

# LM94023

## 1.5V, micro SMD, Dual-Gain Analog Temperature Sensor with Class AB Output

### General Description

The LM94023 is a precision analog output CMOS integrated-circuit temperature sensor that operates at a supply voltage as low as 1.5 Volts. Available in the very small four-bump microSMD 0.8mm x 0.8mm) the LM94023 occupies very little board area. A class-AB output structure gives the LM94023 strong output source and sink current capability for driving heavy loads, making it well suited to source the input of a sample-and-hold analog-to-digital converter with its transient load requirements. This generally means the LM94023 can be used without external components, like resistors and buffers, on the output. While operating over the wide temperature range of  $-50^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ , the LM94023 delivers an output voltage that is inversely proportional to measured temperature. The LM94023's low supply current makes it ideal for battery-powered systems as well as general temperature sensing applications.

A Gain Select (GS) pin sets the gain of the temperature-to-voltage output transfer function. Either of two slopes are selectable:  $-5.5\text{ mV}/^{\circ}\text{C}$  (GS=0) or  $-8.2\text{ mV}/^{\circ}\text{C}$  (GS=1). In the lowest gain configuration, the LM94023 can operate with a 1.5V supply while measuring temperature over the full  $-50^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$  operating range. Tying GS high causes the transfer function to have the largest gain for maximum temperature sensitivity. The gain-select inputs can be tied directly to  $V_{\text{DD}}$  or Ground without any pull-up or pull-down 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.

### Applications

- Cell phones
- Wireless Transceivers

- Battery Management
- Automotive
- Disk Drives
- Games
- Appliances

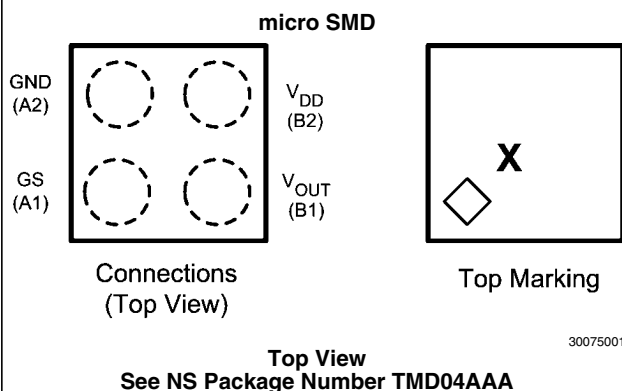
### Features

- Low 1.5V operation
- Push-pull output with  $50\mu\text{A}$  source current capability
- Two selectable gains
- Very accurate over wide temperature range of  $-50^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$
- Low quiescent current
- Output is short-circuit protected
- Extremely small microSMD package
- Footprint compatible with the industry-standard LM20 temperature sensor

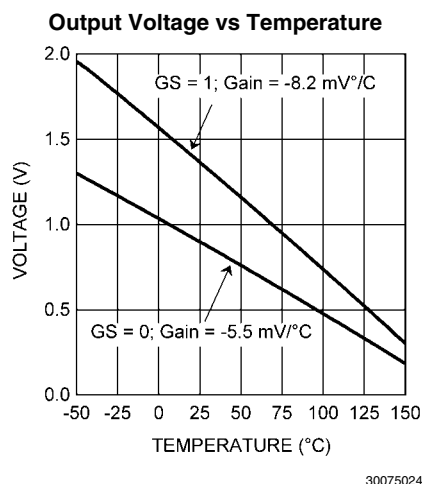
### Key Specifications

|                         |                                                |
|-------------------------|------------------------------------------------|
| ■ Supply Voltage        | 1.5V to 5.5V                                   |
| ■ Supply Current        | 5.4 $\mu\text{A}$ (typ)                        |
| ■ Output Drive          | $\pm 50\text{ }\mu\text{A}$                    |
| ■ Temperature           | $20^{\circ}\text{C}$ to $40^{\circ}\text{C}$   |
| Accuracy                | $-50^{\circ}\text{C}$ to $70^{\circ}\text{C}$  |
|                         | $-50^{\circ}\text{C}$ to $90^{\circ}\text{C}$  |
|                         | $-50^{\circ}\text{C}$ to $150^{\circ}\text{C}$ |
| ■ Operating Temperature | $-50^{\circ}\text{C}$ to $150^{\circ}\text{C}$ |

### Connection Diagram

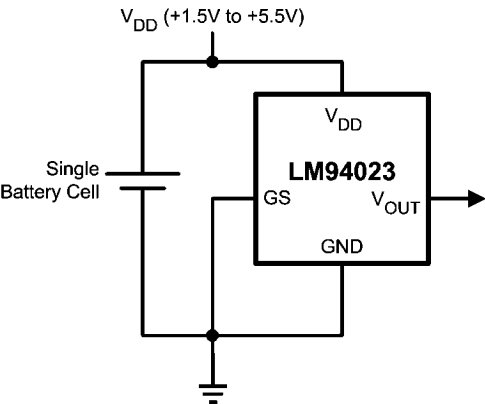


### Typical Transfer Characteristic



# Typical Application

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



30075002

## Ordering Information

| Order Number | Temperature Accuracy | NS Package Number | Device Marking | Transport Media             |
|--------------|----------------------|-------------------|----------------|-----------------------------|
| LM94023BITME | ±1.5°C to ±2.7°C     | TMD04AAA          | Date Code      | 250 Units on Tape and Reel  |
| LM94023BITMX | ±1.5°C to ±2.7°C     | TMD04AAA          | Date Code      | 3000 Units on Tape and Reel |

## Pin Descriptions

| Label            | Pin Number | Type          | Equivalent Circuit | Function                                                                  |
|------------------|------------|---------------|--------------------|---------------------------------------------------------------------------|
| GS               | A1         | Logic Input   |                    | Gain Select - Input for selecting the slope of the analog output response |
| GND              | A2         | Ground        |                    | Power Supply Ground                                                       |
| V <sub>OUT</sub> | B1         | Analog Output |                    | Outputs a voltage which is inversely proportional to temperature          |
| V <sub>DD</sub>  | B2         | Power         |                    | Positive Supply Voltage                                                   |

**Absolute Maximum Ratings** (Note 1)

|                                                  |                              |
|--------------------------------------------------|------------------------------|
| Supply Voltage                                   | −0.3V to +6.0V               |
| Voltage at Output Pin                            | −0.3V to ( $V_{DD} + 0.3V$ ) |
| Output Current                                   | ±7 mA                        |
| Voltage at GS Input Pin                          | −0.3V to +6.0V               |
| Input Current at any pin (Note 2)                | 5 mA                         |
| Storage Temperature                              | −65°C to +150°C              |
| Maximum Junction Temperature ( $T_{JMAX}$ )      | +150°C                       |
| ESD Susceptibility (Note 3):<br>Human Body Model | 2500V                        |

Machine Model

250V

Soldering process must comply with National's  
Reflow Temperature Profile specifications. Refer to  
[www.national.com/packaging](http://www.national.com/packaging). (Note 4)

**Operating Ratings** (Note 1)

|                                      |                                 |
|--------------------------------------|---------------------------------|
| Specified Temperature Range:         | $T_{MIN} \leq T_A \leq T_{MAX}$ |
| LM94023                              | −50°C ≤ $T_A$ ≤ +150°C          |
| Supply Voltage Range ( $V_{DD}$ )    | +1.5 V to +5.5 V                |
| Thermal Resistance ( $\theta_{JA}$ ) |                                 |
| LM94023BITME, LM94023BITMX           | 122.6°C/W                       |

**Accuracy Characteristics**

These limits do not include DC load regulation. These stated accuracy limits are with reference to the values in the LM94023 Transfer Table.

| Parameter                     | Conditions |                                                                              | Limits<br>(Note 7) | Units<br>(Limit) |
|-------------------------------|------------|------------------------------------------------------------------------------|--------------------|------------------|
| Temperature Error<br>(Note 8) | GS=0       | $T_A = +20^\circ\text{C}$ to $+40^\circ\text{C}$ ; $V_{DD} = 1.5V$ to $5.5V$ | ±1.5               | °C (max)         |
|                               |            | $T_A = +0^\circ\text{C}$ to $+70^\circ\text{C}$ ; $V_{DD} = 1.5V$ to $5.5V$  | ±1.8               | °C (max)         |
|                               |            | $T_A = +0^\circ\text{C}$ to $+90^\circ\text{C}$ ; $V_{DD} = 1.5V$ to $5.5V$  | ±2.1               | °C (max)         |
|                               |            | $T_A = +0^\circ\text{C}$ to $+120^\circ\text{C}$ ; $V_{DD} = 1.5V$ to $5.5V$ | ±2.4               | °C (max)         |
|                               |            | $T_A = +0^\circ\text{C}$ to $+150^\circ\text{C}$ ; $V_{DD} = 1.5V$ to $5.5V$ | ±2.7               | °C (max)         |
|                               |            | $T_A = -50^\circ\text{C}$ to $+0^\circ\text{C}$ ; $V_{DD} = 1.6V$ to $5.5V$  | ±1.8               | °C (max)         |
|                               | GS=1       | $T_A = +20^\circ\text{C}$ to $+40^\circ\text{C}$ ; $V_{DD} = 1.8V$ to $5.5V$ | ±1.5               | °C (max)         |
|                               |            | $T_A = +0^\circ\text{C}$ to $+70^\circ\text{C}$ ; $V_{DD} = 1.9V$ to $5.5V$  | ±1.8               | °C (max)         |
|                               |            | $T_A = +0^\circ\text{C}$ to $+90^\circ\text{C}$ ; $V_{DD} = 1.9V$ to $5.5V$  | ±2.1               | °C (max)         |
|                               |            | $T_A = +0^\circ\text{C}$ to $+120^\circ\text{C}$ ; $V_{DD} = 1.9V$ to $5.5V$ | ±2.4               | °C (max)         |
|                               |            | $T_A = +0^\circ\text{C}$ to $+150^\circ\text{C}$ ; $V_{DD} = 1.9V$ to $5.5V$ | ±2.7               | °C (max)         |
|                               |            | $T_A = -50^\circ\text{C}$ to $+0^\circ\text{C}$ ; $V_{DD} = 2.3V$ to $5.5V$  | ±1.8               | °C (max)         |

## Electrical Characteristics

Unless otherwise noted, these specifications apply for  $+V_{DD} = +1.5V$  to  $+5.5V$ . **Boldface limits apply for  $T_A = T_J = T_{MIN}$  to  $T_{MAX}$** ; all other limits  $T_A = T_J = 25^\circ C$ .

| Symbol   | Parameter                                        | Conditions                                                                                   | Typical<br>(Note 6) | Limits<br>(Note 7)                | Units<br>(Limit) |
|----------|--------------------------------------------------|----------------------------------------------------------------------------------------------|---------------------|-----------------------------------|------------------|
|          | Sensor Gain                                      | GS = 0                                                                                       | -5.5                |                                   | mV/ $^\circ C$   |
|          |                                                  | GS = 1                                                                                       | -8.2                |                                   | mV/ $^\circ C$   |
|          | Load Regulation<br>(Note 10)                     | 1.5V $\leq V_{DD} < 5.5V$<br>Source $\leq 50 \mu A$ ,<br>( $V_{DD} - V_{OUT}$ ) $\geq 200mV$ | -0.22               | <b>-1</b>                         | mV (max)         |
|          |                                                  | Sink $\leq 50 \mu A$ ,<br>$V_{OUT} \geq 200mV$                                               | 0.26                | <b>1</b>                          | mV (max)         |
|          | Line Regulation<br>(Note 13)                     |                                                                                              | 200                 |                                   | $\mu V/V$        |
| $I_S$    | Supply Current                                   | $T_A = +30^\circ C$ to $+150^\circ C$ ,<br>( $V_{DD} - V_{OUT}$ ) $\geq 100mV$               | 5.4                 | <b>8.1</b>                        | $\mu A$ (max)    |
|          |                                                  | $T_A = -50^\circ C$ to $+150^\circ C$ ,<br>( $V_{DD} - V_{OUT}$ ) $\geq 100mV$               | 5.4                 | <b>9</b>                          | $\mu A$ (max)    |
| $C_L$    | Output Load Capacitance                          |                                                                                              | 1100                |                                   | pF (max)         |
|          | Power-on Time<br>(Note 11)                       | $C_L = 0$ pF to 1100 pF                                                                      | 0.7                 | <b>1.9</b>                        | ms (max)         |
| $V_{IH}$ | GS1 and GS0 Input Logic<br>"1" Threshold Voltage |                                                                                              |                     | <b><math>V_{DD} - 0.5V</math></b> | V (min)          |
| $V_{IL}$ | GS1 and GS0 Input Logic<br>"0" Threshold Voltage |                                                                                              |                     | <b>0.5</b>                        | V (max)          |
| $I_{IH}$ | Logic "1" Input Current<br>(Note 12)             |                                                                                              | 0.001               | <b>1</b>                          | $\mu A$ (max)    |
| $I_{IL}$ | Logic "0" Input Current<br>(Note 12)             |                                                                                              | 0.001               | <b>1</b>                          | $\mu A$ (max)    |

**Note 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.

**Note 2:** When the input voltage ( $V_I$ ) at any pin exceeds power supplies ( $V_I < GND$  or  $V_I > V^+$ ), the current at that pin should be limited to 5 mA.

**Note 3:** The human body model is a 100 pF capacitor discharged through a 1.5 k $\Omega$  resistor into each pin. The machine model is a 200 pF capacitor discharged directly into each pin.

**Note 4:** Reflow temperature profiles are different for lead-free and non-lead-free packages.

**Note 5:** The junction to ambient thermal resistance ( $\theta_{JA}$ ) is specified without a heat sink in still air.

**Note 6:** Typicals are at  $T_J = T_A = 25^\circ C$  and represent most likely parametric norm.

**Note 7:** Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

**Note 8:** 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  $^\circ C$ ). Accuracy limits include line regulation within the specified conditions. Accuracy limits do not include load regulation; they assume no DC load.

**Note 9:** Changes in output due to self heating can be computed by multiplying the internal dissipation by the thermal resistance.

**Note 10:** Source currents are flowing out of the LM94023. Sink currents are flowing into the LM94023.

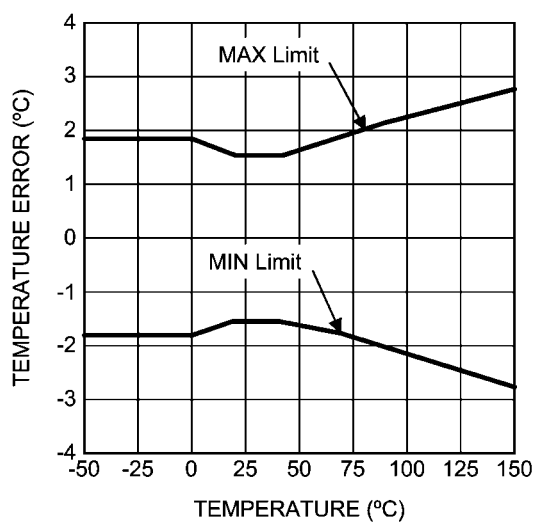
**Note 11:** Guaranteed by design.

**Note 12:** 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.

**Note 13:** 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 Section 5.0.

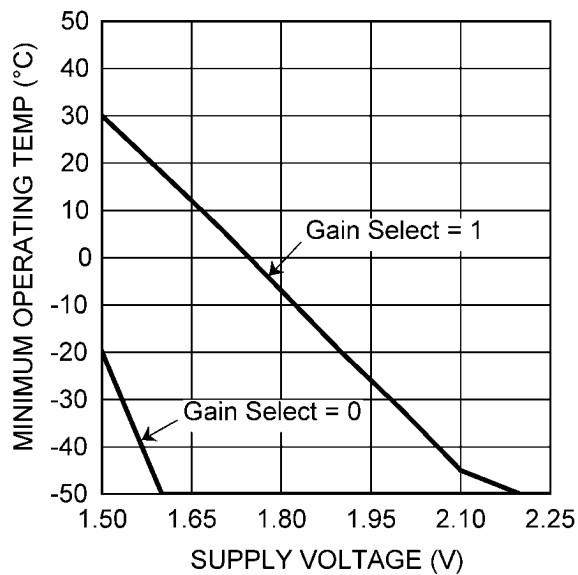
## Typical Performance Characteristics

Temperature Error vs. Temperature



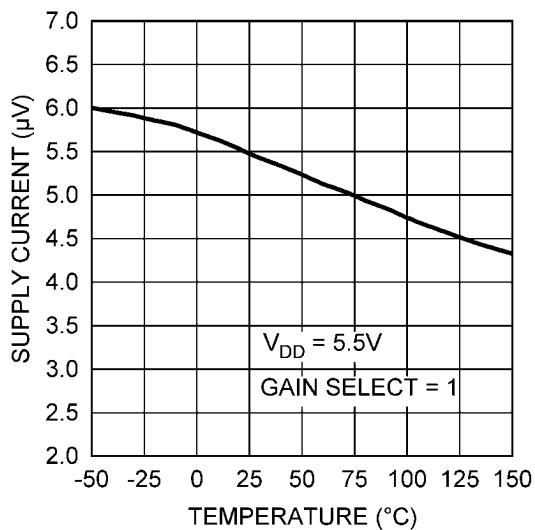
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Minimum Operating Temperature vs. Supply Voltage



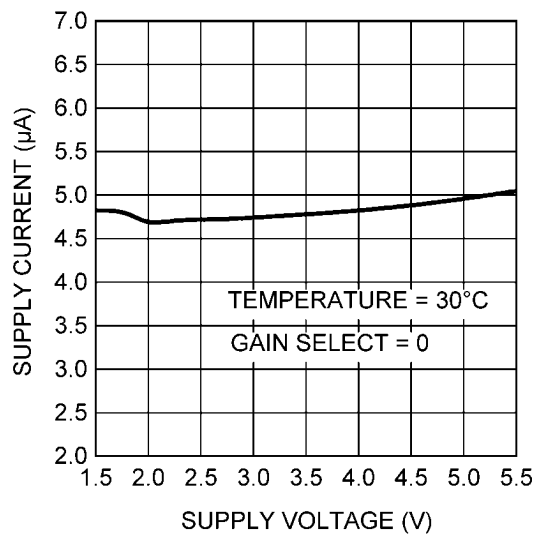
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Supply Current vs. Temperature



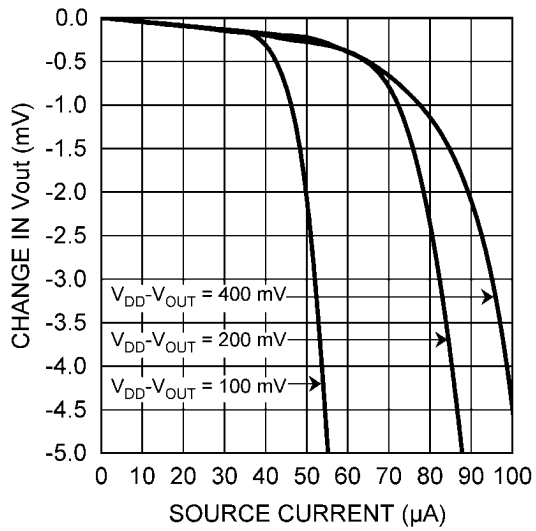
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Supply Current vs. Supply Voltage



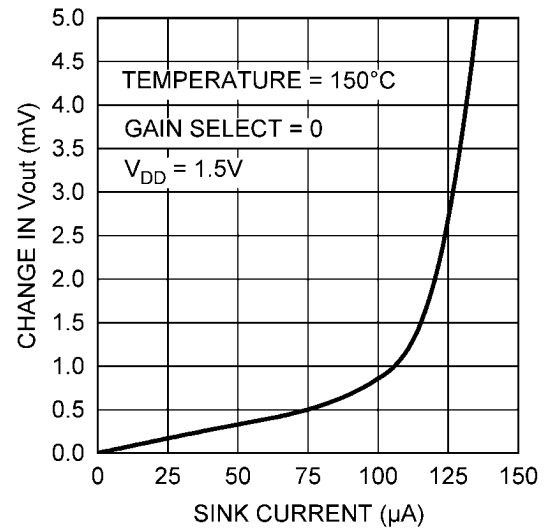
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Load Regulation, Sourcing Current



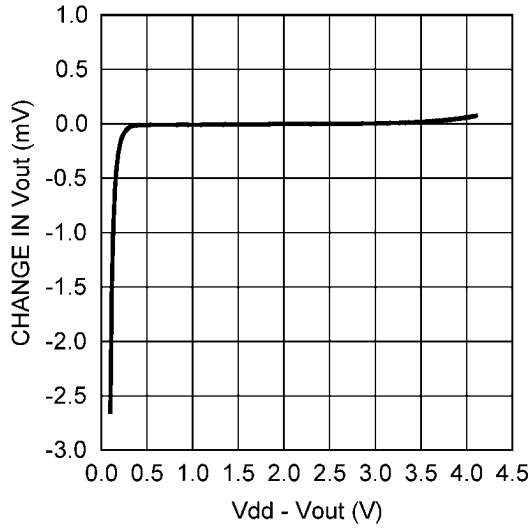
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Load Regulation, Sinking Current



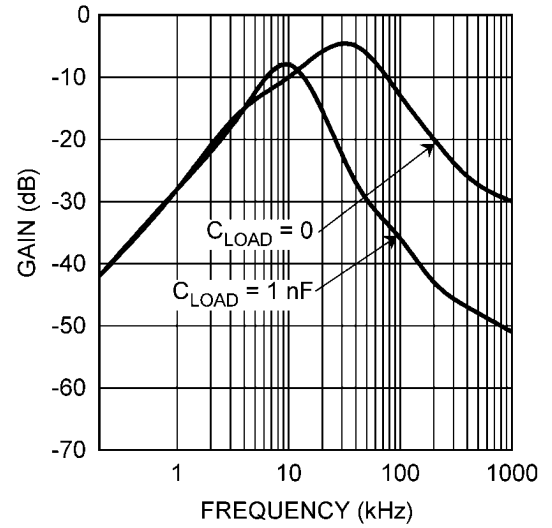
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Line Regulation: Change in Vout vs. Overhead Voltage



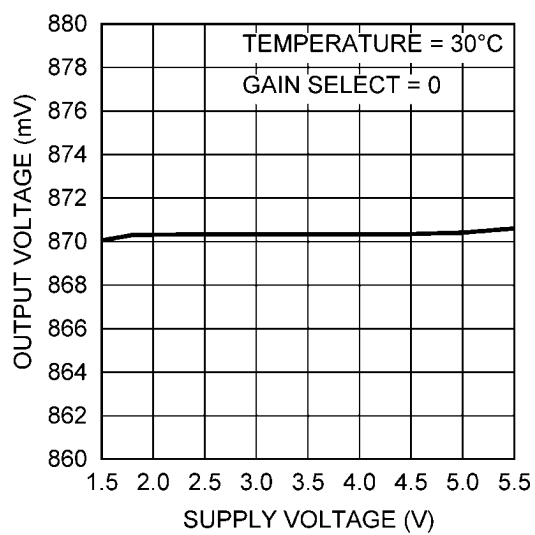
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Supply-Noise Gain vs. Frequency



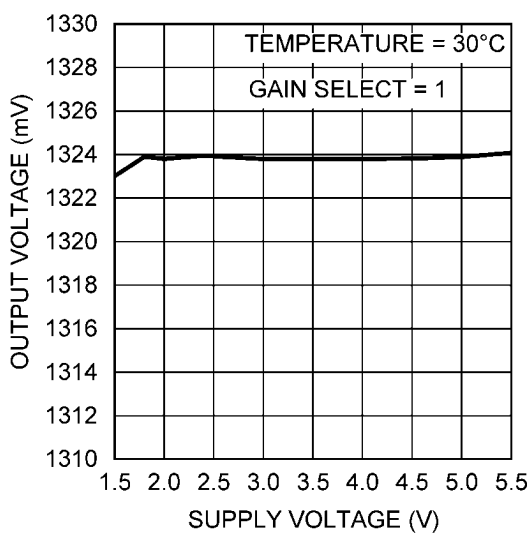
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Line Regulation: Output Voltage vs. Supply Voltage  
Gain Select = 0



30075034

Line Regulation: Output Voltage vs. Supply Voltage  
Gain Select = 1



30075035

## 1.0 LM94023 Transfer Function

The LM94023 has two selectable gains, selected by the Gain Select (GS) input pin. The output voltage for each gain, across the complete operating temperature range is shown in the LM94023 Transfer Table, below. This table is the reference from which the LM94023 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 [www.national.com/appinfo/tempsensors](http://www.national.com/appinfo/tempsensors).

### LM94023 Temperature-Voltage Transfer Table

The output voltages in this table apply for  $V_{DD} = 5V$ .

| Temperature (°C) | GS = 0 (mV) | GS = 1 (mV) |
|------------------|-------------|-------------|
| -50              | 1299        | 1955        |
| -49              | 1294        | 1949        |
| -48              | 1289        | 1942        |
| -47              | 1284        | 1935        |
| -46              | 1278        | 1928        |
| -45              | 1273        | 1921        |
| -44              | 1268        | 1915        |
| -43              | 1263        | 1908        |
| -42              | 1257        | 1900        |
| -41              | 1252        | 1892        |
| -40              | 1247        | 1885        |
| -39              | 1242        | 1877        |
| -38              | 1236        | 1869        |
| -37              | 1231        | 1861        |
| -36              | 1226        | 1853        |
| -35              | 1221        | 1845        |
| -34              | 1215        | 1838        |
| -33              | 1210        | 1830        |
| -32              | 1205        | 1822        |
| -31              | 1200        | 1814        |
| -30              | 1194        | 1806        |
| -29              | 1189        | 1798        |
| -28              | 1184        | 1790        |
| -27              | 1178        | 1783        |
| -26              | 1173        | 1775        |
| -25              | 1168        | 1767        |
| -24              | 1162        | 1759        |
| -23              | 1157        | 1751        |
| -22              | 1152        | 1743        |
| -21              | 1146        | 1735        |
| -20              | 1141        | 1727        |
| -19              | 1136        | 1719        |
| -18              | 1130        | 1711        |
| -17              | 1125        | 1703        |
| -16              | 1120        | 1695        |
| -15              | 1114        | 1687        |
| -14              | 1109        | 1679        |

| Temperature (°C) | GS = 0 (mV) | GS = 1 (mV) |
|------------------|-------------|-------------|
| -13              | 1104        | 1671        |
| -12              | 1098        | 1663        |
| -11              | 1093        | 1656        |
| -10              | 1088        | 1648        |
| -9               | 1082        | 1639        |
| -8               | 1077        | 1631        |
| -7               | 1072        | 1623        |
| -6               | 1066        | 1615        |
| -5               | 1061        | 1607        |
| -4               | 1055        | 1599        |
| -3               | 1050        | 1591        |
| -2               | 1044        | 1583        |
| -1               | 1039        | 1575        |
| 0                | 1034        | 1567        |
| 1                | 1028        | 1559        |
| 2                | 1023        | 1551        |
| 3                | 1017        | 1543        |
| 4                | 1012        | 1535        |
| 5                | 1007        | 1527        |
| 6                | 1001        | 1519        |
| 7                | 996         | 1511        |
| 8                | 990         | 1502        |
| 9                | 985         | 1494        |
| 10               | 980         | 1486        |
| 11               | 974         | 1478        |
| 12               | 969         | 1470        |
| 13               | 963         | 1462        |
| 14               | 958         | 1454        |
| 15               | 952         | 1446        |
| 16               | 947         | 1438        |
| 17               | 941         | 1430        |
| 18               | 936         | 1421        |
| 19               | 931         | 1413        |
| 20               | 925         | 1405        |
| 21               | 920         | 1397        |
| 22               | 914         | 1389        |
| 23               | 909         | 1381        |
| 24               | 903         | 1373        |
| 25               | 898         | 1365        |
| 26               | 892         | 1356        |
| 27               | 887         | 1348        |
| 28               | 882         | 1340        |
| 29               | 876         | 1332        |
| 30               | 871         | 1324        |
| 31               | 865         | 1316        |
| 32               | 860         | 1308        |
| 33               | 854         | 1299        |
| 34               | 849         | 1291        |
| 35               | 843         | 1283        |



| Temperature (°C) | GS = 0 (mV) | GS = 1 (mV) |
|------------------|-------------|-------------|
| 36               | 838         | 1275        |
| 37               | 832         | 1267        |
| 38               | 827         | 1258        |
| 39               | 821         | 1250        |
| 40               | 816         | 1242        |
| 41               | 810         | 1234        |
| 42               | 804         | 1225        |
| 43               | 799         | 1217        |
| 44               | 793         | 1209        |
| 45               | 788         | 1201        |
| 46               | 782         | 1192        |
| 47               | 777         | 1184        |
| 48               | 771         | 1176        |
| 49               | 766         | 1167        |
| 50               | 760         | 1159        |
| 51               | 754         | 1151        |
| 52               | 749         | 1143        |
| 53               | 743         | 1134        |
| 54               | 738         | 1126        |
| 55               | 732         | 1118        |
| 56               | 726         | 1109        |
| 57               | 721         | 1101        |
| 58               | 715         | 1093        |
| 59               | 710         | 1084        |
| 60               | 704         | 1076        |
| 61               | 698         | 1067        |
| 62               | 693         | 1059        |
| 63               | 687         | 1051        |
| 64               | 681         | 1042        |
| 65               | 676         | 1034        |
| 66               | 670         | 1025        |
| 67               | 664         | 1017        |
| 68               | 659         | 1008        |
| 69               | 653         | 1000        |
| 70               | 647         | 991         |
| 71               | 642         | 983         |
| 72               | 636         | 974         |
| 73               | 630         | 966         |
| 74               | 625         | 957         |
| 75               | 619         | 949         |
| 76               | 613         | 941         |
| 77               | 608         | 932         |
| 78               | 602         | 924         |
| 79               | 596         | 915         |
| 80               | 591         | 907         |
| 81               | 585         | 898         |
| 82               | 579         | 890         |
| 83               | 574         | 881         |
| 84               | 568         | 873         |

| Temperature (°C) | GS = 0 (mV) | GS = 1 (mV) |
|------------------|-------------|-------------|
| 85               | 562         | 865         |
| 86               | 557         | 856         |
| 87               | 551         | 848         |
| 88               | 545         | 839         |
| 89               | 539         | 831         |
| 90               | 534         | 822         |
| 91               | 528         | 814         |
| 92               | 522         | 805         |
| 93               | 517         | 797         |
| 94               | 511         | 788         |
| 95               | 505         | 779         |
| 96               | 499         | 771         |
| 97               | 494         | 762         |
| 98               | 488         | 754         |
| 99               | 482         | 745         |
| 100              | 476         | 737         |
| 101              | 471         | 728         |
| 102              | 465         | 720         |
| 103              | 459         | 711         |
| 104              | 453         | 702         |
| 105              | 448         | 694         |
| 106              | 442         | 685         |
| 107              | 436         | 677         |
| 108              | 430         | 668         |
| 109              | 425         | 660         |
| 110              | 419         | 651         |
| 111              | 413         | 642         |
| 112              | 407         | 634         |
| 113              | 401         | 625         |
| 114              | 396         | 617         |
| 115              | 390         | 608         |
| 116              | 384         | 599         |
| 117              | 378         | 591         |
| 118              | 372         | 582         |
| 119              | 367         | 573         |
| 120              | 361         | 565         |
| 121              | 355         | 556         |
| 122              | 349         | 547         |
| 123              | 343         | 539         |
| 124              | 337         | 530         |
| 125              | 332         | 521         |
| 126              | 326         | 513         |
| 127              | 320         | 504         |
| 128              | 314         | 495         |
| 129              | 308         | 487         |
| 130              | 302         | 478         |
| 131              | 296         | 469         |
| 132              | 291         | 460         |
| 133              | 285         | 452         |

| Temperature<br>(°C) | GS = 0<br>(mV) | GS = 1<br>(mV) |
|---------------------|----------------|----------------|
| 134                 | 279            | 443            |
| 135                 | 273            | 434            |
| 136                 | 267            | 425            |
| 137                 | 261            | 416            |
| 138                 | 255            | 408            |
| 139                 | 249            | 399            |
| 140                 | 243            | 390            |
| 141                 | 237            | 381            |
| 142                 | 231            | 372            |
| 143                 | 225            | 363            |
| 144                 | 219            | 354            |
| 145                 | 213            | 346            |
| 146                 | 207            | 337            |
| 147                 | 201            | 328            |
| 148                 | 195            | 319            |
| 149                 | 189            | 310            |
| 150                 | 183            | 301            |

Although the LM94023 is very linear, its response does have a slight downward parabolic shape. This shape is very accurately reflected in the LM94023 Transfer Table. For a linear approximation, a line can easily be calculated over the de-

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

For example, if we want to determine the equation of a line with the Gain Setting at GS1 = 0 and GS0 = 0, over a temperature range of 20°C to 50°C, we would proceed as follows:

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

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

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

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

## 2.0 Mounting and Thermal Conductivity

The LM94023 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 LM94023 die is directly attached to the GND pin (Pin 2). The temperatures of the lands and traces to the other leads of the LM94023 will also affect the temperature reading.

Alternatively, the LM94023 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 LM94023 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 LM94023 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 LM94023's die temperature is

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

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. 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  $0.021^\circ\text{C}$ . Since the LM94023's junction temperature is the actual temperature being measured, care should be taken to minimize the load current that the LM94023 is required to drive. Figure 1 shows the thermal resistance of the LM94023.

| Device Number              | NS Package Number | Thermal Resistance ( $\theta_{JA}$ ) |
|----------------------------|-------------------|--------------------------------------|
| LM94023BITME, LM94023BITMX | TMD04AAA          | 122.6 $^\circ\text{C/W}$             |

FIGURE 1. LM94023 Thermal Resistance

## 3.0 Output and Noise Considerations

A push-pull output gives the LM94023 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 Applications Circuits section for more discussion of this topic. The LM94023 is ideal for this and other applications which require strong source or sink current.

The LM94023's supply-noise gain (the ratio of the AC signal on  $V_{OUT}$  to the AC signal on  $V_{DD}$ ) was measured during bench tests. It's typical attenuation is shown in the Typical Performance 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 LM94023.

## 4.0 Capacitive Loads

The LM94023 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 LM94023 can drive a capacitive load less than or equal to 1100 pF as shown in Figure 2. For capacitive loads greater than 1100 pF, a series resistor may be required on the output, as shown in Figure 3.

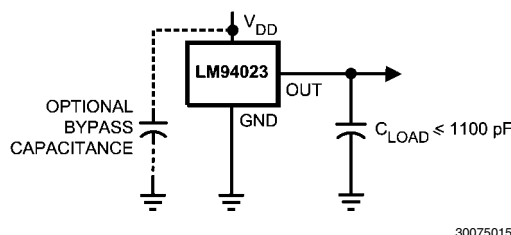
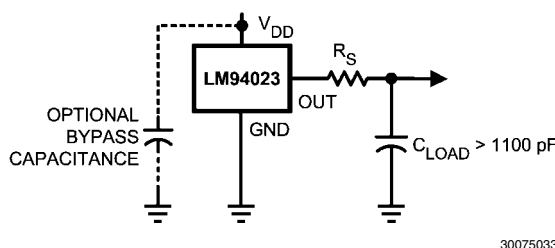


FIGURE 2. LM94023 No Decoupling Required for Capacitive Loads Less than 1100 pF.



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

FIGURE 3. LM94023 with series resistor for capacitive Loading greater than 1100 pF.

## 5.0 Output Voltage Shift

The LM94023 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  $V_{DD} - V_{OUT} = 1.0\text{ V}$ .

This slight shift (a few millivolts) takes place over a wide change (approximately 200 mV) in  $V_{DD}$  or  $V_{OUT}$ . Since the shift takes place over a wide temperature change of  $5^\circ\text{C}$  to  $20^\circ\text{C}$ ,  $V_{OUT}$  is always monotonic. The accuracy specifications in the Electrical Characteristics table already include this possible shift.

## 6.0 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 LM94023 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  $-8.2 \text{ mV}/^{\circ}\text{C}$ . 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 LM94023 output).

Another application advantage of the digitally selectable gain is the ability to perform dynamic testing of the LM94023 while it is running in a system. By toggling the logic levels of the gain select pin and monitoring the resultant change in the output voltage level, the host system can verify the functionality of the LM94023.

## 7.0 Applications Circuits

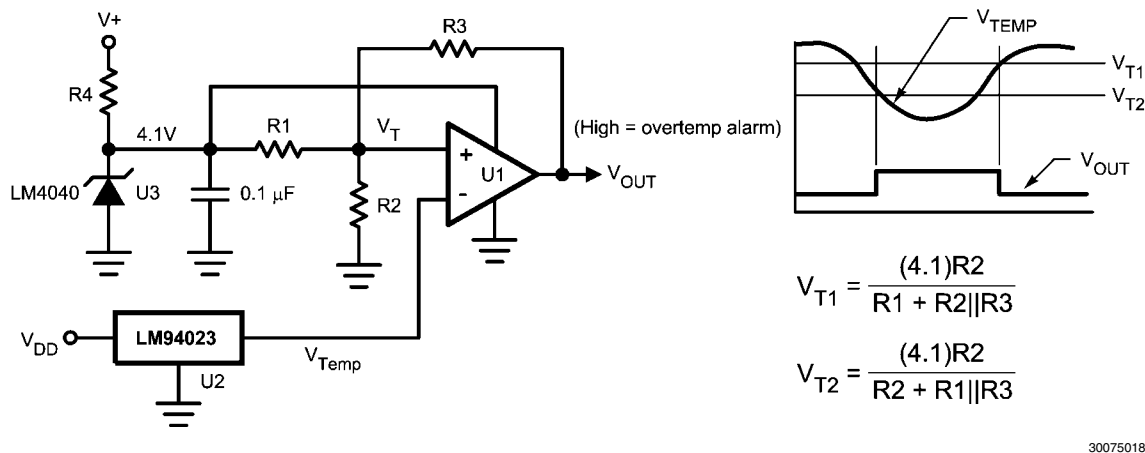


FIGURE 4. Celsius Thermostat

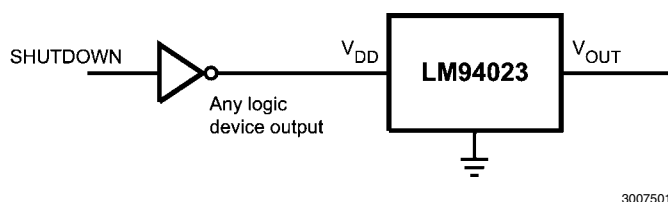
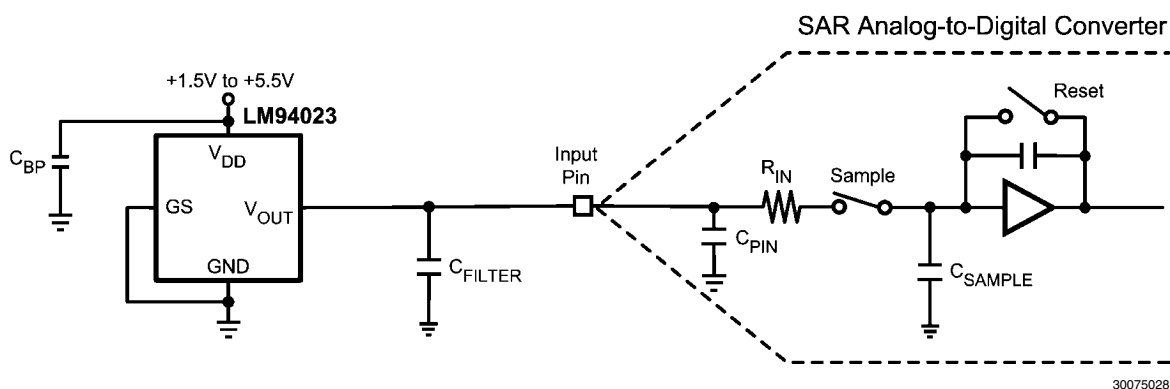


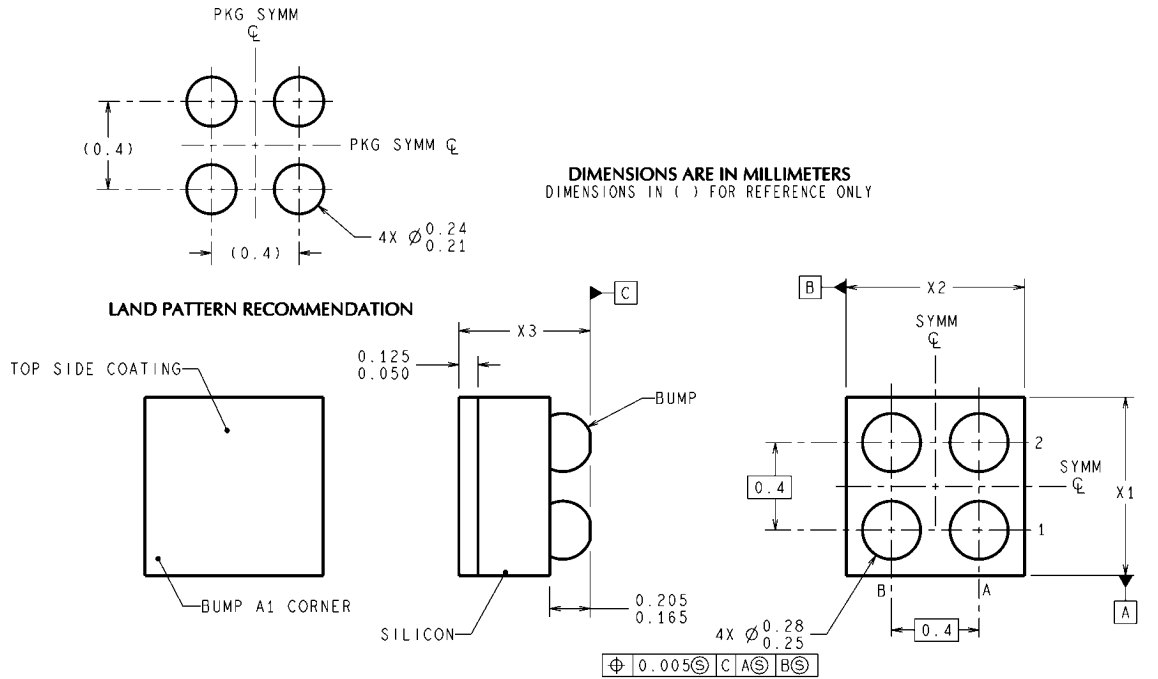
FIGURE 5. Conserving Power Dissipation with Shutdown



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 LM94023 temperature sensor and many op amps. This requirement is easily accommodated by the addition of a capacitor ( $C_{\text{FILTER}}$ ). The size of  $C_{\text{FILTER}}$  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.

FIGURE 6. Suggested Connection to a Sampling Analog-to-Digital Converter Input Stage

# Physical Dimensions inches (millimeters) unless otherwise noted



TMD04XXX (Rev A)

**4-Bump Thin micro SMD Ball Grid Array Package**  
**Order Number LM94023BITME and LM94023BITMX**  
**NS Package Number TMD04AAA**

X1 = 0.815 mm

X2 = 0.815mm

X3 = 0.600mm

## Notes

## Notes

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| LVDS                           | <a href="http://www.national.com/lvds">www.national.com/lvds</a>               | Reference Designs       | <a href="http://www.national.com/refdesigns">www.national.com/refdesigns</a>       |
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| Switching Regulators           | <a href="http://www.national.com/switchers">www.national.com/switchers</a>     |                         |                                                                                    |
| LDOs                           | <a href="http://www.national.com/ldo">www.national.com/ldo</a>                 |                         |                                                                                    |
| LED Lighting                   | <a href="http://www.national.com/led">www.national.com/led</a>                 |                         |                                                                                    |
| PowerWise                      | <a href="http://www.national.com/powerwise">www.national.com/powerwise</a>     |                         |                                                                                    |
| Serial Digital Interface (SDI) | <a href="http://www.national.com/sdi">www.national.com/sdi</a>                 |                         |                                                                                    |
| Temperature Sensors            | <a href="http://www.national.com/tempsensors">www.national.com/tempsensors</a> |                         |                                                                                    |
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