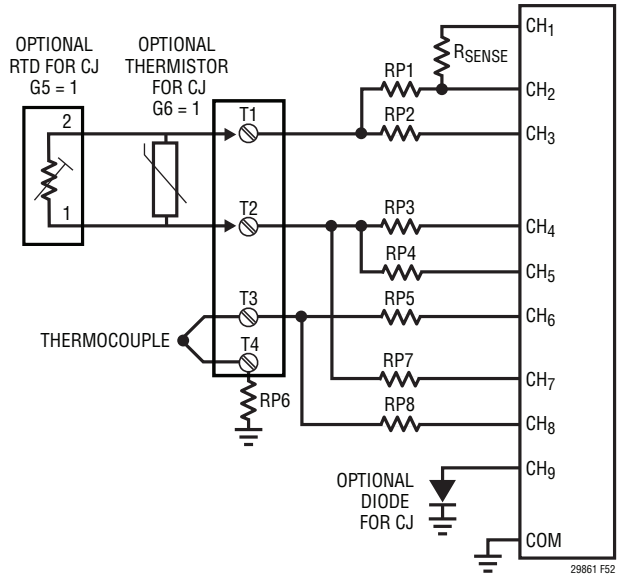


**Figure 52. Protected Multi-Sensor Thermocouple Connection**

### ACTIVE ANALOG TEMPERATURE SENSORS

In addition to passive type temperature sensors, the LTC2986 also supports active analog temperature sensors (i.e. LTC2997). In this mode, the LTC2986 measures the voltage output from the analog temperature sensor and does a table lookup to convert the measured voltage to temperature. This sensor option is fully customizable and can be used for direct temperature measurement or cold junction compensation.

#### Analog Sensor Channel Assignment and Result Formats

For the active analog temperature sensor type = 31 (see Table 4 and Figure 53), the channel assignment word is 0xF800 0000 for differential measurements and 0xFC00 0000 for single-ended. When the LTC2986 is configured for the active analog temperature sensor type, it will take the measured voltage value from the ADC and perform a table lookup to produce a temperature result. The result format of the table lookup will be a 24-bit signed fixed-point temperature result along with the error status byte. The fixed-point format of the temperature is identical to all the other LTC2986 temperature sensor types. This format can be seen in Table 9.

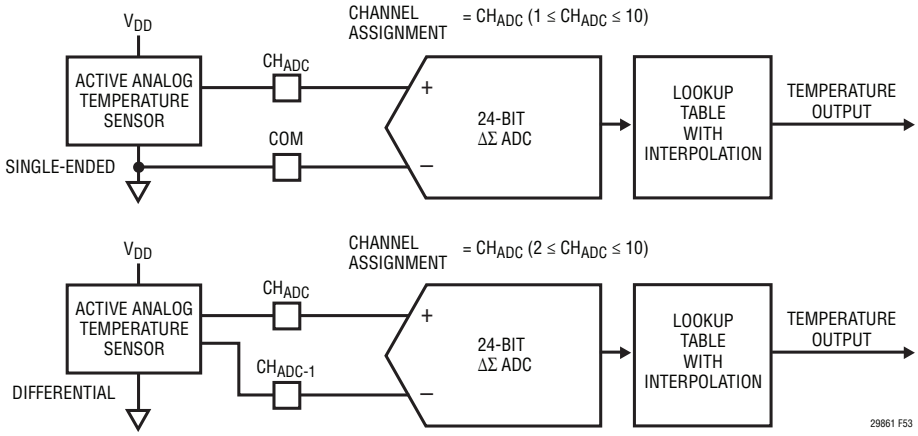


**Figure 53. Active Analog Temperature Sensor Channel Assignment Conventions**

## APPLICATIONS INFORMATION

The error status byte is located in the upper byte of the data output word. Table 68 shows format of the error status byte for the analog sensor type. Bit D31 and D30 indicate a bad ADC reading. This can be a result of either a broken (open) sensor or an excessive noise event (ESD or static discharge into the sensor path). Either of these are a hard error and –999°C or °F is reported. In the case of an excessive noise event, the device should recover and the following conversions will be valid if the noise event was a random, infrequent event. Bits D27 and D26 indicate over or under temperature limits have been exceeded the table limits as described in Table 68. Bit D25 indicates the absolute voltage measured by the ADC is beyond its normal operating range.

### Example: Differential Active Analog Temperature Sensor

In this example, a simplified temperature curve is implemented (see Figure 54). Points P1 to P9 represent the normal operating range of the custom device. Voltage readings above point P9 result in a soft fault and the reported result is a linear extrapolation using a slope determined by points P8 and P9 (the final two table entries). Voltage readings below point P1 are also reported as soft faults. The reported result is the extrapolation between point P1 and P0, where P0 is typically the lowest possible sensor output voltage. Sensor output voltages below P0 (in mV) will report P0 output.

In order to program the LTC2986 with an active analog temperature sensor table, both the mV data and the Kelvin data are converted to 24-bit binary values (represented as two, 3-byte table entries, see Table 69). Since some analog sensors generate negative output voltages, the table mV values are 2's compliment. The sensor output voltage (units = mV) follows the convention shown in Table 71, where the first bit is the sign, the next 11 bits are the integer part and the remaining 12 bits are the fractional part.

**Table 68. Active Analog Temperature Sensor Fault Data Byte**

| BIT | FAULT | ERROR TYPE | DESCRIPTION | OUTPUT RESULT |
|---|---|---|---|---|
| D31 | Hard Fault | Hard | $V_{ADC} < -1.75 \cdot V_{REF}/2$ or $V_{ADC} > 1.75 \cdot V_{REF}/2$ | –999 |
| D30 | Range Hard Fault | Hard | $V_{ADC} < -1.75 \cdot V_{REF}/2$ or $V_{ADC} > 1.75 \cdot V_{REF}/2$ | –999 |
| D29 | Not Used | N/A | NA | NA |
| D28 | Not Used | N/A | NA | NA |
| D27 | Soft Above | Soft | $V_{ADC}$ > Last Table Point Voltage | Suspect Reading |
| D26 | Soft Below | Soft | $V_{ADC}$ < Second Table Point (P1) Voltage | Suspect Reading |
| D25 | Soft Range | Soft | $V_{ADC} < -1.125 \cdot V_{REF}/2$ or $V_{ADC} > 1.125 \cdot V_{REF}/2$ | Suspect Reading |
| D24 | Result Valid (Always 1) | NA | NA | NA |

### Active Analog Temperature Sensor Table Format

**Table 69. Active Analog Temperature Sensor Table Format**

| ADDRESS | BYTE 0 | BYTE 1 | BYTE 2 | BYTE 3 | BYTE 4 | BYTE 5 |
|---|---|---|---|---|---|---|
| 0x250 + 6 • Start Address | Table Entry #1 (mV) | | | Table Entry #1 (Kelvin) | | |
| 0x250 + 6 • Start Address + 6 | Table Entry #2 (mV) | | | Table Entry #2 (Kelvin) | | |
| 0x250 + 6 • Start Address + 12 | Table Entry #3 (mV) | | | Table Entry #3 (Kelvin) | | |
| • | • | | | • | | |
| • | • | | | • | | |
| • | • | | | • | | |
| | | | | | | |
| | | | | | | |
| Max Address = 0x3CA | Table Entry #64 (mV) | | | Table Entry #64 (Kelvin) | | |

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The temperature values are input in Kelvin as unsigned fixed-point values, but the final temperatures reported by the LTC2986 are reported in °C or °F. The sensor temperature (Kelvin) follows the convention shown in Table 72, where the first 14 bits are the integer part and the remaining 10 bits are the fractional part. In this example, a custom analog sensor is tied to CH2, and is programmed with the channel assignment data shown in Table 73. In this case the custom data begins at memory location 0x250 (starting address is 0). The starting address (offset from 0x250) is entered in the analog sensor data pointer field of the channel assignment data. The table data length –1 (9 in this example) is entered into the data length field of the analog temperature sensor channel assignment word. Refer to Table 70 for the location and format of the 10 six-byte table entries.

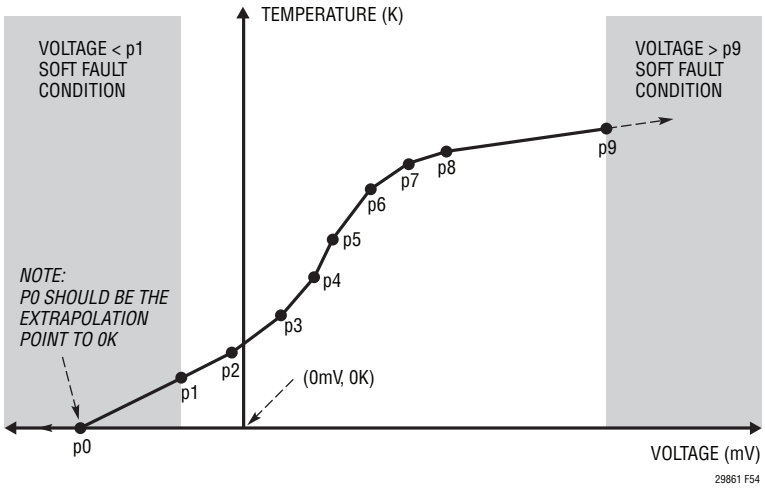



**Figure 54. Active Analog Temperature Sensor Table Example**

**Table 70. Active Analog Temperature Sensor Example Table Data Memory Map**

| POINT | SENSOR OUTPUT VOLTAGE (mV) | TEMPERATURE KELVIN | START ADDRESS | STOP ADDRESS | BYTE 0 | BYTE 1 | BYTE 2 | BYTE 3 | BYTE 4 | BYTE 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| P0 | –50.22 | 0 | 0x250 | 0x255 | | | | | | |
| P1 | –30.2 | 99.1 | 0x256 | 0x25B | | | | | | |
| P2 | –5.3 | 135.4 | 0x25C | 0x261 | | | | | | |
| P3 | 20.33 | 220.3 | 0x262 | 0x267 | | | | | | |
| P4 | 40.2 | 361.2 | 0x268 | 0x26D | mV Data | | | Temperature Data | | |
| P5 | 55.3 | 522.1 | 0x26E | 0x273 | | | | | | |
| P6 | 88.3 | 720.3 | 0x274 | 0x279 | | | | | | |
| P7 | 132.2 | 811.2 | 0x27A | 0x27F | | | | | | |
| P8 | 188.7 | 922.5 | 0x280 | 0x285 | | | | | | |
| P9 | 460.4 | 1000 | 0x286 | 0x28B | | | | | | |

# APPLICATIONS INFORMATION

**Table 71. Example Active Analog Temperature Sensor Voltage Values**

| | BYTE 0 | | | | | | | | BYTE 1 | | | | | | | | BYTE 2 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| mV | Sign | $2^{10}$ | $2^{9}$ | $2^{8}$ | $2^{7}$ | $2^{6}$ | $2^{5}$ | $2^{4}$ | $2^{3}$ | $2^{2}$ | $2^{1}$ | $2^{0}$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ | $2^{-11}$ | $2^{-12}$ |
| –50.22 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| –30.2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| –5.3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 20.33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 40.2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 55.3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 88.3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 132.2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 188.7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 460.4 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |

**Table 72. Example Active Analog Temperature Sensor Temperature Values**

| | BYTE 3 | | | | | | | | BYTE 4 | | | | | | | | BYTE 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| Temperature | $2^{13}$ | $2^{12}$ | $2^{11}$ | $2^{10}$ | $2^{9}$ | $2^{8}$ | $2^{7}$ | $2^{6}$ | $2^{5}$ | $2^{4}$ | $2^{3}$ | $2^{2}$ | $2^{1}$ | $2^{0}$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 99.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| 135.4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| 220.3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 361.2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 522.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| 720.3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 811.2 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 922.5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1000 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 73. Example Active Analog Temperature Sensor Channel Assignment Data**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 214 | | | | | | | MEMORY ADDRESS 215 | | | | | | | | MEMORY ADDRESS 216 | | | | | | | | MEMORY ADDRESS 217 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Analog Temp Sensor | Sensor Type | 5 | 11110 | 1 | 1 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) SE/Diff | Single-Ended or Differential | 1 | 0 | | | | | | 0 | | | | | | | | | | | | | | | | | | | | | | | |
| (3) Not Used | Set to 0 | 14 | 00000000000000 | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | | |
| (4) Direct ADC Table Data Pointer | Start Address = 0 (Start at 0x250) | 6 | 000000 | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| (5) Direct ADC Table Data Length-1 | Data Length-1 = 9 | 6 | 001001 | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 1 | 0 | 0 | 1 |

# APPLICATIONS INFORMATION

## DIRECT ADC MEASUREMENTS

In addition to measuring temperature sensors, the LTC2986 can perform direct ADC (i.e. voltage) measurements. Any channel may be configured to perform direct single-ended or differential measurements. Direct ADC channel assignments follow the general convention shown in Figure 55. The 32-bit channel assignment word is programmed into a memory location corresponding to the input channel.

The Direct ADC mode is configurable to single-ended as well as differential inputs. The positive input channel ties to $CH_{ADC}$ for both single-ended and differential modes. For single-ended measurements the ADC negative input is COM while for differential measurements it is $CH_{ADC-1}$. For single-ended measurements, COM can be driven with any voltage above GND – 50mV and below $V_{DD}$ – 0.3V. The direct ADC results are available in memory at a location corresponding to the conversion channel.

There are two result mode options for direct ADC operation. The first mode is direct voltage output and the second is table-driven output. When configured for direct voltage output, the LTC2986 will return a 24-bit fixed-point voltage result along with the 8-bit fault status byte. When configured for table-lookup, the LTC2986 will perform a table lookup on the raw ADC voltage and return a 24-bit signed-integer table-lookup result along with the 8-bit fault status byte.

Figures 56 to Figures 58 show typical integral nonlinearity variation as a function of supply voltage and temperature for a differential input voltage ($\pm V_{REF}/2$) and $V_{REF}/2$ common mode input voltage.

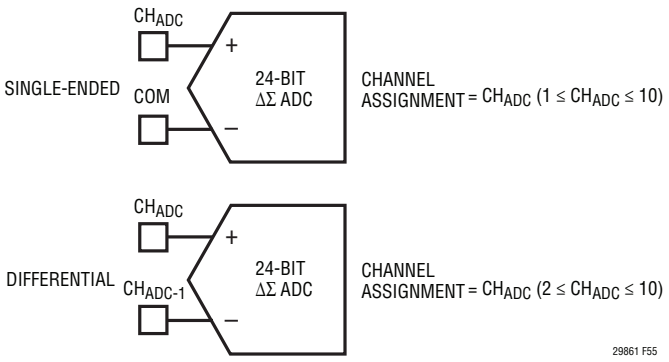



**Figure 55. Direct ADC Channel Assignment Conventions**

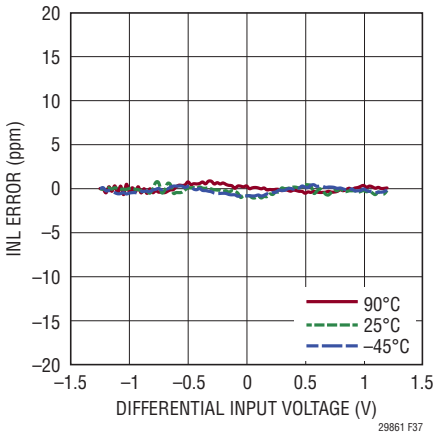



**Figure 56. Integral Nonlinearity as a Function of Temperature at $V_{DD}$ = 5.25V**

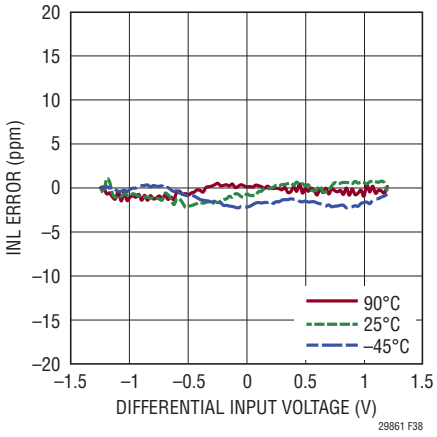



**Figure 57. Integral Nonlinearity as a Function of Temperature at $V_{DD}$ = 3.3V**

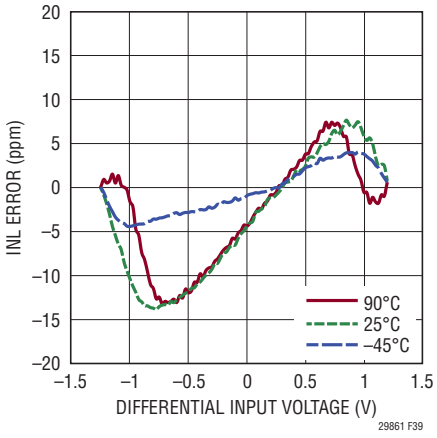



**Figure 58. Integral Nonlinearity as a Function of Temperature at $V_{DD}$ = 2.85V**

# APPLICATIONS INFORMATION

### Voltage Output Mode

For standard (non table mode) voltage output mode, the channel assignment word is 0xF000 0000 for differential readings and 0xF400 0000 for single-ended (see Table 75).

The data is represented as a 32-bit word (see Table 74) where the eight most significant bits are fault bits and the bottom 24 are the ADC reading in volts. For direct ADC readings hard fault errors do not clamp the digital output. Readings beyond ±1.125 • $V_{REF}$/2 exceed the normal accuracy range of the LTC2986 and flag a soft error; these results should be discarded. Readings beyond ±1.75 •$V_{REF}$/2 exceed the usable range of the LTC2986; these result in a hard fault and should be discarded.

**Table 74. Direct ADC Voltage Output Result Format**

| | START ADDRESS | | | | | | | | START ADDRESS + 1 | | | | | | | | START ADDRESS + 2 | | | | | | | | START ADDRESS + 3 (END ADDRESS) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D31 | D30 | D29 | D28 | D27 | D26 | D25 | D24 | D23 | D22 | D21 | D20 | D19 | D18 | D17 | D16 | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
| | Fault Data | | | | | | | | SIGN MSB | | | | | | | | | | | | | | | | | | | | | | | LSB |
| Volts | Sensor Hard Fault | Range Hard Fault | NA | NA | Soft Above | Soft Below | Soft Range | Valid Always 1 | ± 2V | 1V | | 0.5V | 0.25V | ... | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | Integer | | | Fraction | | | | | | | | | | | | | | | | | | | | |
| >$V_{REF}$ | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | CLAMPED to Factory Programmed Value of $V_{REF}$ | | | | | | | | | | | | | | | | | | | | | | | |
| 1.75 • $V_{REF}$/2 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.125 • $V_{REF}$/2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $V_{REF}$/2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $2^{-21}$V | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $-2^{-21}$V | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $-V_{REF}$/2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $-1.125 • V_{REF}$ | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $-1.75 • V_{REF}$ | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| < $-V_{REF}$ | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | CLAMPED to Factory Programmed Value of $-V_{REF}$ | | | | | | | | | | | | | | | | | | | | | | | |

### Example: Direct ADC with Differential Input

**Table 75. Direct ADC Channel Assignment Data**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x200 | | | | | | | | MEMORY ADDRESS 0x201 | | | | | | | | MEMORY ADDRESS 0x202 | | | | | | | | MEMORY ADDRESS 0x203 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Direct ADC | Directly Measure ADC | 5 | 11110 | 1 | 1 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) SE/Diff | Single-Ended or Differential | 1 | 0 | | | | | | 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| (3) TBL | Table Lookup | 1 | 0 | | | | | | | 0 | | | | | | | | | | | | | | | | | | | | | | | |
| (4) Not Used | Set to 0 | 13 | 0000000000000 | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | |
| (4) Direct ADC Table Data Pointer | Start Address = 0 | 6 | 000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| (5) Direct ADC Table Data Length-1 | Data Length-1 = 0 | 6 | 000000 | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 |

# APPLICATIONS INFORMATION

## Table Lookup Mode

For table-driven output mode, the channel assignment word's 1st two bytes are 0xF200 for differential readings and 0xF600 for single-ended. The 12 least significant bits contain length and pointer information for the custom table data. When the LTC2986 is configured for table-driven output data, it will take the voltage value from the ADC and perform a table lookup. The result format of the table lookup will be a 24-bit signed integer along with the error status byte.

**Table 76. Direct ADC Table Lookup Result Format**

| START ADDRESS | | | | | | | | START ADDRESS + 1 | | | | | | | | START ADDRESS + 2 | | | | | | | | START ADDRESS + 3 (END ADDRESS) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D31 | D30 | D29 | D28 | D27 | D26 | D25 | D24 | D23 | D22 | D21 | D20 | D19 | D18 | D17 | D16 | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
| Fault Data | | | | | | | | SIGN MSB | | | | | | | | | | | | | | | | | | | | | | | LSB |
| Sensor Hard Fault | Range Hard Fault | NA | NA | Soft Above | Soft Below | Soft Range | Valid Always 1 | Table Lookup Result – Signed Integer | | | | | | | | | | | | | | | | | | | | | | | |

**Table 77. Direct ADC Table Lookup Fault Data Byte**

| BIT | FAULT | DESCRIPTION |
|---|---|---|
| D31 | Sensor Hard Fault | $V_{ADC} < -1.75 \cdot V_{REF}/2$ or $V_{ADC} > 1.75 \cdot V_{REF}/2$ |
| D30 | Range Hard Fault | $V_{ADC} < -1.75 \cdot V_{REF}/2$ or $V_{ADC} > 1.75 \cdot V_{REF}/2$ |
| D29 | Not Used | NA |
| D28 | Not Used | NA |
| D27 | Soft Above | $V_{ADC}$ > Last Table Point Voltage |
| D26 | Soft Below | $V_{ADC}$ < Second Table Point (P1) Voltage |
| D25 | Soft Range | $V_{ADC} < -1.125 \cdot V_{REF}/2$ or $V_{ADC} > 1.125 \cdot V_{REF}/2$ |
| D24 | Result Valid (Always 1) | NA |

**Table 78. Direct ADC Table Format**

| ADDRESS | BYTE 0 | BYTE 1 | BYTE 2 | BYTE 3 | BYTE 4 | BYTE 5 |
|---|---|---|---|---|---|---|
| 0x250 + 6 • Start Address | Table Entry #1 (mV) | | | Table Entry #1 (Integer Value) | | |
| 0x250 + 6 • Start Address + 6 | Table Entry #2 (mV) | | | Table Entry #2 (Integer Value) | | |
| 0x250 + 6 • Start Address + 12 | Table Entry #3 (mV) | | | Table Entry #3 (Integer Value) | | |
| • | • | | | • | | |
| • | • | | | • | | |
| • | • | | | • | | |
| | | | | | | |
| | | | | | | |
| Max Address = 0x3CA | Table Entry #64 (mV) | | | Table Entry #64 (Integer Value) | | |

# APPLICATIONS INFORMATION

### Example: Direct ADC with Differential Input and Table Lookup

In this example, a simplified custom curve is implemented (see Figure 59). Points P1 to P9 represent the normal operating range of the custom device. Voltage readings above point P9 result in a soft fault and the reported result is a linear extrapolation using a slope determined by points P8 and P9 (the final two table entries). Voltage readings below point P1 are also reported as soft faults. The reported result is the extrapolation between point P1 and P0, where P0 is typically the lowest possible sensor output voltage. Sensor output voltages below P0 (in mV) will report P0 output.

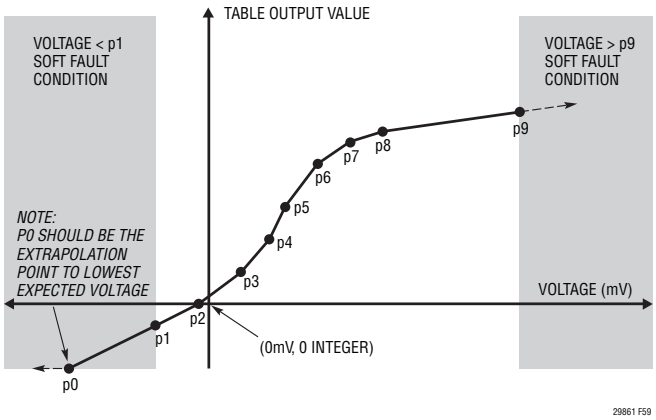



**Figure 59. Direct ADC Table Example**

In order to program the LTC2986 with the custom ADC table, both the mV data and the result data are converted to 24-bit binary values (represented as two 3-byte table entries). To accommodate sensors with bipolar output voltages, the mV values input to the LTC2986 are 2's compliment. The sensor output voltage (units = mV) follows the convention shown in Table 80, where the first bit is the sign, the next 11 bits are the integer part and the remaining 12 bits are the fractional part.

The result-side of table entries are input as signed 24-bit integers, the final result reported by the LTC2986 is also a 24-bit integer. The result format follows the convention shown in Table 81, where the first bit is the sign bit and the remaining 23 bits are the integer magnitude. In this example, a custom differential sensor is tied to CH2 with the channel assignment data shown in Table 82. In this case the custom data begins at memory location 0x250 (starting address is 0). The starting address (offset from 0x250) is entered in the data pointer field of the channel assignment data. The table data length –1 (9 in this example) is entered into the data length field of the sensor channel assignment word. Refer to Table 79 for the location and format of the 10 six-byte table entries.

**Table 79. Direct ADC Table Example Data Memory Map**

| POINT | SENSOR OUTPUT VOLTAGE (mV) | INTEGER OUTPUT DATA | START ADDRESS | STOP ADDRESS | BYTE 0 | BYTE 1 | BYTE 2 | BYTE 3 | BYTE 4 | BYTE 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| P0 | –50.22 | –100 | 0x250 | 0x255 | | | | | | |
| P1 | –30.2 | –50 | 0x256 | 0x25B | | | | | | |
| P2 | –5.3 | 0 | 0x25C | 0x261 | | | | | | |
| P3 | 20.33 | 2203 | 0x262 | 0x267 | | | | | | |
| P4 | 40.2 | 3612 | 0x268 | 0x26D | mV Data | | | Integer Output Data | | |
| P5 | 55.3 | 5221 | 0x26E | 0x273 | | | | | | |
| P6 | 88.3 | 7203 | 0x274 | 0x279 | | | | | | |
| P7 | 132.2 | 8112 | 0x27A | 0x27F | | | | | | |
| P8 | 188.7 | 9225 | 0x280 | 0x285 | | | | | | |
| P9 | 460.4 | 10000 | 0x286 | 0x28B | | | | | | |

# APPLICATIONS INFORMATION

**Table 80. Example ADC Voltage Values**

| | BYTE 0 | | | | | | | | BYTE 1 | | | | | | | | BYTE 2 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| mV | Sign | $2^{10}$ | $2^{9}$ | $2^{8}$ | $2^{7}$ | $2^{6}$ | $2^{5}$ | $2^{4}$ | $2^{3}$ | $2^{2}$ | $2^{1}$ | $2^{0}$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ | $2^{-11}$ | $2^{-12}$ |
| –50.22 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| –30.2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| –5.3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 20.33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 40.2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 55.3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 88.3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 132.2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 188.7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 460.4 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |

**Table 81. Example Table Output Values**

| | BYTE 3 | | | | | | | | BYTE 4 | | | | | | | | BYTE 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| Temperature | Sign | $2^{22}$ | $2^{21}$ | $2^{20}$ | $2^{19}$ | $2^{18}$ | $2^{17}$ | $2^{16}$ | $2^{15}$ | $2^{14}$ | $2^{13}$ | $2^{12}$ | $2^{11}$ | $2^{10}$ | $2^{9}$ | $2^{8}$ | $2^{7}$ | $2^{6}$ | $2^{5}$ | $2^{4}$ | $2^{3}$ | $2^{2}$ | $2^{1}$ | $2^{0}$ |
| –100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| –50 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2203 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| 3612 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 5221 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 |
| 7203 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| 8112 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 9225 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 10000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

**Table 82. Example Table Lookup Mode Channel Assignment Data**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 214 | | | | | | | | MEMORY ADDRESS 215 | | | | | | | | MEMORY ADDRESS 216 | | | | | | | | MEMORY ADDRESS 217 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Direct ADC | Directly Measure ADC | 5 | 11110 | 1 | 1 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) SE/Diff | Single-Ended or Differential | 1 | 0 | | | | | | 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| (3) TBL | Table Lookup | 1 | 1 | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| (4) Not Used | Set to 0 | 13 | 0000000000000 | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | |
| (5) Direct ADC Table Data Pointer | Start Address = 0 (Start at 0x250) | 6 | 000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| (5) Direct ADC Table Data Length-1 | Data Length-1 = 9 | 6 | 001001 | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 1 | 0 | 0 | 1 |

# SUPPLEMENTAL INFORMATION

## 2- AND 3-CYCLE CONVERSION MODES

The LTC2986 performs multiple internal conversions in order to determine the sensor temperature. Normally, two internal conversion cycles are required for each temperature result providing a maximum output time of 167.2ms. The LTC2986 uses these two cycles to automatically remove offset/offset drift errors, reduce 1/f noise, autocalibrate matched internal current sources, and provide simultaneous 50/60Hz noise rejection.

In addition to performing two conversion cycles per result, the LTC2986 also offers several unique features by utilizing a 3rd conversion cycle. In this case, the maximum output time is 251ms and all the benefits of the 2-cycle modes are present (see Table 83).

One feature utilizing the three conversion cycle mode is the internal open circuit detect mode. Typically, thermocouple open circuit detection is performed by adding a high resistance pull-up between the thermocouple and $V_{DD}$. This method can be used with the LTC2986 while operating in the two conversion cycle mode (OC=0). This external pull-up can interact with the input protection circuitry and lead to temperature measurement errors and increased noise. These problems are eliminated by selecting the internal open circuit detection mode (OC=1). In this case, a current is pulsed for 8ms and allowed to settle during one conversion cycle. This is followed by the normal two conversion cycle measurement of the thermocouple. If the thermocouple is broken, the current pulse will result in an open circuit fault.

A second feature taking advantage of the 3rd conversion cycle is thermistor excitation current auto ranging. Since a thermistor's resistance varies many orders of magnitude, the performance in the low resistance regions are compromised by the small currents required by the high resistance regions of operation. The auto ranging mode applies a test current during the first conversion cycle in order to determine the optimum current for the resistance state of the thermistor. It then uses that current to perform the thermistor measurement using the normal 2-cycle measurement. If a 3-cycle thermistor measurement is used as the cold junction sensor for a 2-cycle thermocouple measurement, the thermocouple conversion result is ready after three cycles.

A third feature requiring a 3rd conversion cycle is the three current diode measurement. In this mode, three ratioed currents are applied to the external diode in order to cancel parasitic lead resistance effects. This is useful in applications where the diode is remotely located and significant, unknown parasitic lead resistance requires cancellation. If a 3-cycle diode or thermistor measurement is used as the cold junction sensor for a 2-cycle thermocouple measurement, the thermocouple conversion result is ready after three cycles.

**Table 83. 2- and 3-Cycles Conversion Modes**

| TYPE OF SENSOR | CONFIGURATION | NUMBER OF CONVERSION CYCLES | MAXIMUM OUTPUT TIME |
|---|---|---|---|
| Thermocouple | OC = 0 | 2 | 167.2ms |
| RTD | All | 2 | 167.2ms |
| Thermistor | Non-Autorange Current | 2 | 167.2ms |
| Diode | Two Readings | 2 | 167.2ms |
| Thermocouple | OC = 1 | 3 | 251ms |
| Thermocouple | OC = 0, 3-Cycle Cold Junction | 3 | 251ms |
| Thermistor | Autorange Current | 3 | 251ms |
| Diode | Three Readings | 3 | 251ms |

## RUNNING CONVERSIONS CONSECUTIVELY ON MULTIPLE CHANNELS

Generally, during the Initiate Conversion state, a conversion measurement is started on a single input channel determined by the channel number (bits B[4:0] = 00001 to 01010) written into memory location 0x000. Multiple consecutive conversions can be initiated by writing bits B[4:0]=00000 into memory location 0. Conversions will be initiated on each channel selected in the mask register (see Table 84).

For example, using the mask data shown in Table 85, after 1000000 is written into memory location 0, conversions are initiated consecutively on CH10, CH8, CH6, and CH1.

## SUPPLEMENTAL INFORMATION

Once the conversions begin, the INTERRUPT pin goes LOW and remains LOW until all conversions are complete. If the mask register is set for a channel that has no assignment data, that conversion step is skipped. All the results are stored in the conversion result memory locations and can be read at the conclusion of the measurement cycle.

### ENTERING/EXITING SLEEP MODE

The LTC2986 can be placed into sleep mode by writing 0x97 to memory location 0x000. On the rising edge of $\overline{CS}$ following the memory write (see Figure 2) the device enters the low power sleep state. It remains in this state until $\overline{CS}$ is brought low or $\overline{RESET}$ is asserted. Once one of these two signals is asserted, the LTC2986 begins its start-up cycle as described in State 1: Start-Up section of this data sheet.

### MUX CONFIGURATION DELAY

The LTC2986 performs 2 or 3 internal conversion cycles per temperature result. Each conversion cycle is performed with different excitation and input multiplexer configurations. Prior to each conversion, these excitation circuits and input switch configurations are changed and an internal 1ms (typical) delay ensures settling prior to the conversion cycle in most cases.

If excessive RC time constants are present in external sensor circuits (large bypass capacitors used for thermistors or RTDs) it is possible to increase the settling time between current source excitation and MUX switching. The extra delay is determined by the value written into the MUX configuration delay register (memory location 0x0FF). The value written into this memory location is multiplied by 100µs; therefore, the maximum extra MUX delay is 25.5ms (i.e. 0x0FF = 255 • 100µs).

### REFERENCE CONSIDERATIONS

The mechanical stress of soldering the LTC2986 to a PC board can cause the output voltage reference to shift and temperature coefficient to change. These two changes are not correlated. For example, the voltage may shift but the temperature coefficient may not. To reduce the effects of stress-related shifts, mount the reference near the short edge of the PC board or in a corner.

**Table 84. Multiple Conversion Mask Register**

| MEMORY LOCATION | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|---|
| 0x0F4 | | Reserved | | | | | | |
| 0x0F5 | | | | | | | | |
| 0x0F6 | | | | | | | CH10 | CH9 |
| 0x0F7 | CH8 | CH7 | CH6 | CH5 | CH4 | CH3 | CH2 | CH1 |

**Table 85. Example Mask Register Select CH10, CH8, CH6, and CH1**

| MEMORY LOCATION | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|---|
| 0x0F4 | | Reserved | | | | | | |
| 0x0F5 | | | | | | | | |
| 0x0F6 | | | | | | | 1 | 0 |
| 0x0F7 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

# CUSTOM THERMOCOUPLES

In addition to digitizing standard thermocouples, the LTC2986 can also digitize user-programmable, custom thermocouples (thermocouple type=0b01001, see Table 16). Custom sensor data (minimum of three, maximum of 64 pairs) reside sequentially in memory and are arranged in blocks of six bytes of monotonically increasing tabular data as mV vs temperature (see Table 86).

**Table 86. Custom Thermocouple Tabular Data Format**

| ADDRESS | BYTE 0 BYTE 1 BYTE 2 | BYTE 3 BYTE 4 BYTE 5 |
|---|---|---|
| 0x250 + 6 • Start Address | Table Entry #1 (mV) | Table Entry #1 (Kelvin) |
| 0x250 + 6 • Start Address + 6 | Table Entry #2 (mV) | Table Entry #2 (Kelvin) |
| 0x250 + 6 • Start Address + 12 | Table Entry #3 (mV) | Table Entry #3 (Kelvin) |
| • | • | • |
| • | • | • |
| • | • | • |
| | | |
| | | |
| Max Address = 0x3CA | Table Entry #64 (mV) | Table Entry #64 (Kelvin) |

### Custom Thermocouple Example

In this example, a simplified thermocouple curve is implemented (see Figure 60). Points P1 to P9 represent the normal operating range of the custom thermocouple. Voltage readings above point P9 result in a soft fault and

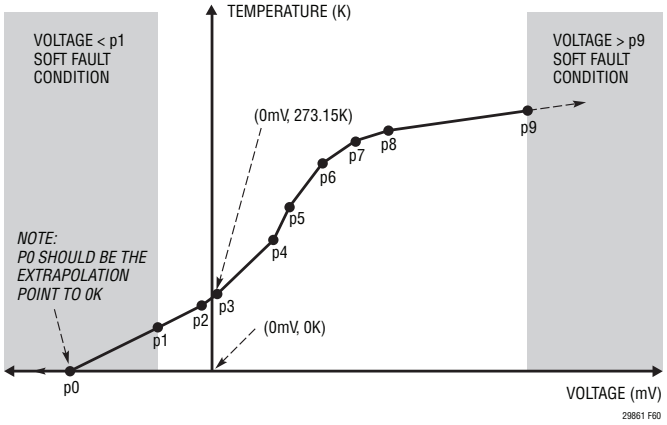



**Figure 60. Custom Thermocouple Example (mV vs Kelvin)**

## CUSTOM THERMOCOUPLES

the reported temperature is a linear extrapolation using a slope determined by points P8 and P9 (the final two table entries in Table 87). Voltage readings below point P1 are also reported as soft faults. The temperature reported is the extrapolation between point P1 and P0, where P0 is typically the sensor output voltage at 0 Kelvin. If P0 is above 0 Kelvin, then all sensor output voltages below P0 (in mV) will report 0 Kelvin. Sensor readings below P1 are reported as soft faults

In order to program the LTC2986 with the custom thermocouple table, both the mV data and the Kelvin data are converted to 24-bit binary values (represented as two 3-byte table entries). Since most thermocouples generate negative output voltages, the mV values input to the LTC2986 are 2's compliment. The sensor output voltage (units=mV), follows the convention shown in Table 88, where the first bit is the sign, the next nine are the integer part and the remaining 14 bits are the fractional part.

**Table 87. Thermocouple Example mV vs Kelvin (K) Data Memory Map**

| POINT | SENSOR OUTPUT VOLTAGE (mV) | TEMPERATURE KELVIN | START ADDRESS | STOP ADDRESS | BYTE 0 | BYTE 1 | BYTE 2 | BYTE 3 | BYTE 4 | BYTE 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| P0 | –50.22 | 0 | 0x250 | 0x255 | | | | | | |
| P1 | –30.2 | 99.1 | 0x256 | 0x25B | | | | | | |
| P2 | –5.3 | 135.4 | 0x25C | 0x261 | | | | | | |
| P3 | 0 | 273.15 | 0x262 | 0x267 | | | | | | |
| P4 | 40.2 | 361.2 | 0x268 | 0x26D | mV Data | | | Temperature Data | | |
| P5 | 55.3 | 522.1 | 0x26E | 0x273 | (see Table 88) | | | (see Table 89) | | |
| P6 | 88.3 | 720.3 | 0x274 | 0x279 | | | | | | |
| P7 | 132.2 | 811.2 | 0x27A | 0x27F | | | | | | |
| P8 | 188.7 | 922.5 | 0x280 | 0x285 | | | | | | |
| P9 | 460.4 | 1000 | 0x286 | 0x28B | | | | | | |

**Table 88. Example Thermocouple Output Voltage Values (mV)**

| | BYTE 0 | | | | | | | | BYTE 1 | | | | | | | | BYTE 2 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| mV | Sign | $2^8$ | $2^7$ | $2^6$ | $2^5$ | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ | $2^{-11}$ | $2^{-12}$ | $2^{-13}$ | $2^{-14}$ |
| –50.22 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |
| –30.2 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| –5.3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40.2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 55.3 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 88.3 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 132.2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 188.7 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 460.4 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |

## CUSTOM THERMOCOUPLES

In order to simplify the temperature field, temperature values are input in Kelvin as an unsigned value, but the final temperatures reported by the LTC2986 are reported in °C or °F (see Table 9). The sensor temperature (Kelvin), follows the convention shown in Table 89, where the first 14 bits are the integer part and the remaining 10 bits are the fractional part.

In this example, a custom thermocouple tied to CH1, with a cold junction sensor on CH2, is programmed with the channel assignment data shown in Table 90 (refer to Figure 9 for similar format). In this case the custom data begins at memory location 0x250 (starting address is 0). The starting address (offset from 0x250) is entered in the custom thermocouple data pointer field of the channel assignment data. The table data length –1 (9 in this example) is entered into the custom thermocouple data length field of the thermocouple channel assignment word. Refer to Table 87 where the number of six byte entries is 10.

**Table 89. Example Thermocouple Temperature Values**

| | BYTE 3 | | | | | | | | BYTE 4 | | | | | | | | BYTE 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| Temperature | $2^{13}$ | $2^{12}$ | $2^{11}$ | $2^{10}$ | $2^{9}$ | $2^{8}$ | $2^{7}$ | $2^{6}$ | $2^{5}$ | $2^{4}$ | $2^{3}$ | $2^{2}$ | $2^{1}$ | $2^{0}$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 99.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| 135.4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| 273.15 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| 361.2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 522.1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| 720.3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 811.2 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 922.5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1000 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 90. Custom Thermocouple Channel Assignment Data**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x200 | | | | | | | | MEMORY ADDRESS 0x201 | | | | | | | | MEMORY ADDRESS 0x202 | | | | | | | | MEMORY ADDRESS 0x203 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Thermocouple Type | Type Custom | 5 | 01001 | 0 | 1 | 0 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Cold Junction Channel Pointer | $CH_2$ | 5 | 00010 | | | | | | 0 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | Single-Ended, 10µA Open Circuit | 4 | 1100 | | | | | | | | | | | 1 | 1 | 0 | 0 | | | | | | | | | | | | | | | | |
| Not Used | Set These Bits to 0 | 6 | 000000 | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | |
| (4) Custom Thermocouple Data Pointer | Start Address = 0 (Start at 0x250) | 6 | 000000 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| Custom Thermocouple Data Length-1 | Data Length –1 = 9 (10 Paired Entries) | 6 | 001001 | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 1 | 0 | 0 | 1 |

## CUSTOM RTDS

In addition to digitizing standard RTDs, the LTC2986 can also digitize custom RTDs (RTD type=0b10010, see Table 30). Custom sensor data (minimum of three, maximum of 64 pairs) reside sequentially in memory and are arranged in blocks of six bytes of monotonically increasing tabular data Ω vs temperature (see Table 91).

**Table 91. Custom RTD/Thermistor Tabular Data Format**

| ADDRESS | BYTE 0 BYTE 1 BYTE 2 | BYTE 3 BYTE 4 BYTE 5 |
|---|---|---|
| 0x250 + 6 • Start Address | Table Entry #1 (Ω) | Table Entry #1 (Kelvin) |
| 0x250 + 6 • Start Address + 6 | Table Entry #2 (Ω) | Table Entry #2 (Kelvin) |
| 0x250 + 6 • Start Address + 12 | Table Entry #3 (Ω) | Table Entry #3 (Kelvin) |
| • | • | • |
| • | • | • |
| • | • | • |
| | | |
| | | |
| Max Address = 0x3CA | Table Entry #64 (Ω) | Table Entry #64 (Kelvin) |

### Custom RTD Example

In this example, a simplified RTD curve is implemented (see Figure 61). Points P1 to P9 represent the normal operating range of the custom RTD. Resistance readings above point P9 result in a soft fault and the reported temperature is a linear extrapolation using a slope determined by points P8 and P9 (the final two table entries). Resistance readings below point P1 are also reported as soft faults. The temperature reported is the extrapolation between point P1 and P0, where P0 is the sensor output temperature at 0Ω (This point should be 0Ω for proper interpolation below point P1).

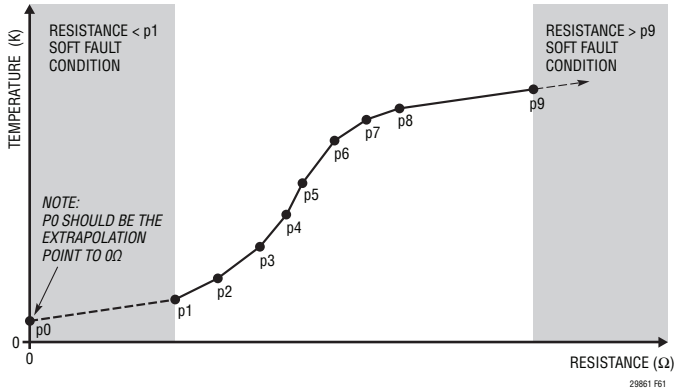



**Figure 61. Custom RTD Example (Ω vs Kelvin )**

## CUSTOM RTDS

Custom RTD table data is formatted in Ω (sensor output resistance) vs Kelvin (see Table 92). Each table entry pair spans six bytes. The first set of data can begin at any memory location greater than or equal to 0x250 and end at or below 0x3CF.

In order to program the LTC2986 with the custom RTD table, both the resistance data and the Kelvin data are converted to 24-bit binary values. The sensor output resistance (units=Ω) follows the convention shown in Table 93, where the first 13 bits are the integer part and the remaining 11 bits are the fractional part.

In order to simplify the temperature field, temperature values are input in Kelvin as an unsigned value, but the final temperatures reported by the LTC2986 are reported in °C or °F. The sensor temperature (Kelvin) follows the

**Table 92. RTD Example Resistance vs Kelvin Data Memory Map**

| POINT | SENSOR OUTPUT RESISTANCE (Ω) | TEMPERATURE (K) | START ADDRESS | STOP ADDRESS | BYTE 1 | BYTE 2 | BYTE 3 | BYTE 1 | BYTE 2 | BYTE 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| P0 | 0 | 112.3 | 0x28C | 0x291 | | | | | | |
| P1 | 80 | 200.56 | 0x292 | 0x297 | | | | | | |
| P2 | 150 | 273.16 | 0x298 | 0x29D | | | | | | |
| P3 | 257.36 | 377.25 | 0x29E | 0x2A3 | | | | | | |
| P4 | 339.22 | 489.66 | 0x2A4 | 0x2A9 | Resistance Data | | | Temperature Data | | |
| P5 | 388.26 | 595.22 | 0x2AA | 0x2AF | | | | | | |
| P6 | 512.99 | 697.87 | 0x2B0 | 0x2B5 | | | | | | |
| P7 | 662.3 | 765.14 | 0x2B6 | 0x2BB | | | | | | |
| P8 | 743.5 | 801.22 | 0x2BC | 0x2C1 | | | | | | |
| P9 | 2001.89 | 900.5 | 0x2C2 | 0x2C7 | | | | | | |

**Table 93. Example RTD Resistance Values**

| | BYTE 1 | | | | | | | | BYTE 2 | | | | | | | | BYTE 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| Resistance | $2^{12}$ | $2^{11}$ | $2^{10}$ | $2^{9}$ | $2^{8}$ | $2^{7}$ | $2^{6}$ | $2^{5}$ | $2^{4}$ | $2^{3}$ | $2^{2}$ | $2^{1}$ | $2^{0}$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ | $2^{-11}$ |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 150 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 257.36 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 339.22 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 388.26 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| 512.99 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 |
| 662.3 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| 743.5 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2001.89 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 |

## CUSTOM RTDS

convention shown in Table 94, where the first 14 bits are the integer part and the remaining 10 bits are the fractional part.

In this example, a custom RTD tied to CH3/CH4, with a sense resistor on CH1/CH2, is programmed with the channel assignment data shown in Table 95 (refer to Figure 18 for a similar format). In this case, the custom data begins at memory location 0x28C (starting address is 10). The starting address (offset from 0x250) is entered in the custom RTD data pointer field of the channel assignment data. The table data length –1 (9 in this case) is entered into the custom RTD data length field of the channel assignment word. Refer to Table 91 where the total number of paired entries is 10.

**Table 94. Example RTD Temperature Values**

| | BYTE 1 | | | | | | | | BYTE 2 | | | | | | | | BYTE 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| Temperature | $2^{13}$ | $2^{12}$ | $2^{11}$ | $2^{10}$ | $2^{9}$ | $2^{8}$ | $2^{7}$ | $2^{6}$ | $2^{5}$ | $2^{4}$ | $2^{3}$ | $2^{2}$ | $2^{1}$ | $2^{0}$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ |
| 112.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 200.56 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 |
| 273.16 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| 377.25 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 489.66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| 595.22 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 697.87 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 |
| 765.14 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 801.22 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 900.5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 95. Custom RTD Channel Assignment Data**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x20C | | | | | | | | MEMORY ADDRESS 0x20D | | | | | | | | MEMORY ADDRESS 0x20E | | | | | | | | MEMORY ADDRESS 0x20F | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) RTD Type | Custom | 5 | 10010 | 1 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_2$ | 5 | 00010 | | | | | | 0 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | 4-Wire, No Rotate, No Share | 4 | 1000 | | | | | | | | | | | 1 | 0 | 0 | 0 | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 25µA | 4 | 0011 | | | | | | | | | | | | | | | 0 | 0 | 1 | 1 | | | | | | | | | | | | |
| (5) Curve | Not Used for Custom | 2 | 00 | | | | | | | | | | | | | | | | | | | 0 | 0 | | | | | | | | | | |
| (6) Custom RTD Data Pointer | Start Address = 10 | 6 | 001010 | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 1 | 0 | 1 | 0 | | | | |
| (6) Custom RTD Data Length-1 | Data Length –1 = 9 10 Paired Entries | 6 | 001001 | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 1 | 0 | 0 | 1 |

# CUSTOM THERMISTORS

In addition to digitizing standard thermistors, the LTC2986 can also digitize custom thermistors (thermistor type=0b11011, see Table 55). Custom sensor data (minimum of three, maximum of 64 pairs) reside sequentially in memory and are arranged in blocks of six bytes of monotonically increasing tabular data Ω vs temperature (see Table 91).

### Custom Thermistor Table Example

In this example, a simplified thermistor NTC (negative temperature coefficient) curve is implemented (see Figure 62). Points P1 to P9 represent the normal operating range of the custom thermistor. Resistance readings above point P9 result in a soft fault and the reported temperature is a linear extrapolation using a slope determined by points P8 and P9 (the final two table entries). Resistance readings below point P1 are also reported as soft faults. The temperature reported is the extrapolation between point P1 and P0, where P0 is the sensor output temperature at 0Ω (This point must be 0Ω for proper interpolation below point P1).

In addition to NTC type thermistors, it is also possible to implement PTC (positive temperature coefficient) type thermistors (see Figure 63). In both cases, table entries start at the minimum resistance and end at the maximum resistance value.

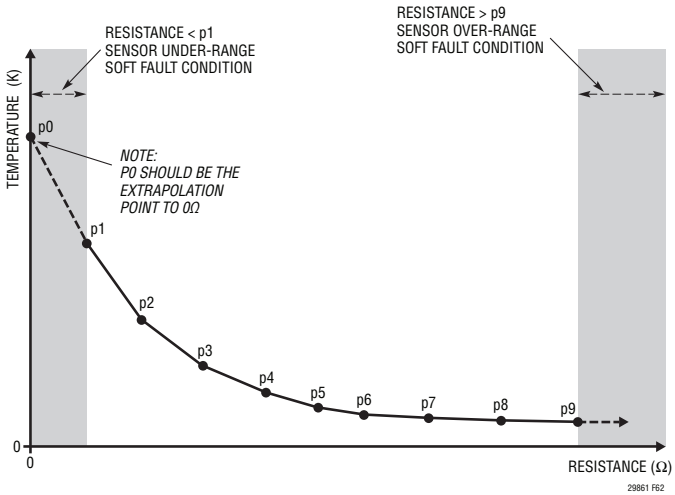



Figure 62. Custom NTC Thermistor Example (Ω vs Kelvin)

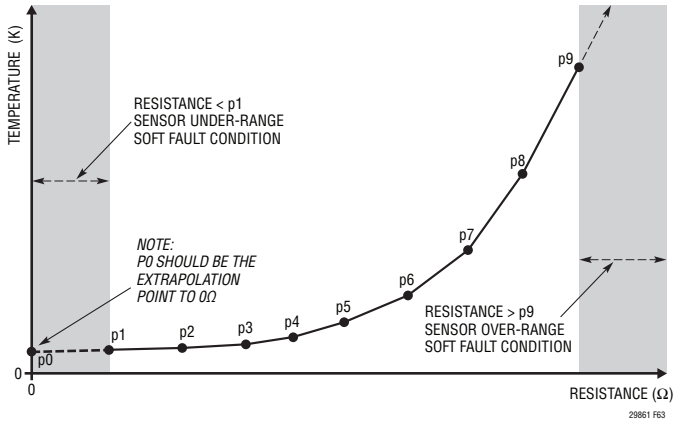



Figure 63. Custom PTC Thermistor Example (Ω vs Kelvin)

## CUSTOM THERMISTORS

Custom thermistor table data is formatted in Ω (sensor output resistance) vs Kelvin (see Table 96). Each table entry pair spans six bytes. The first set of data can begin at any memory location greater than or equal to 0x250 and end below 0x3CF.

In order to program the LTC2986 with the custom thermistor table, both the resistance data and the Kelvin data are converted to 24-bit binary values. The sensor output resistance (units = Ω) follows the convention shown in Table 97, where the first 20 bits are the integer part and the remaining four bits are the fractional part.

In order to simplify the temperature field, temperature values are input in Kelvin as an unsigned value, but the final temperatures reported by the LTC2986 are reported in °C or °F. The sensor temperature (Kelvin) follows the convention shown in Table 98, where the first 14 bits are the integer part and the remaining 10 bits are the fractional part.

**Table 96. NTC Thermistor Example Resistance vs Kelvin Data Memory Map**

| POINT | SENSOR OUTPUT RESISTANCE(Ω) | TEMPERATURE (K) | START ADDRESS | STOP ADDRESS | BYTE 1 | BYTE 2 | BYTE 3 | BYTE 1 | BYTE 2 | BYTE 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| P0 | 0 | 457.5 | 0x2C8 | 0x2CD | | | | | | |
| P1 | 80 | 400.2 | 0x2CE | 0x2D3 | | | | | | |
| P2 | 184 | 372.3 | 0x2D4 | 0x2D9 | | | | | | |
| P3 | 423.2 | 320.1 | 0x2DA | 0x2DF | | | | | | |
| P4 | 973.36 | 290.55 | 0x2E0 | 0x2E5 | Resistance Data | | | Temperature Data | | |
| P5 | 2238.728 | 249.32 | 0x2E6 | 0x2EB | | | | | | |
| P6 | 5149.0744 | 240.3 | 0x2EC | 0x2F1 | | | | | | |
| P7 | 26775.18688 | 230 | 0x2F2 | 0x2F7 | | | | | | |
| P8 | 139230.9718 | 215.3 | 0x2F8 | 0x2FD | | | | | | |
| P9 | 724001.0532 | 200 | 0x2FE | 0x303 | | | | | | |

**Table 97. Example Thermistor Resistance Values**

| | BYTE 1 | | | | | | | | BYTE 2 | | | | | | | | BYTE 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| Resistance | $2^{19}$ | $2^{18}$ | $2^{17}$ | $2^{16}$ | $2^{15}$ | $2^{14}$ | $2^{13}$ | $2^{12}$ | $2^{11}$ | $2^{10}$ | $2^{9}$ | $2^{8}$ | $2^{7}$ | $2^{6}$ | $2^{5}$ | $2^{4}$ | $2^{3}$ | $2^{2}$ | $2^{1}$ | $2^{0}$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 184 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 423.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 973.36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| 2238.728 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 |
| 5149.074 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| 26775.19 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 139231 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 724001.1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |

## CUSTOM THERMISTORS

In this example, a custom thermistor tied to CH5, with a sense resistor on CH3/4, is programmed with the channel assignment data shown in Table 99 (refer to Figure 27 for similar format). In this case the custom data begins at memory location 0x2C8 (starting address is 20). The starting address (offset from 0x250) is entered in the custom thermistor data pointer field of the channel assignment data. The table data length –1 (9 in this case) is entered into the custom thermistor data length field of the thermistor channel assignment word.

**Table 98. Example Thermistor Temperature Values**

| | BYTE 1 | | | | | | | | BYTE 2 | | | | | | | | BYTE 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| Temperature | $2^{13}$ | $2^{12}$ | $2^{11}$ | $2^{10}$ | $2^{9}$ | $2^{8}$ | $2^{7}$ | $2^{6}$ | $2^{5}$ | $2^{4}$ | $2^{3}$ | $2^{2}$ | $2^{1}$ | $2^{0}$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ |
| 457.5 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 400.2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 372.3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 320.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| 290.55 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 249.32 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 |
| 240.3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 230 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 215.3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 200 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 99. Custom Thermistor Channel Assignment Data**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x210 | | | | | | | | MEMORY ADDRESS 0x211 | | | | | | | | MEMORY ADDRESS 0x212 | | | | | | | | MEMORY ADDRESS 0x213 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Thermistor Type | Custom Table | 5 | 11011 | 1 | 1 | 0 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_4$ | 5 | 00100 | | | | | | 0 | 0 | 1 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | Single-Ended | 3 | 100 | | | | | | | | | | | 1 | 0 | 0 | | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 1µA | 4 | 0011 | | | | | | | | | | | | | | 0 | 0 | 1 | 1 | | | | | | | | | | | | | |
| Not Used | Set These Bits to 0 | 3 | 00 | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | | | | | | | | | | |
| (5) Custom Thermistor Data Pointer | Start Address = 20 | 6 | 010100 | | | | | | | | | | | | | | | | | | | | | 0 | 1 | 0 | 1 | 0 | 0 | | | | |
| (5) Custom Thermistor Length-1 | Length –1 = 9 | 6 | 001001 | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 1 | 0 | 0 | 1 |

## CUSTOM THERMISTORS

In addition to custom table driven thermistors, it is also possible to directly input Steinhart-Hart coefficients into the LTC2986 (thermistor Type 11010, see Table 55). Steinhart-Hart coefficients are commonly specified parameters provided by thermistor manufacturers. The Steinhart-Hart equation is:

$$\frac{1}{T} = A + B \bullet \ln(R) + C \bullet \ln(R)^2 + D \bullet \ln(R)^3 + E \bullet \ln(R)^4 + F \bullet \ln(R)^5$$

Steinhart-Hart data is stored sequentially in any memory location greater than or equal to 0x250 and below 0x3CF. Each coefficient is represented by a standard, single-precision, IEEE754 32-bit value (see Table 100).

### Example Custom Steinhart-Hart Thermistor

In this example a Steinhart-Hart equation is entered into memory starting at location 0x2C8 (see Table 101).

**Table 100. Steinhart-Hart Custom Thermistor Data Format**

| ADDRESS | COEFFICIENT | VALUE |
|---|---|---|
| 0x250 + 4 • Start Address | A | 32-Bit Single-Precision Floating Point Format |
| 0x250 + 4 • Start Address + 4 | B | 32-Bit Single-Precision Floating Point Format |
| 0x250 + 4 • Start Address + 8 | C | 32-Bit Single-Precision Floating Point Format |
| 0x250 + 4 • Start Address + 12 | D | 32-Bit Single-Precision Floating Point Format |
| 0x250 + 4 • Start Address + 16 | E | 32-Bit Single-Precision Floating Point Format |
| 0x250 + 4 • Start Address + 20 | F | 32-Bit Single-Precision Floating Point Format |

**Table 101. Custom Steinhart-Hart Data Example**

| COEFFICIENT | VALUE | START ADDRESS | SIGN | EXPONENT | | | | | | | | MANTISSA | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MSB | | | | | | | LSB | MSB | | | | | | | | | | | | | | | | | | | | | | | | | LSB |
| A | 1.45E-03 | 0x2C8 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 |
| B | 2.68E-04 | 0x2CC | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 |
| C | 0 | 0x2D0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D | 1.64E-07 | 0x2D4 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 |
| E | 0 | 0x2D8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F | 0 | 0x2DC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## CUSTOM THERMISTORS

A custom thermistor tied to CH5, with a sense resistor on CH3/4, is programmed with the channel assignment data shown in Table 102 (refer to Figure 27 for a similar format). In this case the custom data begins at memory location 0x2C8 (starting address is 30). The starting address (offset from 0x250) is entered in the custom thermistor data pointer field of the channel assignment data. The data length (set to 0) is always six 32-bit floating point words.

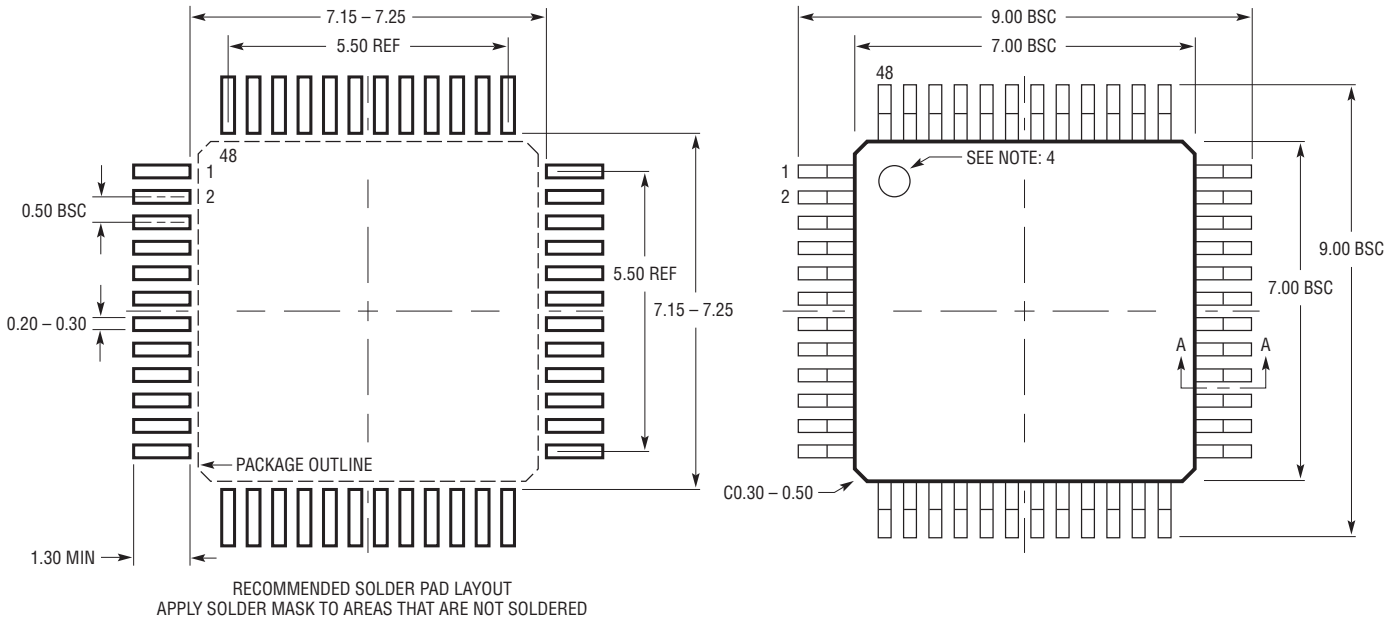
**Table 102. Custom Steinhart-Hart Channel Assignment Data**

| CONFIGURATION FIELD | DESCRIPTION | # BITS | BINARY DATA | MEMORY ADDRESS 0x210 | | | | | | | | MEMORY ADDRESS 0x211 | | | | | | | | MEMORY ADDRESS 0x212 | | | | | | | | MEMORY ADDRESS 0x213 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Thermistor Type | Custom Steinhart-Hart | 5 | 11010 | 1 | 1 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| (2) Sense Resistor Channel Pointer | $CH_4$ | 5 | 00100 | | | | | | 0 | 0 | 1 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| (3) Sensor Configuration | Single-Ended | 3 | 100 | | | | | | | | | | | 1 | 0 | 0 | | | | | | | | | | | | | | | | | |
| (4) Excitation Current | 1µA | 4 | 0011 | | | | | | | | | | | | | | 0 | 0 | 1 | 1 | | | | | | | | | | | | | |
| Not Used | Set These Bits to 0 | 3 | 00 | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | | | | | | | | | | |
| (5) Custom Thermistor Data Pointer | Start Address = 30 | 6 | 011110 | | | | | | | | | | | | | | | | | | | | | 0 | 1 | 1 | 1 | 1 | 0 | | | | | |
| (5) Custom Steinhart-Hart Length Always Set to 0 | Fixed at Six 32-Bit Words | 6 | 000000 | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 |

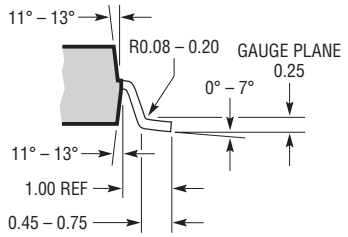
# PACKAGE DESCRIPTION

**Please refer to http://www.linear.com/product/LTC2986#packaging for the most recent package drawings.**

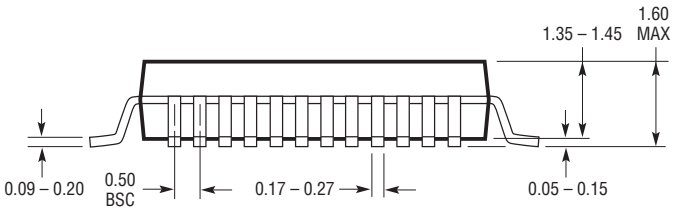
**LX Package**
**48-Lead Plastic LQFP (7mm × 7mm)**
(Reference LTC DWG # 05-08-1760 Rev A)



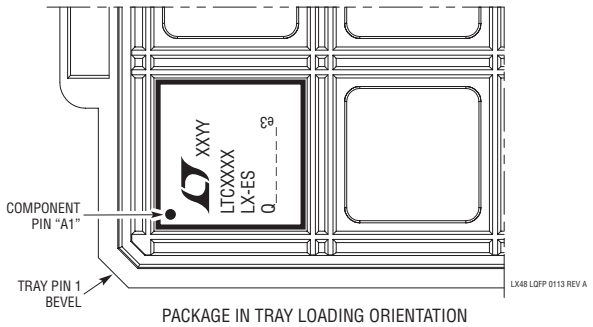

RECOMMENDED SOLDER PAD LAYOUT
APPLY SOLDER MASK TO AREAS THAT ARE NOT SOLDERED




SECTION A – A




NOTE:
1. PACKAGE DIMENSIONS CONFORM TO JEDEC #MS-026 PACKAGE OUTLINE
2. DIMENSIONS ARE IN MILLIMETERS
3. DIMENSIONS OF PACKAGE DO NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.25mm ON ANY SIDE, IF PRESENT
4. PIN-1 INDENTIFIER IS A MOLDED INDENTATION, 0.50mm DIAMETER
5. DRAWING IS NOT TO SCALE




PACKAGE IN TRAY LOADING ORIENTATION

## REVISION HISTORY

| REV | DATE | DESCRIPTION | PAGE NUMBER |
|---|---|---|---|
| A | 09/16 | Added H-grade. | 3 - 5 |



LINEAR TECHNOLOGY

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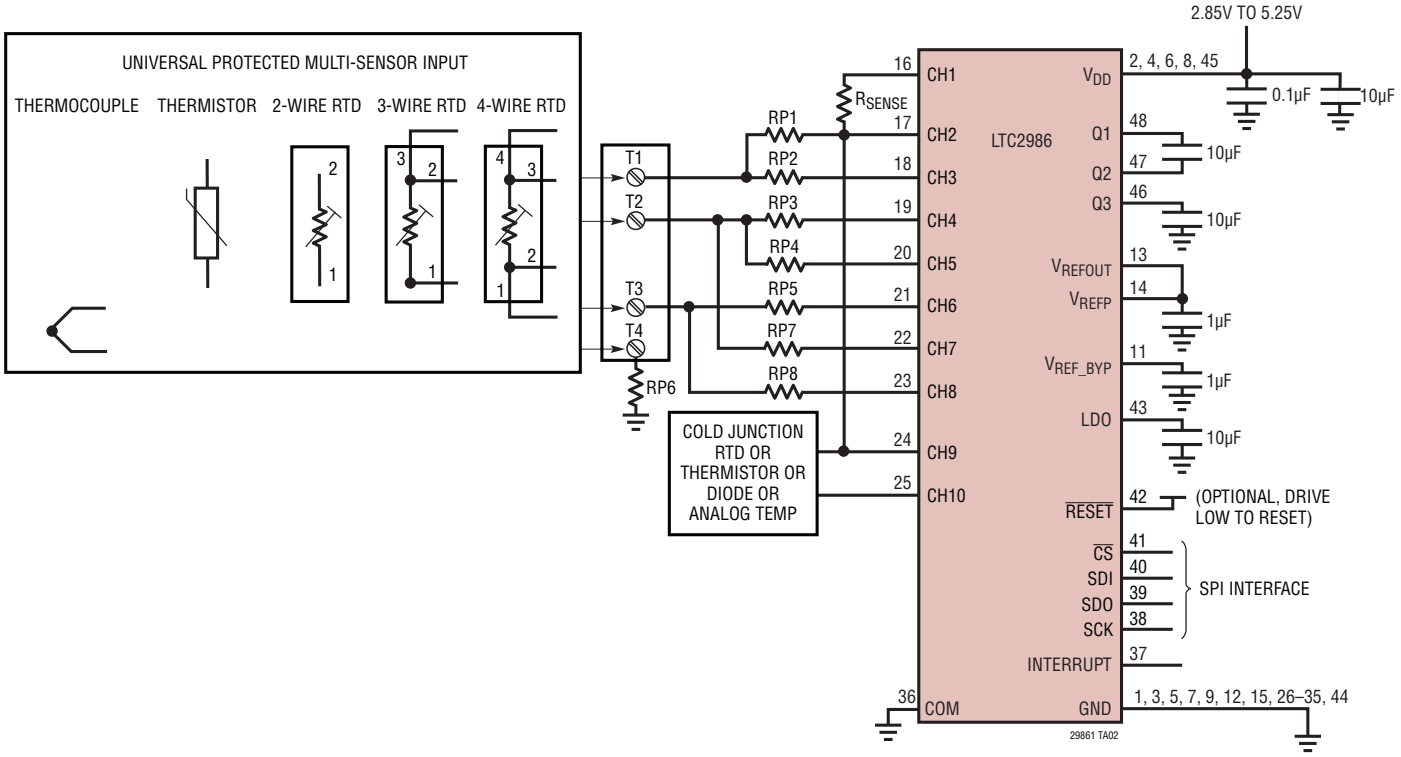
## TYPICAL APPLICATION

**Universal Inputs Allow Common Hardware Sharing for Thermocouples, Diodes, Thermistors, 3-Wire RTDs, and 4-Wire RTDs**




## RELATED PARTS

| PART NUMBER | DESCRIPTION | COMMENTS |
|---|---|---|
| LTC2983 | Multi-Sensor High Accuracy Digital Temperature Measurement System | Pin/Software Compatible 20-Channel Version of LTC2986 |
| LTC2984 | Multi-Sensor High Accuracy Digital Temperature Measurement System with EEPROM | Pin/Software Compatible 20-Channel Version of LTC2986-1 |
| LTC2990 | Quad $I^2C$ Temperature, Voltage and Current Monitor | Remote and Internal Temperatures, 14-Bit Voltages and Current, Internal 10ppm/°C Reference |
| LTC2991 | Octal $I^2C$ Voltage, Current, Temperature Monitor | Remote and Internal Temperatures, 14-Bit Voltages and Current, Internal 10ppm/°C Reference |
| LTC2995 | Temperature Sensor and Voltage Monitor with Alert Outputs | Monitors Temperature and Two Voltages, Adjustable Thresholds, Open-Drain Alert Outputs, Temperature to Voltage Output with Integrated 1.8V Reference, ±1°C (Max) Accuracy |
| LTC2996 | Temperature Sensor with Alert Outputs | Monitors Temperature, Adjustable Thresholds, Open-Drain Alert Outputs, Temperature to Voltage Output with Integrated 1.8V Reference, ±1°C (Max) Accuracy |
| LTC2997 | Remote/Internal Temperature Sensor | Temperature to Voltage Output with Integrated 1.8V Reference, ±1°C (Max) Accuracy |
| LTC2943 | 20V $I^2C$ Coulomb Counter | Monitors Charge, Current, Voltage and Temperature with 1% Accuracy. Works with Any Battery Chemistry and Capacity |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- *Подбор аналогов.*
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