National Semiconductor

December 1994

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

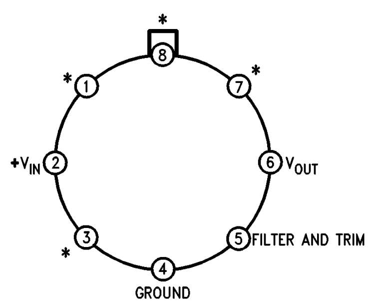
- Low Tempco 3 ppm/°C (max)
- Excellent initial accuracy ±5 mV (max)
- Excellent line regulation 4 ppm/V (max)
- Excellent output impedance ±0.8Ω (max)
- Excellent thermal regulation ±20 ppm/100 mW (max)
- Low noise
- Easy to filter output noise
- Operates in series or shunt mode

Applications

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

Connection Diagrams

Metal Can Package (H)



TL/H/9110–1

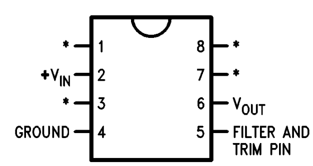
Top View

(Case is connected to ground.)

*Do not connect; internal connection for factory trims.

Order Number LM169H, LM169BH, LM169H/883, LM369H or LM369BH
See NS Package Number H08C

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



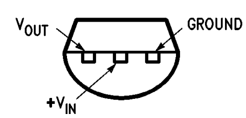
TL/H/9110–5

Top View

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)



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Bottom View

Order Number LM369DRC
See NS Package Number RC03A

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Absolute Maximum Ratings (Note 8)

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

Input Voltage (Series Mode)	35V
Reverse Current (Shunt Mode)	50 mA
Power Dissipation (Note 7)	600 mW
Storage Temperature Range	−60°C to +150°C
Operating Temperature Range	(T_j min to T_j max)
LM169H, LM169H/883	−55°C to +125°C
LM369	0°C to +70°C

Soldering Information

DIP (N) or Plastic (RC) Package, 10 sec.	+260°C
H08 (H) Package, 10 sec.	+300°C
SO (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

C_{zap} = 100 pF, R_{zap} = 1.5k 800V

Electrical Characteristics, LM169, LM369 (Note 1)

Parameter	Conditions	Typical	Tested Limits (Notes 2, 13)	Design Limit (Note 3)	Units (Max Unless Noted)
V_{out} Nominal		+10.000			V
V_{out} Error	(Note 11)	50 0.50	±500 ±5		ppm mV
V_{out} Tempco LM169B, LM369B LM169, LM369 LM369C (Note 6) (Note 11)	 $T_{min} < T_j < T_{max}$ $T_{min} < T_j < T_{max}$ $T_{min} < T_j < T_{max}$	 1.0 2.7 6	 **3.0** **5.0** **10**	 — — —	 ppm/°C ppm/°C ppm/°C
Line Regulation	13V ≤ V_{IN} ≤ 30V	2.0	4.0	**8.0**	ppm/V
Load Regulation Sourcing Sinking (Note 12) (Note 4, Note 9)	 0 to 10 mA 0 to −10 mA	 +3 +80	 ±8.0 +150	 **20.0**	 ppm/mA ppm/mA
Thermal Regulation Sourcing Sinking (Note 12) (Note 5)	(t = 10 msec After Load is Applied)	 3.0 3.0	 ±20 —	 **—** **—**	 ppm/100 mW ppm/100 mW
Supply Current		1.4	1.8	**2.0**	mA
ΔSupply Current	13V ≤ V_{IN} ≤ 30V	0.06	0.12	**0.2**	mA
Short Circuit Current		27	15 50	**11** **65**	mA min mA max
Noise Voltage	10 Hz to 1 kHz 0.1 Hz to 10 Hz (10 Hz to 10 kHz, C_{filter} = 0.1 μF)	10 4 4	30 — —	— — —	μV rms μV p-p μV rms
Long-term Stability (Non-Cumulative) (Note 10)	1000 hours, $T_j < T_{max}$ (Measured at +25°C)	6	—	—	ppm
Temperature Hysteresis of V_{out}	ΔT = 25°C	3	—	—	ppm
Output Shift per 1 μA at Pin 5		1500	2600	—	ppm

Electrical Characteristics LM369D (Note 1)

Parameter	Conditions	Typical	Tested Limits (Notes 2, 13)	Design Limit (Note 3)	Units (Max Unless Noted)
V_{out} Nominal		+10.000			V
V_{out} Error, LM369D		70 0.7	±1000 ±10.0	— —	ppm mV
V_{out} Tempco (Note 6)	$T_{min} \le T_j \le T_{max}$	5		**30**	ppm/°C
Line Regulation	$13V \le V_{IN} \le 30V$	2.4	±6.0	**12**	ppm/V
Load Regulation Sourcing Sinking (Note 12) (Note 4, Note 9)	 0 to 10 mA 0 to −10 mA	 +3 +80	 ±12 +160	 ±**25**	 ppm/mA ppm/mA
Thermal Regulation Sourcing Sinking (Note 12) (Note 5)	(t = 10 msec After Load is Applied)	 4.0 4.0	 ±25 —	 — —	 ppm/100 mW ppm/100 mW
Supply Current		1.5	2.0	**2.4**	mA
ΔSupply Current	$13V \le V_{IN} \le 30V$	0.06	0.16	**0.3**	mA
Short Circuit Current		27	14 50	**10** **65**	mA min mA max
Noise Voltage	10 Hz to 1 kHz 0.1 Hz to 10 Hz (10 Hz to 10 kHz, C_{filter} = 0.1 μF)	10 4 4	30 — —	— — —	μV rms μV p-p μV rms
Long-Term Stability (Non-Cumulative)	1000 Hours, $T_j < T_{max}$ (Measured at +25°C)	8	—	—	ppm
Temperature Hysteresis of V_{out}	ΔT = 25°C	5	—	—	ppm
Output Shift Per 1 μA at Pin 5		1500	2800	—	ppm

Note 1: Unless otherwise noted, these conditions apply: T_j = +25°C, 13V ≤ V_{in} ≤ 17V, 0 ≤ I_{load} ≤ 1.0 mA, C_L = ≤ 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_{in} 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_{OUT} is defined as the worst-case ΔV_{out} 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), θ_{J-C} is 75°C/W and θ_{J-A} is 150°C/W. In plastic DIP, θ_{J-A} is 160°C/W. In S0-8, θ_{J-A} is 180°C/W, in TO-226, θ_{J-A} 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″ below the bottom of the package.

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

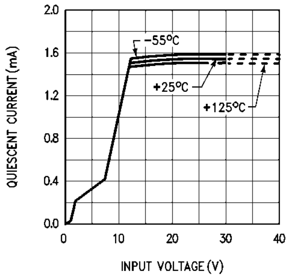
Note 11: Consult factory for availability of devices with tighter Accuracy and Tempco Specifications.

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

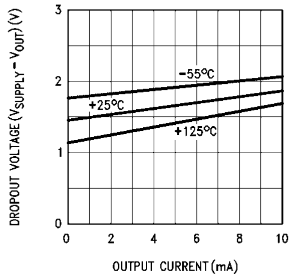
Note 13: A military RETS electrical test specification is available on request.

Typical Performance Characteristics (Note 1)

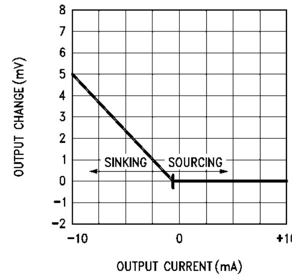
Quiescent Current vs Input Voltage and Temperature



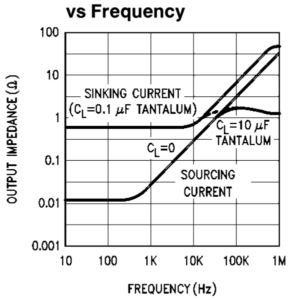
Dropout Voltage vs Output Current (Series Mode Sourcing Current)



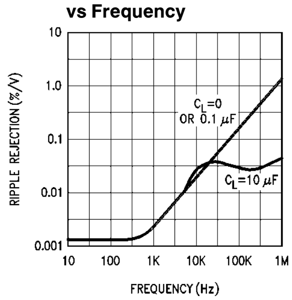
Output Change vs Output Current



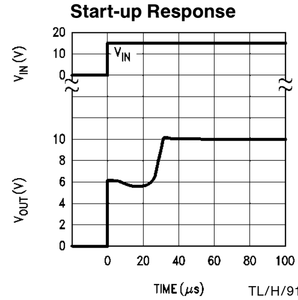
Output Impedance vs Frequency



Ripple Rejection vs Frequency

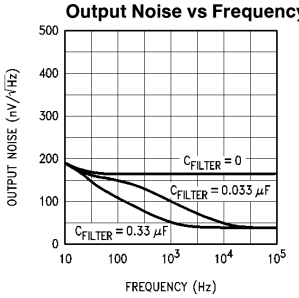


Start-up Response



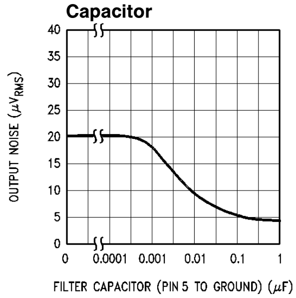
TL/H/9110–6

Output Noise vs Frequency



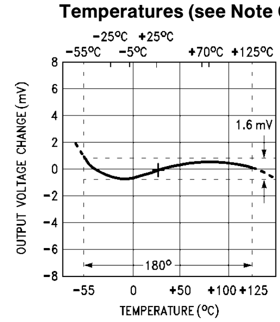
TL/H/9110–24

Output Noise vs Filter Capacitor



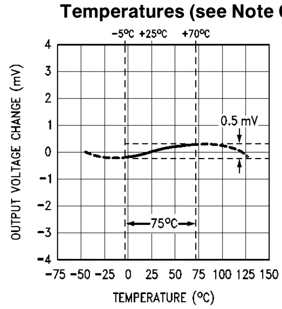
TL/H/9110–25

LM169 Temperature Coefficient Specified Temperatures (see Note 6)



TL/H/9110–26

LM369 Temperature Coefficient Specified Temperatures (see Note 6)



TL/H/9110–27

Typical Temperature Coefficient Calculations:

LM169 (see curve above):
T.C. = 1.6 mV/(180° × 10V)
= 8.9 × 10^{-7} = 0.89 ppm/°C

LM369 (see curve at left):
T.C. = 0.5 mV/(75° × 10V)
= 6.7 × 10^{-7} = 0.67 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, keep them away from large transients or AC signals, as stray capacitance could couple noises into the output. These pins may be cut off if desired. Alternatively, a shield foil can be laid out on the printed circuit board, surrounding these pins and pin 5, and this guard foil can be connected to ground or to V_{out}, effectively acting as a guard against AC coupling and DC leakages.

The trim pin (pin 5) should also be guarded away from noise signals and leakages, as it has a sensitivity of 15 millivolts of ΔV_{out} per microampere. The trim pin can also be used in the circuits shown, to provide an output trim range of ± 10 millivolts. Trimming to a wider range is possible, but is not recommended as it may degrade the Tempco and the Tempco linearity at temperature extremes. For example, if the output were trimmed up to 10.240V, the Tempco would be degraded by 8 ppm/°C. As a general rule, Tempco will be degraded by 1 ppm/°C per 30 mV of output adjustment.

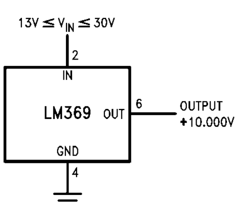
The output can sink current as well as source it, but the output impedance is much better for sourcing current. Also, the LM169/369 requires a 0.1 μF tantalum capacitor (or, 0.1 μF in series with 10Ω) bypass from the output to ground, for stable operation in shunt mode (output sinking current). The output has a class-B stage, so if the load current changes from sourcing to sinking, an output transient will occur. To avoid this transient, it may be advisable to preload the output with a few milliamperes of load to ground. The LM169/369 does have an excellent tolerance of load capacitance, and in cases of load transients, electrolytic or tantalum capacitors in the range 1 to 500 microfarads have been shown to improve the output impedance without degrading the dynamic stability of the device. The LM169/369 are rated to drive an output of ± 10 mA, but for best accuracy, any load current larger than 1 mA can cause thermal errors (such as, 1 mA $\times$ 5V $\times$ 4 ppm/100 mW = 0.2 ppm or 2 microvolts) and degrade the ultimate precision of the output voltage.

The output is short-circuit-proof to ground. However, avoid 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 +20V, 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.

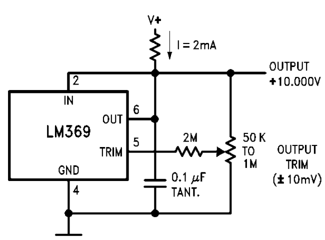
Typical Applications

Series Reference



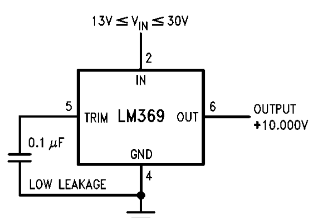
TL/H/9110–2

Shunt Reference with Optional Trim



TL/H/9110–3

Series Reference with Optional Filter for Reduced Noise

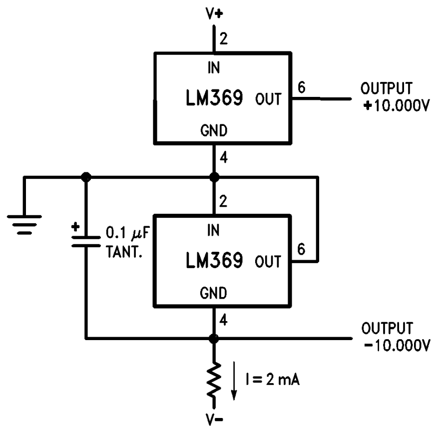


TL/H/9110–4

NOTE: Pin numbers for H, M or N packages.

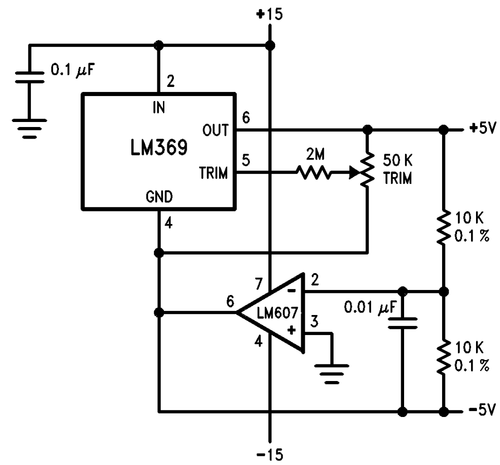
Typical Applications (Continued)

±10V Reference



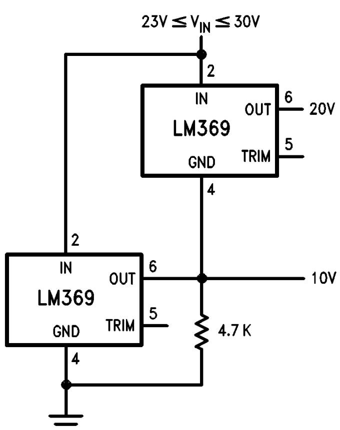
TL/H/9110–7

±5V Reference

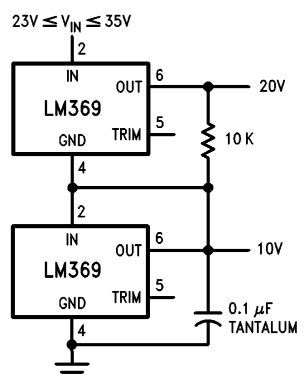


TL/H/9110–8

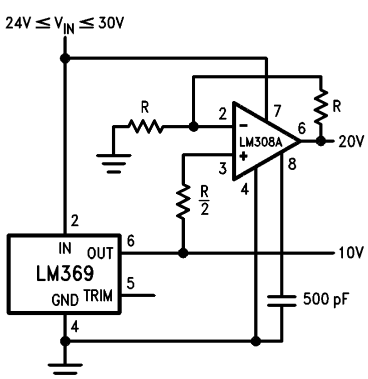
Multiple Output Voltages



TL/H/9110–9



TL/H/9110–10



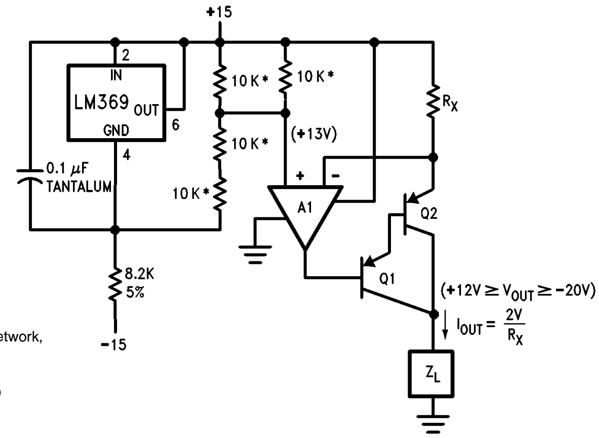
TL/H/9110–11

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



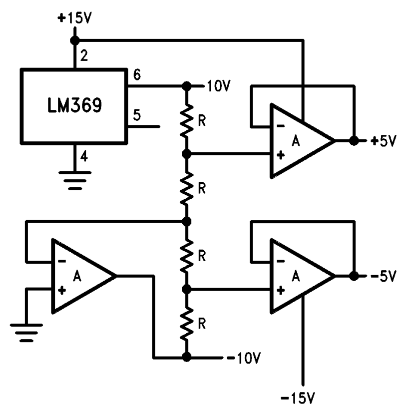
A_1 = LF411A, LM607, LM308A or similar

Q_1, Q_2 = high β 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

TL/H/9110–18

±10V, ±5V References

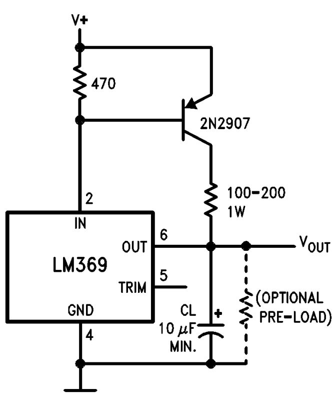


A = ¼ LF444A or ½ LF412A or LM607

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.

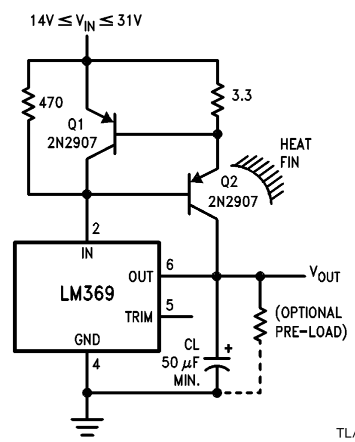
TL/H/9110–12

Reference with Booster



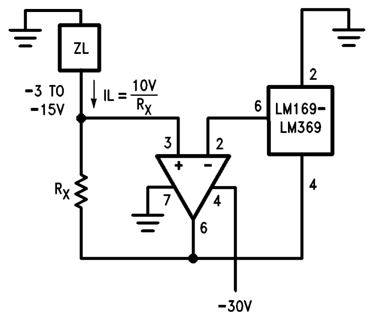
TL/H/9110–13

100 mA Boosted Reference



TL/H/9110–14

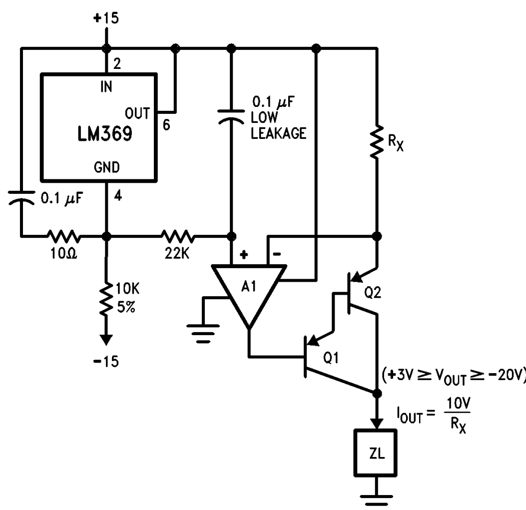
Current Source



$2k \leq Rx \leq 10M$

TL/H/9110–16

Precision Current Source



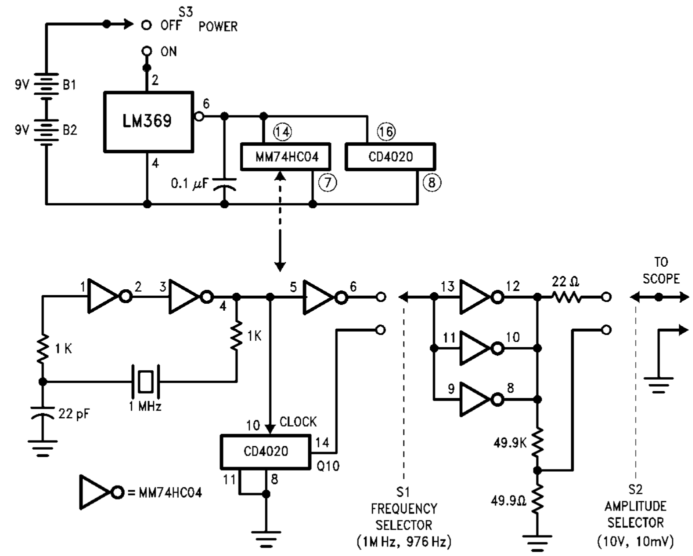
Q_1, Q_2 = high β PNP,
PN4250, 2N3906
or similar

A_1 = LM607, LM11, LF411A
or similar

TL/H/9110–17

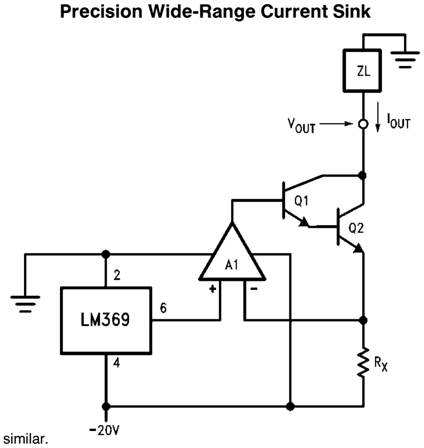
Typical Applications (Continued)

Oscilloscope Calibrator



TL/H/9110–22

Precision Wide-Range Current Sink



$I_{out} = \frac{10V}{Rx}$

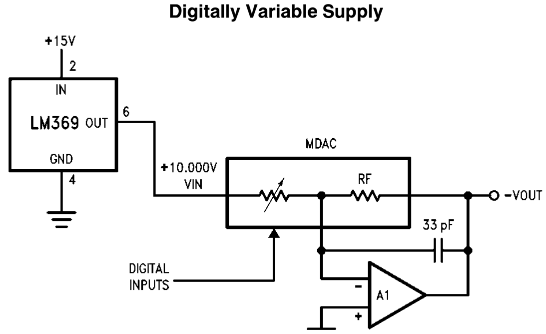
A_1 = LM11, LM607 or similar.

$(V3 + 2V) \leq V_{out} \leq +20V$.

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

TL/H/9110–19

Digitally Variable Supply



$V_{out} = -10V \times$ (Digitally Set Gain).

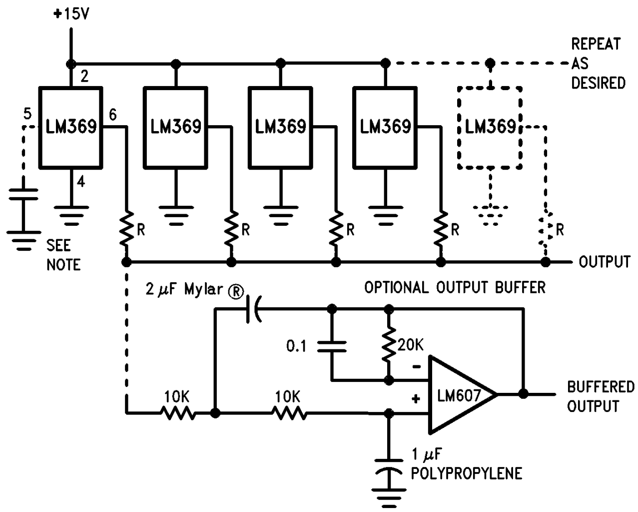
A_1 = LM11A, LM607, or similar.

MDAC = DAC1220, DAC1208, DAC1230, or similar.

TL/H/9110–20

Typical Applications (Continued)

Ultra-Low-Noise Statistical Reference



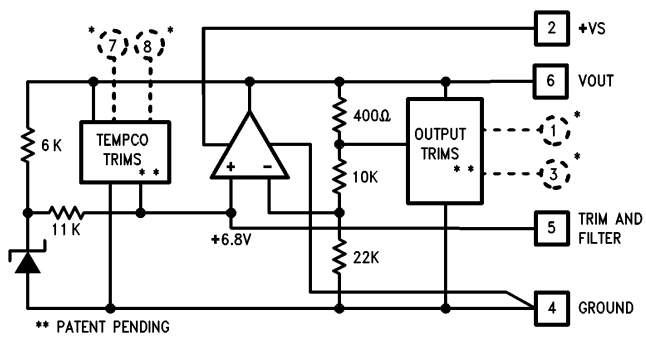
TL/H/9110–23

$200\Omega \leq R \leq 1k$

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.

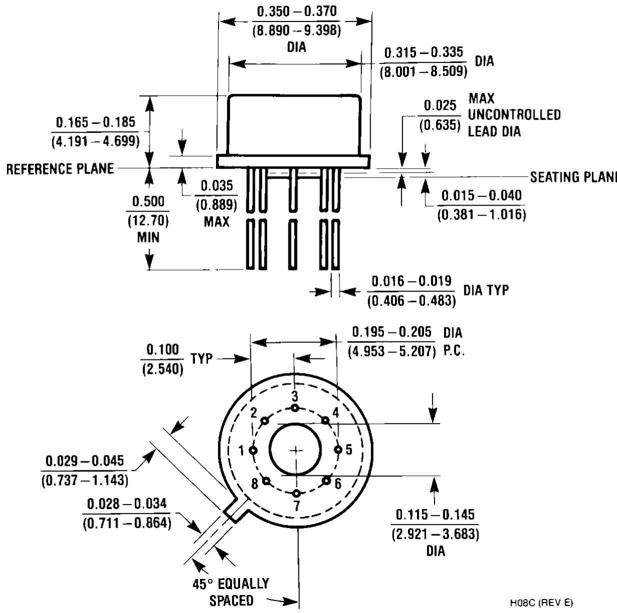
LM169 Block Diagram



TL/H/9110–15

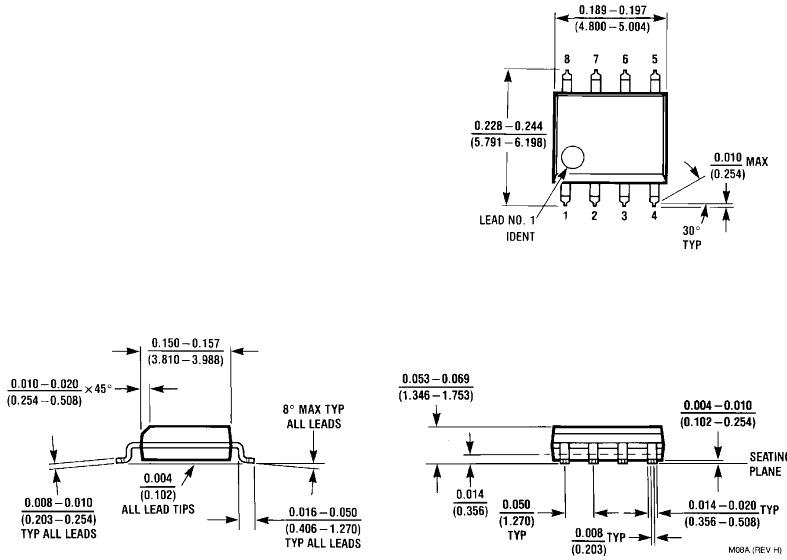
*Do not connect; internal connection for factory trim.

Physical Dimensions inches (millimeters)



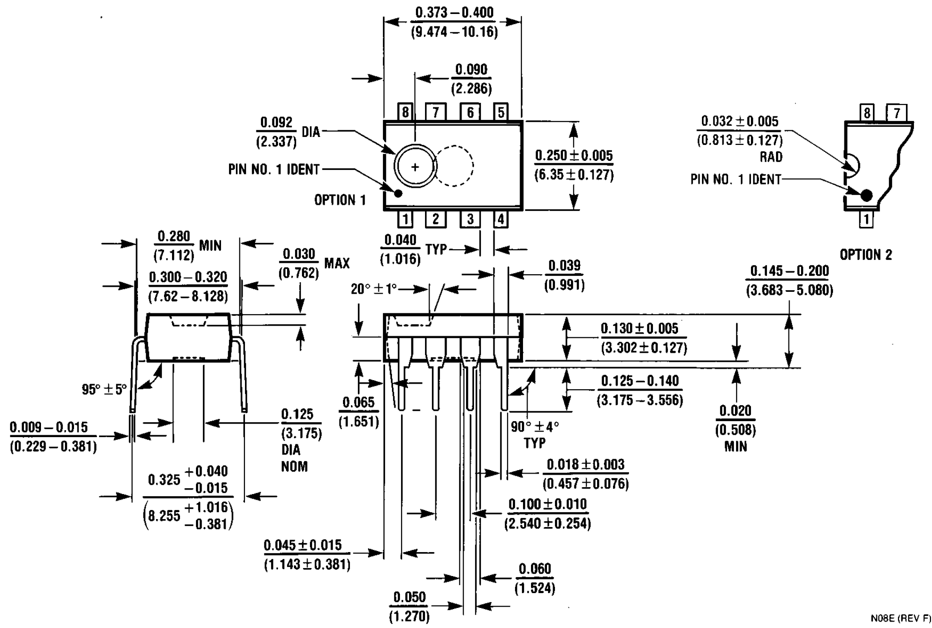
Metal Can Package (H)
Order Number LM169BH, LM169H,
LM169H/883, LM369BH or LM369H
NS Package Number H08C

Physical Dimensions inches (millimeters) (Continued)



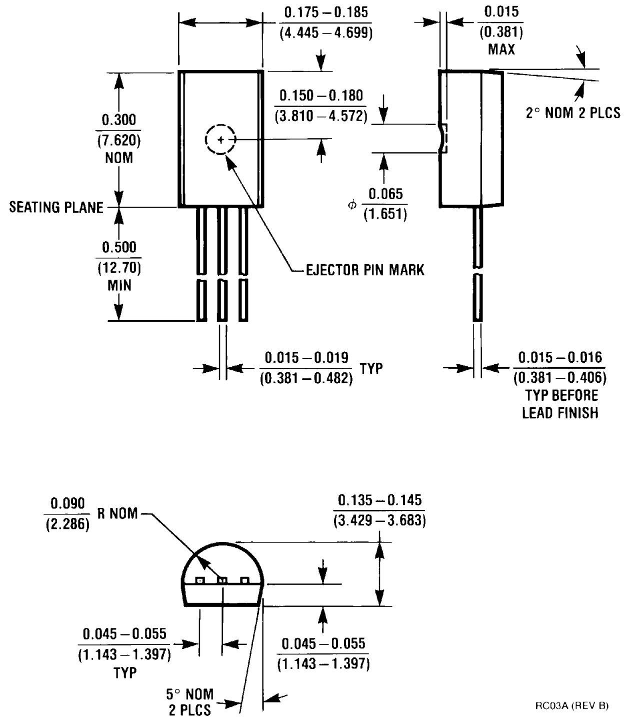
Surface Mount Package (M)
Order Number LM369DM or LM369DMX
NS Package Number M08A

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)



Molded TO-226 Package (RC)
Order Number LM369DRC
NS Package Number RC03A

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