

LMT88 2.4V, 10µA, SC70, DSBGA Temperature Sensor

FEATURES

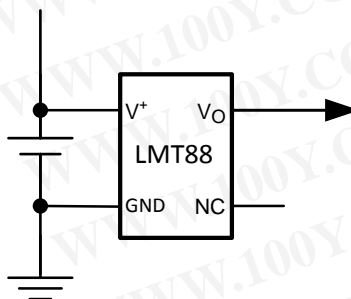
- Cost-Effective Alternative to Thermistors
- Rated for full -55°C to $+130^{\circ}\text{C}$ range
- Available in an SC70 Package
- Predictable Curvature Error
- Suitable for Remote Applications

APPLICATIONS

- Industrial
- HVAC
- Disk Drives
- Automotive
- Portable Medical Instruments
- Computers
- Battery Management
- Printers
- Power Supply Modules
- FAX Machines
- Mobile Phones
- Automotive

TYPICAL APPLICATION

Full-Range Celsius (Centigrade) Temperature Sensor (-55°C TO 130°C) Operating From a Single LI-Ion Battery Cell



$$V_O = (-3.88 \times 10^{-6} \times T^2) + (-1.15 \times 10^{-2} \times T) + 1.8639$$

$$T = -1481.96 + \sqrt{2.1962 \times 10^6 + \frac{(1.8639 - V_O)}{3.88 \times 10^{-6}}}$$

where: T is temperature, and V_O is the measured output voltage of the LMT88.

DESCRIPTION

The LMT88 is a precision analog output CMOS integrated-circuit temperature sensor that operates over a -55°C to 130°C temperature range. The power supply operating range is 2.4 V to 5.5 V. The transfer function of LMT88 is predominately linear, yet has a slight predictable parabolic curvature. The accuracy of the LMT88 when specified to a parabolic transfer function is $\pm 1.5^{\circ}\text{C}$ at an ambient temperature of 30°C . The temperature error increases linearly and reaches a maximum of $\pm 2.5^{\circ}\text{C}$ at the temperature range extremes. The temperature range is affected by the power supply voltage. At a power supply voltage of 2.7 V to 5.5 V the temperature range extremes are 130°C and -55°C . Decreasing the power supply voltage to 2.4 V changes the negative extreme to -30°C , while the positive remains at 130°C .

The LMT88 quiescent current is less than 10 µA. Therefore, self-heating is less than 0.02°C in still air. Shutdown capability for the LMT88 is intrinsic because its inherent low power consumption allows it to be powered directly from the output of many logic gates or does not necessitate shutdown at all.

The LMT88 is a cost-competitive alternative to thermistors.

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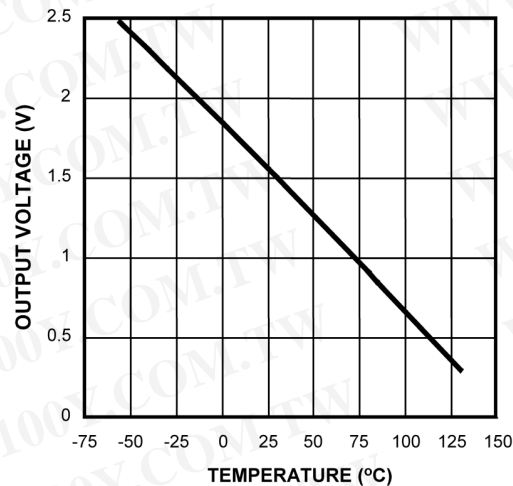
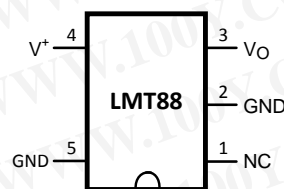


Figure 1. Output Voltage vs Temperature

Table 1. Output Voltage vs Temperature

TEMPERATURE (T)	TYPICAL V_o
130°C	303 mV
100°C	675 mV
80°C	919 mV
30°C	1515 mV
25°C	1574 mV
0°C	1863.9 mV
-30°C	2205 mV
-40°C	2318 mV
-55°C	2485 mV

CONNECTION DIAGRAMS



GND (pin 2) may be grounded or left floating. For optimum thermal conductivity to the pc board ground plane, pin 2 must be grounded.

NC (pin 1) must be left floating or grounded. Other signal traces must not be connected to this pin.

Figure 2. SC70-5 Top View

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ABSOLUTE MAXIMUM RATINGS⁽¹⁾

		VALUES
Supply Voltage		6.5V to -0.2V
Output Voltage		(V ⁺ + 0.6 V) to -0.6 V
Output Current		10 mA
Input Current at any pin ⁽²⁾		5 mA
Storage Temperature		-65°C to 150°C
Maximum Junction Temperature (T _{JMAX})		150°C
ESD Susceptibility ⁽³⁾	Human Body Model	2500 V
	Machine Model	250 V
Soldering process must comply with the Reflow Temperature Profile specifications. Refer to www.ti.com/packaging . ⁽⁴⁾		

- (1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. For specified specifications and test conditions, see the [ELECTRICAL CHARACTERISTICS](#). The specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.
- (2) When the input voltage (V_I) at any pin exceeds power supplies (V_I < GND or V_I > V⁺), the current at that pin should be limited to 5 mA.
- (3) The human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin. The machine model is a 200 pF capacitor discharged directly into each pin.
- (4) Reflow temperature profiles are different for lead-free and non-lead-free packages.

OPERATION RATINGS

Specified Temperature Range:	T _{MIN} ≤ T _A ≤ T _{MAX}
LMT88 with 2.4 V ≤ V ⁺ ≤ 2.7 V	-30°C ≤ T _A ≤ 130°C
LMT88 with 2.7 V ≤ V ⁺ ≤ 5.5 V	-55°C ≤ T _A ≤ 130°C
Supply Voltage Range (V ⁺)	2.4 V to 5.5 V
Thermal Resistance, θ _{JA} ⁽¹⁾ SC70	415°C/W

- (1) The junction to ambient thermal resistance (θ_{JA}) is specified without a heat sink in still air using the printed circuit board layout shown in [PCB Layouts Used For Thermal Measurements](#).

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ELECTRICAL CHARACTERISTICS

Unless otherwise noted, these specifications apply for $V^+ = +2.7 V_{DC}$. **Boldface limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX}** ; all other limits $T_A = T_J = 25^\circ\text{C}$; Unless otherwise noted.

PARAMETER	CONDITIONS	TYPICAL ⁽¹⁾	MAX ⁽²⁾	UNIT (Limit)
Temperature to Voltage Error $V_O = (-3.88 \times 10^{-6} \times T^2) + (-1.15 \times 10^{-2} \times T) + 1.8639\text{V}^{(3)}$	$T_A = 25^\circ\text{C}$ to 30°C	± 1.5	± 4.0	$^\circ\text{C}$ (max)
	$T_A = 130^\circ\text{C}$		± 5.0	$^\circ\text{C}$ (max)
	$T_A = 125^\circ\text{C}$		± 5.0	$^\circ\text{C}$ (max)
	$T_A = 100^\circ\text{C}$		± 4.7	$^\circ\text{C}$ (max)
	$T_A = 85^\circ\text{C}$		± 4.6	$^\circ\text{C}$ (max)
	$T_A = 80^\circ\text{C}$		± 4.5	$^\circ\text{C}$ (max)
	$T_A = 0^\circ\text{C}$		± 4.4	$^\circ\text{C}$ (max)
	$T_A = -30^\circ\text{C}$		± 4.7	$^\circ\text{C}$ (min)
	$T_A = -40^\circ\text{C}$		± 4.8	$^\circ\text{C}$ (max)
	$T_A = -55^\circ\text{C}$		± 5.0	$^\circ\text{C}$ (max)
Output Voltage at 0°C		1.8639		V
Variance from Curve		± 1.0		$^\circ\text{C}$
Non-Linearity ⁽⁴⁾	$-20^\circ\text{C} \leq T_A \leq 80^\circ\text{C}$	$\pm 0.4\%$		
Sensor Gain (Temperature Sensitivity or Average Slope) to equation: $V_O = -11.77 \text{ mV}/^\circ\text{C} \times T + 1.860\text{V}$	$-30^\circ\text{C} \leq T_A \leq 100^\circ\text{C}$	-11.77	-11.0 -12.6	mV/ $^\circ\text{C}$ (min) mV/ $^\circ\text{C}$ (max)
Output Impedance	$0 \mu\text{A} \leq I_L \leq 16 \mu\text{A}$ ^{(5) (6)}		160	Ω (max)
Load Regulation ⁽⁷⁾	$0 \mu\text{A} \leq I_L \leq 16 \mu\text{A}$ ^{(5) (6)}		-2.5	mV (max)
Line Regulation ⁽⁸⁾	$2.4 \text{ V} \leq V^+ \leq 5.0\text{V}$		3.7	mV/V (max)
	$5.0 \text{ V} \leq V^+ \leq 5.5 \text{ V}$		11	mV (max)
Quiescent Current	$2.4\text{V} \leq V^+ \leq 5.0\text{V}$	4.5	7	μA (max)
	$5.0\text{V} \leq V^+ \leq 5.5\text{V}$	4.5	9	μA (max)
	$2.4\text{V} \leq V^+ \leq 5.0\text{V}$	4.5	10	μA (max)
Change of Quiescent Current	$2.4 \text{ V} \leq V^+ \leq 5.5\text{V}$	0.7		μA
Temperature Coefficient of Quiescent Current		-11		nA/ $^\circ\text{C}$
Shutdown Current	$V^+ \leq 0.8 \text{ V}$	0.02		μA

- (1) Typicals are at $T_J = T_A = 25^\circ\text{C}$ and represent most likely parametric norm.
- (2) Limits are specified to TI's AOQL (Average Outgoing Quality Level).
- (3) Accuracy is defined as the error between the measured and calculated output voltage at the specified conditions of voltage, current, and temperature (expressed in $^\circ\text{C}$).
- (4) Non-Linearity is defined as the deviation of the calculated output-voltage-versus-temperature curve from the best-fit straight line, over the temperature range specified.
- (5) Negative currents are flowing into the LMT88. Positive currents are flowing out of the LMT88. Using this convention the LMT88 can at most sink $-1 \mu\text{A}$ and source $16 \mu\text{A}$.
- (6) Load regulation or output impedance specifications apply over the supply voltage range of 2.4V to 5.5V .
- (7) Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.
- (8) Line regulation is calculated by subtracting the output voltage at the highest supply input voltage from the output voltage at the lowest supply input voltage.

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TYPICAL PERFORMANCE CHARACTERISTICS

PCB Layouts Used For Thermal Measurements

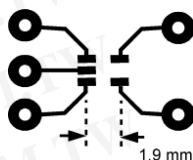


Figure 4. Layout Used For No Heat Sink Measurements

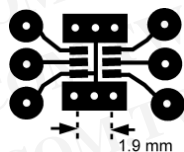


Figure 5. Layout Used For Measurements With Small Heat Sink

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LMT88 TRANSFER FUNCTION

The LMT88 transfer function can be described in different ways with varying levels of precision. A simple linear transfer function, with good accuracy near 25°C, is

$$V_o = -11.69 \text{ mV/}^\circ\text{C} \times T + 1.8663 \text{ V} \tag{1}$$

Over the full operating temperature range of -55°C to 130°C, best accuracy can be obtained by using the parabolic transfer function.

$$V_o = (-3.88 \times 10^{-6} \times T^2) + (-1.15 \times 10^{-2} \times T) + 1.8639 \tag{2}$$

solving for T:

$$T = -1481.96 + \sqrt{2.1962 \times 10^6 + \frac{(1.8639 - V_o)}{3.88 \times 10^{-6}}} \tag{3}$$

A linear transfer function can be used over a limited temperature range by calculating a slope and offset that give best results over that range. A linear transfer function can be calculated from the parabolic transfer function of the LMT88. The slope of the linear transfer function can be calculated using the following equation:

$$m = -7.76 \times 10^{-6} \times T - 0.0115, \tag{4}$$

where T is the middle of the temperature range of interest and m is in V/°C. For example for the temperature range of T_{MIN} = -30 to T_{MAX} = +100°C:

$$T = 35^\circ\text{C} \tag{5}$$

and

$$m = -11.77 \text{ mV/}^\circ\text{C} \tag{6}$$

The offset of the linear transfer function can be calculated using the following equation:

$$b = (V_{OP}(T_{MAX}) + V_{OP}(T) - m \times (T_{MAX}+T))/2 \tag{7}$$

where:

V_{OP}(T_{MAX}) is the calculated output voltage at T_{MAX} using the parabolic transfer function for V_O

V_{OP}(T) is the calculated output voltage at T using the parabolic transfer function for V_O.

Using this procedure the best fit linear transfer function for many popular temperature ranges was calculated in Table 2. As shown in Table 2 the error that is introduced by the linear transfer function increases with wider temperature ranges.

Table 2. First Order Equations Optimized for Different Temperature Ranges

TEMPERATURE RANGE		LINEAR EQUATION	MAXIMUM DEVIATION OF LINEAR EQUATION FROM PARABOLIC EQUATION (°C)
T _{min} (°C)	T _{max} (°C)		
-55	130	$V_O = -11.79 \text{ mV/}^\circ\text{C} \times T + 1.8528 \text{ V}$	±1.41
-40	110	$V_O = -11.77 \text{ mV/}^\circ\text{C} \times T + 1.8577 \text{ V}$	±0.93
-30	100	$V_O = -11.77 \text{ mV/}^\circ\text{C} \times T + 1.8605 \text{ V}$	±0.70
-40	85	$V_O = -11.67 \text{ mV/}^\circ\text{C} \times T + 1.8583 \text{ V}$	±0.65
-10	65	$V_O = -11.71 \text{ mV/}^\circ\text{C} \times T + 1.8641 \text{ V}$	±0.23
35	45	$V_O = -11.81 \text{ mV/}^\circ\text{C} \times T + 1.8701 \text{ V}$	±0.004
20	30	$V_O = -11.69 \text{ mV/}^\circ\text{C} \times T + 1.8663 \text{ V}$	±0.004

MOUNTING

The LMT88 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface. The temperature that the LMT88 is sensing will be within about +0.02°C of the surface temperature to which the LMT88's leads are attached to.

This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature measured would be at an intermediate temperature between the surface temperature and the air temperature.

To ensure good thermal conductivity the backside of the LMT88 die is directly attached to the pin 2 GND pin. The temperatures of the lands and traces to the other leads of the LMT88 will also affect the temperature that is being sensed.

Alternatively, the LMT88 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 LMT88 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to ensure that moisture cannot corrode the LMT88 or its connections.

The thermal resistance junction to ambient (θ_{JA}) is the parameter used to calculate the rise of a device junction temperature due to its power dissipation. For the LMT88 the equation used to calculate the rise in the die temperature is as follows:

$$T_J = T_A + \theta_{JA} [(V^+ I_Q) + (V^+ - V_O) I_L]$$

where I_Q is the quiescent current and I_L is the load current on the output. Since the LMT88's junction temperature is the actual temperature being measured care should be taken to minimize the load current that the LMT88 is required to drive.

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The tables shown in Table 3 summarize the rise in die temperature of the LMT88 without any loading, and the thermal resistance for different conditions.

Table 3. Temperature Rise of LMT88 Due to Self-Heating and Thermal Resistance (θ_{JA})⁽¹⁾

	SC70-5		SC70-5	
	NO HEAT SINK		SMALL HEAT SINK	
	θ_{JA} (°C/W)	$T_J - T_A$ (°C)	θ_{JA} (°C/W)	$T_J - T_A$ (°C)
Still air	412	0.2	350	0.19
Moving air	312	0.17	266	0.15

(1) See PCB Layouts Used For Thermal Measurements for PCB layout samples.

CAPACITIVE LOADS

The LMT88 handles capacitive loading well. Without any precautions, the LMT88 can drive any capacitive load less than 300 pF as shown in Figure 6. Over the specified temperature range the LMT88 has a maximum output impedance of 160 Ω. In an extremely noisy environment it may be necessary to add some filtering to minimize noise pickup. It is recommended that 0.1 μF be added from V⁺ to GND to bypass the power supply voltage, as shown in . In a noisy environment it may even be necessary to add a capacitor from the output to ground with a series resistor as shown in . A 1 μF output capacitor with the 160 Ω maximum output impedance and a 200 Ω series resistor will form a 442 Hz lowpass filter. Since the thermal time constant of the LMT88 is much slower, the overall response time of the LMT88 will not be significantly affected.

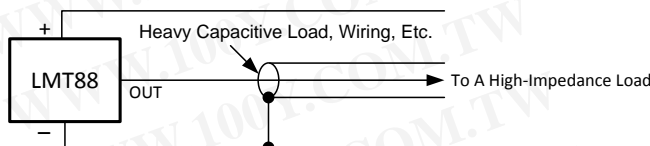
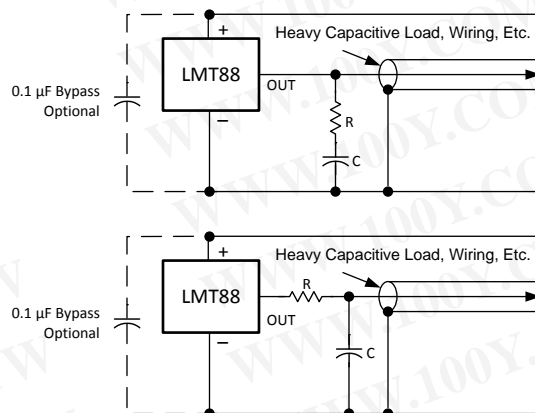


Figure 6. LMT88 No Decoupling Required for Capacitive Loads Less Than 300 pF

R (Ω)	C (μF)
200	1
470	0.1
680	0.01
1 k	0.001

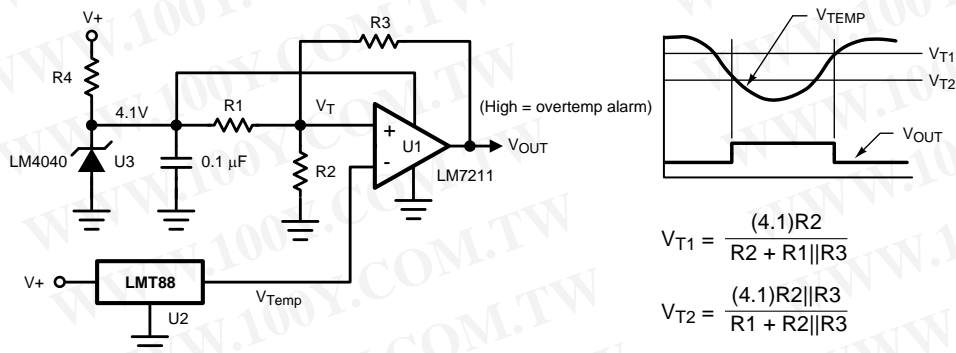
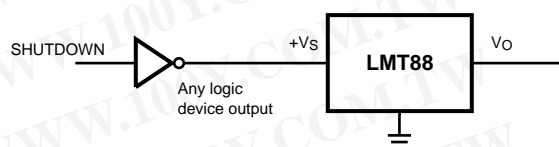
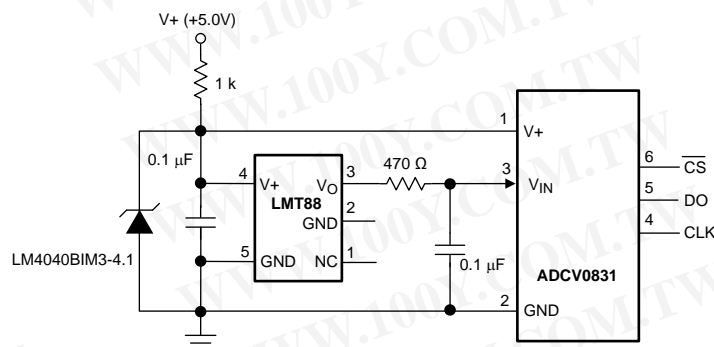


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Figure 7. LMT88 with Filter for Noisy Environment and Capacitive Loading Greater Than 300 pF

NOTE

Either placement of resistor as shown above is just as effective.

APPLICATION CIRCUITS**Figure 8. Centigrade Thermostat****Figure 9. Conserving Power Dissipation with Shutdown****Figure 10. Suggested Connection to a Sampling Analog to Digital Converter Input Stage**

Most CMOS ADCs found in ASICs have a sampled data comparator input structure that is notorious for causing grief to analog output devices such as the LMT88 and many op amps. The cause of this grief is the requirement of instantaneous charge of the input sampling capacitor in the ADC. This requirement is easily accommodated by the addition of a capacitor. Since not all ADCs have identical input stages, the charge requirements will vary necessitating a different value of compensating capacitor. This ADC is shown as an example only. If a digital output temperature is required please refer to devices such as the LM74.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)
LMT88DCKR	ACTIVE	SC70	DCK	5	3000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-55 to 130	T9C
LMT88DCKT	ACTIVE	SC70	DCK	5	250	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-55 to 130	T9C

(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.

OBSELETE: TI has discontinued the production of the device.

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(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)

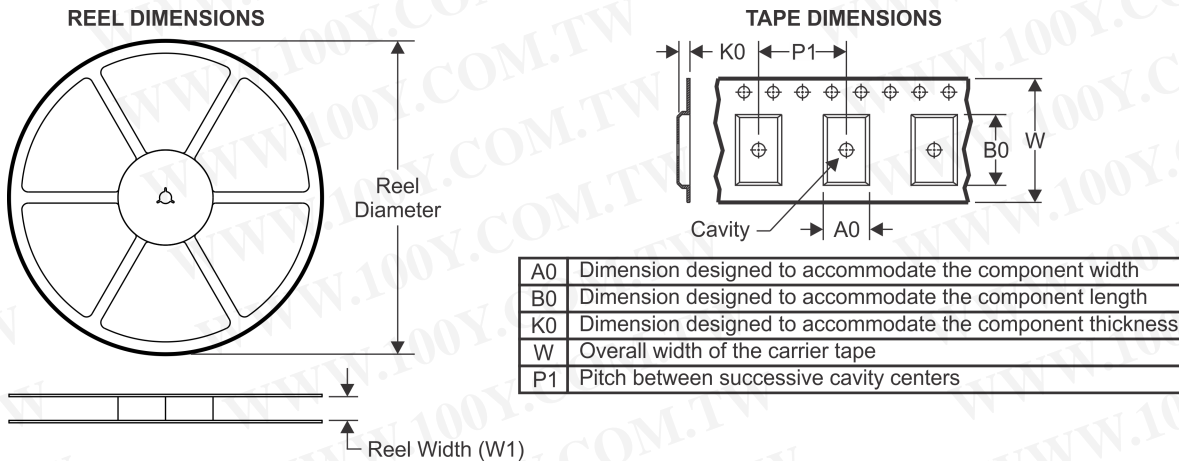
(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) Multiple Top-Side Markings will be inside parentheses. Only one Top-Side 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 Top-Side Marking for that device.

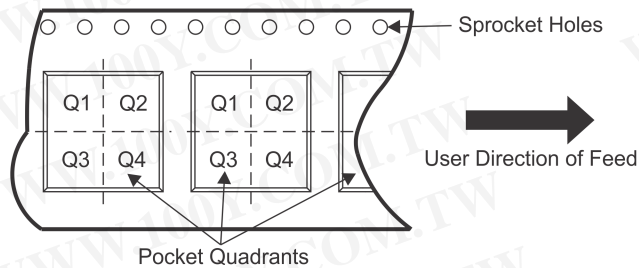
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TAPE AND REEL INFORMATION



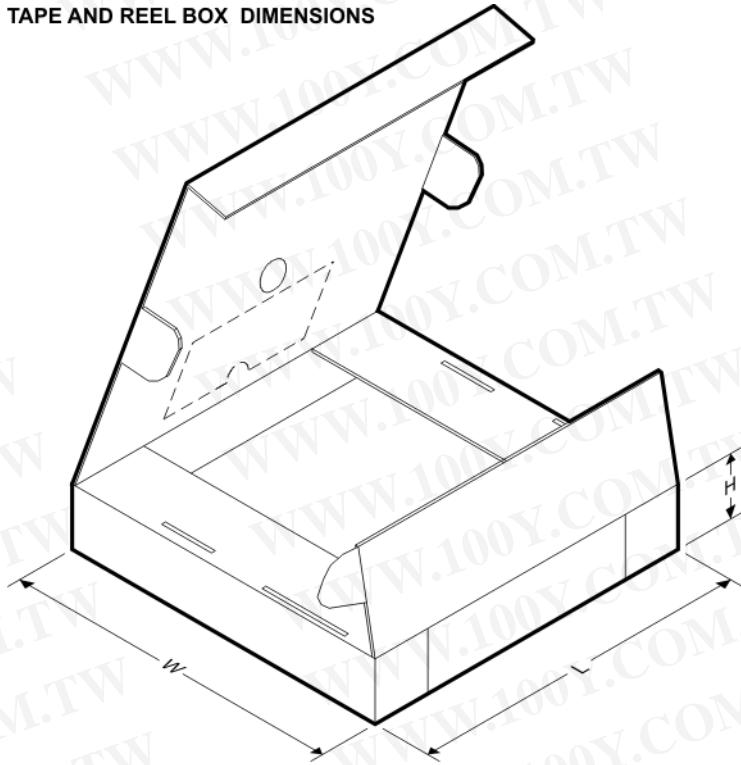
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LMT88DCKR	SC70	DCK	5	3000	178.0	8.4	2.25	2.45	1.2	4.0	8.0	Q3
LMT88DCKT	SC70	DCK	5	250	178.0	8.4	2.25	2.45	1.2	4.0	8.0	Q3

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TAPE AND REEL BOX DIMENSIONS


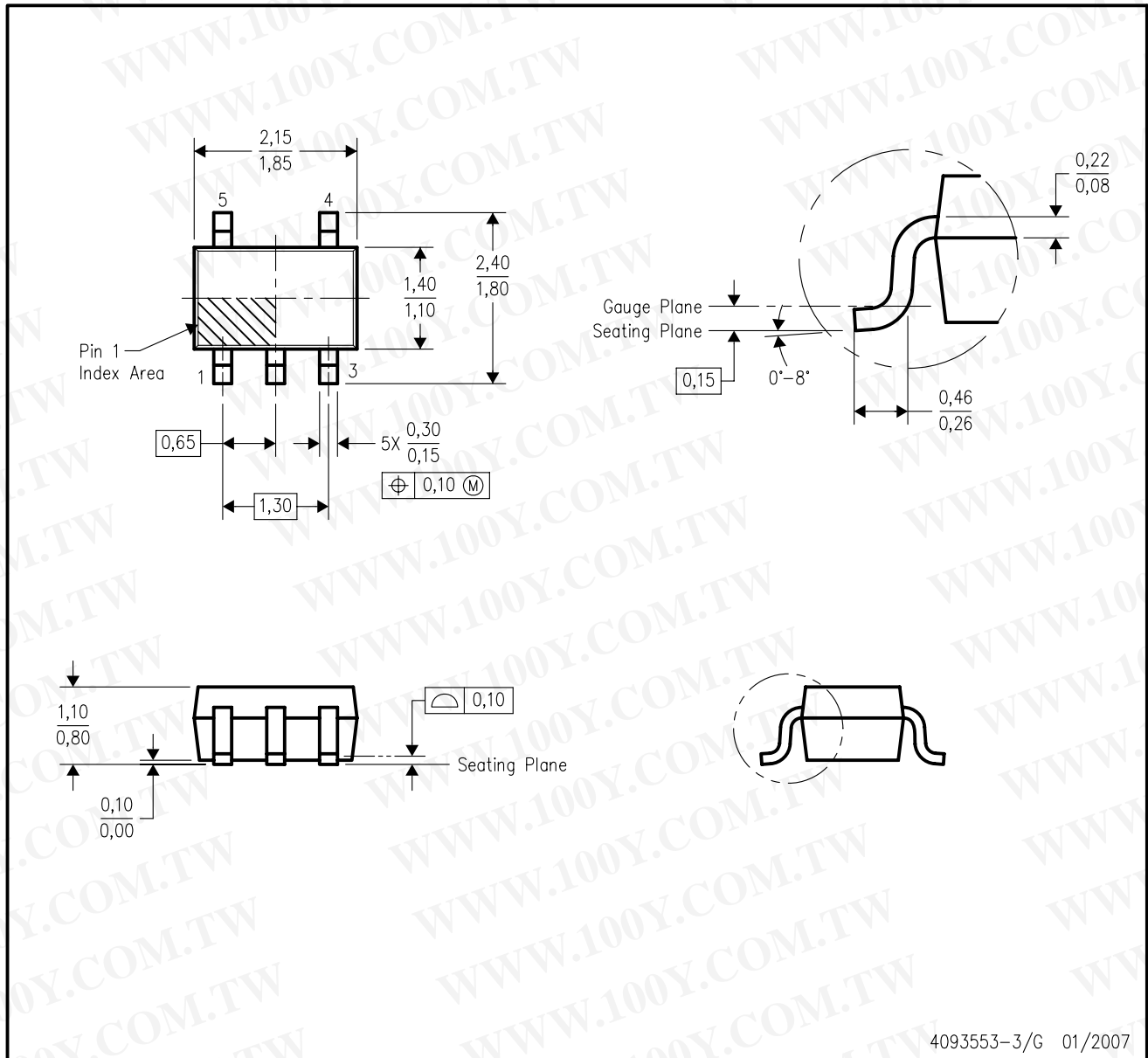
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*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LMT88DCKR	SC70	DCK	5	3000	210.0	185.0	35.0
LMT88DCKT	SC70	DCK	5	250	210.0	185.0	35.0

DCK (R-PDSO-G5)

PLASTIC SMALL-OUTLINE PACKAGE



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
 - D. Falls within JEDEC MO-203 variation AA.

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