



LM611A/LM611

Operational Amplifier and Adjustable Reference

General Description

The operational amplifier is a versatile common-mode-to-the-negative-supply ("single-supply") type similar to the LM124 series, but with improved slew rate, improved power bandwidth, reduced cross-over distortion, and low supply current even while driven beyond swing limits. Lateral PNP input transistors enable low input currents for large differential input voltages and swings above V^+ .

The voltage reference is a three-terminal shunt-type band-gap similar to the adjustable LM185 series, but with improved voltage accuracy to $\pm 0.4\%$ accuracy by wafer trim. Two resistors program the reference from 1.24V to 6.3V. The reference features operation over a current range of 16 μA to 20 mA, low dynamic impedance, broad capacitive load range, and cathode terminal voltage ranging from a diode-drop below V^- to above V^+ .

As a member of National's new Super-Block™ family, the LM611 is a space-saving monolithic alternative to a multi-chip solution, offering a high level of integration without sacrificing performance.

Features (Guaranteed over temperature and supply)

OP AMP

- Low operating current 300 μA (op amp)
16 μA (ref)
- Large supply voltage range 4V to 36V
- Large output swing (10k load) ($V^- + 1\text{V}$) to ($V^+ - 1.8\text{V}$)
- Input common-mode range includes V^- to ($V^+ - 1.4\text{V}$)
- Wide input differential voltage $\pm 36\text{V}$

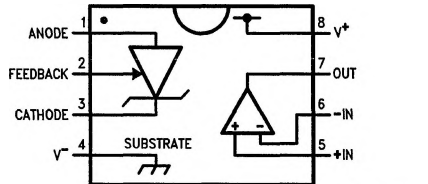
REFERENCE

- Adjustable output voltage 1.2V to 6.3V
- Tight initial tolerance available $\pm 0.4\%$
- Tolerant of load capacitance 0 to ∞

Applications

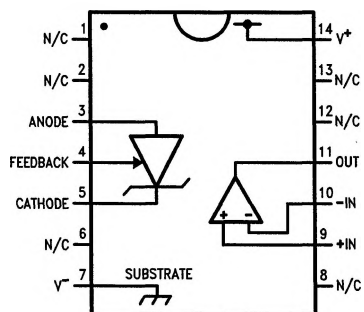
- Power supplies
- Signal conditioning

Connection Diagrams



Top View

See NS Package Number J08A or N08E



Top View

See NS Package Number M14A
M Narrow (0.15")

Order Number

Prime Military ($-55^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$) tested at -55°C , $+25^\circ\text{C}$, $+125^\circ\text{C}$ drift tested at -55°C , $+25^\circ\text{C}$, $+125^\circ\text{C}$	LM611MJ
Prime Industrial ($-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$) tested at $+25^\circ\text{C}$ drift tested at -40°C , $+25^\circ\text{C}$, $+85^\circ\text{C}$	LM611AIN
Industrial ($-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$) tested at $+25^\circ\text{C}$	LM611IN LM611IM
Commercial ($0 \leq T_A \leq +70^\circ\text{C}$) tested at $+25^\circ\text{C}$	LM611CN LM611CM

Packages

J	Hermetic Dual-In-Line
N	Plastic Dual-In-Line
M	Plastic Surface Mount Narrow (0.15")

Absolute Maximum Ratings

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

Voltage on any Pin Except Cathode Pin (referred to V ⁻ pin) (Note 1)	-0.3V (Min)
Military and Industrial	36V
Commercial	32V
Current through any Input Pin & Cathode Pin	± 20 mA
Differential Input Voltage	
Military and Industrial	± 36V
Commercial	± 32V
Short Circuit Duration, Op Amp (Note 2)	Continuous
Storage Temperature Range	-65°C to +150°C
Maximum Junction Temperature	150°C
Operating Junction Temperature Range T _{MIN} to T _{MAX}	
LM611M	-55°C to +125°C
LM611I	-40°C to +85°C
LM611C	0°C to +70°C

Soldering Information

Dual-In-Line Package	
Soldering (10 seconds)	260°C
Small Outline Package	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C

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

Package Thermal Resistance (Note 3)

Hermetic DIP J08	105°C/W
Molded DIP N08	100°C/W
Molded SO M14 Narrow	150°C/W

ESD Tolerance (Note 4)

120 pF, 1.5 kΩ	± 1 kV
200 pF, < 1 Ω	± 250V

Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device beyond its rated operating conditions.

Electrical Characteristics

These specifications apply for V⁻ = GND = 0V, V⁺ = 5V, V_{CM} = V⁺/2, V_{OUT} = V⁺/2, I_R = 100 μA, FEEDBACK pin shorted to GND, any package, unless otherwise specified. Limits in standard typeface are for T_J = 25°C; limits in **boldface type** apply for T_{MIN} to T_{MAX}.

Parameter	Conditions	Typical (Note 5)	LM611M		LM611AI, LM611I		LM611C		Units
			Tested Limit (Note 6)	Design Limit (Note 7)	Tested Limit (Note 6)	Design Limit (Note 7)	Tested Limit (Note 6)	Design Limit (Note 7)	
Total Supply Current	V ⁺ Current, R _{LOAD} = ∞, 4V ≤ V ⁺ ≤ 36V Over T _J Range (Commercial 32V)	210 221	300 320		300	320	350	370	μA max μA max
Supply Voltage Range	Meets Total Supply Current, and See V _R Change with V ⁺ Change Test	2.2 2.9	2.8 3		2.8	3	2.8	3	V min V min
		46 43	37 36		36	36	32	32	V max V max

OPERATIONAL AMPLIFIERS

V _{OS} Over Supply	4V ≤ V ⁺ ≤ 36V (4V ≤ V ⁺ ≤ 32V Commercial)	± 1.5 ± 2.0	± 3.5 ± 5.0		± 3.5	± 6.0	± 5.0	± 7.0	mV max mV max
V _{OS} Over V _{CM}	V _{CM} = 0V through V _{CM} = (V ⁺ - 1.4V), V ⁺ = 30V	± 1.0 ± 1.5	± 3.5 ± 5.0		± 3.5	± 6.0	± 5.0	± 7.0	mV max mV max
Average V _{OS} Drift	(Note 8)	± 15	± 25		± 30				max μV/°C
Input Bias Current	I _{B+IN} and I _{B-IN}	-10 - 11	± 20 ± 25		± 25	± 30	± 35	± 40	nA max nA max
Input Offset Current	I _{OS} = I _{B+IN} - I _{B-IN}	± 0.2 ± 0.3	± 4 ± 4		± 4	± 5	± 4	± 5	nA max nA max
Average I _{OS} Drift		± 4							pA/°C
Input Resistance	Differential:	1800							MΩ
	Common-Mode:	3800							MΩ

Electrical Characteristics

These specifications apply for $T_J = 25^\circ\text{C}$, $V^- = \text{GND} = 0\text{V}$, $V^+ = 5\text{V}$, $V_{\text{CM}} = V^+/2$, $V_{\text{OUT}} = V^+/2$, $I_R = 100\ \mu\text{A}$, FEEDBACK pin shorted to GND, any package, unless otherwise specified. Limits in standard typeface are for $T_J = 25^\circ\text{C}$; limits in **boldface type** apply for T_{MIN} to T_{MAX} . (Continued)

Parameter	Conditions	Typical (Note 5)	LM611M		LM611AI, LM611I		LM611C		Units
			Tested Limit (Note 6)	Design Limit (Note 7)	Tested Limit (Note 6)	Design Limit (Note 7)	Tested Limit (Note 6)	Design Limit (Note 7)	
Input Cap.	C-to-GND, Non-Inverting Input of Follower	5.7							pF
Voltage Noise	100 Hz, Input Referred	74							nV/ $\sqrt{\text{Hz}}$
Current Noise	100 Hz Bias Current Noise	58							fA/ $\sqrt{\text{Hz}}$
Common- Mode Reject Ratio	$V^+ = 30\text{V}$, $0\text{V} \leq V_{\text{CM}} \leq (V^+ - 1.4\text{V})$, $\text{CMRR} = 20 \log \{ \Delta V_{\text{CM}} / \Delta V_{\text{OS}} \}$	95 90	85 80		80	75	75	70	dB min dB min
Power Supply Reject Ratio	$4\text{V} \leq V^+ \leq 30\text{V}$, $V_{\text{CM}} = V^+/2$, $\text{PSRR} = 20 \log \{ \Delta V^+ / \Delta V_{\text{OS}} \}$	110 100	85 80		80	75	75	70	dB min dB min
Voltage Gain, Open Loop	$R_L = 10\ \text{k}\Omega$ to GND, $V^+ = 30\text{V}$, $5\text{V} \leq V_{\text{OUT}} \leq 25\text{V}$, Open-Loop $A_V = \{ \Delta V_{\text{OUT}} / \Delta V_{\text{INDIFF}} \}$	500 50	100 40		100	40	94	40	V/mV min
Slew Rate	$V^+ = 30\text{V}$, (Note 9)	± 0.70 $\pm$ 0.65	± 0.55 $\pm$ 0.45		± 0.55	$\pm$ 0.45	± 0.50	$\pm$ 0.45	V/ μs min
Gain- Band- width	Closed Loop Gain = -1000 , $-3\ \text{dB}$ Frequency $\times$ Gain, $C_L = 50\ \text{pF}$	0.79 0.52							MHz
Output Voltage Swing High	$R_L = 10\ \text{k}\Omega$ to GND $V^+ = 36\text{V}$ (32V Commercial)	$V^+ - 1.4$ $V^+ - 1.6$	$V^+ - 1.6$ $V^+ - 1.8$		$V^+ - 1.7$	$V^+ - 1.9$	$V^+ - 1.8$	$V^+ - 1.9$	V min V min
Output Voltage Swing Low	$R_L = 10\ \text{k}\Omega$ to V^+ $V^+ = 36\text{V}$ (32V Commercial)	$V^- + 0.8$ $V^- + 0.9$	$V^- + 0.90$ $V^- + 1.0$		$V^- + 0.90$	$V^- + 1.0$	$V^- + 0.95$	$V^- + 1.0$	V max V max
I_{OUT} Source	$V_{\text{OUT}} = V^+ - 2.5\text{V}$, $V_{+\text{IN}} = 0\text{V}$, $V_{-\text{IN}} = -0.3\text{V}$	-25 -15	-20 -13		-20	-13	-16	-13	mA max mA max
I_{OUT} Sink	$V_{\text{OUT}} = 1.6\text{V}$, $V_{+\text{IN}} = 0\text{V}$, $V_{-\text{IN}} = 0.3\text{V}$	17 9	15 8		14	11	13	11	mA min mA min
Short- Circuit Current	$V_{\text{OUT}} = 0\text{V}$, $V_{+\text{IN}} = 3\text{V}$, $V_{-\text{IN}} = 2\text{V}$, Source:	-30 -40	-37 -46		-40	-48	-43	-50	mA min mA min
	$V_{\text{OUT}} = 5\text{V}$, $V_{+\text{IN}} = 2\text{V}$, $V_{-\text{IN}} = 3\text{V}$, Sink:	30 32	40 60		60	80	70	90	mA max mA max

Electrical Characteristics

These specifications apply for $T_J = 25^\circ\text{C}$, $V^- = \text{GND} = 0\text{V}$, $V^+ = 5\text{V}$, $V_{\text{CM}} = V^+/2$, $V_{\text{OUT}} = V^+/2$, $I_R = 100\text{ }\mu\text{A}$, FEEDBACK pin shorted to GND, any package, unless otherwise specified. Limits in standard typeface are for $T_J = 25^\circ\text{C}$; limits in **boldface type** apply for T_{MIN} to T_{MAX} . (Continued)

Parameter	Conditions	Typical (Note 5)	LM611M		LM611AI, LM611I		LM611C		Units
			Tested Limit (Note 6)	Design Limit (Note 7)	Tested Limit (Note 6)	Design Limit (Note 7)	Tested Limit (Note 6)	Design Limit (Note 7)	
VOLTAGE REFERENCE (Note 10)									
Reference Voltage		1.244	1.2390 1.2490 (± 0.4%)		1.2365 1.2515 (± 0.6%)		1.2191 1.2689 (± 2%)		V min V max
Average Temp. Drift	(Note 11) LM611AI:	10	20		20	80		150	PPM/°C max
Average Time Drift	T _J = 40°C	400							PPM/ kHr
	T _J = 150°C	1000							PPM/ kHr
Hyster- esis	Hyst = (V _{ro} ' - V _{ro})/ΔT _J (Note 12)	± 3.2							μV/°C
V _R Change with Current	V _R [100 μA] - V _R [16 μA]	0.05 0.1	± 1 ± 1		± 1	± 1.1	± 1	± 1.1	mV max mV max
	V _R [10 mA] - V _R [100 μA] (Note 13)	1.5 2.0	5 5		5	5.5	5	5.5	mV max mV max
Resis- tance	ΔV _R [10 → 0.1 mA]/9.9 mA: ΔV _R [100 → 16 μA]/84 μA:	0.2 0.6		0.51 12		0.56 13		0.56 13	Ω max Ω max
V _R Change with High V _{RO}	V _R [V _{ro} = V _r] - V _R [V _{ro} = 6.3V] {5.06V between Anode and FEEDBACK}	2.5 2.8	5 8		7	10	7	10	mV max mV max
V _R Change with V ⁺ Change	V _R [V ⁺ = 5V] - V _R [V ⁺ = 36V] (V ⁺ = 32V Commercial)	-0.1 -0.1	± 1.2 ± 1.2		± 1.2	± 1.3	± 1.2	± 1.3	mV max mV max
	V _R [V ⁺ = 5V] - V _R [V ⁺ = 3V]	0.01 0.01	± 1 ± 1		± 1	± 1.5	± 1	± 1.5	mV max mV max
V _R Change with V _{ANODE} Change	V ⁺ = V ⁺ _{MAX} ΔV _R = V _R (@ V _{ANODE} = V ⁻ = GND) - V _R (@ V _{ANODE} = V ⁺ - 1.0V)	0.7 3.3	1.5 5.0		1.5	4.0	1.6	3.0	mV max mV max
FEED- BACK Bias Current	I _{FB} ; V _{ANODE} ≤ V _{FB} ≤ 5.06V	-22 -29	-35 -40		-35	-40	-50	-55	nA min nA min
V _R Noise	10 Hz to 10,000 Hz, V _{RO} = V _R	30							μV _{RMS}

Electrical Characteristics Notes

Note 1: More accurately, it is excessive current flow, with resulting excess heating, that limits the voltage on all pins. When any pin is pulled a diode drop below V^- , a parasitic NPN transistor turns ON. No latch-up will occur as long as the current through that pin remains below the Maximum Rating. Operation is undefined and unpredictable when any parasitic diode or transistor is conducting.

Note 2: Simultaneous short-circuit of op amp and reference while using high voltage supplies may force junction temperature above maximum, and thus should not be continuous.

Note 3: Junction temperature may be calculated using $T_J = T_A + P_D \theta_{JA}$. The given thermal resistances are worst-case for packages in sockets in still air. Nominal θ_{JA} are 95°C/W for LM611 in J package, 90°C/W for the N package, 135°C/W for the M package, for packages soldered to copper-clad board with dissipation from one op amp or reference power transistor.

Note 4: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 5: Typical values in standard typeface are for $T_J = 25^\circ\text{C}$; values in **boldface type** apply to the military temperature range. These values represent the most likely parametric norm.

Note 6: Tested limits are guaranteed and 100% tested.

Note 7: Design limits are guaranteed via correlation, but are not 100% tested.

Note 8: Offset voltage drift is calculated from the measurement of the offset voltage at 25°C and at the temperature extremes. The drift is $\Delta V_{OS}/\Delta T$, where ΔV_{OS} is the lowest value subtracted from the highest, and ΔT is the temperature range.

Note 9: Slew rate is measured with the op amp in a voltage follower configuration. For rising slew rate, the input voltage is driven from 5V to 25V, and the output voltage transition is sampled at 10V and 20V. For falling slew rate, the input voltage is driven from 25V to 5V, and the output voltage transition is sampled at 20V and 10V.

Note 10: V_{RO} is the Cathode-to-Anode voltage (1.2V to 6.3V) and V_r is the Cathode-to-FEEDBACK voltage (1.2V).

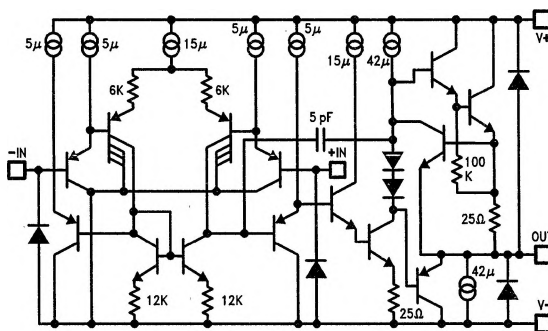
Note 11: Average reference drift is calculated from the measurement of the reference voltage at 25°C and at the temperature extremes. The drift, in ppm/°C, is $10^6 \cdot \Delta V_R / V_R [25^\circ\text{C}] \cdot \Delta T_J$, where ΔV_R is the lowest value subtracted from the highest, $V_R [25^\circ\text{C}]$ is the value at 25°C, and ΔT_J is the temperature range.

Note 12: Hysteresis is $\Delta V_{RO}/\Delta T_J$, where ΔV_{RO} is the change in V_{RO} caused by a change in T_J , after the reference has been "dehysteresized". To dehysteresize the reference, its junction temperature should be cycled in the following pattern, spiraling in toward 25°C: 25°C, 125°C, -55°C, 85°C, -40°C, 70°C, 0°C, 25°C.

Note 13: Low contact resistance is required for accurate measurement.

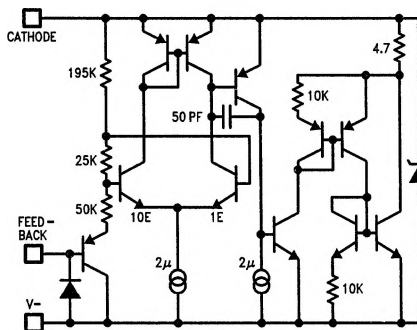
Simplified Schematic Diagrams

Op Amp

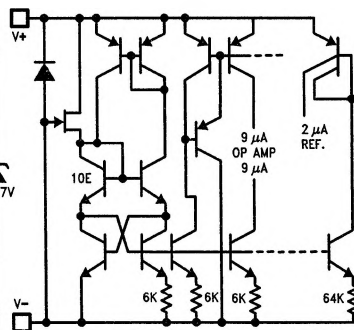


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Reference



Bias

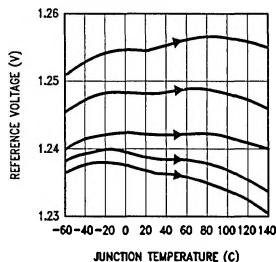


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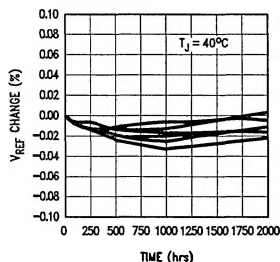
Typical Performance Characteristics (Reference)

$T_J = 25^\circ\text{C}$, FEEDBACK pin shorted to $V^- = 0\text{V}$, unless otherwise noted

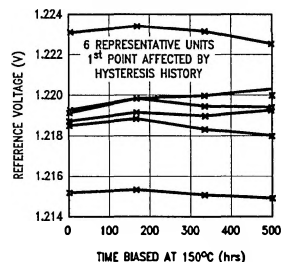
Reference Voltage vs Temp on 5 Representative Units



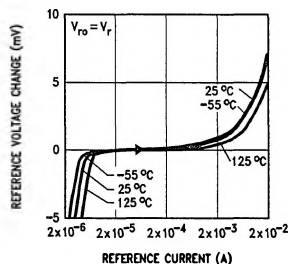
Reference Voltage Drift



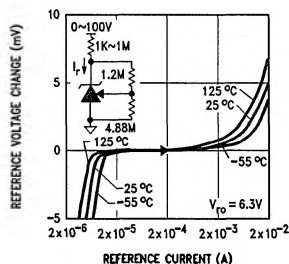
Accelerated Reference Voltage Drift vs Time



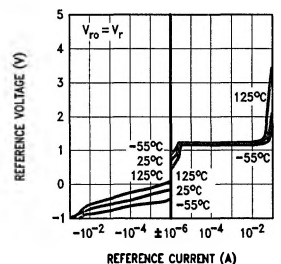
Reference Voltage vs Current and Temperature



Reference Voltage vs Current and Temperature

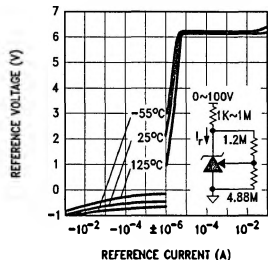


Reference Voltage vs Reference Current

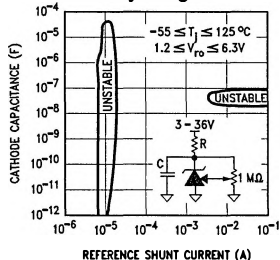


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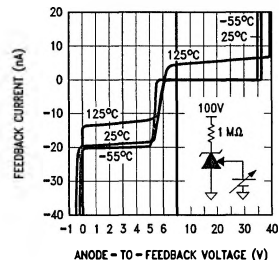
Reference Voltage vs Reference Current



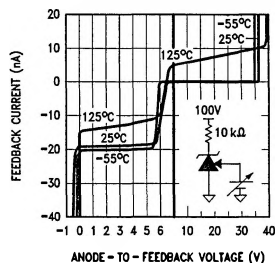
Reference AC Stability Range



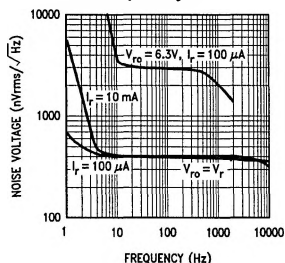
Feedback Current vs Feedback-to-Anode Voltage



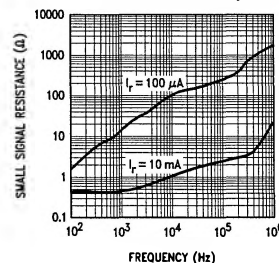
Feedback Current vs Feedback-to-Anode Voltage



Reference Noise Voltage vs Frequency



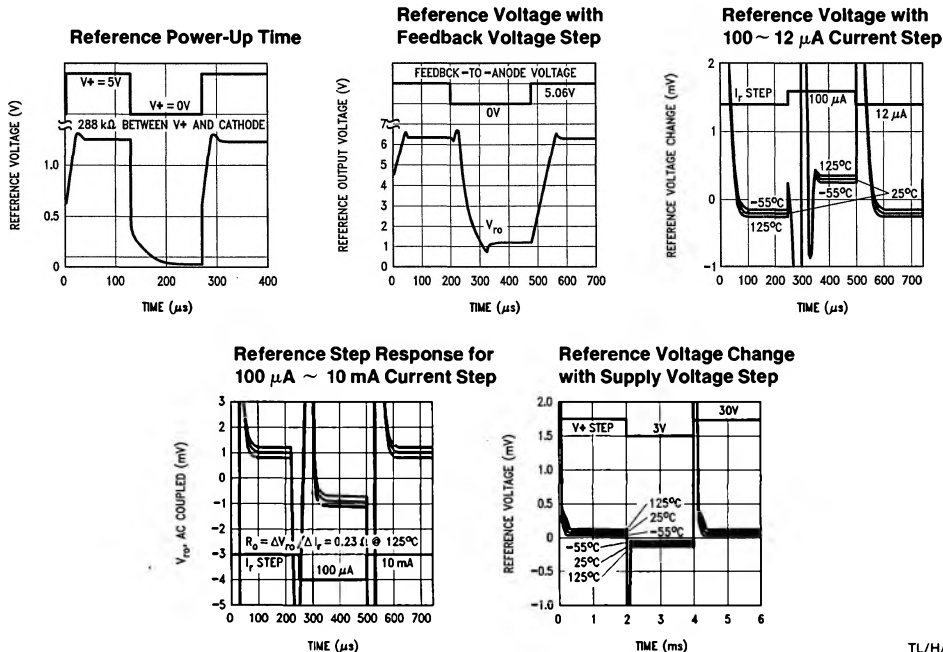
Reference Small-Signal Resistance vs Frequency



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Typical Performance Characteristics (Reference) (Continued)

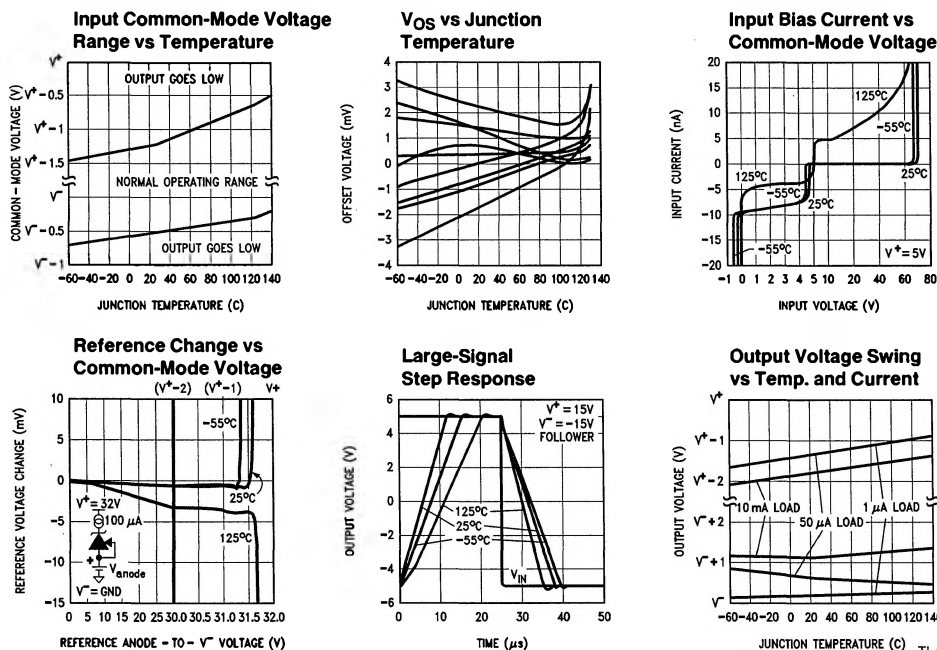
$T_J = 25^\circ\text{C}$, FEEDBACK pin shorted to $V^- = 0\text{V}$, unless otherwise noted



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Typical Performance Characteristics (Op Amps)

$V^+ = 5\text{V}$, $V^- = \text{GND} = 0\text{V}$, $V_{\text{CM}} = V^+ / 2$, $V_{\text{OUT}} = V^+ / 2$, $T_J = 25^\circ\text{C}$, unless otherwise noted

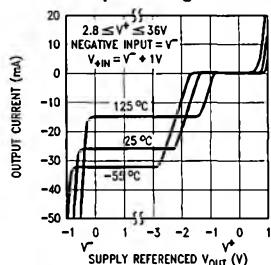


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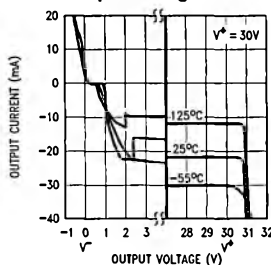
Typical Performance Characteristics (Op Amps) (Continued)

$V^+ = 5V$, $V^- = GND = 0V$, $V_{CM} = V^+/2$, $V_{OUT} = V^+/2$, $T_J = 25^\circ C$, unless otherwise noted

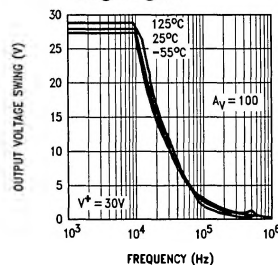
Output Source Current vs Output Voltage and Temp.



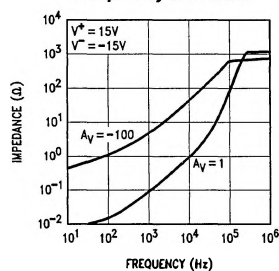
Output Sink Current vs Output Voltage



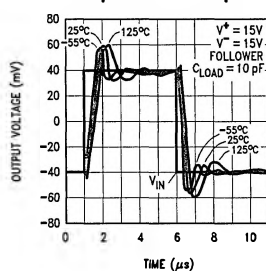
Output Swing, Large Signal



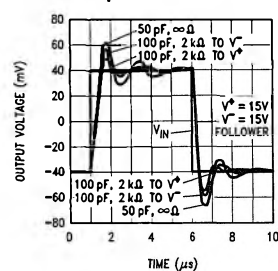
Output Impedance vs Frequency and Gain



Small Signal Pulse Response vs Temp.

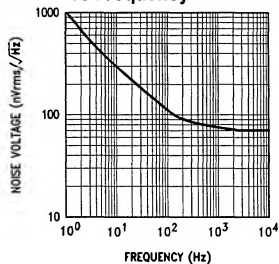


Small-Signal Pulse Response vs Load

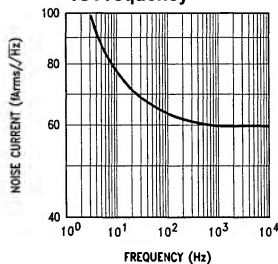


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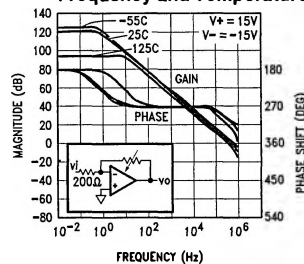
Op Amp Voltage Noise vs Frequency



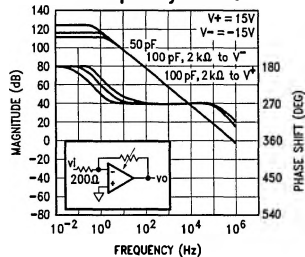
Op Amp Current Noise vs Frequency



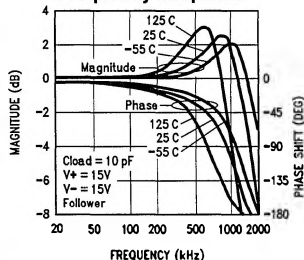
Small-Signal Voltage Gain vs Frequency and Temperature



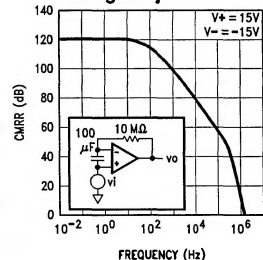
Small-Signal Voltage Gain vs Frequency and Load



Follower Small-Signal Frequency Response



Common-Mode Input Voltage Rejection Ratio

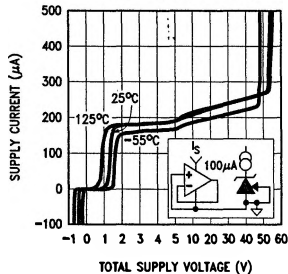


TL/H/9221-10

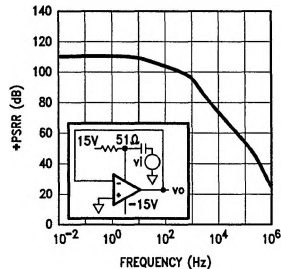
Typical Performance Characteristics (Op Amps) (Continued)

$V^+ = 5V$, $V^- = GND = 0V$, $V_{CM} = V^+/2$, $V_{OUT} = V^+/2$, $T_J = 25^\circ C$, unless otherwise noted

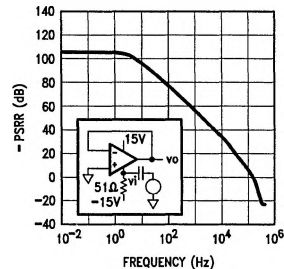
Power Supply Current vs Power Supply Voltage



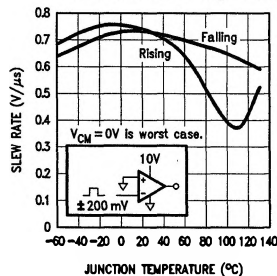
Positive Power Supply Voltage Rejection Ratio



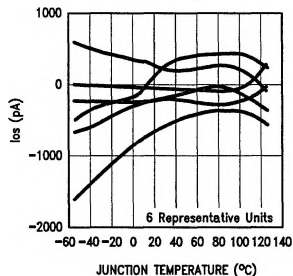
Negative Power Supply Voltage Rejection Ratio



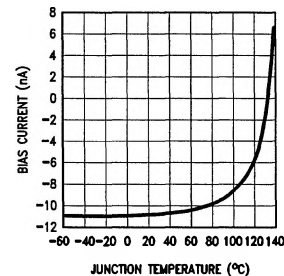
Slew Rate vs Temperature



Input Offset Current vs Junction Temperature



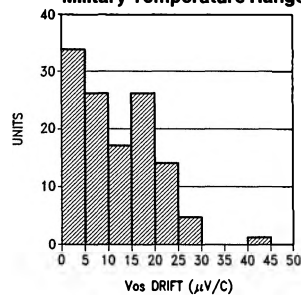
Input Bias Current vs Junction Temperature



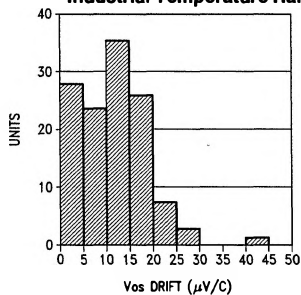
TL/H/9221-11

Typical Performance Distributions

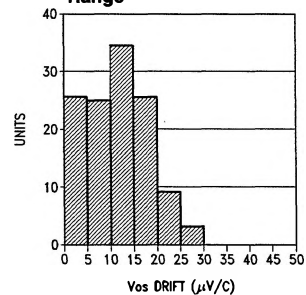
Average V_{OS} Drift Military Temperature Range



Average V_{OS} Drift Industrial Temperature Range



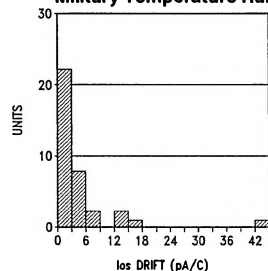
Average V_{OS} Drift Commercial Temperature Range



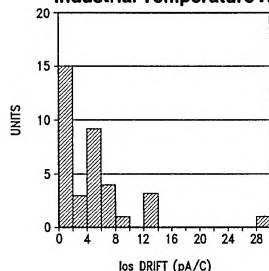
TL/H/9221-12

Typical Performance Distributions (Continued)

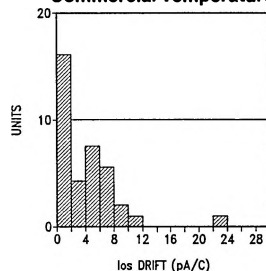
**Average I_{OS} Drift
Military Temperature Range**



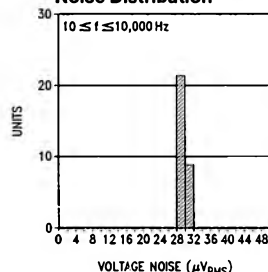
**Average I_{OS} Drift
Industrial Temperature Range**



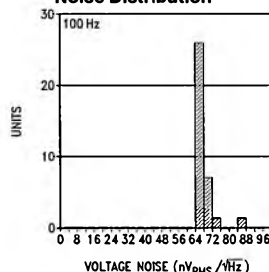
**Average I_{OS} Drift
Commercial Temperature Range**



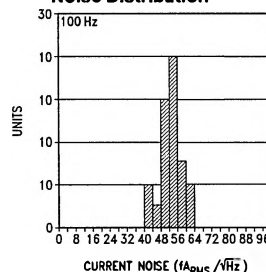
**Voltage Reference Broad-Band
Noise Distribution**



**Op Amp Voltage
Noise Distribution**



**Op Amp Current
Noise Distribution**



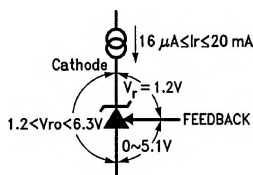
TL/H/9221-13

Application Information

VOLTAGE REFERENCE

Reference Biasing

The voltage reference is of a shunt regulator topology that models as a simple zener diode. With current I_r flowing in the 'forward' direction there is the familiar diode transfer function. I_r flowing in the reverse direction forces the reference voltage to be developed from cathode to anode. The applied voltage to the cathode may range from a diode drop below V^- to the reference voltage or to the avalanche voltage of the parallel protection diode, nominally 7V. A 6.3V reference with $V^+ = 3V$ is allowed.



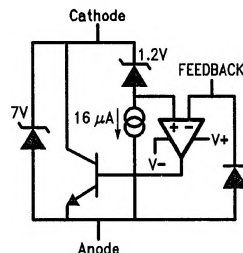
**FIGURE 1. Voltages Associated with Reference
(Current Source I_r is External)**

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The reference equivalent circuit reveals how V_r is held at the constant 1.2V by feedback, and how the FEEDBACK pin passes little current.

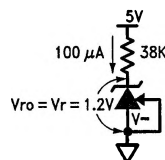
To generate the required reverse current, typically a resistor is connected from a supply voltage higher than the refer-

ence voltage. Varying that voltage, and so varying I_r , has small effect with the equivalent series resistance of less than an ohm at the higher currents. Alternatively, an active current source, such as the LM134 series, may generate I_r .



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FIGURE 2. Reference Equivalent Circuit



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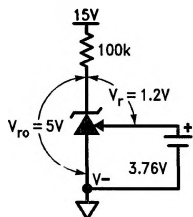
FIGURE 3. 1.2V Reference

Application Information (Continued)

Capacitors in parallel with the reference are allowed. See the Reference AC Stability Range curve for capacitance values—from 20 μA to 3 mA any capacitor value is stable. With the reference's wide stability range with resistive and capacitive loads, a wide range of RC filter values will perform noise filtering.

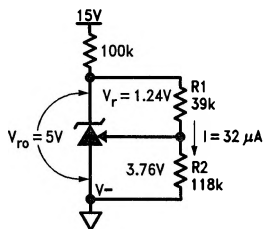
Adjustable Reference

The FEEDBACK pin allows the reference output voltage, V_{ro} , to vary from 1.24V to 6.3V. The reference attempts to hold V_r at 1.24V. If V_r is above 1.24V, the reference will conduct current from Cathode to Anode; FEEDBACK current always remains low. If FEEDBACK is connected to Anode, then $V_{ro} = V_r = 1.24\text{V}$. For higher voltages FEEDBACK is held at a constant voltage above Anode—say 3.76V for $V_{ro} = 5\text{V}$. Connecting a resistor across the constant V_r generates a current $I = R1/V_r$ flowing from Cathode into FEEDBACK node. A Thevenin equivalent 3.76V is generated from FEEDBACK to Anode with $R2 = 3.76/I$. Keep I greater than one thousand times larger than FEEDBACK bias current for <0.1% error— $I \geq 32\text{ }\mu\text{A}$ for the military grade over the military temperature range ($I \geq 5.5\text{ }\mu\text{A}$ for a 1% untrimmed error for a commercial part.)



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FIGURE 4. Thevenin Equivalent of Reference with 5V Output



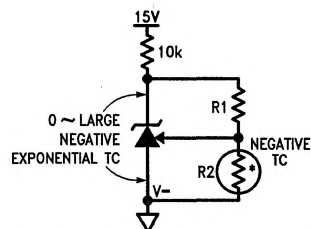
TL/H/9221-18

$$R1 = V_r/I = 1.24/32\mu = 39k$$

$$R2 = R1 \{ (V_{ro}/V_r) - 1 \} = 39k \{ (5/1.24) - 1 \} = 118k$$

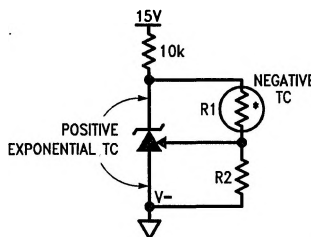
FIGURE 5. Resistors R1 and R2 Program Reference Output Voltage to be 5V

Understanding that V_r is fixed and that voltage sources, resistors, and capacitors may be tied to the FEEDBACK pin, a range of V_r temperature coefficients may be synthesized.



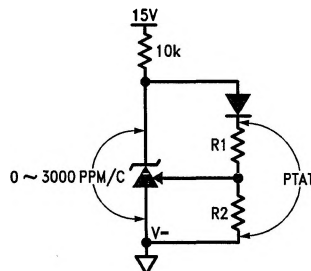
TL/H/9221-19

FIGURE 6. Output Voltage has Negative Temperature Coefficient (TC) if R2 has Negative TC



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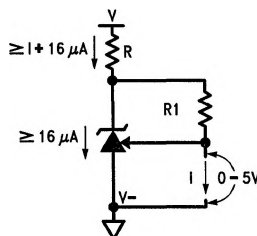
FIGURE 7. Output Voltage has Positive TC if R1 has Negative TC



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FIGURE 8. Diode in Series with R1 Causes Voltage Across R1 and R2 to be Proportional to Absolute Temperature (PTAT)

Connecting a resistor across Cathode-to-FEEDBACK creates a 0 TC current source, but a range of TCs may be synthesized.

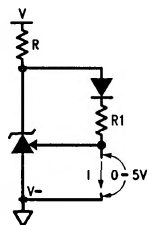


TL/H/9221-22

$$I = V_r/R1 = 1.24/R1$$

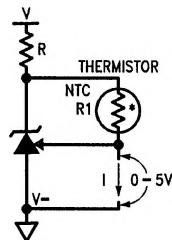
FIGURE 9. Current Source is Programmed by R1

Application Information (Continued)



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FIGURE 10. Proportional-to-Absolute-Temperature Current Source



TL/H/9221-24

FIGURE 11. Negative - TC Current Source

Hysteresis

The reference voltage depends, slightly, on the thermal history of the die. Competitive micro-power products vary—always check the data sheet for any given device. Do not assume that no specification means no hysteresis.

OPERATIONAL AMPLIFIER

The amp or the reference may be biased in any way with no effect on the other, except when a substrate diode conducts (see Guaranteed Electrical Characteristics Note 1). The amp may have inputs outside the common-mode range, may be operated as a comparator, or have all terminals floating with no effect on the reference (tying inverting input

to output and non-inverting input to V^- on unused amp is preferred). Choosing operating points that cause oscillation, such as driving too large a capacitive load, is best avoided.

Op Amp Output Stage

The op amp, like the LM124 series, has a flexible and relatively wide-swing output stage. There are simple rules to optimize output swing, reduce cross-over distortion, and optimize capacitive drive capability:

- 1) Output Swing: Unloaded, the $42\ \mu\text{A}$ pull-down will bring the output within 300 mV of V^- over the military temperature range. If more than $42\ \mu\text{A}$ is required, a resistor from output to V^- will help. Swing across any load may be improved slightly if the load can be tied to V^+ , at the cost of poorer sinking open-loop voltage gain.
- 2) Cross-over Distortion: The LM611 has lower cross-over distortion (a $1\ V_{BE}$ deadband versus $3\ V_{BE}$ for the LM124), and increased slew rate as shown in the characteristic curves. A resistor pull-up or pull-down will force class-A operation with only the PNP or NPN output transistor conducting, eliminating cross-over distortion.
- 3) Capacitive Drive: Limited by the output pole caused by the output resistance driving capacitive loads, a pull-down resistor conducting 1 mA or more reduces the output stage NPN r_e until the output resistance is that of the current limit $25\ \Omega$. 200 pF may then be driven without oscillation.

Op Amp Input Stage

The lateral PNP input transistors, unlike most op amps, have BV_{EBO} equal to the absolute maximum supply voltage. Also, they have no diode clamps to the positive supply nor across the inputs. These features make the inputs look like high impedances to input sources producing large differential and common-mode voltages.

Typical Applications

For typical applications, refer to the LM124 Op Amp and LM185 Adjustable Reference datasheets.