LM169/LM369 Precision Voltage Reference

General Description
The LM169/LM369 are precision monolithic temperature-compensated voltage references. They are based on a buried zener reference as pioneered in the LM199 references, but do not require any heater, as they rely on special temperature-compensation techniques (Patent Pending). The LM169 makes use of thin-film technology enhanced by the discrete laser trimming of resistors to achieve excellent Temperature coefficient (Tempco) of $V_{out}$ (as low as 1 ppm/°C), along with tight initial tolerances (as low as 0.05% max). The trim scheme is such that individual resistors are cut open rather than being trimmed (partially cut), to avoid resistor drift caused by electromigration in the trimmed area. The LM169 also provides excellent stability vs. changes in input voltage and output current (both sourcing and sinking). The devices have a 10.000V output and will operate in either series or shunt mode; the output is short-circuit-proof to ground. A trim pin is available which permits fine-trimming of $V_{out}$, and also permits filtering to greatly decrease the output noise by adding a small capacitor (0.05 to 0.5 μF).

Features
- Low Tempco: 3 ppm/°C (max)
- Excellent initial accuracy: ±5 mV (max)
- Excellent line regulation: 4 ppm/V (max)
- Excellent output impedance: 0.8 Ω (max)
- Excellent thermal regulation: ±20 ppm/100 mW (max)
- Low noise
- Easy to filter output noise
- Operates in series or shunt mode

Applications
- High-Resolution Data Acquisition Systems
- Digital volt meters
- Weighing systems
- Precision current sources
- Test Equipment

Connection Diagrams

Metal Can Package (H)

Dual-In-Line Package (N) or S.O. Package (M)

Order Number LM369DM, LM369DMX, ** LM369N, LM369BN, LM369CN or LM369DN
See NS Package Number M08A or N08E

**X denotes 2500 units on Tape and Reel and is not included in the device part number marking

TO-226 Plastic Package (RC)

Order Number LM369DRC
See NS Package Number RC03A
Absolute Maximum Ratings (Note 8)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Tested Limits (Notes 2, 13)</th>
<th>Design Limit (Note 3)</th>
<th>Units (Max Unless Noted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage (Series Mode)</td>
<td>35V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reverse Current (Shunt Mode)</td>
<td>50 mA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Dissipation (Note 7)</td>
<td>600 mW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>−60°C to +150°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM169H, LM169H/883</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM369B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM369C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Soldering Information

DIP (N) or Plastic (PC) Package, 10 sec. + 260°C
H08 (H) Package, 10 sec. + 300°C
S0 (M) Package, Vapor Phase (60 sec.) + 215°C
Infrared (15 sec.) + 220°C

See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” (Appendix D) for other methods of soldering surface mount devices.

ESD Tolerance

Czap = 100 pF, Rzap = 1.5k 800V

Electrical Characteristics, LM169, LM369 (Note 1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Typical</th>
<th>Tested Limits (Notes 2, 13)</th>
<th>Design Limit (Note 3)</th>
<th>Units (Max Unless Noted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vout Nominal</td>
<td></td>
<td>±10.000 V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vout Error</td>
<td>(Note 11)</td>
<td>50 ppm</td>
<td>±500 ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vout Temperature Coefficient</td>
<td>LM169B, LM369B</td>
<td>Tmin &lt; Tj &lt; Tmax</td>
<td>1.0 ppm/°C</td>
<td>3.0 ppm/°C</td>
<td>ppm/°C</td>
</tr>
<tr>
<td>LM169, LM369</td>
<td>Tmin &lt; Tj &lt; Tmax</td>
<td>2.7 ppm/°C</td>
<td>5.0 ppm/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM369C</td>
<td>Tmin &lt; Tj &lt; Tmax</td>
<td>6 ppm/°C</td>
<td>10 ppm/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line Regulation</td>
<td></td>
<td>13V ≤ VIN ≤ 30V</td>
<td>2.0 ppm/V</td>
<td>4.0 ppm/V</td>
<td>8.0 ppm/V</td>
</tr>
<tr>
<td>Load Regulation Sourcing</td>
<td>0 to 10 mA</td>
<td>+3 ppm/ma</td>
<td>±8.0 ppm/ma</td>
<td>20.0 ppm/ma</td>
<td></td>
</tr>
<tr>
<td>Sinking (Note 12)</td>
<td>0 to −10 mA</td>
<td>+80 ppm/ma</td>
<td>+150 ppm/ma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Regulation Sourcing</td>
<td>(t − 10 msec)</td>
<td>3.0 ppm/100 mW</td>
<td>±20 ppm/100 mW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinking (Note 12)</td>
<td>After Load is Applied</td>
<td>3.0 ppm/100 mW</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supply Current</td>
<td></td>
<td>1.4 mA</td>
<td>1.8 mA</td>
<td>2.0 mA</td>
<td></td>
</tr>
<tr>
<td>ΔSupply Current</td>
<td></td>
<td>0.06 mA</td>
<td>0.12 mA</td>
<td>0.2 mA</td>
<td></td>
</tr>
<tr>
<td>Short Circuit Current</td>
<td>27 μA</td>
<td>15 μA</td>
<td>11 μA</td>
<td></td>
<td>mA min</td>
</tr>
<tr>
<td>Noise Voltage</td>
<td>10 Hz to 1 kHz</td>
<td>10 μV p-p</td>
<td>—</td>
<td></td>
<td>μV p-p</td>
</tr>
<tr>
<td>0.1 Hz to 10 Hz</td>
<td>4 μV p-p</td>
<td>—</td>
<td>—</td>
<td></td>
<td>μV p-p</td>
</tr>
<tr>
<td>(10 Hz to 10 kHz, C_{filter} = 0.1 μF)</td>
<td>4 μV p-p</td>
<td>—</td>
<td>—</td>
<td></td>
<td>μV p-p</td>
</tr>
<tr>
<td>Long-term Stability (Non-Cumulative) (Note 10)</td>
<td>1000 hours, Tj ≪ T_{max} (Measured at + 25°C)</td>
<td>6 ppm</td>
<td>—</td>
<td>—</td>
<td>ppm</td>
</tr>
<tr>
<td>Temperature Hysteresis of Vout</td>
<td>ΔT = 25°C</td>
<td>3 ppm</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Shift per 1 μA at Pin 5</td>
<td></td>
<td>1500 ppm</td>
<td>2600 ppm</td>
<td>—</td>
<td>ppm</td>
</tr>
<tr>
<td>Parameter</td>
<td>Conditions</td>
<td>Typical</td>
<td>Tested Limits (Notes 2, 13)</td>
<td>Design Limit (Note 3)</td>
<td>Units (Max Unless Noted)</td>
</tr>
<tr>
<td>------------------------------</td>
<td>--------------</td>
<td>---------------</td>
<td>----------------------------</td>
<td>-----------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>V&lt;sub&gt;out&lt;/sub&gt; Nominal</td>
<td></td>
<td>+10.000 V</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>V&lt;sub&gt;out&lt;/sub&gt; Error,</td>
<td></td>
<td>70</td>
<td>±1000</td>
<td>—</td>
<td>ppm</td>
</tr>
<tr>
<td>LM369D</td>
<td></td>
<td>0.7</td>
<td>±10.0</td>
<td>—</td>
<td>mV</td>
</tr>
<tr>
<td>V&lt;sub&gt;out&lt;/sub&gt; Tempco</td>
<td>T&lt;sub&gt;min&lt;/sub&gt; ≤ T&lt;sub&gt;j&lt;/sub&gt; ≤ T&lt;sub&gt;max&lt;/sub&gt;</td>
<td>5</td>
<td>30</td>
<td>ppm/°C</td>
<td></td>
</tr>
<tr>
<td>(Note 6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line Regulation</td>
<td>13V ≤ V&lt;sub&gt;IN&lt;/sub&gt; ≤ 30V</td>
<td>2.4</td>
<td>±6.0</td>
<td>12</td>
<td>ppm/V</td>
</tr>
<tr>
<td>Load Regulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sourcing</td>
<td>0 to 10 mA</td>
<td>+3</td>
<td>±12</td>
<td>±25</td>
<td>ppm/mA</td>
</tr>
<tr>
<td>Sinking (Note 12)</td>
<td>0 to –10 mA</td>
<td>+80</td>
<td>+160</td>
<td></td>
<td>ppm/mA</td>
</tr>
<tr>
<td>(Note 4, Note 9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Regulation</td>
<td>(t = 10 msec)</td>
<td>4.0</td>
<td>±23</td>
<td>—</td>
<td>ppm/100 mW</td>
</tr>
<tr>
<td>Sourcing</td>
<td>After Load is Applied</td>
<td>4.0</td>
<td>±25</td>
<td>—</td>
<td>ppm/100 mW</td>
</tr>
<tr>
<td>Sinking (Note 12)</td>
<td>(Note 5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supply Current</td>
<td></td>
<td>1.5</td>
<td>2.0</td>
<td>2.4</td>
<td>mA</td>
</tr>
<tr>
<td>ΔSupply Current</td>
<td>13V ≤ V&lt;sub&gt;IN&lt;/sub&gt; ≤ 30V</td>
<td>0.06</td>
<td>0.16</td>
<td>0.3</td>
<td>mA</td>
</tr>
<tr>
<td>Short Circuit Current</td>
<td></td>
<td>27</td>
<td>14</td>
<td>10</td>
<td>mA min</td>
</tr>
<tr>
<td>Noise Voltage</td>
<td></td>
<td>10</td>
<td>30</td>
<td>—</td>
<td>µV rms</td>
</tr>
<tr>
<td>0.1 Hz to 10 Hz</td>
<td></td>
<td>4</td>
<td>—</td>
<td>—</td>
<td>µV p-p</td>
</tr>
<tr>
<td>(10 Hz to 10 kHz, C&lt;sub&gt;L&lt;/sub&gt; = 0.1 µF)</td>
<td>4</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>µV rms</td>
</tr>
<tr>
<td>Long-Term Stability</td>
<td>1000 Hours, T&lt;sub&gt;j&lt;/sub&gt; &lt; T&lt;sub&gt;max&lt;/sub&gt; (Measured at +25°C)</td>
<td>8</td>
<td>—</td>
<td>—</td>
<td>ppm</td>
</tr>
<tr>
<td>(Non-Cumulative)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature Hysteresis of V&lt;sub&gt;out&lt;/sub&gt;</td>
<td>ΔT = 25°C</td>
<td>5</td>
<td>—</td>
<td>—</td>
<td>ppm</td>
</tr>
<tr>
<td>Output Shift Per 1 µA at Pin 5</td>
<td></td>
<td>1500</td>
<td>2800</td>
<td>—</td>
<td>ppm</td>
</tr>
</tbody>
</table>

Note 1: Unless otherwise noted, these conditions apply: T<sub>j</sub> = +25°C, 13V ≤ V<sub>IN</sub> ≤ 17V, 0 ≤ I<sub>load</sub> ≤ 1.0 mA, C<sub>L</sub> = 200 pF. Specifications in **BOLDFACED TYPE** apply over the rated operating temperature range.

Note 2: Tested limits are guaranteed and 100% tested in production.

Note 3: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not to be used to calculate outgoing quality levels.

Note 4: The LM169 has a Class B output, and will exhibit transients at the crossover point. This point occurs when the device is required to sink approximately 1.0 mA. In some applications it may be advantageous to pre-load the output to either V<sub>IN</sub> or to ground, to avoid this crossover point.

Note 5: Thermal regulation is defined as the change in the output voltage at a time T after a step change of power dissipation of 100 mW.

Note 6: Temperature Coefficient of V<sub>OUT</sub> is defined as the worst-case ΔV<sub>OUT</sub> measured at Specified Temperatures divided by the total span of the Specified Temperature Range (see graphs). There is no guarantee that the Specified Temperatures are exactly at the minimum or maximum deviation.

Note 7: In metal can (H), Δ<sub>J-A</sub> is 75°C/W and Δ<sub>J-A</sub> is 150°C/W. In plastic DIP, Δ<sub>J-A</sub> is 180°C/W, in TO-226, Δ<sub>J-A</sub> is 160°C/W.

Note 8: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications are not guaranteed beyond the Rated Operating Conditions.

Note 9: Regulation is measured at constant temperature using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for Thermal Regulation and Tempco. Load Regulation is measured at a point on the output pin 1/8 x below the bottom of the package.

Note 10: Consult factory for availability of devices with Guaranteed Long-term Stability.

Note 11: Consult factory for availability of devices with tighter Accuracy and Tempco Specifications.

Note 12: In Sinking mode, connect 0.1 µF tantalum capacitor from output to ground.

Note 13: A military RETS electrical test specification is available on request.
Typical Performance Characteristics (Note 1)

- **Quiescent Current vs Input Voltage and Temperature**
- **Dropout Voltage vs Output Current (Series Mode Sourcing Current)**
- **Output Change vs Output Current**
- **Output Impedance vs Frequency**
- **Ripple Rejection vs Frequency**
- **Start-up Response**
- **Output Noise vs Frequency**
- **Output Noise vs Filter Capacitor**
- **LM169 Temperature Coefficient Specified Temperatures (see Note 6)**
- **LM369 Temperature Coefficient Specified Temperatures (see Note 6)**

**Typical Temperature Coefficient Calculations:**
- **LM169 (see curve above):**
  - T.C. = \(1.6 \text{ mV}/(180 \times 10^3 \text{V})\)
  - \(= 8.9 \times 10^{-7} \approx 0.89 \text{ ppm/°C}\)
- **LM369 (see curve at left):**
  - T.C. = \(0.5 \text{ mV}/(75 \times 10^3 \text{V})\)
  - \(= 6.7 \times 10^{-7} \approx 0.67 \text{ ppm/°C}\)
**Application Hints**

The LM169/LM369 can be applied in the same way as any other voltage reference. The adjacent Typical Applications Circuits suggest various uses for the LM169/LM369. The LM169 is recommended for applications where the highest stability and lowest noise is required over the full military temperature range. The LM369 is suitable for limited-temperature operation. The curves showing the Noise vs. Capacitance in the Typical Performance Characteristics section show graphically that a modest capacitance of 0.1 to 0.3 microfarads can cut the broadband noise down to a level of only a few microvolts, less than 1 ppm of the output voltage. The capacitor used should be a low-leakage type. For the temperature range 0 to 50°C, polyester or Mylar® will be suitable, but at higher temperatures, a premium film capacitor such as polypropylene is recommended. For operation at +125°C, a Teflon® capacitor would be required, to ensure sufficiently low leakage. Ceramic capacitors may seem to do the job, but are not recommended for production use, as the high-K ceramics cannot be guaranteed for low leakage, and may exhibit piezo-electric effects, converting vibration or mechanical stress into excessive electrical noise.

Additionally, the inherent superiority of the LM169/369’s buried Zener diode provides freedom from low-frequency noise, wobble, and jitter, in the frequency range 0.01 to 10 Hertz, where capacitive filtering is not feasible.

Pins 1, 3, 7, and 8 of the LM169/369 are connected to internal trim circuits which are used to trim the device’s output voltage and Tempco during final testing at the factory. Do not connect anything to these pins, or improper operation may result. These pins would not be damaged by a short to ground, or by Electrostatic Discharges; however, they may be degraded by overloads at high ambient temperatures, as a prolonged short-circuit may cause the junction temperature to exceed the Absolute Maximum Temperature. The device does not include a thermal shut-down circuit. If the output is pulled to a positive voltage such as +15 or +20 V, the output current will be limited, but overheating may occur. Avoid such overloads for voltages higher than +20 V, for more than 5 seconds, or, at high ambient temperatures.

The LM169/369 has an excellent long-term stability, and is suitable for use in high-resolution Digital Voltmeters or Data Acquisition systems. Its long-term stability is typically 3 to 10 ppm per 1000 hours when held near T max, and slightly better when operated at room temperature. Contact the factory for availability of devices with proven long-term stability.

**Typical Applications**

**Series Reference**

**Shunt Reference with Optional Trim**

**Series Reference with Optional Filter for Reduced Noise**

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**NOTE:** Pin numbers for H, M or N packages.
Typical Applications (Continued)

**± 10V Reference**

- IN
- OUT
- GND
- 2
- 4
- 5
- OUTPUT +10.000V
- OUTPUT -10.000V
- 0.1 µF TANT.
- L = 2 mA
- V =

**± 5V Reference**

- IN
- OUT
- GND
- 2
- 4
- 5
- OUTPUT +5V
- OUTPUT -5V
- 0.1 µF
- 0.01 µF
- 10 K
- 10 K
- 0.1 %
- 0.1 %

**Multiple Output Voltages**

- 23 V ≤ V = 30 V
- IN
- OUT
- GND
- TRIM
- 2
- 4
- 5
- 6
- OUTPUT 20 V
- OUTPUT 10 V
- 4.7 K
- 2 M
- L607

- 23 V ≤ V = 35 V
- IN
- OUT
- GND
- TRIM
- 2
- 4
- 5
- 6
- OUTPUT 20 V
- OUTPUT 10 V
- 0.1 µF TANTALUM

R = Thin Film Resistor Network
0.05% Matching and 5 ppm Tracking
(Beckman 694-3-R-10k-A),
(Caddock T-914-10k-100-05)
(Allen Bradley F08B103A)
or similar.

**NOTE:** Pin numbers for H, M or N packages.
Typical Applications (Continued)

**Precision Wide-Range Current Source**

- $A_1 = $ LF411A, LM607, LM308A or similar
- $Q_1, Q_2 = $ high $\beta$ PNP, PN4250, 2N3906, or similar

* = Part of Precision Resistor Network, ±0.05% Matching,
(Allen Bradley F08B103A)
(Caddock T-914-10K-100-05)
(Beckman 694-3-R-10K-A)
or similar

**± 10V, ± 5V References**

- $R = $ Thin Film Resistor Network
  0.05% Matching and 5 ppm Tracking
  (Beckman 694-3-R-10K-A),
  (Caddock T-914-10K-100-05)
  (Allen Bradley F08B103A)
  or similar.

**Reference with Booster**

**100 mA Boosted Reference**

- $V_0 = \frac{1}{4} LF444A$ or
- $\frac{1}{2} LF412A$ or
- LM607

- $V_0 = \frac{1}{4} LF444A$ or
- $\frac{1}{2} LF412A$ or
- LM607

- $V_0 = \frac{1}{4} LF444A$ or
- $\frac{1}{2} LF412A$ or
- LM607
Typical Applications (Continued)

**Current Source**

\[ \begin{align*}
2k & \leq R_x \leq 10M \\
\end{align*} \]

**Precision Current Source**

\[ \begin{align*}
Q_1, Q_2 & = \text{high } \beta \text{ PNP,} \\
& \text{PN4250, 2N3906} \\
& \text{or similar} \\
A_1 & = \text{LM607, LM11, LF411A} \\
& \text{or similar}
\end{align*} \]
Typical Applications (Continued)

**Oscilloscope Calibrator**

![Oscilloscope Calibrator Circuit Diagram]

- **Iou**
- **Rx**
- **A1**
- **e**

**Precision Wide-Range Current Sink**

![Precision Wide-Range Current Sink Circuit Diagram]

- **Iou**
- **Rx**
- **A1**
- **e**

**Digitally Variable Supply**

![Digitally Variable Supply Circuit Diagram]

- **Vout**
- **Vref**
- **A1**
- **Q1, Q2**

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TL/H/9110–22

TL/H/9110–22

TL/H/9110–22

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A1 = LM11, LM607 or similar.

Q1, Q2 = high Beta NPN, 2N3707, 2N3904 or similar.

Vout = \(-10V \times (\text{Digitally Set Gain})\).

A1 = LM11A, LM607, or similar.

MDAC = DAC1220, DAC1208, DAC1230, or similar.
Typical Applications (Continued)

Ultra-Low-Noise Statistical Reference

When N pieces of LM369 are used, the $V_{out}$ noise is decreased by a factor of $\frac{1}{\sqrt{N}}$.

If the output buffer is not used, for lowest noise add 0.1 µF Mylar® from ground to pin 5 of each LM369.

LM169 Block Diagram

*Do not connect; internal connection for factory trim.
Physical Dimensions inches (millimeters)

Metal Can Package (H)
Order Number LM169BH, LM169H,
LM169H/883, LM369BH or LM369H
NS Package Number H08C
Surface Mount Package (M)
Order Number LM369DM or LM369DMX
NS Package Number M08A
Physical Dimensions  inches (millimeters) (Continued)

Molded Dual-In-Line Package (N)
Order Number LM369BN, LM369N, LM369CN or LM369DN
NS Package Number N08E
Physical Dimensions inches (millimeters) (Continued)

LM169/LM369 Precision Voltage Reference

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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