Octal I²C Voltage, Current, and Temperature Monitor

FEATURES

- **Measures Voltage, Current, Temperature**
- **Measures Four Remote Diode Temperatures**
- **0.7°C (Typ) Accuracy, 0.06°C Resolution**
- **1°C (Typ) Internal Temperature Sensor**
- Series Resistance Cancellation
- 14-Bit ADC Measures Voltage/Current
- PWM Temperature Output
- 3V to 5.5V Supply Operating Voltage
- Eight Selectable Addresses
- Internal 10ppm/°C Voltage Reference
- V1 to V8 Inputs ESD Rated to 6kV HBM
- 16-Lead MSOP Package

APPLICATIONS

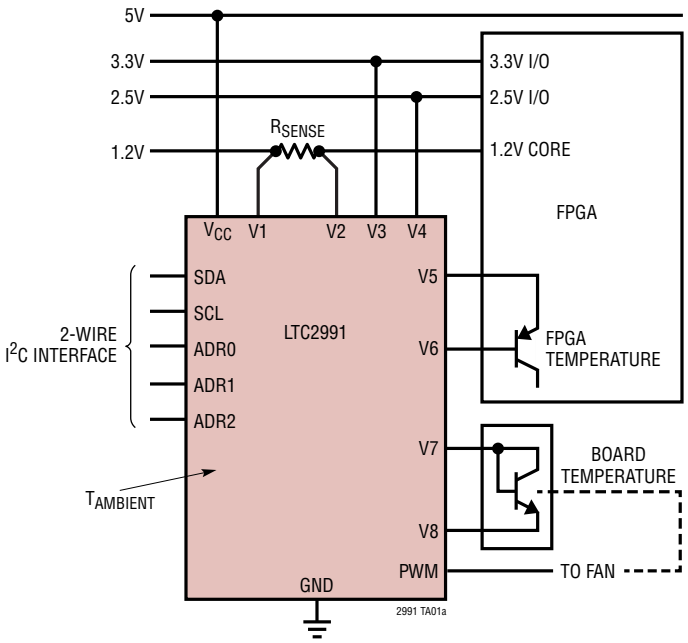
- Temperature Measurement
- Supply Voltage Monitoring
- Current Measurement
- Remote Data Acquisition
- Environmental Monitoring

DESCRIPTION

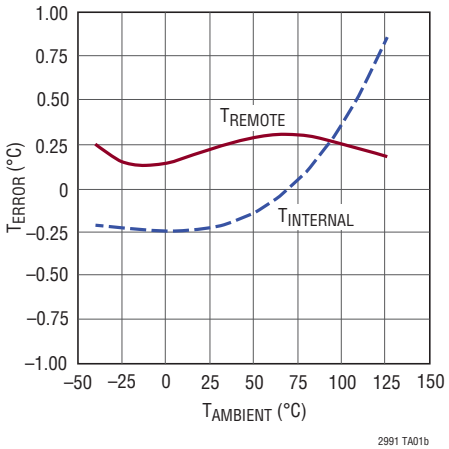
The LTC®2991 is used to monitor system temperatures, voltages and currents. Through the I²C serial interface, the eight monitors can individually measure supply voltages and can be paired for differential measurements of current sense resistors or temperature sensing transistors. Additional measurements include internal temperature and internal V_{CC}. The internal 10ppm reference minimizes the number of supporting components and area required. Selectable address and configurable functionality give the LTC2991 flexibility to be incorporated in various systems needing temperature, voltage or current data. The LTC2991 fits well in systems needing submillivolt voltage resolution, 1% current measurement and 1°C temperature accuracy or any combination of the three.

, LT, LTC, LTM, Linear Technology and the Linear logo are registered trademarks and Easy Drive is a trademark of Linear Technology Corporation. All other trademarks are the property of their respective owners.

TYPICAL APPLICATION



Temperature Total Unadjusted Error

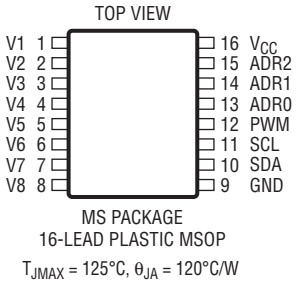


ABSOLUTE MAXIMUM RATINGS

(Note 1)

Supply Voltage (V_{CC}) ..... –0.3V to 6.0V
Input Voltages V1, V2, V3, V4, V5, V6, V7, V8,
SCL, ADR0, ADR1, ADR2 .....–0.3V to (V_{CC} + 0.3V)
Output Voltage PWM .....–0.3V to (V_{CC} + 0.3V)
Output Voltage SDA ..... –0.3V to 6V
Operating Temperature Range
LTC2991C ..... 0°C to 70°C
LTC2991I .....–40°C to 85°C
Storage Temperature Range .....–65°C to 150°C
Lead Temperature (Soldering, 10 sec)
MS Package .....300°C

PIN CONFIGURATION



MS PACKAGE
16-LEAD PLASTIC MSOP

T_{JMAX} = 125°C, θ_{JA} = 120°C/W

ORDER INFORMATION

LEAD FREE FINISH	TAPE AND REEL	PART MARKING*	PACKAGE DESCRIPTION	TEMPERATURE RANGE
LTC2991CMS#PBF	LTC2991CMS#TRPBF	2991	16-Lead Plastic MSOP	0°C to 70°C
LTC2991IMS#PBF	LTC2991IMS#TRPBF	2991	16-Lead Plastic MSOP	–40°C to 85°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/

For more information on tape and reel specifications, go to: http://www.linear.com/tapeandreel/. Some packages are available in 500 unit reels through designated sales channels with #TRMPBF suffix.

ELECTRICAL CHARACTERISTICS

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

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
General							
V_{CC}	Input Supply Range		●	2.9		5.5	V
I_{CC}	Input Supply Current	During Conversion, I^2C Inactive	●		1.1	1.5	mA
I_{SD}	Input Supply Current	Shutdown Mode, I^2C Inactive	●		1	6	µA
$V_{CC(UVL)}$	Input Supply Undervoltage Lockout		●	1.3	2.0	2.6	V
Measurement Accuracy							
$T_{INTERNAL(TUE)}$	Internal Temperature Total Unadjusted Error				±1	±3.5	°C
$T_{RMT(TUE)}$	Remote Diode Temperature Total Unadjusted Error	η = 1.004	●		±0.7	±1.5	°C
$V_{CC(TUE)}$	V_{CC} Voltage Total Unadjusted Error	2.9V ≤ 5.5V	●		±0.05	±0.25	%
$V_{N(TUE)}$	V1 Through V8 Total Unadjusted Error	0V ≤ 4.9V	●		±0.05	±0.25	%
$V_{DIFF(TUE)}$	Differential Voltage Total Unadjusted Error V1 – V2, V3 – V4, V5 – V6, V7 – V8	–300mV≤ V_D ≤300mV	●		±0.1	±0.75	%
$V_{DIFF(MAX)}$	Full-Scale Differential Voltage		●	–312.5		312.5	mV
V_{OFFSET_DIFF}	Differential Offset	V1 through V8 = 0V	●	–12.5	0	12.5	LSB
V_{OFFSET_SE}	Single-Ended Offset	V1 through V8 = 0V	●	–6	0	6	LSB

ELECTRICAL CHARACTERISTICS

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

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
$V_{DIFF(CMR)}$	Differential Voltage Common Mode Range		●	0		V_{CC}	V
$V_{LSB(DIFF)}$	Differential Voltage LSB Weight				19.075		µV
$V_{LSB(SINGLE_ENDED)}$	Single-Ended Voltage LSB Weight				305.18		µV
$V_{LSB(TEMP)}$	Temperature LSB Weight	Celsius or Kelvin			0.0625		Deg
$V_{LSB(DIODE_VOLTAGE)}$	Diode Voltage LSB Weight	Includes Series Resistance IR Drop			38.15		µV
T_{NOISE}	Temperature Noise	Celsius or Kelvin Filter Disengaged			0.2		°RMS
T_{NOISE}	Temperature Noise	Celsius or Kelvin Filter Engaged			0.07		°RMS
RES	Resolution (No Missing Codes)	(Note 2)	●	14			Bits
INL	Integral Nonlinearity	2.9V ≤ V_{CC} ≤ 5.5V, $V_{IN(CM)}$ = 1.5V (Note 2) Single-Ended Differential	 ● ●	 –2 –2		 2 2	 LSB LSB
C_{IN}	V1 Through V8 Input Sampling Capacitance	(Note 2)			0.35		pF
$I_{IN(AVG)}$	V1 Through V8 Input Average Sampling Current	(0 ≤ V_N ≤ 4.9V) (Note 2)			0.6		µA
$I_{DC_LEAK(VIN)}$	V1 Through V8 Input Leakage Current	(0 ≤ V_N ≤ V_{CC})	●	–10		10	nA
PWM							
F_{PWM}	PWM Period		●	0.9		1.2	ms
DC_{PWM}	Duty Cycle Range		●	0		99.8	%
$SCALE_{PWM}$	0% to 100% PWM Temperature Range				32		Deg
Measurement Delay							
$T_{INTERNAL}$, T_{R1}, T_{R2}, T_{R3}, T_{R4}	Per Configured Temperature Measurement		●	37	46	55	ms
V1, V2, V3, V4, V5, V6, V7, V8	Single-Ended Voltage Measurement		●	0.9	1.5	1.8	ms
V1 – V2, V3 – V4, V5 – V6, V7 – V8	Differential Voltage Measurement		●	0.9	1.5	1.8	ms
V_{CC}	V_{CC} Measurement		●	0.9	1.5	1.8	ms
Max Delay	Mode[4:0] = 11101, $T_{INTERNAL}$, T_{R1}, T_{R2}, T_{R3}, T_{R4} V_{CC}		●			277	ms
V1, V3, V5, V7 OUTPUT (Remote Diode Mode Only)							
I_{OUT}	Output Current	Remote Diode Mode	●		260	350	µA
V_{OUT}	Output Voltage		●	0		V_{CC}	V
I^2C Interface							
$V_{ADR(L)}$	ADR Input Low Threshold Voltage	Falling	●			0.3•V_{CC}	V
$V_{ADR(H)}$	ADR Input High Threshold Voltage	Rising	●	0.7•V_{CC}			V
V_{OL1}	SDA Low Level Maximum Voltage	I_O = –3mA, V_{CC} 2.9V to 5.5V	●			0.4	V
V_{IL}	Maximum Low Level Input Voltage	SDA and SCL Pins	●			0.3•V_{CC}	V
V_{IH}	Minimum High Level Input Voltage	SDA and SCL Pins	●	0.7•V_{CC}			V
$I_{SDAI, SCLI}$	SDA, SCL Input Current	0 < $V_{SDA, SCL}$ < V_{CC}	●			±1	µA
$I_{ADR(MAX)}$	Maximum ADR0, ADR1, ADR2 Input Current	ADR0, ADR1 or ADR2 Tied to V_{CC} or GND	●			±1	µA

ELECTRICAL CHARACTERISTICS

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

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
I²C Timing (Note 2)							
$f_{SCL(MAX)}$	Maximum SCL Clock Frequency			400			kHz
t_{LOW}	Minimum SCL Low Period					1.3	µs
t_{HIGH}	Minimum SCL High Period					600	ns
$t_{BUF(MIN)}$	Minimum Bus Free Time Between Stop/Start Condition					1.3	µs
$t_{HD, STA(MIN)}$	Minimum Hold Time After (Repeated) Start Condition					600	ns
$t_{SU, STA(MIN)}$	Minimum Repeated Start Condition Set-Up Time					600	ns
$t_{SU, STO(MIN)}$	Minimum Stop Condition Set-Up Time					600	ns
$t_{HD, DATI(MIN)}$	Minimum Data Hold Time Input					0	ns
$t_{HD, DATO(MIN)}$	Minimum Data Hold Time Output			300		900	ns
$t_{SU, DAT(MIN)}$	Minimum Data Set-Up Time Input					100	ns
$t_{SP(MAX)}$	Maximum Suppressed Spike Pulse Width			50		250	ns
C_X	SCL, SDA Input Capacitance					10	pF

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.

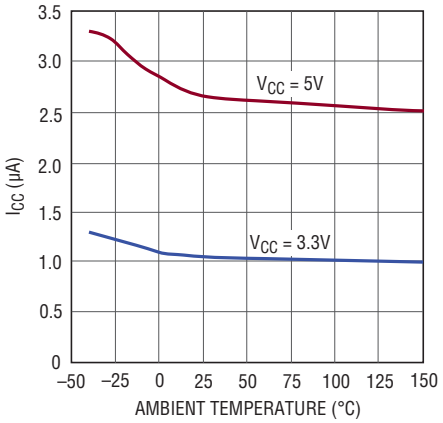
Note 2: Guaranteed by design and not subject to test.

Note 3: Integral nonlinearity is defined as the deviation of a code from a straight line passing through the actual endpoints of the transfer curve. The deviation is measured from the center of the quantization band.

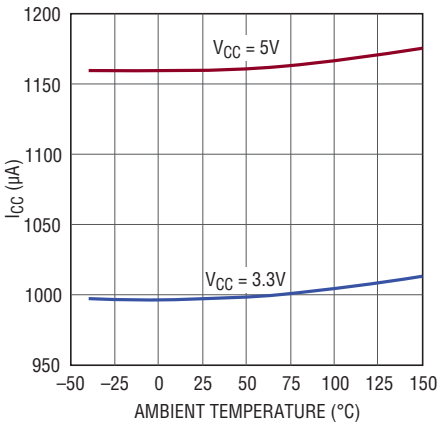
TYPICAL PERFORMANCE CHARACTERISTICS

T_A = 25°C, V_{CC} = 3.3V, unless otherwise noted.

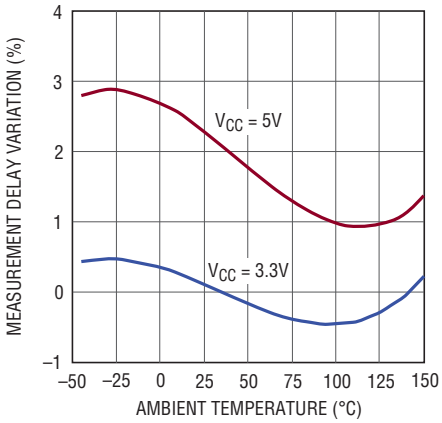
Shutdown Current vs Temperature



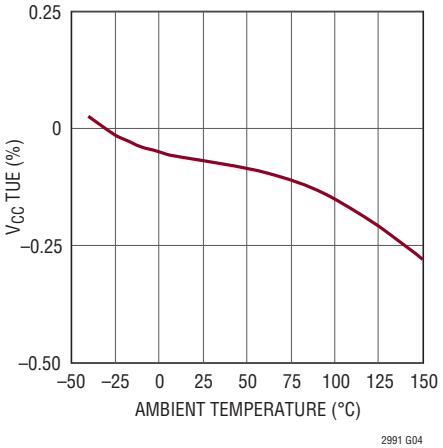
Supply Current vs Temperature



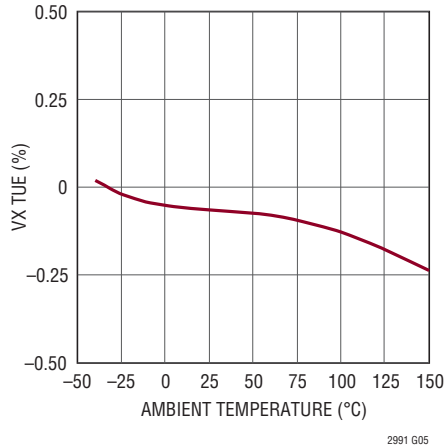
Measurement Delay Variation vs T Normalized to 3.3V, 25°C



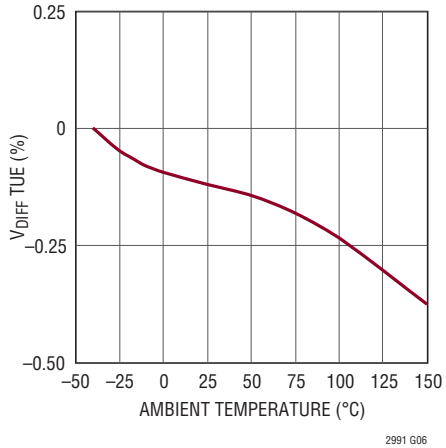
V_{CC} TUE



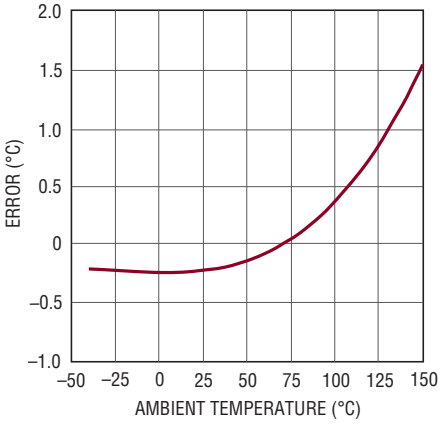
Single-Ended VX TUE



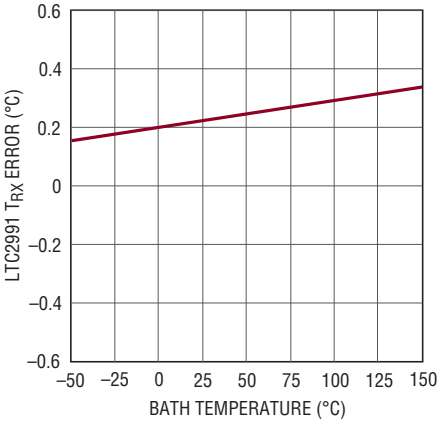
Differential Voltage TUE



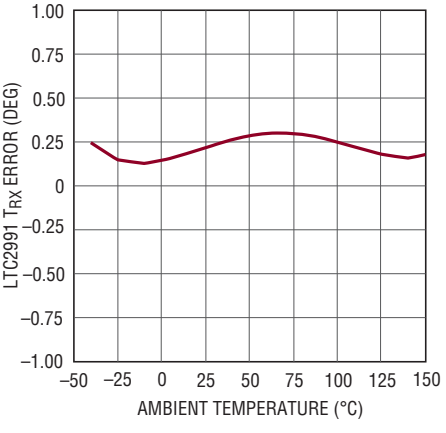
$T_{INTERNAL}$ Error



Remote Diode Error with LTC2991 at 25°C



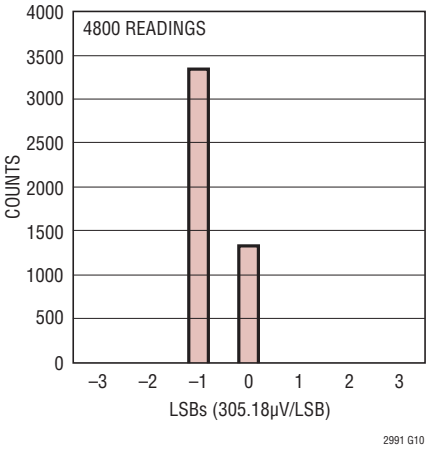
Remote Diode Error with LTC2991 at Same Temperature as Diode



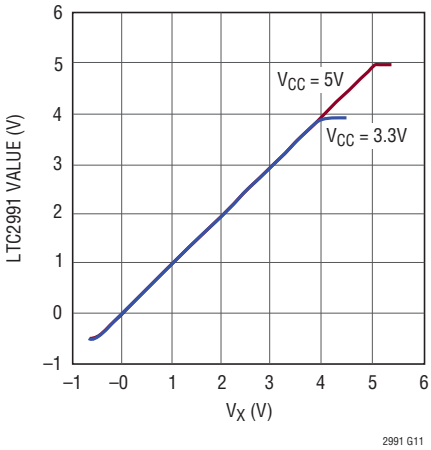
TYPICAL PERFORMANCE CHARACTERISTICS

T_A = 25°C, V_{CC} = 3.3V, unless otherwise noted.

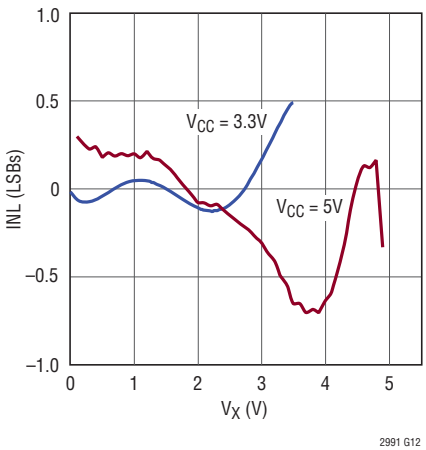
Single-Ended Noise



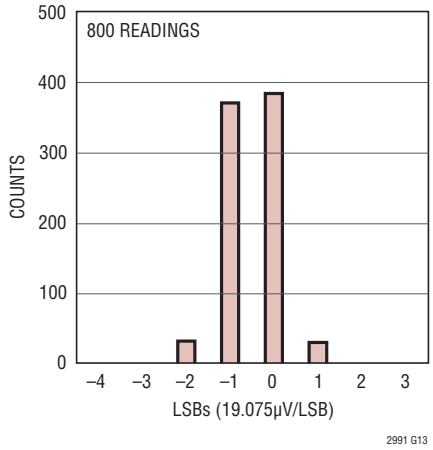
Single-Ended Transfer Function



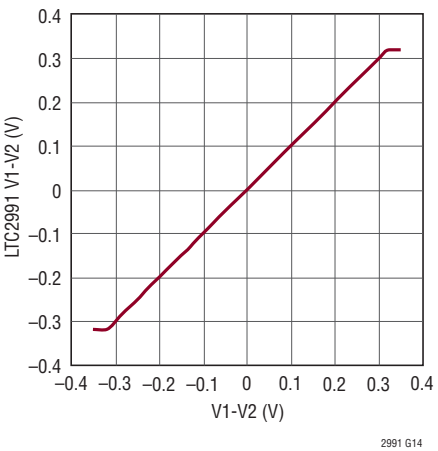
Single-Ended INL



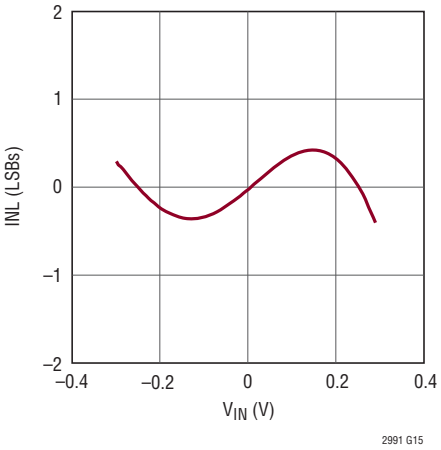
LTC2991 Differential Noise



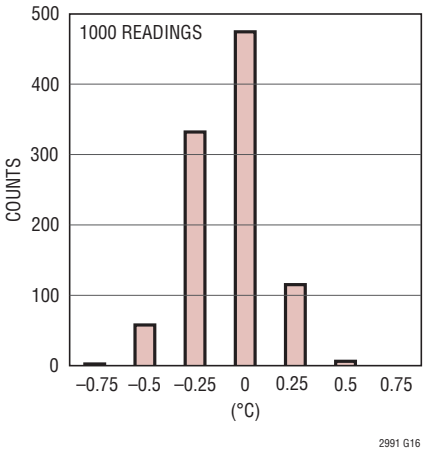
Differential Transfer Function



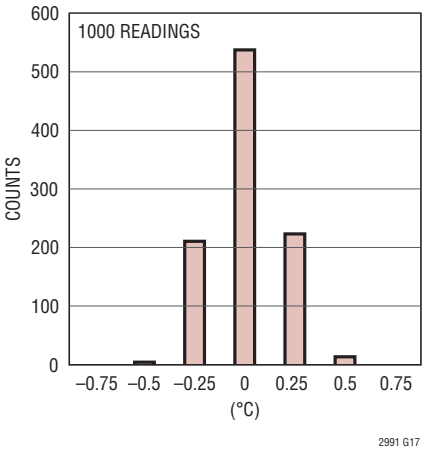
Differential INL



$T_{INTERNAL}$ Noise



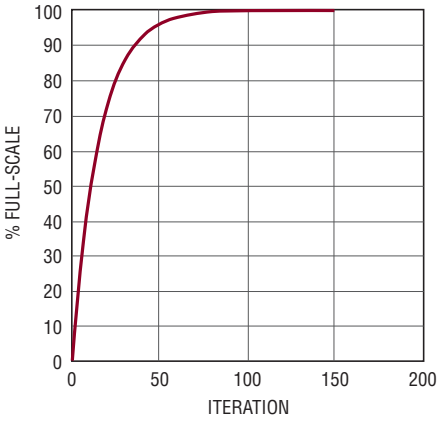
Remote Diode Noise



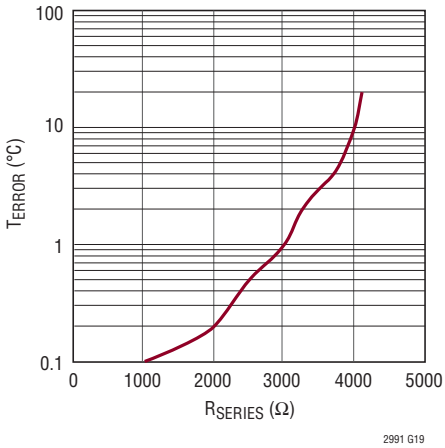
TYPICAL PERFORMANCE CHARACTERISTICS

T_A = 25°C, V_{CC} = 3.3V, unless otherwise noted.

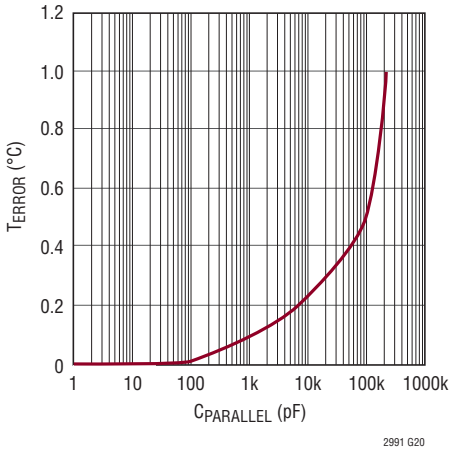
Digital Filter Step Response



T_{ERROR} vs R_{SERIES}



T_{ERROR} vs $C_{PARALLEL}$



PIN FUNCTIONS

V1 (Pin 1): First Monitor Input. This pin can be configured as a single-ended input (0V to 4.9V) or the positive input for a differential or remote diode temperature measurement (in combination with V2). Differential common mode range is 0V to V_{CC}, ±300mV differential. When configured for remote diode temperature, this pin will source a current.

V2 (Pin 2): Second Monitor Input. This pin can be configured as a single-ended input (0V to 4.9V) or the negative input for a differential or remote diode temperature measurement (in combination with V1). Differential common mode range is 0V to V_{CC}, ±300mV differential. When configured for remote diode temperature, this pin will have an internal termination, while the measurement is active.

V3 (Pin 3): Third Monitor Input. This pin can be configured as a single-ended input (0V to 4.9V) or the positive input for a differential or remote diode temperature measurement (in combination with V4). Differential common mode range is 0V to V_{CC}, ±300mV differential. When configured for remote diode temperature, this pin will source a current.

V4 (Pin 4): Fourth Monitor Input. This pin can be configured as a single-ended input (0V to 4.9V) or the negative input for a differential or remote diode temperature measurement (in combination with V3). Differential common mode range is 0V to V_{CC}, ±300mV differential. When configured for remote diode temperature, this pin will have an internal termination, while the measurement is active.

V5 (Pin 5): Fifth Monitor Input. This pin can be configured as a single-ended input (0V to 4.9V) or the positive input for a differential or remote diode temperature measurement (in combination with V6). Differential common mode range is 0V to V_{CC}, ±300mV differential. When configured for remote diode temperature, this pin will source a current.

V6 (Pin 6): Sixth Monitor Input. This pin can be configured as a single-ended input (0V to 4.9V) or the negative input for a differential or remote diode temperature measurement (in combination with V5). Differential common mode range is 0V to V_{CC}, ±300mV differential. When configured for remote diode temperature, this pin will have an internal termination, while the measurement is active.

V7 (Pin 7): Seventh Monitor Input. This pin can be configured as a single-ended input (0V to 4.9V) or the positive input for a differential or remote diode temperature measurement (in combination with V8). Differential common mode range is 0V to V_{CC}, ±300mV differential. When configured for remote diode temperature, this pin will source a current.

V8 (Pin 8): Eighth Monitor Input. This pin can be configured as a single-ended input (0V to 4.9V) or the negative input for a differential or remote diode temperature measurement (in combination with V7). Differential common mode range is 0V to V_{CC}, ±300mV differential. When configured for remote diode temperature, this pin will have an internal termination, while the measurement is active.

GND (Pin 9): Device Ground. Connect this pin through a low impedance connection to system ground.

SDA (Pin 10): Serial Bus Data Input and Output. In the transmitter mode (read), the conversion result is output through the SDA pin, while in the receiver mode (write), the device configuration bits are input through the SDA pin. At data input mode, the pin is high impedance; while at data output mode, it is an open-drain N-channel driver and, therefore, an external pull-up resistor or current source to V_{CC} is needed.

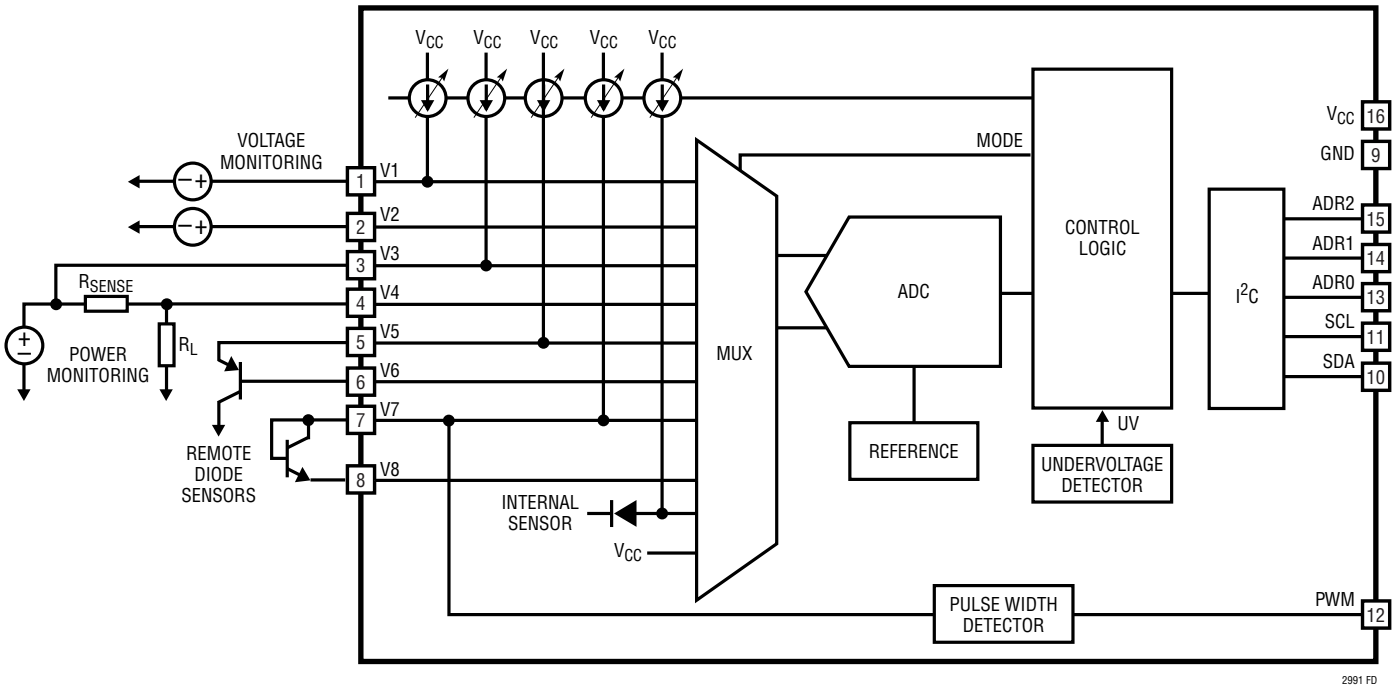
SCL (Pin 11): Serial Bus Clock Input of the I^2C Interface. The LTC2991 can only act as a slave and the SCL pin only accepts external serial clock. The LTC2991 does not implement clock stretching.

PWM (Pin 12): PWM Output. The PWM pin provides a CMOS output level with a duty cycle proportional to the remote diode temperature of the sensor connected to pins V7 and V8.

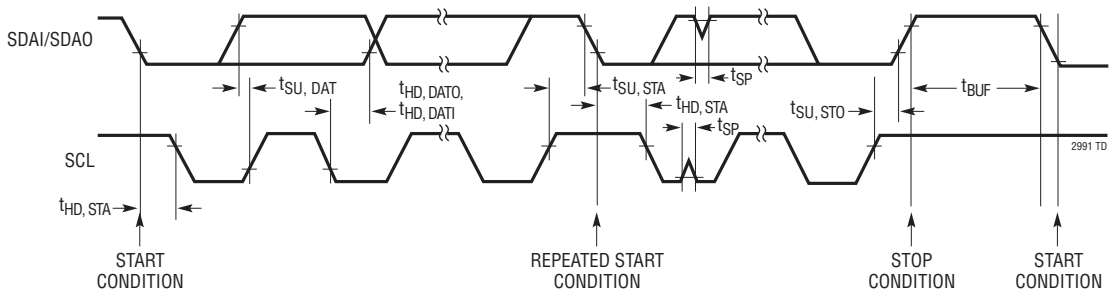
ADR0, ADR1, ADR2 (Pins 13, 14, 15): Serial Bus Address Control Input. The ADR pins are address control bits for the device I^2C address. See Table 1.

V_{CC} (Pin 16): Chip Power. Connect to 2.9V to 5.5V low noise supply. A 0.1µF decoupling capacitor to GND is required for this pin.

FUNCTIONAL DIAGRAM



TIMING DIAGRAM



OPERATION

The LTC2991 monitors voltage, current, internal and remote temperatures. It can be configured through an I²C interface to measure many combinations of these parameters. Single or repeated measurements can be configured. Remote temperature measurements use transistors as temperature sensors, allowing the remote sensor to be a discrete NPN (ex. MMBT3904) or an embedded PNP device in a microprocessor or FPGA. The internal ADC reference minimizes the number of support components required.

The Functional Diagram displays the main functional components of the device. The input signals are selected with an input mux, controlled by the control logic block. The control logic block uses the mode bits in the control registers to manage the sequence and types of data acquisition. The control logic block also controls the current sources during remote temperature acquisition. The order of acquisitions is fixed: V1, V2, V3, V4, V5, V6, V7, V8, $T_{INTERNAL}$ then V_{CC}. The ADC performs the necessary conversion(s) and supplies the data to the control logic for routing to the appropriate data register. The I²C interface supplies access to control, status and data registers. The ADR2, ADR1 and ADR0 pins select one of eight possible I²C addresses (see Table 1). The UVLO inhibits I²C communication below the specified threshold. During an undervoltage condition, the part is in a reset state, and the data and control registers are placed in the default state of 00h.

Remote diode measurements are conducted using multiple ADC conversions and source currents to compensate for sensor series resistance. The V2, V4, V6 or V8 terminals of the LTC2991 are terminated with a diode if that channel is configured for temperature measurements. It is acceptable to ground these pins, but increased noise may result on the temperature measurements. The LTC2991 is calibrated to yield the correct temperature for a remote diode with an ideality factor of 1.004. See the Applications Information section for compensation of sensor ideality factors other than the factory calibrated value of 1.004.

The LTC2991 communicates through an I²C serial interface. The serial interface provides access to control, status and data registers. I²C defines a 2-wire open-drain interface supporting multiple slave devices and masters on a single bus. The LTC2991 supports 100kbit/s in the standard mode and up to 400kbit/s in fast mode. The eight physical addresses supported are listed in Table 1. The I²C interface is used to trigger single conversions, or start repeated conversions by writing to a dedicated trigger register. The data registers contain a destructive read status bit (data valid), which is used in repeated mode to determine if the registers contents have been previously read. This bit is set when the register is updated with new data, and cleared when read.

APPLICATIONS INFORMATION

The basic LTC2991 application circuit is shown in Figure 1.

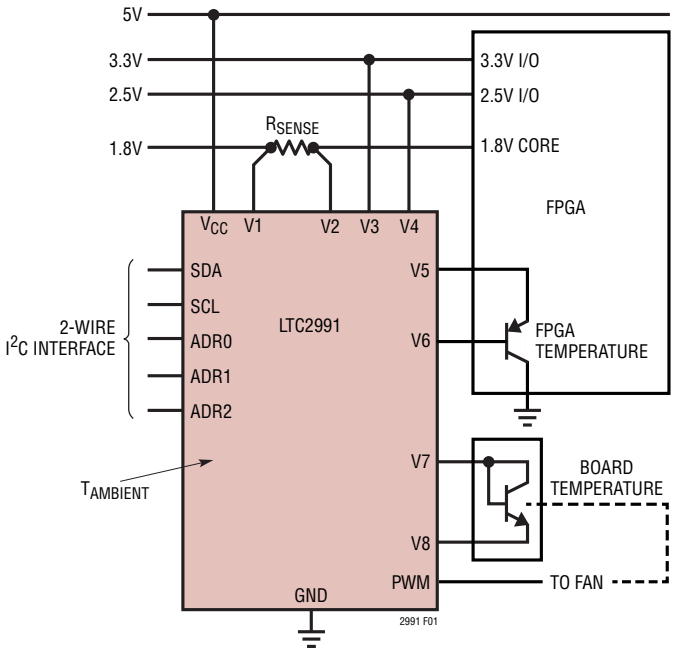


Figure 1.

Power Up

The V_{CC} pin must exceed the undervoltage (UV) threshold of 2.5V to keep the LTC2991 out of power-on reset. Power-on reset will clear all of the data registers and the control registers.

Temperature Measurements

The LTC2991 can measure internal temperature and up to four external diode or transistor sensors. During temperature conversion, current is sourced through the V1, V3, V5 or the V7 pin to forward bias the remote sensing diode. The change in sensor voltage per degree temperature change is hundreds of µV/°C, so environmental noise must be kept to a minimum. Recommended shielding and PCB trace considerations are illustrated in Figure 2.

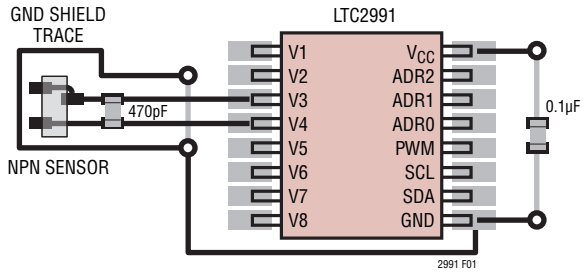


Figure 2. Recommended PCB Layout

The diode equation:

$$V_{BE} = \eta \bullet \frac{k \bullet T}{q} \bullet \ln\left(\frac{I_C}{I_S}\right) \quad (1)$$

can be solved for T, where T is Kelvin degrees, I_S is a process dependent factor on the order of 1E-13, η is the diode ideality factor, k is Boltzmann's constant and q is the electron charge.

$$T = \frac{V_{BE} \bullet q}{\eta \bullet k \bullet \ln\left(\frac{I_C}{I_S}\right)} \quad (2)$$

The LTC2991 makes differential measurements of diode voltage to calculate temperature. Proprietary techniques allow for cancellation of error due to series resistance.

Ideality Factor Scaling

The LTC2991 is calibrated to yield the correct temperature for a remote diode with an ideality factor of 1.004. While this value is typical of target sensors, small deviations can yield significant temperature errors. The ideality factor of the diode sensor can be considered a temperature scaling factor. The temperature error for a 1% accurate ideality factor error is 1% of the Kelvin temperature. Thus, at 25°C, or 298K, a +1% accurate ideality factor error yields a +2.98 degree error. At 85°C, or 358K, a +1% error yields a 3.6 degree error. It is possible to scale the measured Kelvin or Celsius temperature measured using the LTC2991 with a sensor ideality factor other than 1.004, to the correct value. The scaling Equations (3) and (4), are simple, and can be implemented with sufficient precision using 16-bit fixed point math in a microprocessor or microcontroller.

Factory ideality calibration value:

η_{CAL} = 1.004

Actual sensor ideality value:

η_{ACT}

APPLICATIONS INFORMATION

Compensated Kelvin temperature:

$$T_{K_COMP} = \frac{\eta_{CAL}}{\eta_{ACT}} \bullet T_{K_MEAS} \quad (3)$$

Compensated Celsius temperature:

$$T_{C_COMP} = \frac{\eta_{CAL}}{\eta_{ACT}} \left(T_{C_MEAS} + 273.15\right) - 273.15 \quad (4)$$

A 16-bit unsigned number is capable of representing the ratio η_{CAL}/η_{ACT} in a range of 0.00003 to 1.99997, by multiplying the fractional ratio by 2^{15}. The range of scaling encompasses every conceivable target sensor value. The ideality factor scaling granularity yields a worst-case temperature error of 0.01° at +125°C. Multiplying this 16-bit unsigned number and the measured Kelvin (unsigned) temperature represented as a 16-bit number, yields a 32-bit unsigned result. To scale this number back to a 13-bit temperature (9-bit integer part, and a 4-bit fractional part), divide the number by 2^{15}. Similarly, Celsius coded temperature values can be scaled using 16-bit fixed-point arithmetic, using Equation (4). In both cases, the scaled result will have a 9-bit integer (d[12:4]) and the four LSB's (d[3:0]) representing the 4-bit fractional part. To convert the corrected result to decimal, divide the final result by 24, or 16, as you would the register contents. If ideality factor scaling is implemented in the target application, it is beneficial to configure the LTC2991 for Kelvin coded results to limit the number of math operations required in the target processor.

$$T_{K_COMP} = \frac{(\text{UNSIGNED})\left(\frac{\eta_{CAL}}{\eta_{ACT}} 2^{15}\right) T_{K_MEAS}}{2^{15}} \quad (5)$$

$$T_{C_COMP} = \frac{(\text{UNSIGNED})\left(\frac{\eta_{CAL}}{\eta_{ACT}} 2^{15}\right)\left(T_{C_MEAS} + 273.15 \bullet 2^4\right)}{2^{15}} - 273.15 \bullet 2^4 \quad (6)$$

Sampling Currents

Single-ended voltage measurements are directly sampled by the internal ADC. The average ADC input current is a function of the input applied voltage as follows:

$$I_{SAMPLE} = (V_{IN} - 1.49V) \bullet 0.17[\mu A/V]$$

Inputs with source resistance less than 500Ω will yield full-scale gain errors due to source impedance of < ½ LSB for 14-bit conversions. The nominal conversion time is 1.5ms for single-ended conversions.

Current Measurements

The LTC2991 has the ability to perform 14-bit current measurements with the addition of a current sense resistor (see Figure 3).

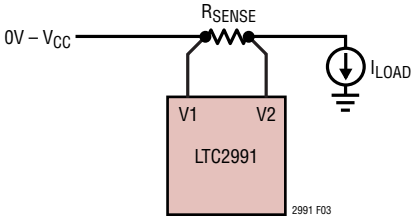


Figure 3. Simplified Current Sense Schematic

In order to achieve 13-bit current sensing a few details must be considered. Differential voltage or current measurements are directly sampled by the internal ADC. The average ADC input current for each leg of the differential input signal during a conversion is:

$$I_{SAMPLE} = (V_{IN} - 1.49V) \bullet 0.34[\mu A/V]$$

The maximum source impedance to yield 14-bit results with ½ LSB full-scale error is ~50Ω.

In order to achieve 14-bit accuracy, 4-point, or Kelvin connected measurements of the sense resistor differential voltage are necessary.

In the case of current measurements, the external sense resistor is typically small, and determined by the full-scale input voltage of the LTC2991. The full-scale differential voltage is 0.300V. The external sense resistance, is then a function of the maximum measurable current, or $R_{EXT_MAX} = 0.300V/I_{MAX}$. For example, if you wanted to measure a

APPLICATIONS INFORMATION

current range of ±5A, the external shunt resistance would equal 0.300V/5A = 60mΩ.

There exists a way to improve the sense resistor's precision using the LTC2991. The LTC2991 measures both differential voltage and remote temperature. It is therefore, possible to compensate for the absolute resistance tolerance of the sense resistor and the temperature coefficient of the sense resistor in software. The resistance would be measured by running a calibrated test current through the discrete resistor. The LTC2991 would measure both the differential voltage across this resistor and the resistor temperature. From this measurement, R_0 and T_0 in the following equation would be known. Using the two equations, the host microprocessor could compensate for both the absolute tolerance and the TCR.

$$R_T = R_0 \bullet [1 + \alpha(T - T_0)], \text{where}$$
$$\alpha = 3930\text{ppm/°C for copper trace}$$
$$\alpha = \pm 2 \text{ to } \sim 200\text{ppm/°C for discrete R} \quad (7)$$
$$I = (V1 - V2)/R_T \quad (8)$$

Device Configuration

The LTC2991 is configured by writing the channel control registers through the serial interface. Refer to Tables 5, 6 and 7 for control register bit definition. The device is capable of many application configurations including voltage, temperature and current measurements. It is possible to configure the device for single or repeated acquisitions. For repeated acquisitions, only the initial trigger is required, and new data is written over the old data. Acquisitions are frozen during serial read data transfers, to prevent the upper and lower data bytes for a particular measurement from becoming out of sync. Internally, both the upper and lower bytes are written at the same instant. Since serial data transfer timeout is not implemented, failure to terminate a read operation will yield an indefinitely frozen wait state. The device can also make single measurements, or with one trigger, all of the measurements for the configuration. When the device is configured for multiple measurements, the order of measurements is fixed. As each new data result is ready, the MSB of the corresponding data register is set, and the corresponding status register bit is set. These bits are cleared when the corresponding data register is addressed. The configuration register value at power-up yields the measurement of the internal temperature sensor and V1 through V8 as single-ended voltages, if triggered. The eight input pins V1 through V8 will be in a high impedance state, until configured otherwise, and a measurement triggered. Please note that when the device is configured for remote temperature measurements (using the control registers 0x06 and/or 0x07), the temperature data (Trx T) is stored in V1, V3, V5 and V7 respectively depending on the channel being used. Similarly, during this configuration the diode voltage (Trx Voltage) is stored in V2, V4, V6 and V8 registers.

Data Format

The data registers are broken into 8-bit upper and lower bytes. Voltage and temperature conversions are 13-bits. The upper bits in the MSB registers provide status on the resulting conversions. These status bits are different for temperature and voltage conversions.

Temperature

Temperature conversions are reported as Celsius or Kelvin results described in Tables 11 and 12, each with 0.0625 degree weighted LSBs. The format is controlled by the control registers. The temperature MSB result register most significant bit (Bit 7) is the DATA_VALID bit, which indicates whether the current register contents have been accessed since the result was written to the register. This bit will be set when new data is written to the register, and cleared when accessed. The LTC2991 internal bias circuitry maintains this voltage above this level during normal operating conditions. Bit 4 through bit 0 of the MSB register are the conversion result bits D[12:8], in two's compliment format. Note in Kelvin results, the result will always be positive. The LSB register contains temperature result bits D[7:0]. To convert the register contents to temperature, use the following equation: T = D[12:0]/16. See Table 16 for conversion value examples. Remote diode voltage is digitized at ~50µA of bias current. The ADC LSB value during these conversions is typically 38.15µV. Voltages are only available for the remote diodes, not the internal sensor. This code repeats at a diode voltage of approximately 0.3125V (see Tables 13 and 14). The absolute temperature of the diode can be used to detect whether the diode is operating (≤0.3125V or ≥ 0.3125V). This mode is useful for testing small relative

APPLICATIONS INFORMATION

changes in temperature using the approximate relationship of –2.1mV/°C of voltage dependence on temperature. With an LSB weight of 38.15µV and a diode temperature relationship of –2.1mV/°C this yields ~0.018 degree resolution. For sensor applications involving heaters, the ability to sense small changes in temperature with low noise can yield significant power savings, allowing the heater power to be reduced. Table 16 has some conversion result examples for various diode voltages.

Voltage/Current

Voltage results are reported in two respective registers, an MSB and LSB register. The Voltage MSB result register most significant bit (bit 7) is the DATA_VALID bit, which indicates whether the current register contents have been accessed since the result was written to the register. This bit will be set when the register contents are new, and cleared when accessed. Bit 6 of the MSB register is the sign bit, bits 5 though 0 represent bits D[13:8] of the two's complement conversion result. The LSB register holds conversion bits D[7:0]. The LSB value is different for single-ended voltage measurements V1 through V8, and differential (current measurements) V1 – V2 , V3 – V4, V5 – V6 and V7 – V8. Single-ended voltages are limited to positive values in the range 0V to 4.9V or V_{CC} + 0.2V, whichever is smaller. Differential voltages can have input values in the range of –0.300V to 0.300V.

Use the following equations to convert the register values (see Table 16 for examples):

V_{SINGLE_ENDED} = D[13:0] • 305.18µV

$V_{DIFFERENTIAL}$ = D[13:0] • 19.075µV, if sign = 0

$V_{DIFFERENTIAL}$ = ($\overline{D[13:0]}$ +1) • –19.075µV, if sign = 1

Current = D[13:0] • 19.075µV/R_{SENSE}, if sign = 0

Current = ($\overline{D[13:0]}$ +1) • –19.075µV/R_{SENSE}, if sign = 1,

Where R_{SENSE} is the current sensing resistor, typically < 1Ω.

V_{CC}

The LTC2991 measures V_{CC}. To convert the contents of the V_{CC} register to voltage, use the following equation: V_{CC} = 2.5 + (D[13:0] • 305.18µV).

PWM Output

A 9-bit, 1kHz PWM output proportional to temperature V7 is available for controlling fans or heaters. PWM_Threshold is a 9-bit value with an LSB weighting of one degree Kelvin. PWM_Threshold is subtracted from V7 and a pulse width proportional to the difference is produced. Note that the PWM threshold is split among two registers, with PWM_Threshold[8:1] in register 09h[7:0] and PWM_Threshold[0] in register 08h[7]. Equation 9 shows the registers involved. The PWM frequency is ~1kHz. The PWM output can be disabled or inverted with the PWM enable and PWM invert bits is register 08h, respectively. Figure 9 illustrates the PWM transfer function. The equation for the duty cycle is:

$$PWM_DUTY_CYCLE(\%) = \frac{100 \bullet (REG7 - PWM \bullet 16)}{512} \quad (9)$$

Where REG7 is bits [12:0] and
PWM is PWM Threshold bits [8:0]

A 50% duty cycle PWM signal would occur, for example, if the PWM threshold was set to 10h (16°C) and register 7 contained 200h (32°C). If channel 7 is configured for Kelvin temperatures, the PWM threshold must also be a Kelvin temperature. The registers are two's compliment numbers. When calculating the duty cycle above for Celsius temperatures care should be taken to sign extend the register 7 and PWM threshold values. For temperatures below the PWM Threshold, the PWM output pin will be a constant logic level 0. For temperatures 32 degrees above

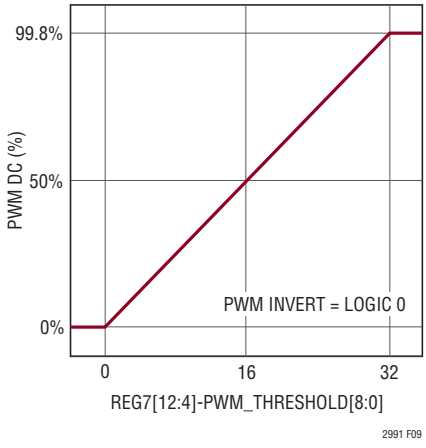


Figure 9. PWM Transfer Function

APPLICATIONS INFORMATION

the PWM Threshold, the PWM output pin will be a constant logic level 1. This relationship is opposite if the PWM invert bit is set. If the filter is enabled for the V7/V8 pair, the filtered result is routed to the PWM block; otherwise, the unfiltered version is used. The PWM CMOS output drive is intended to be buffered to drive large (>100pF) external capacitances or resistors <10k. A recommended noninverting buffer is a NC7SZ125 to increase the drive capability of the PWM signal.

Digital Filter

Each conversion result can be filtered using an on-chip digital filter. The filter equation is:

$$OUTPUT[X] = (15 \bullet (OUTPUT[X - 1]) + SAMPLE[X])/16$$

where output[x] is the register value when enabled. The filter step response is illustrated in the Typical Performance Characteristics section. The filter can be seeded by triggering an unfiltered conversion of each configured measurement, then subsequently enabling the filter. This will cause the filter to converge instantaneously to the value of the initial unfiltered sample. The filter can be enabled or disabled for each channel pair and internal temperature measurements. V_{CC} measurements cannot be filtered.

Digital Interface

The LTC2991 communicates with a bus master using a 2-wire interface compatible with the I²C Bus and the SMBus, an I²C extension for low power devices.

The LTC2991 is a read write slave device and supports SMBus bus read byte data and write byte data, read word data and write word data commands. The data formats for these commands are shown in Tables 3 though 15.

The connected devices can only pull the bus wires LOW and can never drive the bus HIGH. The bus wires are externally connected to a positive supply voltage via a current source or pull-up resistor. When the bus is free, both lines are HIGH. Data on the I²C bus can be transferred at rates of up to 100kbit/s in the standard mode and up to 400kbit/s in the fast mode. Each device on the I²C bus is recognized by a unique address stored in that device and can operate as either a transmitter or receiver, depending on the function of the device. In addition to transmitters and receivers, devices can also be considered as masters or slaves when performing data transfers. A master is the device which initiates a data transfer on the bus and generates the clock signals to permit that transfer. At the same time any device addressed is considered a slave.

The LTC2991 can only be addressed as a slave. Once addressed, it can receive configuration bits or transmit the last conversion result. Therefore the serial clock line SCL is an input only and the data line SDA is bidirectional. The device supports the standard mode and the fast mode for data transfer speeds up to 400kbit/s. The Timing Diagram shows the definition of timing for fast/standard mode devices on the I²C bus. The internal state machine cannot update internal data registers during an I²C read operation. The state machine pauses until the I²C read is complete. It is therefore, important not to leave the LTC2991 in this state for long durations, or increased conversion latency will be experienced.

START and STOP Conditions

When the bus is idle, both SCL and SDA must be high. A bus master signals the beginning of a transmission with a START condition by transitioning SDA from high to low while SCL is high. When the bus is in use, it stays busy if a repeated START (SR) is generated instead of a STOP condition. The repeated START (SR) conditions are functionally identical to the START (S). When the master has finished communicating with the slave, it issues a STOP condition by transitioning SDA from low to high while SCL is high. The bus is then free for another transmission.

I²C Device Addressing

Eight distinct bus addresses are configurable using the ADR0, ADR1 and ADR2 pins. Table 1 shows the correspondence between ADR0, ADR1 and ADR2 pin states and addresses. There is also one global sync address available at EEh which provides an easy way to synchronize multiple LTC2991's on the same I²C bus. This allows write only access to all LTC2991's on the bus for simultaneous triggering.

Acknowledge

The acknowledge signal is used for handshaking between the transmitter and the receiver to indicate that the last byte of data was received. The transmitter always releases the SDA line during the acknowledge clock pulse. When the

APPLICATIONS INFORMATION

slave is the receiver, it must pull down the SDA line so that it remains LOW during this pulse to acknowledge receipt of the data. If the slave fails to acknowledge by leaving SDA HIGH, then the master can abort the transmission by generating a STOP condition. After the master has received the last data bit from the slave, the master must pull down the SDA line during the next clock pulse to indicate receipt of the data. After the last byte has been received the master will leave the SDA line HIGH (not acknowledge) and issue a STOP condition to terminate the transmission.

Write Protocol

The master begins communication with a START condition followed by the 7-bit slave address and the R$\overline{W}$ bit set to zero. The addressed LTC2991 acknowledges the address and then the master sends a command byte which indicates which internal register the master wishes to write. The LTC2991 acknowledges the command byte and then latches the lower five bits of the command byte into its internal register address pointer. The master then delivers the data byte and the LTC2991 acknowledges once more and latches the data into its internal register. The transmission is ended when the master sends a STOP condition. If the master continues sending a second data byte, as in a write word command, the second data byte will be acknowledged by the LTC2991 and written to the next register in sequence, if this register has write access.

Read Protocol

The master begins a read operation with a START condition followed by the 7-bit slave address and the R$\overline{W}$ bit set to zero. The addressed LTC2991 acknowledges this and then the master sends a command byte which indicates which internal register the master wishes to read. The LTC2991 acknowledges this and then latches the lower five bits of the command byte into its internal register address pointer. The master then sends a repeated START condition followed by the same seven bit address with the R$\overline{W}$ bit now set to one. The LTC2991 acknowledges and sends the contents of the requested register. The transmission is ended when the master sends a STOP condition. The register pointer is automatically incremented after each byte is read. If the master acknowledges the transmitted data byte, as in a read word command, the LTC2991 will send the contents of the next sequential register as the second data byte. The byte following register 1Dh is register 00h, or the status register.

Control Registers

The control registers (Tables 5 through 8) determine the selected measurement mode of the device. The LTC2991 can be configured to measure voltages, currents and temperatures. These measurements can be single shot or repeated measurements. Temperatures can be set to report in Celsius or Kelvin temperature scales. The LTC2991 can be configured to run particular measurements, or all possible measurements per the configuration specified by the channel enable register (Table 4). The power-on default configuration of the control registers is 00h, which translates to a single-ended voltage measurement of the triggered channels. This mode prevents the application of remote diode test currents on pins V1, V3, V5 and V7, and remote diode terminations on pins V2, V4, V6 and V8 at power-up.

Status Register

The status registers (Tables 3 and 4) report the status of a particular conversion result. When new data is written into a particular result register, the corresponding DATA_VALID bit is set. When the register is addressed by the I^2C interface, the status bit (as well as the DATA_VALID bit in the respective register) is cleared. The host can then determine if the current available register data is new or stale. The busy bit, when high, indicates a single shot conversion is in progress. The busy bit is always high during repeated mode, after the initial conversion is triggered.

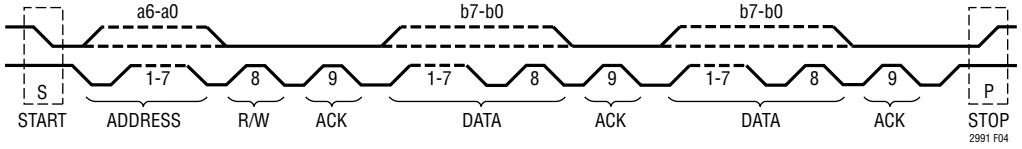


Figure 4. Data Transfer Over I^2C or SMBus

APPLICATIONS INFORMATION

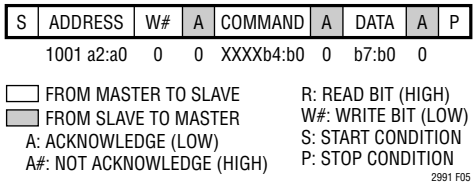


Figure 5. LTC2991 Serial Bus Write Byte Protocol

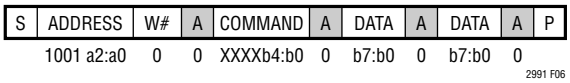


Figure 6. LTC2991 Serial Bus Repeated Write Byte Protocol

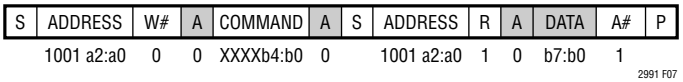


Figure 7. LTC2991 Serial Bus Read Byte Protocol

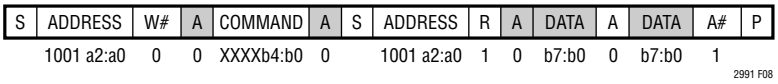


Figure 8. LTC2991 Serial Bus Repeated Read Byte Protocol

Table 1. I²C Base Address

I²C BASE ADDRESS	ADR2	ADR1	ADR0
90h	0	0	0
92h	0	0	1
94h	0	1	0
96h	0	1	1
98h	1	0	0
9Ah	1	0	1
9Ch	1	1	0
9Eh	1	1	1
EEh	Global Sync Address		

APPLICATIONS INFORMATION

Table 2. LTC2991 Register Address and Contents

REGISTER ADDRESS* †	REGISTER NAME	READ/WRITE	DESCRIPTION
00h	STATUS LOW	R	DATA_VALID Bits (V1 Through V8)
01h	CH EN, STAT. HI, TRIGGER**	R/W	CHANNEL ENABLE , V_{CC}, $T_{INTERNAL}$ Conv. Status, Trigger
02h	Reserved	N/A	Reserved
03h	Reserved	N/A	Reserved
04h	Reserved	N/A	Reserved
05h	Reserved	N/A	Reserved
06h	V1, V2 and V3, V4 CONTROL	R/W	V1, V2, V3 and V4 Control Register
07h	V5, V6 and V7, V8 CONTROL	R/W	V5, V6, V7 and V8 Control Register
08h	PWM_Threshold(LSB), V_{CC}, $T_{INTERNAL}$ CONTROL	R/W	PWM Threshold and $T_{INTERNAL}$ Control Register
09h	PWM_Threshold(MSB)	R/W	PWM Threshold
0Ah	V1(MSB)	R	V1 or T_{R1} T MSB
0Bh	V1(LSB)	R	V1 or T_{R1} T LSB
0Ch	V2(MSB)	R	V2, V1 – V2, or T_{R1} Voltage MSB
0Dh	V2(LSB)	R	V2, V1 – V2, or T_{R1} Voltage LSB
0Eh	V3(MSB)	R	V3, or T_{R2} T MSB
0Fh	V3(LSB)	R	V3, or T_{R2} T LSB
10h	V4(MSB)	R	V4, V3 – V4, or T_{R2} Voltage MSB
11h	V4(LSB)	R	V4, V3 – V4, or T_{R2} Voltage LSB
12h	V5(MSB)	R	V5, or T_{R3} T MSB
13h	V5(LSB)	R	V5, or T_{R3} T LSB
14h	V6(MSB)	R	V6, V5 – V6, or T_{R3} Voltage MSB
15h	V6(LSB)	R	V6, V5 – V6, or T_{R3} Voltage LSB
16h	V7(MSB)	R	V7, or T_{R4} T MSB
17h	V7(LSB)	R	V7, or T_{R4} T LSB
18h	V8(MSB)	R	V8, V7 – V8, or T_{R4} Voltage MSB
19h	V8(LSB)	R	V8, V7 – V8, or T_{R4} Voltage LSB
1Ah	$T_{INTERNAL}$(MSB)	R	$T_{INTERNAL}$ MSB
1Bh	$T_{INTERNAL}$(LSB)	R	$T_{INTERNAL}$ LSB
1Ch	V_{CC}(MSB)	R	V_{CC} MSB
1Dh	V_{CC}(LSB)	R	V_{CC} LSB

* Register address MSBs b7 to b5 are ignored.
** Writing any value triggers a conversion.
† Power-on reset sets all registers to 00h.

APPLICATIONS INFORMATION

Table 3. STATUS LOW (00h) Register

BIT	NAME	OPERATION
b7	V8, T4, V7 – V8 Ready	1 = V8 Register Contains New Data, 0 = V8 Register Data Old
b6	V7, T4, V7 – V8 Ready	1 = V7 Register Contains New Data, 0 = V7 Register Data Old
b5	V6, T3, V5 – V6 Ready	1 = V6 Register Contains New Data, 0 = V6 Register Data Old
b4	V5, T3, V5 – V6 Ready	1 = V5 Register Contains New Data, 0 = V5 Register Data Old
b3	V4, T2, V3 – V4 Ready	1 = V4 Register Contains New Data, 0 = V4 Register Data Old
b2	V3, T2, V3 – V4 Ready	1 = V3 Register Contains New Data, 0 = V3 Register Data Old
b1	V2, T1, V1 – V2 Ready	1 = V2 Register Contains New Data, 0 = V2 Register Data Old
b0	V1, T1, V1 – V2 Ready	1 = V1 Register Contains New Data, 0 = V1 Register Data Old

Table 4. STATUS HIGH, CHANNEL ENABLE (01h) Register (Default 00h)

BIT	NAME	R/W	OPERATION
b7	V7 and V8, V7 – V8, T_{R4} Enable	R/W	1 = V7 and V8, or V7 – V8 or T4 Enabled 0 = V7 and V8, or V7 – V8 or T4 Disabled (Default)
b6	V5 and V6, V5 – V6, T_{R3} Enable	R/W	1 = V5 and V6, or V5 – V6 or T3 Enabled 0 = V5 and V6, or V5 – V6 or T3 Disabled (Default)
b5	V3 and V4, V3 – V4, T_{R2} Enable	R/W	1 = V3 and V4, or V3 – V4 or T2 Enabled 0 = V3 and V4, or V3 – V4 or T2 Disabled (Default)
b4	V1 and V2, V1 – V2, T_{R1} Enable	R/W	1 = V1 and V2, or V1 – V2 or T1 Enabled 0 = V1 and V2, or V1 – V2 or T1 Disabled (Default)
b3	$T_{INTERNAL}$ V_{CC} Enable	R/W	1 = $T_{INTERNAL}$ and V_{CC} Enabled 0 = $T_{INTERNAL}$ and V_{CC} Disabled (Default)
b2	BUSY	R	1 = A Conversion Is in Process 0 = Sleep Mode (Default)
b1	$T_{INTERNAL}$	R	1 = $T_{INTERNAL}$ Register Contains New Data 0 = $T_{INTERNAL}$ Register Data Old (Default)
b0	V_{CC}	R	1 = V_{CC} Register Contains New Data 0 = V_{CC} Register Data Old (Default)

Table 5. V1, V2 and V3, V4 CONTROL (06h) Register (Default 00h)

BIT	NAME	OPERATION
b7	V3, V4 Filt	1 = Filter Enabled, 0 = Filter Disabled for V3 and V4, V3 – V4 or T2 (Default)
b6	T_{R2} Kelvin	1 = Kelvin, 0 = Celsius for T2 (Default)
b5	V3, V4 Temperature	1 = Temperature, 0 = Voltage (Per b4 Setting) (Default)
b4	V3, V4 Differential 1	1 = Differential (V3 – V4) and V3 Single-Ended 0 = Single-Ended Voltage (V3 and V4) (Default)
b3	V1, V2 Filt	1 = Filter Enabled, 0 = Filter Disabled for V1 and V2, V1 – V2 or T1 (Default)
b2	T_{R1} Kelvin	1 = Kelvin, 0 = Celsius for T1 (Default)
b1	V1, V2 Temperature	1 = Temperature, 0 = Voltage (Per b0 Setting) (Default)
b0	V1, V2 Differential	1 = Differential (V1 – V2) and V1 Single-Ended 0 = Single-Ended Voltage (V1 and V2) (Default)

APPLICATIONS INFORMATION

Table 6. V5, V6 and V7, V8 CONTROL (07h) Register (Default 00h)

BIT	NAME	OPERATION
b7	V7, V8 Filt	1 = Filter Enabled, 0 = Filter Disabled for V7 and V8, V7 – V8 or T4 (Default)
b6	T_{R4} Kelvin	1 = Kelvin, 0 = Celsius for T4 (Default)
b5	V7, V8 Temperature	1 = Temperature, 0 = Voltage (Per b4 Setting) (Default)
b4	V7, V8 Differential	1 = Differential (V7 – V8) and V7 Single-Ended 0 = Single-Ended Voltage (V7 and V8) (Default)
b3	V5, V6 Filt	1= Filter Enabled, 0 = Filter Disabled for V5 and V6, V5 – V6 or T3 (Default)
b2	T_{R3} Kelvin	1 = Kelvin, 0 = Celsius for T3 (Default)
b1	V5, V6 Temperature	1 = Temperature, 0 = Voltage (Per b0 Setting) (Default)
b0	V5, V6 Differential	1 = Differential (V5 – V6) and V5 Single-Ended 0 = Single-Ended Voltage (V5 and V6) (Default)

Table 7. PWM, V_{CC} and $T_{INTERNAL}$ CONTROL (08h) Register (Default 00h)

BIT	NAME	OPERATION
b7	PWM[0]	PWM Threshold Least Significant Bit (Default = 0)
b6	PWM Invert*	1 = PWM Inverted, 0 = PWM Noninverted (Default)
b5	PWM Enable**	1 = PWM Enabled, 0 = PWM Disabled (Default)
b4	Repeated Acquisition	1 = Repeated Mode 0 = Single Shot (Default)
b3	$T_{INTERNAL}$ Filt	1 = Filter Enabled for $T_{INTERNAL}$ 0 = Filter Disabled $T_{INTERNAL}$ (Default)
b2	$T_{INTERNAL}$ Kelvin	1 = Kelvin, 0 = Celsius for $T_{INTERNAL}$ (Default)
b1	Reserved	Reserved
b0	Reserved	Reserved

* Noninverted would be an increasing duty cycle for an increasing temperature.
** If disabled and noninverted, the PWM pin will be a logic level 0. If disabled and inverted, the PWM pin will be a logic level 1.

Table 8. PWM Register Format (Default 00h)

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
D8	D7	D6	D5	D4	D3	D2	D1

Note: D0 is located in the MSB of PWM, V_{CC} and $T_{INTERNAL}$ CONTROL (08h) Register

Table 9. Voltage/Current Measurement MSB Data Register Format

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
DV*	Sign	D13	D12	D11	D10	D9	D8

*Data valid is set when a new result is written into the register. Data valid is cleared when this register is addressed (read) by the I^2C interface.

Table 10. Voltage/Current Measurement LSB Data Register Format

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
D7	D6	D5	D4	D3	D2	D1	D0

APPLICATIONS INFORMATION

Table 11. Temperature Measurement MSB Data Register Format

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
DV*	X	X	D12	D11	D10	D9	D8

*Data valid is set when a new result is written into the register. Data valid is cleared when this register is addressed (read) by the I^2C interface.

X Unused

Table 12. Temperature Measurement LSB Data Register Format

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
D7	D6	D5	D4	D3	D2	D1	D0

Table 13. Diode Voltage Measurement MSB Data Register Format

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
DV*	X	X	D12	D11	D10	D9	D8

*Data valid is set when a new result is written into the register. Data valid is cleared when this register is addressed (read) by the I^2C interface.

X Unused

Table 14. Diode Voltage Measurement LSB Data Register Format

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
D7	D6	D5	D4	D3	D2	D1	D0

Table 15. PWM Threshold Register Format

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
D7	D6	D5	D4	D3	D2	D1	D0

D7:D0 = PWM[8:1], bit 0 is located in the PWM, V_{CC} and T_{INT} CONTROL Register (Table 7)

Table 16. Conversion Formats

VOLTAGE FORMATS	SIGN	BINARY VALUE D[13:0]	VOLTAGE
Single-Ended LSB = 305.18µV = $2.5/2^{13}$	0	11111111111111	>5
	0	10110011001101	3.5000
	0	01111111111111	2.5000
	0	00000000000000	0.0000
	1	11110000101001	–0.3000
Differential LSB = 19.075µV = $2.5/2^{17}$	0	11110101101111	0.300
	0	10000010001111	0.159
	0	00000000000000	0.0000
	1	01111101110001	–0.159
	1	00001010010001	–0.300
V_{CC} = Result + 2.5V LSB = 305.18µV = $2.5/2^{13}$	0	10110011001101	V_{CC} = 6.0
	0	10000000000000	V_{CC} = 5.0
	0	00001010001111	V_{CC} = 2.7

APPLICATIONS INFORMATION

Table 16. Conversion Formats

TEMPERATURE FORMATS	FORMAT	BINARY VALUE D[12:0]	TEMPERATURE
Temperature Internal, T_{R1} Through T_{R4} LSB = 0.0625 Degrees	Celsius	0011111010000	125.0000
	Celsius	0000110010001	25.0625
	Celsius	0000110010000	25.0000
	Celsius	1110110000000	–40.0000
	Kelvin	1100011100010	398.1250
	Kelvin	1000100010010	273.1250
	Kelvin	0111010010010	233.1250
	Kelvin	0010011010000	77.0000

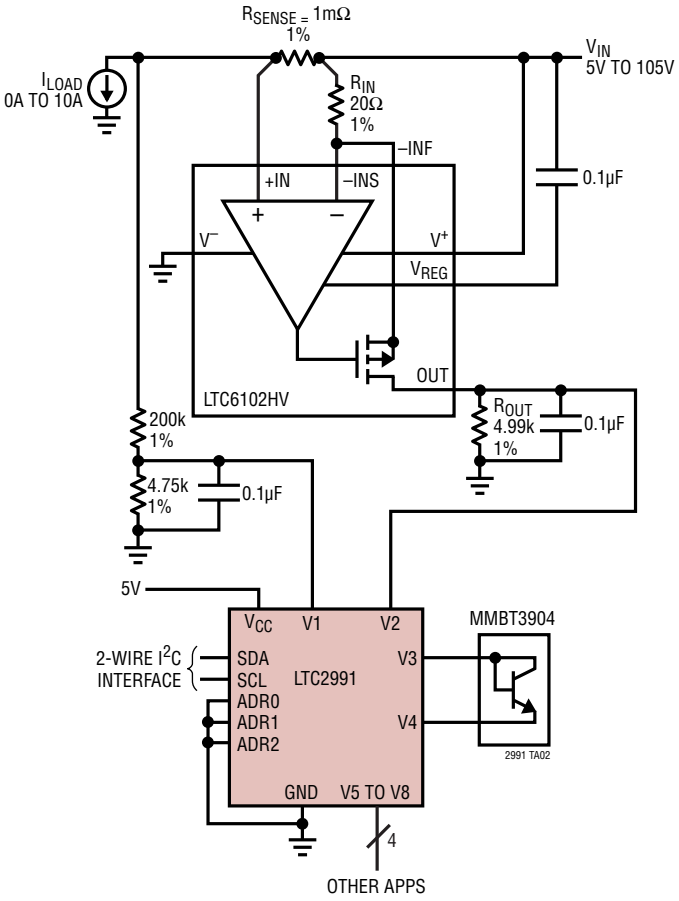
DIODE VOLTAGE FORMATS	Sign	Binary Value D[12:0]	Voltage
Diode Voltage T_{R1} Through T_{R4} LSB = 38.15µV	0	0000000000000	0.0000
	0	1111111111111	0.31249
	0	0000000000000	0.31252
	0	1111111111111	0.62501
	0	0000000000000	0.62505
	0	1001100110010	0.99999

Table 17. Recommended Transistors to Be Used as Temperature Sensors

MANUFACTURER	PART NUMBER	PACKAGE
Fairchild Semiconductor	MMBT3904	SOT-23
Fairchild Semiconductor	FMMT3904	SOT-23
Fairchild Semiconductor	2N3904	TO-92
Central Semiconductor	CMPT3904	SOT-23
Central Semiconductor	CET3904E	SOT-883L
Diodes, Inc.	MMBT3904	SOT-23
On Semiconductor	MMBT3904LT1	SOT-23
NXP	MMBT3904	SOT-23
Infineon	MMBT3904	SC-70
Rohm	UMT3904	SOT-23

TYPICAL APPLICATIONS

High Voltage/Current and Temperature Monitoring



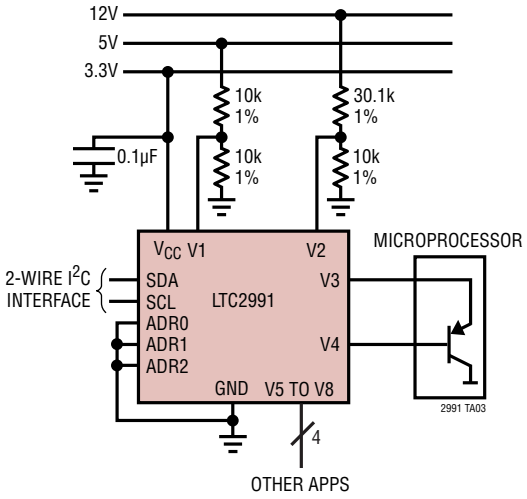
ALL CAPACITORS ±20%

VOLTAGE, CURRENT AND TEMPERATURE CONFIGURATION:
CONTROL REGISTER: 0x06 0xA0

$T_{AMBIENT}$	REG 1A, 1B:	0.0625°C/LSB
V_{LOAD}	REG 0A, 0B:	13.2mV/LSB
$V2(I_{LOAD})$	REG 0C, 0D:	1.223mA/LSB
$T_{PROCESSOR}$	REG 0E, 0F:	0.0625°C/LSB
V_{CC}	REG 1C, 1D:	2.5V + 305.18µV/LSB

TYPICAL APPLICATIONS

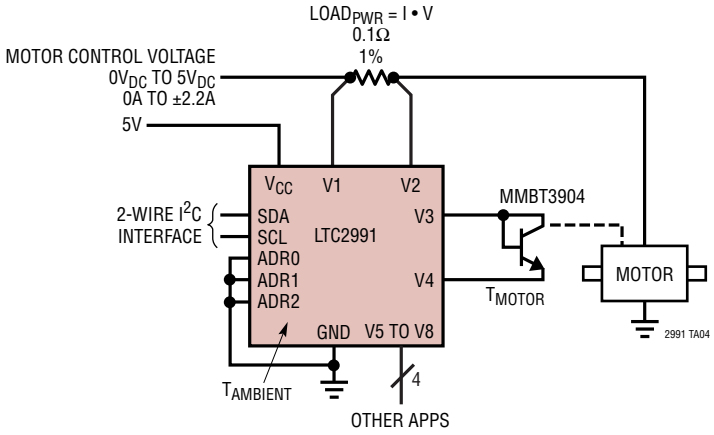
Computer Voltage and Temperature Monitoring



VOLTAGE AND TEMPERATURE CONFIGURATION
CONTROL REGISTER: 0x06 0x0A

$T_{AMBIENT}$	REG 1A, 1B:	0.0625°C/LSB
V1(+5)	REG 0A, 0B:	610µV/LSB
V2(+12)	REG 0C, 0D:	1.22mV/LSB
$T_{PROCESSOR}$	REG 0E, 0F:	0.0625°C/LSB
V_{CC}	REG 1C, 1D:	2.5V + 305.18µV/LSB

Motor Protection/Regulation

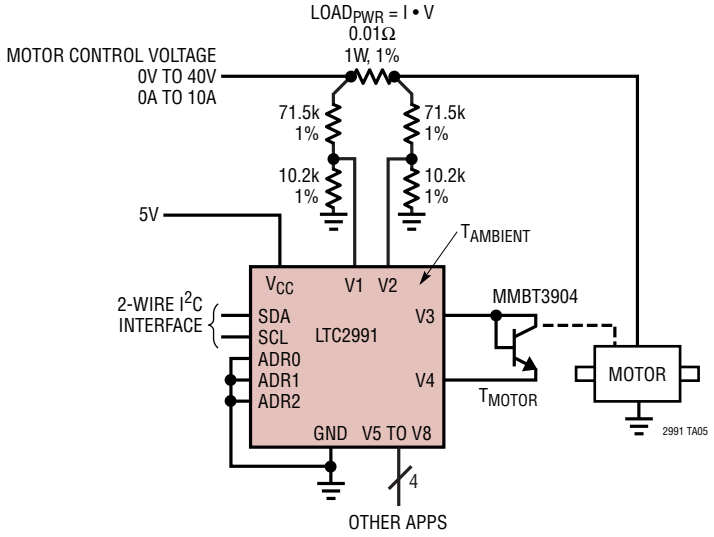


VOLTAGE, CURRENT AND TEMPERATURE CONFIGURATION:
CONTROL REGISTER: 0x06: 0xA1

$T_{AMBIENT}$	REG 1A, 1B:	0.0625°C/LSB
V_{MOTOR}	REG 0A, 0B:	305.18µV/LSB
I_{MOTOR}	REG 0C, 0D:	190.75µA/LSB
T_{MOTOR}	REG 1A, 1B:	0.0625°C/LSB
V_{CC}	REG 1C, 1D:	2.5V + 305.18µV/LSB

TYPICAL APPLICATIONS

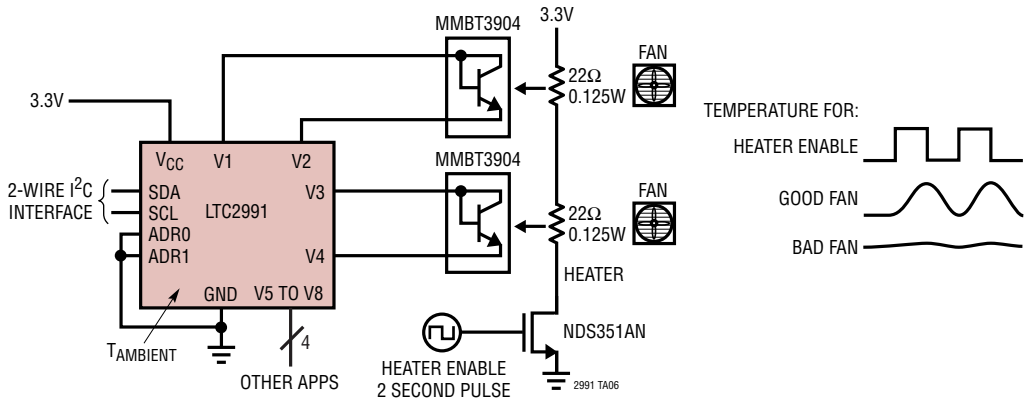
Large Motor Protection/Regulation



VOLTAGE, CURRENT AND TEMPERATURE CONFIGURATION:
CONTROL REGISTER 06: 0xA1

$T_{AMBIENT}$	REG 1A, 1B:	0.0625°C/LSB
V_{MOTOR}	REG 0A, 0B:	2.44mV/LSB
I_{MOTOR}	REG 0C, 0D:	15.54mA/LSB
T_{MOTOR}	REG 0E, 0F:	0.0625°C/LSB
V_{CC}	REG 1C, 1D:	2.5V + 305.18µV/LSB

Fan/Air Filter/Temperature Alarm

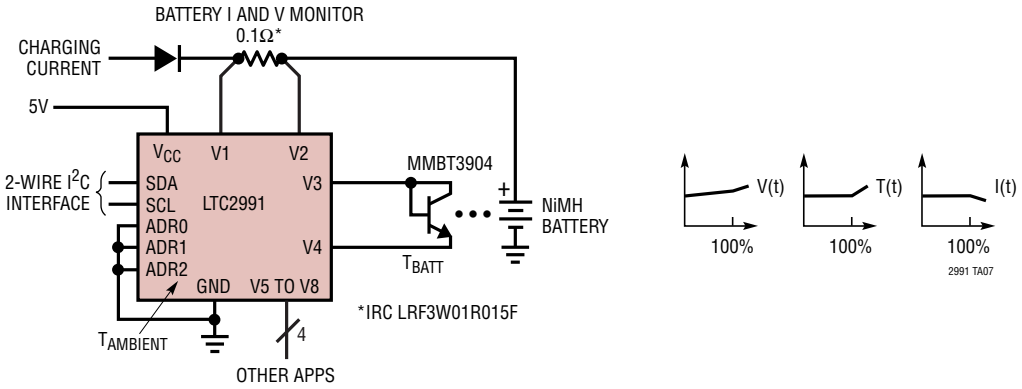


CONTROL REGISTER 0x06 = 0xAA

$T_{AMBIENT}$	REG 1A, 1B:	0.0625°C/LSB
T_{FAN1}	REG 0A, 0B:	0.0625°C/LSB
T_{FAN2}	REG 0C, 0D:	0.0625°C/LSB
V_{CC}	REG 1C, 1D:	2.5V + 305.18µV/LSB

TYPICAL APPLICATIONS

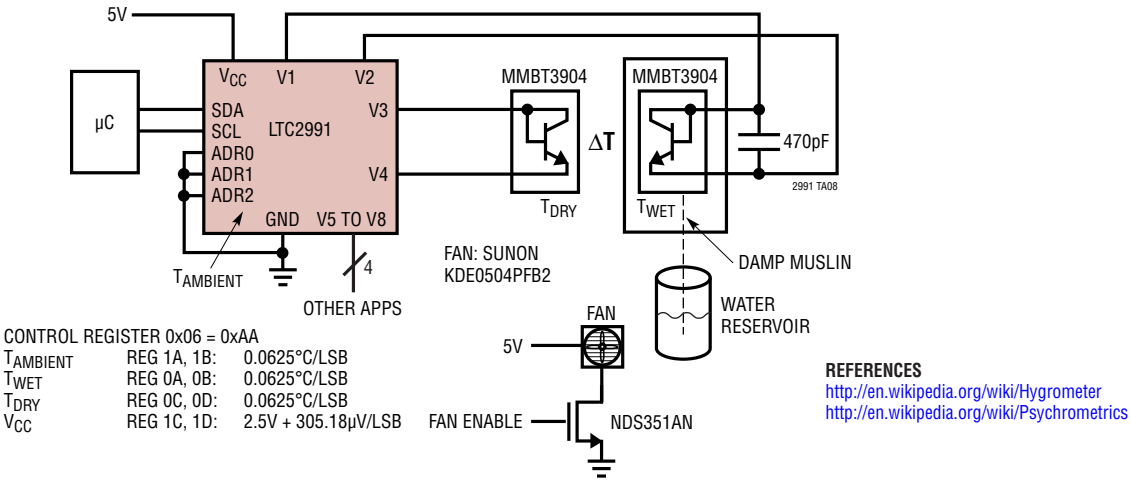
Battery Monitoring



VOLTAGE AND TEMPERATURE CONFIGURATION:
CONTROL REGISTER: 0xA1

$T_{AMBIENT}$	REG 1A, 1B:	0.0625°C/LSB
V_{BAT}	REG 0A, 0B:	305.18µV/LSB
I_{BAT}	REG 0C, 0D:	190.75µA/LSB
T_{BAT}	REG 0E, 0F:	0.0625°C/LSB
V_{CC}	REG 1C, 1D:	2.5V + 305.18µV/LSB

Wet Bulb Psychrometer



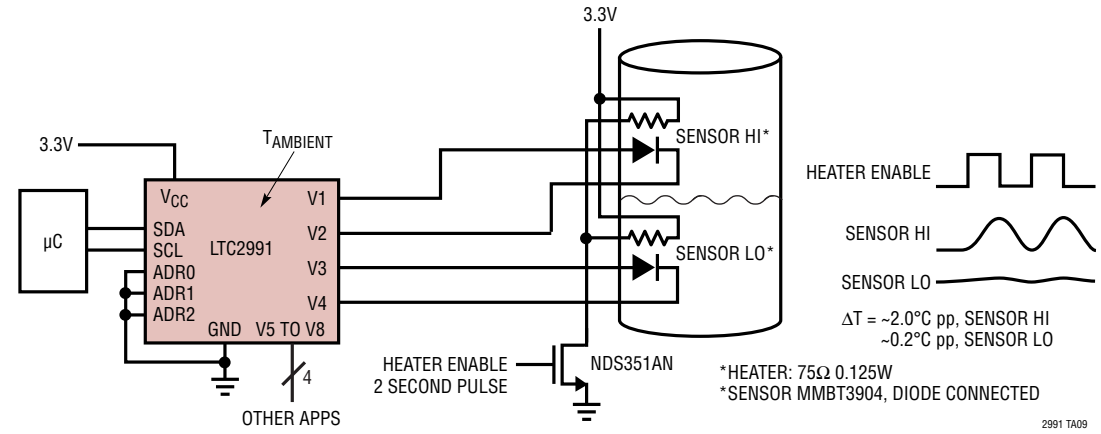
CONTROL REGISTER 0x06 = 0xAA

$T_{AMBIENT}$	REG 1A, 1B:	0.0625°C/LSB
T_{WET}	REG 0A, 0B:	0.0625°C/LSB
T_{DRY}	REG 0C, 0D:	0.0625°C/LSB
V_{CC}	REG 1C, 1D:	2.5V + 305.18µV/LSB

REFERENCES
http://en.wikipedia.org/wiki/Hygrometer
http://en.wikipedia.org/wiki/Psychrometrics

TYPICAL APPLICATIONS

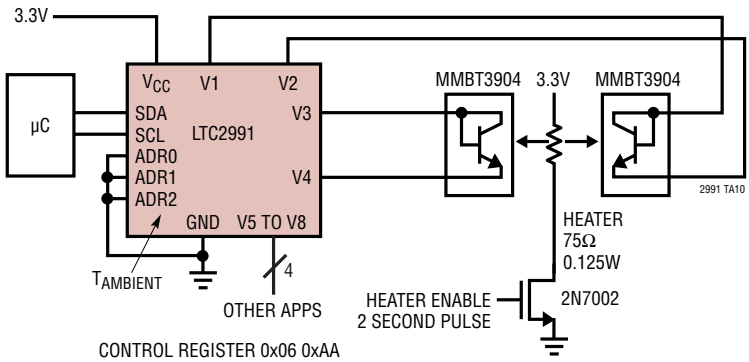
Liquid Level Indicator



CONTROL REGISTER 0x06 = 0xAA

$T_{AMBIENT}$	REG 1A, 1B:	0.0625°C/LSB
T_{DRY}	REG 0A, 0B:	0.0625°C/LSB
T_{WET}	REG 0C, 0D:	0.0625°C/LSB
V_{CC}	REG 1C, 1D:	2.5V + 305.18μV/LSB

Wind Direction/Instrumentation

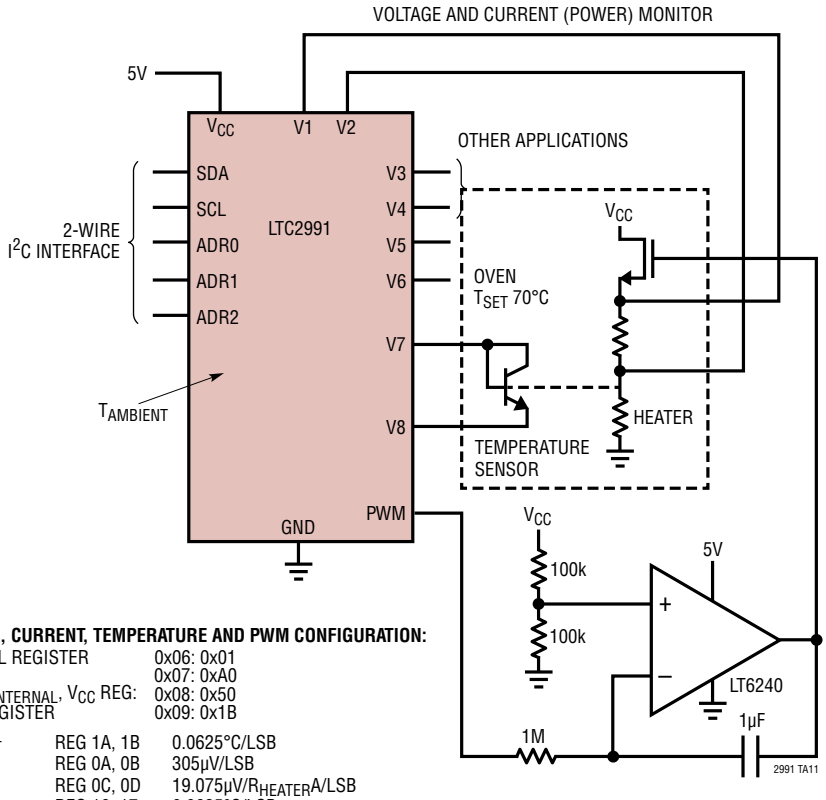


CONTROL REGISTER 0x06 0xAA

$T_{AMBIENT}$	REG 1A, 1B	0.0625°C/LSB
T_{R1}	REG 0A, 0B	0.0625°C/LSB
T_{R2}	REG 0E, 0F	0.0625°C/LSB
V_{CC}	REG 1C, 1D	2.5V + 305.18μV/LSB

TYPICAL APPLICATIONS

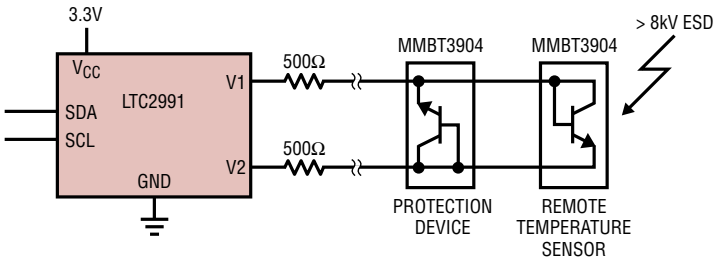
Oven Control with Power Monitor



VOLTAGE, CURRENT, TEMPERATURE AND PWM CONFIGURATION:

CONTROL REGISTER		0x06: 0x01 0x07: 0xA0
PWM, $T_{INTERNAL}$, V_{CC} REG: PWM REGISTER		0x08: 0x50 0x09: 0x1B
$T_{AMBIENT}$	REG 1A, 1B	0.0625°C/LSB
V_{HEATER}	REG 0A, 0B	305µV/LSB
I_{HEATER}	REG 0C, 0D	19.075µV/R_{HEATER}A/LSB
T_{OVEN}	REG 16, 17	0.0625°C/LSB
V_{CC}	REG 1C, 1D	2.5V + 305.18µV/LSB

Remote Temperature Sensing with Extended ESD Performance

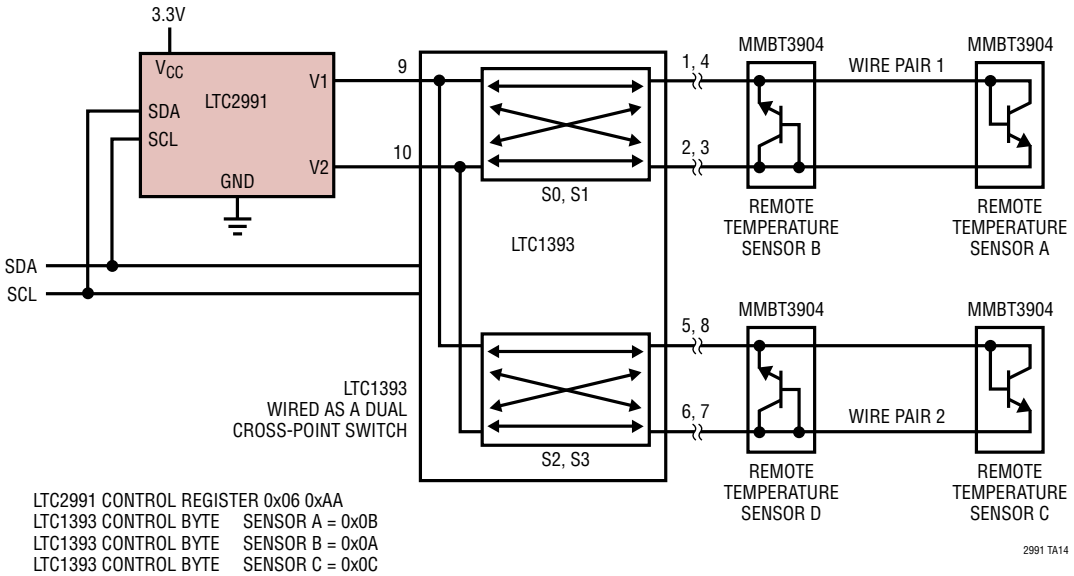


CONTROL REGISTER 0x06 = 0xAA
REMOTE TEMPERATURE SENSOR REG OB, OB: 0.0625 °C/LSB

2991 TA13

TYPICAL APPLICATIONS

QUAD Remote Temperature Sensing with Two Wire Pairs Using One LTC2991 Channel



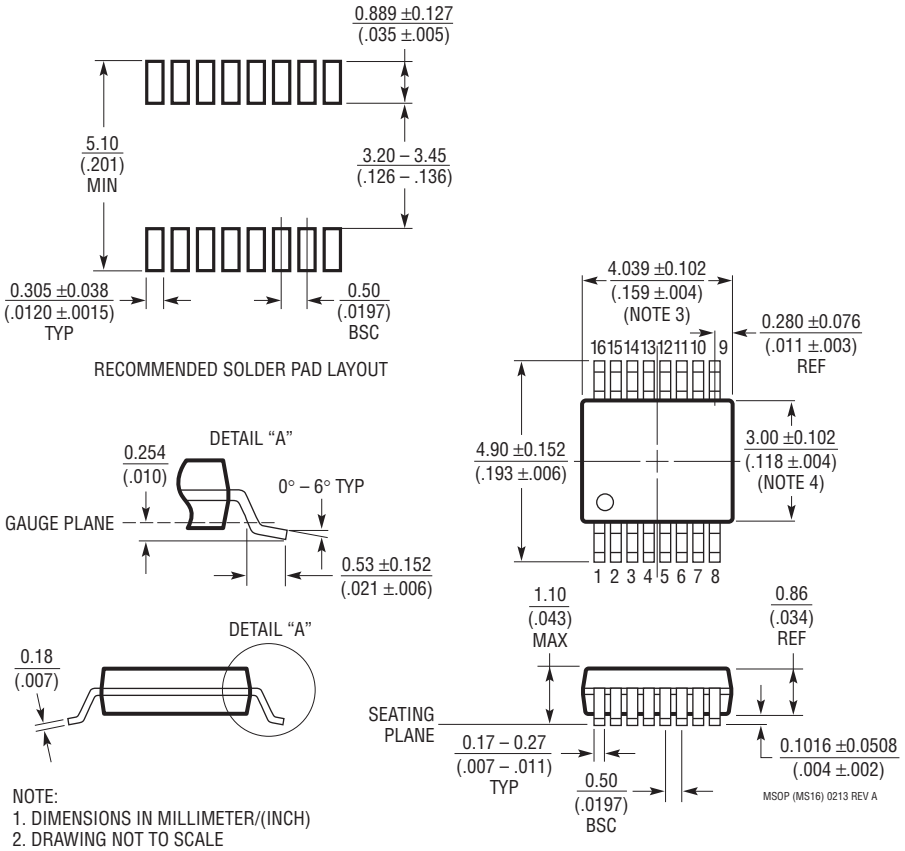
LTC2991 CONTROL REGISTER 0x06 0xAA
LTC1393 CONTROL BYTE SENSOR A = 0x0B
LTC1393 CONTROL BYTE SENSOR B = 0x0A
LTC1393 CONTROL BYTE SENSOR C = 0x0C
LTC1393 CONTROL BYTE SENSOR D = 0x0E

LTC2291 REMOTE TEMPERATURE SENSOR REG OB, OB: 0.0625 °C/LSB

PACKAGE DESCRIPTION

Please refer to http://www.linear.com/product/ltc2991#packaging for the most recent package drawings.

MS Package
16-Lead Plastic MSOP
(Reference LTC DWG # 05-08-1669 Rev A)



NOTE:
1. DIMENSIONS IN MILLIMETER/(INCH)
2. DRAWING NOT TO SCALE
3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.
   MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.
   INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.102mm (.004") MAX

REVISION HISTORY

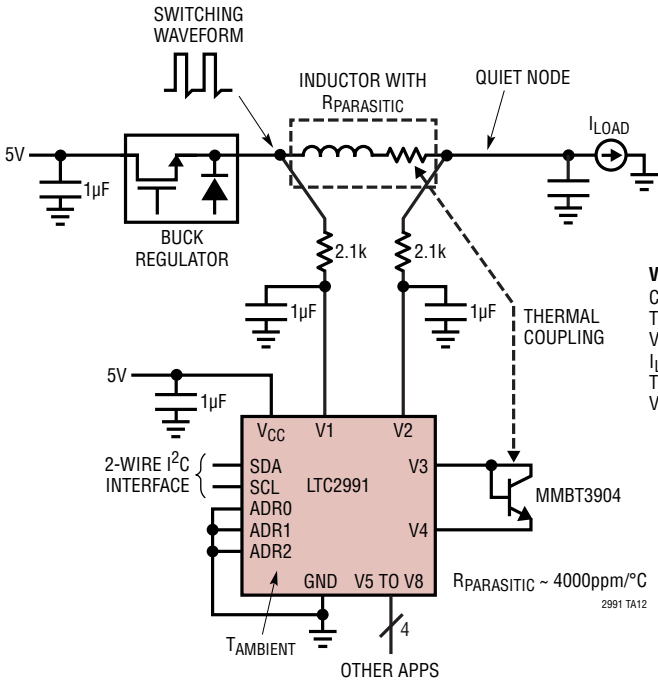
REV	DATE	DESCRIPTION	PAGE NUMBER
A	10/11	Corrected axis label on Figure 9.	14
		Inserted new text in I^2C Device Addressing section.	15
		Inserted new row in Table 1.	17
		Revised component values in Typical Application drawing TA05.	25
B	07/13	Corrected diode voltage value.	13
		Corrected $V_{DIFFERENTIAL}$ and current equations.	14
C	10/13	Corrected slave address in Figures 5, 6, 7 and 8.	17
D	03/14	Corrected LSB size to 19.075µV/LSB and 190.75µA/LSB.	6, 24, 26, 28, 32
E	08/15	Added Single-Ended and Differential V_{OFFSET}.	2
		Inserted new text in Device Configuration.	13
		Updated MSOP Package Description to Rev A.	30
F	10/15	Correct serial bus protocol.	16
		Correct Table 16.	22

LINEAR TECHNOLOGY

Information furnished by Linear Technology Corporation is believed to be accurate and reliable. However, no responsibility is assumed for its use. Linear Technology Corporation makes no representation that the interconnection of its circuits as described herein will not infringe on existing patent rights.

TYPICAL APPLICATION

Parasitic Resistance Voltage and Current Monitoring with Temperature Compensation



VOLTAGE, CURRENT AND TEMPERATURE CONFIGURATION

CONTROL REGISTER 0x06: 0xA1:

$T_{AMBIENT}$	REG 1A, 1B:	0.0625°C/LSB
V_{LOAD}	REG 0A, 0B:	305µV/LSB
I_{LOAD}	REG 0C, 0D:	190.75µA/LSB
$T_{RPARASITIC}$	REG 1A, 1B:	0.0625°C/LSB
V_{CC}	REG 1C, 1D:	2.5V + 305.18µV/LSB

RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LTC2990	Quad I²C Temperature, Voltage and Current Monitor	Remote and Internal Temperatures, 14-Bit Voltages and Current, Internal 10ppm/°C Reference
LTC2997	Remote/Internal Temperature Sensor	Temperature to Voltage with Integrated 1.8V Voltage Reference, ±1°C Accuracy
LTC6102/LTC6102HV	Precision Zero Drift Current Sense Amplifier	5V to 100V, 105V Absolute Maximum (LTC6102HV)
LTC1392	Micropower Temperature, Power Supply and Differential Voltage Monitor	Complete Ambient Temperature Sensor Onboard
LTC2970	Dual I²C Power Supply Monitor and Margining Controller	Integrated Reference and On-Chip Temperature Sensor Sequence, Trim, Margin and Supervise Eight Power Supplies
LTC2977	Octal PMBus Power Supply Manager with EEPROM	Integrated Reference and On-Chip Temperature Sensor and Fault Logging
LTC2945	High Voltage I²C Power Monitor	0V to 80V Range, 12-Bit Voltage and Current. Measurement with 0.75% TUE I²C Interface Calculates 24-Bit Power Value, Stores Minimum and Maximum Values
LTC2487	16-Bit 2-, 4-Channel Delta Sigma ADC with PGA, Easy Drive™ and I²C Interface	Internal Temperature Sensor
LM134	Constant Current Source and Temperature Sensor	Can Be Used as Linear Temperature Sensor
LTC2983	Multi-Sensor High Accuracy Digital Temperature Measurement System	0.1°C Accuracy, Directly Digitize RTDs, Thermocouples, Thermistors and Diodes, 20 Flexible Inputs

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417
(408) 432-1900 • FAX: (408) 434-0507 • www.linear.com/LTC2991
LT 1015 REV F • PRINTED IN USA
© LINEAR TECHNOLOGY CORPORATION 2011