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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

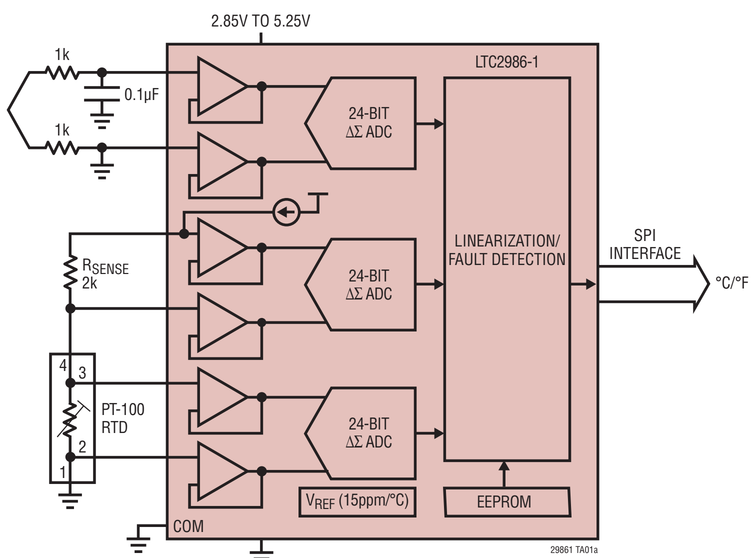
DESCRIPTION

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.

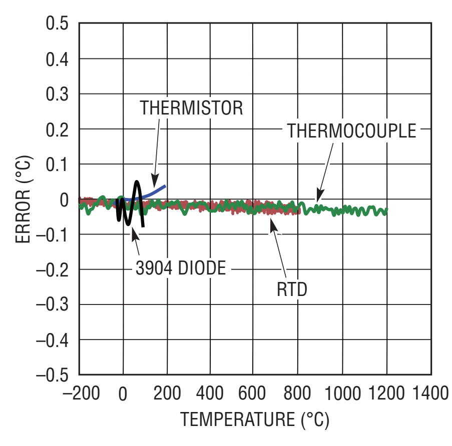
The LTC2986/LTC2986-1 are 10-channel software and pin-compatible versions of the 20-channel LTC2983/LTC2984. Additional features include special modes that enable easy protection in universal multi-sensor applications, custom tables for generic ADC readings, and direct temperature readout from active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

TYPICAL APPLICATION

Thermocouple Measurement with Automatic Cold Junction Compensation



Typical Temperature Error Contribution



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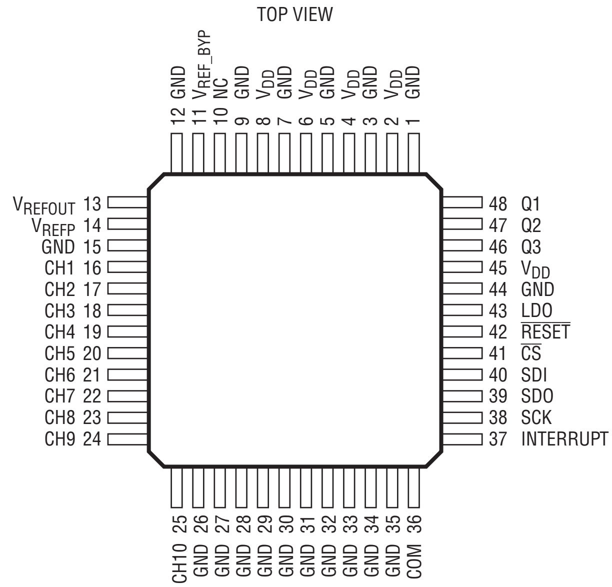
ABSOLUTE MAXIMUM RATINGS

(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, θ_{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) H-Grade	● ●			1 10	nA 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) H-Grade	● ●		0.8	1.5 2.0	$µV_{RMS}$ $µV_{RMS}$
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		$µV_{P-P}$
	10Hz ≤ f ≤ 1kHz			4.5		$µV_{P-P}$
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/√kHr
Hysteresis (Note 14)	ΔT = 0°C to 70°C ΔT = –40°C to 85°C			30 70		ppm 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.

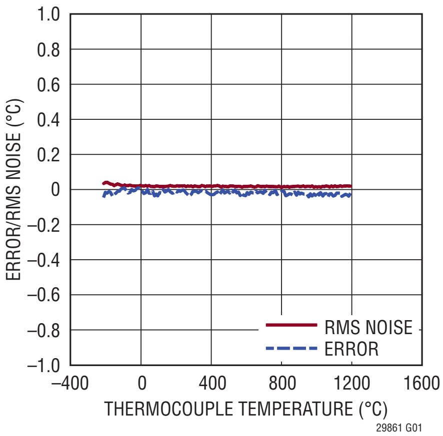
Note 17: 10-year data retention guaranteed for up to 1000 program cycles.

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.

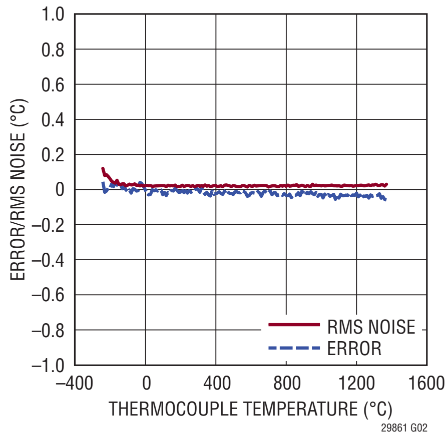
Note 19: Input leakage measured with V_{IN} = –10mV and V_{IN} = 2.5V.

TYPICAL PERFORMANCE CHARACTERISTICS

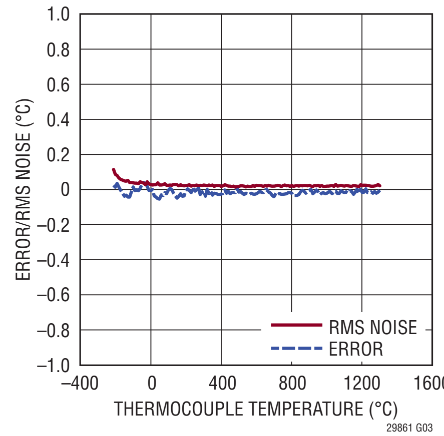
Type J Thermocouple Error and RMS Noise vs Temperature



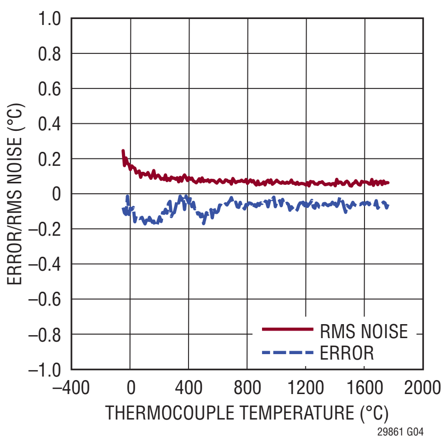
Type K Thermocouple Error and RMS Noise vs Temperature



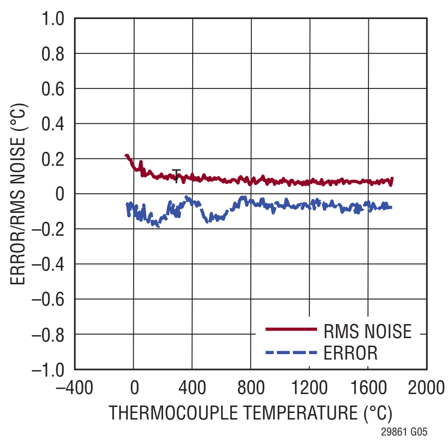
Type N Thermocouple Error and RMS Noise vs Temperature



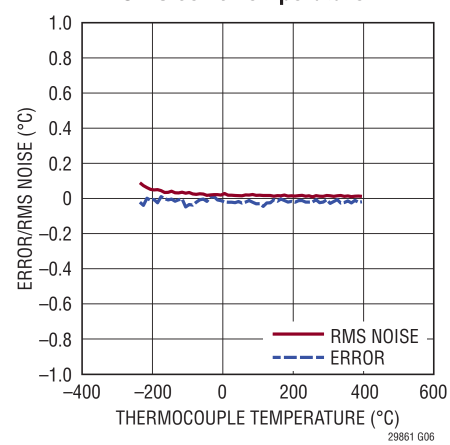
Type R Thermocouple Error and RMS Noise vs Temperature



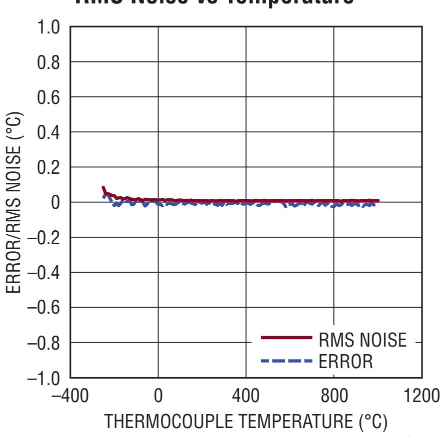
Type S Thermocouple Error and RMS Noise vs Temperature



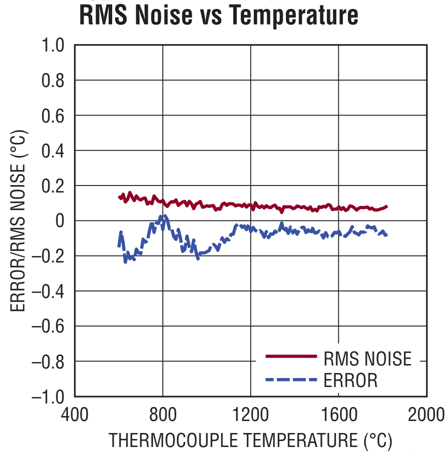
Type T Thermocouple Error and RMS Noise vs Temperature



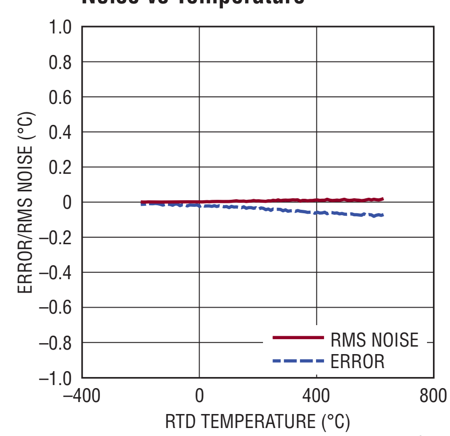
Type E Thermocouple Error and RMS Noise vs Temperature



Type B Thermocouple Error and RMS Noise vs Temperature

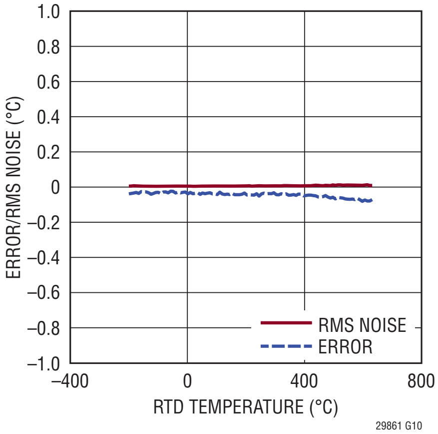


RTD PT-1000 Error and RMS Noise vs Temperature

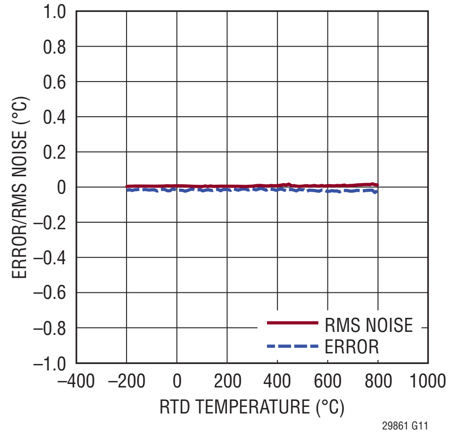


TYPICAL PERFORMANCE CHARACTERISTICS

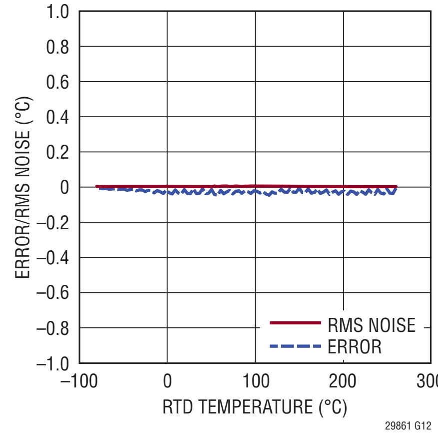
RTD PT-200 Error and RMS Noise vs Temperature



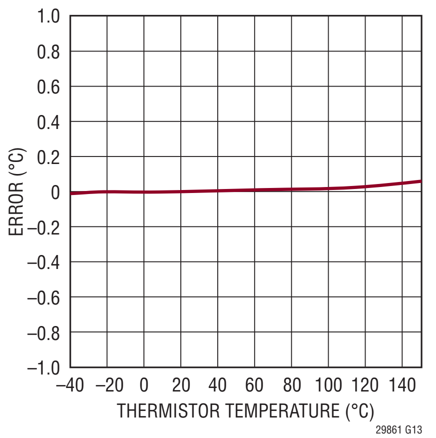
RTD PT-100 Error and RMS Noise vs Temperature



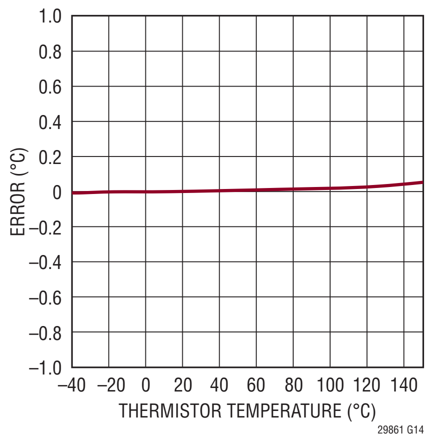
RTD NI-120 RTD Error and RMS Noise vs Temperature



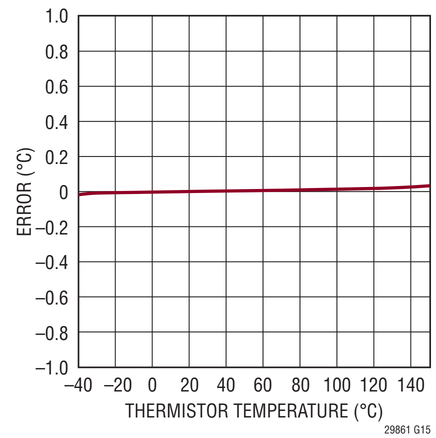
2.252k Thermistor Error vs Temperature



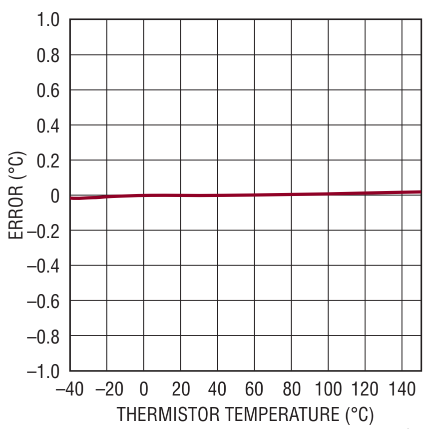
3k Thermistor Error vs Temperature



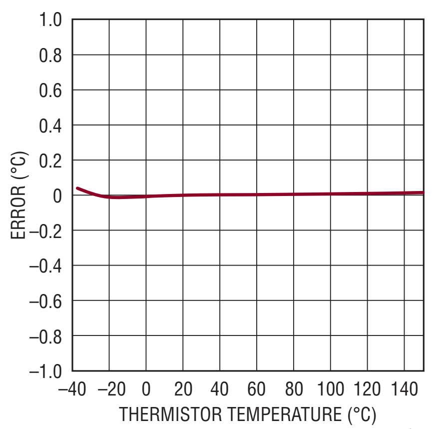
5k Thermistor Error vs Temperature



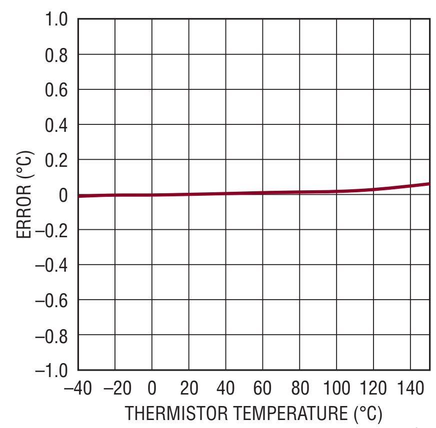
10k Thermistor Error vs Temperature



30k Thermistor Error vs Temperature

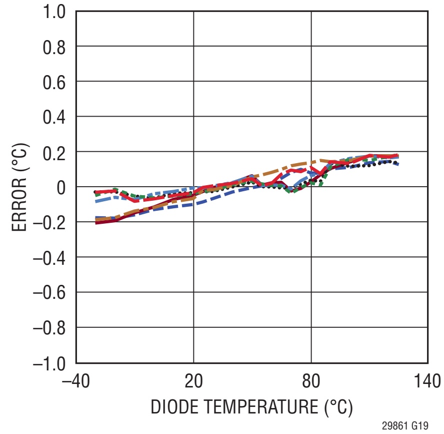


YSI-400 Thermistor Error vs Temperature

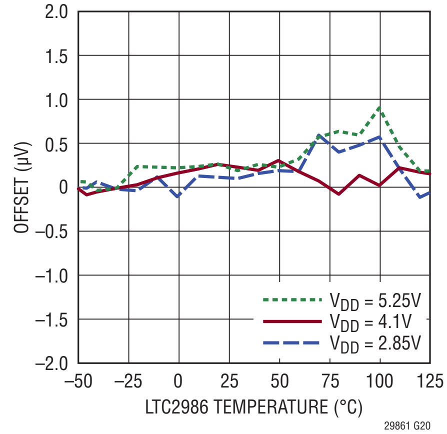


TYPICAL PERFORMANCE CHARACTERISTICS

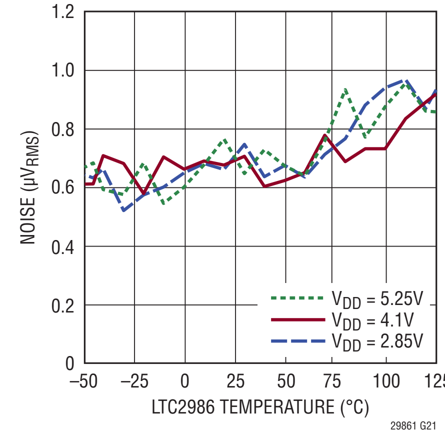
Diode Error and Repeatability vs Temperature



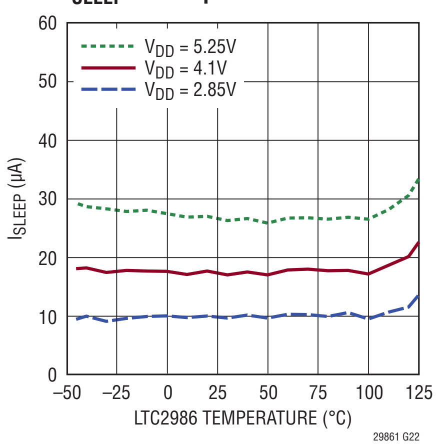
Offset vs Temperature



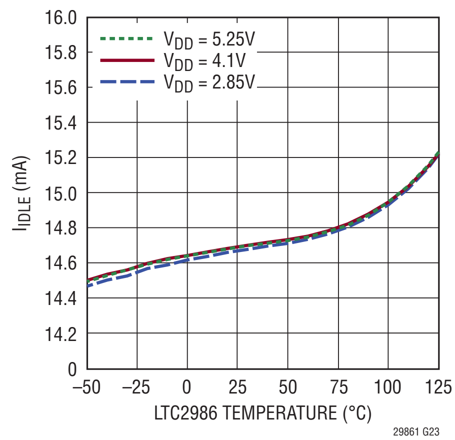
Noise vs Temperature



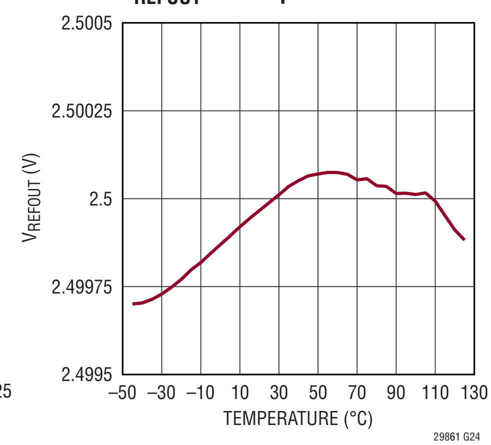
I_{SLEEP} vs Temperature



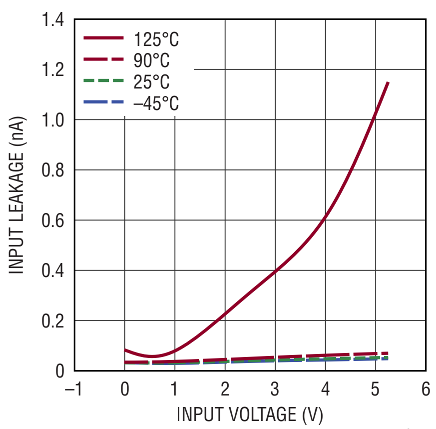
One Shot Conversion Current vs Temperature



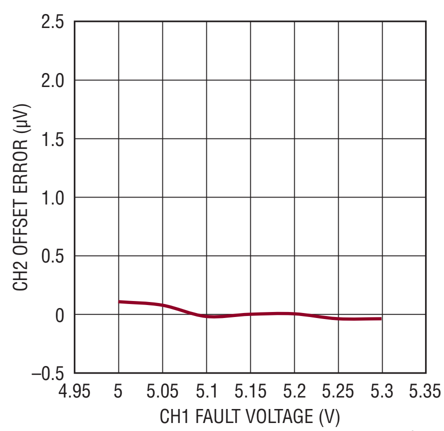
V_{REFOUT} vs Temperature



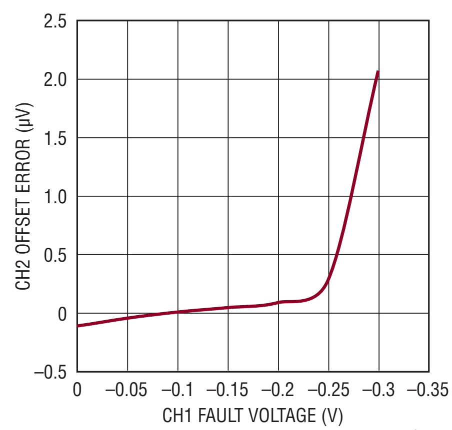
Channel Input Leakage Current vs Temperature



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.

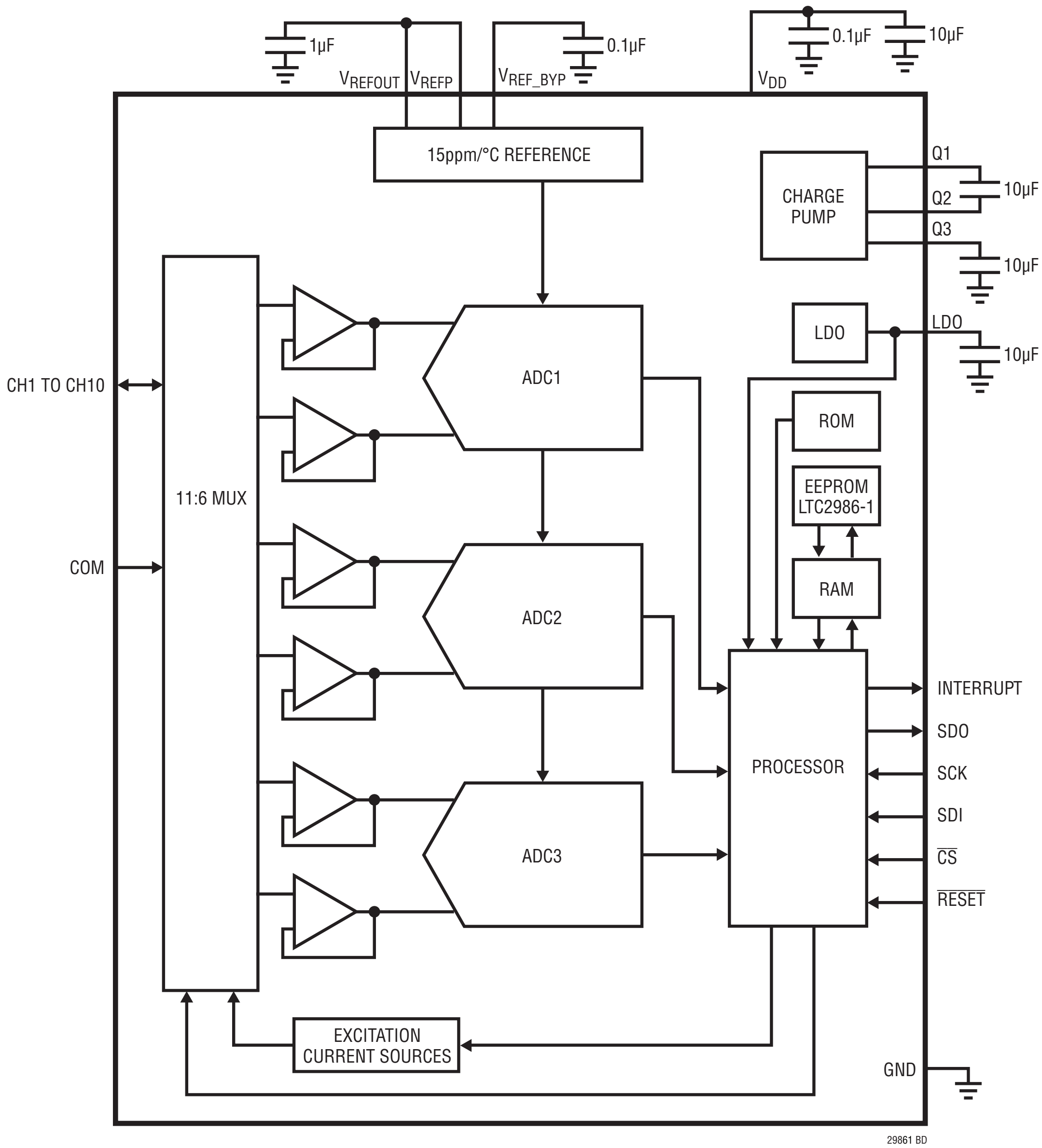
$\overline{CS}$ (Pin 41): Active Low Chip Select. A low on this pin enables the digital input/output. A HIGH on this pin places SDO in a high impedance state. A falling edge on $\overline{CS}$ marks the beginning of a SPI transaction and a rising edge marks the end.

$\overline{RESET}$ (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.

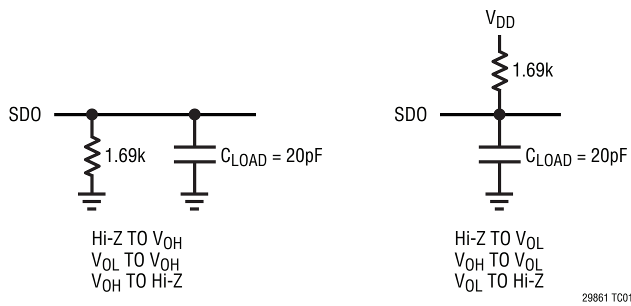
LDO (Pin 43): 2.5V LDO Output. Bypass with a 10µF capacitor to GND. This is an internal supply pin, do not load this pin with external circuitry.

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

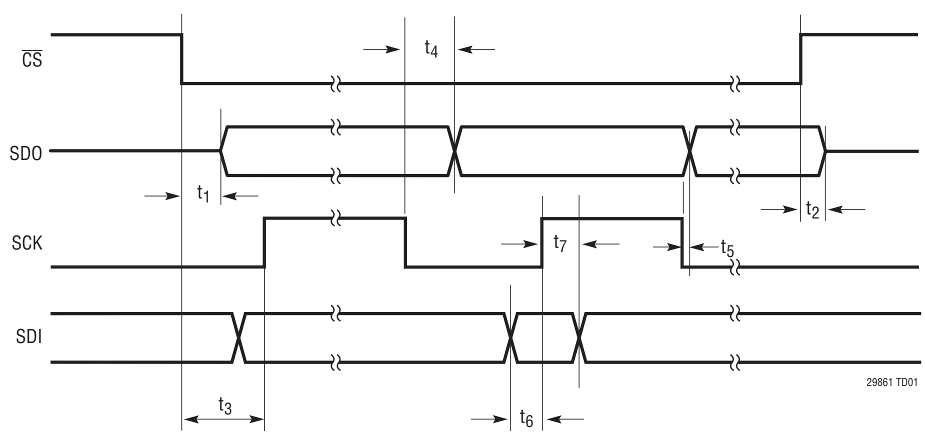


TEST CIRCUITS



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 (ΔV_{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 0°C to 1372°C	±(Temperature • 0.23% + 0.05)°C ±(Temperature • 0.12% + 0.05)°C	±0.08°C
Type J Thermocouple	–210°C to 0°C 0°C to 1200°C	±(Temperature • 0.23% + 0.05)°C ±(Temperature • 0.12% + 0.05)°C	±0.07°C
Type E Thermocouple	–200°C to 0°C 0°C to 1000°C	±(Temperature • 0.18% + 0.05)°C ±(Temperature • 0.10% + 0.05)°C	±0.06°C
Type N Thermocouple	–200°C to 0°C 0°C to 1300°C	±(Temperature • 0.27% + 0.08)°C ±(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 0°C to 400°C	±(Temperature • 0.15% + 0.05)°C ±(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 Platinum RTD – PT-100, R_{SENSE} = 2kΩ Platinum RTD – PT-500, R_{SENSE} = 2kΩ Platinum RTD – PT-1000, R_{SENSE} = 2kΩ	–200°C to 800°C –200°C to 800°C –200°C to 800°C –200°C to 800°C	±0.1°C ±0.1°C ±0.1°C ±0.1°C	±0.05°C ±0.05°C ±0.02°C ±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

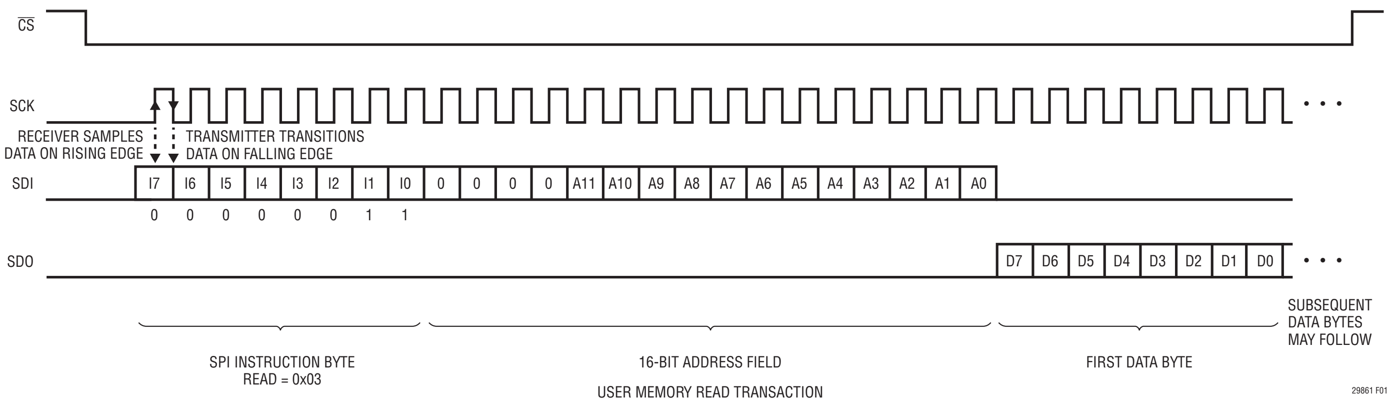


Figure 1. Memory Read Operation

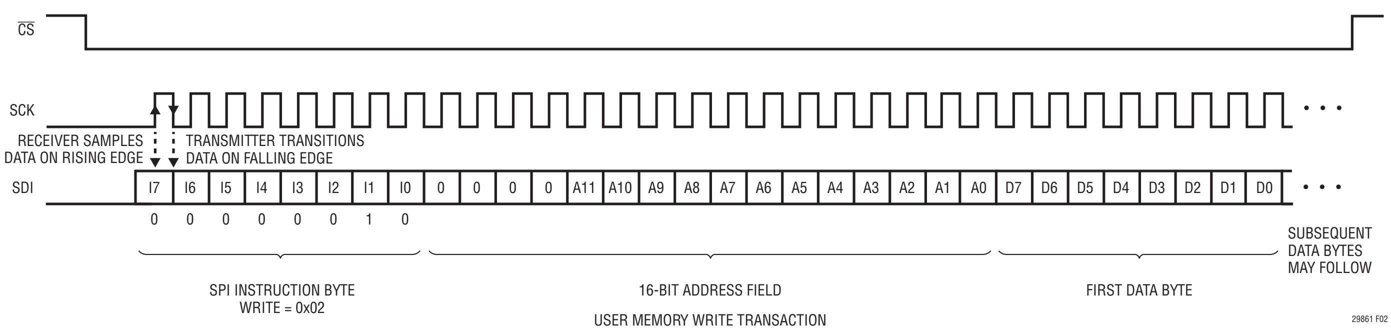


Figure 2. Memory Write Operation

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).

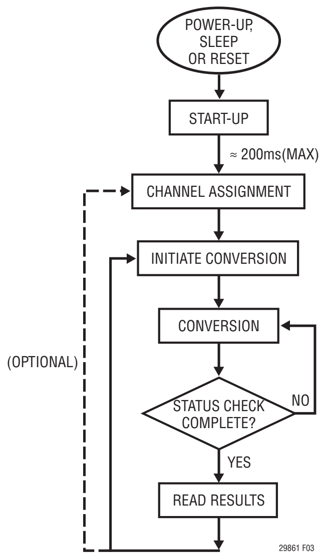


Figure 3. Basic Operation

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

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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

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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

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

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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

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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

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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

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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.

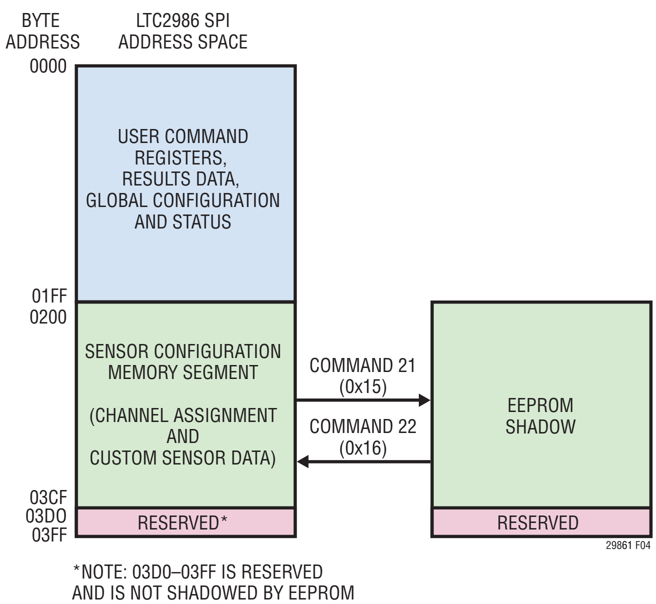

Figure 4. Shadow EEPROM Memory Map

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).

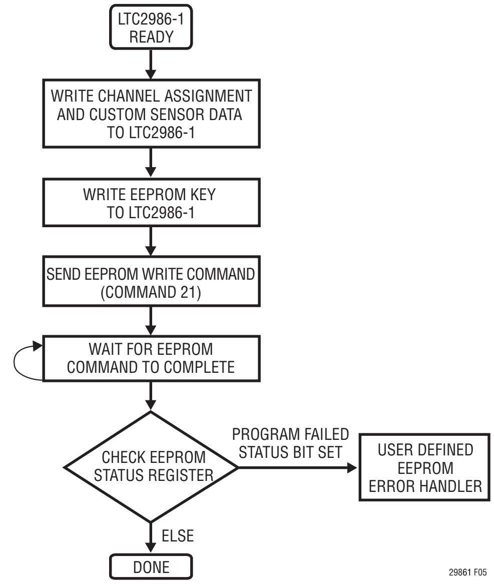

Figure 5. EEPROM Write Operation

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)

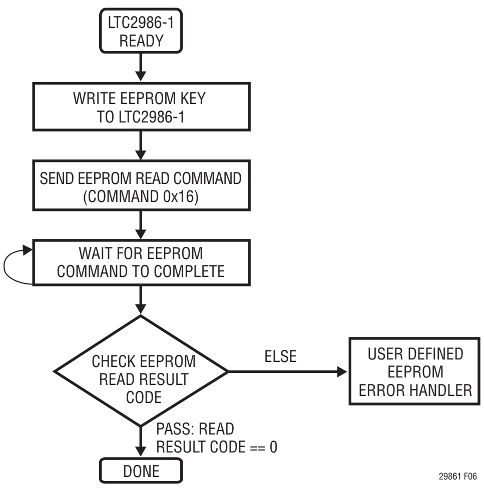

Figure 6. Read Operation

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 0x00 = PASS 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

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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

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