TEXAS INSTRUMENTS

**LM124-N, LM224-N
LM2902-N, LM324-N**

SNOSC16D – MARCH 2000 – REVISED JANUARY 2015

LMx24-N, LM2902-N Low-Power, Quad-Operational Amplifiers

1 Features

- Internally Frequency Compensated for Unity Gain
- Large DC Voltage Gain 100 dB
- Wide Bandwidth (Unity Gain) 1 MHz (Temperature Compensated)
- Wide Power Supply Range:
  - Single Supply 3 V to 32 V
  - or Dual Supplies ±1.5 V to ±16 V
- Very Low Supply Current Drain (700 μA) —Essentially Independent of Supply Voltage
- Low Input Biasing Current 45 nA (Temperature Compensated)
- Low Input Offset Voltage 2 mV and Offset Current: 5 nA
- Input Common-Mode Voltage Range Includes Ground
- Differential Input Voltage Range Equal to the Power Supply Voltage
- Large Output Voltage Swing 0 V to $V^+ - 1.5$ V
- **Advantages:**
  - Eliminates Need for Dual Supplies
  - Four Internally Compensated Op Amps in a Single Package
  - Allows Direct Sensing Near GND and V_{OUT} also Goes to GND
  - Compatible With All Forms of Logic
  - Power Drain Suitable for Battery Operation
  - In the Linear Mode the Input Common-Mode, Voltage Range Includes Ground and the Output Voltage
  - Can Swing to Ground, Even Though Operated from Only a Single Power Supply Voltage
  - Unity Gain Cross Frequency is Temperature Compensated
  - Input Bias Current is Also Temperature Compensated

2 Applications

- Transducer Amplifiers
- DC Gain Blocks
- Conventional Op Amp Circuits

3 Description

The LM124-N series consists of four independent, high-gain, internally frequency compensated operational amplifiers designed to operate from a single power supply over a wide range of voltages. Operation from split-power supplies is also possible and the low-power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM124-N series can directly operate off of the standard 5-V power supply voltage which is used in digital systems and easily provides the required interface electronics without requiring the additional ±15 V power supplies.

Device Information[1]

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM124-N	CDIP (14)	19.56 mm × 6.67 mm
LM224-N		
LM324-N	CDIP (14)	19.56 mm × 6.67 mm
	PDIP (14)	19.177 mm × 6.35 mm
	SOIC (14)	8.65 mm × 3.91 mm
	TSSOP (14)	5.00 mm × 4.40 mm
LM2902-N	PDIP (14)	19.177 mm × 6.35 mm
	SOIC (14)	8.65 mm × 3.91 mm
	TSSOP (14)	5.00 mm × 4.40 mm

(1) For all available packages, see the orderable addendum at the end of the datasheet.
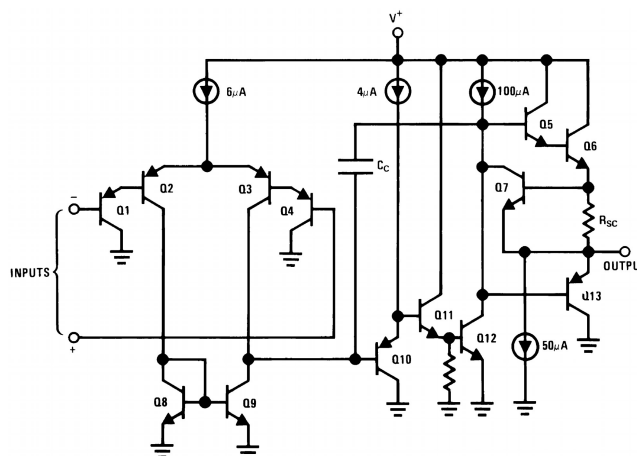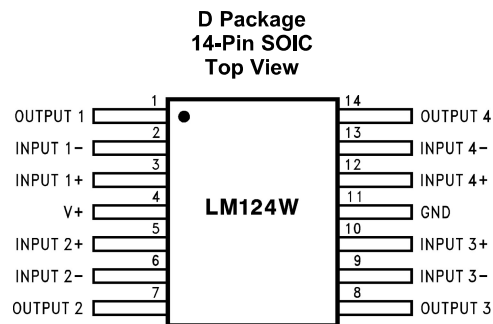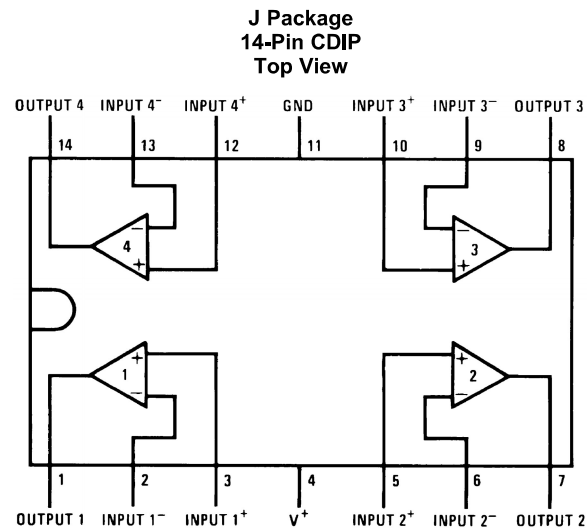
Schematic Diagram

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4 Revision History

Changes from Revision C (November 2012) to Revision D   **Page**

- Added *Pin Configuration and Functions* section, *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section 1

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*

5 Pin Configuration and Functions

J Package
14-Pin CDIP
Top View

D Package
14-Pin SOIC
Top View

Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
OUTPUT1	1	O	Output, Channel 1
INPUT1-	2	I	Inverting Input, Channel 1
INPUT1+	3	I	Noninverting Input, Channel 1
V+	4	P	Positive Supply Voltage
INPUT2+	5	I	Nonnverting Input, Channel 2
INPUT2-	6	I	Inverting Input, Channel 2
OUTPUT2	7	O	Output, Channel 2
OUTPUT3	8	O	Output, Channel 3
INPUT3-	9	I	Inverting Input, Channel 3
INPUT3+	10	I	Noninverting Input, Channel 3
GND	11	P	Ground or Negative Supply Voltage
INPUT4+	12	I	Noninverting Input, Channel 4
INPUT4-	13	I	Inverting Input, Channel 4
OUTPUT4	14	O	Output, Channel 4

6 Specifications

6.1 Absolute Maximum Ratings

See [1][2].

		LM124-N/LM224-N/LM324-N LM124A/LM224A/LM324A		LM2902-N		
		MIN	MAX	MIN	MAX	UNIT
Supply Voltage, V⁺			32		26	V
Differential Input Voltage			32		26	V
Input Voltage		−0.3	32	−0.3	26	V
Input Current (V_{IN} < −0.3 V)[3]			50		50	mA
Power Dissipation[4]	PDIP		1130		1130	mW
	CDIP		1260		1260	mW
	SOIC Package		800		800	mW
Output Short-Circuit to GND (One Amplifier)[5]	V⁺ ≤ 15 V and T_A = 25°C	Continuous		Continuous		
Lead Temperature (Soldering, 10 seconds)			260		260	°C
Soldering Information	Dual-In-Line Package	Soldering (10 seconds)	260		260	°C
	Small Outline Package	Vapor Phase (60 seconds)	215		215	°C
		Infrared (15 seconds)	220		220	°C
Storage temperature, T_{stg}		−65	150	−65	150	°C

(1) Refer to RETS124AX for LM124A military specifications and refer to RETS124X for LM124-N military specifications.
(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.
(3) This input current will only exist when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistors becoming forward biased and thereby acting as input diode clamps. In addition to this diode action, there is also lateral NPN parasitic transistor action on the IC chip. This transistor action can cause the output voltages of the op amps to go to the V⁺voltage level (or to ground for a large overdrive) for the time duration that an input is driven negative. This is not destructive and normal output states will re-establish when the input voltage, which was negative, again returns to a value greater than −0.3 V (at 25°C).
(4) For operating at high temperatures, the LM324-N/LM324A/LM2902-N must be derated based on a 125°C maximum junction temperature and a thermal resistance of 88°C/W which applies for the device soldered in a printed circuit board, operating in a still air ambient. The LM224-N/LM224A and LM124-N/LM124A can be derated based on a 150°C maximum junction temperature. The dissipation is the total of all four amplifiers—use external resistors, where possible, to allow the amplifier to saturate of to reduce the power which is dissipated in the integrated circuit.
(5) Short circuits from the output to V⁺ can cause excessive heating and eventual destruction. When considering short circuits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V⁺. At values of supply voltage in excess of 15 V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001[1]	±250	V

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

	MIN	MAX	UNIT
Supply Voltage (V⁺ - V⁻): LM124-N/LM124A/LM224-N/LM224A/LM324-N/LM324A	3	32	V
Supply Voltage (V⁺ - V⁻): LM2902-N	3	26	V
Operating Input Voltage on Input pins	0	V+	V
Operating junction temperature, T_J: LM124-N/LM124A	-55	125	°C
Operating junction temperature, T_J: L2902-N	-40	85	°C
Operating junction temperature, T_J: LM224-N/LM224A	-25	85	°C
Operating junction temperature, T_J: LM324-N/LM324A	0	70	°C

Product Folder Links: LM124-N LM224-N LM2902-N LM324-N

6.4 Thermal Information

	THERMAL METRIC[1]	LM124-N / LM224-N	LM324-N / LM2902-N	UNIT
		J/CDIP	D/SOIC	
		14 PINS	14 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	88	88	°C/W

(1)   For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

6.5 Electrical Characteristics: LM124A/224A/324A

V^+ = 5.0 V, [1], unless otherwise stated

PARAMETER		TEST CONDITIONS	LM124A			LM224A			LM324A			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Input Offset Voltage		T_A = 25°C[2]		1	2		1	3		2	3	mV
Input Bias Current[3]		$I_{IN(+)}$ or $I_{IN(-)}$, V_{CM} = 0 V, T_A = 25°C		20	50		40	80		45	100	nA
Input Offset Current		$I_{IN(+)}$ or $I_{IN(-)}$, V_{CM} = 0 V, T_A = 25°C		2	10		2	15		5	30	nA
Input Common-Mode Voltage Range[4]		V^+ = 30 V, (LM2902-N, V^+ = 26 V), T_A = 25°C	0		V^+−1.5	0		V^+−1.5	0		V^+−1.5	V
Supply Current		Over Full Temperature Range, R_L = ∞ On All Op Amps V^+ = 30 V (LM2902-N V^+ = 26 V)		1.5	3		1.5	3		1.5	3	mA
		V^+ = 5 V		0.7	1.2		0.7	1.2		0.7	1.2	
Large Signal Voltage Gain		V^+ = 15 V, R_L≥ 2 kΩ, (V_O = 1 V to 11 V), T_A = 25°C	50	100		50	100		25	100		V/mV
Common-Mode Rejection Ratio		DC, V_{CM} = 0 V to V^+ − 1.5 V, T_A = 25°C	70	85		70	85		65	85		dB
Power Supply Rejection Ratio		V^+ = 5 V to 30 V, (LM2902-N, V^+ = 5V to 26 V), T_A = 25°C	65	100		65	100		65	100		dB
Amplifier-to-Amplifier Coupling[5]		f = 1 kHz to 20 kHz, T_A = 25°C, (Input Referred)		−120			−120			−120		dB
Output Current	Source	V_{IN}^+ = 1 V, V_{IN}^- = 0 V, V^+ = 15 V, V_O = 2 V, T_A = 25°C	20	40		20	40		20	40		mA
	Sink	V_{IN}^- = 1 V, V_{IN}^+ = 0 V, V^+ = 15 V, V_O = 2 V, T_A = 25°C	10	20		10	20		10	20		µA
		V_{IN}^- = 1 V, V_{IN}^+ = 0 V, V^+ = 15 V, V_O = 200 mV, T_A = 25°C	12	50		12	50		12	50		
Short Circuit to Ground		V^+ = 15 V, T_A = 25°C[6]		40	60		40	60		40	60	mA
Input Offset Voltage		See[2]			4			4			5	mV
V_{OS} Drift		R_S = 0 Ω		7	20		7	20		7	30	µV/°C
Input Offset Current		$I_{IN(+)}$ − $I_{IN(-)}$, V_{CM} = 0 V			30			30			75	nA

(1)   These specifications are limited to −55°C ≤ T_A ≤ +125°C for the LM124-N/LM124A. With the LM224-N/LM224A, all temperature specifications are limited to −25°C ≤ T_A ≤ +85°C, the LM324–N/LM324A temperature specifications are limited to 0°C ≤ T_A ≤ +70°C, and the LM2902-N specifications are limited to −40°C ≤ T_A ≤ +85°C.
(2) V_O ≈ 1.4V, R_S = 0 Ω with V^+ from 5 V to 30 V; and over the full input common-mode range (0 V to V^+ − 1.5 V) for LM2902-N, V^+ from 5 V to 26 V.
(3)   The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.
(4)   The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3 V (at 25°C). The upper end of the common-mode voltage range is V^+ − 1.5 V (at 25°C), but either or both inputs can go to 32 V without damage (26 V for LM2902-N), independent of the magnitude of V^+.
(5)   Due to proximity of external components, insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequencies.
(6)   Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V^+. At values of supply voltage in excess of 15 V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.

Electrical Characteristics: LM124A/224A/324A (continued)

V^+ = 5.0 V, [1], unless otherwise stated

PARAMETER		TEST CONDITIONS		LM124A			LM224A			LM324A			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
I_{OS} Drift		R_S = 0 Ω			10	200		10	200		10	300	pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$			40	100		40	100		40	200	nA
Input Common-Mode Voltage Range[4]		V^+ = 30 V, (LM2902-N, V^+ = 26 V)		0		V^+−2	0		V^+−2	0		V^+−2	V
Large Signal Voltage Gain		V^+ = 15 V (V_OSwing = 1 V to 11 V), R_L ≥ 2 kΩ		25			25			15			V/mV
Output Voltage Swing	V_{OH}	V^+ = 30 V (LM2902-N, V^+ = 26 V)	R_L = 2 kΩ	26			26			26			V
			R_L = 10 kΩ	27	28		27	28		27	28		
	V_{OL}	V^+ = 5 V, R_L = 10 kΩ			5	20		5	20		5	20	mV
Output Current	Source	V_O = 2 V	V_{IN}^+ = +1V, V_{IN}^- = 0V, V^+ = 15V	10	20		10	20		10	20		mA
	Sink		V_{IN}^- = +1V, V_{IN}^+ = 0V, V^+ = 15V	10	15		5	8		5	8		

6.6 Electrical Characteristics: LM124-N/224-N/324-N/2902-N

V^+ = +5.0V, [1], unless otherwise stated

PARAMETER	TEST CONDITIONS	LM124-N / LM224-N			LM324-N			LM2902-N			UNIT
		MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Input Offset Voltage	T_A = 25°C[2]		2	5		2	7		2	7	mV
Input Bias Current[3]	$I_{IN(+)}$ or $I_{IN(-)}$, V_{CM} = 0 V, T_A = 25°C		45	150		45	250		45	250	nA
Input Offset Current	$I_{IN(+)}$ or $I_{IN(-)}$, V_{CM} = 0 V, T_A = 25°C		3	30		5	50		5	50	nA
Input Common-Mode Voltage Range[4]	V^+ = 30 V, (LM2902-N, V^+ = 26V), T_A = 25°C	0		V^+−1.5	0		V^+−1.5	0		V^+−1.5	V
Supply Current	Over Full Temperature Range R_L = ∞ On All Op Amps, V^+ = 30 V (LM2902-N V^+ = 26 V)		1.5	3		1.5	3		1.5	3	mA
	V^+ = 5 V		0.7	1.2		0.7	1.2		0.7	1.2	
Large Signal Voltage Gain	V^+ = 15V, R_L ≥ 2 kΩ, (V_O = 1 V to 11 V), T_A = 25°C	50	100		25	100		25	100		V/mV
Common-Mode Rejection Ratio	DC, V_{CM} = 0 V to V^+ − 1.5 V, T_A = 25°C	70	85		65	85		50	70		dB
Power Supply Rejection Ratio	V^+ = 5 V to 30 V (LM2902-N, V^+ = 5 V to 26 V), T_A = 25°C	65	100		65	100		50	100		dB
Amplifier-to-Amplifier Coupling[5]	f = 1 kHz to 20 kHz, T_A = 25°C (Input Referred)		−120			−120			−120		dB

(1) These specifications are limited to −55°C ≤ T_A ≤ +125°C for the LM124-N/LM124A. With the LM224-N/LM224A, all temperature specifications are limited to −25°C ≤ T_A ≤ +85°C, the LM324-N/LM324A temperature specifications are limited to 0°C ≤ T_A ≤ +70°C, and the LM2902-N specifications are limited to −40°C ≤ T_A ≤ +85°C.

(2) V_O ≃ 1.4V, R_S = 0 Ω with V^+ from 5 V to 30 V; and over the full input common-mode range (0 V to V^+ − 1.5 V) for LM2902-N, V^+ from 5 V to 26 V.

(3) The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.

(4) The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3 V (at 25°C). The upper end of the common-mode voltage range is V^+ − 1.5 V (at 25°C), but either or both inputs can go to 32 V without damage (26 V for LM2902-N), independent of the magnitude of V^+.

(5) Due to proximity of external components, insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequencies.

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*

Electrical Characteristics: LM124-N/224-N/324-N/2902-N (continued)

V^+ = +5.0V, [1], unless otherwise stated

PARAMETER		TEST CONDITIONS		LM124-N / LM224-N			LM324-N			LM2902-N			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Output Current	Source	V_{IN}^+ = 1 V, V_{IN}^- = 0 V, V^+ = 15 V, V_O = 2 V, T_A = 25°C		20	40		20	40		20	40		mA
	Sink	V_{IN}^- = 1 V, V_{IN}^+ = 0 V, V^+ = 15 V, V_O = 2 V, T_A = 25°C		10	20		10	20		10	20		mA
		V_{IN}^- = 1 V, V_{IN}^+ = 0 V, V^+ = 15 V, V_O = 200 mV, T_A = 25°C		12	50		12	50		12	50		µA
Short Circuit to Ground		V^+ = 15 V, T_A = 25°C[6]			40	60		40	60		40	60	mA
Input Offset Voltage		See [2]				7			9			10	mV
V_{OS} Drift		R_S = 0 Ω			7			7			7		µV/°C
Input Offset Current		$I_{IN(+)}$ − $I_{IN(-)}$, V_{CM} = 0 V				100			150		45	200	nA
I_{OS} Drift		R_S = 0 Ω			10			10			10		pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$			40	300		40	500		40	500	nA
Input Common-Mode Voltage Range[4]		V^+ = 30 V, (LM2902-N, V^+ = 26 V)		0		V^+−2	0		V^+−2	0		V^+−2	V
Large Signal Voltage Gain		V^+ = 15 V (V_O Swing = 1V to 11V), R_L ≥ 2 kΩ		25			15			15			V/mV
Output Voltage Swing	V_{OH}	V^+ = 30 V (LM2902-N, V^+ = 26 V)	R_L = 2 kΩ	26			26			22			V
			R_L = 10 kΩ	27	28		27	28		23	24		
	V_{OL}	V^+ = 5 V, R_L = 10 kΩ			5	20		5	20		5	100	mV
Output Current	Source	V_O = 2 V	V_{IN}^+ = 1 V, V_{IN}^- = 0 V, V^+ = 15 V	10	20		10	20		10	20		mA
	Sink		V_{IN}^- = 1 V, V_{IN}^+ = 0 V, V^+ = 15 V	5	8		5	8		5	8		mA

(6) Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V^+. At values of supply voltage in excess of 15 V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.

Product Folder Links: LM124-N LM224-N LM2902-N LM324-N

6.7 Typical Characteristics
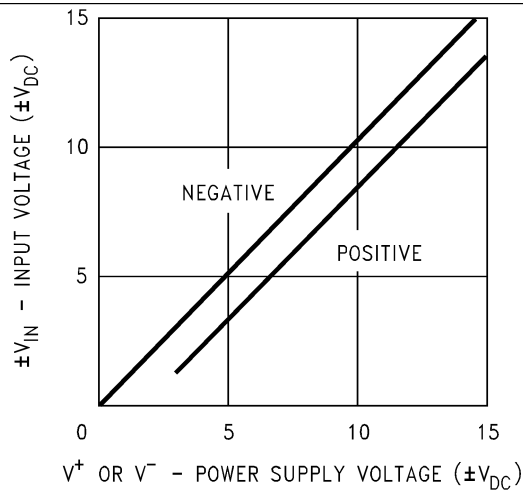
Figure 1. Input Voltage Range
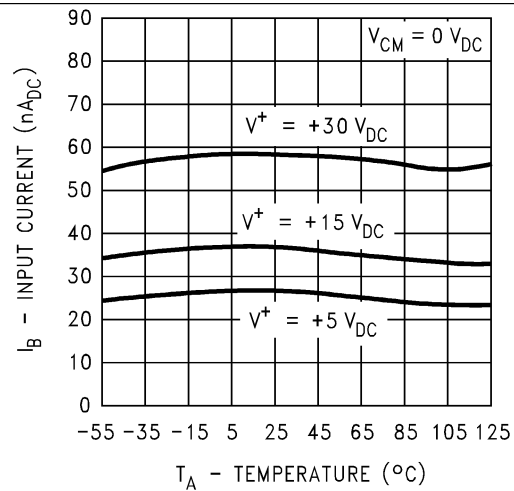
Figure 2. Input Current
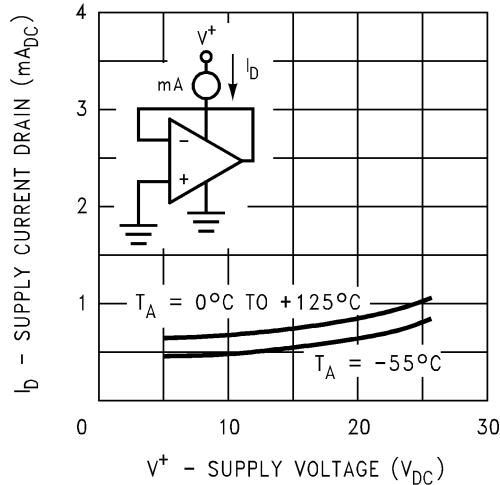
Figure 3. Supply Current
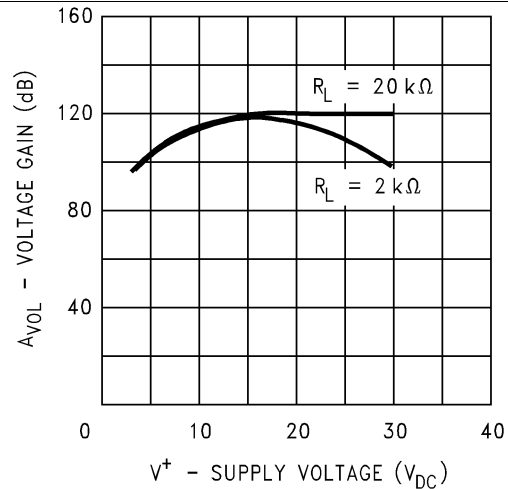
Figure 4. Voltage Gain
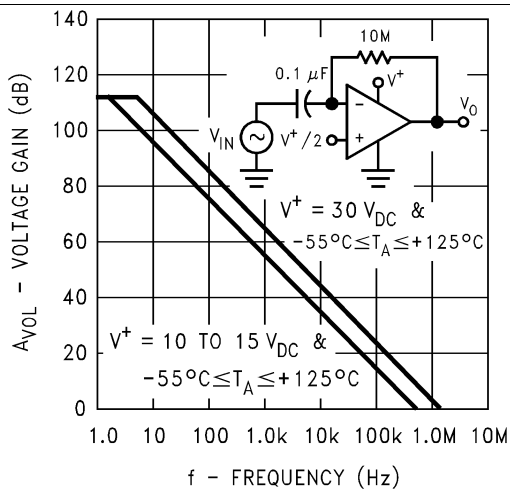
Figure 5. Open-Loop Frequency Response
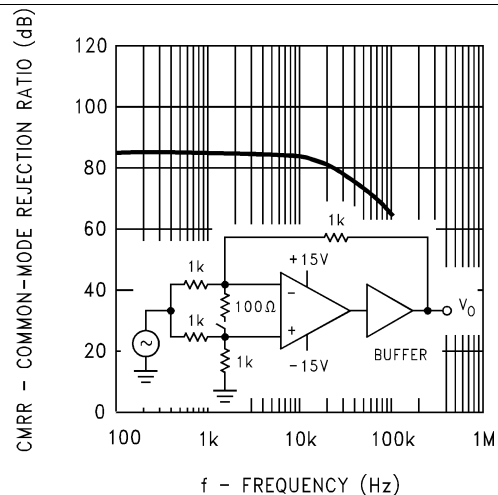
Figure 6. Common Mode Rejection Ratio

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*
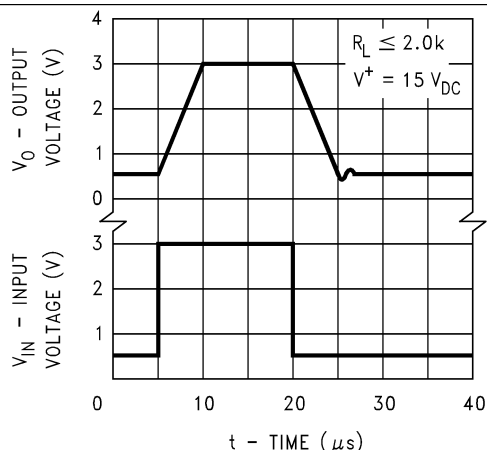
Typical Characteristics (continued)

Figure 7. Voltage Follower Pulse Response
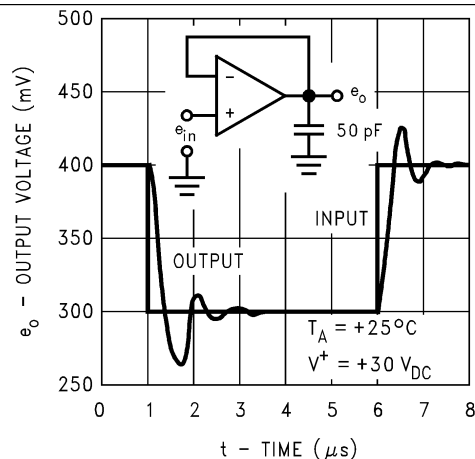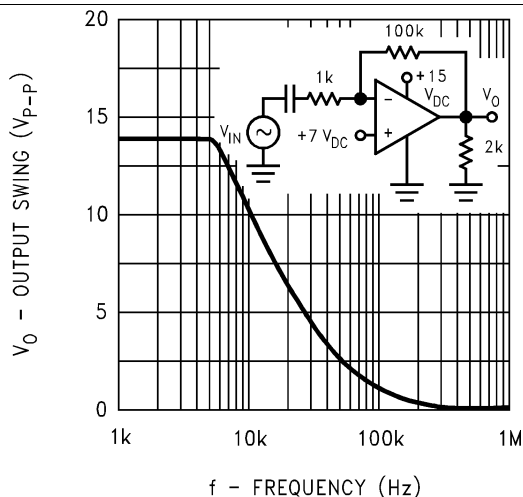

Figure 8. Voltage Follower Pulse Response (Small Signal)

Figure 9. Large Signal Frequency Response
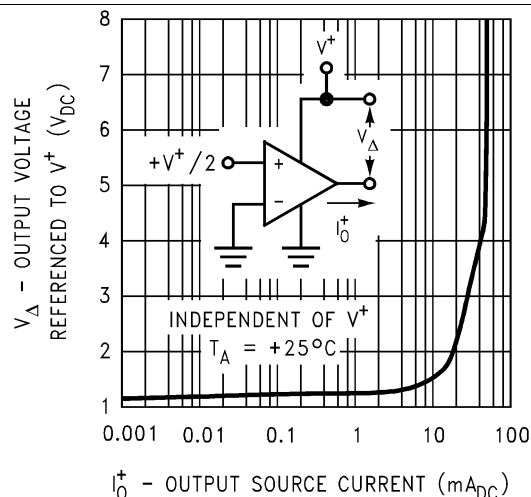
Figure 10. Output Characteristics Current Sourcing
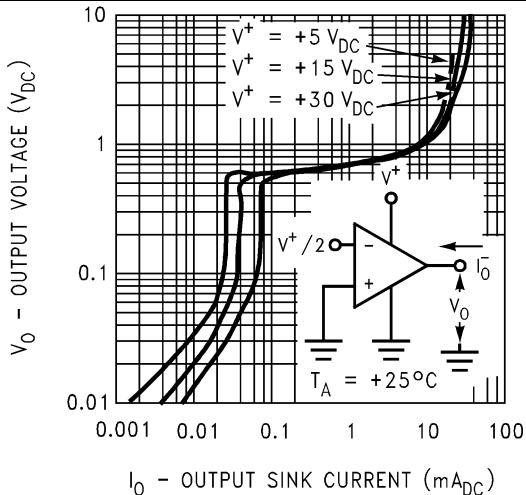
Figure 11. Output Characteristics Current Sinking
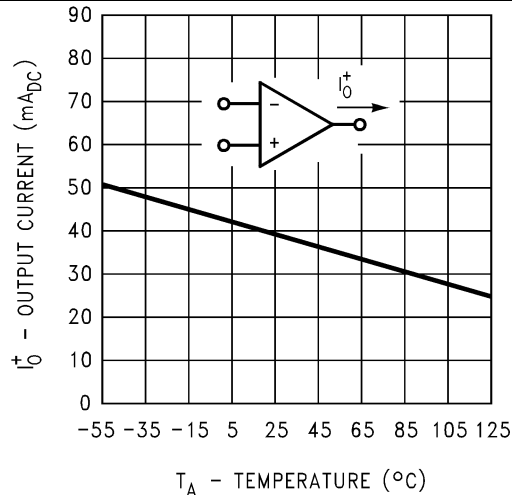
Figure 12. Current Limiting

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*

Typical Characteristics (continued)

Figure 13. Input Current (LM2902-N Only)

Figure 14. Voltage Gain (LM2902-N Only)
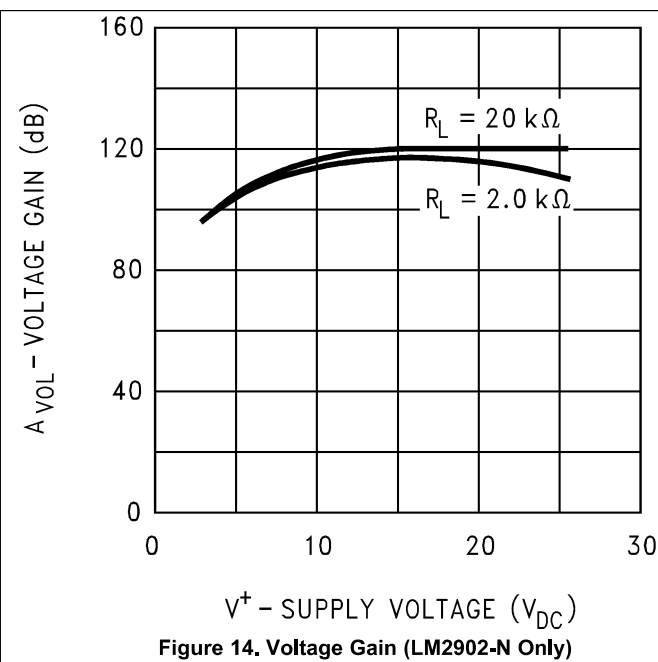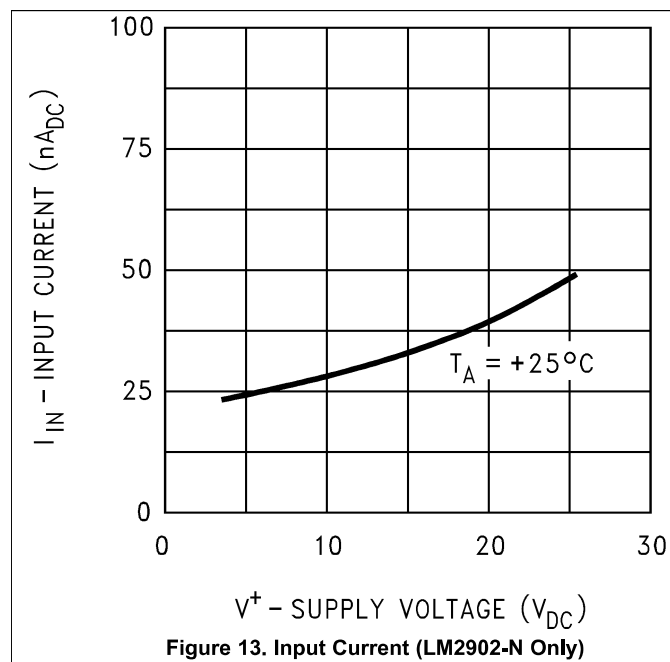
7 Detailed Description

7.1 Overview

The LM124-N series are op amps which operate with only a single power supply voltage, have true-differential inputs, and remain in the linear mode with an input common-mode voltage of 0 V_{DC}. These amplifiers operate over a wide range of power supply voltage with little change in performance characteristics. At 25°C amplifier operation is possible down to a minimum supply voltage of 2.3 V_{DC}.

7.2 Functional Block Diagram
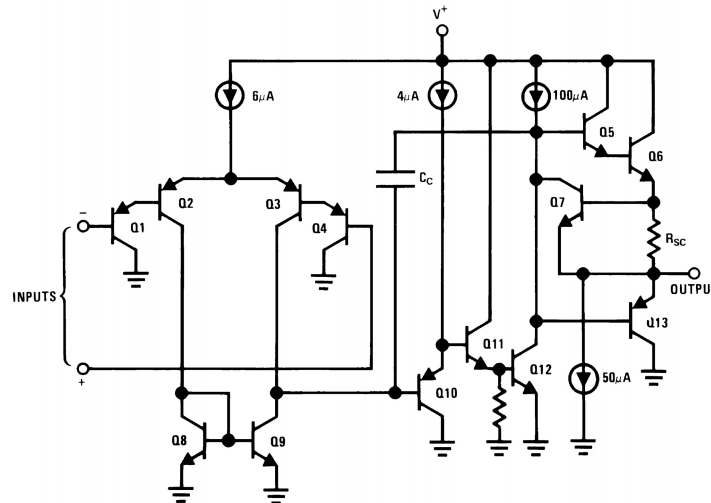
7.3 Feature Description

The LM124 provides a compelling balance of performance versus current consumption. The 700 µA of supply current draw over the wide operating conditions with a 1-MHz gain-bandwidth and temperature compensated bias currents makes the LM124 an effective solution for large variety of applications. The input offset voltage of 2 mV and offset current of 5 nA, along with the 45n-A bias current across a wide supply voltage means a single design can be used in a large number of different implementations.

7.4 Device Functional Modes

Large differential input voltages can be easily accommodated and, as input differential voltage protection diodes are not needed, no large input currents result from large differential input voltages. The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than −0.3 V_{DC} (at 25°C). An input clamp diode with a resistor to the IC input terminal can be used.

To reduce the power supply drain, the amplifiers have a class A output stage for small signal levels which converts to class B in a large signal mode. This allows the amplifiers to both source and sink large output currents. Therefore both NPN and PNP external current boost transistors can be used to extend the power capability of the basic amplifiers. The output voltage needs to raise approximately 1 diode drop above ground to bias the on-chip vertical PNP transistor for output current sinking applications.

For ac applications, where the load is capacitively coupled to the output of the amplifier, a resistor should be used, from the output of the amplifier to ground to increase the class A bias current and prevent crossover distortion.

Where the load is directly coupled, as in dc applications, there is no crossover distortion.

Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50 pF can be accommodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if larger load capacitance must be driven by the amplifier.

Device Functional Modes (continued)

The bias network of the LM124-N establishes a drain current which is independent of the magnitude of the power supply voltage over the range of from 3 V_{DC} to 30 V_{DC}.

Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive junction temperatures. Putting direct short-circuits on more than one amplifier at a time will increase the total IC power dissipation to destructive levels, if not properly protected with external dissipation limiting resistors in series with the output leads of the amplifiers. The larger value of output source current which is available at 25°C provides a larger output current capability at elevated temperatures (see *Typical Characteristics*) than a standard IC op amp.

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*

8 Application and Implementation

> **NOTE**
> Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The LM124 series of amplifiers is specified for operation from 3 V to 32 V (±1.5 V to ±16 V). Many of the specifications apply from –40°C to 125°C. Parameters that can exhibit significant variance with regards to operating voltage or temperature are presented in *Typical Characteristics*.

8.2 Typical Applications

Figure 15 emphasizes operation on only a single power supply voltage. If complementary power supplies are available, all of the standard op amp circuits can be used. In general, introducing a pseudo-ground (a bias voltage reference of $V^+/2$) will allow operation above and below this value in single power supply systems. Many application circuits are shown which take advantage of the wide input common-mode voltage range which includes ground. In most cases, input biasing is not required and input voltages which range to ground can easily be accommodated.

8.2.1 Non-Inverting DC Gain (0 V Input = 0 V Output)
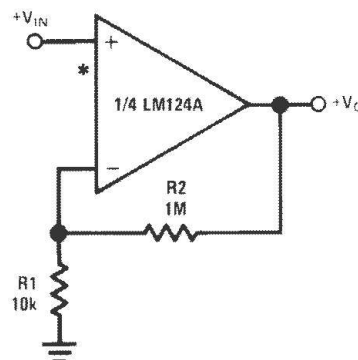
*R not needed due to temperature independent I_{IN}

Figure 15. Non-Inverting Amplifier with G=100

8.2.1.1 Design Requirements

For this example application, the required signal gain is a non-inverting 100x±5% with a supply voltage of 5 V.

8.2.1.2 Detailed Design Procedure

Using the equation for a non-inverting gain configuration, $A_v = 1+R2/R1$. Setting the R1 to 10 kΩ, R2 is 99 times larger than R1, which is 990 kΩ. A 1MΩ is more readily available, and provides a gain of 101, which is within the desired specification.

The gain-frequency characteristic of the amplifier and its feedback network must be such that oscillation does not occur. To meet this condition, the phase shift through amplifier and feedback network must never exceed 180° for any frequency where the gain of the amplifier and its feedback network is greater than unity. In practical applications, the phase shift should not approach 180° since this is the situation of conditional stability. Obviously the most critical case occurs when the attenuation of the feedback network is zero.

Typical Applications (continued)
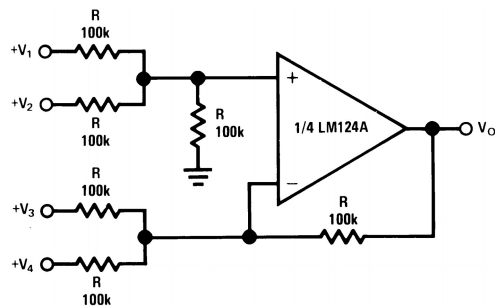
8.2.1.3 Application Curve
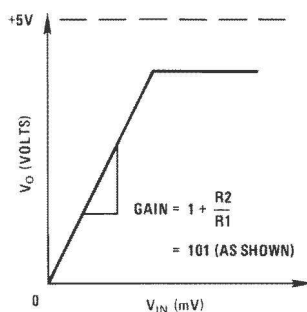
Figure 16. Non-Inverting Amplified Response Curve

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*

Typical Applications (continued)

8.2.2 Other Application Circuits at V$^+$ = 5.0 V$_{DC}$

Where: $V_0 = V_1 + V_2 - V_3 - V_4$

$(V_1 + V_2) \geq (V_3 + V_4)$ to keep $V_O > 0$ V$_{DC}$

Figure 17. DC Summing Amplifier
(V$_{IN'S}$ ≥ 0 V$_{DC}$ And V$_O$ ≥ V$_{DC}$)
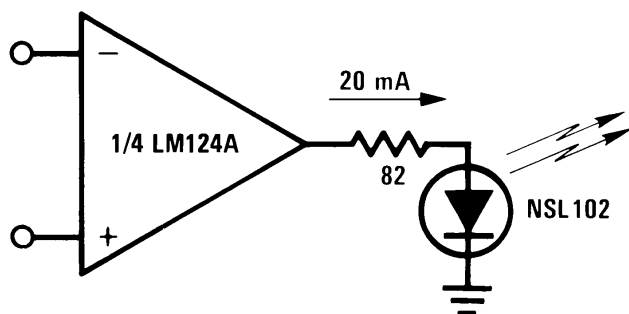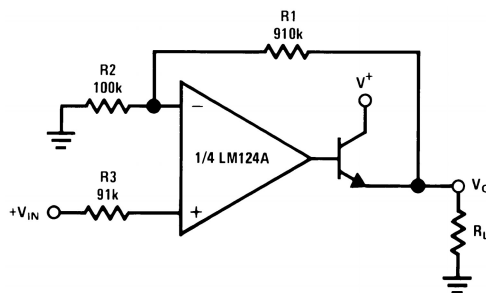
Where: $V_0 = 0$ V$_{DC}$ for $V_{IN} = 0$ V$_{DC}$

$A_V = 10$

Figure 18. Power Amplifier

Figure 19. LED Driver
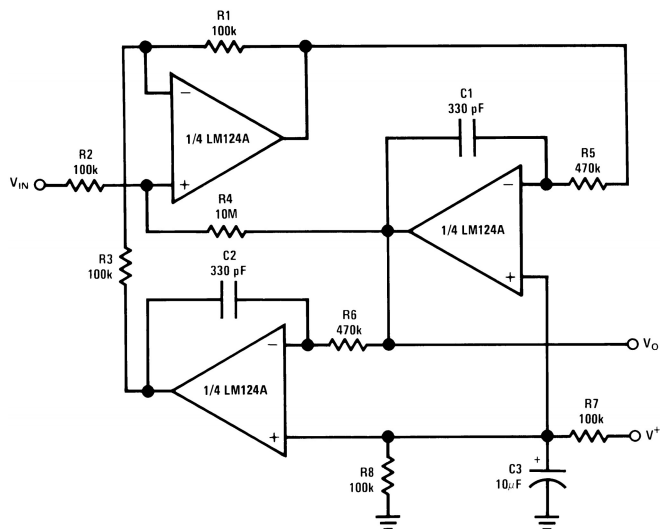
$f_o = 1$ kHz   Q = 50 $A_V = 100$ (40 dB)

Figure 20. "BI-QUAD" RC Active Bandpass Filter

Typical Applications (continued)
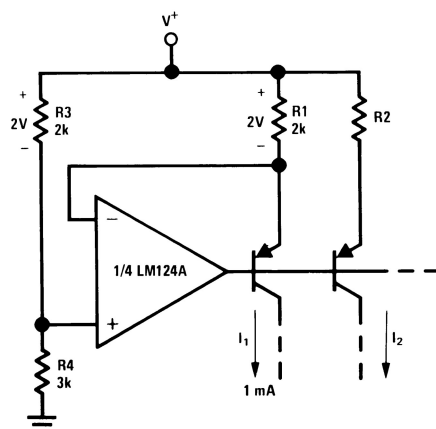
$$I_2 = \left(\frac{R1}{R2}\right) I_1$$

Figure 21. Fixed Current Sources

*(Increase R1 for I_L small)

Figure 22. Lamp Driver

Figure 23. Current Monitor
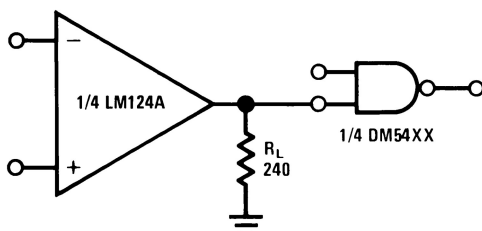
Figure 24. Driving TTL
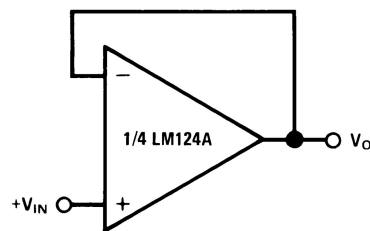
Figure 25. Voltage Follower

Typical Applications (continued)
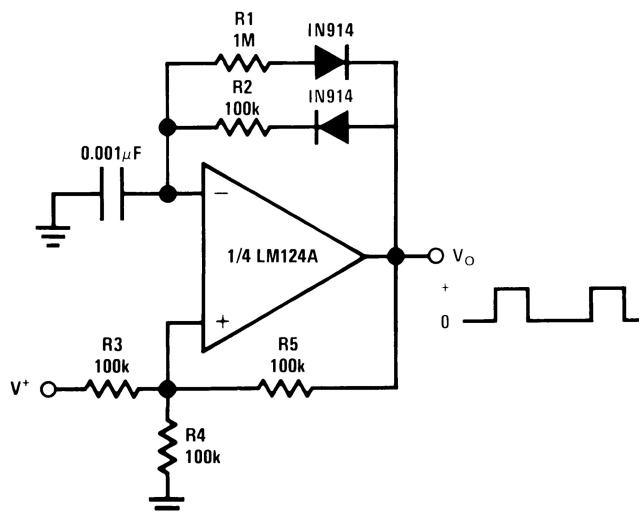
Figure 26. Pulse Generator
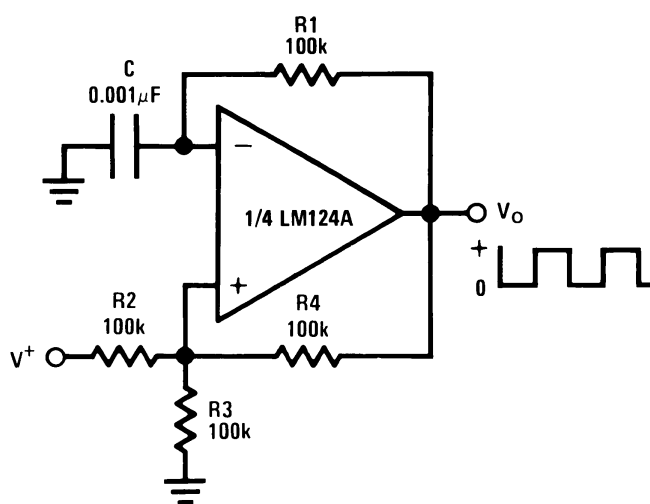
Figure 27. Squarewave Oscillator
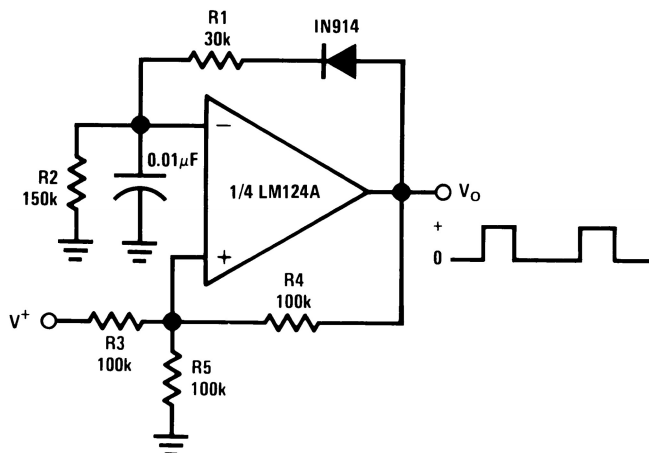
Figure 28. Pulse Generator
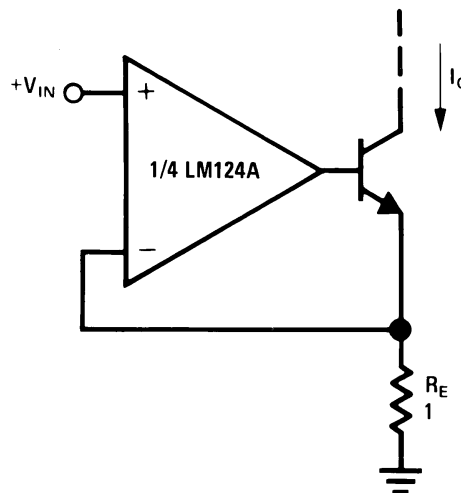
$I_O = 1$ amp/volt V_{IN} (Increase R_E for I_o small)

Figure 29. High Compliance Current Sink

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*

Typical Applications (continued)
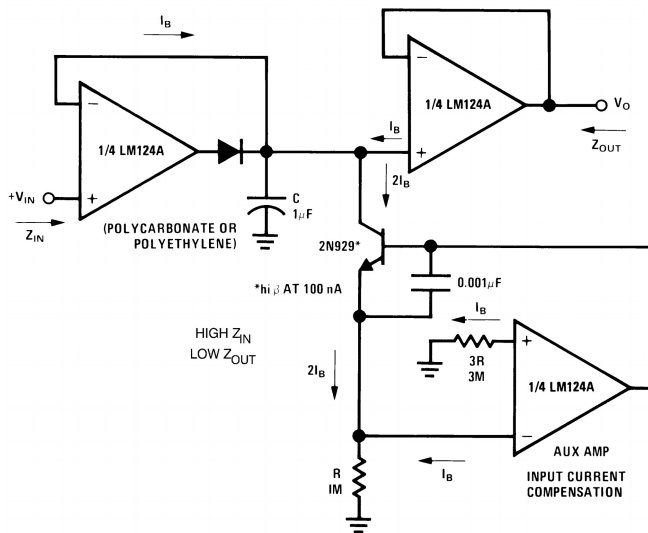
Figure 30. Low Drift Peak Detector
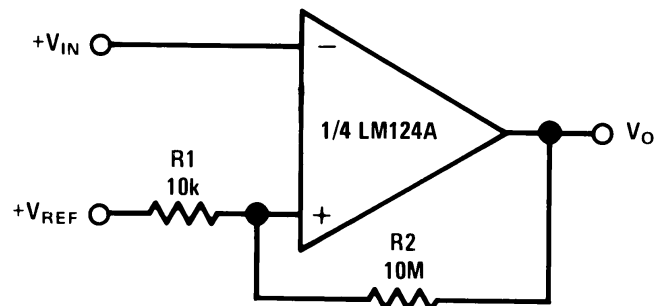
Figure 31. Comparator With Hysteresis
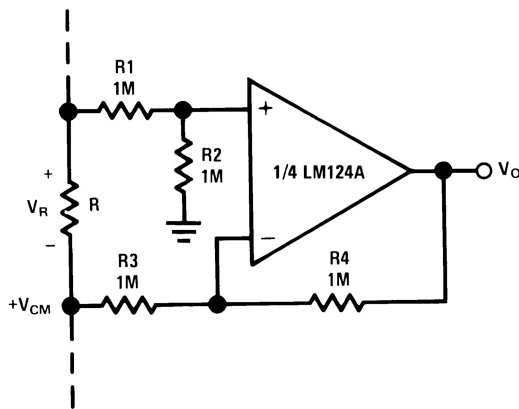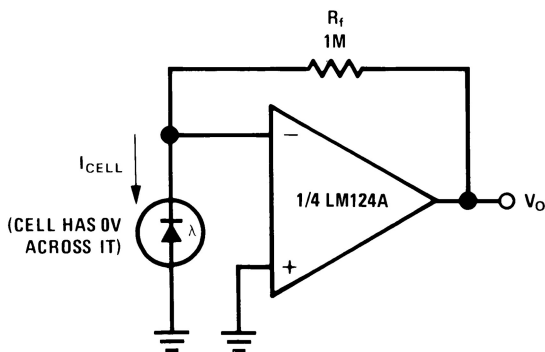

$$V_O = V_R$$

Figure 32. Ground Referencing a Differential Input Signal
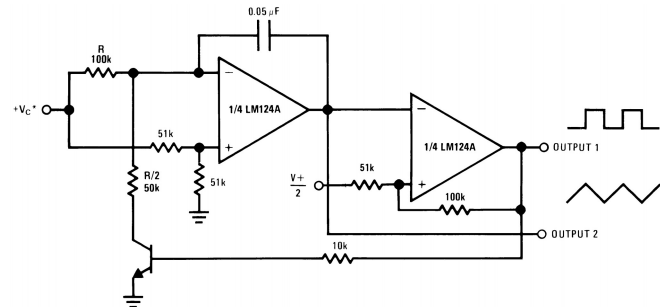
*Wide control voltage range:
$0 \ V_{DC} \leq V_C \leq 2 \ (V^+ - 1.5 \ V_{DC})$

Figure 33. Voltage Controlled Oscillator Circuit

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*

Typical Applications (continued)

$$Q = 1 \qquad A_V = 2$$

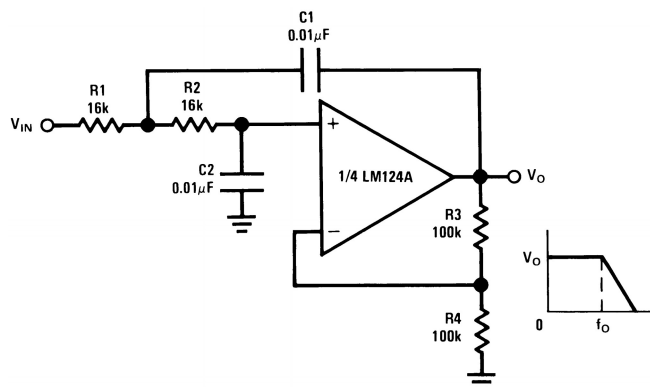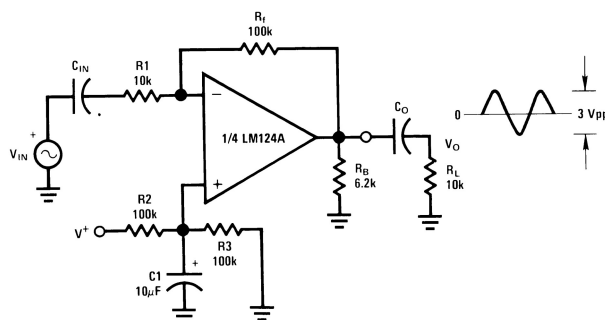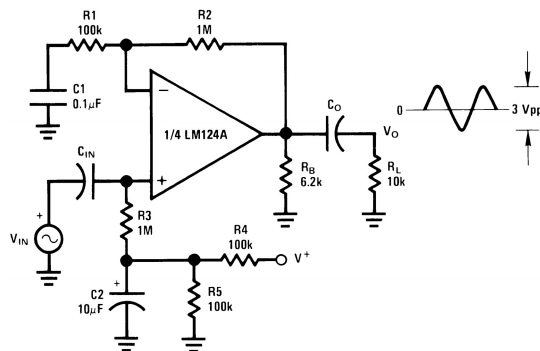**Figure 34. Photo Voltaic-Cell Amplifier**

Figure 35. DC Coupled Low-Pass RC Active Filter

$$A_V = \frac{R_f}{R1} \text{ (As shown, } A_V = 10\text{)}$$

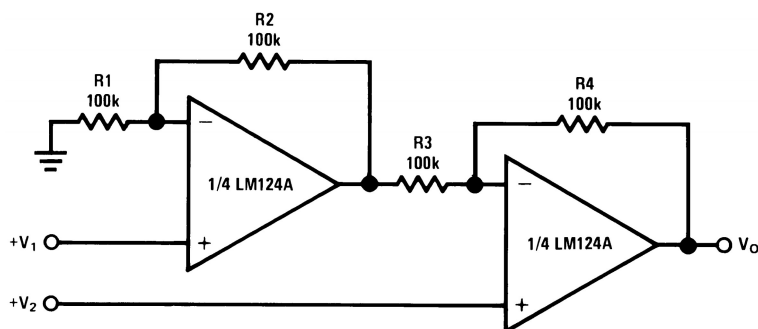**Figure 36. AC Coupled Inverting Amplifier**

$$A_V = 1 + \frac{R2}{R1}$$
$$A_V = 11 \text{ (As shown)}$$

Figure 37. AC Coupled Non-Inverting Amplifier

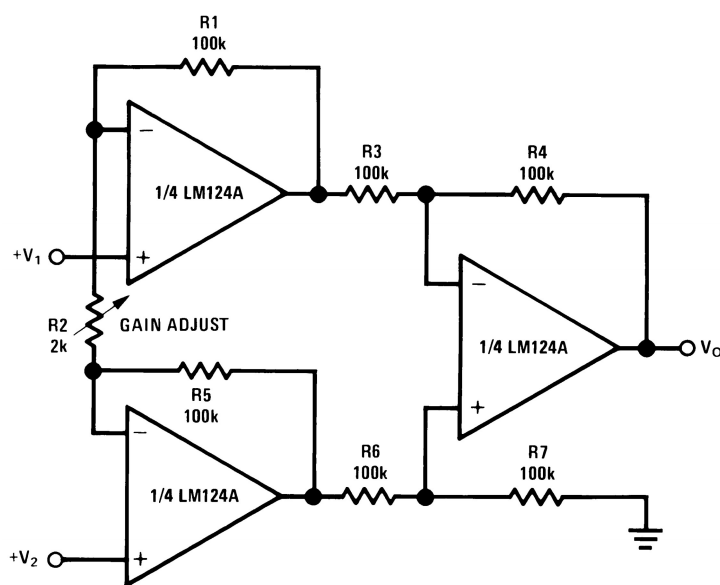Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*

Typical Applications (continued)

For $\dfrac{R1}{R2} = \dfrac{R4}{R3}$ (CMRR depends on this resistor ratio match)

$$V_O = 1 + \dfrac{R4}{R3} (V_2 - V_1)$$

As shown: $V_O = 2(V_2 - V_1)$

Figure 38. High Input Z, DC Differential Amplifier

If R1 = R5 & R3 = R4 = R6 = R7 (CMRR depends on match)

$$V_O = 1 + \dfrac{2R1}{R2} (V_2 - V_1)$$

As shown $V_O = 101 (V_2 - V_1)$

Figure 39. High Input Z Adjustable-Gain DC Instrumentation Amplifier

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*

Typical Applications (continued)

For δ << 1 and R_f >> R

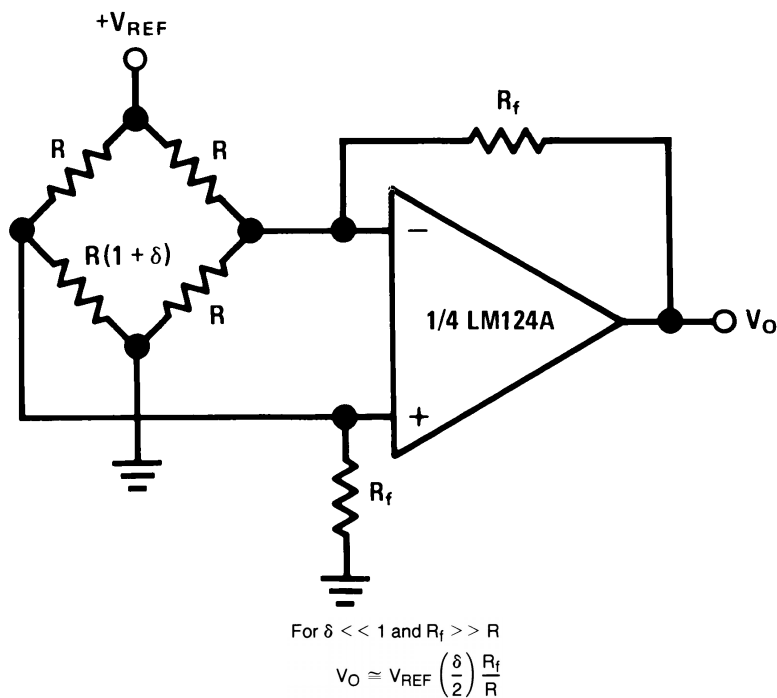$$V_O \cong V_{REF} \left(\frac{\delta}{2}\right) \frac{R_f}{R}$$

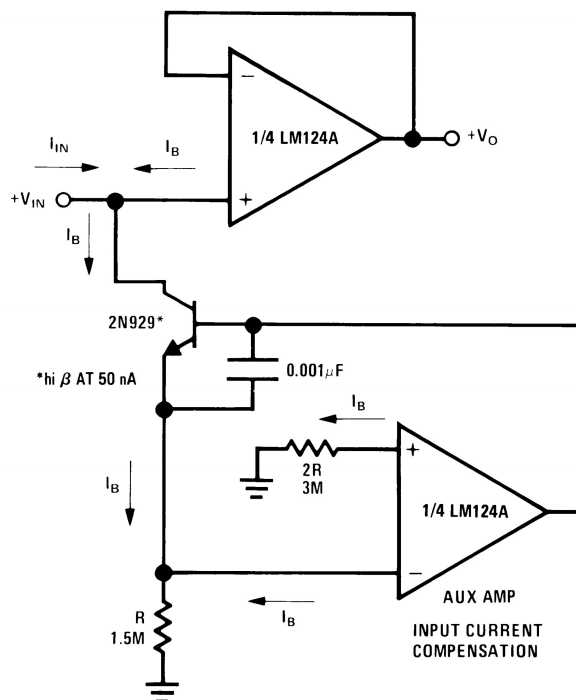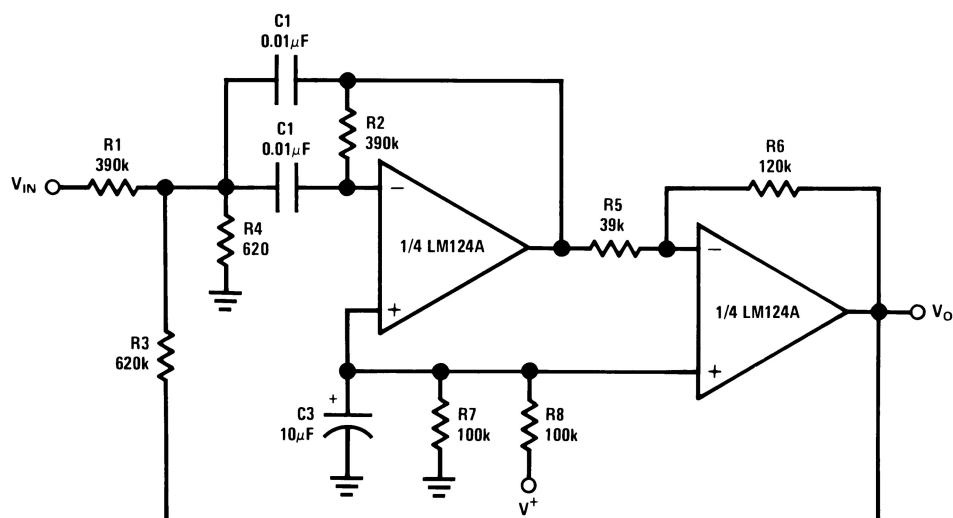**Figure 40. Bridge Current Amplifier**

Figure 41. Using Symmetrical Amplifiers to Reduce Input Current (General Concept)

Typical Applications (continued)

$f_O = 1$ kHz   Q = 25

Figure 42. Bandpass Active Filter

9 Power Supply Recommendations

The pinouts of the package have been designed to simplify PC board layouts. Inverting inputs are adjacent to outputs for all of the amplifiers and the outputs have also been placed at the corners of the package (pins 1, 7, 8, and 14).

Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

10 Layout

10.1 Layout Guidelines

The V + pin should be bypassed to ground with a low-ESR capacitor. The optimum placement is closest to the V + and ground pins.

Take care to minimize the loop area formed by the bypass capacitor connection between V + and ground.

The ground pin should be connected to the PCB ground plane at the pin of the device.

The feedback components should be placed as close to the device as possible minimizing strays.
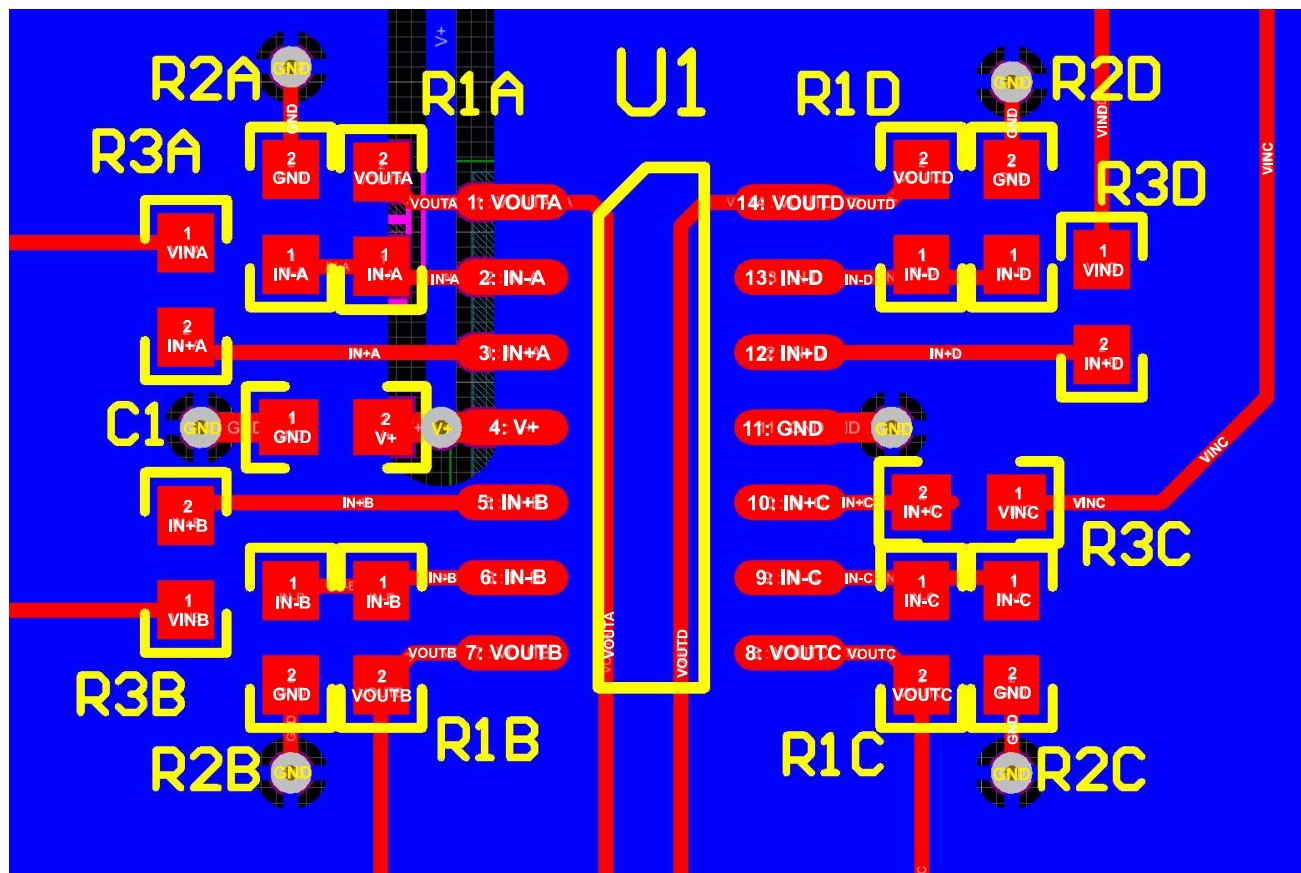
10.2 Layout Example

Figure 43. Layout Example

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*

11 Device and Documentation Support

11.1 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 1. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
LM124-N	Click here	Click here	Click here	Click here	Click here
LM224-N	Click here	Click here	Click here	Click here	Click here
LM2902-N	Click here	Click here	Click here	Click here	Click here
LM324-N	Click here	Click here	Click here	Click here	Click here

11.2 Trademarks

All trademarks are the property of their respective owners.

11.3 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

11.4 Glossary

SLYZ022 — *TI Glossary*.
    This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

Product Folder Links: *LM124-N LM224-N LM2902-N LM324-N*