

TLVx888 Low-Noise, Zero-Drift, Wide-Bandwidth, Mux-Friendly, Operational Amplifiers

1 Features

- High dc precision:
 - Zero drift: $0.01\mu\text{V}/^\circ\text{C}$
 - Low offset voltage: $3\mu\text{V}$
 - High PSRR: 150dB
 - High CMRR: 150dB
- Excellent ac performance:
 - Gain bandwidth: 14MHz
 - Slew rate: $40\text{V}/\mu\text{s}$
 - Low noise: $7.5\text{nV}/\sqrt{\text{Hz}}$
- Input to the negative rail, rail-to-rail output
- Low quiescent current: 1.5mA
- RFI/EMI filtered inputs
- Supply range: 4.5V to 36V
- Temperature: -40°C to $+125^\circ\text{C}$

2 Applications

- [PC PSU and game console unit](#)
- [Merchant DC/DC](#)
- [Flow transmitter](#)
- [Pressure transmitter](#)
- [Merchant battery charger](#)
- [Electricity meter](#)

3 Description

The TLV888, TLV2888, and TLV4888 (TLVx888) are wide-bandwidth, low noise, zero-drift operational amplifiers (op amps). These op amps feature only $15\mu\text{V}$ of offset voltage (max) and $0.1\mu\text{V}/^\circ\text{C}$ of offset voltage drift (max) over a wide temperature range.

The TLVx888 feature very fast settling time due in part to the wide gain bandwidth and very high slew rate. The settling time is further enhanced in multichannel systems by the proprietary MUX-friendly input architecture.

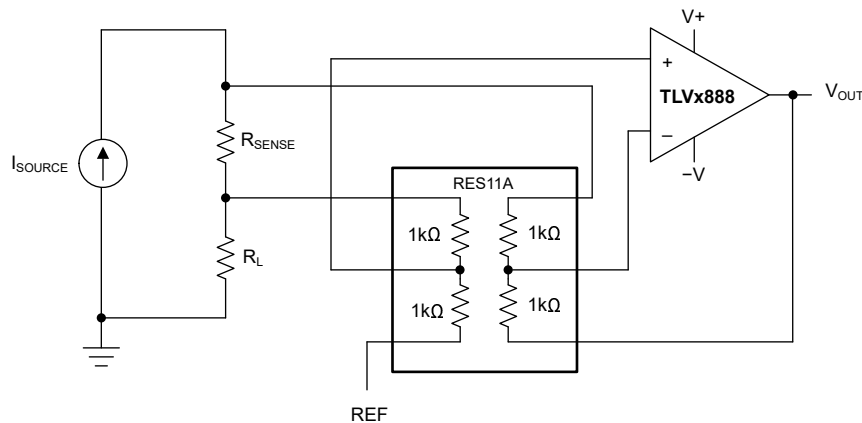
The combination of high precision, fast settling, and low noise make the TLVx888 an excellent choice for a wide range of applications, including signal measurement, precision instrumentation, and data acquisition.

The TLVx888 are available in industry standard packages as well as micro-size packages to fit in the most space constrained applications. The devices are specified for operation from -40°C to $+125^\circ\text{C}$.

Device Information

PART NUMBER	CHANNEL COUNT	PACKAGE ⁽¹⁾
TLV888 ⁽²⁾	Single	D (SOIC, 8)
		DBV (SOT-23, 5)
		DRL (SOT, 5)
TLV2888	Dual	D (SOIC, 8)
		DDF (SOT-23, 8) ⁽²⁾
		DGK (VSSOP-8) ⁽²⁾
		DSG (WSON-8) ⁽²⁾
TLV4888 ⁽²⁾	Quad	D (SOIC, 14)
		PW (TSSOP-14)

- (1) For more information, see [Section 10](#).
- (2) Preview information (not Advance Information).



High-Side Current Shunt Monitor Application



Table of Contents

1 Features	1	7 Application and Implementation	17
2 Applications	1	7.1 Application Information.....	17
3 Description	1	7.2 Typical Applications.....	20
4 Pin Configuration and Functions	2	7.3 Power Supply Recommendations.....	24
5 Specifications	3	7.4 Layout.....	24
5.1 Absolute Maximum Ratings.....	3	8 Device and Documentation Support	26
5.2 ESD Ratings.....	3	8.1 Device Support.....	26
5.3 Recommended Operating Conditions.....	3	8.2 Documentation Support.....	26
5.4 Thermal Information: TLV2888.....	3	8.3 Receiving Notification of Documentation Updates....	26
5.5 Electrical Characteristics.....	4	8.4 Support Resources.....	26
5.6 Typical Characteristics.....	6	8.5 Trademarks.....	27
6 Detailed Description	13	8.6 Electrostatic Discharge Caution.....	27
6.1 Overview.....	13	8.7 Glossary.....	27
6.2 Functional Block Diagram.....	13	9 Revision History	27
6.3 Feature Description.....	13	10 Mechanical, Packaging, and Orderable	
6.4 Device Functional Modes.....	16	Information	27

4 Pin Configuration and Functions

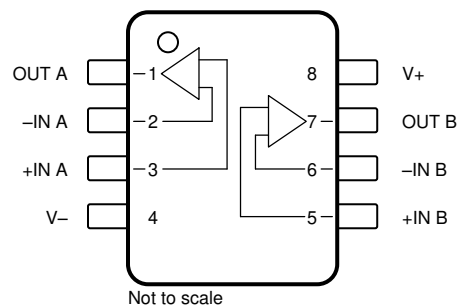


Figure 4-1. TLV2888: D Package, 8-Pin SOIC (Top View)

Table 4-1. Pin Functions: TLV2888

PIN		TYPE	DESCRIPTION
NAME	NO.		
-IN A	2	Input	Inverting input channel A
-IN B	6	Input	Inverting input channel B
+IN A	3	Input	Noninverting input channel A
+IN B	5	Input	Noninverting input channel B
OUT A	1	Output	Output channel A
OUT B	7	Output	Output channel B
V-	4	Power	Negative supply
V+	8	Power	Positive supply

5 Specifications

5.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)⁽¹⁾

		MIN	MAX	UNIT	
V _S	Supply voltage		40	V	
	Signal input voltage	Common-mode	(V ⁻) – 0.5	(V ⁺) + 0.5	V
		Differential	(V ⁺) – (V ⁻)		
	Current		±10	mA	
	Output short circuit ⁽²⁾	Continuous			
T _A	Operating temperature	–55	150	°C	
T _J	Junction temperature		150	°C	
T _{stg}	Storage temperature	–65	150	°C	

- (1) Operation outside the *Absolute Maximum Ratings* may cause permanent device damage. *Absolute Maximum Ratings* do not imply functional operation of the device at these or any other conditions beyond those listed under *Recommended Operating Conditions*. If used outside the *Recommended Operating Conditions* but within the *Absolute Maximum Ratings*, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.
- (2) Short-circuit to ground, one amplifier per package.

5.2 ESD Ratings

			VALUE	UNIT
V _(ESD)	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾	±1000	V
		Charged-device model (CDM), per ANSI/ESDA/JEDEC JS-002 ⁽²⁾	±250	

- (1) JEDEC document JEP155 states that 500V HBM allows safe manufacturing with a standard ESD control process.
- (2) JEDEC document JEP157 states that 250V CDM allows safe manufacturing with a standard ESD control process.

5.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
V _S	Supply voltage, (V ⁺) – (V ⁻)	Single supply	4.5	36	V
		Dual supply	±2.25	±18	
T _A	Operating temperature	–40		125	°C

5.4 Thermal Information: TLV2888

THERMAL METRIC ⁽¹⁾		TLV2888	UNIT
		D (SOIC)	
		8 PINS	
R _{θJA}	Junction-to-ambient thermal resistance	148	°C/W
R _{θJC(top)}	Junction-to-case (top) thermal resistance	88	°C/W
R _{θJB}	Junction-to-board thermal resistance	91	°C/W
Ψ _{JT}	Junction-to-top characterization parameter	37	°C/W
Ψ _{JB}	Junction-to-board characterization parameter	91	°C/W
R _{θJC(bot)}	Junction-to-case (bottom) thermal resistance	N/A	°C/W

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

5.5 Electrical Characteristics

at $T_A = 25^\circ\text{C}$, $V_S = 4.5\text{V}$ to 36V , $V_{CM} = V_{OUT} = V_S / 2$, and $R_{LOAD} = 10\text{k}\Omega$ connected to $V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OFFSET VOLTAGE							
V_{OS}	Input offset voltage ⁽¹⁾				±3	±15	μV
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				±20	
dV_{OS}/dT	Input offset voltage drift ⁽¹⁾	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			±0.01	±0.05	$\mu\text{V}/^\circ\text{C}$
PSRR	Power-supply rejection ratio ⁽¹⁾	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			±0.03	±0.5	$\mu\text{V}/\text{V}$
INPUT BIAS CURRENT							
I_B	Input bias current ⁽¹⁾				±50	±350	μA
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				±7	nA
I_{OS}	Input offset current ⁽¹⁾				±100	±600	μA
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				±3	nA
NOISE							
E_n	Input voltage noise	$f = 0.1\text{Hz}$ to 10Hz			0.180		μV_{PP}
e_n	Input voltage noise density	$f = 10\text{Hz}$			7.6		$\text{nV}/\sqrt{\text{Hz}}$
		$f = 100\text{Hz}$			7.6		
		$f = 1\text{kHz}$			7.5		
i_n	Input current noise density	$f = 1\text{kHz}$			175		$\text{fA}/\sqrt{\text{Hz}}$
INPUT VOLTAGE							
V_{CM}	Common-mode voltage			$(V-) - 0.1$		$(V+) - 1.7$	V
CMRR	Common-mode rejection ratio	$(V-) - 0.1\text{V} \leq V_{CM} \leq (V+) - 1.7\text{V}$	$V_S = \pm 2.25\text{V}$	118	135		dB
			$V_S = \pm 18\text{V}$	140	150		
		$(V-) - 0.1\text{V} \leq V_{CM} \leq (V+) - 1.7\text{V}$, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$	$V_S = \pm 2.25\text{V}$	118	130		
			$V_S = \pm 18\text{V}$	140	150		
INPUT IMPEDANCE							
Z_{id}	Differential input impedance				100 1.6		$\text{M}\Omega$ pF
Z_{ic}	Common-mode input impedance				1 1.9		$\text{T}\Omega$ pF
OPEN-LOOP GAIN							
A_{OL}	Open-loop voltage gain	$V_S = \pm 15\text{V}$, $(V-) + 0.6\text{V} < V_O < (V+) - 0.6\text{V}$, $R_{LOAD} = 10\text{k}\Omega$	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		130	148	dB
					130		
		$V_S = \pm 15\text{V}$, $(V-) + 1\text{V} < V_O < (V+) - 1\text{V}$, $R_{LOAD} = 2\text{k}\Omega$	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		130	144	
					130		

5.5 Electrical Characteristics (continued)

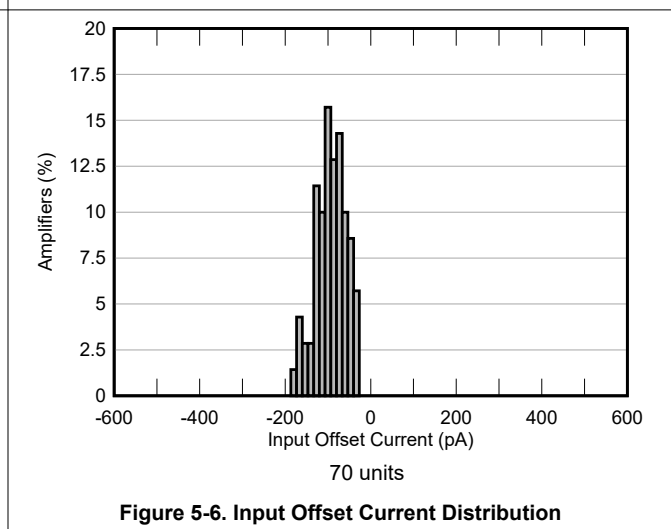
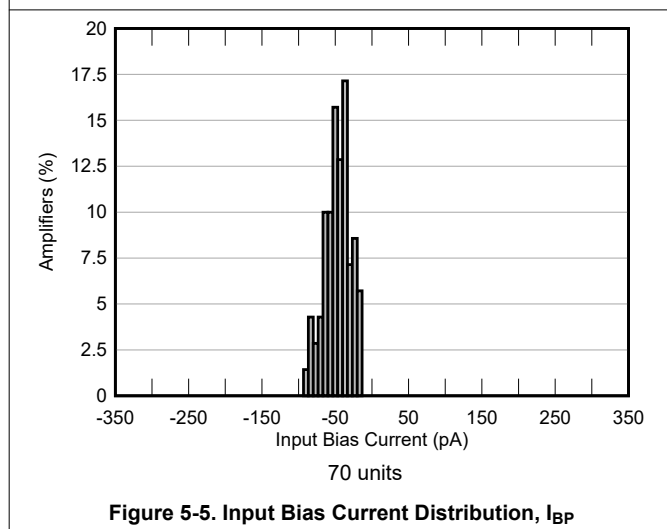
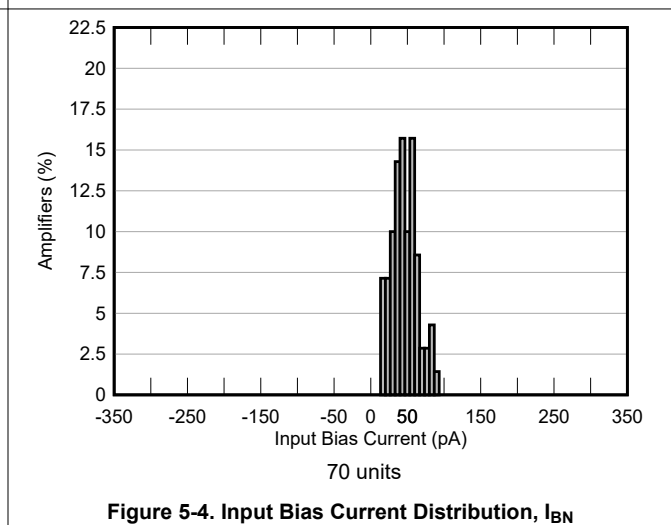
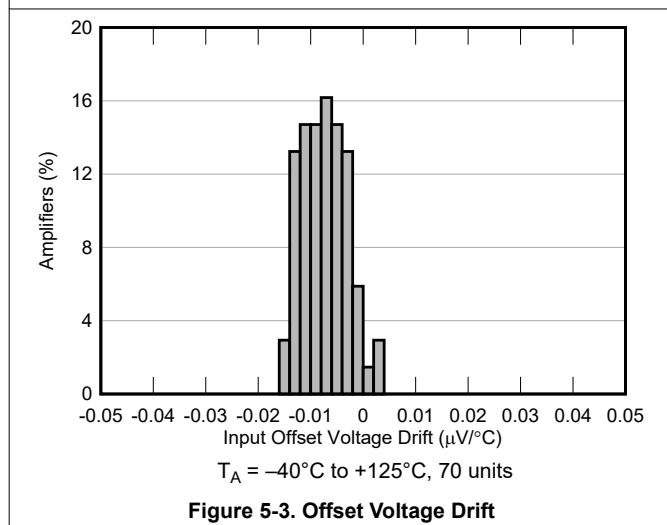
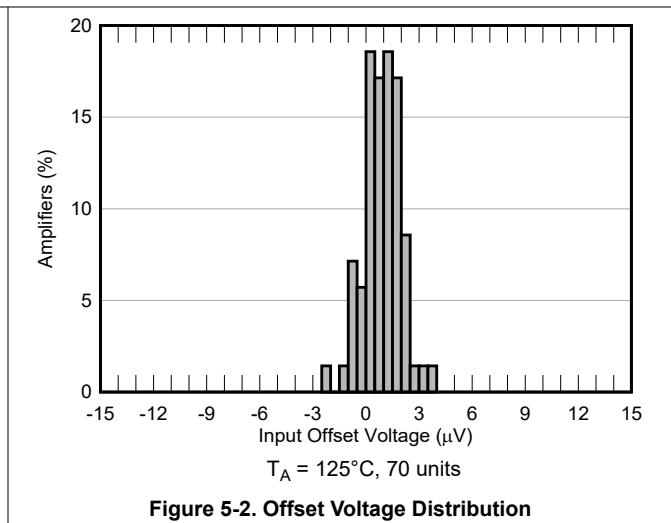
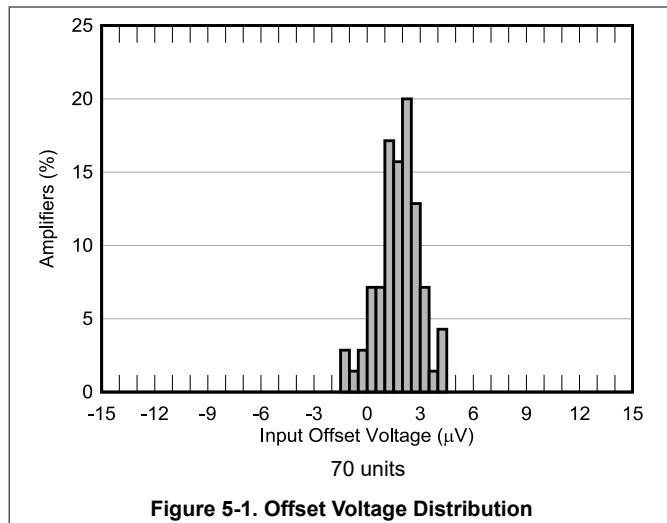
at $T_A = 25^\circ\text{C}$, $V_S = 4.5\text{V}$ to 36V , $V_{CM} = V_{OUT} = V_S / 2$, and $R_{LOAD} = 10\text{k}\Omega$ connected to $V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
FREQUENCY RESPONSE							
GBW	Gain-bandwidth product			14			MHz
SR	Slew rate	Gain = 1, 10V step		40			V/ μs
THD+N	Total harmonic distortion + noise	Gain = 1, $f = 1\text{kHz}$, $V_{OUT} = 4V_{RMS}$		0.00012%			
	Crosstalk	$f = 100\text{kHz}$		110			dB
t_S	Settling time	$V_S = \pm 18\text{V}$, gain = 1, 10V step	To 0.1%	1			μs
			To 0.01%	15			
t_{OR}	Overload recovery time	$V_{IN} \times \text{gain} = V_S = \pm 18\text{V}$		460			ns
OUTPUT							
V_O	Voltage output swing from rail	Positive rail, $V_S = 30\text{V}$	No load	26	30	mV	
			$R_{LOAD} = 10\text{k}\Omega$	122	150		
			$R_{LOAD} = 2\text{k}\Omega$	500	575		
		Negative rail, $V_S = 30\text{V}$	No load	20	25		
			$R_{LOAD} = 10\text{k}\Omega$	120	135		
			$R_{LOAD} = 2\text{k}\Omega$	515	575		
$R_{LOAD} = 10\text{k}\Omega$, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$, both rails ⁽¹⁾			225				
I_{SC}	Short-circuit current			± 42			mA
C_{LOAD}	Capacitive load drive			See Typical Characteristics			pF
Z_O	Open-loop output impedance	$f = 1\text{MHz}$		220			Ω
POWER SUPPLY							
I_Q	Quiescent current per amplifier	$V_S = \pm 2.25\text{V}$ ($V_S = 4.5\text{V}$), $I_O = 0\text{A}$		1.5	1.8	mA	
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$ ⁽¹⁾	1.5	1.9		
		$V_S = \pm 18\text{V}$ ($V_S = 36\text{V}$), $I_O = 0\text{A}$		1.5	1.8		
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$ ⁽¹⁾	1.5	1.9		

(1) Specification established from device population bench system measurements across multiple lots.

5.6 Typical Characteristics

at $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{V}$, $V_{CM} = V_S / 2$, and $R_L = 10\text{k}\Omega$ (unless otherwise noted)



5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{V}$, $V_{CM} = V_S / 2$, and $R_L = 10\text{k}\Omega$ (unless otherwise noted)

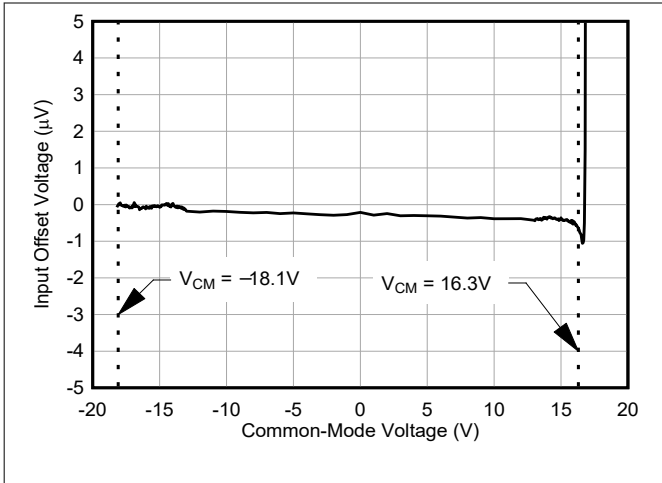


Figure 5-7. Offset Voltage vs Common-Mode Voltage

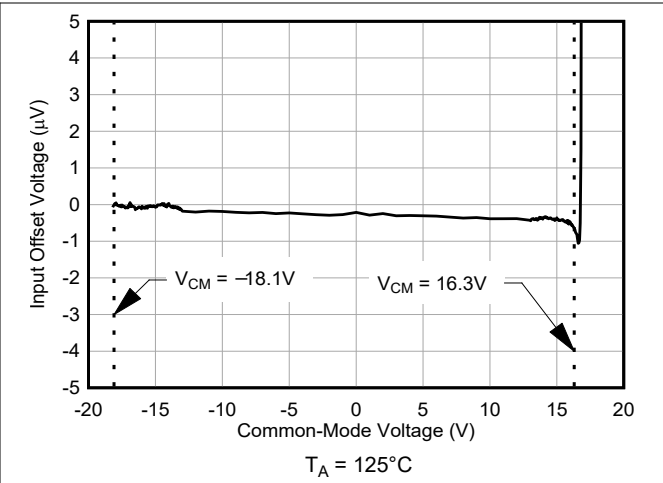


Figure 5-8. Offset Voltage vs Common-Mode Voltage

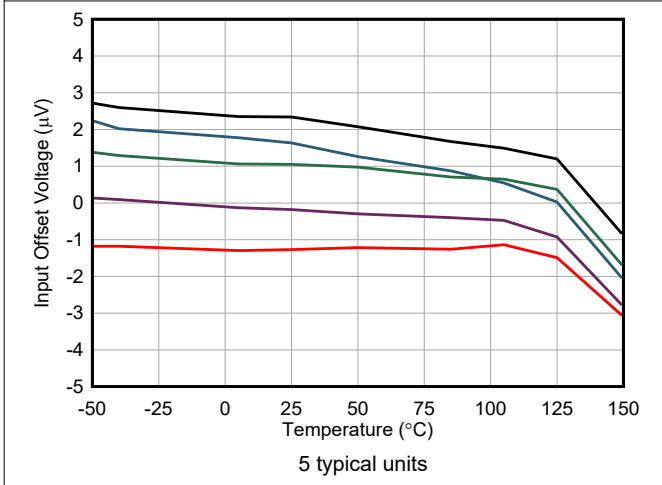


Figure 5-9. Offset Voltage vs Temperature

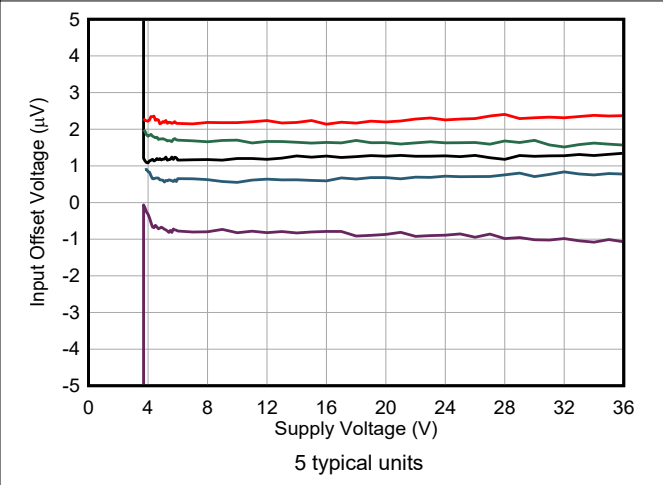


Figure 5-10. Offset Voltage vs Supply Voltage

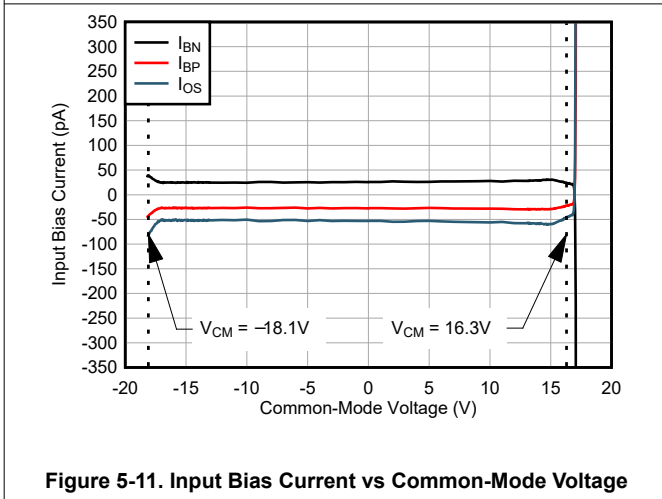


Figure 5-11. Input Bias Current vs Common-Mode Voltage

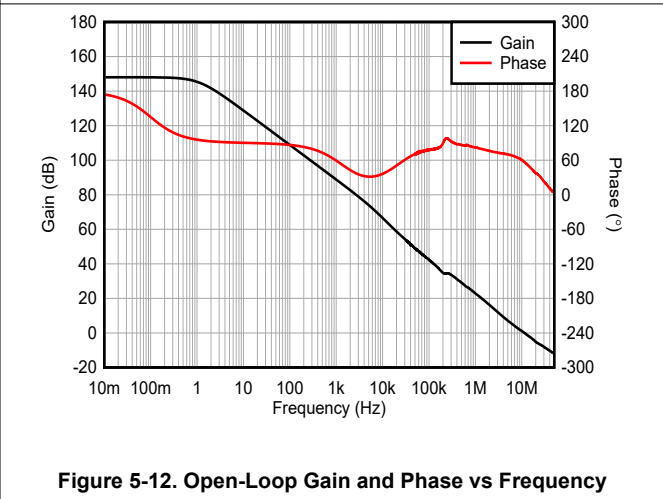


Figure 5-12. Open-Loop Gain and Phase vs Frequency

5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{V}$, $V_{CM} = V_S / 2$, and $R_L = 10\text{k}\Omega$ (unless otherwise noted)

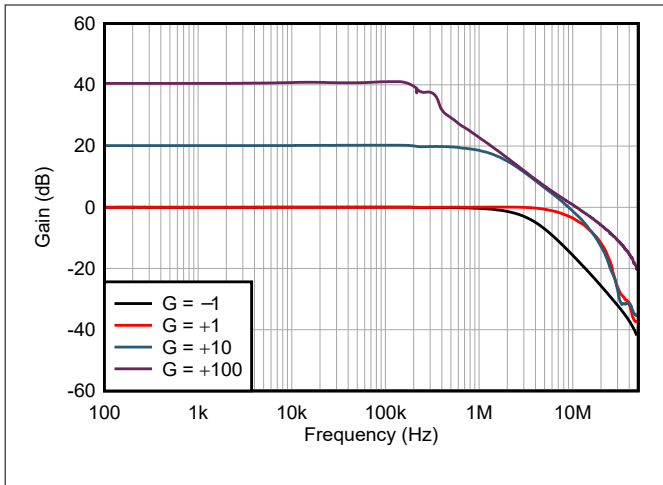


Figure 5-13. Closed-Loop Gain vs Frequency

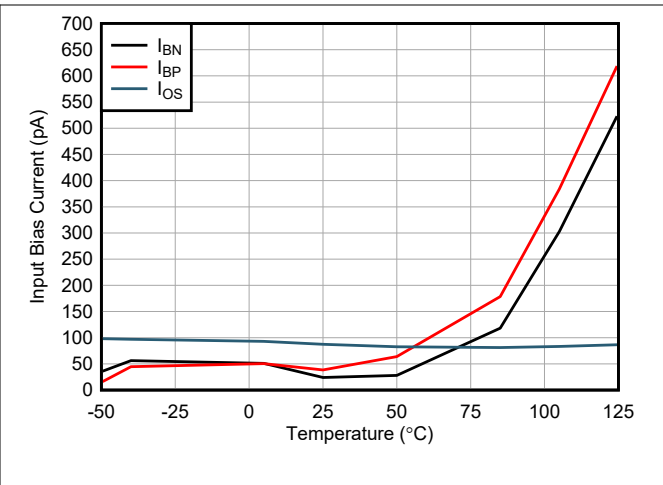


Figure 5-14. Input Bias Current and Offset Current vs Temperature

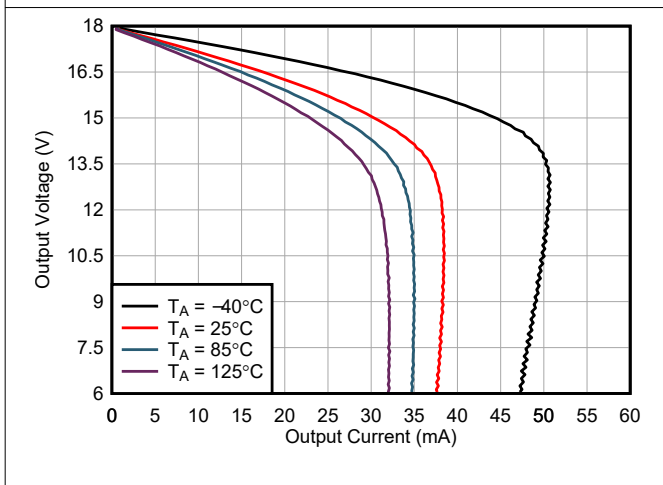


Figure 5-15. Output Voltage Swing vs Output Current (Sourcing)

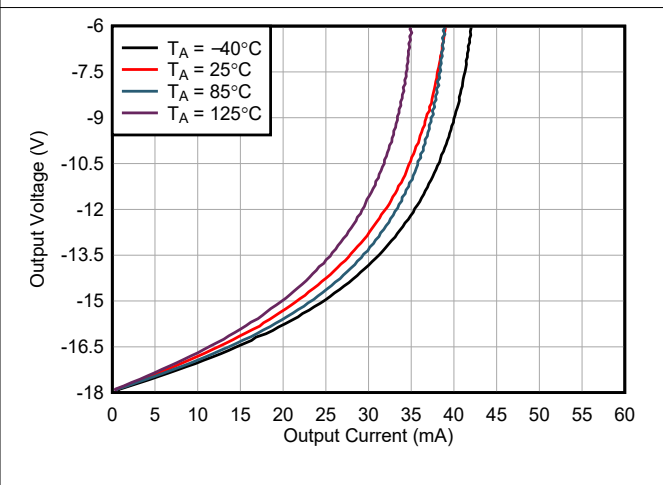


Figure 5-16. Output Voltage Swing vs Output Current (Sinking)

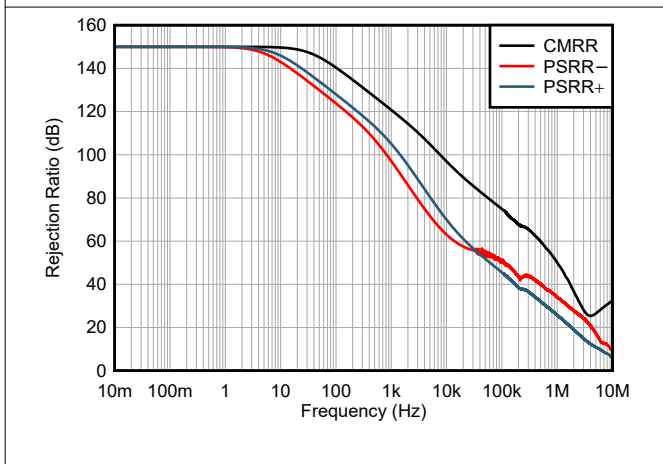


Figure 5-17. CMRR and PSRR vs Frequency

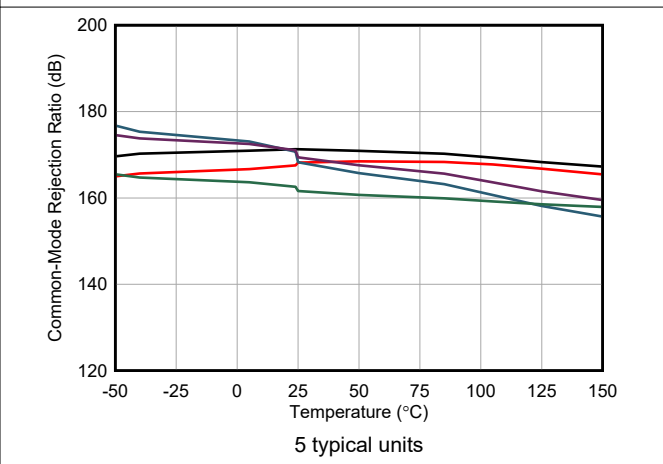
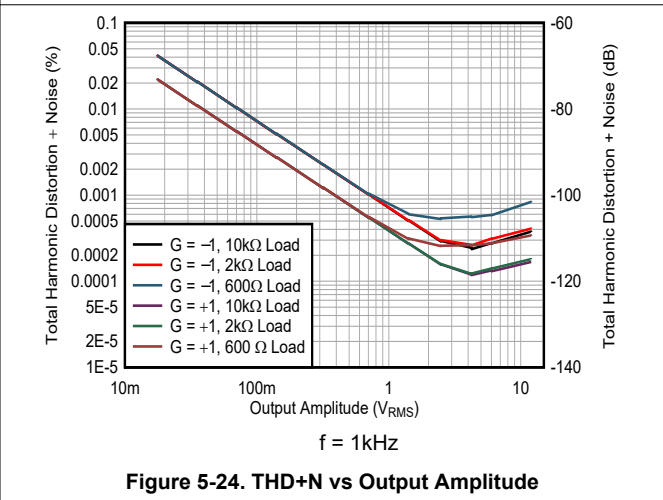
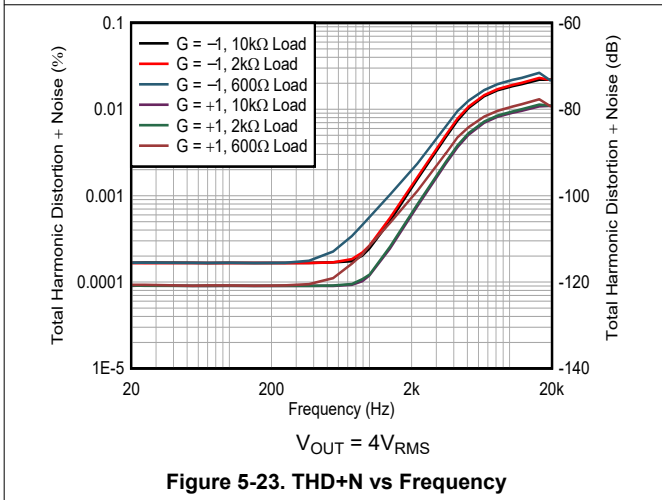
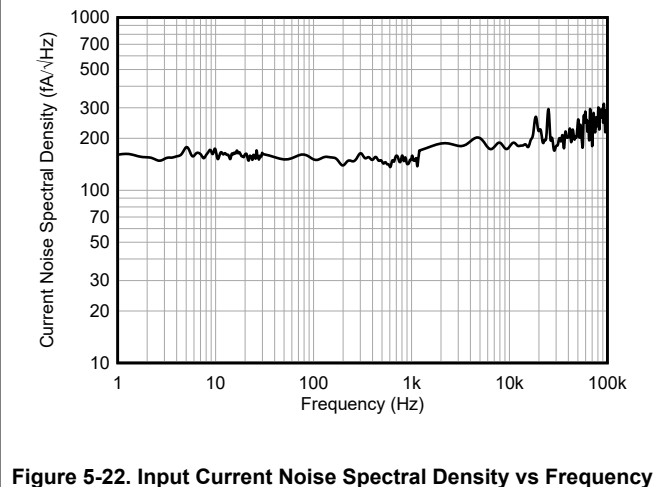
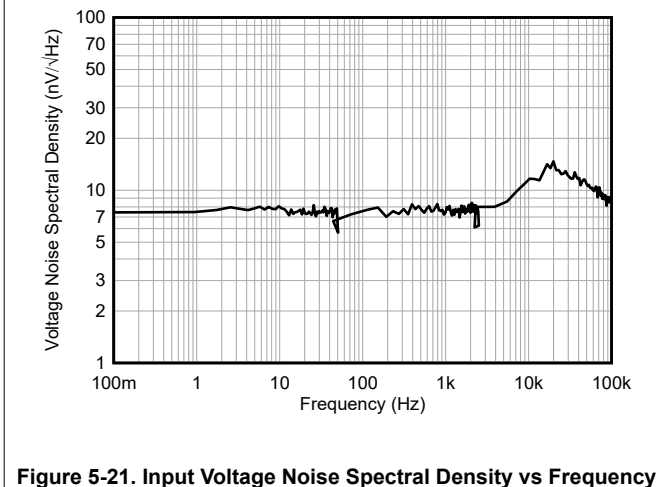
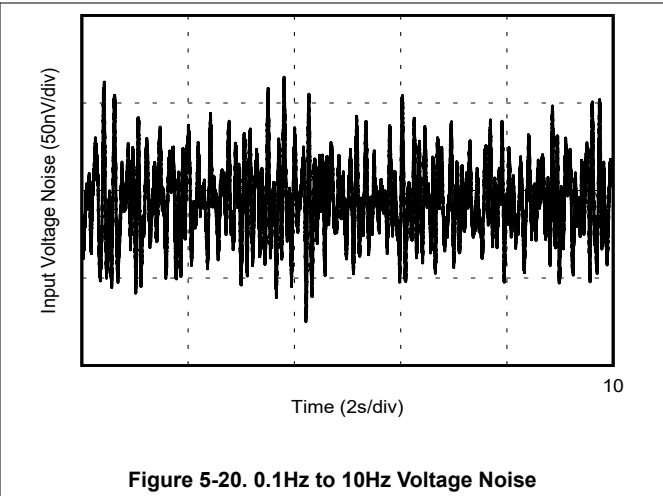
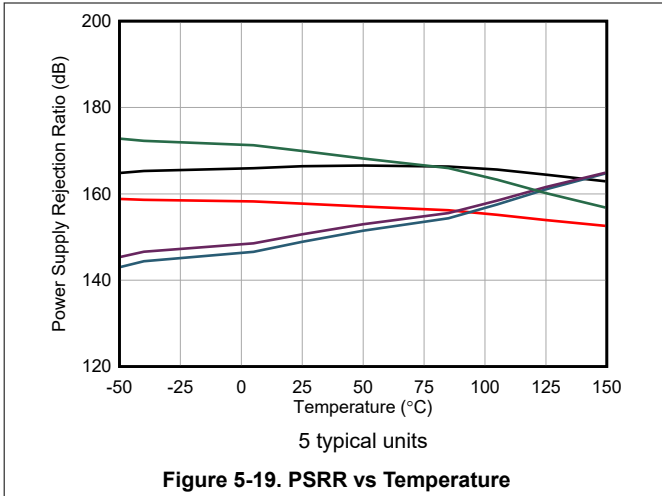


Figure 5-18. CMRR vs Temperature
5 typical units

5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{V}$, $V_{CM} = V_S / 2$, and $R_L = 10\text{k}\Omega$ (unless otherwise noted)



5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{V}$, $V_{CM} = V_S / 2$, and $R_L = 10\text{k}\Omega$ (unless otherwise noted)

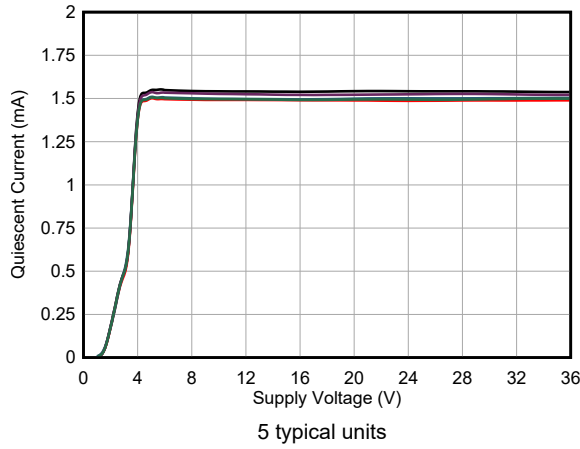


Figure 5-25. Quiescent Current vs Supply Voltage

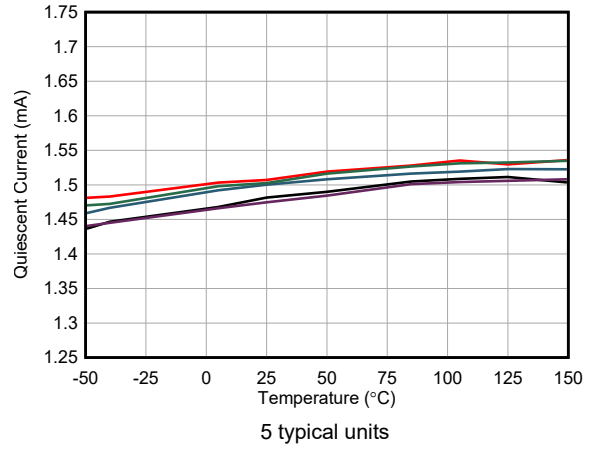


Figure 5-26. Quiescent Current vs Temperature

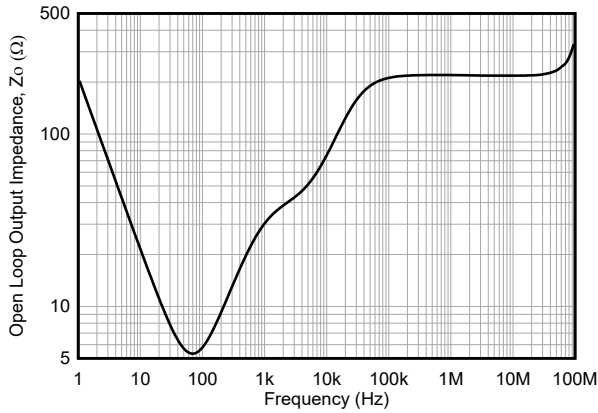


Figure 5-27. Open-Loop Output Impedance vs Frequency

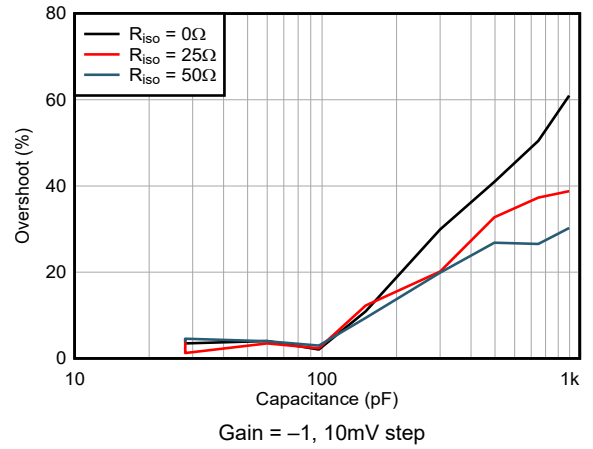


Figure 5-28. Small-Signal Overshoot vs Capacitive Load

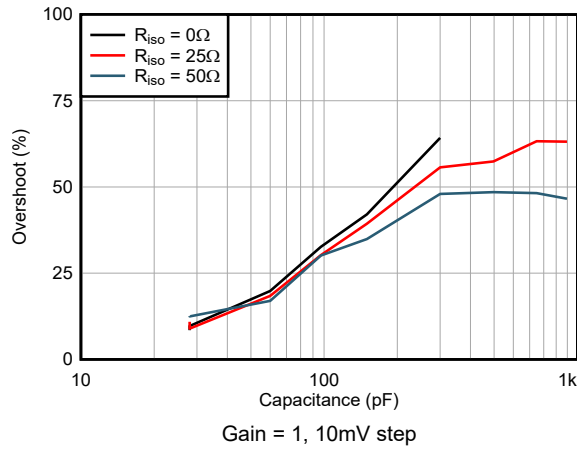


Figure 5-29. Small-Signal Overshoot vs Capacitive Load

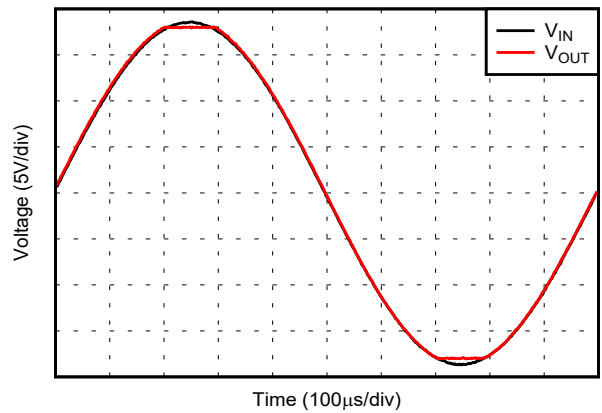


Figure 5-30. No Phase Reversal

5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{V}$, $V_{CM} = V_S / 2$, and $R_L = 10\text{k}\Omega$ (unless otherwise noted)

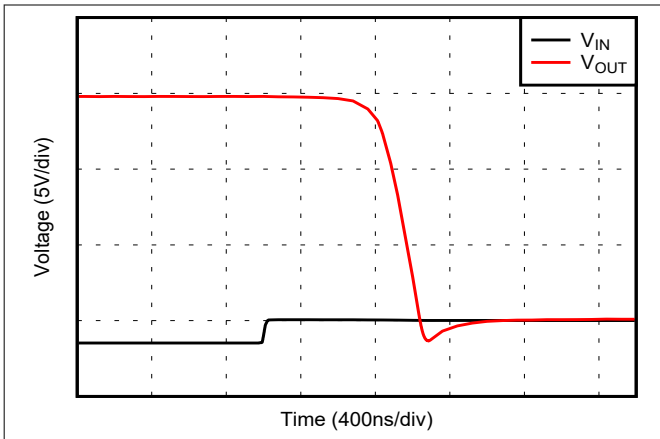


Figure 5-31. Positive Overload Recovery

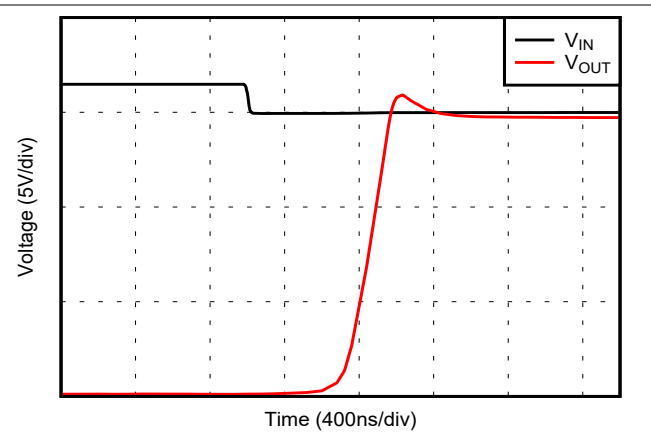


Figure 5-32. Negative Overload Recovery

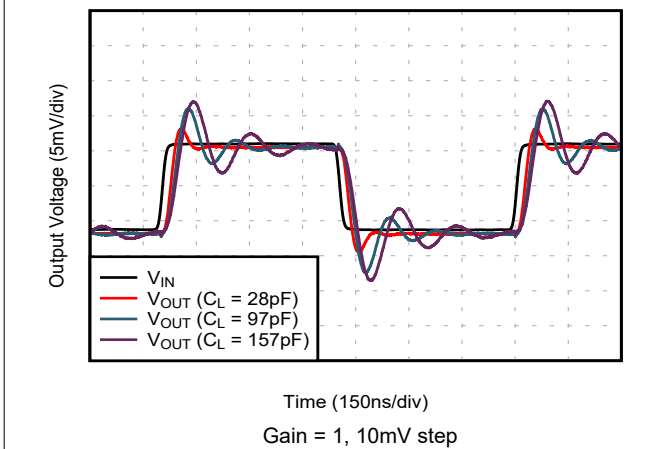


Figure 5-33. Small-Signal Step Response

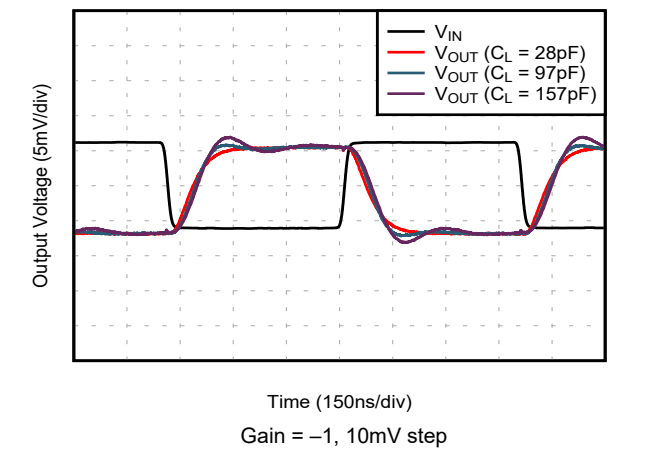


Figure 5-34. Small-Signal Step Response

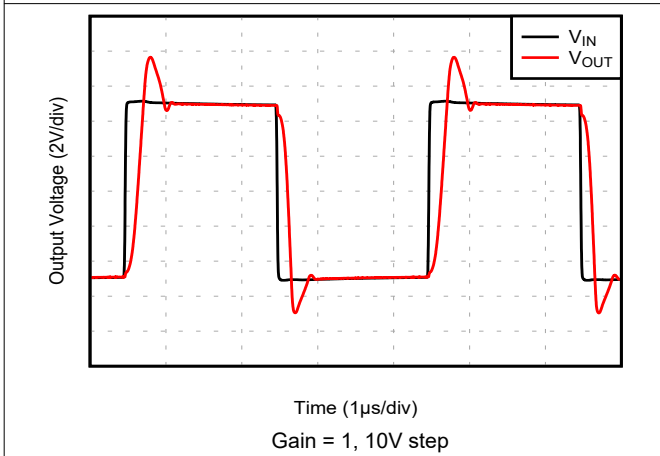


Figure 5-35. Large-Signal Step Response

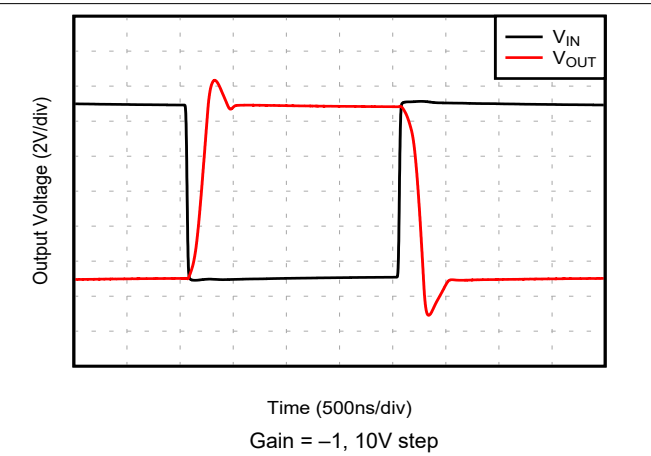


Figure 5-36. Large-Signal Step Response

5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{V}$, $V_{CM} = V_S / 2$, and $R_L = 10\text{k}\Omega$ (unless otherwise noted)

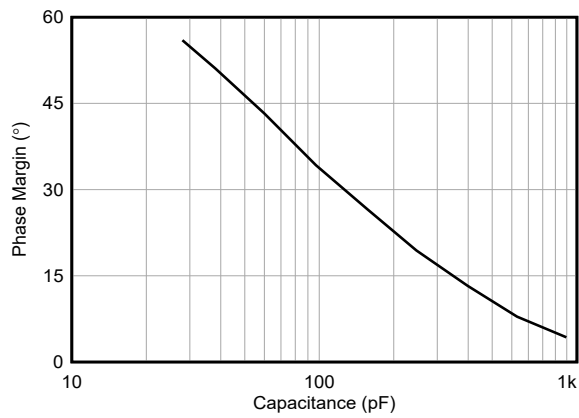


Figure 5-37. Phase Margin vs Capacitive Load

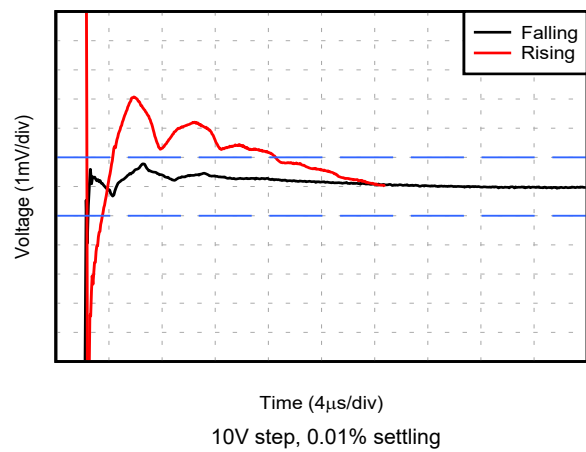


Figure 5-38. Settling Time

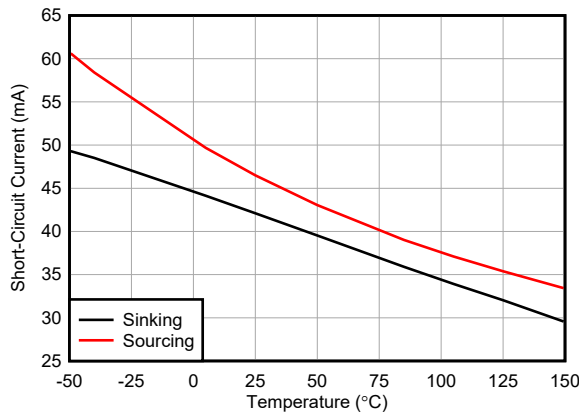


Figure 5-39. Short Circuit Current vs Temperature

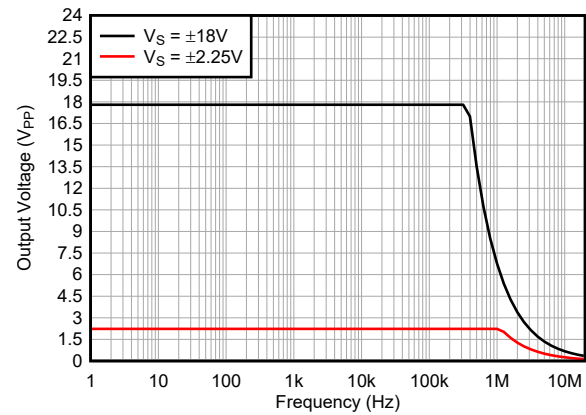


Figure 5-40. Maximum Output Voltage vs Frequency

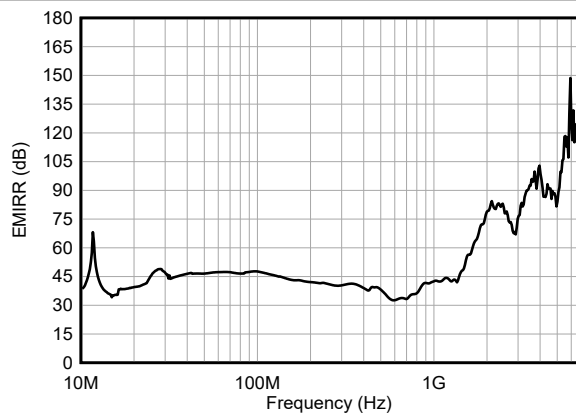


Figure 5-41. EMIRR vs Frequency

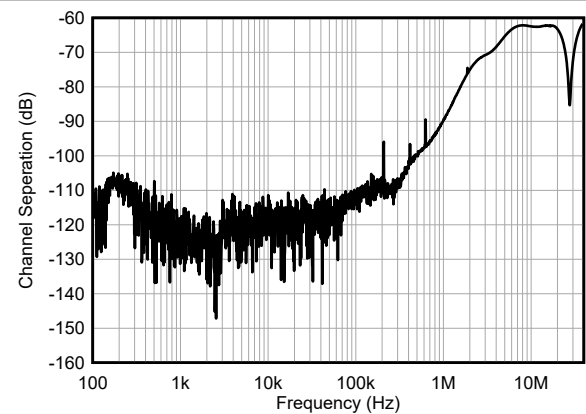


Figure 5-42. Channel Separation

6 Detailed Description

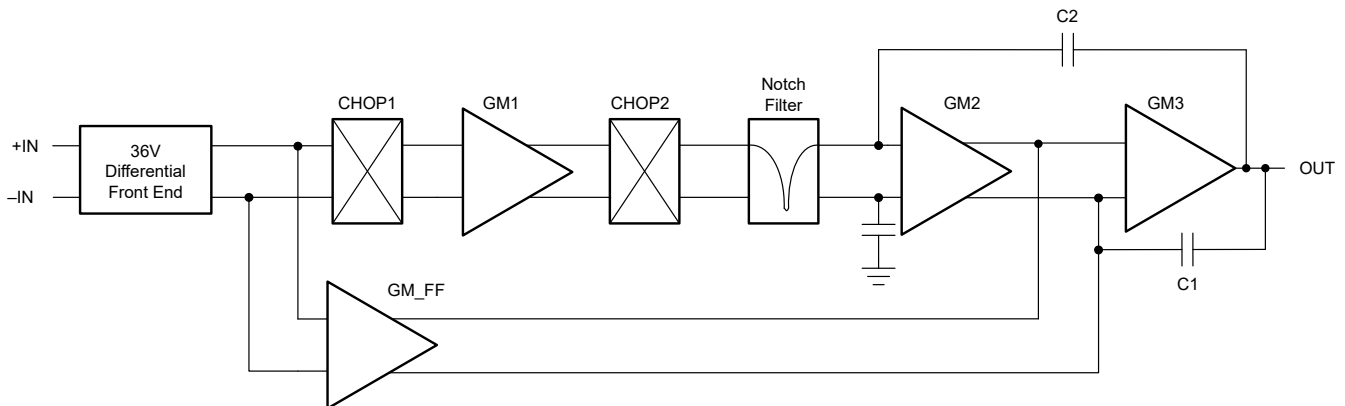
6.1 Overview

The TLVx888 operational amplifiers combine precision offset and drift with excellent overall performance, making the device a great choice for a wide variety of precision applications. The precision offset drift of only $0.01\mu\text{V}/^\circ\text{C}$ provides stability over the entire operating temperature range of -40°C to $+125^\circ\text{C}$. In addition, this device offers excellent linear performance with high CMRR, PSRR, and A_{OL} . As with all amplifiers, applications with noisy or high-impedance power supplies require decoupling capacitors close to the device pins. In most cases, $0.1\mu\text{F}$ capacitors are adequate. For details and a layout example, see [Section 7.4](#).

The TLVx888 is part of a family of zero-drift, MUX-friendly operational amplifiers. This device operates from 4.5V to 36V, is unity-gain stable, and is designed for a wide range of general-purpose and precision applications. The zero-drift architecture provides ultra-low input offset voltage and near-zero input offset voltage drift over temperature and time. This choice of architecture also offers outstanding ac performance, such as ultra-low broadband noise, zero flicker noise, and outstanding distortion performance when operating at less than the chopper frequency.

The following section shows a representation of the proprietary TLVx888 architecture.

6.2 Functional Block Diagram



6.3 Feature Description

The TLVx888 operational amplifiers use a proprietary, periodic autocalibration technique to provide extremely low input offset voltage and input offset voltage drift over time and temperature. The devices have several integrated features to help maintain a high level of precision through a variety of applications. These include a phase-reversal protection, EMI rejection, electrical overstress protection, and MUX-friendly inputs.

Several design techniques and considerations to maintain the specified performance of the TLVx888 are detailed in the [Optimizing Chopper Amplifier Accuracy](#) and [Op Amp Offset Voltage and Bias Current Limitations](#) application notes.

6.3.1 Input Common-Mode Range

The TLVx888 are specified for operation from 4.5V to 36V ($\pm 2.25\text{V}$ to $\pm 18\text{V}$). The TLVx888 provide a wide input common-mode voltage (V_{CM}) range that includes the negative rail making them an excellent choice for single supply operation. The input common-mode voltage to the positive rail is limited to $(V+) - 1.7\text{V}$. Limit the input common mode voltage to $(V-) - 0.1\text{V} \leq V_{CM} \leq (V+) - 1.7\text{V}$ to maintain specified performance.

6.3.2 Phase-Reversal Protection

The TLVx888 have internal phase-reversal protection. Some op amps exhibit a phase reversal when the input is driven beyond the linear common-mode range. This condition is most often encountered in noninverting circuits when the input is driven beyond the specified common-mode voltage range, causing the output to reverse into the opposite rail. The TLVx888 input prevents phase reversal with excessive common-mode voltage. Instead, the output limits into the appropriate rail. [Figure 6-1](#) shows this performance.

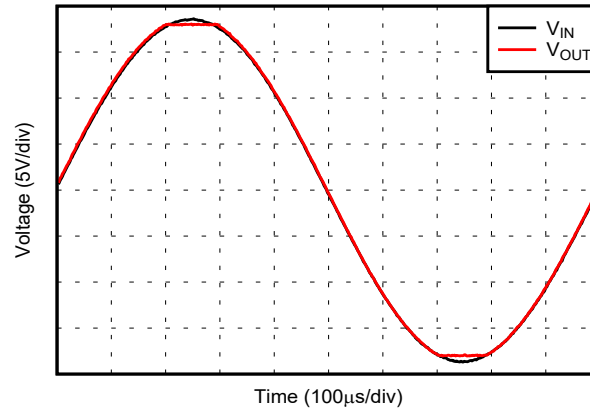


Figure 6-1. No Phase Reversal

6.3.3 Chopping Transients

Zero-drift amplifiers such as the TLVx888 use a switching architecture on the inputs to correct for the intrinsic offset and drift of the amplifier. Charge injection from the integrated switches on the inputs can introduce short transients in the input bias current of the amplifier. The extremely short duration of these pulses prevents the pulses from amplifying; however, the pulses can be coupled to the output of the amplifier through the feedback network. Use low value resistors to minimize the input transient effects at the output of the amplifier. Use a low-pass filter, such as an RC network, to minimize any additional noise attributed to the transients. The chopping frequency of the TLVx888 is typically 200kHz.

6.3.4 EMI Rejection

The TLVx888 uses integrated electromagnetic interference (EMI) filtering to reduce the effects of EMI interference from sources such as wireless communications and densely-populated boards with a mix of analog signal chain and digital components. EMI immunity can be improved with circuit design techniques; the TLVx888 benefits from these design improvements.

High-frequency signals conducted or radiated to any pin of the operational amplifier can result in adverse effects, as there is insufficient amplifier loop gain to correct for signals with spectral content outside the bandwidth. Conducted or radiated EMI on inputs, power supply, or output can result in unexpected dc offsets, transient voltages, or other unknown behavior. Take care to properly shield and isolate sensitive analog nodes from noisy radio signals and digital clocks and interfaces.

6.3.5 Electrical Overstress

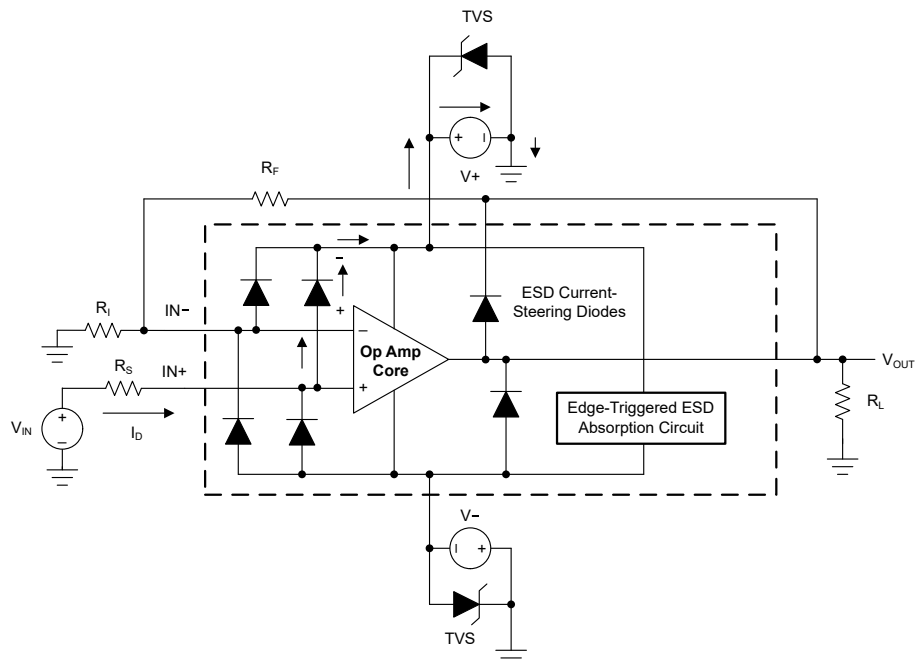
Designers often ask questions about the capability of an operational amplifier to withstand electrical overstress. These questions tend to focus on the device inputs, but can involve the supply voltage pins or even the output pin. Each of these different pin functions have electrical stress limits determined by the voltage breakdown characteristics of the particular semiconductor fabrication process and specific circuits connected to the pin. Additionally, internal electrostatic discharge (ESD) protection is built into these circuits to protect from accidental ESD events both before and during product assembly.

A good understanding of this basic ESD circuitry and the relevance to an electrical overstress event is helpful. Figure 6-2 shows an illustration of the ESD circuits contained in the TLVx888 (shows as the dashed line area). The ESD protection circuitry involves several current-steering diodes connected from the input and output pins and routed back to the internal power-supply lines, where the diodes meet at an absorption device internal to the op amp. This protection circuitry is intended to remain inactive during normal circuit operation.

An ESD event produces a short-duration, high-voltage pulse that is transformed into a short-duration, high-current pulse while discharging through a semiconductor device. The ESD protection circuits are designed to provide a current path around the operational amplifier core to prevent damage. The energy absorbed by the protection circuitry is then dissipated as heat.

When an ESD voltage develops across two or more amplifier device pins, current flows through one or more steering diodes. Depending on the path that the current takes, the absorption device can activate. The absorption device has a trigger or threshold voltage that is greater than the normal operating voltage of the TLVx888, but less than the device breakdown voltage level. When this threshold is exceeded, the absorption device quickly activates and clamps the voltage across the supply rails to a safe level.

Figure 6-2 shows that when the operational amplifier connects into a circuit, the ESD protection components are intended to remain inactive, and do not become involved in the application circuit operation. However, circumstances can arise where an applied voltage exceeds the operating voltage range of a given pin. If this condition occurs, there is a risk that some internal ESD protection circuits are biased on and conduct current. Any such current flow occurs through steering-diode paths and rarely involves the absorption device.



Notes: $V_{IN} = (V+) + 500\text{mV}$.

TVS: $V+ < V_{TVSBR(\text{min})} < 40\text{V}$, where $V_{TVSBR(\text{min})}$ is the minimum specified value for the TVS breakdown voltage.

Suggested value for R_S is approximately $5\text{k}\Omega$ in an overvoltage condition.

Figure 6-2. Equivalent Internal ESD Circuitry Relative to a Typical Circuit Application

Figure 6-2 shows a specific example where the input voltage (V_{IN}) exceeds the positive supply voltage ($V+$) by 500mV or more. Much of what happens in the circuit depends on the supply characteristics. If $V+$ can sink the current, one of the upper input steering diodes conducts and directs current to $+V_S$. Excessively high current levels can flow with increasingly higher V_{IN} . As a result, the data sheet specifications recommend that applications limit the input current to 10mA.

If the supply is not capable of sinking the current, V_{IN} can begin sourcing current to the operational amplifier, and then take over as the source of positive supply voltage. The danger in this case is that the voltage can rise to levels that exceed the operational amplifier absolute maximum ratings.

Another common question involves what happens to the amplifier if an input signal is applied to the input while the power supplies $V+$ or $V-$ are at 0V. Again, this question depends on the supply characteristic while at 0V, or at a level below the input signal amplitude. If the supplies appear as high impedance, then the operational amplifier supply current can be supplied by the input source through the current-steering diodes. This state is not a normal biasing condition for the amplifier and can result in specification degradation or abnormal operation. If the supplies are low impedance, then the current through the steering diodes can become quite high. The current level depends on the ability of the input source to deliver current, and any resistance in the input path.

If there is any uncertainty about the ability of the supply to absorb this current, add external transient voltage suppressor (TVS) diodes to the supply pins; see also Figure 6-2. The breakdown voltage must be selected such that the diode does not turn on during normal operation. However, the breakdown voltage must be low enough so that the TVS diode conducts if the supply pin begins to rise above the safe operating supply voltage level.

6.3.6 MUX-Friendly Inputs

The TLVx888 features a proprietary input stage design that allows an input differential voltage to be applied while maintaining high input impedance. Typically, high-voltage CMOS or bipolar-junction input amplifiers feature antiparallel diodes that protect input transistors from large V_{GS} voltages that can exceed the semiconductor process maximum and permanently damage the device. Large V_{GS} voltages can be forced when applying a large input step, switching between channels, or attempting to use the amplifier as a comparator.

The TLVx888 solves these problems with a switched-input technique that prevents large input bias currents when large differential voltages are applied. This input architecture addresses many issues seen in switched or multiplexed applications, where large disruptions to RC filtering networks are caused by fast switching between large potentials. Figure 6-3 shows a typical application where MUX-Friendly inputs can improve settling time performance. The TLVx888 offers outstanding settling performance as a result of these design innovations and built-in slew-rate boost and wide bandwidth. The TLVx888 can also be used as a comparator. Differential and common-mode input ranges still apply.

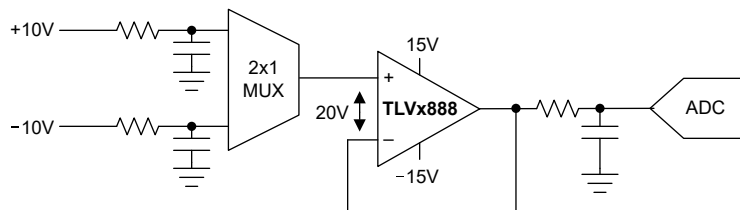


Figure 6-3. Multiplexed Application

6.4 Device Functional Modes

The TLVx888 has a single functional mode, and is operational when the power-supply voltage is greater than 4.5V ($\pm 2.25V$). The recommended power supply voltage for the TLVx888 is 36V ($\pm 18V$).

7 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, as well as validating and testing their design implementation to confirm system functionality.

7.1 Application Information

The TLVx888 operational amplifier combines precision offset and drift with excellent overall performance, making the device an excellent choice for many precision applications. The precision offset drift of only $0.01\mu\text{V}/^\circ\text{C}$ provides stability over the entire temperature range. In addition, the device pairs excellent CMRR, PSRR, and A_{OL} dc performance with outstanding low-noise operation. As with all amplifiers, applications with noisy or high-impedance power supplies require decoupling capacitors close to the device pins. In most cases, $0.1\mu\text{F}$ capacitors are adequate.

7.1.1 Basic Noise Calculations

Low-noise circuit design requires careful analysis of all noise sources. In many cases, external noise sources can dominate; consider the effect of source resistance on overall op-amp noise performance. Total noise of the circuit is the root-sum-square combination of all noise components.

The resistive portion of the source impedance produces thermal noise proportional to the square root of the resistance. The source impedance is usually fixed; consequently, select op amp and the feedback resistors that minimize the respective contributions to the total noise.

[Figure 7-1](#) shows the noninverting op-amp circuit configurations with gain. [Figure 7-2](#) shows the inverting op-amp circuit configurations with gain. In circuit configurations with gain, the feedback network resistors also contribute noise. In general, the current noise of the op amp reacts with the feedback resistors to create additional noise components. However, the low current noise of the TLVx888 means that the current noise contribution can be ignored.

The feedback resistor values can generally be chosen to make these noise sources negligible. Low impedance feedback resistors load the output of the amplifier. The equations for total noise are shown for both configurations.

For additional resources on noise calculations, visit [TI Precision Labs](#).

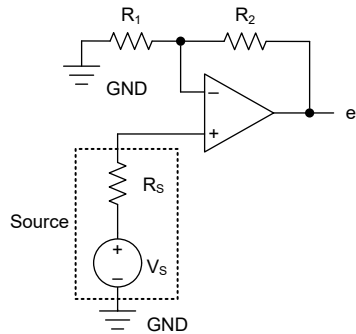


Figure 7-1. Noise Calculation in Noninverting Gain Configurations

$$E_o = e_o \sqrt{BW_N} [V_{RMS}] \quad (1)$$

$$e_o = \left(1 + \frac{R_2}{R_1}\right) \sqrt{e_s^2 + e_n^2 + (e_{R_1 \parallel R_2})^2 + (i_n R_s)^2 + \left(i_n \frac{R_1 R_2}{R_1 + R_2}\right)^2} \left[\frac{V}{\sqrt{Hz}}\right] \quad (2)$$

$$e_s = \sqrt{4k_B T(K) R_s} \left[\frac{V}{\sqrt{Hz}}\right] \quad (3)$$

$$e_{R_1 \parallel R_2} = \sqrt{4k_B T(K) \left(\frac{R_1 R_2}{R_1 + R_2}\right)} \left[\frac{V}{\sqrt{Hz}}\right] \quad (4)$$

$$k_B = 1.38065 \times 10^{-23} \left[\frac{J}{K}\right] \quad (5)$$

$$T(K) = 2.37.15 + T(^{\circ}C) [K] \quad (6)$$

where

- e_n is the voltage noise spectral density of the amplifier. For the TLVx888, $e_n = 7.5nV/\sqrt{Hz}$ at 1kHz)
- e_o is the total noise density
- e_s is the thermal noise of R_s
- $e_{R_1 \parallel R_2}$ is the thermal noise of $R_1 \parallel R_2$
- k_B is the Boltzmann constant
- $T(K)$ is the temperature in kelvins

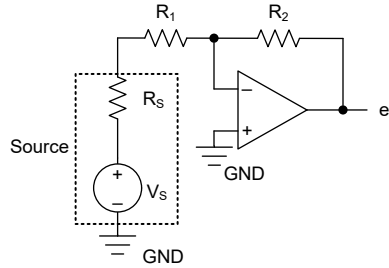


Figure 7-2. Noise Calculation in Inverting Gain Configurations

$$E_o = e_o \sqrt{BW_N} \text{ [VRMS]} \quad (7)$$

$$e_o = \left(1 + \frac{R_2}{R_S + R_1} \right) \sqrt{e_n^2 + (e_{R_1 + R_S} \parallel R_2)^2 + \left(i_n \frac{(R_S + R_1)R_2}{R_S + R_1 + R_2} \right)^2} \left[\frac{V}{\sqrt{\text{Hz}}} \right] \quad (8)$$

$$e_{R_1 + R_S} \parallel R_2 = \sqrt{4k_B T(K) \left(\frac{(R_S + R_1)R_2}{R_S + R_1 + R_2} \right)} \left[\frac{V}{\sqrt{\text{Hz}}} \right] \quad (9)$$

$$k_B = 1.38065 \times 10^{-23} \left[\frac{J}{K} \right] \quad (10)$$

$$T(K) = 2.37.15 + T(^{\circ}\text{C}) \text{ [K]} \quad (11)$$

where

- See
- e_n is the voltage noise spectral density of the amplifier. For the TLVx888, $e_n = 7.5\text{nV}/\sqrt{\text{Hz}}$ at 1kHz)
- e_o is the total noise density
- e_s is the thermal noise of R_S
- $e_{(R_1 + R_S) \parallel R_2}$ is the thermal noise of $(R_1 + R_S) \parallel R_2$
- k_B is the Boltzmann constant
- $T(K)$ is the temperature in kelvins

7.2 Typical Applications

7.2.1 High-Side Current Sensing

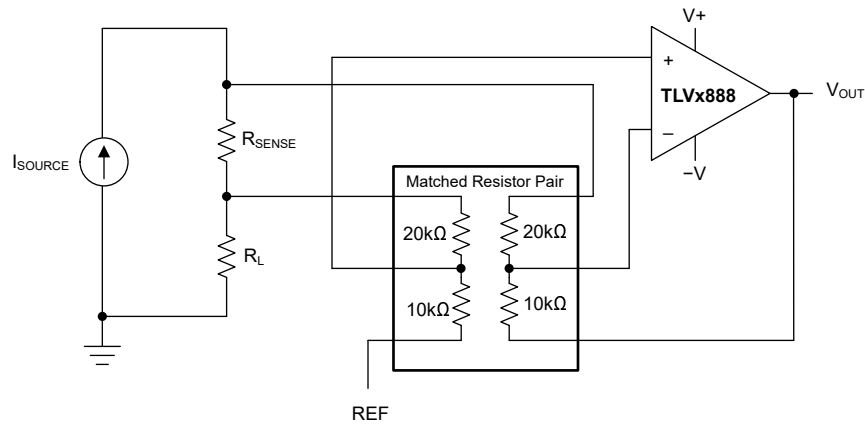


Figure 7-3. High-Side Current Monitor

7.2.1.1 Design Requirements

A common systems requirement is to monitor the current being delivered to a load. Monitoring confirms that normal current levels are being maintained, and also provides an alert if an overcurrent condition occurs.

Fortunately, a relatively simple current monitor circuit can be achieved using a precision op amp, such as the TLVx888. This device has exceptional precision and wide gain bandwidth product to accommodate for very high gain configurations.

The TLVx888 is configured as a difference amplifier with a predetermined gain. The difference amplifier inputs are connected across a sense resistor through which the load current flows. The sense resistor can be connected to the high side or low side of the circuit through which the load current flows. Commonly, high-side current sensing is applied. [Figure 7-3](#) shows an applicable TLVx888 configuration. Low-side current sensing can be applied as well if the sense resistor can be placed between the load and ground.

Use the following parameters for this design example:

- Dual supply: $\pm 15\text{V}$
- Linear output voltage range: 0V to 5V
- Load current, I_L : 1mA to 100mA

The following design details and equations can be used to reconfigure this design for different output voltage ranges and current loads.

7.2.1.2 Detailed Design Procedure

Designing a high-side current monitor circuit is straightforward, provided that the amplifier electrical characteristics are carefully considered so that linear operation is maintained. Other additional characteristics, such as the input voltage range of the analog to digital converter (ADC) that follows the current monitor stage, must also be considered when configuring the system.

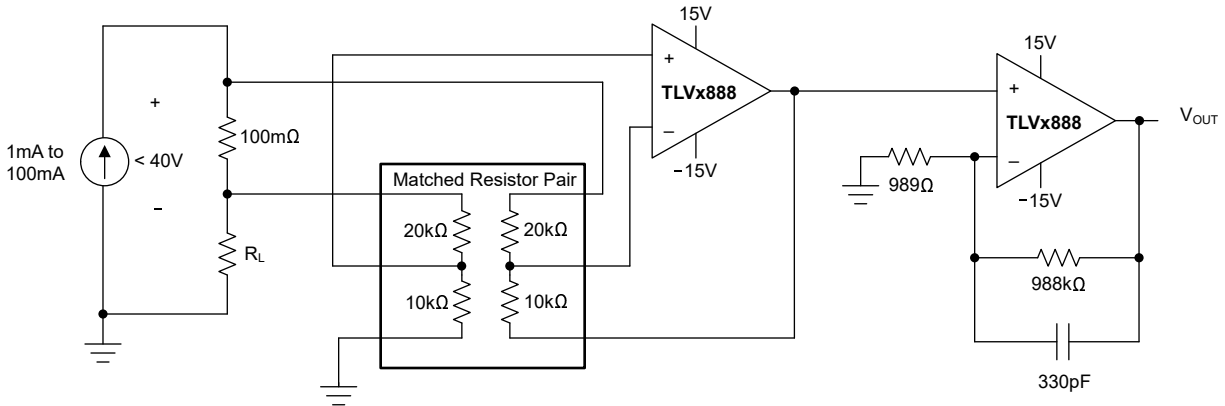


Figure 7-4. High Side Current Sense With Gain Stage

For example, consider the design of a TLVx888 high-side current monitor with an output voltage range set to be compatible with the input of an ADC with a full-scale input range of 0V to 5V. Although the TLVx888 is specified as a rail-to-rail output amplifier, the linear output operating range (like all amplifiers) does not quite extend all the way to the supply rails. This linear operating range must be considered.

In this design example, the TLVx888 is powered by $\pm 15\text{V}$; therefore, the device is easily capable of providing the 0V to 5V swing; or even more, if the ADC has a wider input range.

The best measure of an op-amp linear output voltage range comes from the open-loop voltage gain (A_{OL}) specification listed in the *Electrical Characteristics* table. The A_{OL} test conditions specify a linear swing range from 600mV from each supply rail ($R_L = 10\text{k}\Omega$).

A nominal load current (I_L) of 100mA is used in this example. In most applications, however, the ability to monitor current levels far less than 100mA is useful.

Selection of current sense resistor R_S comes down to how much voltage drop can be tolerated at maximum current and the permissible power loss or dissipation. A good compromise for a 100mA sense application is an R_S of 100m Ω . That value results in a power dissipation of 1mW, and a 10mV drop at 100mA.

Next, determine the gain of the TLVx888 difference amplifier circuit. The maximum current of 100mA flowing through a 100m Ω sense resistor results in 100mV across the resistor. The gain of the difference amplifier is limited by the required input common-mode voltage. A gain of 1/2, for example, provides a 1/3 attenuation of the high side voltage seen by the circuit. The attenuation is enough to keep the input common-mode within the range of the TLVx888, $(V^+) - 1.7\text{V}$.

The differential voltage that is applied across the TLVx888 difference amplifier circuit inputs is attenuated by the difference amplifier and a gain stage is needed for proper scaling. Conveniently, the second channel of the TLV2888 can be used. The ultra-low offset and wide-bandwidth enable very high gain configurations. In this example, a gain of 1000V/V provides the necessary scaling for a 0V to 5V output.

The TLVx888 output voltage is intentionally limited to 5V. However, because of the $\pm 15\text{V}$ supply, the output voltage can be much higher to allow for a higher voltage data converter with a wider dynamic range.

The TLVx888 output, as well as other CMOS output amplifiers, often swing closer to 0V (in single supply configurations) than the linear output parameters suggest. The voltage output swing, V_O (see the *Electrical Characteristics* table), is not an indication of the linear output range, but rather how close the output can move towards the supply rail. In that region, the amplifier output approaches saturation, and the amplifier ceases to

operate linearly. Thus, in the current-monitor application, the current-measurement capability can continue to much less than the 600mV output level. However, keep in mind that the linearity errors are becoming large.

Lastly, some notes about maximizing the high-side current monitor performance:

1. All resistor values are critical for accurate gain results. Match resistor pairs of [R1 and R3] and [R2 and R4] as closely as possible to minimize common-mode mismatch error. Use a 0.1% tolerance, or better. Often, selecting two adjacent resistors on a reel provides close matching compared to random selection. The *RES21A* provides an even more elegant circuit design with better performance than discrete 0.1% resistors.
2. Keep the closed-loop gain, G , of the difference amplifier set to a reasonable value to reduce gain error and maximize bandwidth. The high bandwidth of TLVx888 enables very high gain configurations.
3. Although current monitoring is often used for monitoring dc supply currents, ac current can also be monitored. Special attention to the -3dB cutoff frequency of the circuit is warranted.

For more information about amplifier-based, high-side current monitors, see the [TI Analog Engineer's Circuit Cookbook: Amplifiers](#).

7.2.1.3 Application Curve

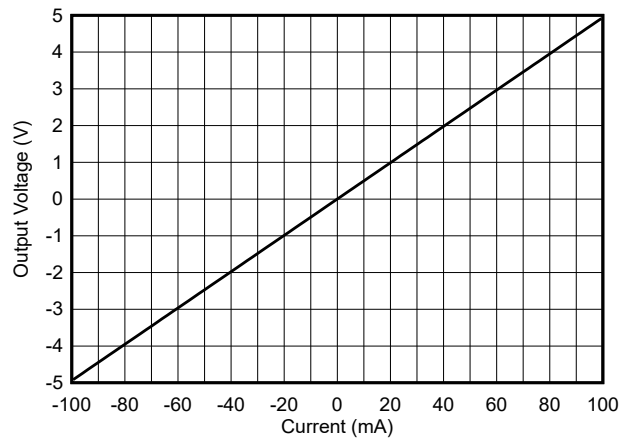


Figure 7-5. Current Sense Measurement Results

7.2.2 Programmable Current Source

Figure 7-6 shows the basic configuration for a precision current source using the TLVx888. The circuit provides a configurable current source to a floating load. Figure 7-6 uses a digital-to-analog converter (DAC) to set the current level. For example, a 5V full-scale voltage at the input of the amplifier provides a 100mA current source.

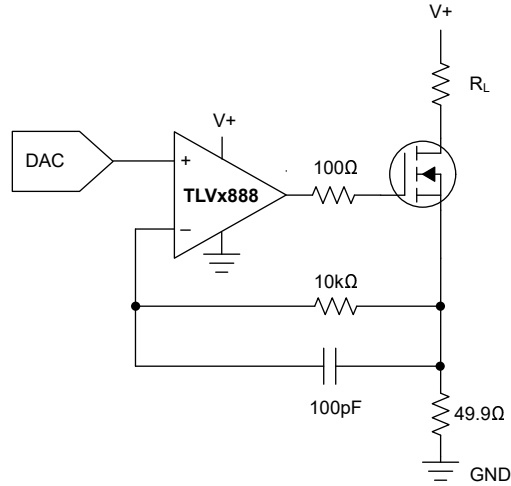


Figure 7-6. Programmable, Precision Current Source

7.2.3 Programmable Current Source For A Grounded Load

Figure 7-7 shows the TLVx888 configured as a programmable current source for a ground referenced load. To achieve single supply operation, a two stage design is employed. The first stage sets a reference current, and the second stage acts as a current mirror with gain. The TLVx888 are used to regulate the current sourced from the transistors in both stages.

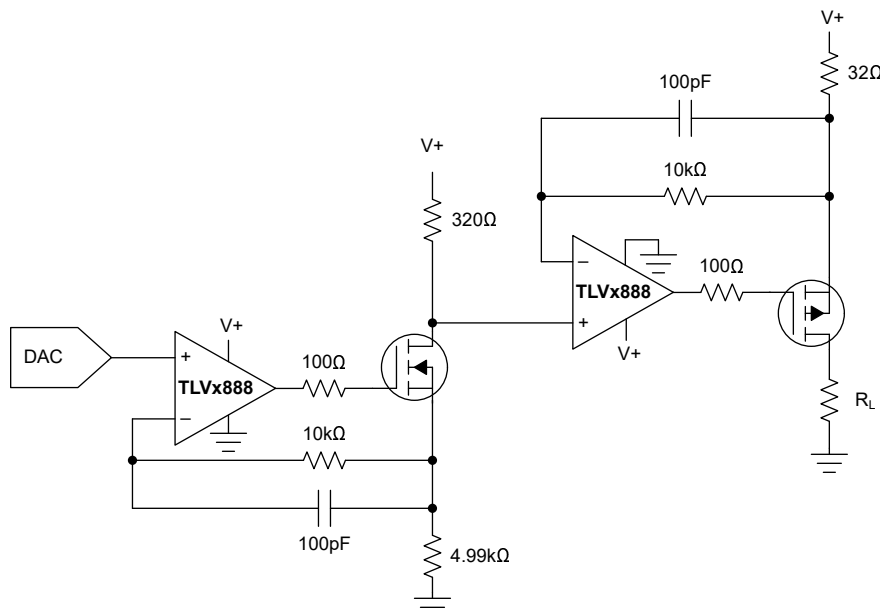


Figure 7-7. Single Supply Programmable Current Source For A Ground Referenced Load

7.3 Power Supply Recommendations

The TLVx888 are specified for operation from 4.5V to 36V ($\pm 2.25V$ to $\pm 18V$). The TLVx888 operates on both single and dual supplies. The TLVx888 do not require symmetrical supplies; the op amps only require a minimum voltage of 4.5V to operate.

CAUTION

Supply voltages larger than 40V can permanently damage the device (see the *Absolute Maximum Ratings* table).

Place 0.1 μ F bypass capacitors close to the power-supply pins to reduce errors coupling in from noisy or high-impedance power supplies. For more detailed information on bypass capacitor placement, see [Section 7.4](#).

7.4 Layout

7.4.1 Layout Guidelines

For best operational performance of the device, use good PCB layout practices:

- For the lowest offset voltage, avoid temperature gradients that create thermoelectric (Seebeck) effects in the thermocouple junctions formed from connecting dissimilar conductors. Also:
 - Use low thermoelectric-coefficient conditions (avoid dissimilar metals).
 - Thermally isolate components from power supplies or other heat sources.
 - Shield operational amplifier and input circuitry from air currents, such as cooling fans.
- Noise can propagate into analog circuitry through the power pins of the op amp and the circuit as a whole. Bypass capacitors reduce the coupled noise by providing low-impedance power sources local to the analog circuitry.
 - Connect low-ESR, 0.1 μ F ceramic bypass capacitors between each supply pin and ground, placed as close as possible to the device. A single bypass capacitor from V+ to ground is applicable for single-supply applications.
- Separate grounding for analog and digital portions of circuitry is one of the simplest and most effective methods of noise suppression. One or more layers on multilayer PCBs are usually devoted to ground planes. A ground plane helps distribute heat and reduces EMI noise pickup. Physically separate digital and analog grounds paying attention to the flow of the ground current. For more detailed information, see the [The PCB is a component of op amp design analog application journal](#).
- To reduce parasitic coupling, run the input traces as far away as possible from the supply or output traces. If these traces cannot be separated, cross the sensitive trace perpendicular as opposed to in parallel with the noisy trace.
- Place the external components as close as possible to the device. As [Figure 7-9](#) shows, keep the feedback resistor (R3) and gain resistor (R4) close to the inverting input to minimize parasitic capacitance.
- Keep the length of input traces as short as possible. Short traces to the inverting input help to minimize parasitic capacitance on the inverting input. Always remember that the input traces are the most sensitive part of the circuit.
- For best performance, clean the PCB following board assembly.
- Any precision integrated circuit can experience performance shifts due to moisture ingress into the plastic package. Following any aqueous PCB cleaning process, bake the PCB assembly to remove moisture introduced into the device packaging during the cleaning process. A low-temperature, post-cleaning bake at 85°C for 30 minutes is sufficient for most circumstances.

7.4.2 Layout Example

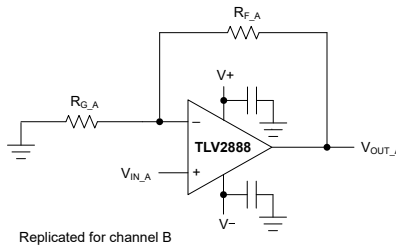


Figure 7-8. Schematic Representation

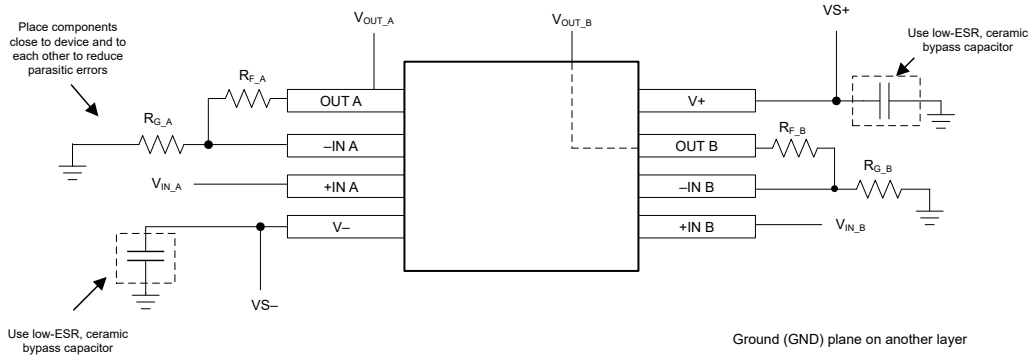


Figure 7-9. Operational Amplifier Board Layout for Noninverting Amplifier Configuration

8 Device and Documentation Support

8.1 Device Support

8.1.1 Development Support

8.1.1.1 PSpice® for TI

PSpice® for TI is a design and simulation environment that helps evaluate performance of analog circuits. Create subsystem designs and prototype solutions before committing to layout and fabrication, reducing development cost and time to market.

8.1.1.2 TINA-TI™ Simulation Software (Free Download)

TINA-TI™ simulation software is a simple, powerful, and easy-to-use circuit simulation program based on a SPICE engine. TINA-TI simulation software is a free, fully-functional version of the TINA™ software, preloaded with a library of macromodels, in addition to a range of both passive and active models. TINA-TI simulation software provides all the conventional dc, transient, and frequency domain analysis of SPICE, as well as additional design capabilities.

Available as a [free download](#) from the [Design and simulation tools](#) web page, TINA-TI simulation software offers extensive post-processing capability that allows users to format results in a variety of ways. Virtual instruments offer the ability to select input waveforms and probe circuit nodes, voltages, and waveforms, creating a dynamic quick-start tool.

Note

These files require that either the TINA software or TINA-TI software be installed. Download the free TINA-TI simulation software from the [TINA-TI™ software folder](#).

8.2 Documentation Support

8.2.1 Related Documentation

For related documentation see the following:

- Texas Instruments, [Zero-drift Amplifiers: Features and Benefits](#) application brief
- Texas Instruments, [The PCB is a component of op amp design](#) application note
- Texas Instruments, [Operational amplifier gain stability, Part 3: AC gain-error analysis](#)
- Texas Instruments, [Operational amplifier gain stability, Part 2: DC gain-error analysis](#)
- Texas Instruments, [Using infinite-gain, MFB filter topology in fully differential active filters](#) application note
- Texas Instruments, [Op Amp Performance Analysis](#)
- Texas Instruments, [Single-Supply Operation of Operational Amplifiers](#) application note
- Texas Instruments, [Shelf-Life Evaluation of Lead-Free Component Finishes](#) application note
- Texas Instruments, [Feedback Plots Define Op Amp AC Performance](#) application note
- Texas Instruments, [EMI Rejection Ratio of Operational Amplifiers](#) application note
- Texas Instruments, [Analog Linearization of Resistance Temperature Detectors](#) application note
- Texas Instruments, [TI Precision Design TIPD102 High-Side Voltage-to-Current \(V-I\) Converter](#)

8.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on [ti.com](#). Click on [Notifications](#) 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.

8.4 Support Resources

[TI E2E™ support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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8.5 Trademarks

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8.6 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.

8.7 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

9 Revision History

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

DATE	REVISION	NOTES
December 2024	*	Initial Release

10 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 Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TLV2888DR	ACTIVE	SOIC	D	8	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	TL2888	Samples

(1) The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSELETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices 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.

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D0008A

PACKAGE OUTLINE

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed $.006$ [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.

EXAMPLE BOARD LAYOUT

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X



SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

- 6. Publication IPC-7351 may have alternate designs.
- 7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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