

## LF412-N-MIL Low Offset, Low Drift Dual JFET Input Operational Amplifier

### 1 Features

- Internally Trimmed Offset Voltage: 1 mV (Max)
- Input Offset Voltage Drift: 7  $\mu\text{V}/^{\circ}\text{C}$  (Typ)
- Low Input Bias Current: 50 pA
- Low Input Noise Current: 0.01 pA /  $\sqrt{\text{Hz}}$
- Wide Gain Bandwidth: 3 MHz (Min)
- High Slew Rate: 10V/ $\mu\text{s}$  (Min)
- Low Supply Current: 1.8 mA/Amplifier
- High Input Impedance:  $10^{12} \Omega$
- Low Total Harmonic Distortion:  $\leq 0.02\%$
- Low 1/f Noise Corner: 50 Hz
- Fast Settling Time to 0.01%: 2  $\mu\text{s}$

### 2 Applications

- High Speed Integrators
- Fast D/A Converters
- Sample and Hold Circuits

### 3 Description

These devices are low cost, high speed, JFET input operational amplifiers with very low input offset voltage and input offset voltage drift. They require low supply current yet maintain a large gain bandwidth product and fast slew rate. In addition, well matched high voltage JFET input devices provide very low input bias and offset currents. The LF412-N-MIL dual is pin compatible with the LM1558, allowing designers to immediately upgrade the overall performance of existing designs.

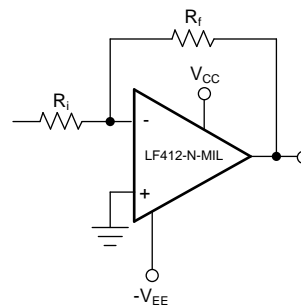
These amplifiers may be used in applications such as high speed integrators, fast D/A converters, sample and hold circuits and many other circuits requiring low input offset voltage and drift, low input bias current, high input impedance, high slew rate and wide bandwidth.

#### Device Information<sup>(1)</sup>

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LF412-N-MIL	PDIP (8)	9.59 mm x 6.35 mm
	TO (8)	9.14 mm diameter

(1) For all available packages, see the orderable addendum at the end of the data sheet.

#### Inverting Amplifier



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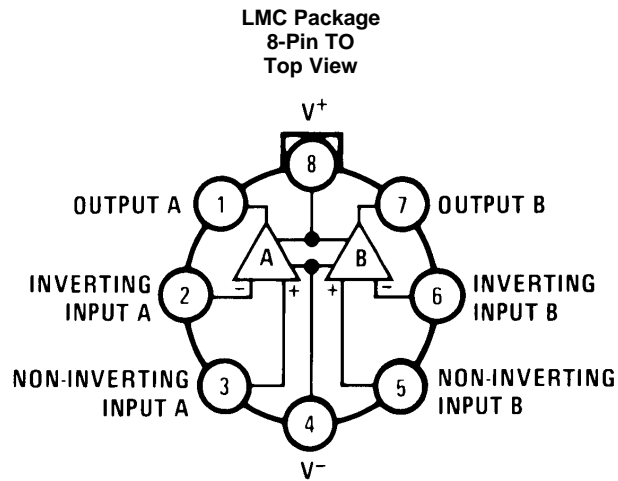
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## 4 Revision History

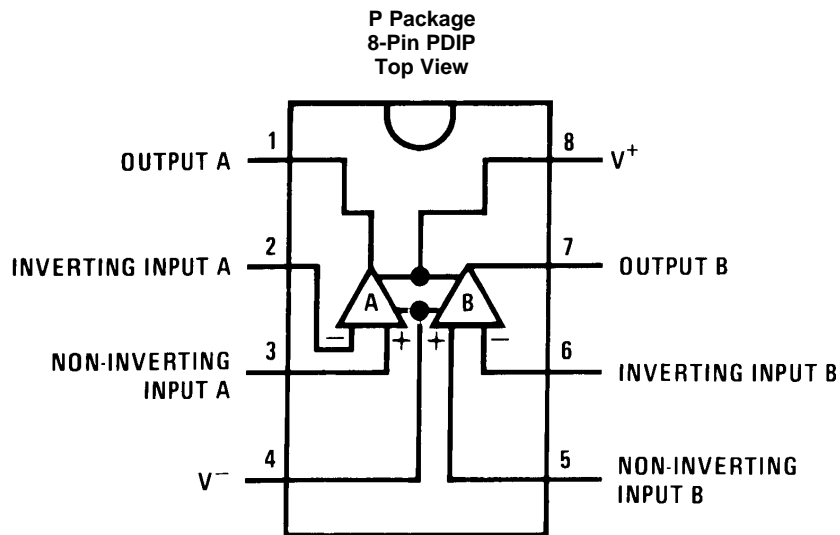
NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

DATE	REVISION	NOTES
June 2017	*	Initial release.

## 5 Pin Configuration and Functions



Note. Pin 4 connected to case.



### Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
Inverting input A	2	I	Amplifier A inverting input
Inverting input B	6	I	Amplifier B inverting input
Noninverting input A	3	I	Amplifier A noninverting input
Noninverting input B	5	I	Amplifier B noninverting input
Output A	1	O	Amplifier A output
Output B	7	O	Amplifier B output
V+	8	P	Positive supply
V-	4	P	Negative supply

## 6 Specifications

### 6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

	MIN	MAX	UNIT
Supply voltage	–18	18	V
Differential input voltage	–30	30	V
Input voltage range			
Output short circuit duration	Continuous		
Power dissipation	670		mW
T <sub>J</sub> maximum	115		°C
Operating temperature range	See <a href="#">Thermal Information</a>		
Storage temperature, T <sub>stg</sub>	–65	150	°C

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

### 6.2 ESD Ratings

		VALUE	UNIT
V <sub>(ESD)</sub> Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>	±1700	V
	Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup>	±1700	

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process. Manufacturing with less than 500-V HBM is possible with the necessary precautions. Pins listed as ±1700 V may actually have higher performance.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process. Manufacturing with less than 250-V CDM is possible with the necessary precautions. Pins listed as ±1700 V may actually have higher performance.

### 6.3 Recommended Operating Conditions

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

	MIN	NOM	MAX	UNIT
Supply voltage			±15	V

### 6.4 Thermal Information

THERMAL METRIC <sup>(1)</sup>	LF412-N-MIL		UNIT
	LMC (TO)	P (PDIP)	
	8 PINS	8 PINS	
R <sub>θJA</sub> Junction-to-ambient thermal resistance (typical)	152	115	°C/W

- (1) For more information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application report.

## 6.5 DC Electrical Characteristics

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

PARAMETER		TEST CONDITIONS	LF412-N-MIL <sup>(1)</sup>			UNIT
			MIN	TYP	MAX	
V <sub>OS</sub>	Input offset voltage	R <sub>S</sub> = 10 kΩ, T <sub>A</sub> = 25°C		1	3	mV
ΔV <sub>OS</sub> /ΔT	Average TC of input offset voltage	R <sub>S</sub> = 10 kΩ		7		μV/°C
I <sub>OS</sub>	Input offset current	V <sub>S</sub> = ±15 V <sup>(2)</sup>		25	100	pA
					2	nA
					25	nA
I <sub>B</sub>	Input bias current	V <sub>S</sub> = ±15 V <sup>(2)(2)</sup>		50	200	pA
					4	nA
					50	nA
R <sub>IN</sub>	Input resistance	T <sub>J</sub> = 25°C		10 <sup>12</sup>		Ω
A <sub>VOL</sub>	Large signal voltage gain	R <sub>L</sub> = 2 k, T <sub>A</sub> = 25°C, V <sub>S</sub> = ±15 V, V <sub>O</sub> = ±10 V	25	200		V/mV
		Over temperature	15	200		
V <sub>O</sub>	Output voltage swing	V <sub>S</sub> = ±15 V, R <sub>L</sub> = 10 k	±12	±13.5		V
V <sub>CM</sub>	Input common-mode voltage range		±11	14.5		V
				-11.5		V
CMRR	Common-mode rejection ratio	R <sub>S</sub> ≤ 10 k	70	100		dB
PSRR	Supply voltage rejection ratio		<sup>(3)</sup> 70	100		dB
I <sub>S</sub>	Supply current	V <sub>O</sub> = 0 V, R <sub>L</sub> = ∞		3.6	6.5	mA

- (1) Unless otherwise specified, the specifications apply over the full temperature range and for V<sub>S</sub> = ±15 V for the LF412-N-MIL. V<sub>OS</sub>, I<sub>B</sub>, and I<sub>OS</sub> are measured at V<sub>CM</sub> = 0.
- (2) The input bias currents are junction leakage currents which approximately double for every 10°C increase in the junction temperature, T<sub>J</sub>. Due to limited production test time, the input bias currents measured are correlated to junction temperature. In normal operation the junction temperature rises above the ambient temperature as a result of internal power dissipation, P<sub>D</sub>. T<sub>J</sub> = T<sub>A</sub> + θ<sub>JA</sub> P<sub>D</sub> where θ<sub>JA</sub> is the thermal resistance from junction to ambient. Use of a heat sink is recommended if input bias current is to be kept to a minimum.
- (3) Supply voltage rejection ratio is measured for both supply magnitudes increasing or decreasing simultaneously in accordance with common practice. V<sub>S</sub> = ±6 V to ±15 V.

## 6.6 AC Electrical Characteristics

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

PARAMETER		TEST CONDITIONS	LF412-N-MIL <sup>(1)</sup>			UNIT
			MIN	TYP	MAX	
	Amplifier to amplifier coupling	$T_A = 25^\circ\text{C}$ $f = 1\text{ Hz} - 20\text{ kHz}$ (Input referred)		-120		dB
SR	Slew rate	$V_S = \pm 15\text{ V}$ $T_A = 25^\circ\text{C}$	8	15		V/ $\mu\text{s}$
GBW	Gain-bandwidth product	$V_S = \pm 15\text{ V}$ $T_A = 25^\circ\text{C}$	2.7	4		MHz
THD	Total harmonic dist	$A_V = 10$ $R_L = 10\text{ k}$ $V_O = 20\text{ Vp-p}$ $\text{BW} = 20\text{ Hz} - 20\text{ kHz}$		$\leq 0.02\%$		
$e_n$	Equivalent input noise voltage	$T_A = 25^\circ\text{C}$ $R_S = 100\ \Omega$ $f = 1\text{ kHz}$		25		nV / $\sqrt{\text{Hz}}$
$i_n$	Equivalent input noise current	$T_A = 25^\circ\text{C}$ , $f = 1\text{ kHz}$		0.01		pA / $\sqrt{\text{Hz}}$

(1) Unless otherwise specified, the specifications apply over the full temperature range and for  $V_S = \pm 15\text{ V}$  for the LF412-N-MIL.  $V_{OS}$ ,  $I_B$ , and  $I_{OS}$  are measured at  $V_{CM} = 0$ .

## 6.7 Typical Characteristics

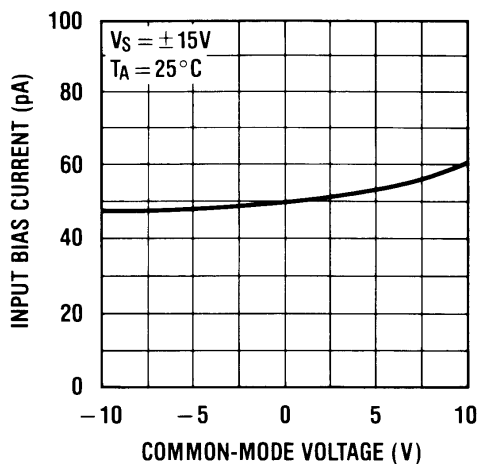


Figure 1. Input Bias Current

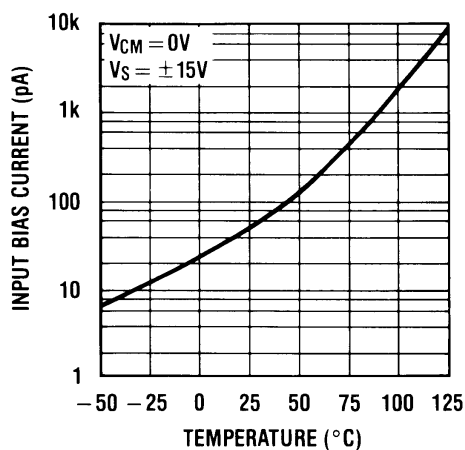


Figure 2. Input Bias Current

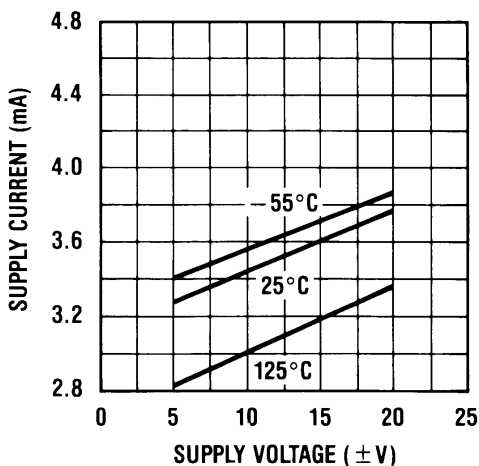


Figure 3. Supply Current

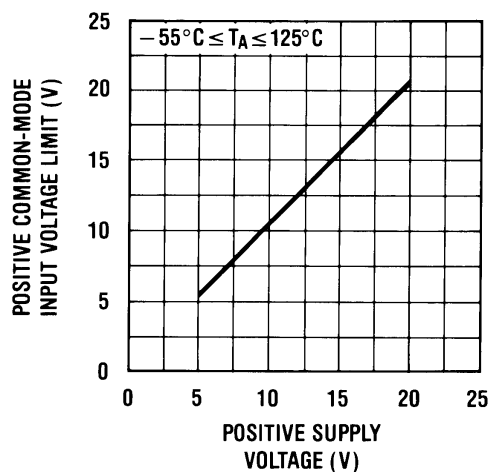


Figure 4. Positive Common-Mode Input Voltage Limit

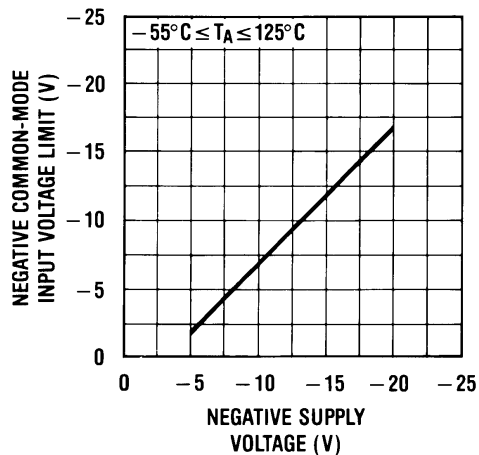


Figure 5. Negative Common-Mode Input Voltage Limit

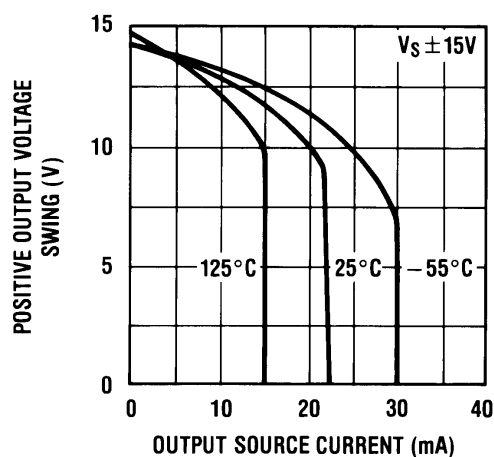


Figure 6. Positive Current Limit

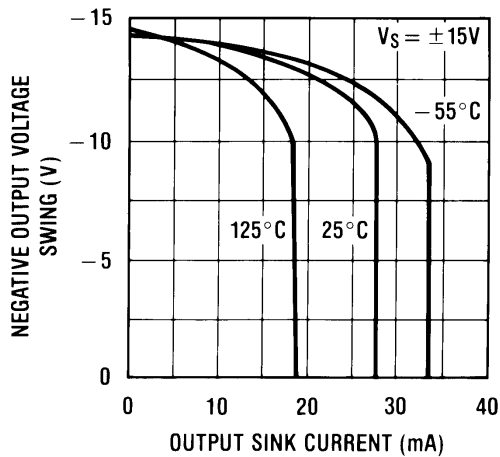
**Typical Characteristics (continued)**


Figure 7. Negative Current Limit

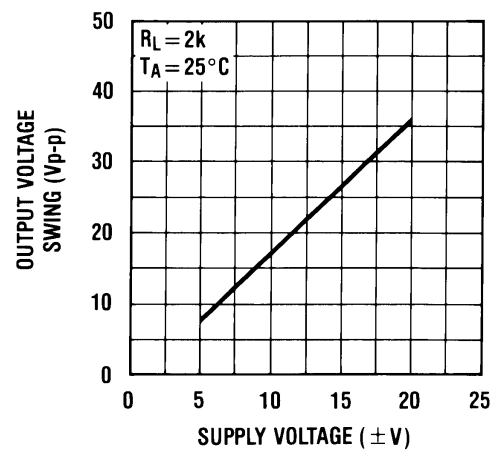


Figure 8. Output Voltage Swing

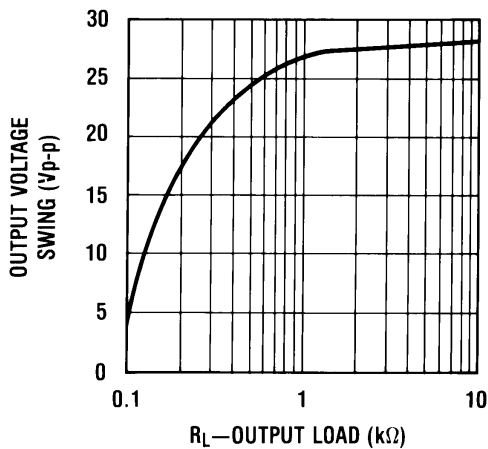


Figure 9. Output Voltage Swing

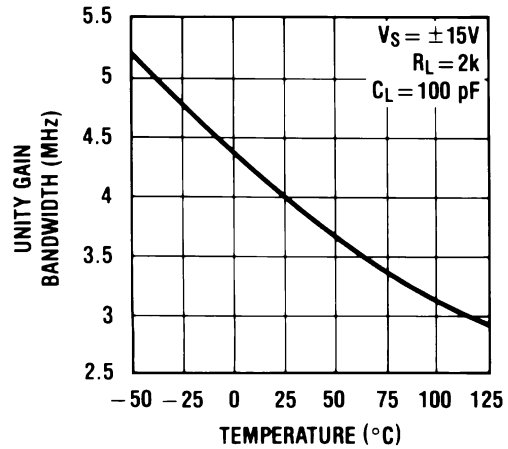


Figure 10. Gain Bandwidth

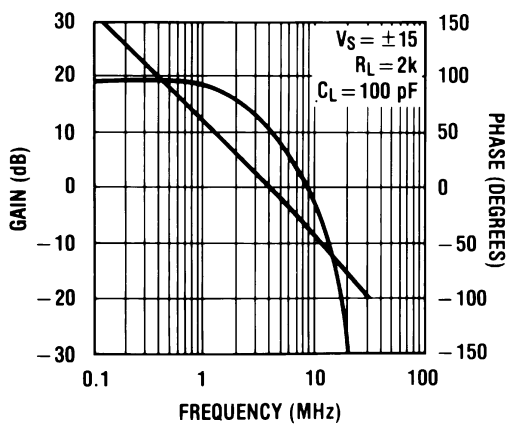


Figure 11. Bode Plot

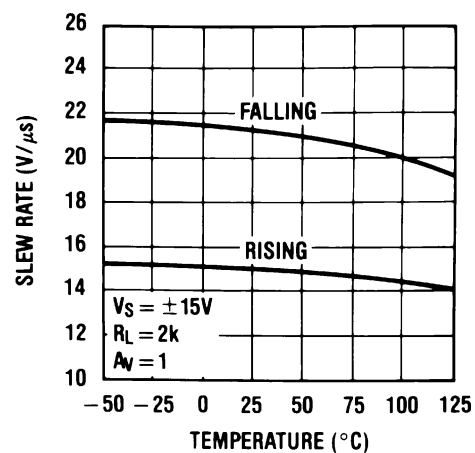


Figure 12. Slew Rate



## Typical Characteristics (continued)

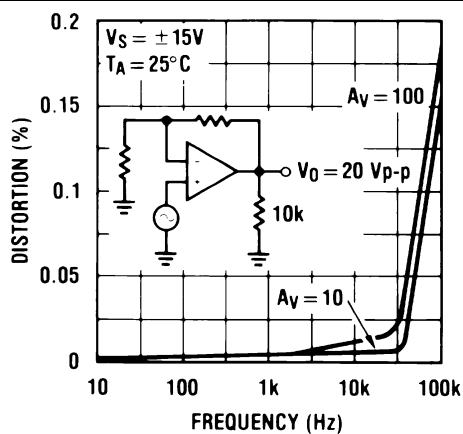


Figure 13. Distortion vs Frequency

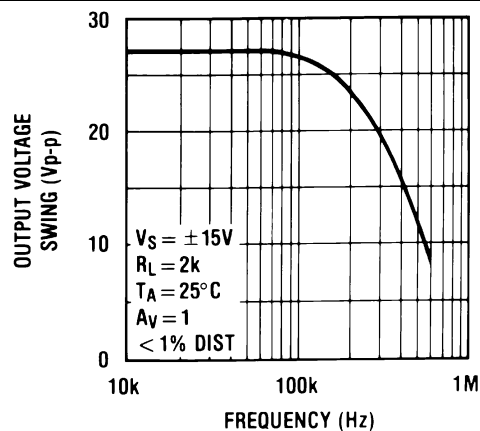


Figure 14. Undistorted Output Voltage Swing

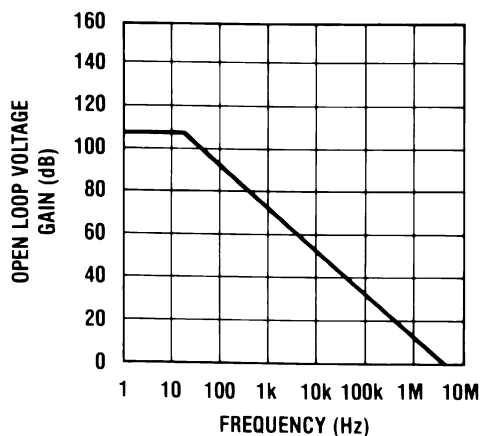


Figure 15. Open Loop Frequency Response

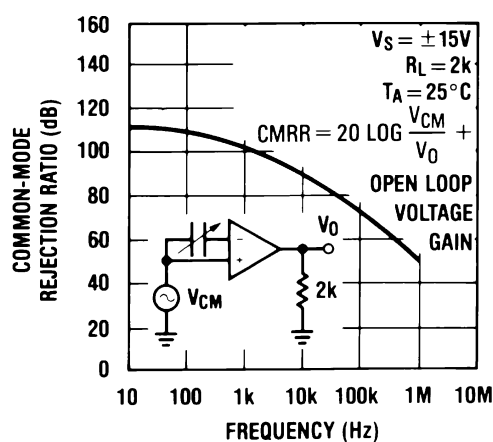


Figure 16. Common-Mode Rejection Ratio

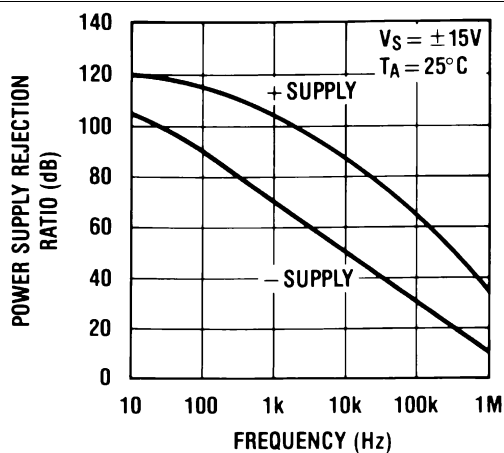


Figure 17. Power Supply Rejection Ratio

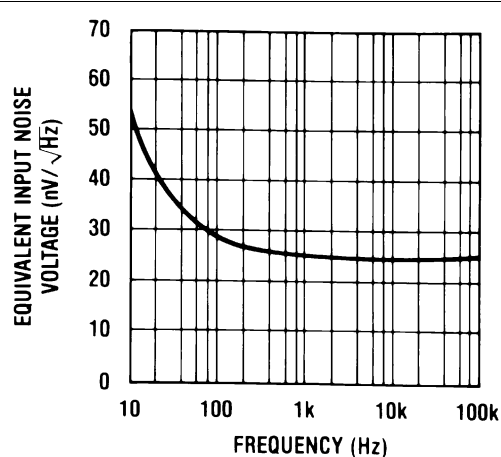


Figure 18. Equivalent Input Noise Voltage

## Typical Characteristics (continued)

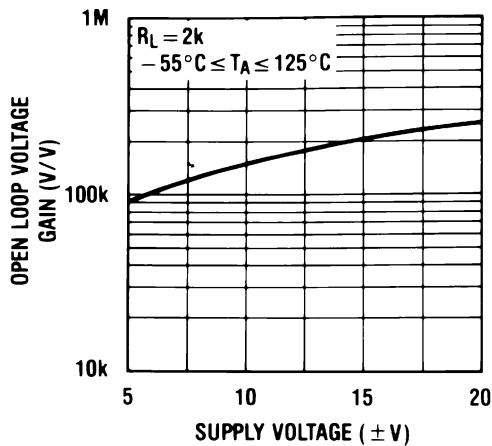


Figure 19. Open Loop Voltage Gain

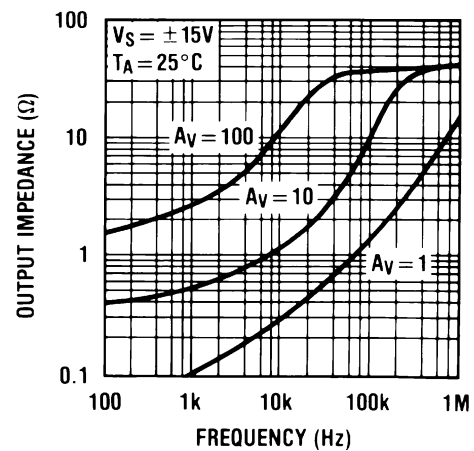


Figure 20. Output Impedance

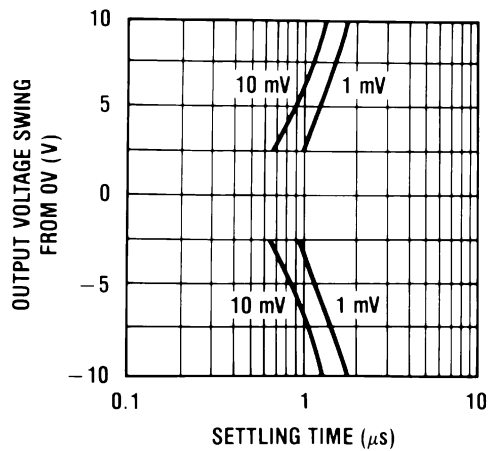


Figure 21. Inverter Settling Time

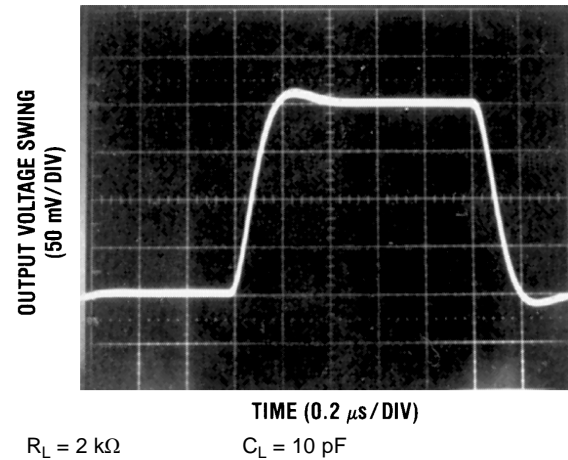


Figure 22. Small Signal Inverting

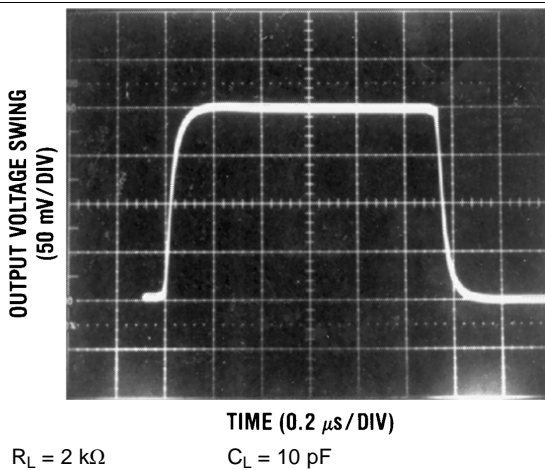


Figure 23. Small Signal Non-Inverting

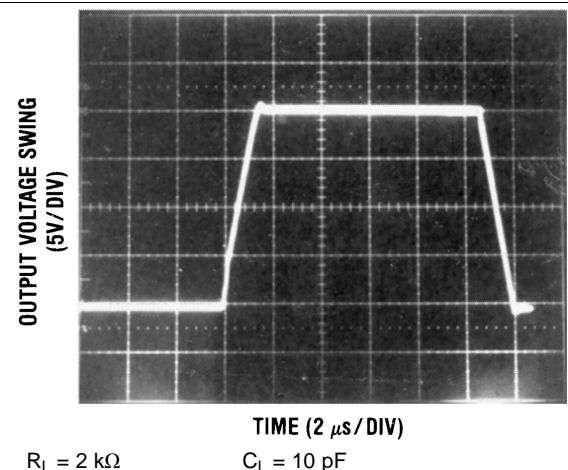
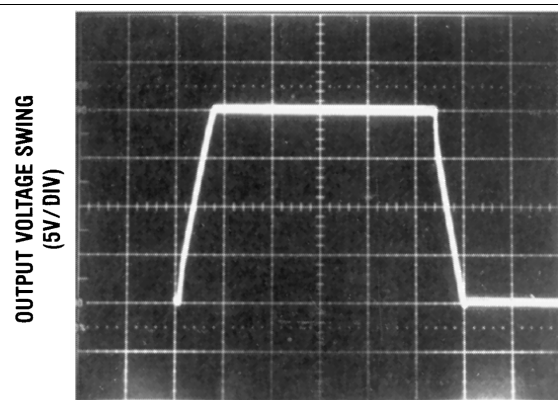


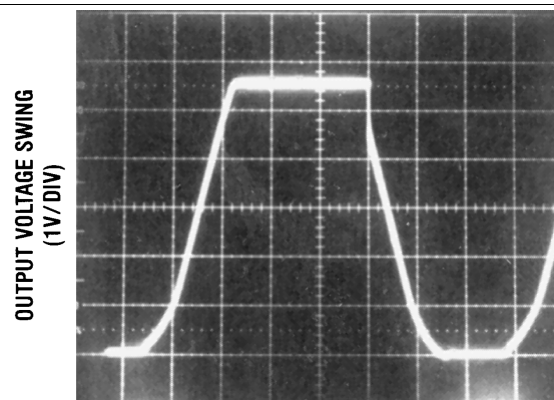
Figure 24. Large Signal Inverting

## Typical Characteristics (continued)



$R_L = 2\text{ k}\Omega$        $C_L = 10\text{ pF}$

**Figure 25. Large Signal Non-Inverting**



$R_L = 100\ \Omega$        $C_L = 10\text{ pF}$

**Figure 26. Current Limit**

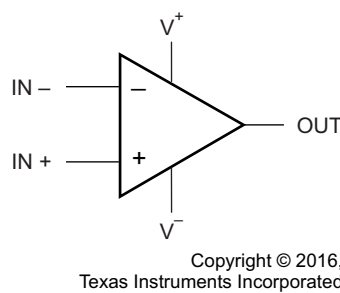
## 7 Detailed Description

### 7.1 Overview

The LF412-N-MIL devices are low cost, high speed, JFET input operational amplifiers with very low input offset voltage and input offset voltage drift. They require low supply current yet maintain a large gain bandwidth product and fast slew rate. In addition, well matched high voltage JFET input devices provide very low input bias and offset currents. The LF412-N-MIL dual is pin compatible with the LM1558, allowing designers to immediately upgrade the overall performance of existing designs.

These amplifiers may be used in applications such as high speed integrators, fast D/A converters, sample and hold circuits and many other circuits requiring low input offset voltage and drift, low input bias current, high input impedance, high slew rate and wide bandwidth.

### 7.2 Functional Block Diagram



**Figure 27. Each Amplifier**

### 7.3 Feature Description

The amplifier's differential inputs consist of a non-inverting input (+IN) and an inverting input (-IN). The amplifier amplifies only the difference in voltage between the two inputs, which is called the differential input voltage. The output voltage of the op-amp  $V_{OUT}$  is given by the equation  $V_{OUT} = A_{OL}(IN+ - IN-)$ .

## 7.4 Device Functional Modes

### 7.4.1 Input and Output Stage

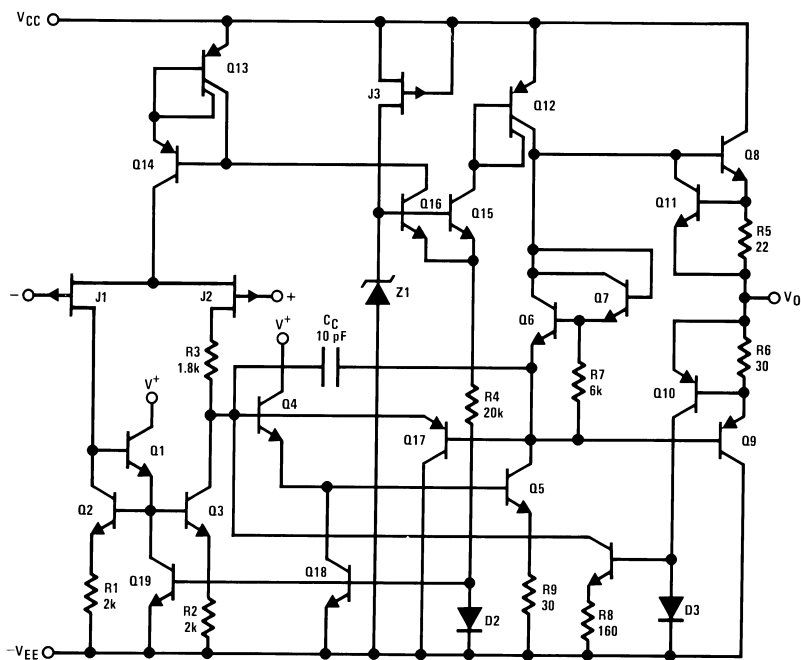


Figure 28. 1/2 Dual LF412-N-MIL

## 8 Application and Implementation

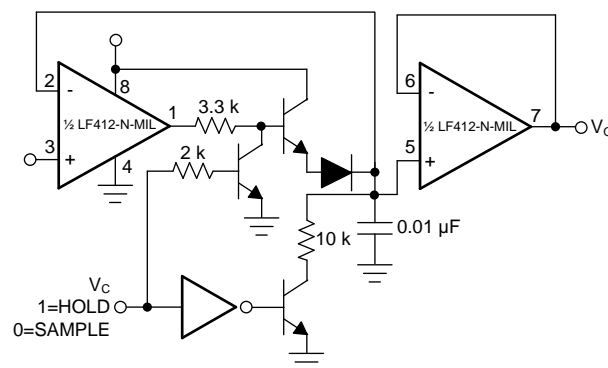
### NOTE

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 LF412-N-MIL series of JFET input dual op amps are internally trimmed (BI-FET II™) providing very low input offset voltages and input offset voltage drift. These JFETs have large reverse breakdown voltages from gate to source and drain eliminating the need for clamps across the inputs. Therefore, large differential input voltages can easily be accommodated without a large increase in input current. The maximum differential input voltage is independent of the supply voltages. However, neither of the input voltages should be allowed to exceed the negative supply as this will cause large currents to flow which can result in a destroyed unit.

### 8.2 Typical Application



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**Figure 29. Single-Supply Sample and Hold**

#### 8.2.1 Design Requirements

Single-supply.

#### 8.2.2 Detailed Design Procedure

Exceeding the negative common-mode limit on either input will cause a reversal of the phase to the output and force the amplifier output to the corresponding high or low state.

Exceeding the negative common-mode limit on both inputs will force the amplifier output to a high state. In neither case does a latch occur since raising the input back within the common-mode range again puts the input stage and thus the amplifier in a normal operating mode.

Exceeding the positive common-mode limit on a single input will not change the phase of the output, however, if both inputs exceed the limit, the output of the amplifier may be forced to a high state.

The amplifiers will operate with a common-mode input voltage equal to the positive supply; however, the gain bandwidth and slew rate may be decreased in this condition. When the negative common-mode voltage swings to within 3V of the negative supply, an increase in input offset voltage may occur.

Each amplifier is individually biased by a zener reference which allows normal circuit operation on  $\pm 6$  V power supplies. Supply voltages less than these may result in lower gain bandwidth and slew rate.

## Typical Application (continued)

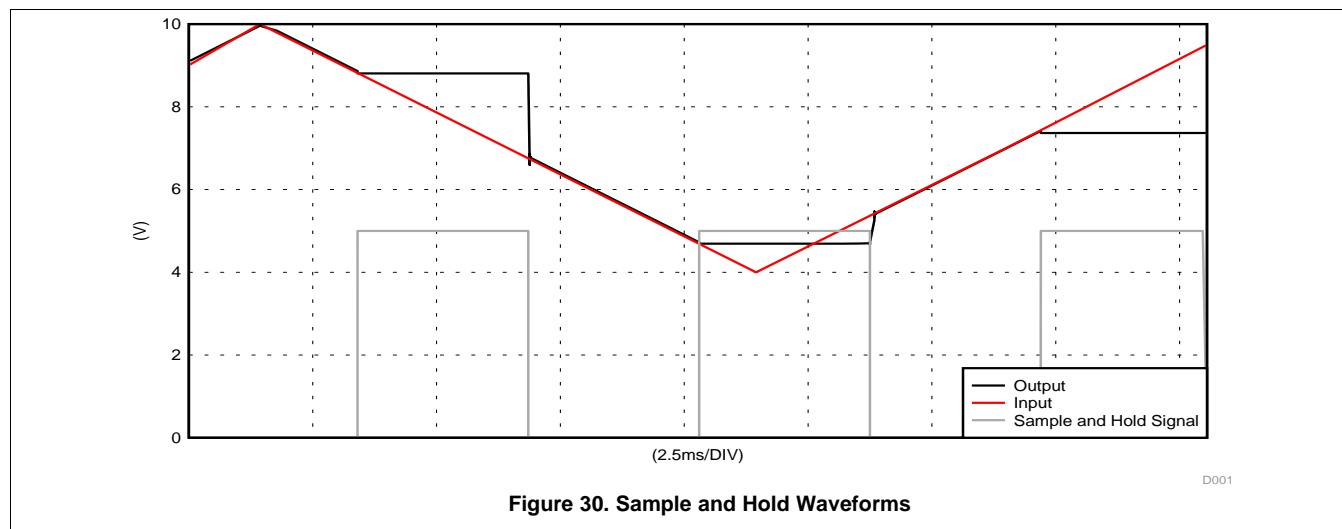
The amplifiers will drive a 2 k $\Omega$  load resistance to  $\pm 10$  V over the full temperature range. If the amplifier is forced to drive heavier load currents, however, an increase in input offset voltage may occur on the negative voltage swing and finally reach an active current limit on both positive and negative swings.

Precautions should be taken to ensure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a 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.

As with most amplifiers, care should be taken with lead dress, component placement and supply decoupling in order to ensure stability. For example, resistors from the output to an input should be placed with the body close to the input to minimize “pick-up” and maximize the frequency of the feedback pole by minimizing the capacitance from the input to ground.

A feedback pole is created when the feedback around any amplifier is resistive. The parallel resistance and capacitance from the input of the device (usually the inverting input) to AC ground set the frequency of the pole. In many instances the frequency of this pole is much greater than the expected 3 dB frequency of the closed loop gain and consequently there is negligible effect on stability margin. However, if the feedback pole is less than approximately 6 times the expected 3 dB frequency a lead capacitor should be placed from the output to the input of the op amp. The value of the added capacitor should be such that the RC time constant of this capacitor and the resistance it parallels is greater than or equal to the original feedback pole time constant.

### 8.2.3 Application Curves



## 9 Power Supply Recommendations

For proper operation, the power supplies must be properly decoupled. For decoupling the supply lines it is suggested that 0.1  $\mu\text{F}$  capacitors be placed as close as possible to the op amp power supply pins. The minimum power supply voltage is  $\pm 5\text{ V}$ .

## 10 Layout

### 10.1 Layout Guidelines

As with most amplifiers, care should be taken with lead dress, component placement and supply decoupling in order to ensure stability. For example, resistors from the output to an input should be placed with the body close to the input to minimize “pick-up” and maximize the frequency of the feedback pole by minimizing the capacitance from the input to ground.

### 10.2 Layout Example

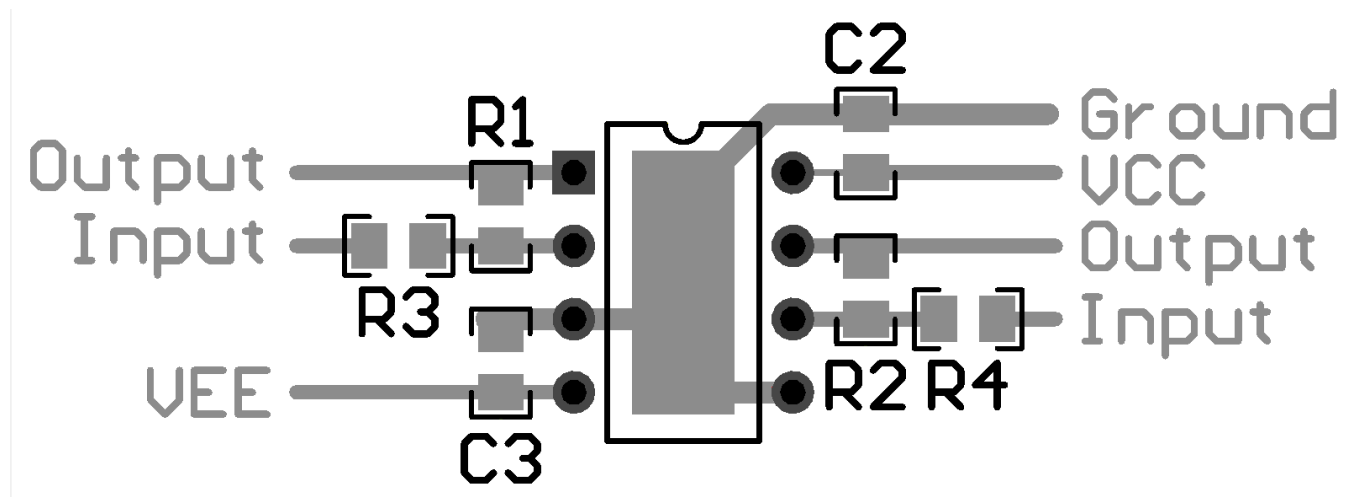


Figure 31. LF412-N-MIL Layout



## 11 Device and Documentation Support

### 11.1 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

### 11.2 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

**TI E2E™ Online Community** *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

### 11.3 Trademarks

BI-FET II, E2E are trademarks of Texas Instruments.

All other trademarks are the property of their respective owners.

### 11.4 Electrostatic Discharge Caution



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

### 11.5 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.

## PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package   Pins	Package qty   Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
LF412MH	Active	Production	TO-99 (LMC)   8	500   OTHER	No	Call TI	Level-1-NA-UNLIM	-55 to 125	( LF412MH, LF412MH )
LF412MH/NOPB	Active	Production	TO-99 (LMC)   8	500   OTHER	Yes	Call TI	Level-1-NA-UNLIM	-55 to 125	( LF412MH, LF412MH )

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

<sup>(2)</sup> **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

<sup>(4)</sup> **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

<sup>(5)</sup> **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

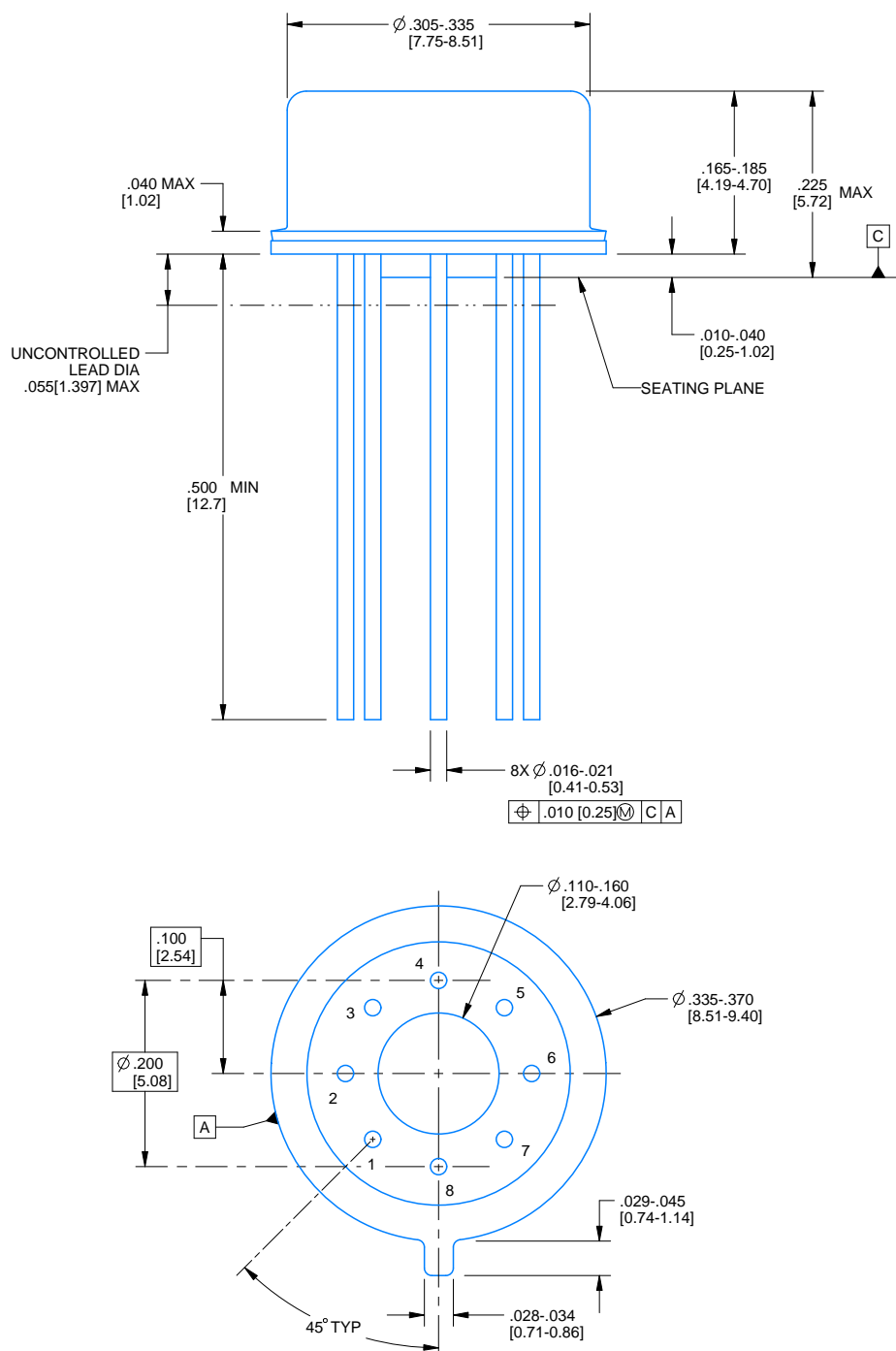
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

# PACKAGE OUTLINE

LMC0008A

TO-CAN - 5.72 mm max height

TRANSISTOR OUTLINE



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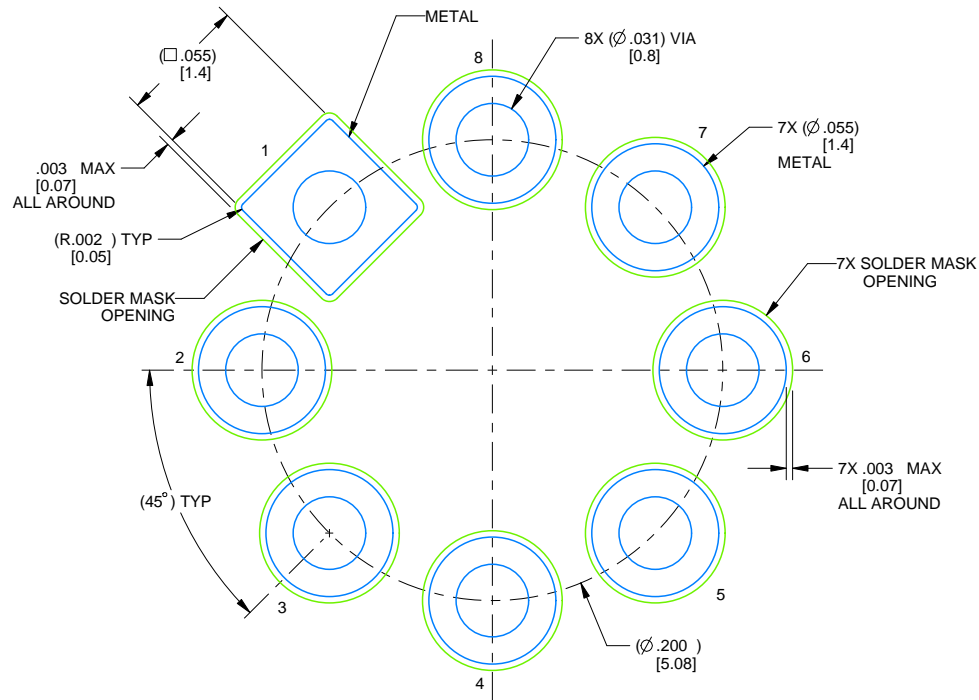
## NOTES:

1. All linear dimensions are in inches [millimeters]. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Pin numbers shown for reference only. Numbers may not be marked on package.
4. Reference JEDEC registration MO-002/TO-99.

# LMC0008A

**TO-CAN - 5.72 mm max height**

## TRANSISTOR OUTLINE



LAND PATTERN EXAMPLE  
NON-SOLDER MASK DEFINED  
SCALE: 12X

4220610/B 09/2024

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