

## LMT86 2.2-V, SC70/TO-92/TO-92S, Analog Temperature Sensors

### 1 Features

- LMT86LPG (TO-92S package) has a Fast Thermal Time Constant, 10-s Typical (1.2 m/s Airflow)
- Very Accurate:  $\pm 0.4^{\circ}\text{C}$  Typical
- Low 2.2-V Operation
- Average Sensor Gain of  $-10.9\text{ mV}/^{\circ}\text{C}$
- Low  $5.4\text{-}\mu\text{A}$  Quiescent Current
- Wide Temperature Range:  $-50^{\circ}\text{C}$  to  $150^{\circ}\text{C}$
- Output is Short-Circuit Protected
- Push-Pull Output With  $\pm 50\text{-}\mu\text{A}$  Drive Capability
- Footprint Compatible With the Industry-Standard LM20/19 and LM35 Temperature Sensors
- Cost-Effective Alternative to Thermistors

### 2 Applications

- Infotainment and Cluster
- Powertrain Systems
- Smoke and Heat Detectors
- Drones
- Appliances

### 3 Description

The LMT86 are precision CMOS temperature sensors with  $\pm 0.4^{\circ}\text{C}$  typical accuracy ( $\pm 2.7^{\circ}\text{C}$  maximum) and a linear analog output voltage that is inversely proportional to temperature. The 2.2-V supply voltage operation,  $5.4\text{-}\mu\text{A}$  quiescent current, and  $0.7\text{-ms}$  power-on time enable effective power-cycling architectures to minimize power consumption for battery-powered applications such as drones and sensor nodes. The LMT86LPG through-hole TO-92S package fast thermal time constant supports off-board time-temperature sensitive applications such as smoke and heat detectors. The accuracy over the wide operating range and other features make the LMT86 an excellent alternative to thermistors.

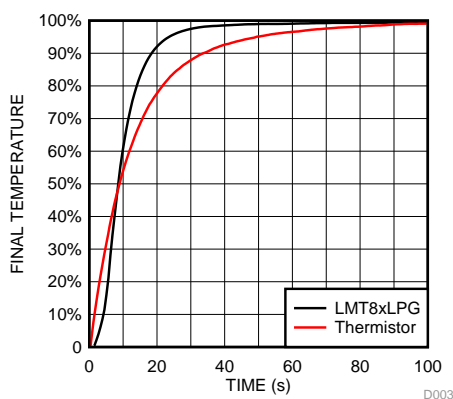
For devices with different average sensor gains and comparable accuracy, refer to [Comparable Alternative Devices](#) for alternative devices in the LMT8x family.

#### Device Information<sup>(1)</sup>

| PART NUMBER | PACKAGE   | BODY SIZE (NOM)   |
|-------------|-----------|-------------------|
| LMT86       | SOT (5)   | 2.00 mm x 1.25 mm |
|             | TO-92 (3) | 4.30 mm x 3.50 mm |

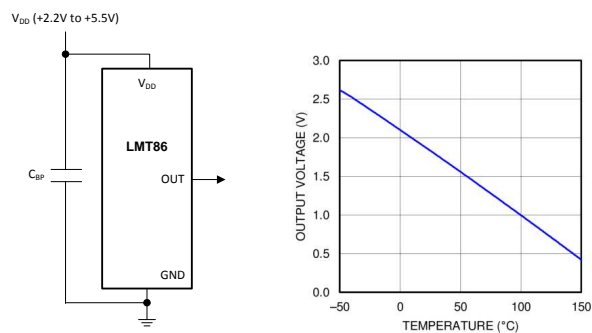
(1) For all available packages, see the orderable addendum at the end of the data sheet.

#### Thermal Time Constant



\* Fast thermal response NTC

#### Output Voltage vs Temperature



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## 4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| Changes from Revision D (June 2017) to Revision E                        | Page |
|--|------|
| • Moved the automotive device to a standalone data sheet (SNIS201) ..... | 1    |
| • Changed TO-92 GND pin number from: 1 to: 3 .....                       | 4    |
| • Changed TO-92 V <sub>DD</sub> pin number from: 3 to: 1 .....           | 4    |

| Changes from Revision C (October 2015) to Revision D   | Page |
|--|------|
| • Updated data sheet text to the latest documentation and translations standards .....               | 1    |
| • Added AEC-Q100 automotive qualification bullets to <i>Features</i> .....                           | 1    |
| • Added Time Constant graph.....   | 1    |
| • Removed disk drivers, games, wireless transceivers, and cell phones from <i>Applications</i> ..... | 1    |
| • Added LPG (TO-92S) package .....   | 4    |
| • Added <a href="#">Figure 10</a> to <i>Typical Characteristics</i> .....                            | 7    |

| Changes from Revision B (May 2014) to Revision C   | Page |
|--|------|
| • Deleted all mentions of TO-126 package .....   | 1    |
| • Added TO-92 LPM pin configuration graphic .....  | 4    |
| • Changed Handling Ratings to ESD Ratings and moved Storage Temperature to Absolute Maximum Ratings table..... | 5    |
| • Changed KV to V .....  | 5    |
| • Added layout recommendation for TO-92 LP and LPM packages.....   | 15   |

| Changes from Revision A (June 2013) to Revision B   | Page |
|---|------|
| • Changed data sheet flow and layout to conform with new TI standards. Added the following sections: Application and Implementation, Power Supply Recommendations, Layout, Device and Documentation Support, Mechanical, Packaging, and Orderable Information ..... | 1    |
| • Added TO92 and TO126 package information.....   | 1    |

- Changed from 450°C/W to 275 °C/W. New specification is derived using TI 's latest methodology. .... 5
- Changed Temperature Accuracy  $V_{DD}$  condition from 2.4V to 2.2V for range of 40°C to 150°C. .... 6
- Deleted Note: The input current is leakage only and is highest at high temperature. It is typically only 0.001  $\mu$ A. The 1  $\mu$ A limit is solely based on a testing limitation and does not reflect the actual performance of the part..... 6

## 5 Device Comparison Tables

**Table 1. Available Device Packages**

| ORDER NUMBER <sup>(1)</sup> | PACKAGE                              | PIN | BODY SIZE (NOM)   | MOUNTING TYPE                |
|-----------------------------|--------------------------------------|-----|-------------------|------------------------------|
| LMT86DCK                    | SOT (AKA <sup>(2)</sup> : SC70, DCK) | 5   | 2.00 mm × 1.25 mm | Surface Mount                |
| LMT86LP                     | TO-92 (AKA <sup>(2)</sup> : LP)      | 3   | 4.30 mm × 3.50 mm | Through-hole; straight leads |
| LMT86LPG                    | TO-92S (AKA <sup>(2)</sup> : LPG)    | 3   | 4.00 mm × 3.15 mm | Through-hole; straight leads |
| LMT86LPM                    | TO-92 (AKA <sup>(2)</sup> : LPM)     | 3   | 4.30 mm × 3.50 mm | Through-hole; formed leads   |
| LMT86DCK-Q1                 | SOT (AKA <sup>(2)</sup> : SC70, DCK) | 5   | 2.00 mm × 1.25 mm | Surface Mount                |

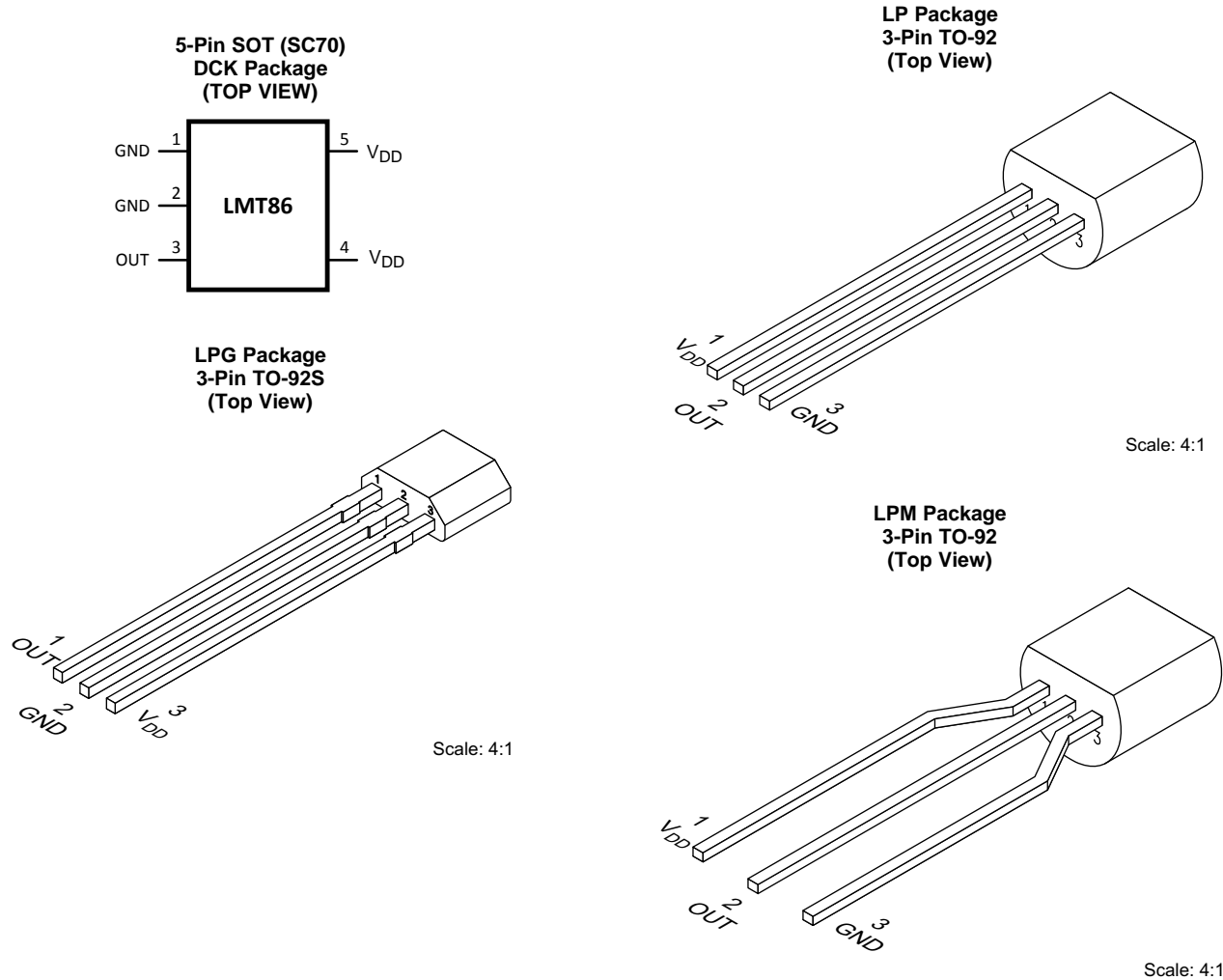
(1) For all available packages and complete order numbers, see the Package Option addendum at the end of the data sheet.

(2) AKA = Also Known As

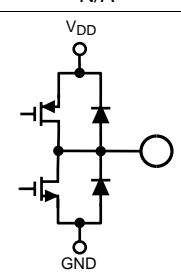
**Table 2. Comparable Alternative Devices**

| DEVICE NAME           | AVERAGE OUTPUT SENSOR GAIN | POWER SUPPLY RANGE |
|-----------------------|----------------------------|--------------------|
| <a href="#">LMT84</a> | –5.5 mV/°C                 | 1.5 V to 5.5 V     |
| <a href="#">LMT85</a> | –8.2 mV/°C                 | 1.8 V to 5.5 V     |
| <a href="#">LMT86</a> | –10.9 mV/°C                | 2.2 V to 5.5 V     |
| <a href="#">LMT87</a> | –13.6 mV/°C                | 2.7 V to 5.5 V     |

## 6 Pin Configuration and Functions



### Pin Functions

| NAME            | PIN                 |       |        | TYPE          | DESCRIPTION  |   |
|-----------------|---------------------|-------|--------|---------------|--|---|
|                 | SOT (SC70)          | TO-92 | TO-92S |               | EQUIVALENT CIRCUIT   | FUNCTION  |
| GND             | 1, 2 <sup>(1)</sup> | 3     | 2      | Ground        | N/A  | Power Supply Ground   |
| OUT             | 3                   | 2     | 1      | Analog Output |  | Outputs a voltage that is inversely proportional to temperature |
| V <sub>DD</sub> | 4, 5                | 1     | 3      | Power         | N/A  | Positive Supply Voltage   |

(1) Direct connection to the back side of the die

## 7 Specifications

### 7.1 Absolute Maximum Ratings

 See <sup>(1)(2)</sup>

|   | MIN  | MAX                     | UNIT |
|---|------|-------------------------|------|
| Supply voltage                                    | -0.3 | 6                       | V    |
| Voltage at output pin                             | -0.3 | (V <sub>DD</sub> + 0.5) | V    |
| Output current                                    | -7   | 7                       | mA   |
| Input current at any pin <sup>(3)</sup>           | -5   | 5                       | mA   |
| Maximum junction temperature (T <sub>JMAX</sub> ) |      | 150                     | °C   |
| Storage temperature, T <sub>stg</sub>             | -65  | 150                     | °C   |

- 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.
- Soldering process must comply with TI's Reflow Temperature Profile specifications. Refer to [www.ti.com/packaging](http://www.ti.com/packaging). Reflow temperature profiles are different for lead-free and non-lead-free packages.
- When the input voltage (V<sub>I</sub>) at any pin exceeds power supplies (V<sub>I</sub> < GND or V<sub>I</sub> > V), the current at that pin should be limited to 5 mA.

### 7.2 ESD Ratings

|                          |                         | VALUE  | UNIT  |
|--------------------------|-------------------------|--|-------|
| LMT86LP in TO-92 package |                         |  |       |
| V <sub>(ESD)</sub>       | Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)(2)</sup>           | ±2500 |
|                          |                         | Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(3)</sup> | ±1000 |
| LMT86DCK in SC70 package |                         |  |       |
| V <sub>(ESD)</sub>       | Electrostatic discharge | Human-body model (HBM), per JESD22-A114 <sup>(2)</sup>                         | ±2500 |
|                          |                         | Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(3)</sup> | ±1000 |

- JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
- The human body model is a 100-pF capacitor discharged through a 1.5-kΩ resistor into each pin.
- JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

### 7.3 Recommended Operating Conditions

|                                   | MIN  | MAX | UNIT |
|-----------------------------------|--|-----|------|
| Specified temperature             | T <sub>MIN</sub> ≤ T <sub>A</sub> ≤ T <sub>MAX</sub> |     | °C   |
|                                   | -50 ≤ T <sub>A</sub> ≤ 150                           |     | °C   |
| Supply voltage (V <sub>DD</sub> ) | 2.2  | 5.5 | V    |

### 7.4 Thermal Information <sup>(1)</sup>

| THERMAL METRIC <sup>(2)</sup>   | LMT86          | LMT86LP        | LMT86LPG     | UNIT |
|---|----------------|----------------|--------------|------|
|   | DCK (SOT/SC70) | LP/LPM (TO-92) | LPG (TO-92S) |      |
|   | 5 PINS         | 3 PINS         | 3 PINS       |      |
| R <sub>θJA</sub> Junction-to-ambient thermal resistance <sup>(3)(4)</sup> | 275            | 167            | 130.4        | °C/W |
| R <sub>θJC(top)</sub> Junction-to-case (top) thermal resistance           | 84             | 90             | 64.2         | °C/W |
| R <sub>θJB</sub> Junction-to-board thermal resistance                     | 56             | 146            | 106.2        | °C/W |
| ψ <sub>JT</sub> Junction-to-top characterization parameter                | 1.2            | 35             | 14.6         | °C/W |
| ψ <sub>JB</sub> Junction-to-board characterization parameter              | 55             | 146            | 106.2        | °C/W |

- For information on self-heating and thermal response time, see section [Mounting and Thermal Conductivity](#).
- For more information about traditional and new thermal metrics, see the [IC Package Thermal Metrics](#) application report.
- The junction to ambient thermal resistance (R<sub>θJA</sub>) under natural convection is obtained in a simulation on a JEDEC-standard, High-K board as specified in JESD51-7, in an environment described in JESD51-2. Exposed pad packages assume that thermal vias are included in the PCB, per JESD 51-5.
- Changes in output due to self-heating can be computed by multiplying the internal dissipation by the thermal resistance.

## 7.5 Accuracy Characteristics

These limits do not include DC load regulation. These stated accuracy limits are with reference to the values in [Table 3](#).

| PARAMETER                           | CONDITIONS                                      | MIN <sup>(1)</sup> | TYP <sup>(2)</sup> | MAX <sup>(1)</sup> | UNIT |
|-------------------------------------|---|--------------------|--------------------|--------------------|------|
| Temperature accuracy <sup>(3)</sup> | 40°C to 150°C; V <sub>DD</sub> = 2.2 V to 5.5 V | -2.7               | ±0.4               | 2.7                | °C   |
|                                     | 0°C to 40°C; V <sub>DD</sub> = 2.4 V to 5.5 V   | -2.7               | ±0.7               | 2.7                | °C   |
|                                     | 0°C to 70°C; V <sub>DD</sub> = 3.0 V to 5.5 V   |                    | ±0.3               |                    | °C   |
|                                     | -50°C to 0°C; V <sub>DD</sub> = 3.0 V to 5.5 V  | -2.7               | ±0.7               | 2.7                | °C   |
|                                     | -50°C to 0°C; V <sub>DD</sub> = 3.6 V to 5.5 V  |                    | ±0.25              |                    | °C   |

- (1) Limits are specified to TI's AOQL (Average Outgoing Quality Level).
- (2) Typical values are at T<sub>J</sub> = T<sub>A</sub> = 25°C and represent most likely parametric norm.
- (3) Accuracy is defined as the error between the measured and reference output voltages, tabulated in the Transfer Table at the specified conditions of supply gain setting, voltage, and temperature (expressed in °C). Accuracy limits include line regulation within the specified conditions. Accuracy limits do not include load regulation; they assume no dc load.

## 7.6 Electrical Characteristics

Unless otherwise noted, these specifications apply for +V<sub>DD</sub> = 2.2 V to 5.5 V. MIN and MAX limits apply for T<sub>A</sub> = T<sub>J</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>, unless otherwise noted; typical values apply for T<sub>A</sub> = T<sub>J</sub> = 25°C.

| PARAMETER  | TEST CONDITIONS   | MIN <sup>(1)</sup> | TYP <sup>(2)</sup> | MAX <sup>(1)</sup> | UNIT  |
|--|---|--------------------|--------------------|--------------------|-------|
| Average sensor gain (output transfer function slope) | -30°C and 90°C used to calculate average sensor gain                            |                    | -10.9              |                    | mV/°C |
| Load regulation <sup>(3)</sup>                       | Source ≤ 50 μA, (V <sub>DD</sub> - V <sub>OUT</sub> ) ≥ 200 mV                  | -1                 | -0.22              |                    | mV    |
|  | Sink ≤ 50 μA, V <sub>OUT</sub> ≥ 200 mV   |                    | 0.26               | 1                  | mV    |
| Line regulation <sup>(4)</sup>                       |   |                    | 200                |                    | μV/V  |
| I <sub>S</sub> Supply current                        | T <sub>A</sub> = 30°C to 150°C, (V <sub>DD</sub> - V <sub>OUT</sub> ) ≥ 100 mV  |                    | 5.4                | 8.1                | μA    |
|  | T <sub>A</sub> = -50°C to 150°C, (V <sub>DD</sub> - V <sub>OUT</sub> ) ≥ 100 mV |                    | 5.4                | 9                  | μA    |
| C <sub>L</sub> Output load capacitance               |   |                    | 1100               |                    | pF    |
| Power-on time <sup>(5)</sup>                         | C <sub>L</sub> = 0 pF to 1100 pF  |                    | 0.7                | 1.9                | ms    |
| Output drive   | T <sub>A</sub> = T <sub>J</sub> = 25°C  | -50                |                    | 50                 | μA    |

- (1) Limits are specific to TI's AOQL (Average Outgoing Quality Level).
- (2) Typical values are at T<sub>J</sub> = T<sub>A</sub> = 25°C and represent most likely parametric norm.
- (3) Source currents are flowing out of the LMT86. Sink currents are flowing into the LMT86.
- (4) Line regulation (DC) is calculated by subtracting the output voltage at the highest supply voltage from the output voltage at the lowest supply voltage. The typical DC line regulation specification does not include the output voltage shift discussed in [Output Voltage Shift](#).
- (5) Specified by design and characterization.

### 7.7 Typical Characteristics

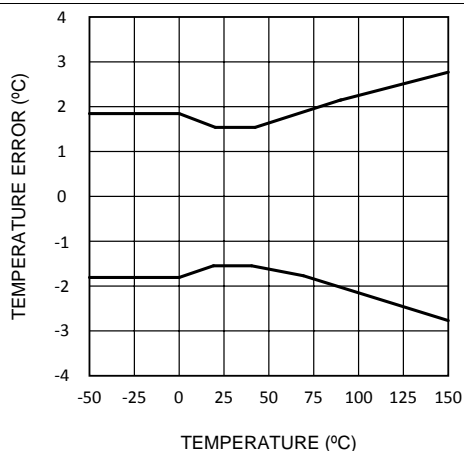


Figure 1. Temperature Error vs Temperature

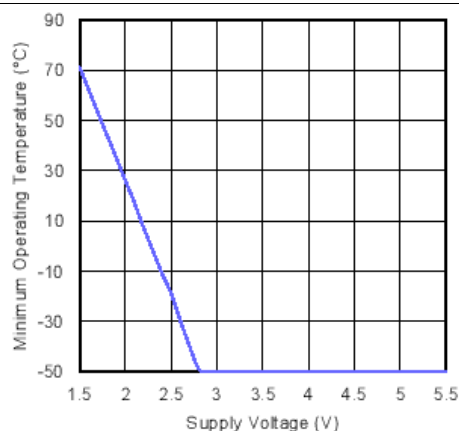


Figure 2. Minimum Operating Temperature vs Supply Voltage

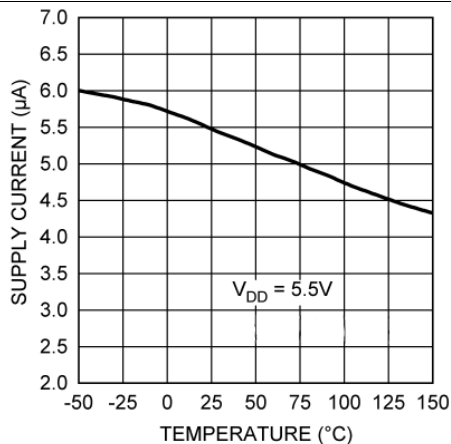


Figure 3. Supply Current vs Temperature

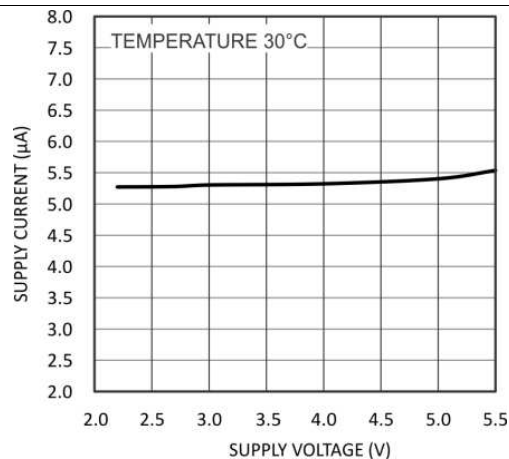


Figure 4. Supply Current vs Supply Voltage

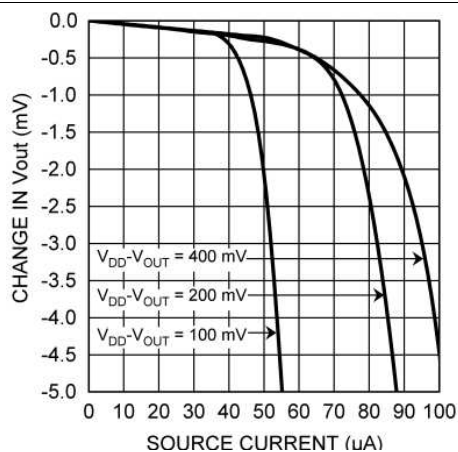


Figure 5. Load Regulation, Sourcing Current

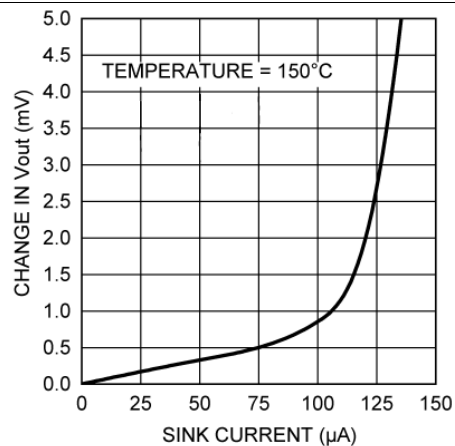


Figure 6. Load Regulation, Sinking Current

Typical Characteristics (continued)

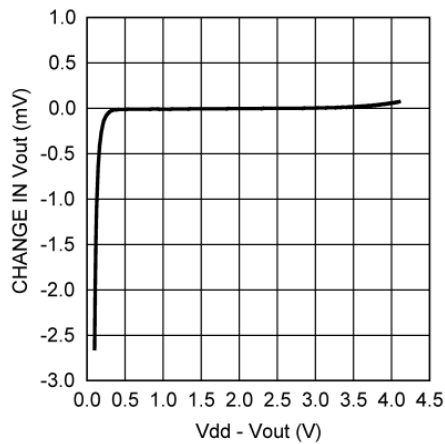


Figure 7. Change in  $V_{OUT}$  vs Overhead Voltage

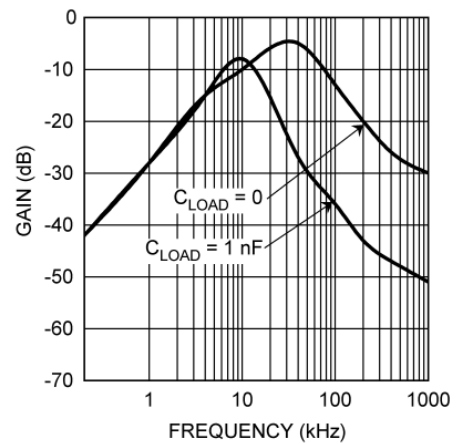


Figure 8. Supply-Noise Gain vs Frequency

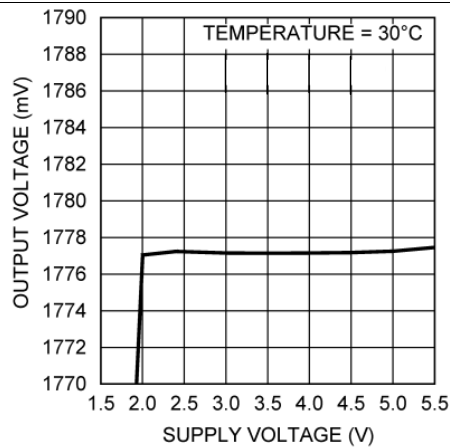


Figure 9. Output Voltage vs Supply Voltage

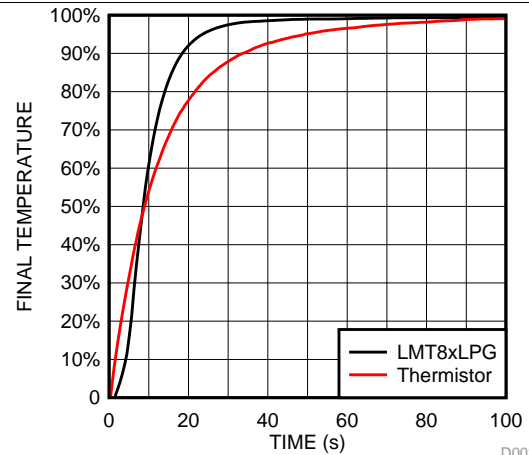


Figure 10. LMT86LPG Thermal Response vs Common Leaded Thermistor With 1.2-m/s Airflow



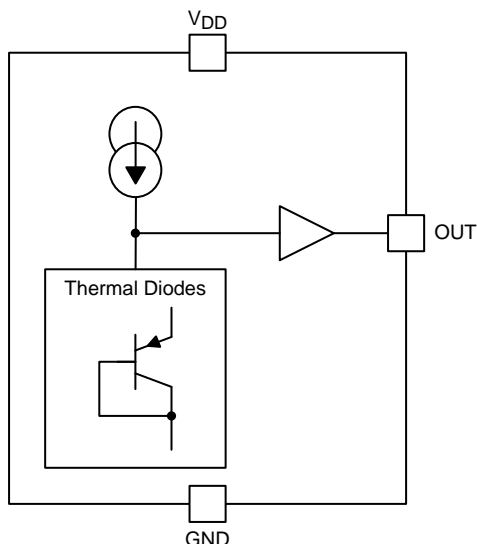
## 8 Detailed Description

### 8.1 Overview

The LMT86 is an analog output temperature sensor. The temperature-sensing element is comprised of a simple base emitter junction that is forward biased by a current source. The temperature-sensing element is then buffered by an amplifier and provided to the OUT pin. The amplifier has a simple push-pull output stage thus providing a low impedance output source.

### 8.2 Functional Block Diagram

Full-Range Celsius Temperature Sensor (–50°C to +150°C)



### 8.3 Feature Description

#### 8.3.1 LMT86 Transfer Function

The output voltage of the LMT86, across the complete operating temperature range, is shown in [Table 3](#). This table is the reference from which the LMT86 accuracy specifications (listed in the [Accuracy Characteristics](#) section) are determined. This table can be used, for example, in a host processor look-up table. A file containing this data is available for download at [LMT86](#) product folder under *Tools and Software Models*.

**Table 3. LMT86 Transfer Table**

| TEMP (°C) | V <sub>OUT</sub> (mV) | TEMP (°C) | V <sub>OUT</sub> (mV) | TEMP (°C) | V <sub>OUT</sub> (mV) | TEMP (°C) | V <sub>OUT</sub> (mV) | TEMP (°C) | V <sub>OUT</sub> (mV) |
|-----------|-----------------------|-----------|-----------------------|-----------|-----------------------|-----------|-----------------------|-----------|-----------------------|
| -50       | 2616                  | -10       | 2207                  | 30        | 1777                  | 70        | 1335                  | 110       | 883                   |
| -49       | 2607                  | -9        | 2197                  | 31        | 1766                  | 71        | 1324                  | 111       | 872                   |
| -48       | 2598                  | -8        | 2186                  | 32        | 1756                  | 72        | 1313                  | 112       | 860                   |
| -47       | 2589                  | -7        | 2175                  | 33        | 1745                  | 73        | 1301                  | 113       | 849                   |
| -46       | 2580                  | -6        | 2164                  | 34        | 1734                  | 74        | 1290                  | 114       | 837                   |
| -45       | 2571                  | -5        | 2154                  | 35        | 1723                  | 75        | 1279                  | 115       | 826                   |
| -44       | 2562                  | -4        | 2143                  | 36        | 1712                  | 76        | 1268                  | 116       | 814                   |
| -43       | 2553                  | -3        | 2132                  | 37        | 1701                  | 77        | 1257                  | 117       | 803                   |
| -42       | 2543                  | -2        | 2122                  | 38        | 1690                  | 78        | 1245                  | 118       | 791                   |
| -41       | 2533                  | -1        | 2111                  | 39        | 1679                  | 79        | 1234                  | 119       | 780                   |
| -40       | 2522                  | 0         | 2100                  | 40        | 1668                  | 80        | 1223                  | 120       | 769                   |
| -39       | 2512                  | 1         | 2089                  | 41        | 1657                  | 81        | 1212                  | 121       | 757                   |
| -38       | 2501                  | 2         | 2079                  | 42        | 1646                  | 82        | 1201                  | 122       | 745                   |
| -37       | 2491                  | 3         | 2068                  | 43        | 1635                  | 83        | 1189                  | 123       | 734                   |

**Feature Description (continued)**
**Table 3. LMT86 Transfer Table (continued)**

| TEMP (°C) | V <sub>OUT</sub> (mV) | TEMP (°C) | V <sub>OUT</sub> (mV) | TEMP (°C) | V <sub>OUT</sub> (mV) | TEMP (°C) | V <sub>OUT</sub> (mV) | TEMP (°C) | V <sub>OUT</sub> (mV) |
|-----------|-----------------------|-----------|-----------------------|-----------|-----------------------|-----------|-----------------------|-----------|-----------------------|
| -36       | 2481                  | 4         | 2057                  | 44        | 1624                  | 84        | 1178                  | 124       | 722                   |
| -35       | 2470                  | 5         | 2047                  | 45        | 1613                  | 85        | 1167                  | 125       | 711                   |
| -34       | 2460                  | 6         | 2036                  | 46        | 1602                  | 86        | 1155                  | 126       | 699                   |
| -33       | 2449                  | 7         | 2025                  | 47        | 1591                  | 87        | 1144                  | 127       | 688                   |
| -32       | 2439                  | 8         | 2014                  | 48        | 1580                  | 88        | 1133                  | 128       | 676                   |
| -31       | 2429                  | 9         | 2004                  | 49        | 1569                  | 89        | 1122                  | 129       | 665                   |
| -30       | 2418                  | 10        | 1993                  | 50        | 1558                  | 90        | 1110                  | 130       | 653                   |
| -29       | 2408                  | 11        | 1982                  | 51        | 1547                  | 91        | 1099                  | 131       | 642                   |
| -28       | 2397                  | 12        | 1971                  | 52        | 1536                  | 92        | 1088                  | 132       | 630                   |
| -27       | 2387                  | 13        | 1961                  | 53        | 1525                  | 93        | 1076                  | 133       | 618                   |
| -26       | 2376                  | 14        | 1950                  | 54        | 1514                  | 94        | 1065                  | 134       | 607                   |
| -25       | 2366                  | 15        | 1939                  | 55        | 1503                  | 95        | 1054                  | 135       | 595                   |
| -24       | 2355                  | 16        | 1928                  | 56        | 1492                  | 96        | 1042                  | 136       | 584                   |
| -23       | 2345                  | 17        | 1918                  | 57        | 1481                  | 97        | 1031                  | 137       | 572                   |
| -22       | 2334                  | 18        | 1907                  | 58        | 1470                  | 98        | 1020                  | 138       | 560                   |
| -21       | 2324                  | 19        | 1896                  | 59        | 1459                  | 99        | 1008                  | 139       | 549                   |
| -20       | 2313                  | 20        | 1885                  | 60        | 1448                  | 100       | 997                   | 140       | 537                   |
| -19       | 2302                  | 21        | 1874                  | 61        | 1436                  | 101       | 986                   | 141       | 525                   |
| -18       | 2292                  | 22        | 1864                  | 62        | 1425                  | 102       | 974                   | 142       | 514                   |
| -17       | 2281                  | 23        | 1853                  | 63        | 1414                  | 103       | 963                   | 143       | 502                   |
| -16       | 2271                  | 24        | 1842                  | 64        | 1403                  | 104       | 951                   | 144       | 490                   |
| -15       | 2260                  | 25        | 1831                  | 65        | 1391                  | 105       | 940                   | 145       | 479                   |
| -14       | 2250                  | 26        | 1820                  | 66        | 1380                  | 106       | 929                   | 146       | 467                   |
| -13       | 2239                  | 27        | 1810                  | 67        | 1369                  | 107       | 917                   | 147       | 455                   |
| -12       | 2228                  | 28        | 1799                  | 68        | 1358                  | 108       | 906                   | 148       | 443                   |
| -11       | 2218                  | 29        | 1788                  | 69        | 1346                  | 109       | 895                   | 149       | 432                   |
|           |                       |           |                       |           |                       |           |                       | 150       | 420                   |

Although the LMT86 is very linear, its response does have a slight umbrella parabolic shape. This shape is very accurately reflected in [Table 3](#). The Transfer Table can be calculated by using the parabolic equation ([Equation 1](#)).

$$V_{TEMP} (mV) = 1777.3mV - \left[ 10.888 \frac{mV}{^{\circ}C} (T - 30^{\circ}C) \right] - \left[ 0.00347 \frac{mV}{^{\circ}C^2} (T - 30^{\circ}C)^2 \right] \quad (1)$$

The parabolic equation is an approximation of the transfer table and the accuracy of the equation degrades slightly at the temperature range extremes. [Equation 1](#) can be solved for T resulting in:

$$T = \frac{10.888 - \sqrt{(-10.888)^2 + 4 \times 0.00347 \times (1777.3 - V_{TEMP} (mV))}}{2 \times (-0.00347)} + 30 \quad (2)$$

For an even less accurate linear approximation, a line can easily be calculated over the desired temperature range from the table using the two-point equation ([Equation 3](#)):

$$V - V_1 = \left( \frac{V_2 - V_1}{T_2 - T_1} \right) \times (T - T_1)$$

where

- V is in mV,
- T is in °C,
- T<sub>1</sub> and V<sub>1</sub> are the coordinates of the lowest temperature,
- and T<sub>2</sub> and V<sub>2</sub> are the coordinates of the highest temperature.

(3)

For example, if the user wanted to resolve this equation, over a temperature range of 20°C to 50°C, they would proceed as follows:

$$V - 1885 \text{ mV} = \left( \frac{1558 \text{ mV} - 1885 \text{ mV}}{50^\circ\text{C} - 20^\circ\text{C}} \right) \times (T - 20^\circ\text{C}) \quad (4)$$

$$V - 1885 \text{ mV} = (-10.9 \text{ mV} / ^\circ\text{C}) \times (T - 20^\circ\text{C}) \quad (5)$$

$$V = (-10.9 \text{ mV} / ^\circ\text{C}) \times T + 2103 \text{ mV} \quad (6)$$

Using this method of linear approximation, the transfer function can be approximated for one or more temperature ranges of interest.

## 8.4 Device Functional Modes

### 8.4.1 Mounting and Thermal Conductivity

The LMT86 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 thermal conductivity, the backside of the LMT86 die is directly attached to the GND pin. The temperatures of the lands and traces to the other leads of the LMT86 will also affect the temperature reading.

Alternatively, the LMT86 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 LMT86 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. If moisture creates a short circuit from the output to ground or  $V_{DD}$ , the output from the LMT86 will not be correct. Printed-circuit coatings are often used to ensure that moisture cannot corrode the leads or circuit traces.

The thermal resistance junction to ambient ( $R_{\theta JA}$  or  $\theta_{JA}$ ) is the parameter used to calculate the rise of a device junction temperature due to its power dissipation. Use [Equation 7](#) to calculate the rise in the LMT86 die temperature:

$$T_J = T_A + \theta_{JA} [(V_{DD} I_S) + (V_{DD} - V_O) I_L]$$

where

- $T_A$  is the ambient temperature,
- $I_S$  is the supply current,
- $I_L$  is the load current on the output,
- and  $V_O$  is the output voltage. (7)

For example, in an application where  $T_A = 30^\circ\text{C}$ ,  $V_{DD} = 5 \text{ V}$ ,  $I_S = 5.4 \mu\text{A}$ ,  $V_O = 1777 \text{ mV}$  junction temp  $30.014^\circ\text{C}$  self-heating error of  $0.014^\circ\text{C}$ . Because the junction temperature of the LMT86 is the actual temperature being measured, take care to minimize the load current that the LMT86 is required to drive. [Thermal Information<sup>\(1\)</sup>](#) shows the thermal resistance of the LMT86.

### 8.4.2 Output Noise Considerations

A push-pull output gives the LMT86 the ability to sink and source significant current. This is beneficial when, for example, driving dynamic loads like an input stage on an analog-to-digital converter (ADC). In these applications the source current is required to quickly charge the input capacitor of the ADC. The LMT86 is ideal for this and other applications which require strong source or sink current.

The LMT86 supply-noise gain (the ratio of the AC signal on  $V_{OUT}$  to the AC signal on  $V_{DD}$ ) was measured during bench tests. The typical attenuation is shown in [Figure 8](#) found in the [Typical Characteristics](#) section. A load capacitor on the output can help to filter noise.

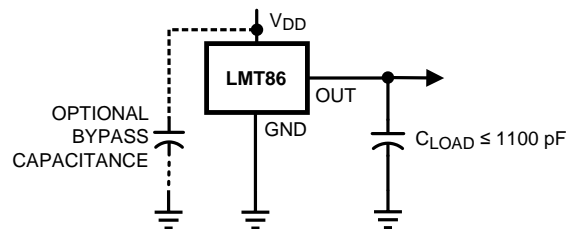
For operation in very noisy environments, some bypass capacitance should be present on the supply within approximately 5 centimeters of the LMT86.

(1) For information on self-heating and thermal response time, see section [Mounting and Thermal Conductivity](#).

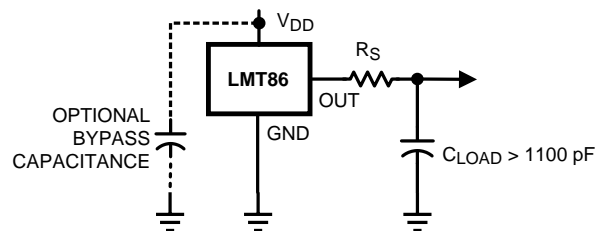
## Device Functional Modes (continued)

### 8.4.3 Capacitive Loads

The LMT86 handles capacitive loading well. In an extremely noisy environment, or when driving a switched sampling input on an ADC, it may be necessary to add some filtering to minimize noise coupling. Without any precautions, the LMT86 can drive a capacitive load less than or equal to 1100 pF as shown in [Figure 11](#). For capacitive loads greater than 1100 pF, a series resistor may be required on the output, as shown in [Figure 12](#).



**Figure 11. LMT86 No Decoupling Required for Capacitive Loads Less Than 1100 pF**



**Figure 12. LMT86 With Series Resistor for Capacitive Loading Greater Than 1100 pF**

**Table 4. Recommended Series Resistor Values**

| $C_{LOAD}$       | MINIMUM $R_S$  |
|------------------|----------------|
| 1.1 nF to 99 nF  | 3 k $\Omega$   |
| 100 nF to 999 nF | 1.5 k $\Omega$ |
| 1 $\mu$ F        | 800 $\Omega$   |

### 8.4.4 Output Voltage Shift

The LMT86 device is very linear over temperature and supply voltage range. Due to the intrinsic behavior of an NMOS/PMOS rail-to-rail buffer, a slight shift in the output can occur when the supply voltage is ramped over the operating range of the device. The location of the shift is determined by the relative levels of  $V_{DD}$  and  $V_{OUT}$ . The shift typically occurs when  $V_{DD} - V_{OUT} = 1$  V.

This slight shift (a few millivolts) takes place over a wide change (approximately 200 mV) in  $V_{DD}$  or  $V_{OUT}$ . Because the shift takes place over a wide temperature change of 5°C to 20°C,  $V_{OUT}$  is always monotonic. The accuracy specifications in the [Accuracy Characteristics](#) table already include this possible shift.

## 9 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.

### 9.1 Application Information

The LMT86 features make it suitable for many general temperature-sensing applications. It can operate down to 2.2-V supply with 5.4- $\mu$ A power consumption, making it ideal for battery-powered devices. Package options like the through-hole TO-92 package allow the LMT86 to be mounted onboard, off-board, to a heat sink, or on multiple unique locations in the same application.

### 9.2 Typical Applications

#### 9.2.1 Connection to an ADC

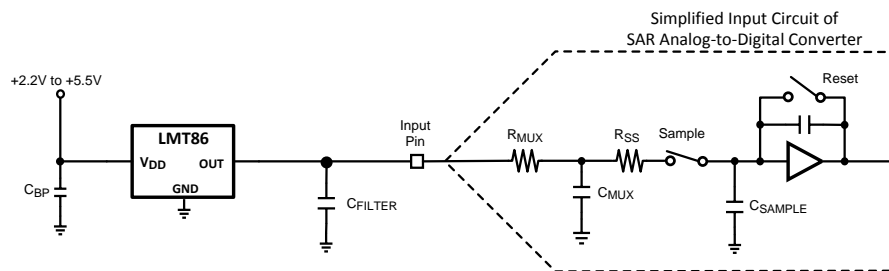


Figure 13. Suggested Connection to a Sampling Analog-to-Digital Converter Input Stage

##### 9.2.1.1 Design Requirements

Most CMOS ADCs found in microcontrollers and ASICs have a sampled data comparator input structure. When the ADC charges the sampling cap, it requires instantaneous charge from the output of the analog source such as the LMT86 temperature sensor and many op amps. This requirement is easily accommodated by the addition of a capacitor,  $C_{FILTER}$ .

##### 9.2.1.2 Detailed Design Procedure

The size of  $C_{FILTER}$  depends on the size of the sampling capacitor and the sampling frequency. Because not all ADCs have identical input stages, the charge requirements will vary. This general ADC application is shown as an example only.

##### 9.2.1.3 Application Curve

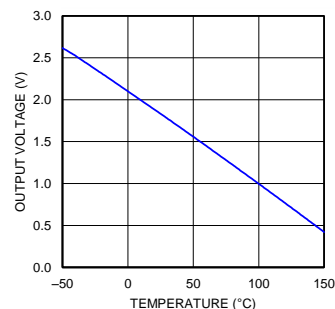


Figure 14. Analog Output Transfer Function

## Typical Applications (continued)

### 9.2.2 Conserving Power Dissipation With Shutdown

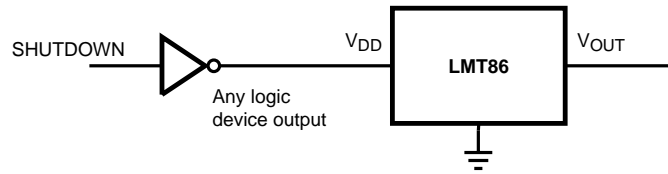


Figure 15. Conserving Power Dissipation With Shutdown

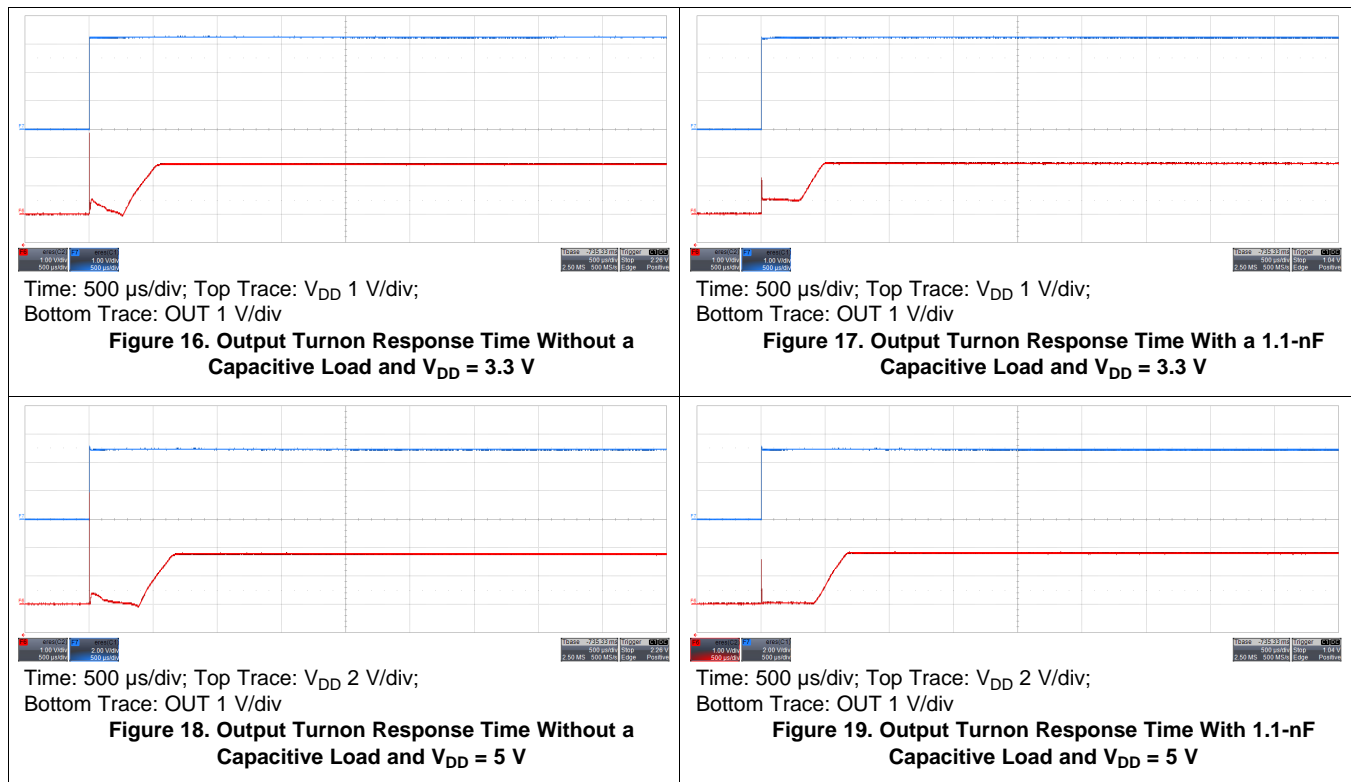
#### 9.2.2.1 Design Requirements

Because the power consumption of the LMT86 is less than  $9\ \mu\text{A}$ , it can simply be powered directly from any logic gate output and therefore not require a specific shutdown pin. The device can even be powered directly from a microcontroller GPIO. In this way, it can easily be turned off for cases such as battery-powered systems where power savings are critical.

#### 9.2.2.2 Detailed Design Procedure

Simply connect the  $V_{DD}$  pin of the LMT86 directly to the logic shutdown signal from a microcontroller.

#### 9.2.2.3 Application Curves



## 10 Power Supply Recommendations

The low supply current and supply range (2.2 V to 5.5 V) of the LMT86 allow the device to easily be powered from many sources. Power supply bypassing is optional and is mainly dependent on the noise on the power supply used. In noisy systems, it may be necessary to add bypass capacitors to lower the noise that is coupled to the output of the LMT86.

## 11 Layout

### 11.1 Layout Guidelines

The LMT86 is extremely simple to layout. If a power-supply bypass capacitor is used, it should be connected as shown in the [Layout Example](#).

### 11.2 Layout Example

○ VIA to ground plane

○ VIA to power plane

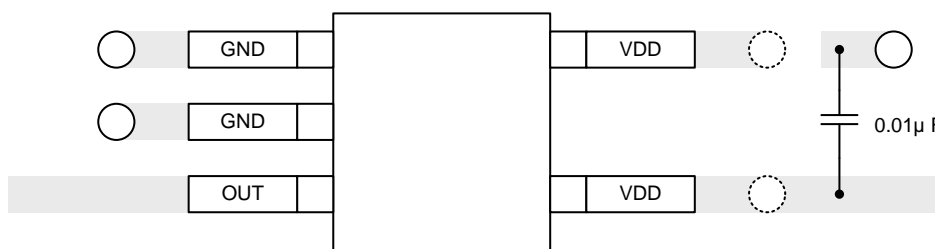


Figure 20. SC70 Package Recommended Layout

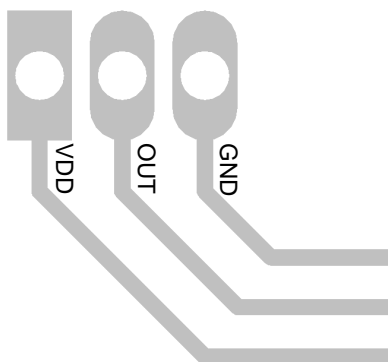


Figure 21. TO-92 LP Package Recommended Layout

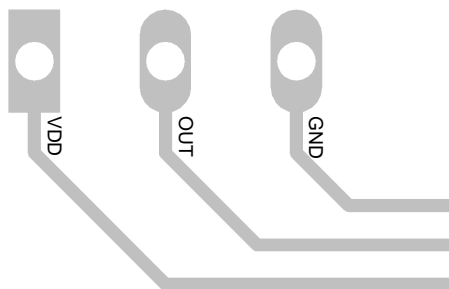


Figure 22. TO-92 LPM Package Recommended Layout

## 12 Device and Documentation Support

### 12.1 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

### 12.2 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

**TI E2E™ Online Community** *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

### 12.3 Trademarks

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### 12.4 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.

### 12.5 Glossary

[SLYZ022](#) — *TI Glossary*.

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

## 13 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<br>(1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan<br>(2)         | Lead/Ball Finish<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|--------------|-----------------|------|-------------|-------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| LMT86DCKR        | ACTIVE        | SC70         | DCK             | 5    | 3000        | Green (RoHS & no Sb/Br) | CU SN                   | Level-1-260C-UNLIM   | -50 to 150   | BSA                     | <a href="#">Samples</a> |
| LMT86DCKT        | ACTIVE        | SC70         | DCK             | 5    | 250         | Green (RoHS & no Sb/Br) | CU SN                   | Level-1-260C-UNLIM   | -50 to 150   | BSA                     | <a href="#">Samples</a> |
| LMT86LP          | ACTIVE        | TO-92        | LP              | 3    | 1800        | Green (RoHS & no Sb/Br) | CU SN                   | N / A for Pkg Type   | -50 to 150   | LMT86                   | <a href="#">Samples</a> |
| LMT86LPG         | ACTIVE        | TO-92        | LPG             | 3    | 1000        | Green (RoHS & no Sb/Br) | CU SN                   | N / A for Pkg Type   | -50 to 150   | LMT86                   | <a href="#">Samples</a> |
| LMT86LPGM        | ACTIVE        | TO-92        | LPG             | 3    | 3000        | Green (RoHS & no Sb/Br) | CU SN                   | N / A for Pkg Type   | -50 to 150   | LMT86                   | <a href="#">Samples</a> |
| LMT86LPM         | ACTIVE        | TO-92        | LP              | 3    | 2000        | Green (RoHS & no Sb/Br) | CU SN                   | N / A for Pkg Type   | -50 to 150   | LMT86                   | <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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(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.

<sup>(6)</sup> 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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**OTHER QUALIFIED VERSIONS OF LMT86 :**

- Automotive: [LMT86-Q1](#)

NOTE: Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

**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 |
|-----------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| LMT86DCKR | SC70         | DCK             | 5    | 3000 | 178.0              | 8.4                | 2.25    | 2.45    | 1.2     | 4.0     | 8.0    | Q3            |
| LMT86DCKT | SC70         | DCK             | 5    | 250  | 178.0              | 8.4                | 2.25    | 2.45    | 1.2     | 4.0     | 8.0    | Q3            |

**TAPE AND REEL BOX DIMENSIONS**


\*All dimensions are nominal

| Device    | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|-----------|--------------|-----------------|------|------|-------------|------------|-------------|
| LMT86DCKR | SC70         | DCK             | 5    | 3000 | 210.0       | 185.0      | 35.0        |
| LMT86DCKT | SC70         | DCK             | 5    | 250  | 210.0       | 185.0      | 35.0        |

# LPG0003A



# PACKAGE OUTLINE

## TO-92 - 5.05 mm max height

TRANSISTOR OUTLINE



4221343/C 01/2018

### NOTES:

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

LPG0003A

TO-92 - 5.05 mm max height

TRANSISTOR OUTLINE



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

4221343/C 01/2018

# TAPE SPECIFICATIONS

LPG0003A

TO-92 - 5.05 mm max height

TRANSISTOR OUTLINE



4221343/C 01/2018

## GENERIC PACKAGE VIEW

LP 3

TO-92 - 5.34 mm max height

TRANSISTOR OUTLINE



Images above are just a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.

4040001-2/F



LP0003A



# PACKAGE OUTLINE

TO-92 - 5.34 mm max height

TO-92



4215214/B 04/2017

## NOTES:

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.
3. Lead dimensions are not controlled within this area.
4. Reference JEDEC TO-226, variation AA.
5. Shipping method:
  - a. Straight lead option available in bulk pack only.
  - b. Formed lead option available in tape and reel or ammo pack.
  - c. Specific products can be offered in limited combinations of shipping medium and lead options.
  - d. Consult product folder for more information on available options.



LAND PATTERN EXAMPLE  
STRAIGHT LEAD OPTION  
NON-SOLDER MASK DEFINED  
SCALE:15X



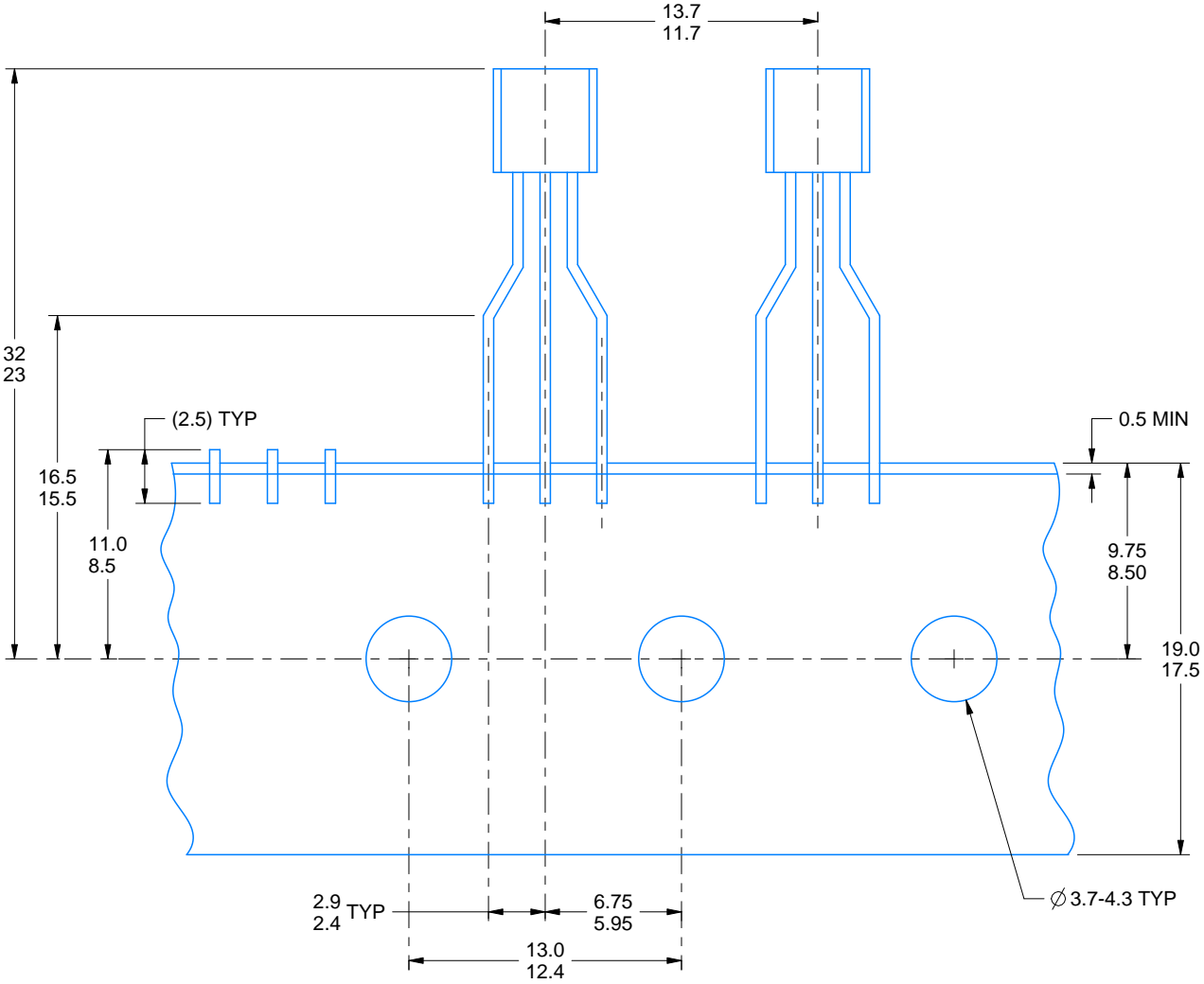
LAND PATTERN EXAMPLE  
FORMED LEAD OPTION  
NON-SOLDER MASK DEFINED  
SCALE:15X

# TAPE SPECIFICATIONS

LP0003A

TO-92 - 5.34 mm max height

TO-92

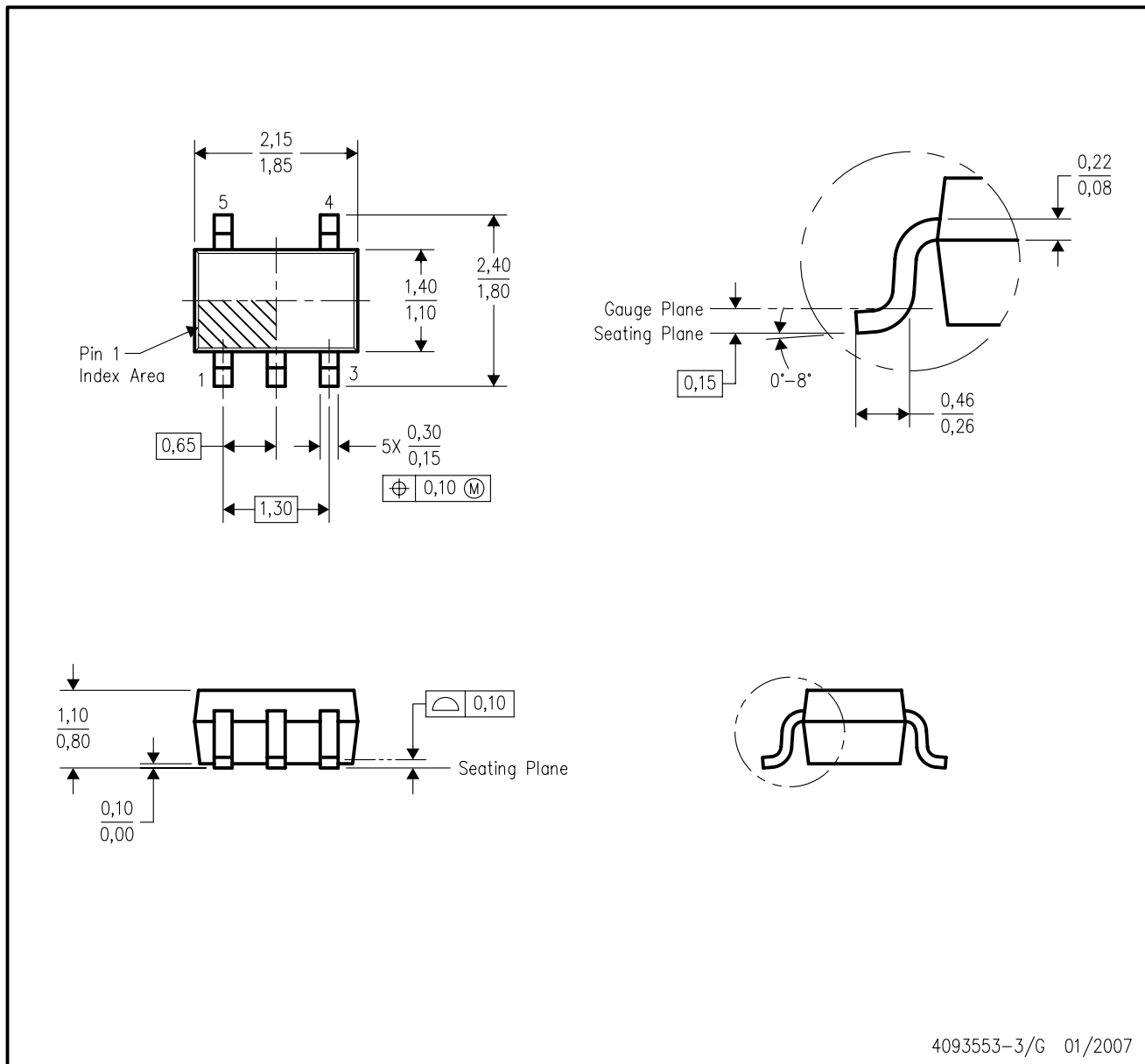


FOR FORMED LEAD OPTION PACKAGE

4215214/B 04/2017

DCK (R-PDSO-G5)

PLASTIC SMALL-OUTLINE PACKAGE



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

DCK (R-PDSO-G5)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
  - D. Publication IPC-7351 is recommended for alternate designs.
  - E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC-7525 for other stencil recommendations.

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