

# LMT01 0.5°C Accurate 2-Pin Digital Output Temperature Sensor with Pulse Count Interface

## 1 Features

- High Accuracy Over  $-50^{\circ}\text{C}$  to  $150^{\circ}\text{C}$  Wide Temperature Range
  - $-20^{\circ}\text{C}$  to  $90^{\circ}\text{C}$ :  $\pm 0.5^{\circ}\text{C}$  (max)
  - $90^{\circ}\text{C}$  to  $150^{\circ}\text{C}$ :  $\pm 0.62^{\circ}\text{C}$  (max)
  - $-50^{\circ}\text{C}$  to  $-20^{\circ}\text{C}$ :  $\pm 0.7^{\circ}\text{C}$  (max)
- Precision Digital Temperature Measurement Simplified in a 2-Pin Package
- Single-wire Pulse Count Digital Output Easily Read with Processor Timer Input
- Number of Output Pulses is Proportional to Temperature with  $0.0625^{\circ}\text{C}$  Resolution
- Communication Frequency: 88 kHz
- Continuous Conversion Plus Data-Transmission Period: 100 ms
- Conversion Current:  $34\ \mu\text{A}$
- Floating 2 V to 5.5 V (VP–VN) Supply Operation with Integrated EMI Immunity
- 2-Pin Package Offering TO-92/LPG (3.1 mm × 4 mm × 1.5 mm) –  $\frac{1}{2}$  the Size of Traditional TO-92

## 2 Applications

- Digital Output Wired Probes
- White Goods
- HVAC
- Power Supplies
- Industrial Internet of Things (IoT)
- Automotive
- Battery Management

## 3 Description

The LMT01 is a high-accuracy, 2-pin temperature sensor with an easy-to-use pulse count interface which makes it an ideal digital replacement for PTC or NTC thermistors both on and off board in automotive, industrial, and consumer markets. The LMT01 digital pulse count output and high accuracy over a wide temperature range allow pairing with any MCU without concern for integrated ADC quality or availability, while minimizing software overhead. TI's LMT01 achieves flat  $\pm 0.5^{\circ}\text{C}$  accuracy with very fine resolution ( $0.0625^{\circ}\text{C}$ ) over a wide temperature range of  $-20^{\circ}\text{C}$  to  $90^{\circ}\text{C}$  without system calibration or hardware/software compensation.

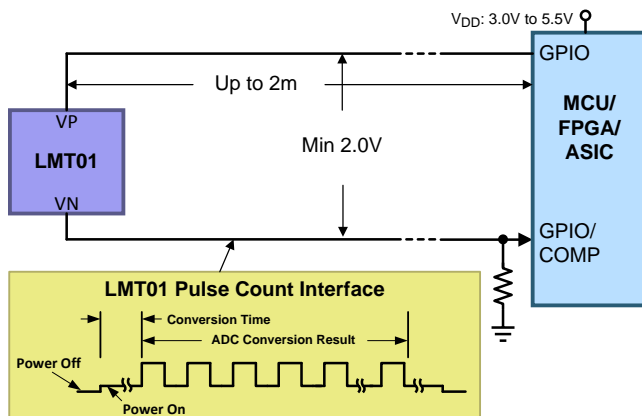
Unlike other digital IC temperature sensors, LMT01's single wire interface is designed to directly interface with a GPIO or comparator input, thereby simplifying hardware implementation. Similarly, the LMT01's integrated EMI suppression and simple 2-pin architecture makes it ideal for on-board and off-board temperature sensing. The LMT01 offers all the simplicity of analog NTC or PTC thermistors with the added benefits of a digital interface, wide specified performance, EMI immunity, and minimum processor resources.

### Device Information

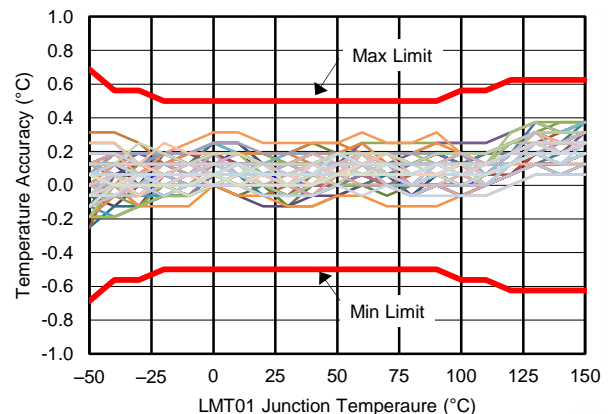
PART NUMBER	PACKAGE	BODY SIZE (NOM)
LMT01	TO-92 / LPG (2)	4.00 mm × 3.15 mm

- For all available packages, see the orderable addendum at the end of the data sheet.

### 2-Pin IC Temperature Sensor



### LMT01 Accuracy



Typical units plotted in center of curve.



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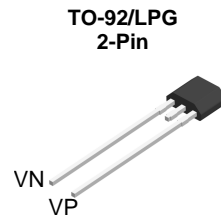
## 4 Revision History

### Changes from Original (June 2015) to Revision A

Page

• Added full datasheet. ....	<b>1</b>
• Added clarification note. ....	<b>1</b>

## 5 Pin Configuration and Functions



**Table 1. Pin Functions**

PIN NAME	I/O	DESCRIPTION
VP	Input	Positive voltage pin - may be connected to system power supply or bias resistor
VN	Output	Negative voltage pin - may be connected to system ground or a bias resistor

## 6 Specifications

### 6.1 Absolute Maximum Ratings <sup>(1)(2)</sup>

	MIN	MAX	UNIT
Voltage drop (VP-VN)	-0.3V	6V	V
Storage temperature range, T <sub>stg</sub>	-65	175°C	°C

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) Soldering process must comply with Reflow Temperature Profile specifications. Refer to [www.ti.com/packaging](http://www.ti.com/packaging).

### 6.2 ESD Ratings

		VALUE	UNIT
V <sub>(ESD)</sub> Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>	±2000	V
	Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup>	±750	

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

### 6.3 Recommended Operating Conditions

	MIN	NOM	MAX	UNIT
Free-air temperature range	-50		150	°C
Voltage drop range (VP-VN)	2.0		5.5	V

### 6.4 Thermal Information

THERMAL METRIC <sup>(1)</sup>		LMT01 TO-92/LPG 2 PINS	UNIT
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	177	°C/W
R <sub>θJC(top)</sub>	Junction-to-case (top) thermal resistance	94	
R <sub>θJB</sub>	Junction-to-board thermal resistance	152	
ψ <sub>JT</sub>	Junction-to-top characterization parameter	33	
ψ <sub>JB</sub>	Junction-to-board characterization parameter	152	
	Stirred Oil thermal response time to 63% of final value	0.8	sec
	Still air thermal response time to 63% of final value	28	sec

- (1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](http://www.ti.com/lit/zip/Spra953).

## 6.5 Electrical Characteristics

Over operating free-air temperature range and operating VP-VN range (unless otherwise noted).

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>ACCURACY</b>						
Temperature accuracy <sup>(1)(2)</sup>	VP-VN of 2.15 V to 5.5 V	150°C	-0.625		0.625	°C
		120°C	-0.625		0.625	°C
		110°C	-0.5625		0.5625	°C
		100°C	-0.5625		0.5625	°C
		90°C	-0.5		0.5	°C
		25°C	-0.5	±0.125	0.5	°C
		-20°C	-0.5		0.5	°C
		-30°C	-0.5625		0.5625	°C
		-40°C	-0.625		0.625	°C
		-50°C	-0.6875		0.6875	°C
<b>PULSE COUNT TRANSFER FUNCTION</b>						
	Number of pulses at 0°C		800	808	816	
	Output pulse range		15		3228	
		Theoretical max (exceeds device rating)	1		4095	
	Resolution of one pulse			0.0625		°C
<b>OUTPUT CURRENT</b>						
I <sub>OL</sub>	Output current variation	Low level	28	34	39	µA
I <sub>OH</sub>		High level	112.5	125	143	µA
	High to Low level output current ratio		3.1	3.7	4.5	
<b>POWER SUPPLY</b>						
	Accuracy sensitivity to change in VP-VN	2.15 V ≤ VP-VN ≤ 5.0 V <sup>(3)</sup>		40	133	m°C/V
	Leakage Current VP-VN	VDD ≤ 0.4 V		0.002	1	µA

- (1) Calculated using Pulse Count to Temperature LUT and 0.0625°C resolution per pulse, see section [Electrical Characteristics - Pulse Count to Temperature LUT](#).
- (2) Error can be linearly interpolated between temperatures given in table as shown in the Accuracy vs Temperature curves in section [Typical Characteristics](#).
- (3) Limit is using end point calculation.

## 6.6 Electrical Characteristics - Pulse Count to Temperature LUT

Over operating free-air temperature range and operating VP-VN range (unless otherwise noted). LUT is short for Look-up Table.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Digital output code	-50°C	15	26	37	pulses
	-40°C	172	181	190	
	-30°C	329	338	347	
	-20°C	486	494	502	
	-10°C	643	651	659	
	0°C	800	808	816	
	10°C	958	966	974	
	20°C	1117	1125	1133	
	30°C	1276	1284	1292	
	40°C	1435	1443	1451	
	50°C	1594	1602	1610	
	60°C	1754	1762	1770	
	70°C	1915	1923	1931	
	80°C	2076	2084	2092	
	90°C	2237	2245	2253	
	100°C	2398	2407	2416	
	110°C	2560	2569	2578	
120°C	2721	2731	2741		
130°C	2883	2893	2903		
140°C	3047	3057	3067		
150°C	3208	3218	3228		

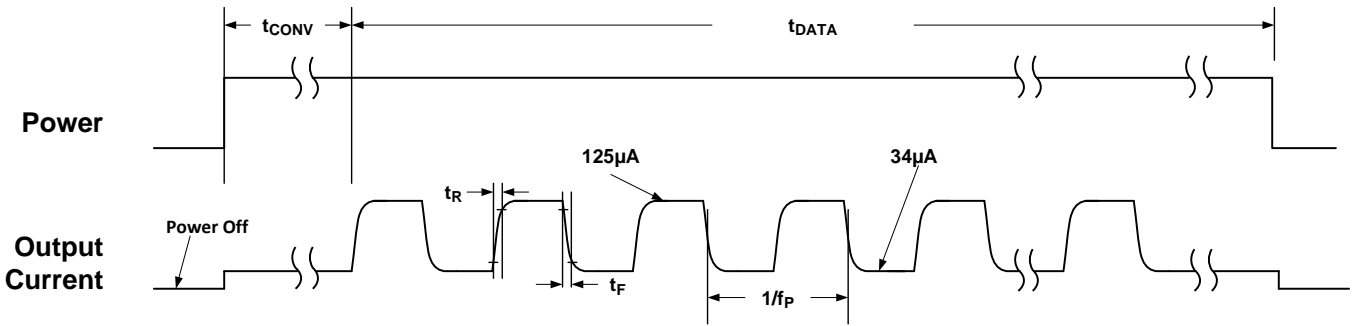
## 6.7 Switching Characteristics

Over operating free-air temperature range and operating VP-VN range (unless otherwise noted).

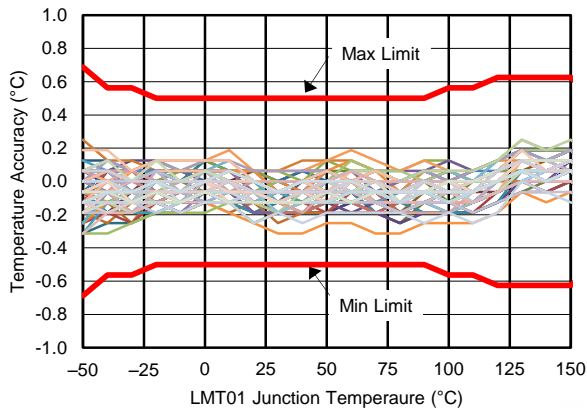
PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
$t_R, t_F$	Output current rise and fall time CL=10 pF, RL=8 k		1.45		$\mu$ s
$f_P$	Output current pulse frequency	82	88	94	kHz
	Output current duty cycle	40%	50%	60%	
$t_{CONV}$	Temperature conversion time <sup>(1)</sup>	46	50	54	ms
$t_{DATA}$	Data transmission time	44	47	50	ms

(1) Conversion time includes power up time or device turn on time that is typically 3 ms after POR threshold of 1.2V is exceeded.

### 6.8 Timing Specification Waveform

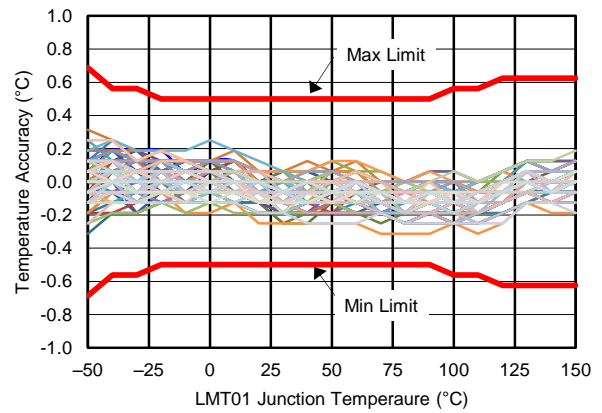


### 6.9 Typical Characteristics



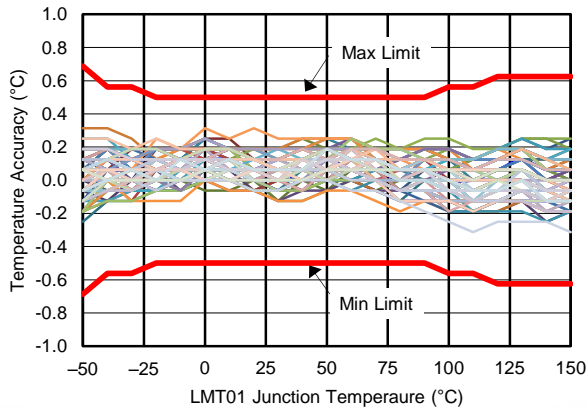
Using [Electrical Characteristics - Pulse Count to Temperature LUT](#)  
VP - VN = 2.15 V

Figure 1. Accuracy vs LMT01 Junction Temperature



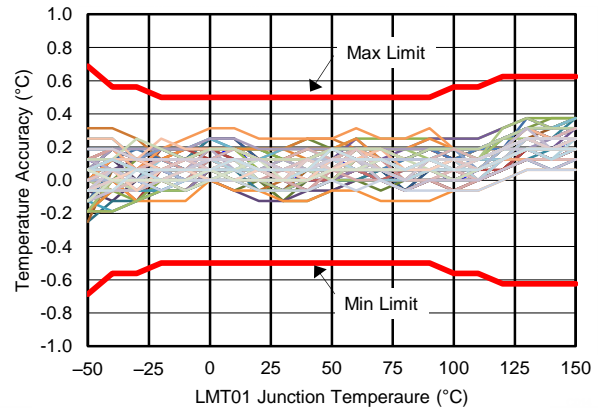
Using [Electrical Characteristics - Pulse Count to Temperature LUT](#)  
VP - VN = 2.4 V

Figure 2. Accuracy vs LMT01 Junction Temperature



Using [Electrical Characteristics - Pulse Count to Temperature LUT](#)  
VP - VN = 2.7 V

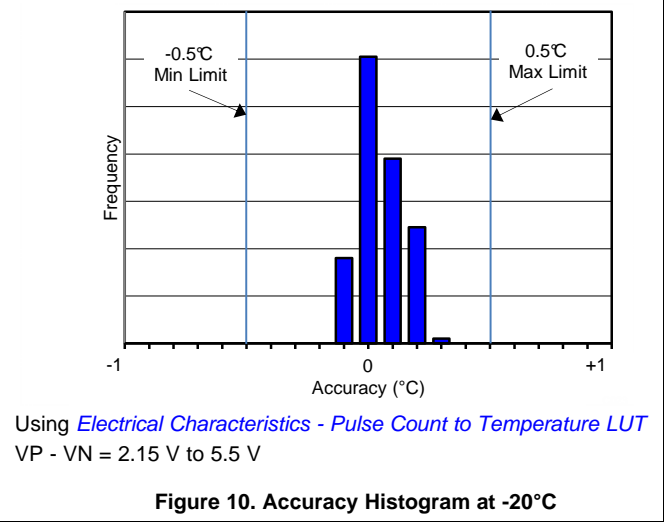
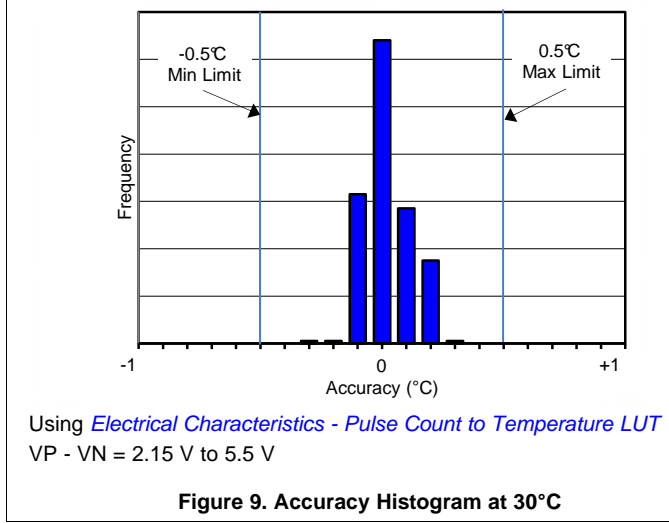
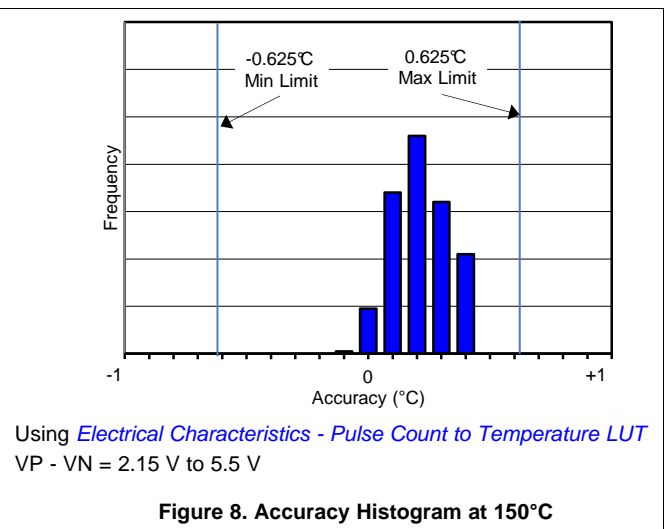
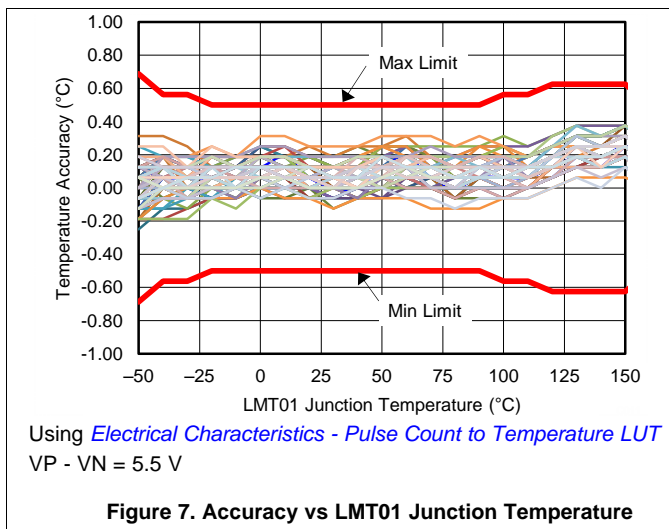
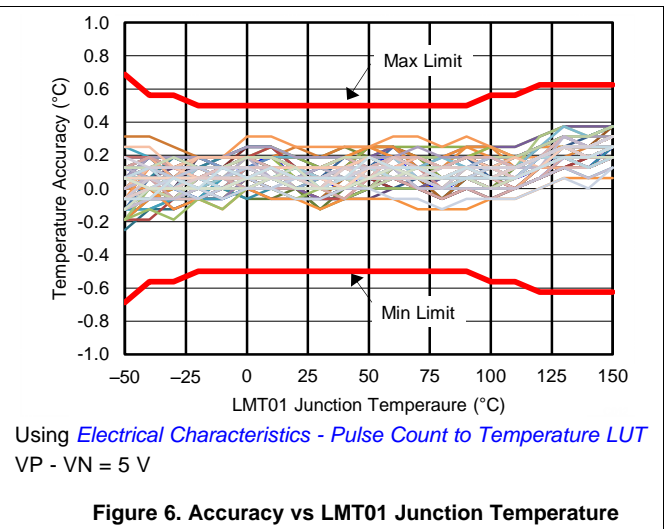
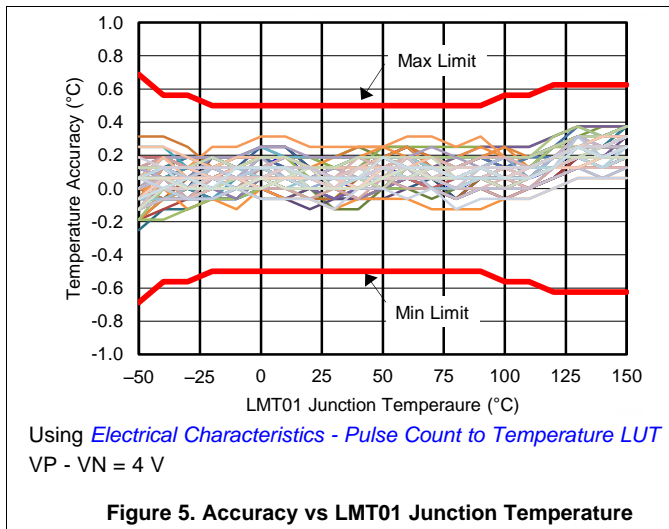
Figure 3. Accuracy vs LMT01 Junction Temperature



Using [Electrical Characteristics - Pulse Count to Temperature LUT](#)  
VP - VN = 3 V

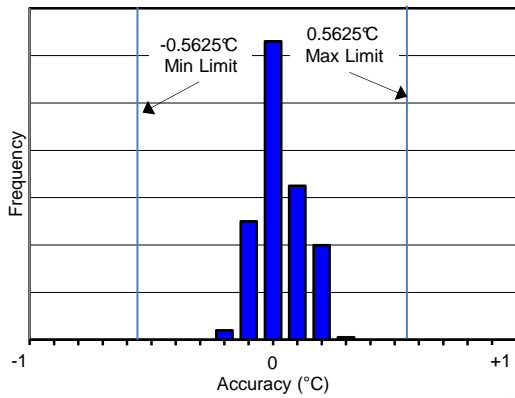
Figure 4. Accuracy vs LMT01 Junction Temperature

Typical Characteristics (continued)



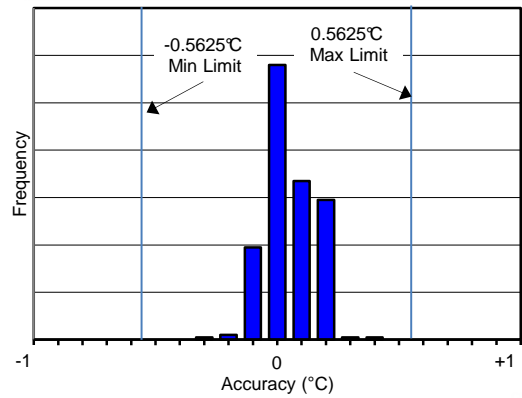


Typical Characteristics (continued)



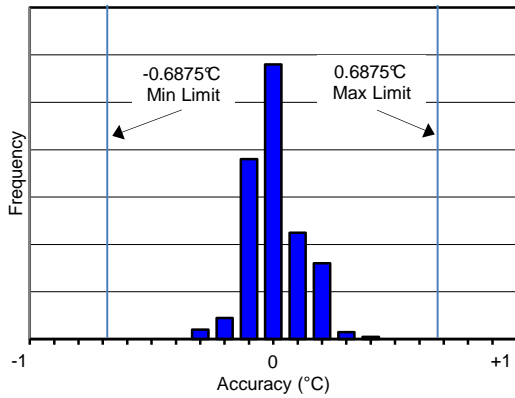
Using LUT *Electrical Characteristics - Pulse Count to Temperature LUT*  
 VP - VN = 2.15 V to 5.5 V

Figure 11. Accuracy Histogram at -30°C



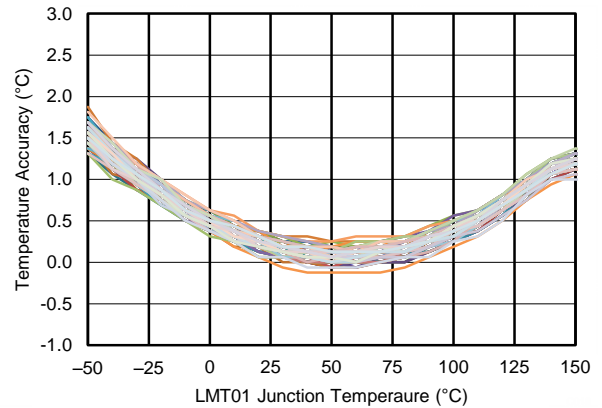
Using *Electrical Characteristics - Pulse Count to Temperature LUT*  
 VP - VN = 2.15 V to 5.5 V

Figure 12. Accuracy Histogram at -40°C



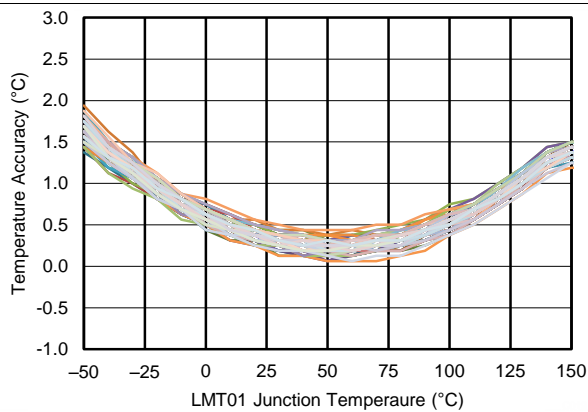
Using LUT *Electrical Characteristics - Pulse Count to Temperature LUT*  
 VP - VN = 2.15 V to 5.5 V

Figure 13. Accuracy Histogram at -50°C



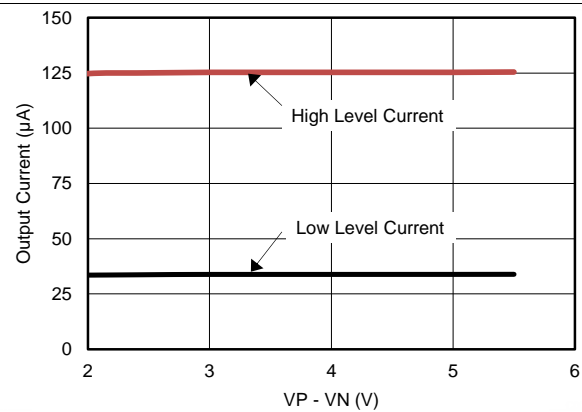
Using  $Temp = (PC/4096 \times 256^\circ C) - 50^\circ C$   
 VP - VN = 2.15 V

Figure 14. Accuracy Using Linear Transfer Function



Using  $Temp = (PC/4096 \times 256^\circ C) - 50^\circ C$   
 VP - VN = 5.5V

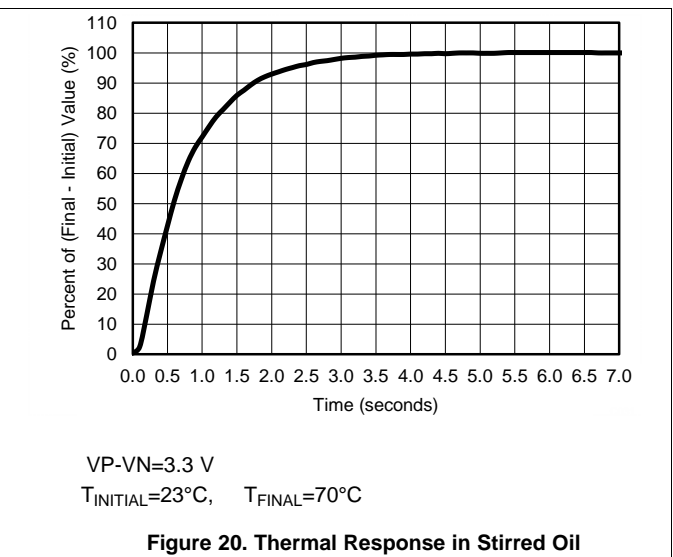
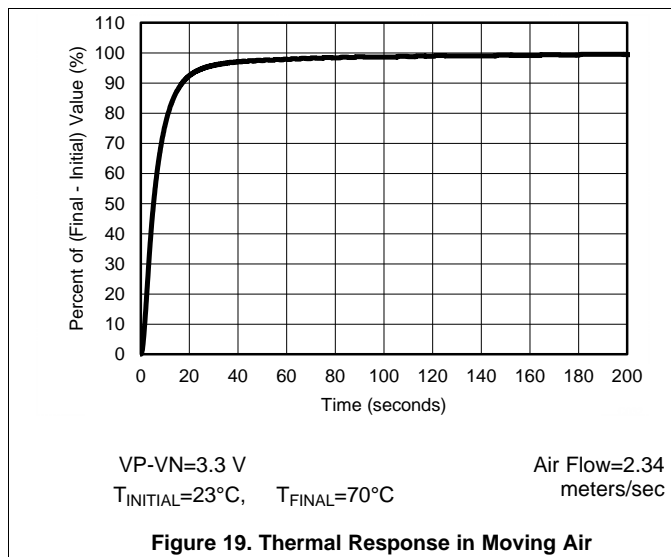
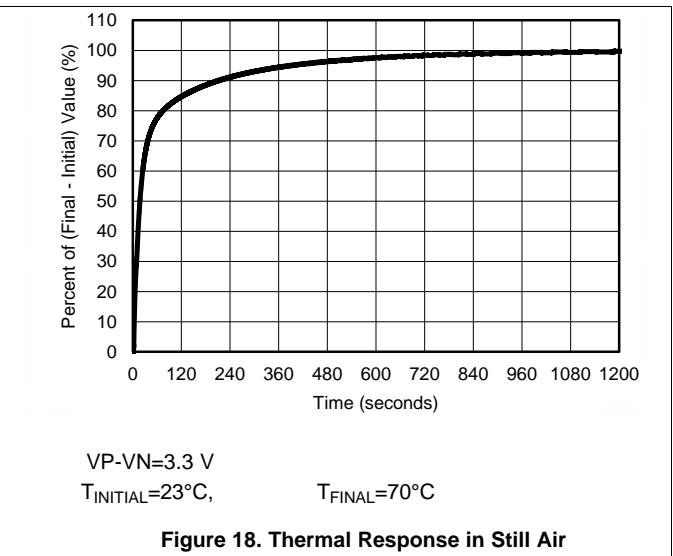
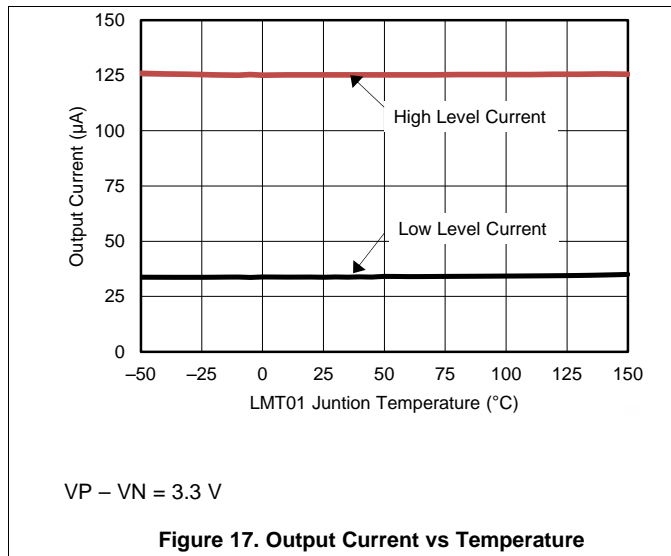
Figure 15. Accuracy Using Linear Transfer Function



T<sub>A</sub> = 30°C

Figure 16. Output Current vs VP-VN Voltage

Typical Characteristics (continued)



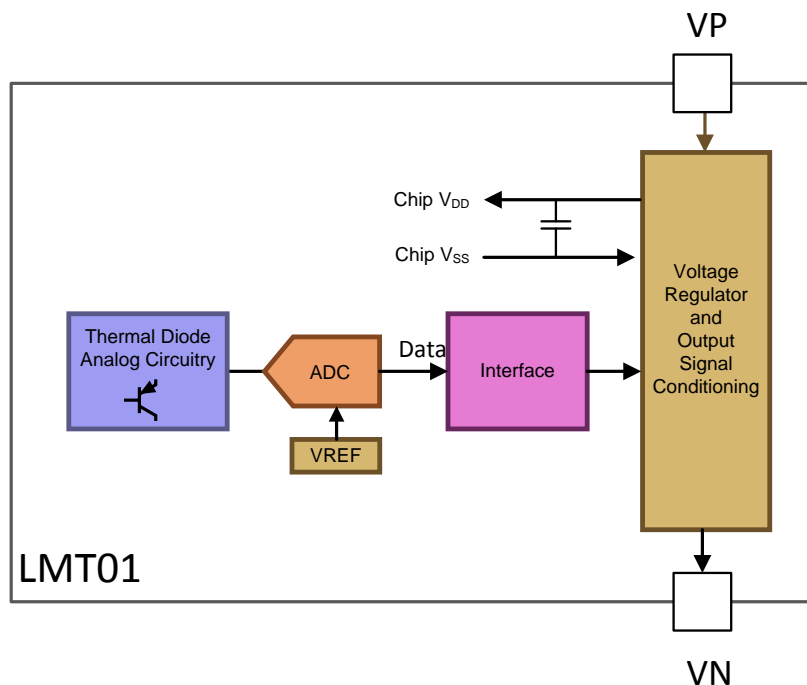
## 7 Detailed Description

### 7.1 Overview

The LMT01 temperature output is transmitted over a single wire using a train of current pulses that typically change from 34  $\mu\text{A}$  to 125  $\mu\text{A}$ . A simple resistor can then be used to convert the current pulses to a voltage. With a 10 k $\Omega$  the output voltage levels range from 340 mV to 1.25 V, typically. A simple microcontroller comparator or external transistor can be used convert this signal to valid logic levels the microcontroller can process properly through a GPIO pin. The temperature can be determined by gating a simple counter on for a specific time interval to count the total number of output pulses. After power is first applied to the device the current level will remain below 34  $\mu\text{A}$  for at most 54ms while the LMT01 is determining the temperature. Once the temperature is determined the pulse train will begin. The individual pulse frequency is typically 88 kHz. The LMT01 will continuously convert and transmit data when the power is applied approximately every 104 ms (max).

The LMT01 uses thermal diode analog circuitry to detect the temperature. The temperature signal is then amplified and applied to the input of a  $\Sigma\Delta$  ADC that is driven by an internal reference voltage. The  $\Sigma\Delta$  ADC output is then processed through the interface circuitry into a digital pulse train. The digital pulse train is then converted to a current pulse train by the output signal conditioning circuitry that includes high and low current regulators. The voltage applied across the LMT01's pins is regulated by an internal voltage regulator to provide a consistent Chip  $V_{DD}$  that is used by the ADC and its associated circuitry.

### 7.2 Functional Block Diagram



### 7.3 Feature Description

#### 7.3.1 Output Interface

The LMT01 provides a digital output in the form of a pulse count that is transmitted by a train of current pulses. After the LMT01 is powered up it will transmit a very low current of 34  $\mu\text{A}$  for less than 54 ms while the part executes a temperature to digital conversion, as shown in [Figure 21](#). Once the temperature to digital conversion has completed the LMT01 will start to transmit a pulse train that toggles from the low current of 34  $\mu\text{A}$  to a high current level of 125  $\mu\text{A}$ . The pulse train total time interval is at maximum 50 ms. The LMT01 will transmit a series

### Feature Description (continued)

of pulses equivalent to the pulse count at a given temperature as described in [Electrical Characteristics - Pulse Count to Temperature LUT](#). After the pulse count has been transmitted the LMT01 current level will remain low for the remainder of the 50 ms. The total time for the temperature to digital conversion and the pulse train time interval is 104 ms (max). If power is continuously applied the pulse train output will repeat start every 104 ms (max).

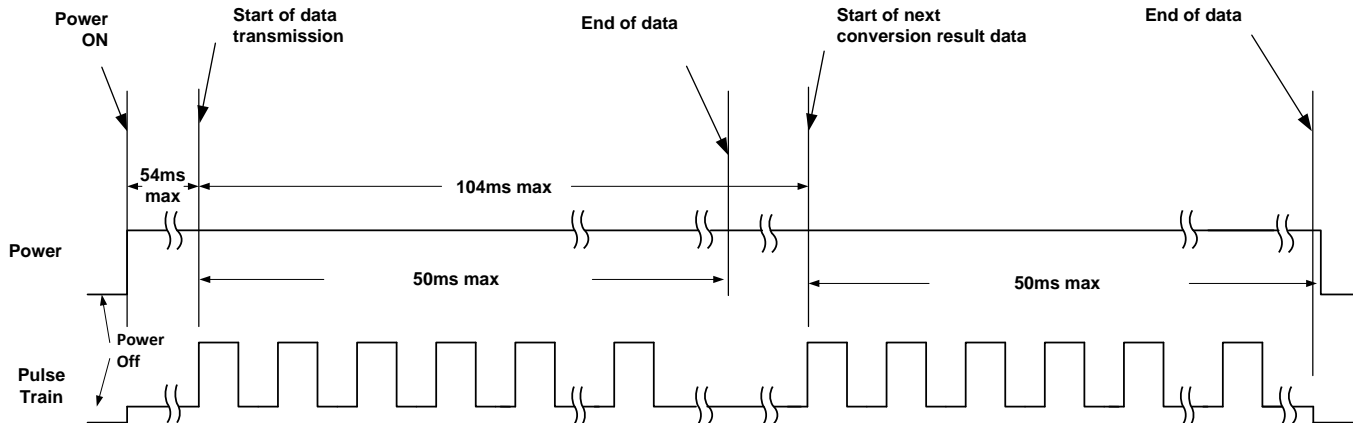


Figure 21. Temperature to digital pulse train timing cycle

The LMT01 can be powered down at any time thus conserving system power. Care should be taken though, that a power down wait time of 50ms, minimum, be used before the device is turned on again.

### 7.3.2 Output Transfer Function

The LMT01 will output at minimum 1 pulse and a theoretical maximum 4095 pulses. Each pulse has a weight of 0.0625°C. One pulse corresponds to a temperature less than -50°C while a pulse count of 4096 corresponds to a temperature greater than 200°C. Note that the LMT01 is only guaranteed to operate up to 150°C. Exceeding this temperature by more than 5°C may damage the device. The accuracy of the device degrades as well when 150°C is exceeded.

Two different methods of converting the pulse count to a temperature value will be discussed in this section. The first method that will be discussed is the least accurate and uses a first order equation. The second method is the most accurate and uses linear interpolation of the values found in the look-up table (LUT) as described in [Electrical Characteristics - Pulse Count to Temperature LUT](#).

The output transfer function appears to be linear and can be approximated by the following first order equation:

$$\text{Temp} = \left( \frac{\text{PC}}{4096} \times 256^\circ\text{C} \right) - 50^\circ\text{C}$$

where

- PC is the Pulse Count
- Temp is the temperature reading

(1)

Table 2 shows some sample calculations using [Equation 1](#)

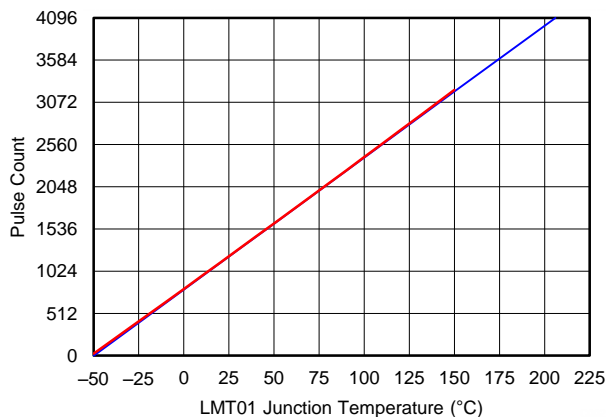
Table 2. Sample Calculations Using Equation 1

TEMPERATURE (°C)	NUMBER OF PULSES
-49.9375	1
-49.875	2
-20	480
0	800
30	1280
50	1600

**Table 2. Sample Calculations Using Equation 1 (continued)**

TEMPERATURE (°C)	NUMBER OF PULSES
100	2400
150	3200
205.9375	4095

The curve shown in Figure 22 shows the output transfer function using equation Equation 1 (blue line) and the look-up table (LUT) found in *Electrical Characteristics - Pulse Count to Temperature LUT* (red line). The LMT01 output transfer function as described by the LUT appears to be linear, but upon close inspection it can be seen that it truly is not linear. To actually see the difference, the accuracy obtained by the two methods must be compared.


**Figure 22. LMT01 Output Transfer Function**

For more exact temperature readings the output pulse count can be converted to temperature using linear interpolation of the values found in *Electrical Characteristics - Pulse Count to Temperature LUT* and repeated here for convenience.

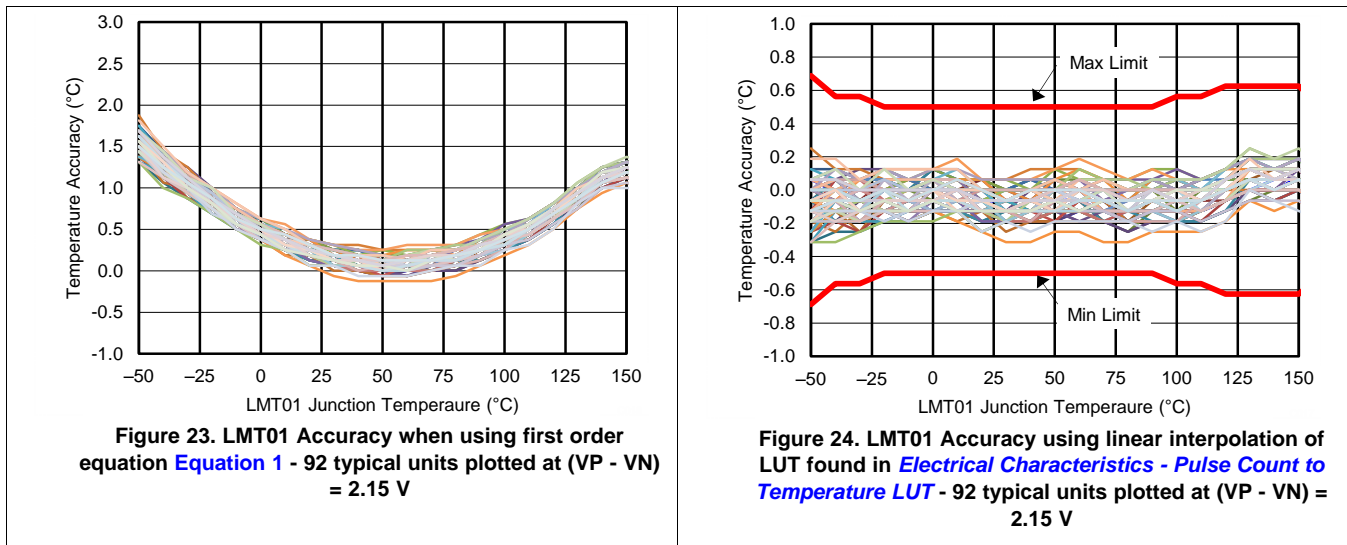
**Table 3. Pulse Count to Temperature Look-up Table**

TEMPERATURE (°C)	PULSE COUNT		
	MINIMUM	TYPICAL	MAXIMUM
-50	15	26	37
-40	172	181	190
-30	329	338	347
-20	486	494	502
-10	643	651	659
0	800	808	816
10	958	966	974
20	1117	1125	1133
30	1276	1284	1292
40	1435	1443	1451
50	1594	1602	1610
60	1754	1762	1770
70	1915	1923	1931
80	2076	2084	2092
90	2237	2245	2253
100	2398	2407	2416
110	2560	2569	2578
120	2721	2731	2741

**Table 3. Pulse Count to Temperature Look-up Table (continued)**

TEMPERATURE (°C)	PULSE COUNT		
	MINIMUM	TYPICAL	MAXIMUM
130	2883	2893	2903
140	3047	3057	3067
150	3208	3218	3228

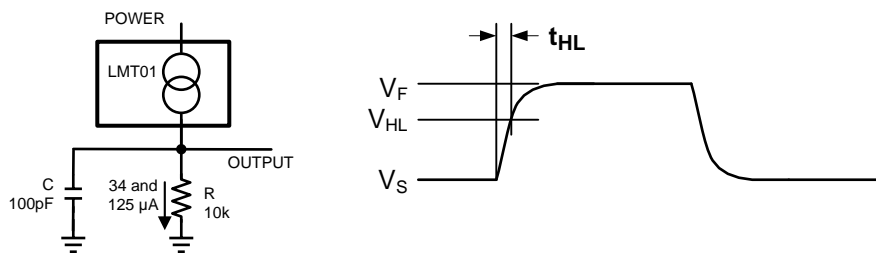
The curves in [Figure 23](#) and [Figure 24](#), show the accuracy of typical units when using the [Equation 1](#) and linear interpolation using [Electrical Characteristics - Pulse Count to Temperature LUT](#), respectively. When compared, the improved performance when using the LUT linear interpolation method can clearly be seen. For a limited temperature range of 25°C to 80°C the error shown in [Figure 23](#) is flat and thus the linear equation will provide good results. For a wide temperature range it is recommended that linear interpolation and the LUT be used.



### 7.3.3 Current Output Conversion to Voltage

The minimum voltage drop across the LMT01 must be maintained at 2.15 V during the conversion cycle. After the conversion cycle the minimum voltage drop can decrease to 2.0 V. Thus the LMT01 can be used for low voltage applications. See Application Information section on low voltage operation and other information on picking the actual resistor value for different applications conditions. The resistor value is dependent on the power supply level and its variation and the threshold level requirements of the circuitry it's driving (i.e. MCU GPIO or Comparator).

Stray capacitance can be introduced when connecting the LMT01 through a long wire. This stray capacitance will influence the signal rise and fall times. The wire inductance has negligible effect on the AC signal integrity. A simple RC time constant model as shown in [Figure 25](#) can be used to determine the rise and fall times.



**Figure 25. Simple RC Model for Rise and Fall Times**

$$t_{HL} = R \times C \times \ln \left( \frac{V_F - V_S}{V_F - V_{HL}} \right)$$

where

- RC as shown in [Figure 25](#)
  - $V_{HL}$  is the target high level
  - the final voltage  $V_F = 125 \mu\text{A} \times R$
  - the start voltage  $V_S = 34 \mu\text{A} \times R$
- (2)

For the 10% to 90% level rise time ( $t_r$ ), [Equation 2](#) simplifies to:

$$t_r = R \times C \times 2.197$$
(3)

Care should be taken to ensure under reverse bias conditions that the LMT01 voltage drop does not exceed 300mV, as given in the Absolute Maximum Ratings.

## 7.4 Device Functional Modes

The only functional mode the LMT01 has is that it provides a pulse count output that is directly proportional to temperature.

## 8 Application and Implementation

### NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 8.1 Application Information

#### 8.1.1 Mounting, Temperature Conductivity and Self Heating

The LMT01 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface to ensure good temperature conductivity. The temperatures of the lands and traces to the leads of the LMT01 will also affect the temperature reading so they should be as thin as possible.

Alternatively, the LMT01 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LMT01 and accompanying wiring and circuits must be kept insulated and dry, to avoid excessive leakage and corrosion. Printed-circuit coatings are often used to ensure that moisture cannot corrode the leads or circuit traces.

The LMT01's junction temperature is the actual temperature being measured by the device. The thermal resistance junction-to-ambient ( $R_{\theta JA}$ ) is the parameter (from

[Thermal Information](#)) used to calculate the rise of a device junction temperature (self heating) due to its average power dissipation. The average power dissipation of the LMT01 is dependent on the temperature it is transmitting as it effects the output pulse count and the voltage across the device. [Equation 4](#) is used to calculate the self heating in the LMT01's die temperature ( $T_{SH}$ ).

$$T_{SH} = \left[ I_{OL} \times \frac{t_{CONV}}{(t_{CONV} + t_{DATA})} \times V_{CONV} \right] + \left[ \left( \frac{PC}{4096} \times \frac{(I_{OL} + I_{OH})}{2} \right) + \left( \frac{(4096 - PC)}{4096} \times I_{OL} \right) \right] \times \frac{t_{DATA}}{(t_{CONV} + t_{DATA})} \times V_{DATA} \times R_{\theta JA}$$

where

- $T_{SH}$  is the ambient temperature,
- $I_{OL}$  and  $I_{OH}$  are the output low and high current level respectively,
- $V_{CONV}$  is the voltage across the LMT01 during conversion,
- $V_{DATA}$  is the voltage across the LMT01 during data transmission,
- $t_{CONV}$  is the conversion time,
- $t_{DATA}$  is the data transmission time,
- PC is the output pulse count,
- $R_{\theta JA}$  is the junction to ambient package thermal resistance (4)

Plotted in the curve [Figure 26](#) are the typical average supply current (black line using left y axis) and the resulting self heating (red and violet lines using right y axis) during continuous conversions. A temperature range of  $-50^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ , a  $V_{CONV}$  of 5 V (red line) and 2.15 V (violet line) were used for the self heating calculation. As can be seen in the curve the average power supply current and thus the average self heating changes linearly over temperature because the number of pulses increases with temperature. A negligible self heating of about  $45\text{m}^{\circ}\text{C}$  is observed at  $150^{\circ}\text{C}$  with continuous conversions. If temperature readings are not required as frequently as every 100ms, self heating can be minimized by shutting down power to the part periodically thus lowering the average power dissipation.



## Application Information (continued)

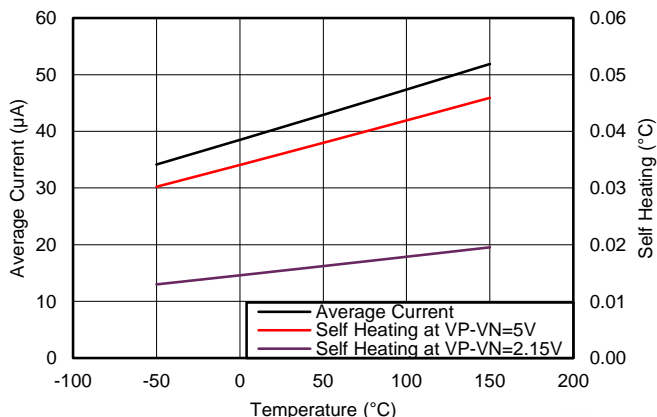


Figure 26. Average current draw and self heating over temperature

## 8.2 Typical Applications

### 8.2.1 3.3V System VDD MSP430 Interface - Using Comparator Input

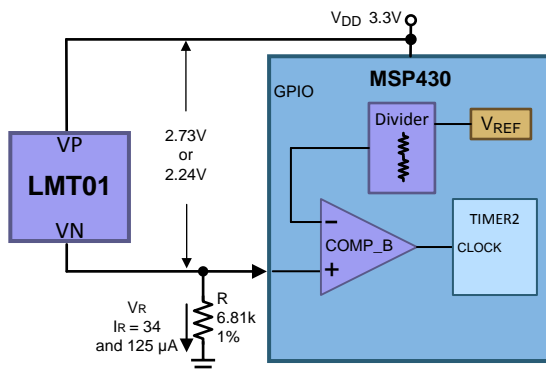


Figure 27. MSP430 Comparator Input Implementation

#### 8.2.1.1 Design Requirements

The following design requirements will be used in the detailed design procedure.

VDD	3.3 V
VDD minimum	3.0 V
LMT01 VP – VN minimum during conversion	2.15 V
LMT01 VP – VN minimum during data transmission	2.0 V
Noise margin	50 mV min
Comparator input current over temperature range of interest	< 1 µA
Resistor tolerance	1%

#### 8.2.1.2 Detailed Design Procedure

First select the R and determine the maximum logic low voltage and the minimum logic high voltage while ensuring, that when the LMT01 is converting, the minimum (VP - VN) requirement of 2.15 V is met.

1. Select R using minimum VP-VN during data transmission (2 V) and maximum output current of the LMT01 (143.75 µA)

- $R = (3.0\text{ V} - 2\text{ V}) / 143.75\ \mu\text{A} = 6.993\text{ k}$  the closest 1% resistor is 6.980 k
- 6.993 k is the maximum resistance so if using 1% tolerance resistor the actual resistor value needs to be 1% less than 6.993 k and 6.98 k is 0.2% less than 6.993 k thus 6.81 k should be used.
- 2. Check to see if the LMT01's 2.15 V minimum voltage during conversion requirement is met with maximum  $I_{OL}$  of 39  $\mu\text{A}$  and maximum R of 6.81 k + 1%:
  - $V_{LMT01} = 3\text{ V} - (6.81\text{ k} \times 1.01) \times 39\ \mu\text{A} = 2.73\text{ V}$
- 3. Find the maximum low level voltage range using maximum R of 6.81k and maximum  $I_{OL}$  39  $\mu\text{A}$ :
  - $V_{RLmax} = (6.81\text{ k} \times 1.01) \times 39\ \mu\text{A} = 268\text{ mV}$
- 4. Find the minimum high level voltage using the minimum R of 6.81k and minimum  $I_{OH}$  of 112.5  $\mu\text{A}$ :
  - $V_{RHmin} = (6.81\text{ k} \times 0.99) \times 112.5\ \mu\text{A} = 758\text{ mV}$

Now select the MSP430 comparator threshold voltage that will enable the LMT01 to communicate to the MSP430 properly.

1. The MSP430 voltage will be selected by selecting the internal  $V_{REF}$  and then choosing the appropriate 1 of n/32 settings for n of 1 to 31.
  - $V_{MID} = (V_{RLmax} - V_{RHmin}) / 2 + V_{RHmin} = (758\text{ mV} - 268\text{ mV}) / 2 + 268\text{ mV} = 513\text{ mV}$
  - $n = (V_{MID} / V_{REF}) \times 32 = (0.513 / 2.5) \times 32 = 7$
2. In order to prevent oscillation of the comparator output hysteresis needs to be implemented. The MSP430 allows this by enabling different n for rising edge and falling edge of the comparator output. Thus for a falling comparator output transition N should be set to 6.
3. Determine the noise margin caused by variation in comparator threshold level. Even though the comparator threshold level theoretically is set to  $V_{MID}$ , the actual level will vary from device to device due to  $V_{REF}$  tolerance, resistor divider tolerance, and comparator offset. For proper operation the COMP\_B worst case input threshold levels must be within the minimum high and maximum low voltage levels presented across R,  $V_{RHmin}$  and  $V_{RLmax}$  respectively

$$V_{CHmax} = V_{REF} \times (1 + V_{REF\_TOL}) \times \frac{(N + N\_TOL)}{32} + COMP\_OFFSET$$

where

- $V_{REF}$  is the MSP430 COMP\_B reference voltage for this example 2.5V,
- $V_{REF\_TOL}$  is the tolerance of the  $V_{REF}$  of 1% or 0.01,
- N is the divisor for the MSP430 or 7
- $N\_TOL$  is the tolerance of the divisor or 0.5
- $COMP\_OFFSET$  is the comparator offset specification or 10mV

(5)

$$V_{CLmin} = V_{REF} \times (1 - V_{REF\_TOL}) \times \frac{(N - N\_TOL)}{32} - COMP\_OFFSET$$

where

- $V_{REF}$  is the MSP430 COMP\_B reference voltage for this example 2.5V,
- $V_{REF\_TOL}$  is the tolerance of the  $V_{REF}$  of 1% or 0.01,
- N is the divisor for the MSP430 for the hysteresis setting or 6,
- $N\_TOL$  is the tolerance of the divisor or 0.5,
- $COMP\_OFFSET$  is the comparator offset specification or 10mV

(6)

The noise margin is the minimum of the two differences:

$$(V_{RHmin} - V_{CHmax}) \text{ OR } (V_{CHmin} - V_{RLmax}) \tag{7}$$

which works out to be 145 mV.

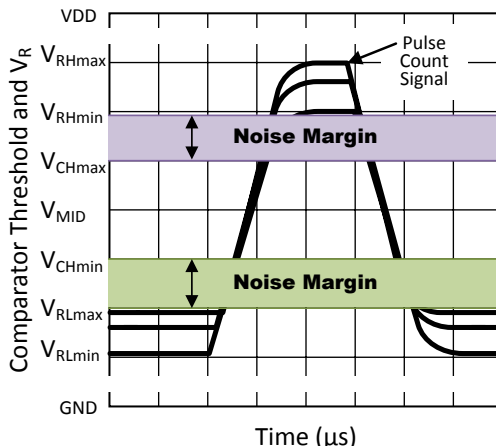
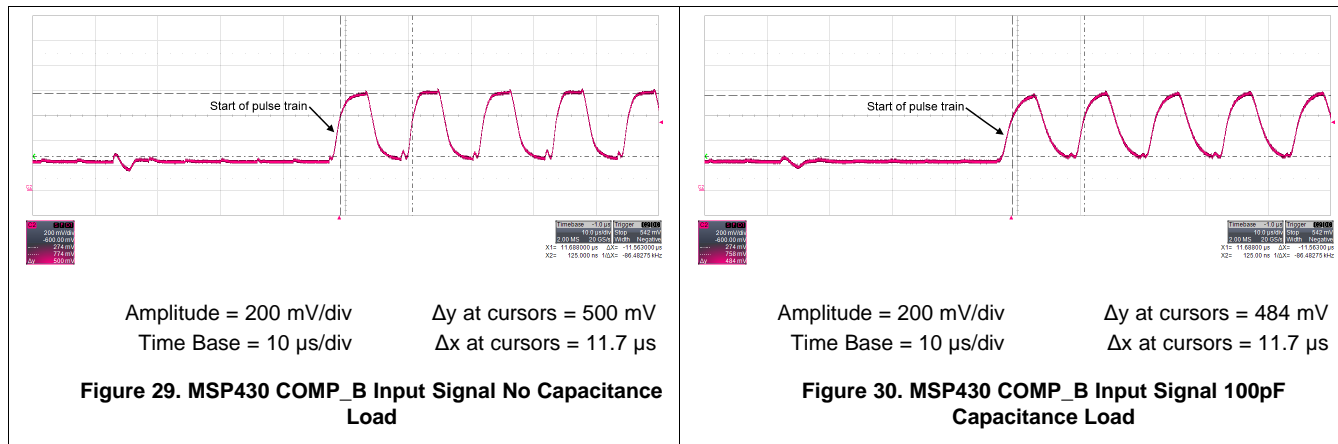


Figure 28. Pulse Count Signal Amplitude Variation

### 8.2.1.3 Setting the MSP430 Threshold and Hysteresis

The comparator hysteresis will determine the noise level that the signal can support without causing the comparator to trip falsely thus resulting in an inaccurate pulse count. The comparator hysteresis is set by the precision of the MSP430 and what thresholds it is capable of. For this case as the input signal transitions high the comparator threshold is dropped by 77 mV thus if the noise on the signal as it transitions is kept below this level the comparator will not trip falsely. In addition the MSP430 has a digital filter on the COMP\_B output that be used to further filter output transitions that occur too quickly.

### 8.2.1.4 Application Curves



### 8.3 System Examples

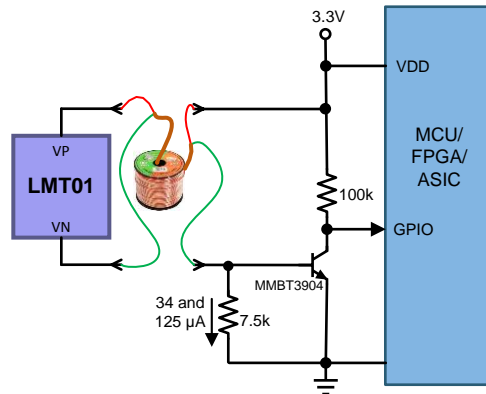


Figure 31. Transistor Level Shifting

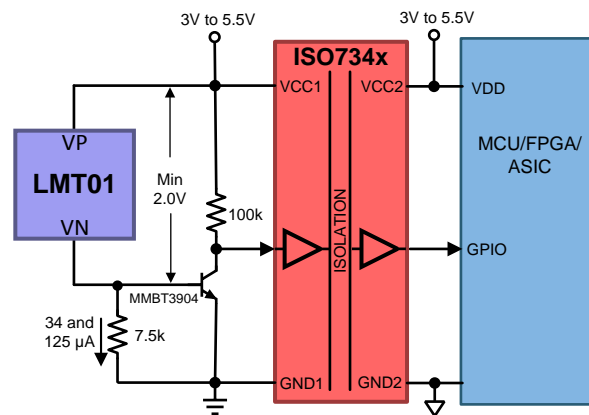
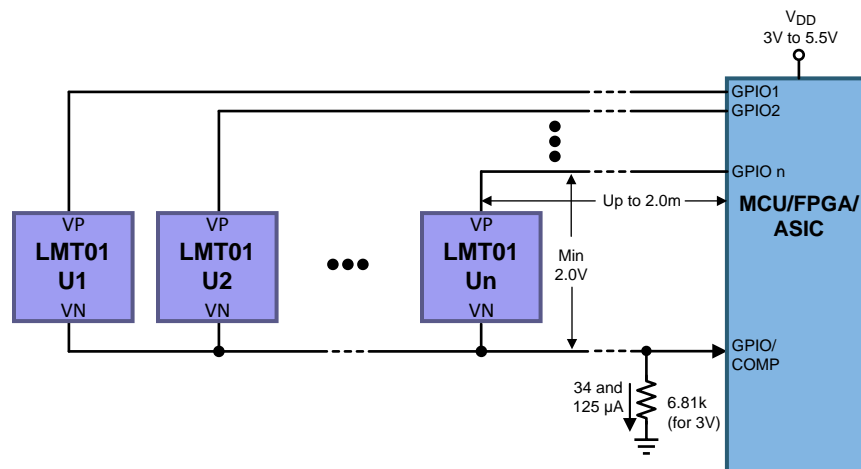


Figure 32. Isolation



Note: to turn off an LMT01 set the GPIO pin connected to VP to high impedance state as setting it low would cause the off LMT01 to be reverse biased.

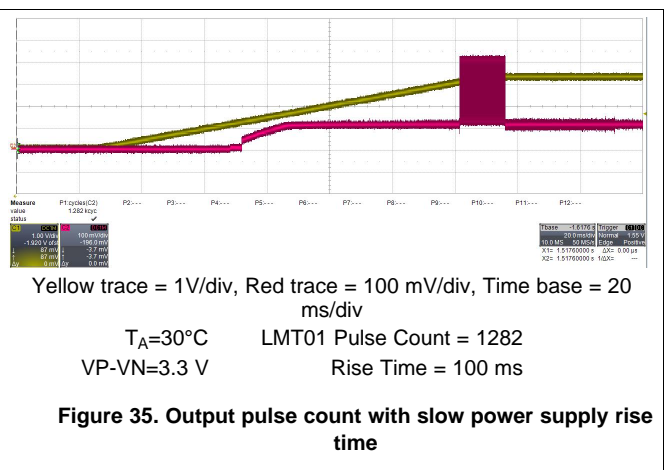
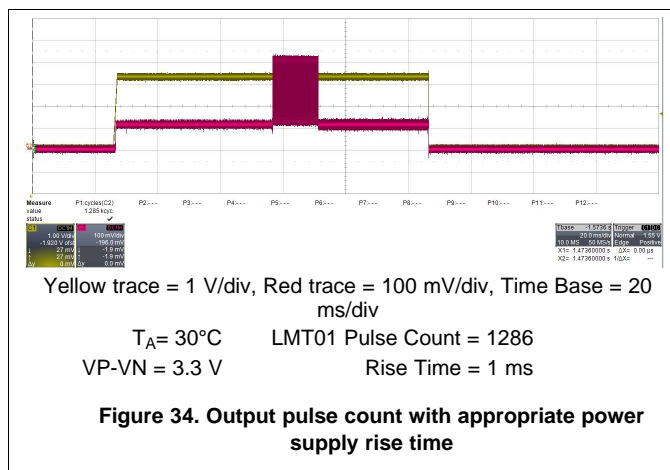
Figure 33. Connecting Multiple Devices to One MCU Input Pin

## 9 Power Supply Recommendations

Since the LMT01 is only a 2-pin device the power pins are common with the signal pins, thus the LMT01 has a floating supply that can vary greatly. The LMT01 has an internal regulator that provides a stable voltage to internal circuitry.

Care should be taken to prevent reverse biasing of the LMT01 as exceeding the absolute maximum ratings may cause damage to the device.

Power supply ramp rate can effect the accuracy of the first result transmitted by the LMT01. As shown in Figure 34 with a 1ms rise time the LMT01 output code is at 1286 which converts to 30.125°C. The scope photo shown in Figure 35 reflects what happens when the rise time is too slow. As can be seen the power supply (yellow trace) is still ramping up to final value while the LMT01 (red trace) has already started a conversion. This causes the output pulse count to decrease from the 1286, shown previously, to 1282 or 29.875°C. Thus, for slow ramp rates it is recommended that the first conversion be discarded. For even slower ramp rates more than one conversion may have to be discarded as it is recommended that either the power supply be within final value before a conversion is used or that ramp rates be faster than 2.5 ms.



## 10 Layout

### 10.1 Layout Guidelines

The LMT01 can be mounted to a PCB as shown in Figure 36. Care should be taken to make the traces leading to the LMT01's pads as small as possible in order to minimize their effect on the temperature the LMT01 is measuring.

### 10.2 Layout Example

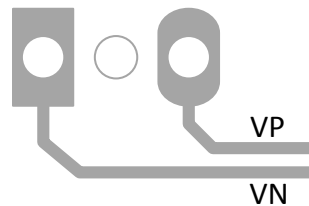


Figure 36.

## 11 Device and Documentation Support

### 11.1 Documentation Support

### 11.2 Community Resources

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### 11.3 Trademarks

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### 11.4 Electrostatic Discharge Caution



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

### 11.5 Glossary

[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

## 12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

**PACKAGING INFORMATION**

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LMT01LPG	ACTIVE	TO-92	LPG	2	1000	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type	-50 to 150	LMT01	<a href="#">Samples</a>
LMT01LPGM	ACTIVE	TO-92	LPG	2	3000	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type	-50 to 150	LMT01	<a href="#">Samples</a>

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

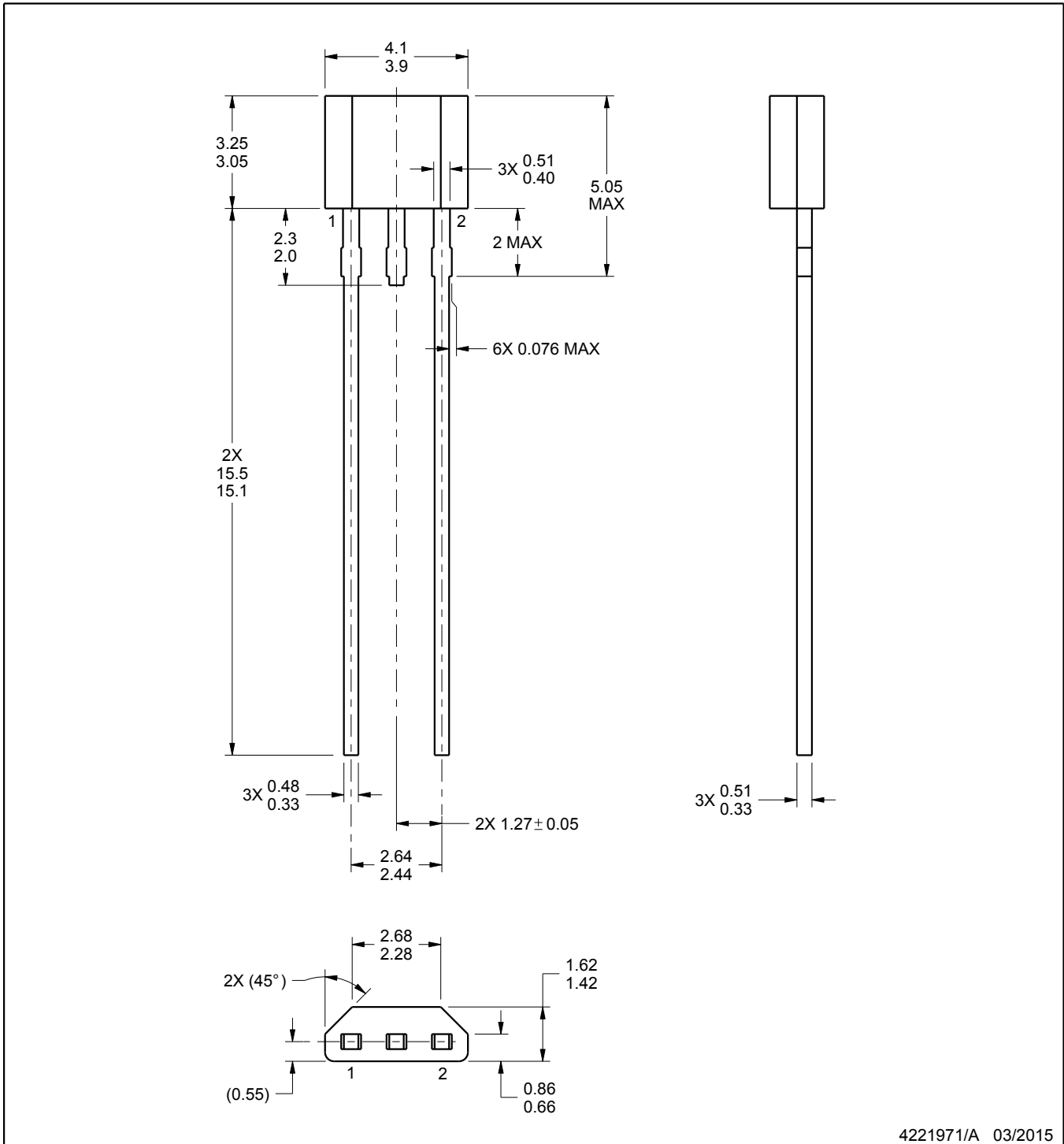
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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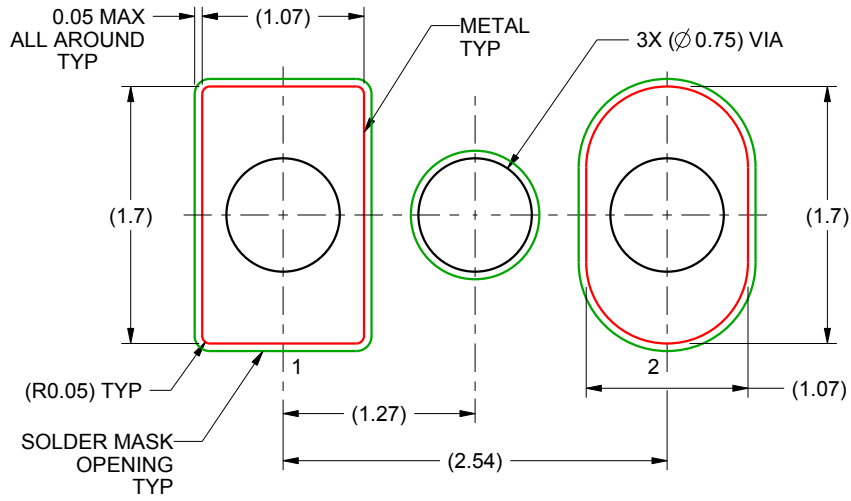
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.

# EXAMPLE BOARD LAYOUT

LPG0002A

TO-92 - 5.05 mm max height

TO-92



LAND PATTERN EXAMPLE  
NON-SOLDER MASK DEFINED  
SCALE:20X

4221971/A 03/2015

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DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
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### Applications

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Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
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Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
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