



# LM94022/-Q1 1.5-V, SC70, Multi-Gain Analog Temperature Sensor With Class-AB Output

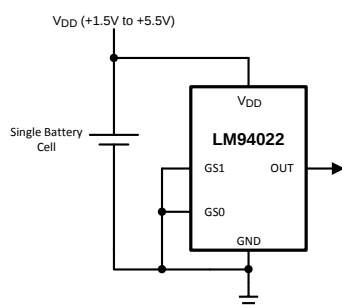
## 1 Features

- LM94022/-Q1 is AEC-Q100 Grade 0 qualified and is Manufactured on an Automotive Grade Flow
- Low 1.5-V to 5.5-V Operation With Low 5.4- $\mu$ A Supply Current
- Push-Pull Output With  $\pm 50$ - $\mu$ A Source Current Capability
- Four Selectable Gains
- Very Accurate Over Wide Temperature Range of  $-50^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ :
  - $\pm 1.5^{\circ}\text{C}$  Temperature Accuracy for  $20^{\circ}\text{C}$  to  $40^{\circ}\text{C}$  Range
  - $\pm 1.8^{\circ}\text{C}$  Temperature Accuracy for  $-50^{\circ}\text{C}$  to  $70^{\circ}\text{C}$  Range
  - $\pm 2.1^{\circ}\text{C}$  Temperature Accuracy for  $-50^{\circ}\text{C}$  to  $90^{\circ}\text{C}$  Range
  - $\pm 2.7^{\circ}\text{C}$  Temperature Accuracy for  $-50^{\circ}\text{C}$  to  $150^{\circ}\text{C}$  Range
- Output is Short-Circuit Protected
- Extremely Small SC70 Package
- For the Similar Functionality in a TO-92 Package, See [LMT84](#), [LMT85](#), [LMT86](#), or [LMT87](#)
- Footprint Compatible With the Industry-Standard LM20 Temperature Sensor

## 2 Applications

- Automotive
- Cell Phones
- Wireless Transceivers
- Battery Management
- Disk Drives
- Games
- Appliances

### Full-Range Celsius Temperature Sensor ( $-50^{\circ}\text{C}$ to $+150^{\circ}\text{C}$ ) Operating from a Single Cell Battery



## 3 Description

The LM94022/-Q1 device is a precision analog output CMOS integrated-circuit temperature sensor with selectable linear negative temperature coefficient (NTC). A class-AB output structure gives the LM94022/-Q1 strong output source and sink current capability for driving heavy transient loads such as that presented by the input of a sample-and-hold analog-to-digital converter. The low 5.4- $\mu$ A supply current and 1.5-V operating voltage of the LM94022/-Q1 make it ideal for battery-powered systems as well as general temperature-sensing applications.

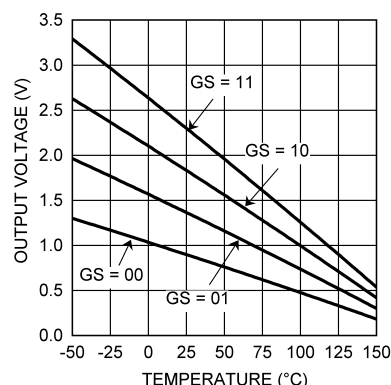
The Gain Select 1 (GS1) and Gain Select 0 (GS0) logic inputs select one of four gains for the temperature-to-voltage output transfer function:  $-5.5\text{ mV}/^{\circ}\text{C}$ ,  $-8.2\text{ mV}/^{\circ}\text{C}$ ,  $-10.9\text{ mV}/^{\circ}\text{C}$ , and  $-13.6\text{ mV}/^{\circ}\text{C}$ . Selecting  $-5.5\text{ mV}/^{\circ}\text{C}$  (GS1 and GS0 both tied low), allows the LM94022/-Q1 to operate down to 1.5-V supply while measuring temperature over the full range of  $-50^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ . Maximum temperature sensitivity,  $-13.6\text{ mV}/^{\circ}\text{C}$ , is selected when GS1 and GS0 are both tied high. The gain-select inputs can be tied directly to  $V_{\text{DD}}$  or Ground without any pullup or pulldown resistors, reducing component count and board area. These inputs can also be driven by logic signals allowing the system to optimize the gain during operation or system diagnostics.

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

| PART NUMBER | PACKAGE  | BODY SIZE (NOM)          |
|-------------|----------|--------------------------|
| LM94022     | SC70 (5) | 2.00 mm $\times$ 1.25 mm |
| LM94022-Q1  |          |                          |

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

### Output Temperature Characteristic



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## 4 Revision History

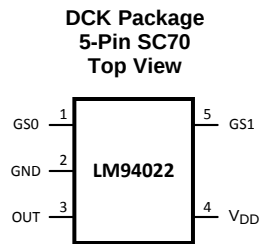
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|                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| <b>Changes from Revision E (June 2013) to Revision F</b>                                                                                                                                                                                                                                                                                                                                                                                                        | <b>Page</b> |
| <ul style="list-style-type: none"> <li>Added or changed: <i>Pin Configuration and Functions</i> section, <i>ESD Ratings</i> table, <i>Feature Description</i> section, <i>Device Functional Modes</i>, <i>Application and Implementation</i> section, <i>Power Supply Recommendations</i> section, <i>Layout</i> section, <i>Device and Documentation Support</i> section, and <i>Mechanical, Packaging, and Orderable Information</i> section .....</li> </ul> | <b>1</b>    |

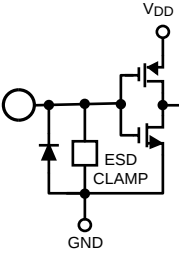
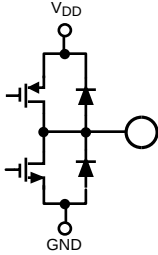
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| <b>Changes from Revision D (February 2013) to Revision E</b>                                     | <b>Page</b> |
| <ul style="list-style-type: none"> <li>added parabolic equation for LM94022/-Q1 .....</li> </ul> | <b>1</b>    |

|                                                                                                            |             |
|------------------------------------------------------------------------------------------------------------|-------------|
| <b>Changes from Revision C (May 2005) to Revision D</b>                                                    | <b>Page</b> |
| <ul style="list-style-type: none"> <li>Changed layout of National Data Sheet to TI format .....</li> </ul> | <b>17</b>   |

## 5 Pin Configuration and Functions



### Pin Functions

| PIN             |     | TYPE          | EQUIVALENT CIRCUIT                                                                  | FUNCTION                                                                               |
|-----------------|-----|---------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| NAME            | NO. |               |                                                                                     |                                                                                        |
| GS1             | 5   | Logic Input   |    | Gain Select 1 - One of two logic inputs for selecting the slope of the output response |
| GS0             | 1   | Logic Input   |                                                                                     | Gain Select 0 - One of two logic inputs for selecting the slope of the output response |
| OUT             | 3   | Analog Output |  | Outputs a voltage which is inversely proportional to temperature                       |
| V <sub>DD</sub> | 4   | Power         | —                                                                                   | Positive Supply Voltage                                                                |
| GND             | 2   | Ground        | —                                                                                   | Power Supply Ground                                                                    |

## 6 Specifications

### 6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<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                      | mA   |
| Voltage at GS0 and GS1 Input Pins               | −0.3 | 6                       | V    |
| Input Current at any pin <sup>(3)</sup>         |      | 5                       | mA   |
| Maximum Junction Temperature, T <sub>JMAX</sub> |      | 150                     | °C   |
| Storage temperature, T <sub>stg</sub>           | −65  | 150                     | °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 <http://www.ti.com/packaging>
- (3) 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<sup>+</sup>), the current at that pin should be limited to 5 mA.

### 6.2 ESD Ratings

|                                            | VALUE                                    | UNIT  |
|--------------------------------------------|------------------------------------------|-------|
| V <sub>(ESD)</sub> Electrostatic discharge | Human body model (HBM) <sup>(1)(2)</sup> | ±2500 |
|                                            | Machine model <sup>(2)</sup>             | ±250  |
|                                            |                                          | V     |

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

### 6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

|                                                                                              | MIN | MAX | UNIT |
|----------------------------------------------------------------------------------------------|-----|-----|------|
| Free Air or Specified Temperature<br>(T <sub>MIN</sub> ≤ T <sub>A</sub> ≤ T <sub>MAX</sub> ) | −50 | 150 | °C   |
| Supply Voltage (V <sub>DD</sub> )                                                            | 1.5 | 5.5 | V    |

- (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 guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

### 6.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup>                           | LM94022, LM94022-Q1 | UNIT |
|---------------------------------------------------------|---------------------|------|
|                                                         | DCK (SC70)          |      |
|                                                         | 5 PINS              |      |
| R <sub>θJA</sub> Junction-to-ambient thermal resistance | 415                 | °C/W |

- (1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, [SPRA953](#).

## 6.5 Electrical Characteristics

Unless otherwise noted, these specifications apply for  $V_{DD} = 1.5\text{ V}$  to  $5.5\text{ V}$ ; all limits  $T_A = T_J = 25^\circ\text{C}$  unless otherwise specified. These limits do not include DC load regulation. These stated accuracy limits are with reference to the values in the [Table 2](#).

| PARAMETER                        | CONDITIONS         | MIN                                                                                             | TYP <sup>(1)</sup> | MAX <sup>(2)</sup> | UNIT             |
|----------------------------------|--------------------|-------------------------------------------------------------------------------------------------|--------------------|--------------------|------------------|
| <b>ACCURACY CHARACTERISTICS</b>  |                    |                                                                                                 |                    |                    |                  |
| Temperature Error <sup>(3)</sup> | GS1 = 0<br>GS0 = 0 | $T_A = +20^\circ\text{C}$ to $+40^\circ\text{C}$ ;<br>$V_{DD} = 1.5\text{ V}$ to $5.5\text{ V}$ | –1.5               | 1.5                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+70^\circ\text{C}$ ;<br>$V_{DD} = 1.5\text{ V}$ to $5.5\text{ V}$  | –1.8               | 1.8                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+90^\circ\text{C}$ ;<br>$V_{DD} = 1.5\text{ V}$ to $5.5\text{ V}$  | –2.1               | 2.1                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+120^\circ\text{C}$ ;<br>$V_{DD} = 1.5\text{ V}$ to $5.5\text{ V}$ | –2.4               | 2.4                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+150^\circ\text{C}$ ;<br>$V_{DD} = 1.5\text{ V}$ to $5.5\text{ V}$ | –2.7               | 2.7                | $^\circ\text{C}$ |
|                                  |                    | $T_A = -50^\circ\text{C}$ to $+0^\circ\text{C}$ ;<br>$V_{DD} = 1.6\text{ V}$ to $5.5\text{ V}$  | –1.8               | 1.8                | $^\circ\text{C}$ |
|                                  | GS1 = 0<br>GS0 = 1 | $T_A = +20^\circ\text{C}$ to $+40^\circ\text{C}$ ;<br>$V_{DD} = 1.8\text{ V}$ to $5.5\text{ V}$ | –1.5               | 1.5                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+70^\circ\text{C}$ ;<br>$V_{DD} = 1.9\text{ V}$ to $5.5\text{ V}$  | –1.8               | 1.8                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+90^\circ\text{C}$ ;<br>$V_{DD} = 1.9\text{ V}$ to $5.5\text{ V}$  | –2.1               | 2.1                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+120^\circ\text{C}$ ;<br>$V_{DD} = 1.9\text{ V}$ to $5.5\text{ V}$ | –2.4               | 2.4                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+150^\circ\text{C}$ ;<br>$V_{DD} = 1.9\text{ V}$ to $5.5\text{ V}$ | –2.7               | 2.7                | $^\circ\text{C}$ |
|                                  |                    | $T_A = -50^\circ\text{C}$ to $+0^\circ\text{C}$ ;<br>$V_{DD} = 2.3\text{ V}$ to $5.5\text{ V}$  | –1.8               | 1.8                | $^\circ\text{C}$ |
|                                  | GS1 = 1<br>GS0 = 0 | $T_A = +20^\circ\text{C}$ to $+40^\circ\text{C}$ ;<br>$V_{DD} = 2.2\text{ V}$ to $5.5\text{ V}$ | –1.5               | 1.5                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+70^\circ\text{C}$ ;<br>$V_{DD} = 2.4\text{ V}$ to $5.5\text{ V}$  | –1.8               | 1.8                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+90^\circ\text{C}$ ;<br>$V_{DD} = 2.4\text{ V}$ to $5.5\text{ V}$  | –2.1               | 2.1                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+120^\circ\text{C}$ ;<br>$V_{DD} = 2.4\text{ V}$ to $5.5\text{ V}$ | –2.4               | 2.4                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+150^\circ\text{C}$ ;<br>$V_{DD} = 2.4\text{ V}$ to $5.5\text{ V}$ | –2.7               | 2.7                | $^\circ\text{C}$ |
|                                  |                    | $T_A = -50^\circ\text{C}$ to $+0^\circ\text{C}$ ;<br>$V_{DD} = 3.0\text{ V}$ to $5.5\text{ V}$  | –1.8               | 1.8                | $^\circ\text{C}$ |
|                                  | GS1 = 1<br>GS0 = 1 | $T_A = +20^\circ\text{C}$ to $+40^\circ\text{C}$ ;<br>$V_{DD} = 2.7\text{ V}$ to $5.5\text{ V}$ | –1.5               | 1.5                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+70^\circ\text{C}$ ;<br>$V_{DD} = 3.0\text{ V}$ to $5.5\text{ V}$  | –1.8               | 1.8                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+90^\circ\text{C}$ ;<br>$V_{DD} = 3.0\text{ V}$ to $5.5\text{ V}$  | –2.1               | 2.1                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+120^\circ\text{C}$ ;<br>$V_{DD} = 3.0\text{ V}$ to $5.5\text{ V}$ | –2.4               | 2.4                | $^\circ\text{C}$ |
|                                  |                    | $T_A = +0^\circ\text{C}$ to $+150^\circ\text{C}$ ;<br>$V_{DD} = 3.0\text{ V}$ to $5.5\text{ V}$ | –2.7               | 2.7                | $^\circ\text{C}$ |
|                                  |                    | $T_A = -50^\circ\text{C}$ to $+0^\circ\text{C}$ ;<br>$V_{DD} = 3.6\text{ V}$ to $5.5\text{ V}$  | –1.8               | 1.8                | $^\circ\text{C}$ |

(1) Typicals are at  $T_J = T_A = 25^\circ\text{C}$  and represent most likely parametric norm.

(2) Limits are warranted to TI's AOQL (Average Outgoing Quality Level).

(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  $^\circ\text{C}$ ). Accuracy limits include line regulation within the specified conditions. Accuracy limits do not include load regulation; they assume no DC load.

**LM94022, LM94022-Q1**

SNIS140F – MAY 2006 – REVISED SEPTEMBER 2015

[www.ti.com](http://www.ti.com)
**Electrical Characteristics (continued)**

Unless otherwise noted, these specifications apply for  $V_{DD} = 1.5\text{ V}$  to  $5.5\text{ V}$ ; all limits  $T_A = T_J = 25^\circ\text{C}$  unless otherwise specified. These limits do not include DC load regulation. These stated accuracy limits are with reference to the values in [Table 2](#).

| PARAMETER                                            | CONDITIONS                                                                           | MIN                                                     | TYP <sup>(1)</sup> | MAX <sup>(2)</sup> | UNIT            |
|------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------|--------------------|--------------------|-----------------|
| Sensor Gain                                          | GS1 = 0, GS0 = 0                                                                     |                                                         | –5.5               |                    | mV/°C           |
|                                                      | GS1 = 0, GS0 = 1                                                                     |                                                         | –8.2               |                    | mV/°C           |
|                                                      | GS1 = 1, GS0 = 0                                                                     |                                                         | –10.9              |                    | mV/°C           |
|                                                      | GS1 = 1, GS0 = 1                                                                     |                                                         | –13.6              |                    | mV/°C           |
| Load Regulation <sup>(4)</sup>                       | Source $\leq 50\text{ }\mu\text{A}$ ,<br>( $V_{DD} - V_{OUT}$ ) $\geq 200\text{ mV}$ |                                                         | –0.22              |                    | mV              |
|                                                      | $T_A = T_J = T_{MIN}$ to $T_{MAX}$                                                   |                                                         |                    | –1                 |                 |
|                                                      | Sink $\leq 50\text{ }\mu\text{A}$ ,<br>$V_{OUT} \geq 200\text{ mV}$                  |                                                         | 0.26               |                    | mV              |
|                                                      | $T_A = T_J = T_{MIN}$ to $T_{MAX}$                                                   |                                                         |                    | 1                  |                 |
| Line Regulation <sup>(5)</sup>                       |                                                                                      |                                                         | 200                |                    | $\mu\text{V/V}$ |
| $I_S$ Supply Current                                 | $(V_{DD} - V_{OUT}) \geq 100\text{ mV}$                                              |                                                         | 5.4                |                    | $\mu\text{A}$   |
|                                                      |                                                                                      | $T_A = T_J = +30^\circ\text{C}$ to $+150^\circ\text{C}$ |                    | 8.1                |                 |
|                                                      | $(V_{DD} - V_{OUT}) \geq 100\text{ mV}$                                              |                                                         | 5.4                |                    | $\mu\text{A}$   |
|                                                      |                                                                                      | $T_A = T_J = T_{MIN}$ to $T_{MAX}$                      |                    | 9                  |                 |
| $C_L$ Output Load Capacitance                        |                                                                                      |                                                         | 1100               |                    | pF              |
| Power-ON Time <sup>(6)</sup>                         | $C_L = 0\text{ pF}$ to $1100\text{ pF}$                                              |                                                         | 0.7                |                    | ms              |
|                                                      |                                                                                      | $T_A = T_J = T_{MIN}$ to $T_{MAX}$                      |                    | 1.9                |                 |
| $V_{IH}$ GS1 and GS0 Input Logic 1 Threshold Voltage | $T_A = T_J = T_{MIN}$ to $T_{MAX}$                                                   | $V_{DD} - 0.5$                                          |                    |                    | V               |
| $V_{IL}$ GS1 and GS0 Input Logic 0 Threshold Voltage | $T_A = T_J = T_{MIN}$ to $T_{MAX}$                                                   |                                                         |                    | 0.5                | V               |
| $I_{IH}$ Logic 1 Input Current <sup>(7)</sup>        |                                                                                      |                                                         | 0.001              |                    | $\mu\text{A}$   |
|                                                      | $T_A = T_J = T_{MIN}$ to $T_{MAX}$                                                   |                                                         |                    | 1                  |                 |
| $I_{IL}$ Logic 0 Input Current <sup>(7)</sup>        |                                                                                      |                                                         | 0.001              |                    | $\mu\text{A}$   |
|                                                      | $T_A = T_J = T_{MIN}$ to $T_{MAX}$                                                   |                                                         |                    | 1                  |                 |

(4) Source currents are flowing out of the LM94022/-Q1. Sink currents are flowing into the LM94022/-Q1.

(5) 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](#).

(6) Warrantied by design and characterization.

(7) The input current is leakage only and is highest at high temperature. It is typically only  $0.001\text{ }\mu\text{A}$ . The  $1\text{-}\mu\text{A}$  limit is solely based on a testing limitation and does not reflect the actual performance of the part.

## 6.6 Typical Characteristics

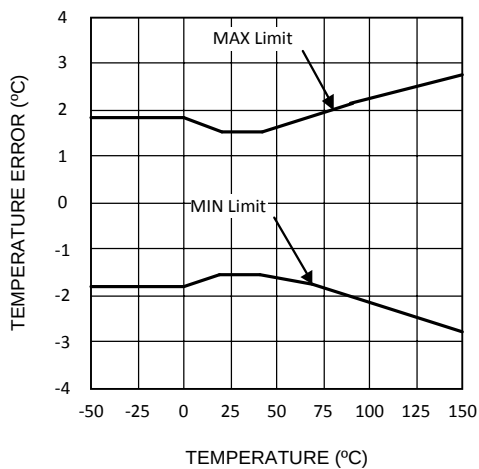


Figure 1. Temperature Error vs. Temperature

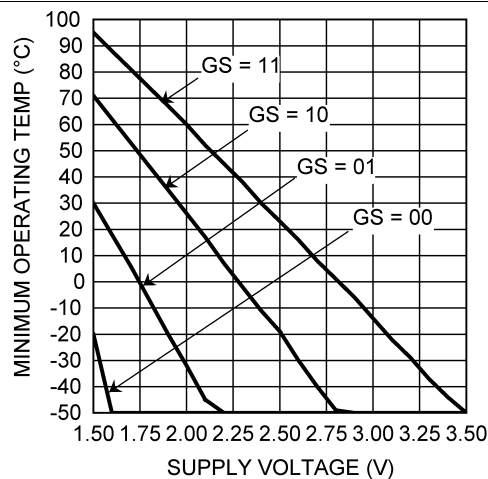


Figure 2. Minimum Operating Temperature vs. Supply Voltage

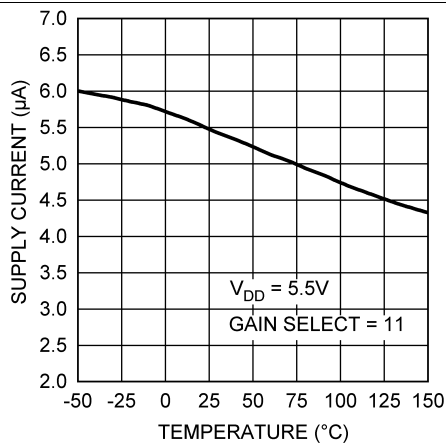


Figure 3. Supply Current vs. Temperature

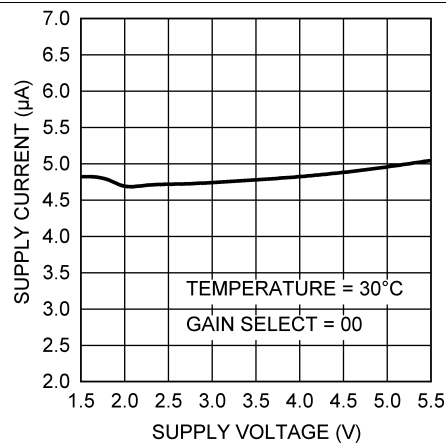


Figure 4. Supply Current vs. Supply Voltage

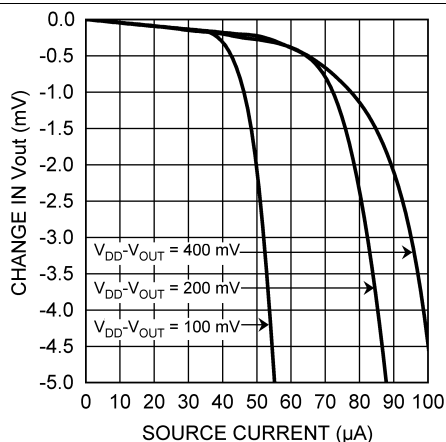


Figure 5. Load Regulation, Sourcing Current

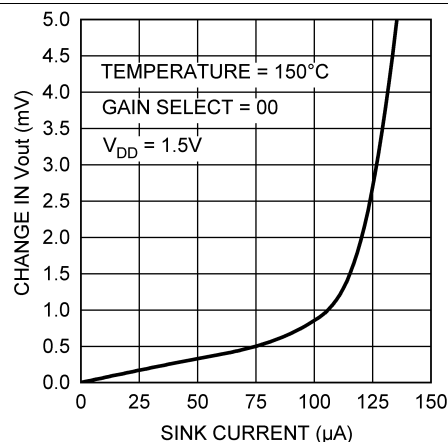
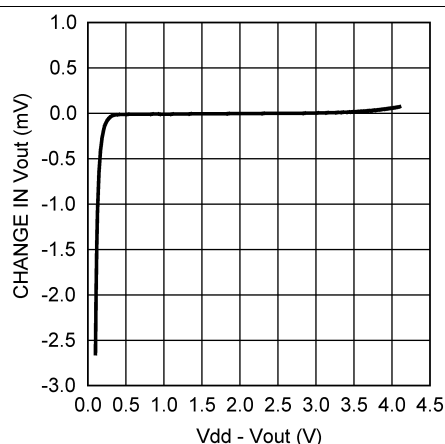
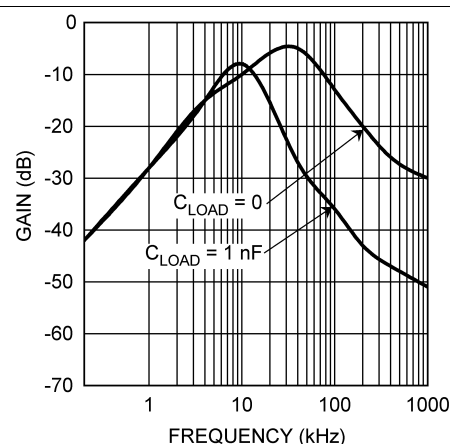
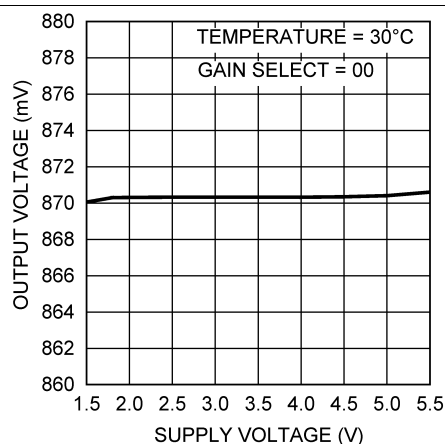
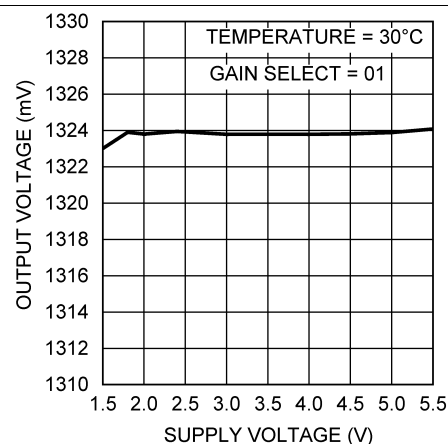
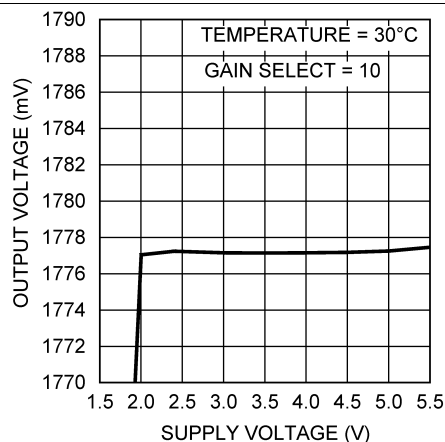
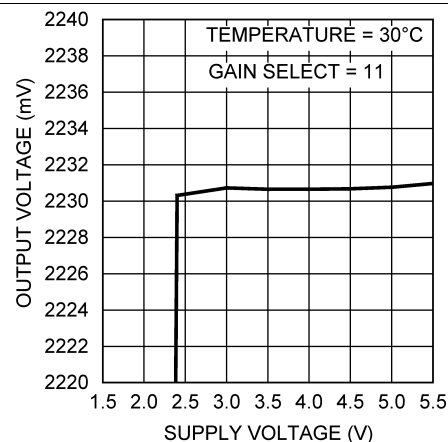


Figure 6. Load Regulation, Sinking Current

**Typical Characteristics (continued)**

**Figure 7. Change in Vout vs. Overhead Voltage**

**Figure 8. Supply-Noise Gain vs. Frequency**

**Figure 9. Output Voltage vs. Supply Voltage  
Gain Select = 00**

**Figure 10. Output Voltage vs. Supply Voltage  
Gain Select = 01**

**Figure 11. Output Voltage vs. Supply Voltage  
Gain Select = 10**

**Figure 12. Output Voltage vs. Supply Voltage  
Gain Select = 11**

## 7 Detailed Description

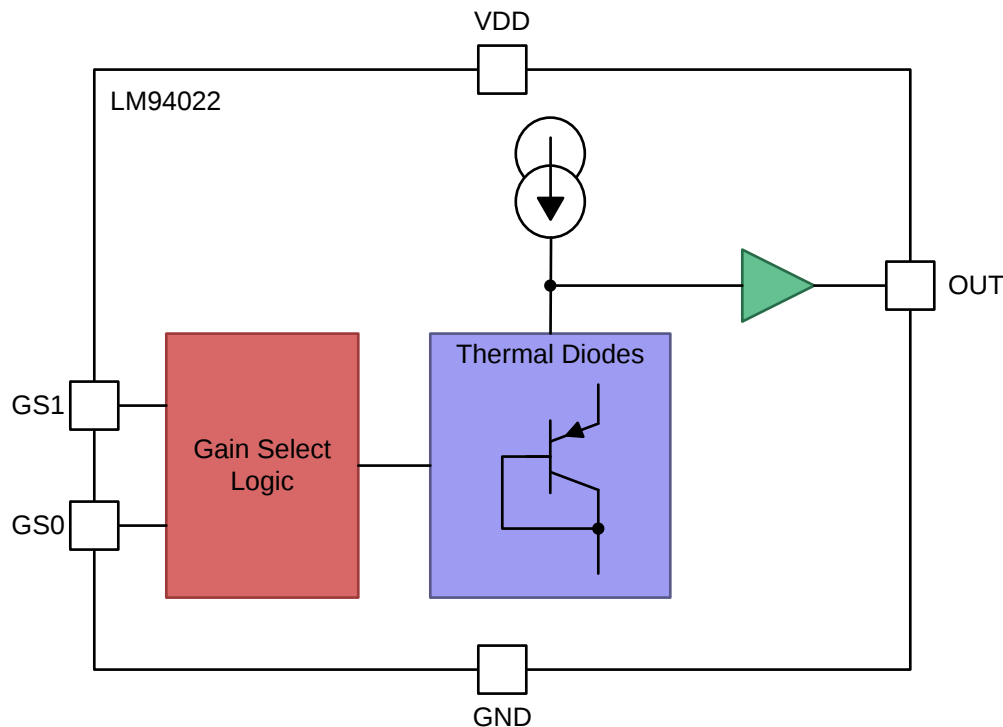
### 7.1 Overview

The LM94022/-Q1 is an analog output temperature sensor with a selectable negative temperature coefficient output (NTC). The temperature-sensing element is comprised of stacked transistor base emitter junctions (thermal diodes) that are forward biased by a current source. The number of stacked thermal diodes determines the output gain or slope. The gain select pins (GS1 and GS0) are simple logic inputs that control the number of stacked thermal diodes thus selecting the output gain as shown in the [Table 1](#) table. The temperature sensing element is buffered by a simple amplifier that drives the output pin. The simple class AB output stage of the amplifier can source or sink current and provides low-impedance, high-current drive.

**Table 1. Gain Select Pin Function**

| GS1 LOGIC LEVEL | GS0 LOGIC LEVEL | SELECTED AVERAGE GAIN |
|-----------------|-----------------|-----------------------|
| 0               | 0               | –5.5 mV/°C            |
| 0               | 1               | –8.2 mV/°C            |
| 1               | 0               | –10.9 mV/°C           |
| 1               | 1               | –13.6 mV/°C           |

### 7.2 Functional Block Diagram



### 7.3 Feature Description

#### 7.3.1 LM94022/-Q1 Transfer Function Gain Selection

The LM94022/-Q1 has four selectable gains, each of which can be selected by the GS1 and GS0 input pins. The output voltage for each gain, across the complete operating temperature range is shown in [Table 2](#). This table is the reference from which the LM94022/-Q1 accuracy specifications (listed in the [Electrical 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 LM94022 product folder under [Tools and Software](#).

**Table 2. LM94022/LM94022-Q1 Transfer Table**

| TEMPERATURE<br>(°C) | GS = 00<br>(mV) | GS = 01<br>(mV) | GS = 10<br>(mV) | GS = 11<br>(mV) |
|---------------------|-----------------|-----------------|-----------------|-----------------|
| –50                 | 1299            | 1955            | 2616            | 3277            |
| –49                 | 1294            | 1949            | 2607            | 3266            |
| –48                 | 1289            | 1942            | 2598            | 3254            |
| –47                 | 1284            | 1935            | 2589            | 3243            |
| –46                 | 1278            | 1928            | 2580            | 3232            |
| –45                 | 1273            | 1921            | 2571            | 3221            |
| –44                 | 1268            | 1915            | 2562            | 3210            |
| –43                 | 1263            | 1908            | 2553            | 3199            |
| –42                 | 1257            | 1900            | 2543            | 3186            |
| –41                 | 1252            | 1892            | 2533            | 3173            |
| –40                 | 1247            | 1885            | 2522            | 3160            |
| –39                 | 1242            | 1877            | 2512            | 3147            |
| –38                 | 1236            | 1869            | 2501            | 3134            |
| –37                 | 1231            | 1861            | 2491            | 3121            |
| –36                 | 1226            | 1853            | 2481            | 3108            |
| –35                 | 1221            | 1845            | 2470            | 3095            |
| –34                 | 1215            | 1838            | 2460            | 3082            |
| –33                 | 1210            | 1830            | 2449            | 3069            |
| –32                 | 1205            | 1822            | 2439            | 3056            |
| –31                 | 1200            | 1814            | 2429            | 3043            |
| –30                 | 1194            | 1806            | 2418            | 3030            |
| –29                 | 1189            | 1798            | 2408            | 3017            |
| –28                 | 1184            | 1790            | 2397            | 3004            |
| –27                 | 1178            | 1783            | 2387            | 2991            |
| –26                 | 1173            | 1775            | 2376            | 2978            |
| –25                 | 1168            | 1767            | 2366            | 2965            |
| –24                 | 1162            | 1759            | 2355            | 2952            |
| –23                 | 1157            | 1751            | 2345            | 2938            |
| –22                 | 1152            | 1743            | 2334            | 2925            |
| –21                 | 1146            | 1735            | 2324            | 2912            |
| –20                 | 1141            | 1727            | 2313            | 2899            |
| –19                 | 1136            | 1719            | 2302            | 2886            |
| –18                 | 1130            | 1711            | 2292            | 2873            |
| –17                 | 1125            | 1703            | 2281            | 2859            |
| –16                 | 1120            | 1695            | 2271            | 2846            |
| –15                 | 1114            | 1687            | 2260            | 2833            |
| –14                 | 1109            | 1679            | 2250            | 2820            |
| –13                 | 1104            | 1671            | 2239            | 2807            |
| –12                 | 1098            | 1663            | 2228            | 2793            |
| –11                 | 1093            | 1656            | 2218            | 2780            |
| –10                 | 1088            | 1648            | 2207            | 2767            |
| –9                  | 1082            | 1639            | 2197            | 2754            |
| –8                  | 1077            | 1631            | 2186            | 2740            |
| –7                  | 1072            | 1623            | 2175            | 2727            |
| –6                  | 1066            | 1615            | 2164            | 2714            |
| –5                  | 1061            | 1607            | 2154            | 2700            |
| –4                  | 1055            | 1599            | 2143            | 2687            |

**Table 2. LM94022/LM94022-Q1 Transfer Table (continued)**

| TEMPERATURE<br>(°C) | GS = 00<br>(mV) | GS = 01<br>(mV) | GS = 10<br>(mV) | GS = 11<br>(mV) |
|---------------------|-----------------|-----------------|-----------------|-----------------|
| –3                  | 1050            | 1591            | 2132            | 2674            |
| –2                  | 1044            | 1583            | 2122            | 2660            |
| –1                  | 1039            | 1575            | 2111            | 2647            |
| 0                   | 1034            | 1567            | 2100            | 2633            |
| 1                   | 1028            | 1559            | 2089            | 2620            |
| 2                   | 1023            | 1551            | 2079            | 2607            |
| 3                   | 1017            | 1543            | 2068            | 2593            |
| 4                   | 1012            | 1535            | 2057            | 2580            |
| 5                   | 1007            | 1527            | 2047            | 2567            |
| 6                   | 1001            | 1519            | 2036            | 2553            |
| 7                   | 996             | 1511            | 2025            | 2540            |
| 8                   | 990             | 1502            | 2014            | 2527            |
| 9                   | 985             | 1494            | 2004            | 2513            |
| 10                  | 980             | 1486            | 1993            | 2500            |
| 11                  | 974             | 1478            | 1982            | 2486            |
| 12                  | 969             | 1470            | 1971            | 2473            |
| 13                  | 963             | 1462            | 1961            | 2459            |
| 14                  | 958             | 1454            | 1950            | 2446            |
| 15                  | 952             | 1446            | 1939            | 2433            |
| 16                  | 947             | 1438            | 1928            | 2419            |
| 17                  | 941             | 1430            | 1918            | 2406            |
| 18                  | 936             | 1421            | 1907            | 2392            |
| 19                  | 931             | 1413            | 1896            | 2379            |
| 20                  | 925             | 1405            | 1885            | 2365            |
| 21                  | 920             | 1397            | 1874            | 2352            |
| 22                  | 914             | 1389            | 1864            | 2338            |
| 23                  | 909             | 1381            | 1853            | 2325            |
| 24                  | 903             | 1373            | 1842            | 2311            |
| 25                  | 898             | 1365            | 1831            | 2298            |
| 26                  | 892             | 1356            | 1820            | 2285            |
| 27                  | 887             | 1348            | 1810            | 2271            |
| 28                  | 882             | 1340            | 1799            | 2258            |
| 29                  | 876             | 1332            | 1788            | 2244            |
| 30                  | 871             | 1324            | 1777            | 2231            |
| 31                  | 865             | 1316            | 1766            | 2217            |
| 32                  | 860             | 1308            | 1756            | 2204            |
| 33                  | 854             | 1299            | 1745            | 2190            |
| 34                  | 849             | 1291            | 1734            | 2176            |
| 35                  | 843             | 1283            | 1723            | 2163            |
| 36                  | 838             | 1275            | 1712            | 2149            |
| 37                  | 832             | 1267            | 1701            | 2136            |
| 38                  | 827             | 1258            | 1690            | 2122            |
| 39                  | 821             | 1250            | 1679            | 2108            |
| 40                  | 816             | 1242            | 1668            | 2095            |
| 41                  | 810             | 1234            | 1657            | 2081            |
| 42                  | 804             | 1225            | 1646            | 2067            |
| 43                  | 799             | 1217            | 1635            | 2054            |

**Table 2. LM94022/LM94022-Q1 Transfer Table (continued)**

| TEMPERATURE<br>(°C) | GS = 00<br>(mV) | GS = 01<br>(mV) | GS = 10<br>(mV) | GS = 11<br>(mV) |
|---------------------|-----------------|-----------------|-----------------|-----------------|
| 44                  | 793             | 1209            | 1624            | 2040            |
| 45                  | 788             | 1201            | 1613            | 2026            |
| 46                  | 782             | 1192            | 1602            | 2012            |
| 47                  | 777             | 1184            | 1591            | 1999            |
| 48                  | 771             | 1176            | 1580            | 1985            |
| 49                  | 766             | 1167            | 1569            | 1971            |
| 50                  | 760             | 1159            | 1558            | 1958            |
| 51                  | 754             | 1151            | 1547            | 1944            |
| 52                  | 749             | 1143            | 1536            | 1930            |
| 53                  | 743             | 1134            | 1525            | 1916            |
| 54                  | 738             | 1126            | 1514            | 1902            |
| 55                  | 732             | 1118            | 1503            | 1888            |
| 56                  | 726             | 1109            | 1492            | 1875            |
| 57                  | 721             | 1101            | 1481            | 1861            |
| 58                  | 715             | 1093            | 1470            | 1847            |
| 59                  | 710             | 1084            | 1459            | 1833            |
| 60                  | 704             | 1076            | 1448            | 1819            |
| 61                  | 698             | 1067            | 1436            | 1805            |
| 62                  | 693             | 1059            | 1425            | 1791            |
| 63                  | 687             | 1051            | 1414            | 1777            |
| 64                  | 681             | 1042            | 1403            | 1763            |
| 65                  | 676             | 1034            | 1391            | 1749            |
| 66                  | 670             | 1025            | 1380            | 1735            |
| 67                  | 664             | 1017            | 1369            | 1721            |
| 68                  | 659             | 1008            | 1358            | 1707            |
| 69                  | 653             | 1000            | 1346            | 1693            |
| 70                  | 647             | 991             | 1335            | 1679            |
| 71                  | 642             | 983             | 1324            | 1665            |
| 72                  | 636             | 974             | 1313            | 1651            |
| 73                  | 630             | 966             | 1301            | 1637            |
| 74                  | 625             | 957             | 1290            | 1623            |
| 75                  | 619             | 949             | 1279            | 1609            |
| 76                  | 613             | 941             | 1268            | 1595            |
| 77                  | 608             | 932             | 1257            | 1581            |
| 78                  | 602             | 924             | 1245            | 1567            |
| 79                  | 596             | 915             | 1234            | 1553            |
| 80                  | 591             | 907             | 1223            | 1539            |
| 81                  | 585             | 898             | 1212            | 1525            |
| 82                  | 579             | 890             | 1201            | 1511            |
| 83                  | 574             | 881             | 1189            | 1497            |
| 84                  | 568             | 873             | 1178            | 1483            |
| 85                  | 562             | 865             | 1167            | 1469            |
| 86                  | 557             | 856             | 1155            | 1455            |
| 87                  | 551             | 848             | 1144            | 1441            |
| 88                  | 545             | 839             | 1133            | 1427            |
| 89                  | 539             | 831             | 1122            | 1413            |
| 90                  | 534             | 822             | 1110            | 1399            |

**Table 2. LM94022/LM94022-Q1 Transfer Table (continued)**

| TEMPERATURE<br>(°C) | GS = 00<br>(mV) | GS = 01<br>(mV) | GS = 10<br>(mV) | GS = 11<br>(mV) |
|---------------------|-----------------|-----------------|-----------------|-----------------|
| 91                  | 528             | 814             | 1099            | 1385            |
| 92                  | 522             | 805             | 1088            | 1371            |
| 93                  | 517             | 797             | 1076            | 1356            |
| 94                  | 511             | 788             | 1065            | 1342            |
| 95                  | 505             | 779             | 1054            | 1328            |
| 96                  | 499             | 771             | 1042            | 1314            |
| 97                  | 494             | 762             | 1031            | 1300            |
| 98                  | 488             | 754             | 1020            | 1286            |
| 99                  | 482             | 745             | 1008            | 1272            |
| 100                 | 476             | 737             | 997             | 1257            |
| 101                 | 471             | 728             | 986             | 1243            |
| 102                 | 465             | 720             | 974             | 1229            |
| 103                 | 459             | 711             | 963             | 1215            |
| 104                 | 453             | 702             | 951             | 1201            |
| 105                 | 448             | 694             | 940             | 1186            |
| 106                 | 442             | 685             | 929             | 1172            |
| 107                 | 436             | 677             | 917             | 1158            |
| 108                 | 430             | 668             | 906             | 1144            |
| 109                 | 425             | 660             | 895             | 1130            |
| 110                 | 419             | 651             | 883             | 1115            |
| 111                 | 413             | 642             | 872             | 1101            |
| 112                 | 407             | 634             | 860             | 1087            |
| 113                 | 401             | 625             | 849             | 1073            |
| 114                 | 396             | 617             | 837             | 1058            |
| 115                 | 390             | 608             | 826             | 1044            |
| 116                 | 384             | 599             | 814             | 1030            |
| 117                 | 378             | 591             | 803             | 1015            |
| 118                 | 372             | 582             | 791             | 1001            |
| 119                 | 367             | 573             | 780             | 987             |
| 120                 | 361             | 565             | 769             | 973             |
| 121                 | 355             | 556             | 757             | 958             |
| 122                 | 349             | 547             | 745             | 944             |
| 123                 | 343             | 539             | 734             | 929             |
| 124                 | 337             | 530             | 722             | 915             |
| 125                 | 332             | 521             | 711             | 901             |
| 126                 | 326             | 513             | 699             | 886             |
| 127                 | 320             | 504             | 688             | 872             |
| 128                 | 314             | 495             | 676             | 858             |
| 129                 | 308             | 487             | 665             | 843             |
| 130                 | 302             | 478             | 653             | 829             |
| 131                 | 296             | 469             | 642             | 814             |
| 132                 | 291             | 460             | 630             | 800             |
| 133                 | 285             | 452             | 618             | 786             |
| 134                 | 279             | 443             | 607             | 771             |
| 135                 | 273             | 434             | 595             | 757             |
| 136                 | 267             | 425             | 584             | 742             |
| 137                 | 261             | 416             | 572             | 728             |

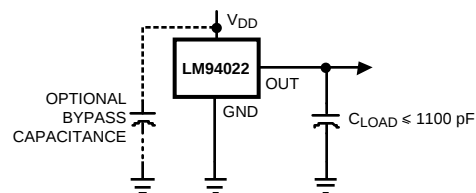
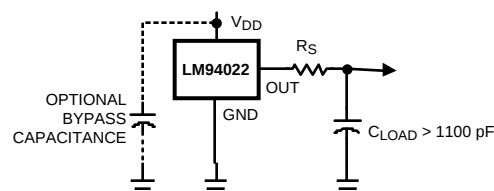
**Table 2. LM94022/LM94022-Q1 Transfer Table (continued)**

| TEMPERATURE<br>(°C) | GS = 00<br>(mV) | GS = 01<br>(mV) | GS = 10<br>(mV) | GS = 11<br>(mV) |
|---------------------|-----------------|-----------------|-----------------|-----------------|
| 138                 | 255             | 408             | 560             | 713             |
| 139                 | 249             | 399             | 549             | 699             |
| 140                 | 243             | 390             | 537             | 684             |
| 141                 | 237             | 381             | 525             | 670             |
| 142                 | 231             | 372             | 514             | 655             |
| 143                 | 225             | 363             | 502             | 640             |
| 144                 | 219             | 354             | 490             | 626             |
| 145                 | 213             | 346             | 479             | 611             |
| 146                 | 207             | 337             | 467             | 597             |
| 147                 | 201             | 328             | 455             | 582             |
| 148                 | 195             | 319             | 443             | 568             |
| 149                 | 189             | 310             | 432             | 553             |
| 150                 | 183             | 301             | 420             | 538             |

## 7.4 Device Functional Modes

### 7.4.1 Capacitive Loads

The LM94022/-Q1 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 LM94022/-Q1 can drive a capacitive load less than or equal to 1100 pF as shown in [Figure 13](#). For capacitive loads greater than 1100 pF, a series resistor may be required on the output, as shown in [Figure 14](#).


**Figure 13. LM94022/-Q1 No Decoupling Required for Capacitive Loads Less than 1100 pF**

**Figure 14. LM94022/-Q1 With Series Resistor for Capacitive Loading Greater than 1100 pF**

| C <sub>LOAD</sub> | MINIMUM R <sub>S</sub> |
|-------------------|------------------------|
| 1.1 nF to 99 nF   | 3 kΩ                   |
| 100 nF to 999 nF  | 1.5 kΩ                 |
| 1 μF              | 800 Ω                  |

### 7.4.2 Output Voltage Shift

The LM94022/-Q1 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  $V_{DD} - V_{OUT} = 1\text{ V}$ .

This slight shift (a few mV) 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 [Electrical Characteristics](#) table already include this possible shift.

### 7.4.3 Selectable Gain for Optimization and in Situ Testing

The Gain Select digital inputs can be tied to the rails or can be driven from digital outputs such as microcontroller GPIO pins. In low-supply voltage applications, the ability to reduce the gain to  $-5.5\text{ mV}/^{\circ}\text{C}$  allows the LM94022/-Q1 to operate over the full  $-50^{\circ}\text{C}$  to  $150^{\circ}\text{C}$  range. When a larger supply voltage is present, the gain can be increased as high as  $-13.6\text{ mV}/^{\circ}\text{C}$ . The larger gain is optimal for reducing the effects of noise (for example, noise coupling on the output line or quantization noise induced by an analog-to-digital converter which may be sampling the LM94022/-Q1 output).

Another application advantage of the digitally selectable gain is the ability to perform dynamic testing of the LM94022/-Q1 while it is running in a system. By toggling the logic levels of the gain select pins and monitoring the resultant change in the output voltage level, the host system can verify the functionality of the LM94022/-Q1.

## 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

The LM94022/-Q1 features make it suitable for many general temperature sensing applications. It can operate over a supply range of 1.5 V to 5.5 V with programmable output slope and a wide  $-50^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$  temperature range, thus allowing flexibility for different temperature and supply voltage range combinations.

#### 8.1.1 LM94022 Transfer Function

The LM94022 has four selectable gains, each of which can be selected by the GS1 and GS0 input pins. The output voltage for each gain, across the complete operating temperature range is shown in [Table 2](#). This table is the reference from which the LM94022 accuracy specifications (listed in the [Electrical Characteristics](#) section) are determined.

Although the LM94022 transfer curves are very linear, they do have a slight umbrella parabolic shape. This shape is very accurately reflected in [Table 2](#). The transfer table was used to calculate the following equations.

$$\begin{aligned}
 J2, G00 : V_{TEMP} (mV) &= 870.6mV - 5.506 \frac{mV}{^{\circ}\text{C}} (T - 30^{\circ}\text{C}) - 0.00176 \frac{mV}{^{\circ}\text{C}^2} (T - 30^{\circ}\text{C})^2 \\
 J3, G01 : V_{TEMP} (mV) &= 1324.0mV - 8.194 \frac{mV}{^{\circ}\text{C}} (T - 30^{\circ}\text{C}) - 0.00262 \frac{mV}{^{\circ}\text{C}^2} (T - 30^{\circ}\text{C})^2 \\
 J4, G10 : V_{TEMP} (mV) &= 1777.3mV - 10.888 \frac{mV}{^{\circ}\text{C}} (T - 30^{\circ}\text{C}) - 0.00347 \frac{mV}{^{\circ}\text{C}^2} (T - 30^{\circ}\text{C})^2 \\
 J5, G11 : V_{TEMP} (mV) &= 2230.8mV - 13.582 \frac{mV}{^{\circ}\text{C}} (T - 30^{\circ}\text{C}) - 0.00433 \frac{mV}{^{\circ}\text{C}^2} (T - 30^{\circ}\text{C})^2
 \end{aligned} \tag{1}$$

A linear approximation can be useful over a narrow temperature range. A line can easily be calculated over the desired temperature range from the table using the two-point equation:

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

where

- V is in mV,
  - T is in  $^{\circ}\text{C}$ ,
  - $T_1$  and  $V_1$  are the coordinates of the lowest temperature,
  - $T_2$  and  $V_2$  are the coordinates of the highest temperature.
- (2)

For example, to determine the equation of a line with the Gain Setting at GS1 = 0 and GS0 = 0, over a temperature range of  $20^{\circ}\text{C}$  to  $50^{\circ}\text{C}$ , proceed as follows:

$$V - 925 \text{ mV} = \left( \frac{760 \text{ mV} - 925 \text{ mV}}{50^{\circ}\text{C} - 20^{\circ}\text{C}} \right) \times (T - 20^{\circ}\text{C}) \tag{3}$$

$$V - 925 \text{ mV} = (-5.50 \text{ mV} / ^{\circ}\text{C}) \times (T - 20^{\circ}\text{C}) \tag{4}$$

$$V = (-5.50 \text{ mV} / ^{\circ}\text{C}) \times T + 1035 \text{ mV} \tag{5}$$

Using this method of linear approximation, the transfer function can be approximated for one or more temperature ranges of interest. The accuracy will suffer slightly in favor of easy conversion of the output voltage to temperature.

## 8.2 Typical Application

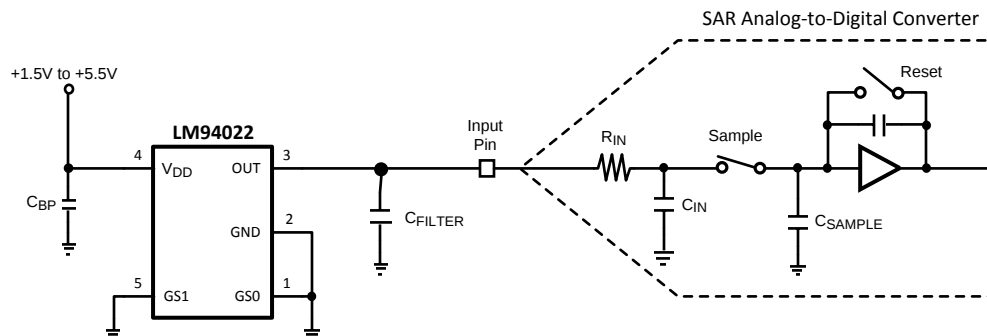


Figure 15. Suggested Connection to a Sampling Analog-to-Digital Converter Input Stage

### 8.2.1 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 LM94022/-Q1 temperature sensor and many op amps. This requirement is easily accommodated by the addition of a capacitor  $C_{FILTER}$ ).

### 8.2.2 Detailed Design Procedure

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

### 8.2.3 Application Curve

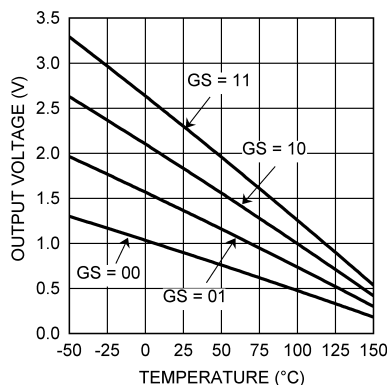
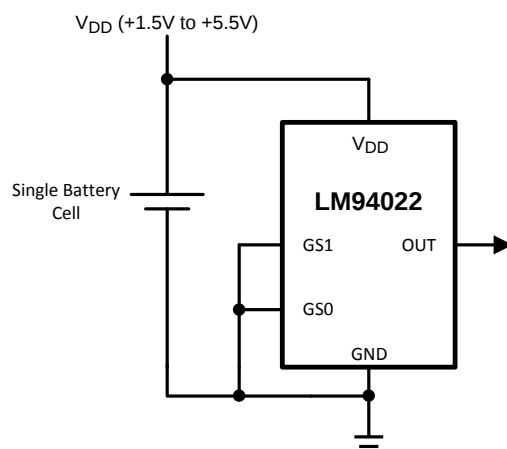


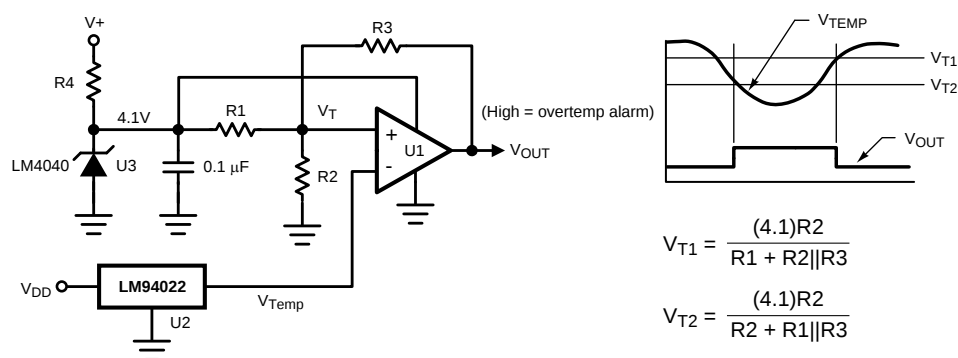
Figure 16. Programmable Analog Output Transfer Function

## 8.3 System Examples

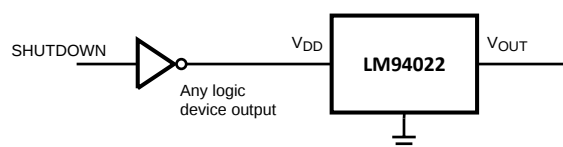
### 8.3.1 Application Circuits



**Figure 17. Full-Range Celsius Temperature Sensor (-50°C to +150°C) Operating from a Single Battery Cell**



**Figure 18. Celsius Thermostat**



**Figure 19. Conserving Power Dissipation With Shutdown**

## 9 Power Supply Recommendations

The LM94022/-Q1 low supply current and supply range of 1.5 V to 5.5 V 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. In noisy systems it may be necessary to add bypass capacitors to the lower the noise that couples to the output of the LM94022/-Q1.

## 10 Layout

### 10.1 Layout Guidelines

#### 10.1.1 Mounting and Thermal Conductivity

The LM94022/-Q1 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 LM94022/-Q1 die is directly attached to the GND pin (Pin 2). The temperatures of the lands and traces to the other leads of the LM94022/-Q1 will also affect the temperature reading.

Alternatively, the LM94022/-Q1 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 LM94022/-Q1 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 LM94022/-Q1 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 ( $\theta_{JA}$ ) is the parameter used to calculate the rise of a device junction temperature due to its power dissipation. The equation used to calculate the rise in the die temperature of the LM94022/-Q1 is:

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

where

- $T_A$  is the ambient temperature,
- $I_Q$  is the quiescent current,
- $I_L$  is the load current on the output,
- and  $V_O$  is the output voltage.

(6)

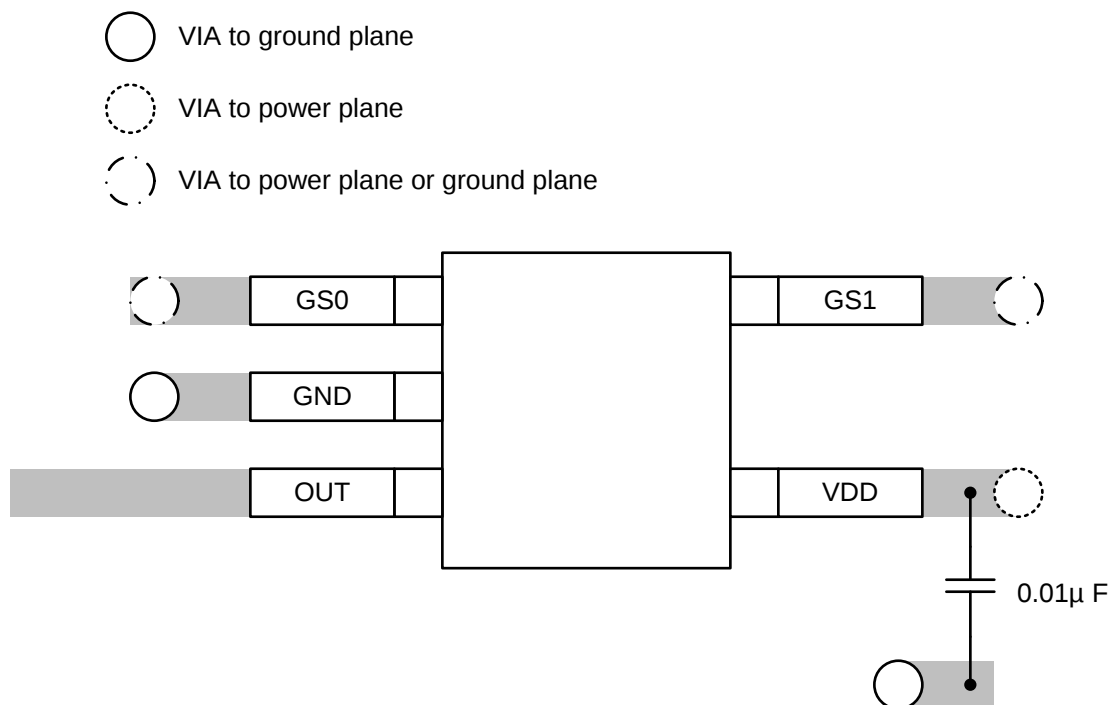
For example, in an application where  $T_A = 30^\circ\text{C}$ ,  $V_{DD} = 5\text{ V}$ ,  $I_{DD} = 9\text{ }\mu\text{A}$ , Gain Select = 11,  $V_{OUT} = 2.231\text{ mV}$ , and  $I_L = 2\text{ }\mu\text{A}$ , the junction temperature would be  $30.021^\circ\text{C}$ , showing a self-heating error of only  $0.021^\circ\text{C}$ . Because the junction temperature of the LM94022 is the actual temperature being measured, take care to minimize the load current that the LM94022/-Q1 is required to drive. [Table 3](#) shows the thermal resistance of the LM94022/-Q1.

**Table 3. LM94022/LM94022-Q1 Thermal Resistance**

| DEVICE NUMBER | NS PACKAGE NUMBER | THERMAL RESISTANCE ( $\theta_{JA}$ ) |
|---------------|-------------------|--------------------------------------|
| LM94022BIMG   | DCK0005A          | 415°C/W                              |

## 10.2 Layout Example

The LM94022/-Q1 is extremely simple to layout electrically. If a power supply bypass capacitor is used it should be connected as shown in [Figure 20](#). The device pins and layout greatly influence the temperature that the LM94022/-Q1 die is measuring thus thermal modeling is recommended to ensure that the device is sensing the proper temperature.



**Figure 20. Recommended Layout**

## 10.3 Output and Noise Considerations

A push-pull output gives the LM94022/-Q1 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. See the [Application Circuits](#) section for more discussion of this topic. The LM94022/-Q1 is ideal for this and other applications which require strong source or sink current.

The supply-noise gain of the LM94022 (the ratio of the AC signal on  $V_{OUT}$  to the AC signal on  $V_{DD}$ ) was measured during bench tests. Its typical attenuation is shown 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 2 inches of the LM94022/-Q1.

## 11 Device and Documentation Support

### 11.1 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

**Table 4. Related Links**

| PARTS      | PRODUCT FOLDER             | SAMPLE & BUY               | TECHNICAL DOCUMENTS        | TOOLS & SOFTWARE           | SUPPORT & COMMUNITY        |
|------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| LM94022    | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> |
| LM94022-Q1 | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> |

### 11.2 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](http://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.

### 11.3 Trademarks

E2E is a trademark of Texas Instruments.  
All other trademarks are the property of their respective owners.

### 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 part number              | Status<br>(1) | Material type<br>(2) | Package   Pins | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|------------------------------------|---------------|----------------------|----------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| LM94022BIMG                        | NRND          | Production           | SC70 (DCK)   5 | 1000   LARGE T&R      | No          | Call TI                              | Level-1-260C-UNLIM                | -50 to 150   | 22B                 |
| LM94022BIMG.A                      | NRND          | Production           | SC70 (DCK)   5 | 1000   LARGE T&R      | No          | Call TI                              | Level-1-260C-UNLIM                | -50 to 150   | 22B                 |
| LM94022BIMG.B                      | NRND          | Production           | SC70 (DCK)   5 | 1000   LARGE T&R      | No          | Call TI                              | Level-1-260C-UNLIM                | -50 to 150   | 22B                 |
| <a href="#">LM94022BIMGX/NOPB</a>  | Active        | Production           | SC70 (DCK)   5 | 3000   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -50 to 150   | 22B                 |
| LM94022BIMGX/NOPB.A                | Active        | Production           | SC70 (DCK)   5 | 3000   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -50 to 150   | 22B                 |
| LM94022BIMGX/NOPB.B                | Active        | Production           | SC70 (DCK)   5 | 3000   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -50 to 150   | 22B                 |
| <a href="#">LM94022QBIMG/NOPB</a>  | Obsolete      | Production           | SC70 (DCK)   5 | -                     | -           | Call TI                              | Call TI                           | -50 to 150   | 22Q                 |
| <a href="#">LM94022QBIMGX/NOPB</a> | Active        | Production           | SC70 (DCK)   5 | 3000   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -50 to 150   | 22Q                 |
| LM94022QBIMGX/NOPB.A               | Active        | Production           | SC70 (DCK)   5 | 3000   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -50 to 150   | 22Q                 |

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

<sup>(2)</sup> **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

<sup>(4)</sup> **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

<sup>(5)</sup> **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "-" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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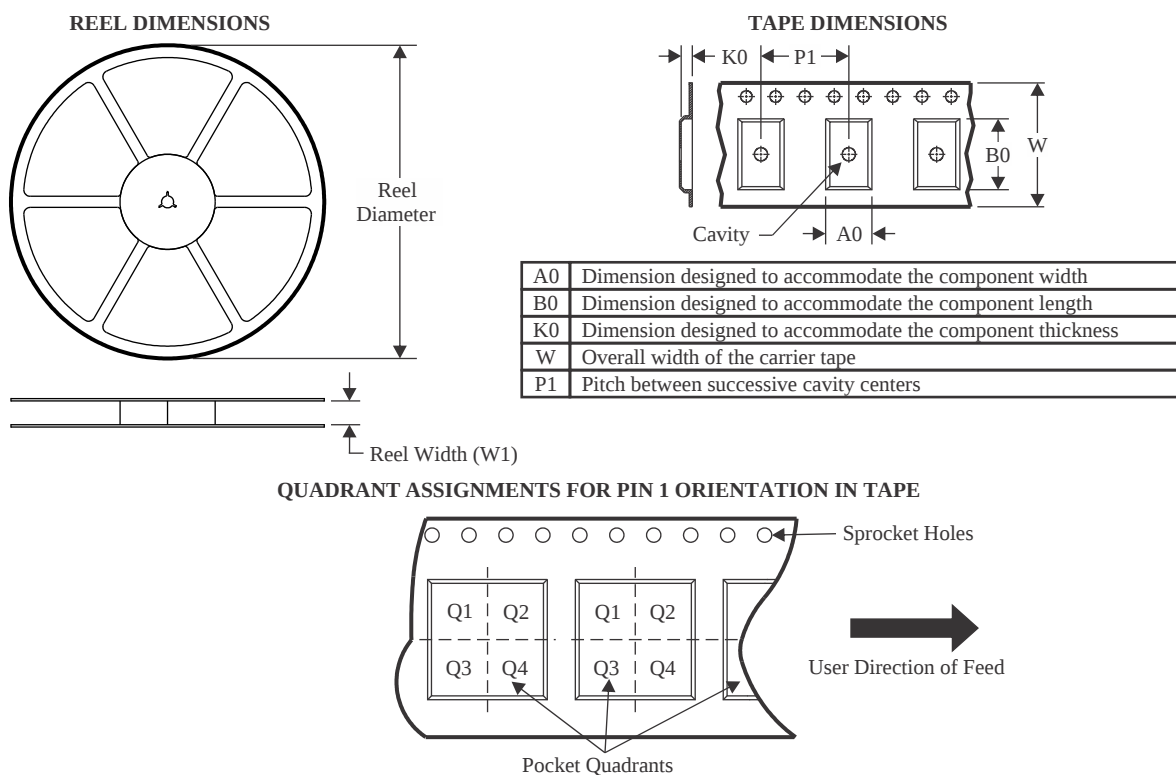
**OTHER QUALIFIED VERSIONS OF LM94022, LM94022-Q1 :**

- Catalog : [LM94022](#)
- Automotive : [LM94022-Q1](#)

NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product
- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

## TAPE AND REEL INFORMATION



\*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 |
|--------------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| LM94022BIMGX/NOPB  | SC70         | DCK             | 5    | 3000 | 178.0              | 8.4                | 2.25    | 2.45    | 1.2     | 4.0     | 8.0    | Q3            |
| LM94022QBIMGX/NOPB | SC70         | DCK             | 5    | 3000 | 178.0              | 8.4                | 2.25    | 2.45    | 1.2     | 4.0     | 8.0    | Q3            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

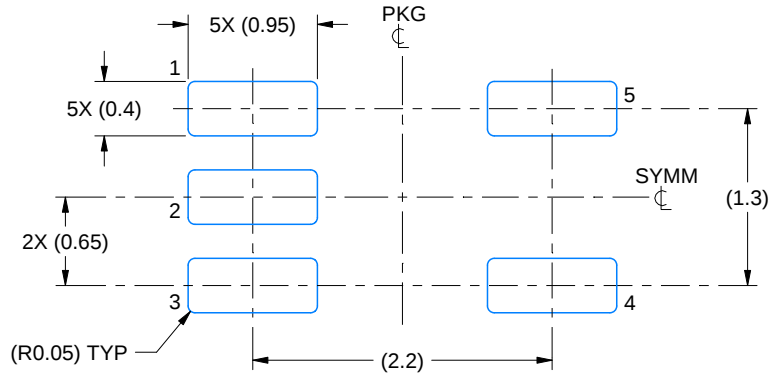
| Device             | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------------|--------------|-----------------|------|------|-------------|------------|-------------|
| LM94022BIMGX/NOPB  | SC70         | DCK             | 5    | 3000 | 208.0       | 191.0      | 35.0        |
| LM94022QBIMGX/NOPB | SC70         | DCK             | 5    | 3000 | 208.0       | 191.0      | 35.0        |



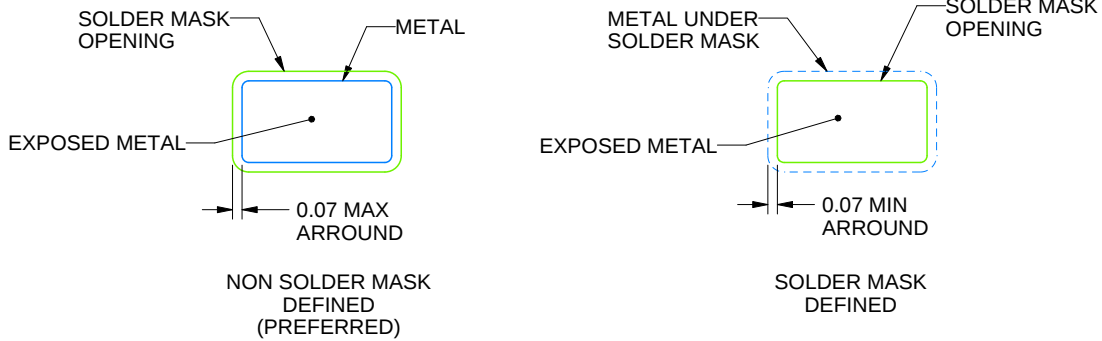
### SOT - 1.1 max height

[illegible]

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. Reference JEDEC MO-203.
4. Support pin may differ or may not be present.
5. Lead width does not comply with JEDEC.
6. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25mm per side



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:18X

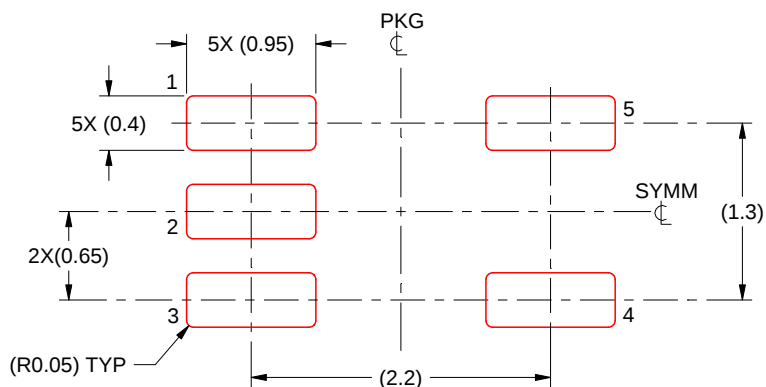


SOLDER MASK DETAILS

4214834/G 11/2024

NOTES: (continued)

7. Publication IPC-7351 may have alternate designs.
8. Solder mask tolerances between and around signal pads can vary based on board fabrication site.



SOLDER PASTE EXAMPLE  
BASED ON 0.125 THICK STENCIL  
SCALE:18X

4214834/G 11/2024

NOTES: (continued)

9. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
10. Board assembly site may have different recommendations for stencil design.

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