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National Semiconductor

LM4051
Precision Micropower Shunt Voltage Reference

General Description

Ideal for space critical applications, the LM4051 precision voltage reference is available in the sub-miniature (3 mm x 1.3 mm) SOT-23 surface-mount package. The LM4051's advanced design eliminates the need for an external stabilizing capacitor while ensuring stability with any capacitive load, thus making the LM4051 easy to use. Further reducing design effort is the availability of a fixed (1.225V) and adjustable reverse breakdown voltage. The minimum operating current is 60 µA for the LM4051-1.2 and the LM4051-ADJ. Both versions have a maximum operating current of 12 mA.

The LM4051 comes in three grades (A, B, and C). The best grade devices (A) have an initial accuracy of 0.1%, while the B-grade have 0.2% and the C-grade 0.5%, all with a tempco of 50 ppm/˚C guaranteed from –40˚C to 125˚C.

The LM4051 utilizes fuse and zener-zap trim of reference voltage during wafer sort to ensure that the prime parts have an accuracy of better than ±0.1% (A grade) at 25˚C.

Features

- Small packages: SOT-23
- No output capacitor required
- Tolerates capacitive loads
- Reverse breakdown voltage options of 1.225V and adjustable

Key Specifications (LM4051-1.2)

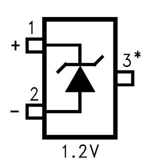
■ Output voltage tolerance (A grade, 25˚C)	±0.1%(max)
■ Low output noise (10 Hz to 10kHz)	20µV_{rms}
■ Wide operating current range	60µA to 12mA
■ Industrial temperature range	–40˚C to +85˚C
■ Extended temperature range	–40˚C to +125˚C
■ Low temperature coefficient	50 ppm/˚C (max)

Applications

- Portable, Battery-Powered Equipment
- Data Acquisition Systems
- Instrumentation
- Process Control
- Energy Management
- Automotive and Industrial
- Precision Audio Components
- Base Stations
- Battery Chargers
- Medical Equipment
- Communication

Connection Diagrams

SOT-23



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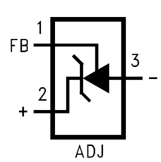

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*This pin must be left floating or connected to pin 2.

Top View
See NS Package Number MF03A

Ordering Information

Industrial Temperature Range (−40˚C to +85˚C)

Reverse Breakdown Voltage Tolerance at 25˚C and Average Reverse Breakdown Voltage Temperature Coefficient	LM4051 Supplied as 1000 Units, Tape and Reel	LM4051 Supplied as 3000 Units, Tape and Reel
±0.1%, 50 ppm/˚C max (A grade)	LM4051AIM3-1.2	LM4051AIM3X-1.2
	LM4051AIM3-ADJ	LM4051AIM3X-ADJ
±0.2%, 50 ppm/˚C max (B grade)	LM4051BIM3-1.2	LM4051BIM3X-1.2
	LM4051BIM3-ADJ	LM4051BIM3X-ADJ
±0.5%, 50 ppm/˚C max (C grade)	LM4051CIM3-1.2	LM4051CIM3X-1.2
	LM4051CIM3-ADJ	LM4051CIM3X-ADJ

Extended Temperature Range (−40˚C to +125˚C)

Reverse Breakdown Voltage Tolerance at 25˚C and Average Reverse Breakdown Voltage Temperature Coefficient	LM4051 Supplied as 1000 Units, Tape and Reel	LM4051 Supplied as 3000 Units, Tape and Reel
±0.1%, 50 ppm/˚C max (A grade)	LM4051AEM3-1.2	LM4051AEM3X-1.2
	LM4051AEM3-ADJ	LM4051AEM3X-ADJ
±0.2%, 50 ppm/˚C max (B grade)	LM4051BEM3-1.2	LM4051BEM3X-1.2
	LM4051BEM3-ADJ	LM4051BEM3X-ADJ
±0.5%, 50 ppm/˚C max (C grade)	LM4051CEM3-1.2	LM4051CEM3X-1.2
	LM4051CEM3-ADJ	LM4051CEM3X-ADJ

SOT-23 Package Marking Information

Only three fields of marking are possible on the SOT-23's small surface. This table gives the meaning of the three fields.

Part Marking	Field Definition
RHA	First Field:
RIA	R = Reference
RHB	Second Field:
RIB	H = 1.225V Voltage Option
RHC	I = Adjustable
RIC	Third Field:
	A–C = Initial Reverse Breakdown Voltage or Reference Voltage Tolerance
	A = ±0.1%, B = ±0.2%, C = ±0.5%

Absolute Maximum Ratings (Note 1)

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

Reverse Current	20 mA
Forward Current	10 mA
Maximum Output Voltage	
(LM4051-ADJ)	15V
Power Dissipation (T_A = 25˚C) (Note 2)	
M3 Package	280 mW
Storage Temperature	−65˚C to +150˚C
Lead Temperature	
M3 Packages	
Vapor phase (60 seconds)	+215˚C
Infrared (15 seconds)	+220˚C
ESD Susceptibility	
Human Body Model (Note 3)	2 kV
Machine Model (Note 3)	200V

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

Operating Ratings (Note 2)

Temperature Range	(T_{min} ≤ T_A ≤ T_{max})
Industrial Temperature Range	−40˚C ≤ T_A ≤ +85˚C
Extended Temperature Range	−40˚C ≤ T_A ≤ +125˚C
Reverse Current	
LM4051-1.2	60 µA to 12 mA
LM4051-ADJ	60 µA to 12 mA
Output Voltage Range	
LM4051-ADJ	1.24V to 10V

LM4051-1.2 Electrical Characteristics

Boldface limits apply for T_A = T_J = T_{MIN} to T_{MAX}; all other limits T_A = T_J = 25˚C. The grades A, B and C designate initial Reverse Breakdown Voltage tolerances of ±0.1%, ±0.2% and ±0.5% respectively.

Symbol	Parameter	Conditions	Typical (Note 4)	LM4051AIM3 LM4051AEM3 (Limits) (Note 5)	LM4051BIM3 LM4051BEM3 (Limits) (Note 5)	LM4051CIM3 LM4051CEM3 (Limts) (Note 5)	Units (Limit)
V_R	Reverse Breakdown Voltage	I_R = 100 µA	1.225				V
	Reverse Breakdown Voltage Tolerance (Note 6)	I_R = 100 µA		±1.2	±2.4	±6	mV (max)
		Industrial Temp. Range		**±5.2**	**±6.4**	**±10.1**	mV (max)
		Extended Temp. Range		**±7.4**	**±8.6**	**±12.2**	mV (max)
I_{RMIN}	Minimum Operating Current		39				µA
				60	60	60	µA (max)
				65	**65**	**65**	µA (max)
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient (Note 6)	I_R= 10 mA	±20				ppm/˚C
		I_R = 1 mA	±15				ppm/˚C
		I_R = 100 µA ΔT = −40˚C to 125˚C	±15	**±50**	**±50**	**±50**	ppm/˚C (max)
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	I_{RMIN} ≤ I_R ≤ 1 mA	0.3				mV
				1.1	1.1	1.1	mV (max)
				1.5	**1.5**	**1.5**	mV (max)
		1 mA ≤ I_R ≤ 12 mA	1.8				mV
				6.0	6.0	6.0	mV (max)
				8.0	**8.0**	**8.0**	mV (max)
Z_R	Reverse Dynamic Impedance	I_R = 1 mA, f = 120 Hz	0.5				Ω
e_N	Wideband Noise	I_R = 100 µA 10 Hz ≤ f ≤ 10 kHz	20				$µV_{rms}$
ΔV_R	Reverse Breakdown Voltage Long Term Stability (Note 9)	t = 1000 hrs T = 25˚C ±0.1˚C I_R = 100 µA	120				ppm
V_{HYST}	Thermal Hysteresis (Note 10)	ΔT = −40˚C to 125˚C	0.36				mV/V

LM4051-ADJ (Adjustable) Electrical Characteristics

Boldface limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX}; all other limits T_J = 25˚C unless otherwise specified (SOT-23, see (Note 7) , $I_{RMIN} \le I_R \le$ 12 mA, $V_{REF} \le V_{OUT} \le$ 10V. The grades A, B and C designate initial Reference Voltage Tolerances of ±0.1%, ±0.2% and ±0.5%, respectively for V_{OUT} = 5V.

Symbol	Parameter	Conditions	Typical (Note 4)	LM4051AIM3 LM4051AEM3 (Limits) (Note 5)	LM4051BIM3 LM4051BEM3 (Limits) (Note 5)	LM4051CIM3 LM4051CEM3 (Limits) (Note 5)	Units (Limit)
V_{REF}	Reference Voltage	I_R = 100 µA, V_{OUT} = 5V	1.212				V
	Reference Voltage Tolerance (Note 6), (Note 8)	I_R = 100 µA, V_{OUT} = 5V		±1.2	±2.4	±6	mV (max)
		Industrial Temp. Range		**±5.2**	**±6.4**	**±10.1**	mV (max)
		Extended Temp. Range		**±7.4**	**±8.6**	**±12.2**	mV (max)
I_{RMIN}	Minimum Operating Current		36				µA
				60	60	65	µA (max)
		Industrial Temp. Range		**65**	**65**	**70**	µA (max)
		Extended Temp. Range		**70**	**70**	**75**	µA (max)
$\Delta V_{REF}/\Delta I_R$	Reference Voltage Change with Operating Current Change	$I_{RMIN} \le I_R \le$ 1mA $V_{OUT} \ge$ 1.6V (Note 7)	0.3				mV
				1.1	1.1	1.1	mV(max)
				1.5	**1.5**	**1.5**	mV(max)
		1 mA $\le I_R \le$ 12 mA $V_{OUT} \ge$ 1.6V(Note 7)	0.6				mV
				6	6	6	mV (max)
				8	**8**	**8**	mV (max)
$\Delta V_{REF}/\Delta V_O$	Reference Voltage Changewith Output Voltage Change	I_R = 0.1 mA	−1.69				mV/V
				−2.8	−2.8	−2.8	mV/V (max)
				−3.5	**−3.5**	**−3.5**	mV/V (max)
I_{FB}	Feedback Current		70				nA
				130	130	130	nA (max)
				150	150	150	nA (max)
$\Delta V_{REF}/\Delta T$	Average Reference Voltage Temperature Coefficient (Note 8)	V_{OUT} = 2.5V					
		I_R = 10mA	20				ppm/˚C
		I_R = 1mA	15				ppm/˚C
		I_R =100µA	15	**±50**	**±50**	**±50**	ppm/˚C (max)
		ΔT = −40˚C to +125˚C					
Z_{OUT}	Dynamic Output Impedance	I_R = 1 mA, f = 120 Hz, I_{AC} = 0.1 I_R					
		$V_{OUT} = V_{REF}$ V_{OUT} = 10V	0.3 2				Ω Ω
e_N	Wideband Noise	I_R = 100 µA $V_{OUT} = V_{REF}$ 10 Hz ≤ f ≤ 10 kHz	20				μV_{rms}
ΔV_{REF}	Reference Voltage Long Term Stability (Note 9)	t = 1000 hrs, I_R = 100 µA T = 25˚C ±0.1˚C	120				ppm
V_{HYST}	Thermal Hysteresis (Note 10)	ΔT = −40˚C to +125˚C	0.3				mV/V

LM4051-ADJ (Adjustable) Electrical Characteristics (Continued)

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: The maximum power dissipation must be derated at elevated temperatures and is dictated by T_{Jmax} (maximum junction temperature), θ_{JA} (junction to ambient thermal resistance), and T_A (ambient temperature). The maximum allowable power dissipation at any temperature is $PD_{max} = (T_{Jmax} - T_A)/\theta_{JA}$ or the number given in the Absolute Maximum Ratings, whichever is lower. For the LM4051, T_{Jmax} = 125˚C, and the typical thermal resistance (θ_{JA}), when board mounted, is 280˚C/W for the SOT-23 package.

Note 3: 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.

Note 4: Typicals are at T_J = 25˚C and represent most likely parametric norm.

Note 5: Limits are 100% production tested at 25˚C. Limits over temperature are guaranteed through correlation using Statistical Quality Control (SQC) methods. The limits are used to calculate National's AOQL.

Note 6: The boldface (over-temperature) limit for Reverse Breakdown Voltage Tolerance is defined as the room temperature Reverse Breakdown Voltage Tolerance $\pm[(\Delta V_R/\Delta T)(\max \Delta T)(V_R)]$. Where, $\Delta V_R/\Delta T$ is the V_R temperature coefficient, maxΔT is the maximum difference in temperature from the reference point of 25 ˚C to T_{MAX} or T_{MIN}, and V_R is the reverse breakdown voltage. The total over-temperature tolerance for the different grades in the industrial temperature range where maxΔT=65˚C is shown below:

A-grade: ±0.425% = ±0.1% ±50 ppm/˚C x 65˚C

B-grade: ±0.525% = ±0.2% ±50 ppm/˚C x 65˚C

C-grade: ±0.825% = ±0.5% ±50 ppm/˚C x 65˚C

Therefore, as an example, the A-grade LM4051-1.2 has an over-temperature Reverse Breakdown Voltage tolerance of ±1.2V x 0.425% = ±5.2 mV.

Note 7: When $V_{OUT} \leq$ 1.6V, the LM4051-ADJ in the SOT-23 package must operate at reduced I_R. This is caused by the series resistance of the die attach between the die (-) output and the package (-) output pin. See the Output Saturation curve in the Typical Performance Characteristics section.

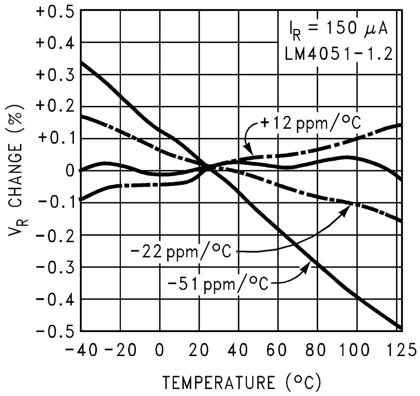
Note 8: Reference voltage and temperature coefficient will change with output voltage. See Typical Performance Characteristics curves.

Note 9: Long term stability is V_R @ 25˚C measured during 1000 hrs.

Note 10: Thermal hysteresis is defined as the difference in voltage measured at +25˚C after cycling to temperature -40˚C and the 25˚C measurement after cycling to temperature +125˚C.

Typical Performance Characteristics

Temperature Drift for Different Average Temperature Coefficient



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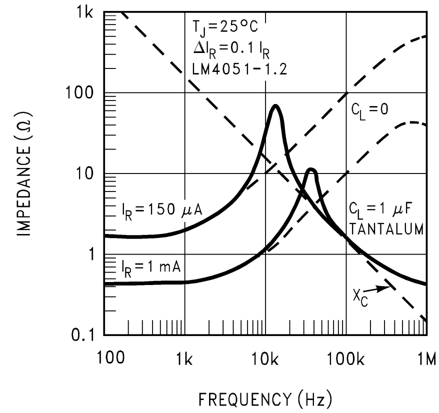
Output Impedance vs Frequency



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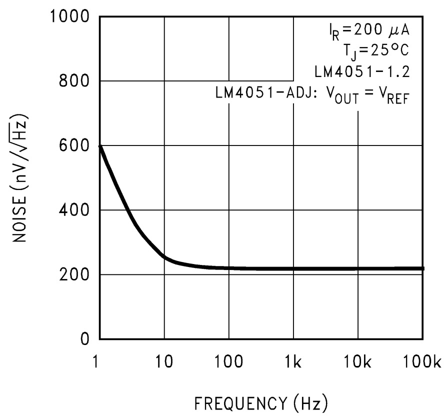
Noise Voltage



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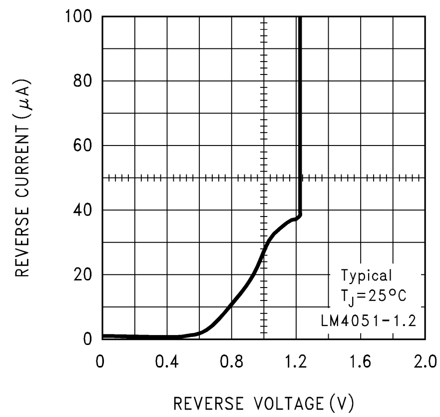
Reverse Characteristics and Minimum Operating Current



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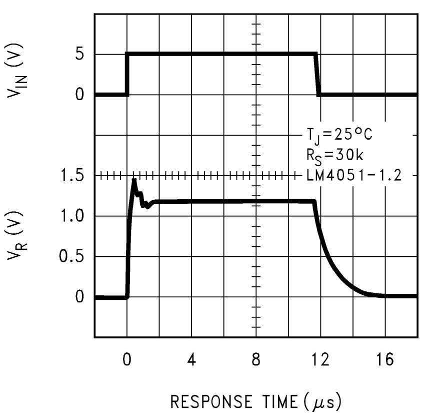
Start-Up Characteristics



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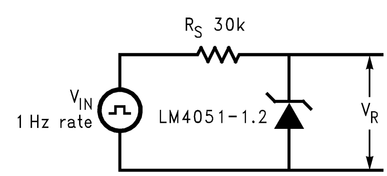

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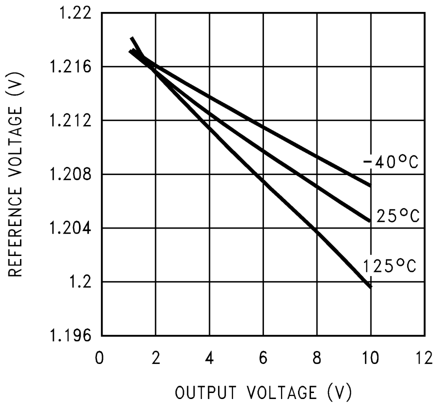
Typical Performance Characteristics (Continued)

Reference Voltage vs Output Voltage and Temperature



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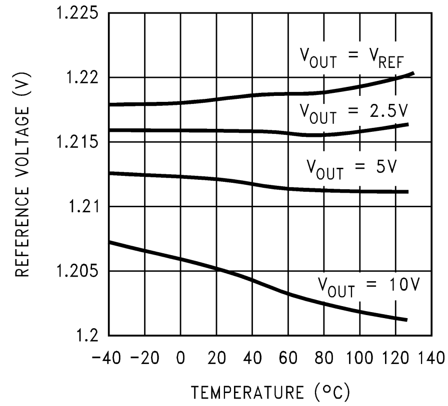
Reference Voltage vs Temperature and Output Voltage



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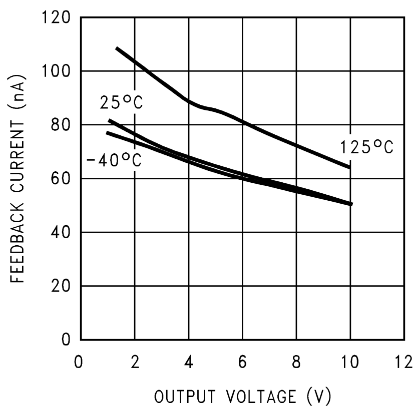
Feedback Current vs Output Voltage and Temperature



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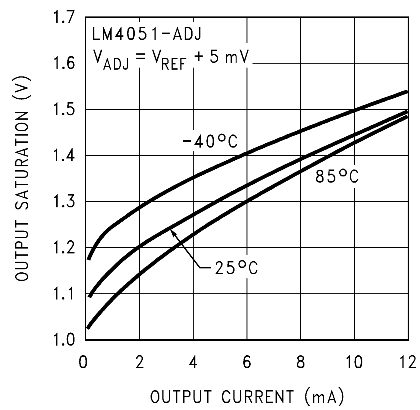
Output Saturation (SOT-23 Only)



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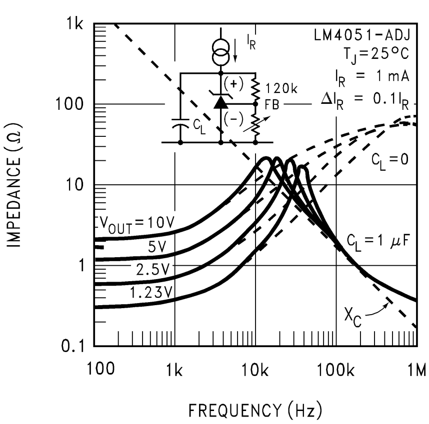
Output Impedance vs Frequency



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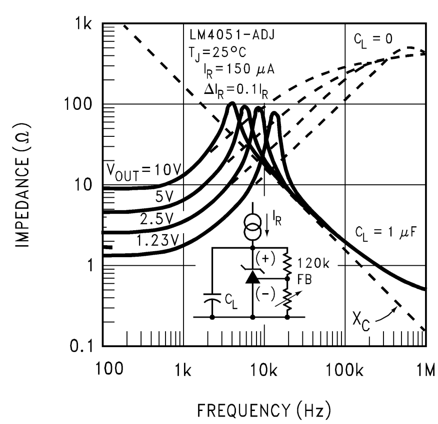
Output Impedance vs Frequency



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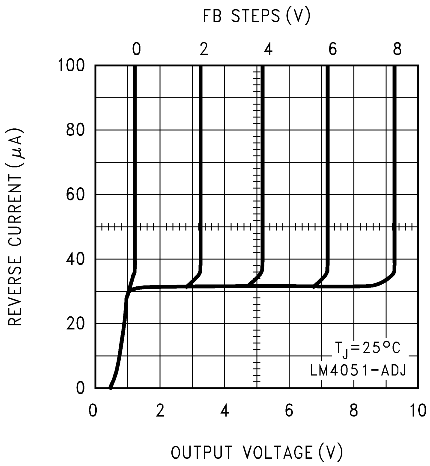
Typical Performance Characteristics (Continued)

Reverse Characteristics



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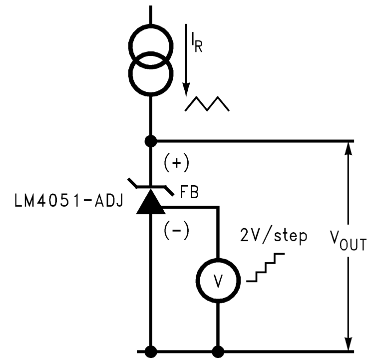

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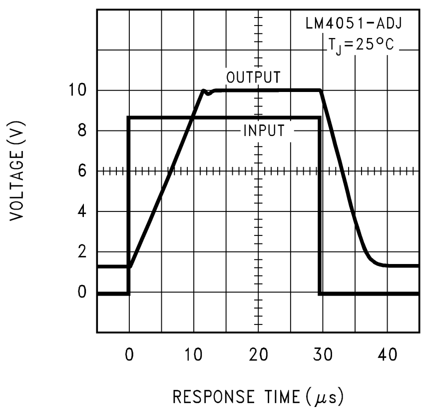
Large Signal Response



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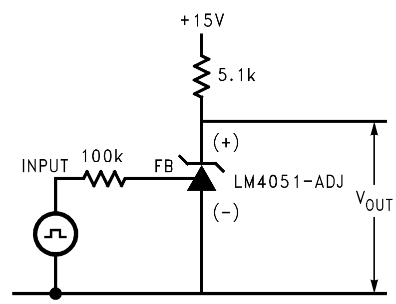

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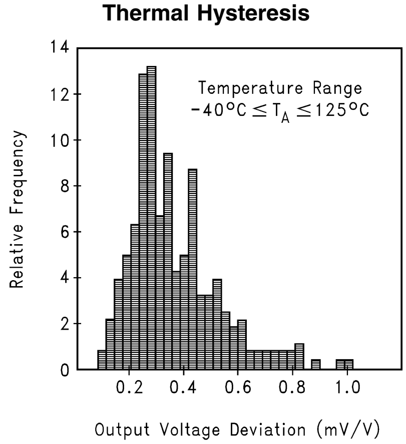
Thermal Hysteresis



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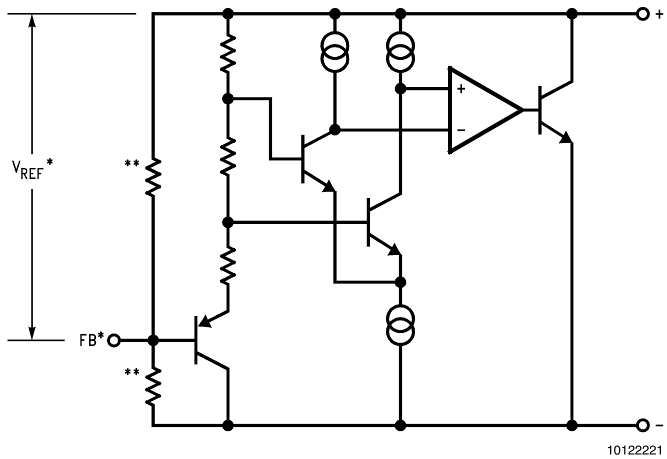
Functional Block Diagram



*LM4051-ADJ only

**LM4051-1.2 only

Applications Information

The LM4051 is a precision micro-power curvature-corrected bandgap shunt voltage reference. For space critical applications, the LM4051 is available in the sub-miniature SOT-23 surface-mount package. The LM4051 has been designed for stable operation without the need of an external capacitor connected between the "+" pin and the "−" pin. If, however, a bypass capacitor is used, the LM4051 remains stable. Design effort is further reduced with the choice of either a fixed 1.2V or an adjustable reverse breakdown voltage. The minimum operating current is 60 µA for the LM4051-1.2 and the LM4051-ADJ. Both versions have a maximum operating current of 12 mA.

LM4051s using the SOT-23 package have pin 3 connected as the (-) output through the package's die attach interface. Therefore, the LM4051-1.2's pin 3 must be left floating or connected to pin 2 and the LM4051-ADJ's pin 3 is the (-) output.

The typical thermal hysteresis specification is defined as the change in +25˚C voltage measured after thermal cycling. The device is thermal cycled to temperature -40˚C and then measured at 25˚C. Next the device is thermal cycled to temperature +125˚C and again measured at 25˚C. The resulting V_{OUT} delta shift between the 25˚C measurements is thermal hysteresis. Thermal hysteresis is common in precision references and is induced by thermal-mechanical package stress. Changes in environmental storage temperature, operating temperature and board mounting temperature are all factors that can contribute to thermal hysteresis.

In a conventional shunt regulator application *(Figure 1*), an external series resistor (R_S) is connected between the supply voltage and the LM4051. R_S determines the current that flows through the load (I_L) and the LM4051 (I_Q). Since load current and supply voltage may vary, R_S should be small enough to supply at least the minimum acceptable I_Q to the LM4051 even when the supply voltage is at its minimum and the load current is at its maximum value. When the supply voltage is at its maximum and I_L is at its minimum, R_S should be large enough so that the current flowing through the LM4051 is less than 12 mA.

R_S should be selected based on the supply voltage, (V_S), the desired load and operating current, (I_L and I_Q), and the LM4051's reverse breakdown voltage, V_R.

$$R_S = \frac{V_S - V_R}{I_L + I_Q}$$

The LM4051-ADJ's output voltage can be adjusted to any value in the range of 1.24V through 10V. It is a function of the internal reference voltage (V_{REF}) and the ratio of the external feedback resistors as shown in *Figure 2* . The output voltage is found using the equation

$$V_O = V_{REF}[(R2/R1) + 1] \quad (1)$$

$$R_S = \frac{V_S - V_R}{I_L + I_Q + I_F} \quad (2)$$

where V_O is the output voltage. The actual value of the internal V_{REF} is a function of V_O. The "corrected" V_{REF} is determined by

$$V_{REF} = V_O\ (\Delta V_{REF}/\Delta V_O) + V_Y \quad (3)$$

where

$$V_Y = 1.22V$$

$\Delta V_{REF}/\Delta V_O$ is found in the Electrical Characteristics and is typically −1.55 mV/V. You can get a more accurate indication of the output voltage by replacing the value of V_{REF} in equation (1) with the value found using equation (3).

Typical Applications

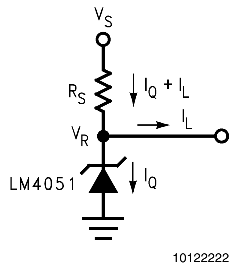


FIGURE 1. Shunt Regulator

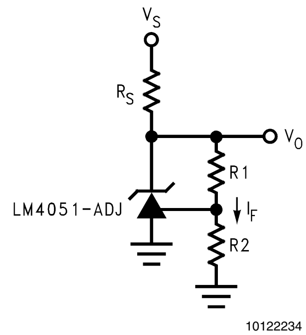


FIGURE 2. Adjustable Shunt Regulator

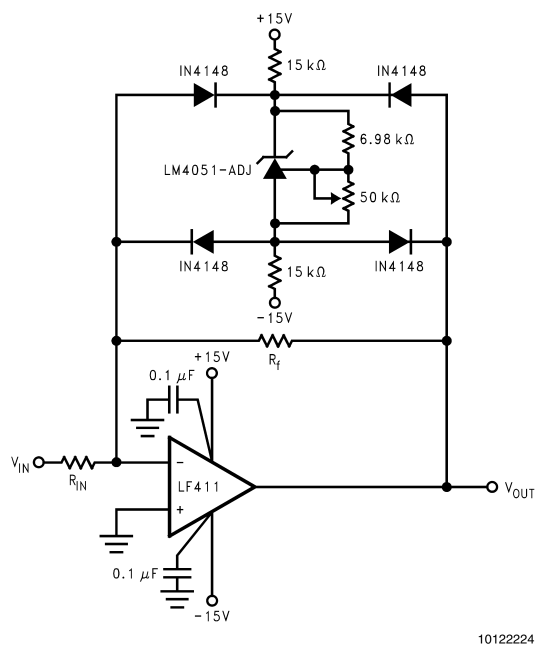


FIGURE 3. Bounded amplifier reduces saturation-induced delays and can prevent succeeding stage damage. Nominal clamping voltage is ±V_O (LM4051's reverse breakdown voltage) +2 diode V_F.

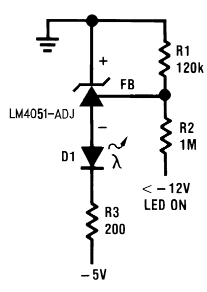


FIGURE 4. Voltage Level Detector

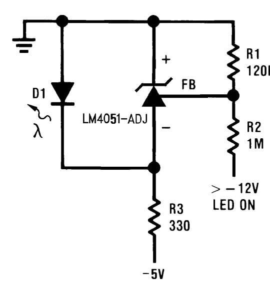
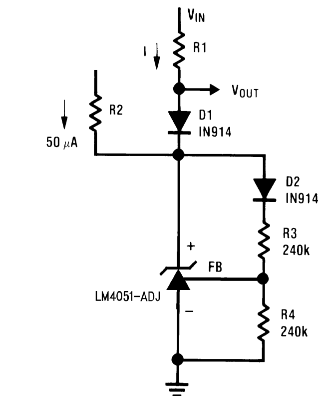


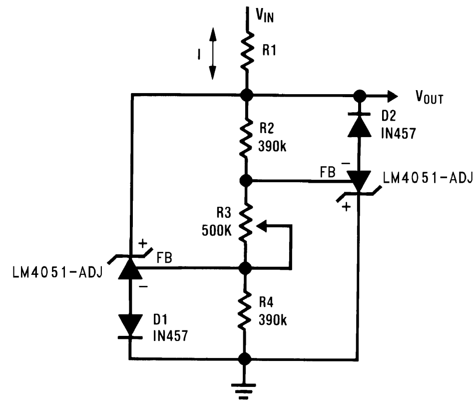
FIGURE 5. Voltage Level Detector

Typical Applications (Continued)



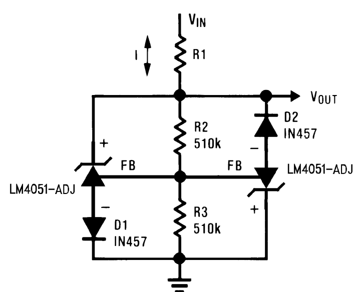
10122225

FIGURE 6. Fast Positive Clamp 2.4V + V_{D1}



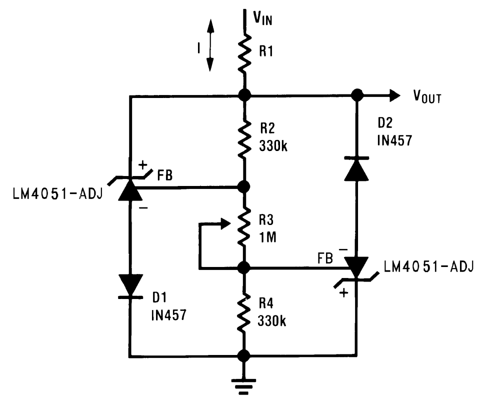
10122235

FIGURE 8. Bidirectional Adjustable Clamp ±18V to ±2.4V



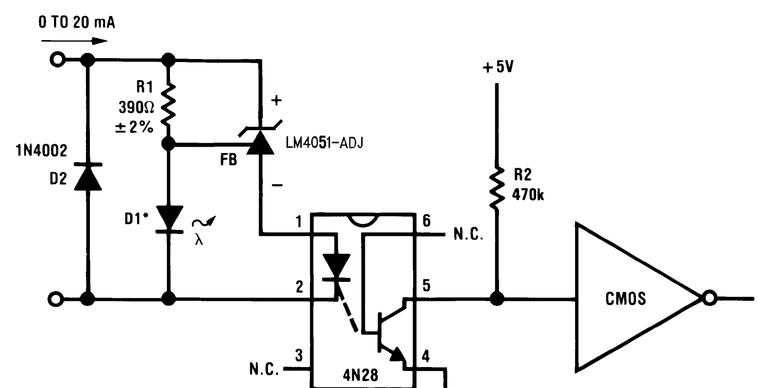
10122226

FIGURE 7. Bidirectional Clamp ±2.4V



10122236

FIGURE 9. Bidirectional Adjustable Clamp ±2.4V to ±6V



$$I_{THRESHOLD} = \frac{1.24V}{R1} + \frac{5\ \mu A}{4N28\ GAIN} \cong 3.2\ mA$$

10122237

FIGURE 10. Simple Floating Current Detector

Typical Applications (Continued)

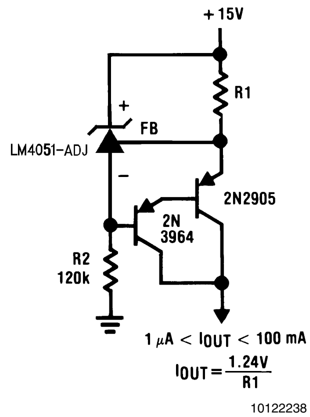


FIGURE 11. Current Source

Note 11: *D1 can be any LED, V_F = 1.5V to 2.2V at 3 mA. D1 may act as an indicator. D1 will be on if $I_{THRESHOLD}$ falls below the threshold current, except with I = O.

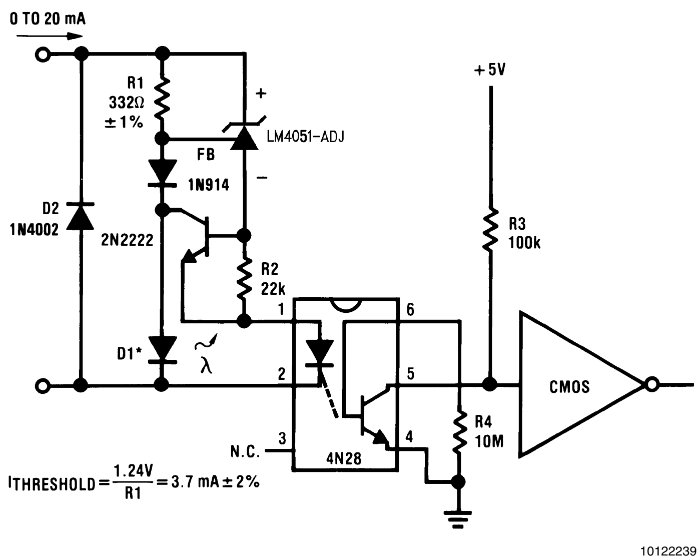
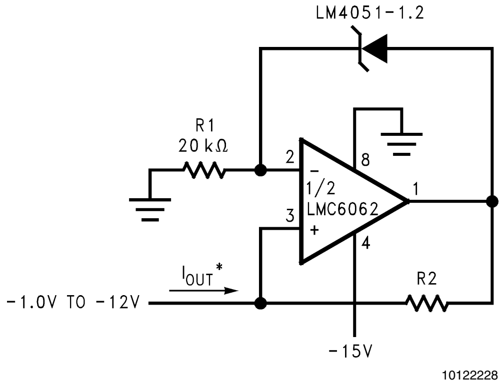
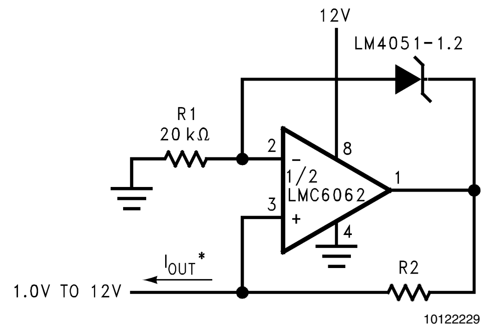


FIGURE 12. Precision Floating Current Detector

Typical Applications (Continued)

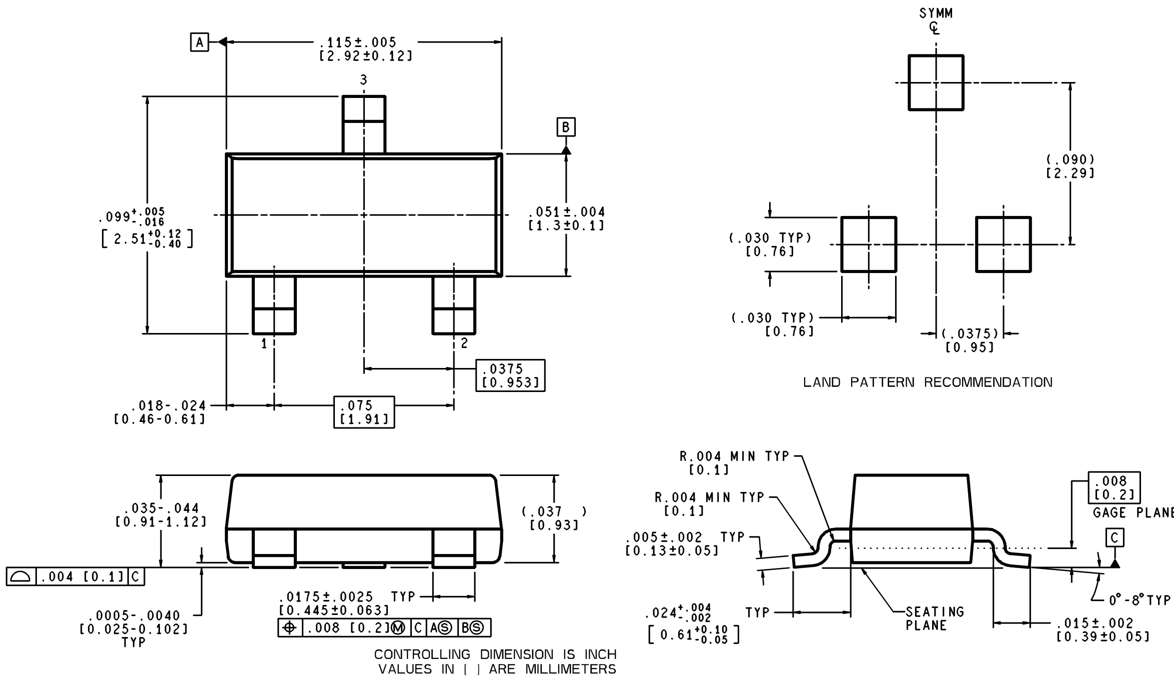




$$*I_{OUT} = \frac{1.2V}{R2}$$

FIGURE 13. Precision 1 µA to 1 mA Current Sources

Physical Dimensions inches (millimeters) unless otherwise noted



MF03A (Rev A)

Plastic Surface Mount Package (M3)
NS Package Number MF03A
(JEDEC Registration TO-236AB)

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