

# INA848 Ultra-Low-Noise ( $1.5 \text{ nV}/\sqrt{\text{Hz}}$ ), High-Bandwidth Instrumentation Amplifier With Fixed Gain of 2000

## 1 Features

- Fixed gain of 2000 V/V
- Access to internal nodes for filtering
- Ultra-low noise:  $1.5 \text{ nV}/\sqrt{\text{Hz}}$  input voltage noise (maximum)
- Precision super-beta input performance:
  - Low offset voltage:  $35 \text{ } \mu\text{V}$  (maximum)
  - Low offset voltage drift:  $0.45 \text{ } \mu\text{V}/^\circ\text{C}$  (maximum)
  - Low input bias current:  $25 \text{ nA}$  (typical)
  - Low gain drift:  $5 \text{ ppm}/^\circ\text{C}$  (maximum)
- Bandwidth:  $2.8 \text{ MHz}$
- Slew rate:  $45 \text{ V}/\mu\text{s}$
- Common-mode rejection:  $132 \text{ dB}$  (minimum)
- Supply range:
  - Single supply:  $8 \text{ V}$  to  $36 \text{ V}$
  - Dual supply:  $\pm 4 \text{ V}$  to  $\pm 18 \text{ V}$
- Specified temperature range:  $-40^\circ\text{C}$  to  $+125^\circ\text{C}$
- Package: 8-pin SOIC

## 2 Applications

- [Surgical equipment](#)
- [Electrocardiogram \(ECG\)](#)
- [Ultrasound scanner](#)
- [Semiconductor test](#)
- [Data acquisition \(DAQ\)](#)
- [Vibrational analysis](#)

## 3 Description

The INA848 is a fixed-gain instrumentation amplifier optimized for high-precision measurements, such as very-small, fast, differential input signals. TI's super-beta topology provides a very low input bias current and current noise. The well-matched transistors help achieve a very low offset and offset drift. Matching of the internal resistors yields a high common-mode rejection ratio of  $132 \text{ dB}$  across the full input-voltage range, and a very low gain drift error of  $5 \text{ ppm}/^\circ\text{C}$  (max).

The current-feedback topology of the INA848 produces a wide bandwidth of  $2.8 \text{ MHz}$  at a fixed gain of 2000, thereby eliminating the need for subsequent gain stages. The very-low noise floor of  $1.3 \text{ nV}/\sqrt{\text{Hz}}$  minimizes the impact on the equivalent number of bits (ENOB) when interfacing with high-resolution analog-to-digital converters (ADCs). The INA848 provides the flexibility of adding filters between the gain stages (pins 2 and 3) to maintain an adequate signal integrity.

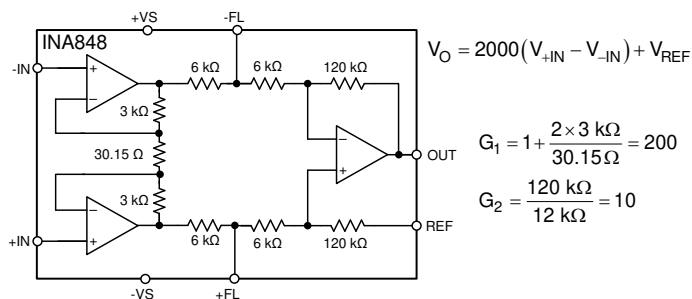
These unique features of the INA848 make this device an excellent choice for applications requiring high-precision measurements, such as high-end medical instrumentation, electroencephalography, vibration sensing, and displacement measurements.

This device is designed for  $8\text{-V}$  to  $36\text{-V}$  single supplies, or  $\pm 4\text{-V}$  to  $\pm 18\text{-V}$  on dual supplies.

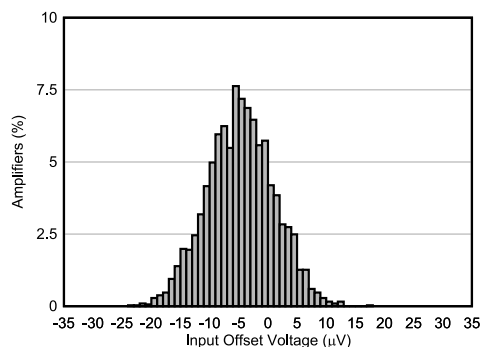
### Device Information

PART NUMBER <sup>(1)</sup>	PACKAGE	BODY SIZE (NOM)
INA848	SOIC (8)	$4.90 \text{ mm} \times 3.91 \text{ mm}$

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



**INA848 Simplified Internal Schematic**



**Typical Distribution of Input Offset Voltage**



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## 4 Revision History

DATE	REVISION	NOTES
September 2020	*	Initial release

## 5 Device Comparison Table

DEVICE	DESCRIPTION
<a href="#">INA821</a>	35- $\mu$ V $V_{OS}$ , 0.4 $\mu$ V/ $^{\circ}$ C $V_{OS}$ drift, 7-nV/ $\sqrt{\text{Hz}}$ Noise, HighBandwidth, Precision Instrumentation Amplifier
<a href="#">INA819</a>	35- $\mu$ V $V_{OS}$ , 0.4 $\mu$ V/ $^{\circ}$ C $V_{OS}$ Drift, 8-nV/ $\sqrt{\text{Hz}}$ Noise, Low-Power, Precision Instrumentation Amplifier
<a href="#">INA333</a>	25- $\mu$ V $V_{OS}$ , 0.1 $\mu$ V/ $^{\circ}$ C $V_{OS}$ drift, 1.8-V to 5-V, RRO, 50- $\mu$ A $I_Q$ , chopper-stabilized INA
<a href="#">PGA280</a>	20-mV to $\pm$ 10-V programmable gain IA with 3-V or 5-V differential output; analog supply up to $\pm$ 18 V
<a href="#">PGA112</a>	Precision programmable gain op amp with SPI

## 6 Pin Configuration and Functions

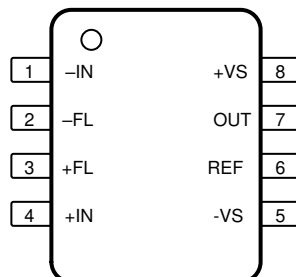


Figure 6-1. D Package, 8-Pin SOIC, Top View

### Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
-IN	1	I	Negative (inverting) input
+IN	4	I	Positive (noninverting) input
OUT	7	O	Output
-FL	2	I	Negative Filter Terminal.
+FL	3	I	Positive Filter Terminal.
REF	6	I	Reference input. This pin must be driven by a low impedance source.
-VS	5	—	Negative supply
+VS	8	—	Positive supply

## 7 Specifications

### 7.1 Absolute Maximum Ratings

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

			MIN	MAX	UNIT
$V_S$	Supply voltage	Single supply, $V_S = (+V_S)$		40	V
		Dual supply, $V_S = (+V_S) - (-V_S)$		$\pm 20$	
$V_{IN}$	Signal input pins	Common Mode <sup>(2)</sup>	$(-V_S) - 0.5$	$(+V_S) + 0.5$	V
		Differential <sup>(3)</sup>		$\pm 0.5$	
$V_{REF}$	VREF pin		$(-V_S) - 0.5$	$(+V_S) + 0.5$	V
$V_{FL}$	Filter input pins +FL, -FL		$(-V_S) - 0.5$	$(+V_S) + 0.5$	V
$V_O$	Signal output pins maximum voltage		$(-V_S) - 0.5$	$(+V_S) + 0.5$	V
$I_O$	Signal output pins maximum current		-50	50	mA
$I_S$	Output short-circuit <sup>(4)</sup>		-50	50	mA
$T_A$	Operating temperature <sup>(5)</sup>			125	°C
$T_J$	Junction temperature <sup>(5)</sup>			175	°C
$T_{stg}$	Storage temperature			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.
- (2) Input terminals are diode-clamped to the power-supply rails. Input signals that swing more than 0.5 V beyond the supply rails must be current-limited to 10 mA or less.
- (3) Input terminals are anti-parallel diode-clamped to each other. Input signals that cause differential voltages of swing more than  $\pm 0.5$  V must be current-limited to 10 mA or less.
- (4) Short-circuit to  $V_S / 2$ .
- (5) As a result of the quiescent current, a supply voltage and load-dependent self-heating of the device must be considered.

### 7.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>	$\pm 2000$	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup>	$\pm 750$	

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

### 7.3 Recommended Operating Conditions

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

			MIN	MAX	UNIT
$V_S$	Supply voltage	Single supply, $V_S = (+V_S)$	8	36	V
		Dual supply, $V_S = (+V_S) - (-V_S)$	$\pm 4$	$\pm 18$	
$T_A$	Specified temperature		-40	125	°C

## 7.4 Thermal Information

THERMAL METRIC <sup>(1)</sup>		INA848	UNIT
		D (SOIC)	
		8 PINS	
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	119.6	°C/W
R <sub>θJC(top)</sub>	Junction-to-case (top) thermal resistance	66.3	°C/W
R <sub>θJB</sub>	Junction-to-board thermal resistance	61.9	°C/W
Ψ <sub>JT</sub>	Junction-to-top characterization parameter	20.5	°C/W
Ψ <sub>JB</sub>	Junction-to-board characterization parameter	61.4	°C/W
R <sub>θJC(bot)</sub>	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.

## 7.5 Electrical Characteristics

at T<sub>A</sub> = 25°C, V<sub>S</sub> = ±15 V, R<sub>L</sub> = 10 kΩ, G = 2000 (fixed) and V<sub>REF</sub> = 0 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V <sub>OSI</sub>	Input offset voltage			±10	±35	μV
		T <sub>A</sub> = −40°C to +125°C <sup>(1)</sup>			±80	
	Input offset voltage drift	T <sub>A</sub> = −40°C to +125°C		±0.1	±0.45	μV/°C
PSRR	Power-supply rejection ratio	±4 V ≤ (V <sub>S</sub> ) ≤ ±18 V	125	150		dB
Z <sub>in</sub>	Input impedance			1    7		GΩ    pF
	RFI filter, −3-dB frequency			250		MHz
V <sub>CM</sub>	Operating input voltage <sup>(3)</sup>	V <sub>S</sub> = ±4 V to ±18 V	(−V <sub>S</sub> ) + 2.5		(+V <sub>S</sub> ) − 2.5	V
		V <sub>S</sub> = ±4 V to ±18 V, T <sub>A</sub> = −40°C to +125°C	See <a href="#">Figure 7-9</a>			
CMRR	Common-mode rejection ratio	At dc to 60 Hz, RTI (−V <sub>S</sub> ) + 2.5 V < V <sub>CM</sub> < (+V <sub>S</sub> ) − 2.5 V	132	150		dB
		At 50 kHz, RTI (−V <sub>S</sub> ) + 2.5 V < V <sub>CM</sub> < (+V <sub>S</sub> ) − 2.5 V		110		
BIAS CURRENT						
I <sub>B</sub>	Input bias current	V <sub>CM</sub> = V <sub>S</sub> / 2		25	50	nA
	Input bias current dift	T <sub>A</sub> = −40°C to +125°C		40		pA/°C
I <sub>OS</sub>	Input offset current	V <sub>CM</sub> = V <sub>S</sub> / 2		2	10	nA
	Input offset current drift	T <sub>A</sub> = −40°C to +125°C		10		pA/°C
NOISE VOLTAGE						
e <sub>NI</sub>	Input voltage noise	f = 1 kHz, R <sub>S</sub> = 0 Ω		1.3	1.5 <sup>(2)</sup>	nV/√Hz
		f <sub>B</sub> = 0.1 Hz to 10 Hz, R <sub>S</sub> = 0 Ω		55		nV <sub>PP</sub>
I <sub>n</sub>	Input current noise	f = 1 kHz		1.85		pA/√Hz
		f <sub>B</sub> = 0.1 Hz to 10 Hz		75		pA <sub>PP</sub>
GAIN						
G	First stage gain			200		V/V
	Subtractor stage gain			10		V/V
GE	Total gain error	V <sub>O</sub> = ±10 V		0.05	0.15 <sup>(1)</sup> (2)	%
	Total gain drift	T <sub>A</sub> = −40°C to +125°C			5 <sup>(1)</sup> (2)	ppm/°C
	Total gain nonlinearity	V <sub>O</sub> = −10 V to +10 V, no load		10		ppm

## 7.5 Electrical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $G = 2000$  (fixed) and  $V_{\text{REF}} = 0\text{ V}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
THD+N	Total harmonic distortion and noise	f = 20 kHz, V <sub>O</sub> = 10 V <sub>pp</sub>	−109			dBc
HD2	Second-order harmonic distortion	f = 20 kHz, V <sub>O</sub> = 10 V <sub>pp</sub>	−112			dBc
HD3	Third-order harmonic distortion	f = 20 kHz, V <sub>O</sub> = 10 V <sub>pp</sub>	−119			dBc
THD+N	Total harmonic distortion and noise	R <sub>L</sub> = 1 MΩ, f = 20 kHz, V <sub>O</sub> = 10 V <sub>pp</sub>	−111			dBc
HD2	Second-order harmonic distortion	R <sub>L</sub> = 1 MΩ, f = 20 kHz, V <sub>O</sub> = 10 V <sub>pp</sub>	−117			dBc
HD3	Third-order harmonic distortion	R <sub>L</sub> = 1 MΩ, f = 20 kHz, V <sub>O</sub> = 10 V <sub>pp</sub>	−118			dBc
OUTPUT						
	Output voltage swing		(−V <sub>S</sub> ) + 0.15	(+V <sub>S</sub> ) − 0.15		V
C <sub>L</sub>	Load capacitance	In stable condition	1000			pF
I <sub>SC</sub>	Short-circuit current	Continuous to V <sub>S</sub> / 2	±30			mA
FREQUENCY RESPONSE						
BW	Bandwidth, −3 dB		2.8			MHz
SR	Slew rate	V <sub>STEP</sub> = 10 V	35 <sup>(1)</sup>	45		V/μs
t <sub>S</sub>	Settling time	0.01%, V <sub>STEP</sub> = 10 V	0.5			μs
		0.001%, V <sub>STEP</sub> = 10 V	0.9			
REFERENCE INPUT						
R <sub>IN</sub>	Input impedance		132			kΩ
I <sub>IN</sub>	Input current		6.5			μA
	Reference input voltage		−V <sub>S</sub>		+V <sub>S</sub>	V
	Gain to output		1			V/V
	Reference gain error		0.01			%
FILTER INPUTS						
R <sub>FIL</sub>	Input impedance, filter terminal		6			kΩ
	Voltage range, filter terminal		−V <sub>S</sub>		+V <sub>S</sub>	V
POWER SUPPLY						
I <sub>Q</sub>	Quiescent current	V <sub>IN</sub> = 0 V	6.2		6.6	mA
		T <sub>A</sub> = −40°C to +85°C			7.9	
		T <sub>A</sub> = −40°C to +125°C			8.8	

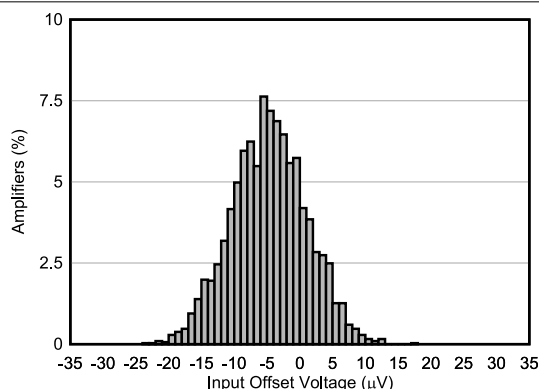
(1) Specified by characterization.

(2) Specified by design.

(3) The input voltage range depends on the common-mode voltage, differential voltage, gain, and reference voltage.

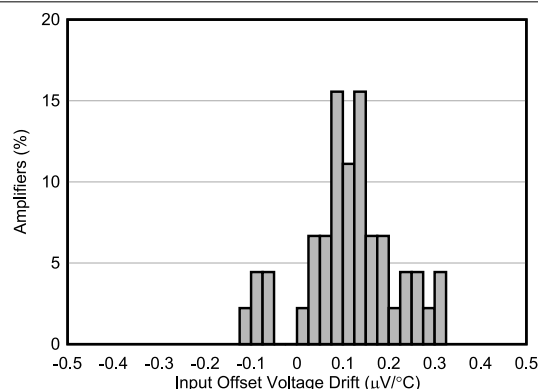
## 7.6 Typical Characteristics

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{\text{REF}} = 0\text{ V}$ , and  $G = 2000$  (unless otherwise noted)



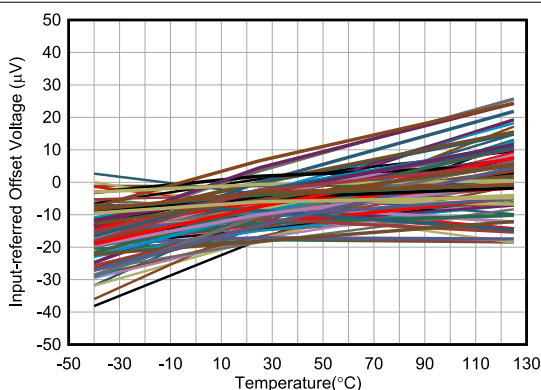
N = 3172, mean =  $-4.678\text{ }\mu\text{V}$ , std dev =  $5.715\text{ }\mu\text{V}$

**Figure 7-1. Typical Distribution of Input Offset Voltage**



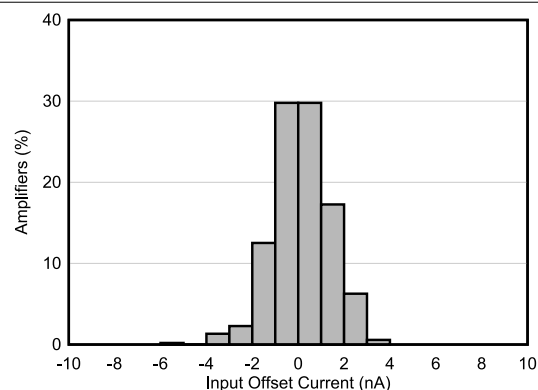
N = 45, mean =  $0.116\text{ }\mu\text{V}/^\circ\text{C}$ , std dev =  $0.102\text{ }\mu\text{V}/^\circ\text{C}$

**Figure 7-2. Typical Distribution of Input Offset Voltage Drift**



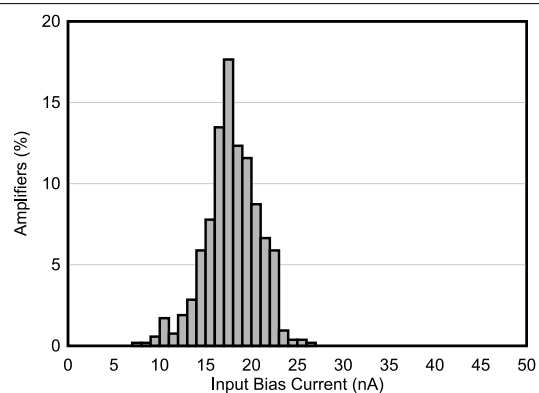
N = 48

**Figure 7-3. Input-referred Offset Voltage vs Temperature**



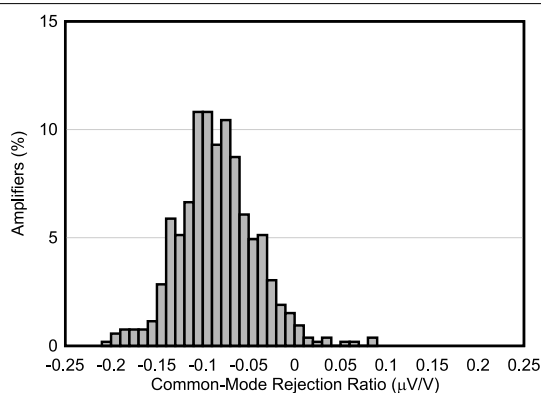
N = 527, mean =  $0.1369\text{ nA}$ , std dev =  $1.222\text{ nA}$

**Figure 7-4. Typical Distribution of Input Offset Current**



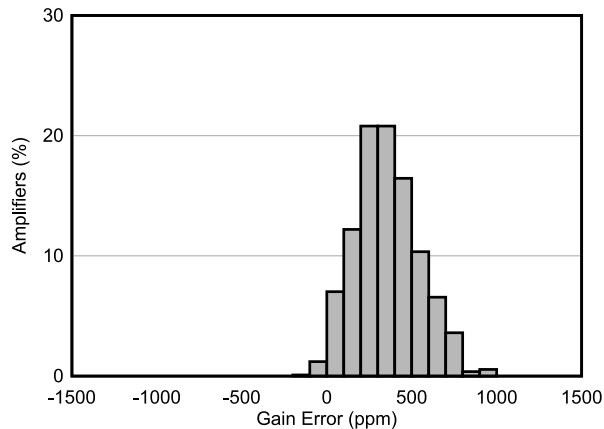
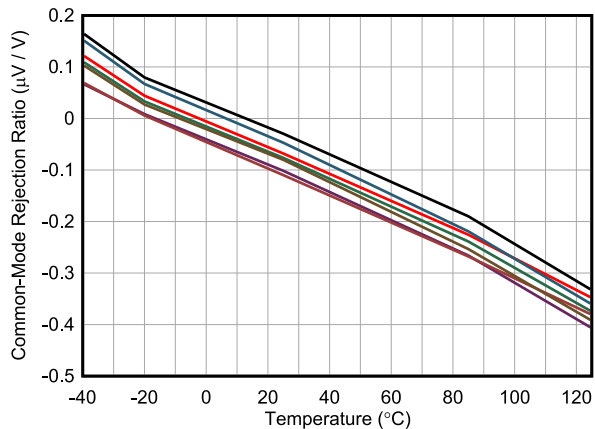
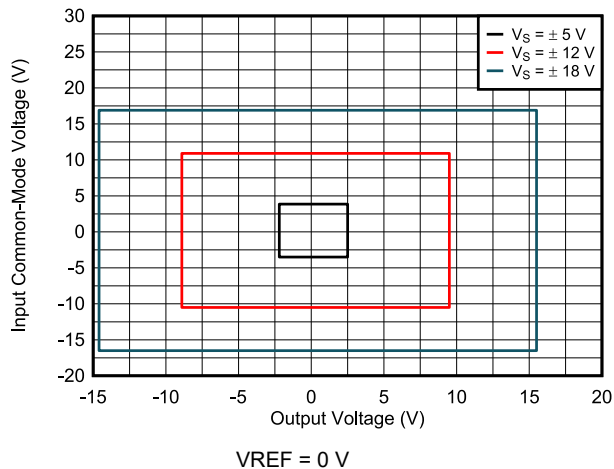
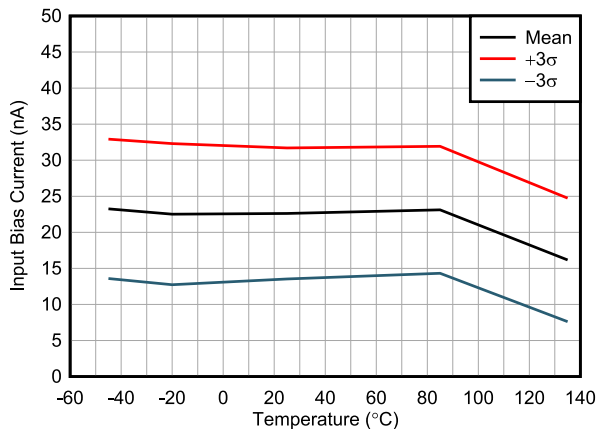
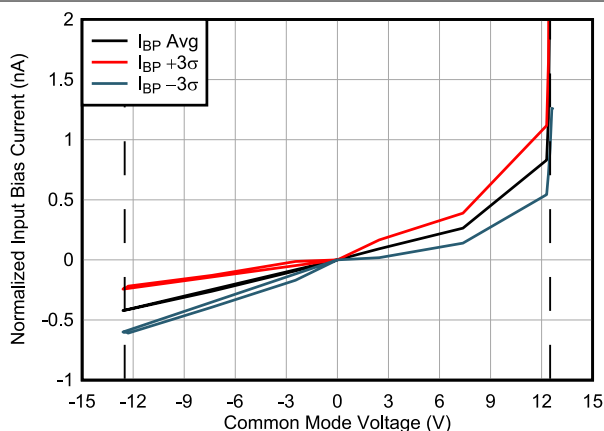
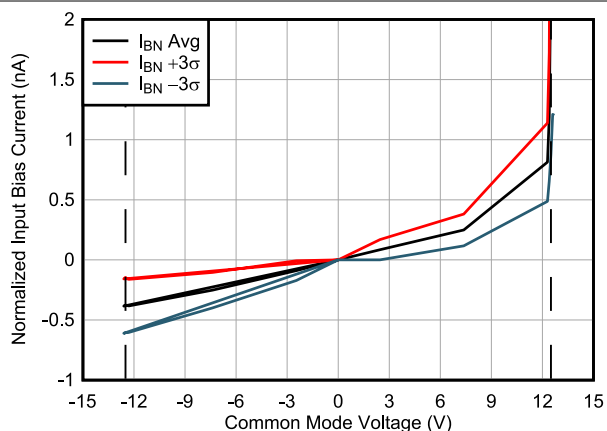
N = 527, mean =  $17.876\text{ nA}$ , std dev =  $2.875\text{ nA}$

**Figure 7-5. Typical Distribution of Input Bias Current**

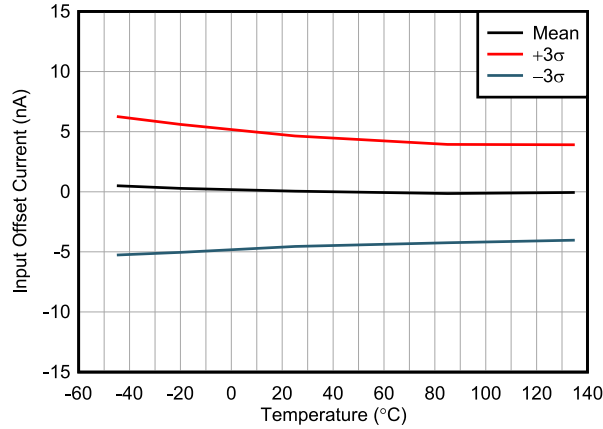


N = 527, mean =  $-0.0840\text{ }\mu\text{V}/\text{V}$ , std dev =  $0.0420\text{ }\mu\text{V}/\text{V}$

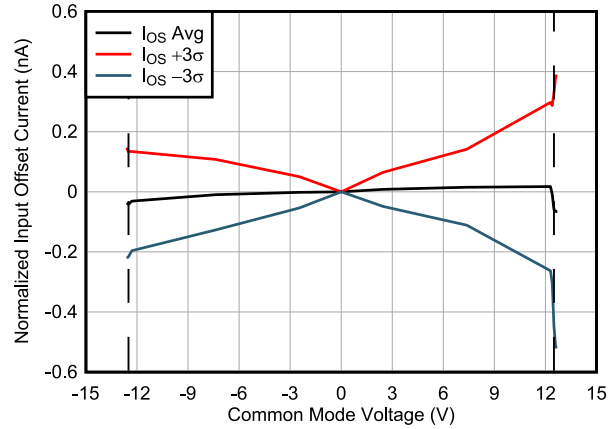
**Figure 7-6. Typical CMRR Distribution**


**Figure 7-7. Typical Distribution of Gain Error**

**Figure 7-8. CMRR vs Temperature**

**Figure 7-9. Input Common-Mode Voltage vs Output Voltage**

**Figure 7-10. Input Bias Current vs Temperature**

**Figure 7-11. Positive Input Bias Current vs Input Common-Mode Voltage**

**Figure 7-12. Negative Input Bias Current vs Input Common-Mode Voltage**

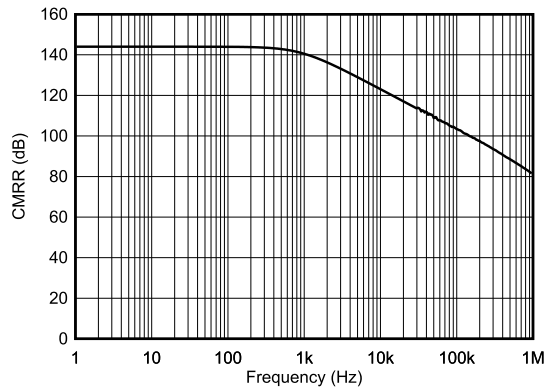




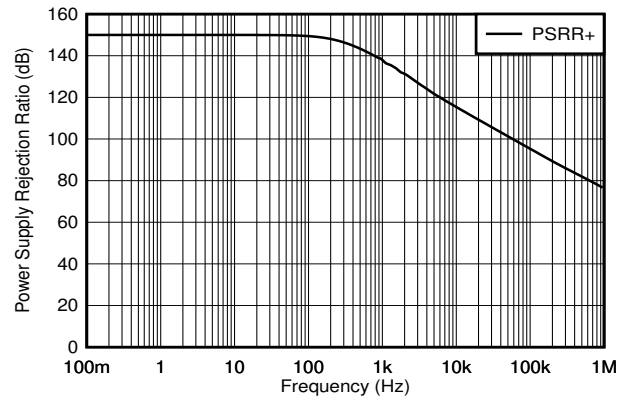
**Figure 7-13. Input Offset Current vs Temperature**



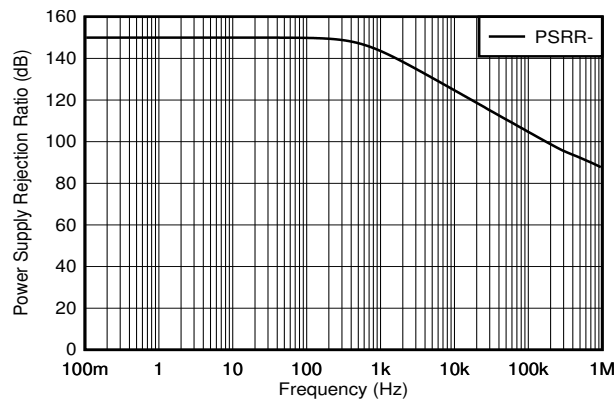
**Figure 7-14. Input Offset Current vs Input Common-Mode Voltage**



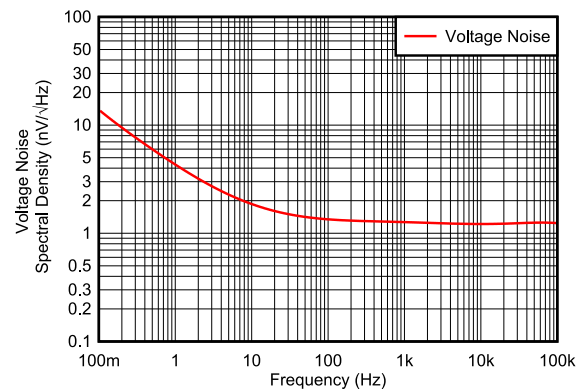
**Figure 7-15. CMRR vs Frequency (RTI)**



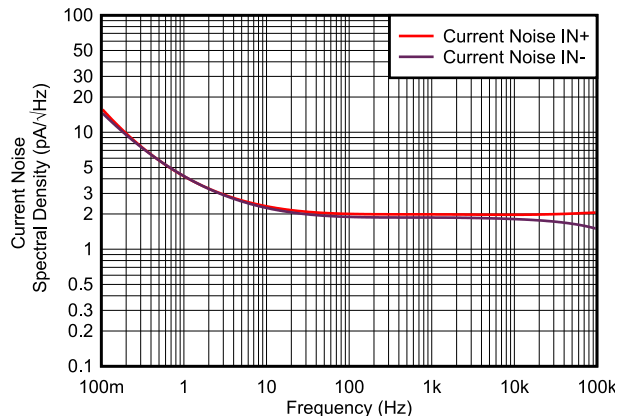
**Figure 7-16. Positive PSRR vs Frequency (RTI)**



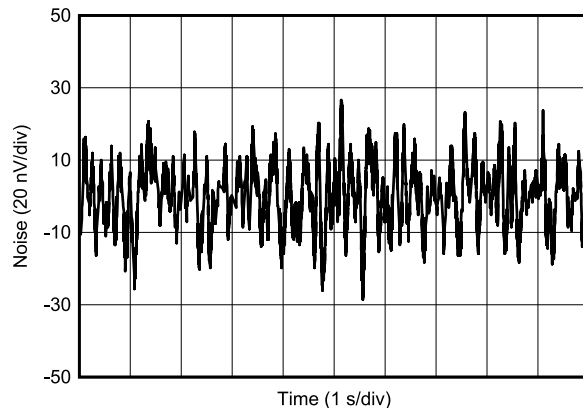
**Figure 7-17. Negative PSRR vs Frequency (RTI)**



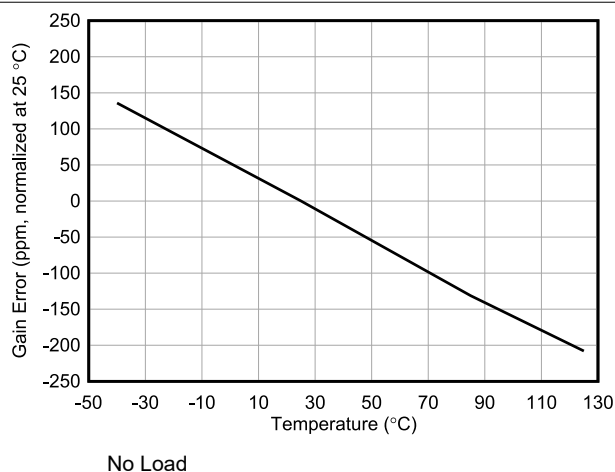
**Figure 7-18. Voltage Noise Spectral Density vs Frequency (RTI)**



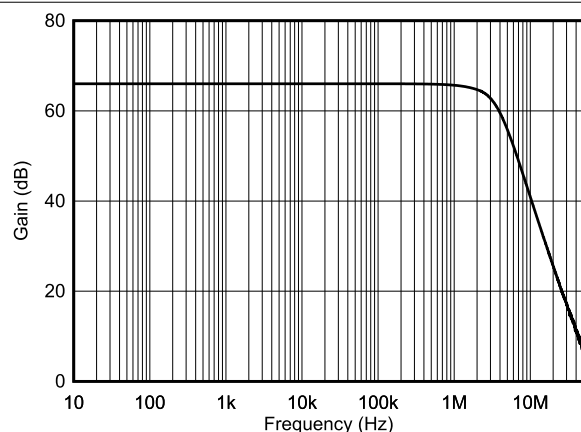
**Figure 7-19. Current Noise Spectral Density vs Frequency (RTI)**



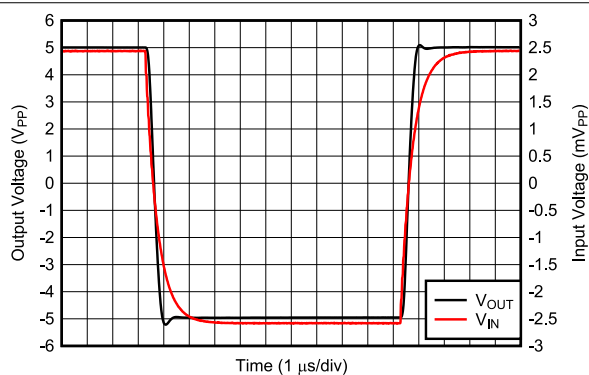
**Figure 7-20. 0.1-Hz to 10-Hz RTI Voltage Noise**



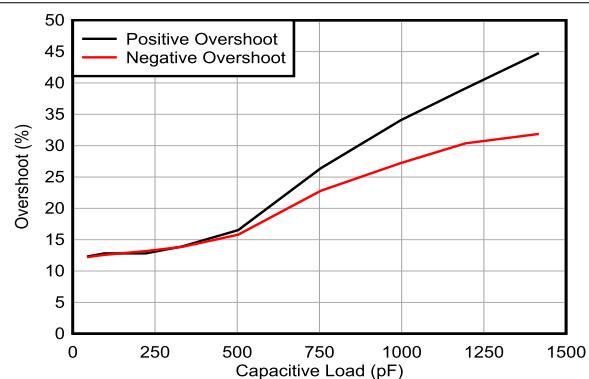
**Figure 7-21. Gain Error vs Temperature**



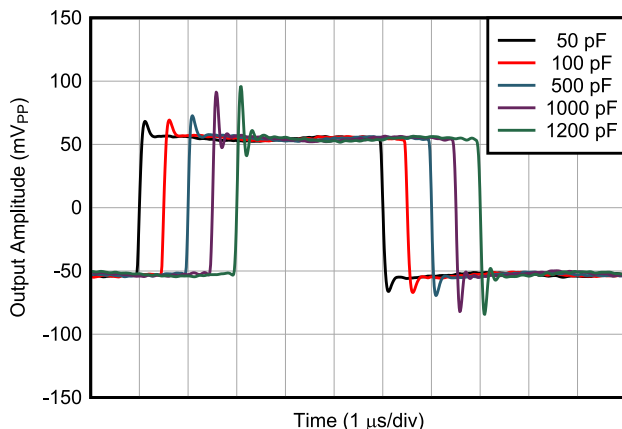
**Figure 7-22. Closed Loop Gain vs Frequency**



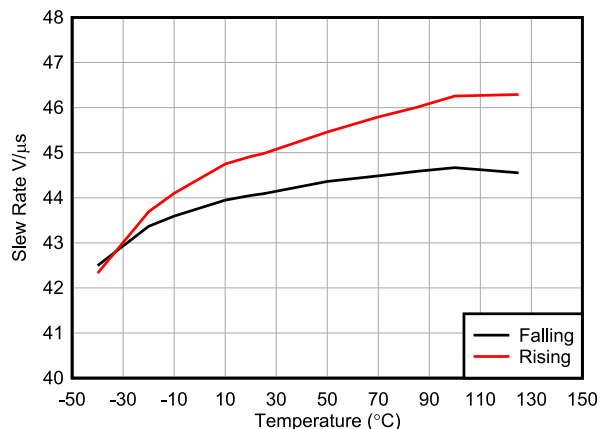
**Figure 7-23. Large-Signal Step Response**



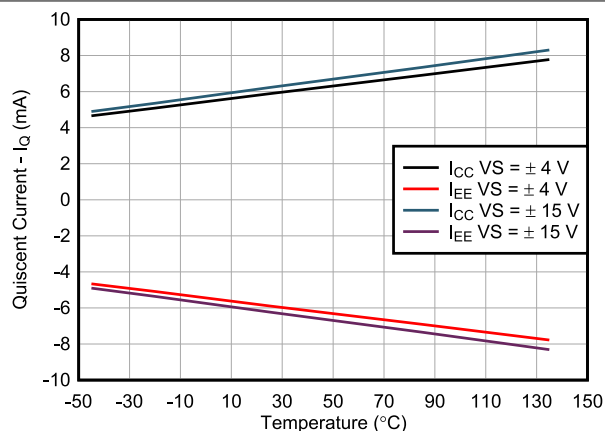
**Figure 7-24. Small Signal Response vs Capacitive Loads**



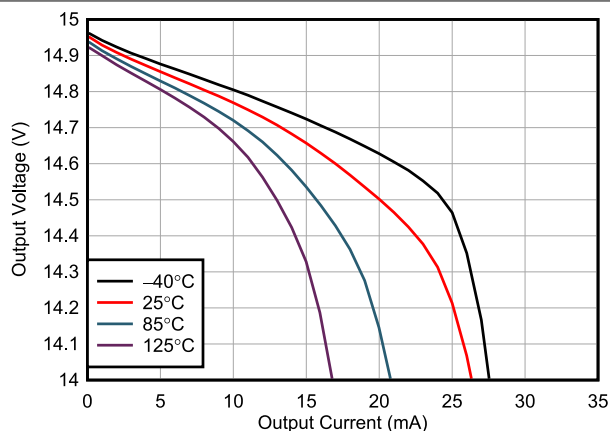
**Figure 7-25. Small Signal Response**



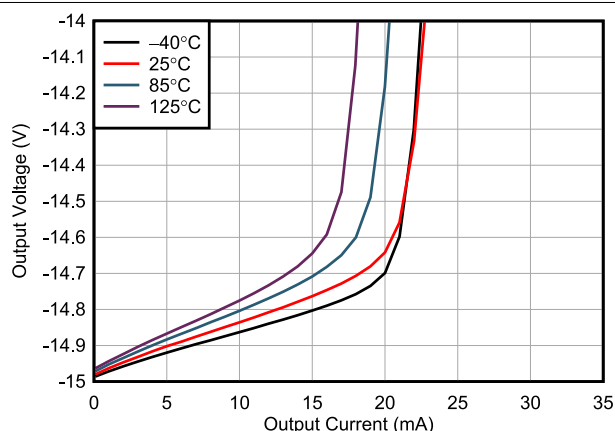
**Figure 7-26. Slew Rate vs Temperature**



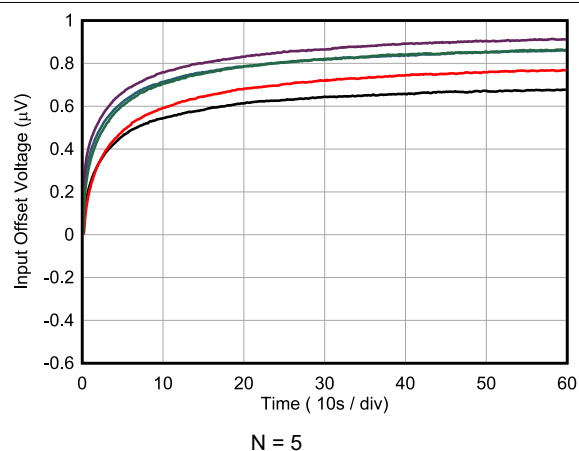
**Figure 7-27. Supply Current vs Temperature**



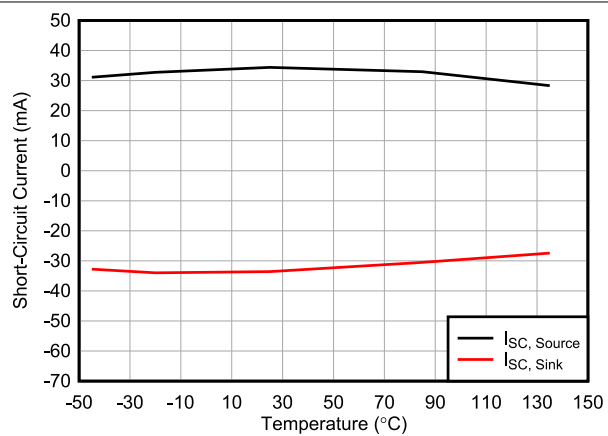
**Figure 7-28. Positive Output Voltage Swing vs Output Current**



**Figure 7-29. Negative Output Voltage Swing vs Output Current**



**Figure 7-30. Input-Referred Offset Voltage vs Settling Time**



**Figure 7-31. Short Circuit Current (Source + Sink) vs Temperature**

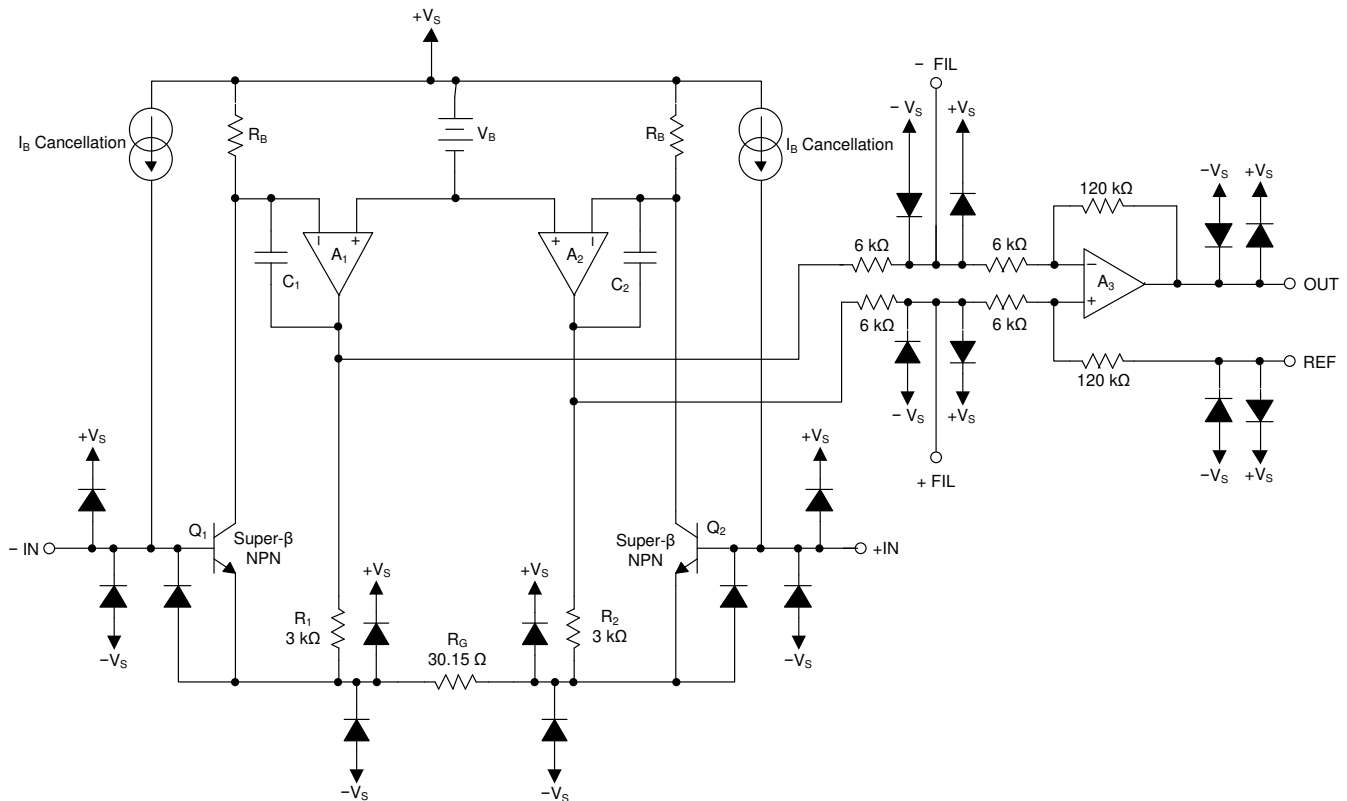
## 8 Detailed Description

### 8.1 Overview

The INA848 is a monolithic precision instrumentation amplifier incorporating a current-feedback input stage and a four-resistor difference amplifier output stage. The differential input voltage is buffered by  $Q_1$  and  $Q_2$  and is forced across  $R_G$ , which causes a signal current to flow through  $R_G$ ,  $R_1$ , and  $R_2$ . The output difference amplifier ( $A_3$ ) removes the common-mode component of the input signal and refers the output signal to the REF pin. The  $V_{BE}$  and voltage drop across  $R_1$  and  $R_2$  produce output voltages on  $A_1$  and  $A_2$  that are approximately 0.8 V lower than the input voltages.

In common instrumentation amplifiers, an external gain resistor is used to set the gain. However, this external gain resistor affects the gain drift due to the mismatch in temperature coefficient between the external and internal resistors. The INA848 integrates the gain setting resistor with a fixed gain of 2000, thus matching the temperature drifts of the resistor network. This integration results in an total gain accuracy of 5 ppm/°C (maximum).

### 8.2 Functional Block Diagram



## 8.3 Feature Description

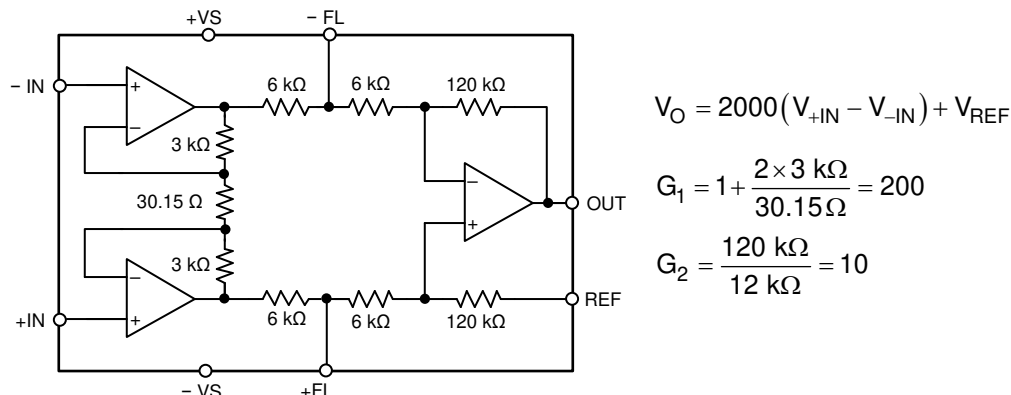
### 8.3.1 Topology

The INA848 is designed with TI's modern bipolar process that features super-beta input transistors.

Traditional bipolar transistors feature excellent voltage noise and offset drift, but suffer a tradeoff in high input bias current and high input bias current noise.

TI's super-beta transistors offer the benefits of low voltage noise, low offset voltage drift with an additional improvement in reduction of the input bias current noise.

As shown in [Figure 8-1](#), the INA848 is designed with a current feedback input stage that is optimized for high bandwidth in high gains. The device consists of three operational amplifiers configured at the front with a gain stage that integrates the gain resistor. This input stage preamplifies the differential input signal at a gain of 200. The output stage with the difference amplifier provides additional amplification of a gain of 10.

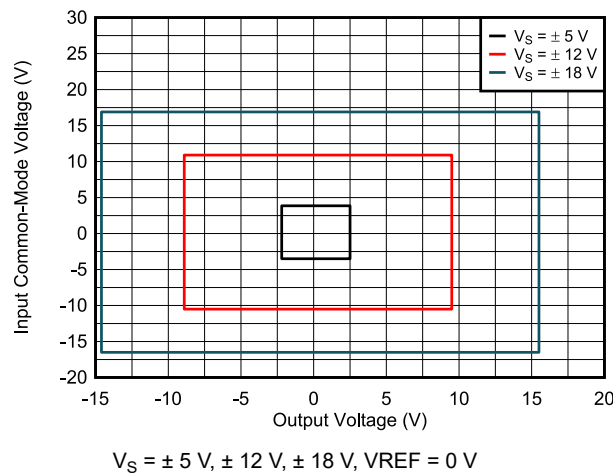


**Figure 8-1. Simplified Diagram of the INA848 With Gain and Output Equations**

### 8.3.2 Input Common-Mode Range

The typical three-op-amp topology gains up the input differential signal in the front stage and rejects the common-mode signals in the back end at the difference amplifier stage. The difficulty in particular is to excel driving high gains, and thus tiny input signals, and still be able to reject high common-mode signals. A low-noise instrumentation amplifier such as the INA848 is designed for such requirements, with the ability to measure the smallest input signals surrounded by noisy or large common-mode voltages.

The methodology here is achieved by splitting up the gain stages. The front end preamplifies the input signal at a gain of 200, and the difference amplifier further amplifies at a gain of 10. The resulting advantage is that the common-mode range versus the differential signal is improved compared to single gain stage approach, as shown in Figure 8-2.



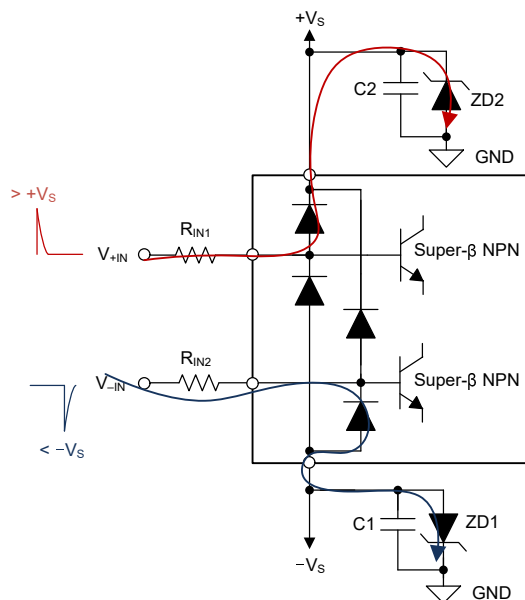
**Figure 8-2. Input Common-Mode Voltage vs Output Voltage**

The INA848 gives the super-beta input stage features very low input bias current as compared to standard bipolar technology. The low input bias current and current noise make the INA848 an excellent choice for high-performance applications. See Figure 7-10 through Figure 7-12 for reference.

### 8.3.3 Input Protection

The inputs of the INA848 device are individually protected for voltages up to  $\pm 20$  V which is stated in [Section 7.1](#). If these rating cannot be met, additional protection circuitry must be considered at the input pins to minimize the current flowing in case of fault.

During an input overvoltage condition, current flows through the input protection diodes into the power supplies; see [Figure 8-3](#). If the power supplies are unable to sink current, then Zener diode clamps (ZD1 and ZD2) must be placed on the power supplies to provide a current pathway to ground.



**Figure 8-3. Input Current Path During an Overvoltage Condition**

For an overvoltage condition, use an external resistor ( $R_{IN1}$ ,  $R_{IN2}$ ) to limit the current. The following equation gives the calculation for the protection resistors:

$$R_{IN1} = \frac{(V_{+IN}) - (+V_S)}{I_{MAX}} \quad (1)$$

where:

- $V_{+IN}$  is the maximum input voltage
- $+V_S$  is the positive supply rail
- $I_{MAX}$  is the maximum current allowed = 10 mA

Calculate  $R_{IN2}$  using the same method, substituting with  $V_{-IN}$ ,  $-V_S$ , and  $-I_{MAX}$ .

Any additional resistance to the input pins adds more noise to the system. For more details, see [Section 9.2.2.2](#).

### 8.4 Device Functional Modes

The INA848 has a single functional mode and is operational when the power supply voltage is greater than 4.5 V ( $\pm 2.25$  V). The maximum power-supply voltage for the INA848 is 36 V ( $\pm 18$  V).



## 9 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.

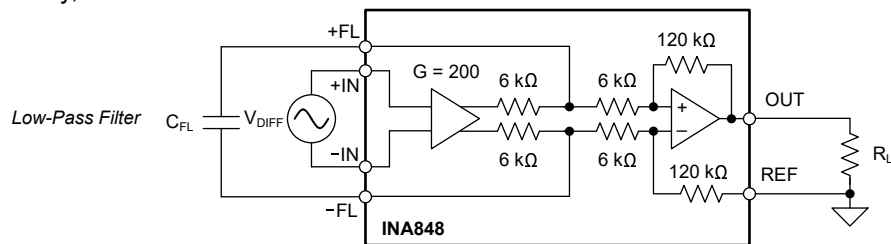
### 9.1 Application Information

#### 9.1.1 Filter Pin

The INA848 allows access between the two amplification stages. In applications surrounded from high input noise, adding filter stages can be of high benefit. [Figure 9-1](#) and [Figure 9-2](#) show two different filter scenarios that help filter out undesired differential signals.

##### 9.1.1.1 RC Filter Network

In environments where known high-frequency noise must be eliminated, use a low-pass filter containing a capacitor, and optionally, a resistor.



**Figure 9-1. Low-pass Filter**

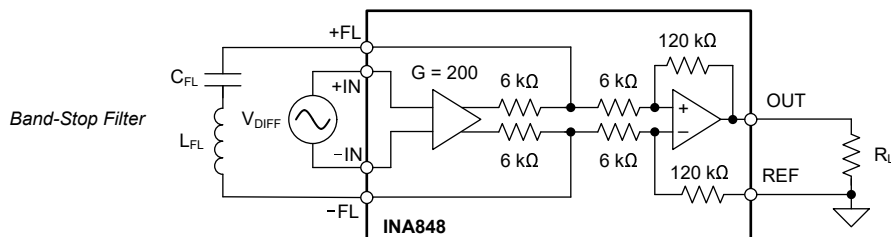
The -3-dB cross frequency is determined given following equation:

$$f_{FL1} = \frac{1}{2\pi \cdot 6k\Omega \cdot C_{FL}} \quad (2)$$

Where 6 kΩ represents the internal resistor network. Use the [Analog Engineer's Calculator](#) for fast and easy bode plot visualization.

##### 9.1.1.2 RLC Filter Network

In environments where a known, narrow-frequency band must be attenuated, a series LC filter network can be added between the filter pins, as shown in [Figure 9-2](#). The connection adds to the internal resistor network, and results in a RLC filter network that is also commonly known as bandstop filter.



**Figure 9-2. Bandstop Filter**

Use [Equation 3](#) to calculate the middle frequency of the filter:

$$f_{FL2} = \frac{1}{2\pi \cdot \sqrt{C_{FL} \cdot L_{FL}}} \quad (3)$$

In general, the width of the stopband is between one and two decades, meaning that the highest attenuation is between 10 to 100 around the middle frequency. This indication is commonly defined as the quality factor (Q factor) of the filter and is calculated by:

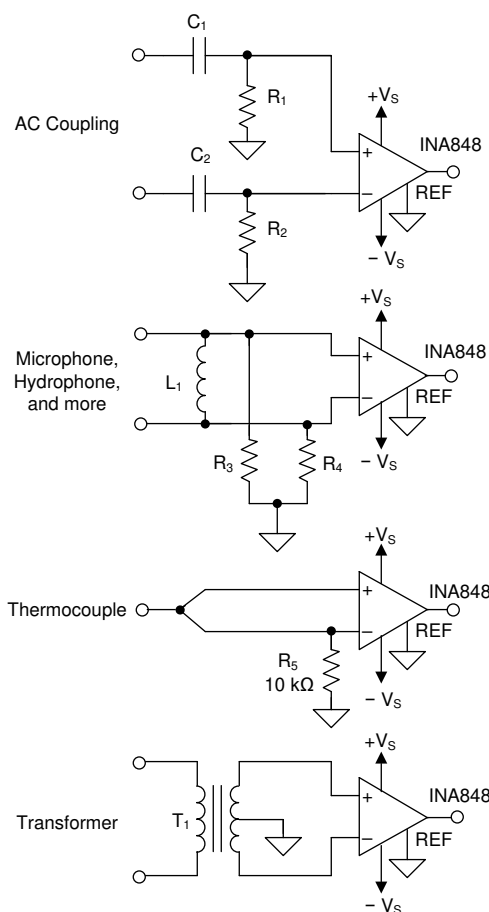
$$Q = \frac{1}{R} \cdot \sqrt{\frac{L_{FL}}{C_{FL}}} \quad (4)$$

The resistor is given by the internal resistor of 6 kΩ; therefore, the damping factor of the filter can further be affected of the series resistance of the inductor  $L_{FL}$ . For stable operation of the filter, choose an inductor in the range of 100 μH.

### 9.1.2 Input Bias Current Return Path

The input impedance of the INA848 is extremely high (approximately 100 GΩ). However, a path must be provided for the input bias current of both inputs. This input bias current is typically 25 nA. High input impedance means that this input bias current changes little with varying input voltage.

Input circuitry must provide a path for this input bias current for proper operation. Figure 9-3 shows various provisions for an input bias current path. Without a bias current path, the inputs float to a potential that exceeds the common-mode range of the INA848, and the input amplifiers saturate. If the differential source resistance is low, the bias current return path connects to one input (as shown in the thermocouple example in Figure 9-3). With a higher source impedance, using two equal resistors provides a balanced input with possible advantages of a lower input offset voltage as a result of bias current, and better high-frequency common-mode rejection.

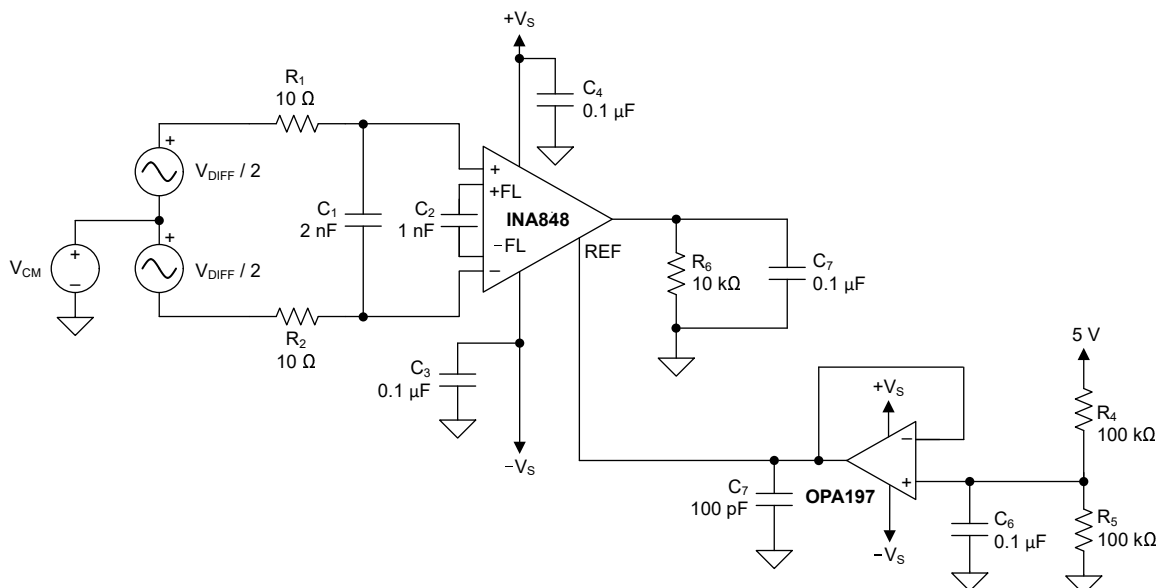


NOTE: Center tap in the transformer provides bias current return.

**Figure 9-3. Providing an Input Common-Mode Current Path**

## 9.2 Typical Application

Figure 9-4 shows a typical application for the INA848.



**Figure 9-4. Sensor Conditioning ( $V_{DIFF} < 5 \text{ mV}$ ,  $V_{S\pm} = 15 \text{ V}$ )**

### 9.2.1 Design Requirements

For this application, the design requirements are:

- Differential input signal of  $V_{DIFF} = 2.5 \text{ mV}$
- Common-mode input voltage of  $V_{CM} = 10 \text{ V}$
- Power-supply voltage of  $V_S = \pm 15 \text{ V}$
- Reference voltage buffered to  $V_{REF} = 2.5 \text{ V}$
- Output range within  $0 \text{ V}$  to  $5 \text{ V}$
- First-order filter stage with  $-3\text{-dB}$  frequency of  $27 \text{ kHz}$

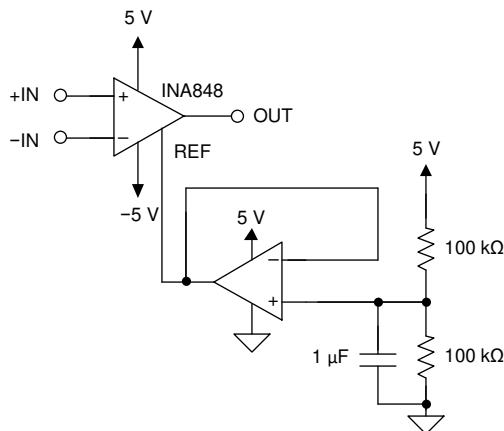
## 9.2.2 Detailed Design Procedure

### 9.2.2.1 Reference Pin

The output voltage of the INA848 is developed with respect to the voltage on the reference pin (REF.)

The voltage source applied to the reference pin of the INA848 must have a low output impedance ( $R_{REF} > 5\ \Omega$ ). Any additional resistance at the reference pin creates an imbalance in the four resistors of the internal difference amplifier, resulting in degraded common-mode rejection ratio (CMRR).

Voltage reference devices are an excellent option for providing a low-impedance voltage source for the reference pin. However, if a resistor voltage divider generates a reference voltage, the divider must be buffered by an op amp, as shown in [Figure 9-5](#), to avoid CMRR degradation.



**Figure 9-5. Buffer to drive the Reference Voltage**

Often in dual-supply operation, the reference pin connects to the low-impedance system ground. The degradation effect of common-mode rejection ratio is thus negligible as long as the output voltage ( $V_{OUT}$ ) is referred to the reference pin (REF).

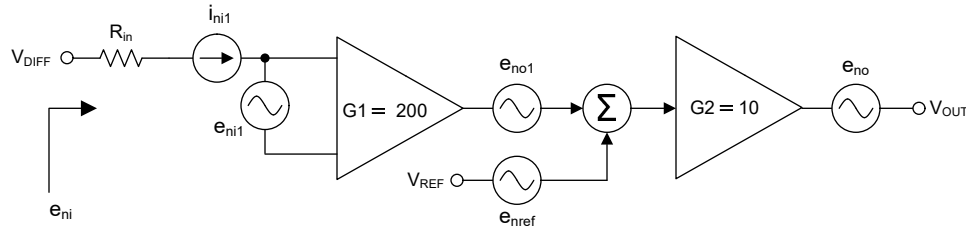
In single-supply operation, the output signal is offset to a precise midsupply level (for example, 2.5 V in a 5-V supply environment). In applications where the output voltage is offset to a reference voltage but referred to system ground, the degradation effect of common-mode rejection ratio must be considered.

### 9.2.2.2 Noise Analysis

Low-noise instrumentation amplifiers such as the INA848 are designed to serve stringent and sensitive applications, such as surgical tools, microphones or other precision monitoring systems. A thorough noise analysis is a key element in the design process.

TI's super-beta transistors offer the benefits of low voltage noise and low current noise, thus allowing the INA848 excellent noise performance.

Figure 9-6 shows a simplified noise model including the gain stages of the INA848.



**Figure 9-6. Simplified Noise Model**

To get the total input-referred noise,  $e_{ni}$ , consider the source resistance seen by the positive and negative input pins of the instrumentation amplifier. The key elements that must be considered for a noise analysis in an instrumentation amplifier are:

- Current noise density  $i_{ni1}$  of the INA, see [Section 7.5](#)
- Voltage noise density  $e_{ni1}$  of the INA, see [Section 7.5](#)
- Voltage noise density caused by source resistance  $i_{ni} \times R_{in}$
- Resistor noise from source resistance  $e_{nRin}$ , given by:  $\sqrt{R_{in}} \times 4.04 \text{ nV}/\sqrt{\text{Hz}}$
- Reference voltage noise  $e_{nref}$

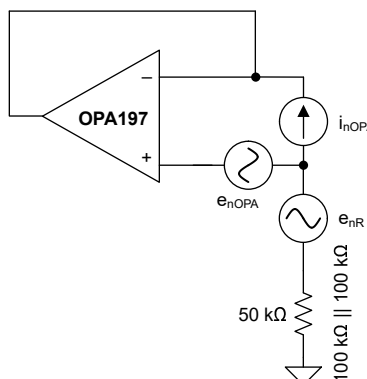
The noise sources are uncorrelated (that is, the noise signal is unpredictable). The result of multiple uncorrelated noise sources is the square root of the sum of their squares (RSS). Thus, the total RTI noise density,  $e_{ni}$ , in  $\text{nV}/\sqrt{\text{Hz}}$  can be derived from the following equation:

$$e_{ni} = \sqrt{e_{ni1}^2 + e_{n(Rin)}^2 + (i_{ni1} \cdot R_{in})^2 + \left(\frac{e_{n(REF)}}{G1}\right)^2} \quad (5)$$

### 9.2.2.2.1 Reference Voltage Noise Contribution

Figure 9-7 shows the noise model of the reference buffer circuit given by Figure 9-5 using the OPA197 amplifier.

To compute the total noise for the reference buffer circuit, consider the thermal noise of the divider (that is a parallel network from noise perspective), the amplifier voltage noise (that is,  $e_{nOPA} = 5.5 \text{ nV}/\sqrt{\text{Hz}}$ ), and the voltage noise developed from the current noise of the amplifier (that is,  $i_{nOPA} = 1.5 \text{ fA}/\sqrt{\text{Hz}}$ ) through the divider.



**Figure 9-7. Reference Voltage Noise Model**

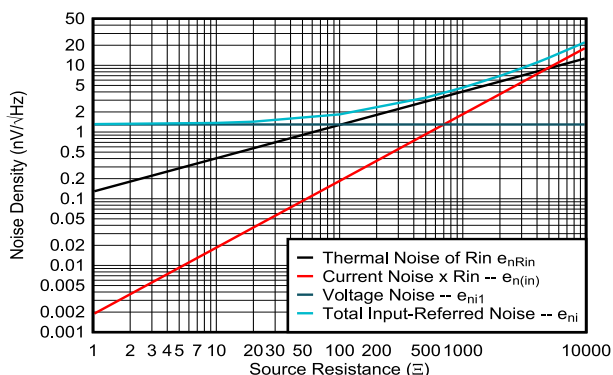
Thus the total reference noise can be derived from following equation:

$$e_{n(REF)} = \sqrt{e_{nOPA}^2 + (\sqrt{R} \cdot 4.04 \text{ nV}/\sqrt{\text{Hz}})^2 + (i_{nOPA} \cdot R)^2} \quad (6)$$

The reference noise is divided by the first gain stage of 200 at the INA848 to compute the input-referred noise. For reference noise less than  $80 \text{ nV}/\sqrt{\text{Hz}}$ , this contribution can be neglected in the analysis. The given example results in a total reference noise of  $29 \text{ nV}/\sqrt{\text{Hz}}$ , and thus is neglected.

### 9.2.3 Application Curves

From Figure 9-6, the source resistance is shown to be one main contributor. Figure 9-8 plots all the individual noise contributors depending on the source resistance. The reference voltage noise is negligible.



**Figure 9-8. Noise Density vs Source Resistance**

If the source resistance is below  $20 \Omega$ , the voltage noise of the INA (typically  $1.3 \text{ nV}/\sqrt{\text{Hz}}$ ) is dominating. If the source resistance is increasing ( $> 20 \Omega$ ) the thermal noise of the source resistance is dominating. At this point the low-noise advantage of the INA848 does not provide additional value. In applications with even higher source resistance ( $> 1 \text{ k}\Omega$ ), the current noise of the INA starts to dominate, and thus, should be optimized.

## 10 Power Supply Recommendations

The nominal performance of the INA848 is specified with a supply voltage of  $\pm 15$  V and midsupply reference voltage. The device operates using power supplies from  $\pm 4$  V (8 V) to  $\pm 18$  V (36 V) and non-midsupply reference voltages with excellent performance.

### CAUTION

Supply voltages higher than 40 V ( $\pm 20$  V) can permanently damage the device. Parameters that vary over supply voltage or temperature are shown in [Section 7.6](#) of this data sheet.

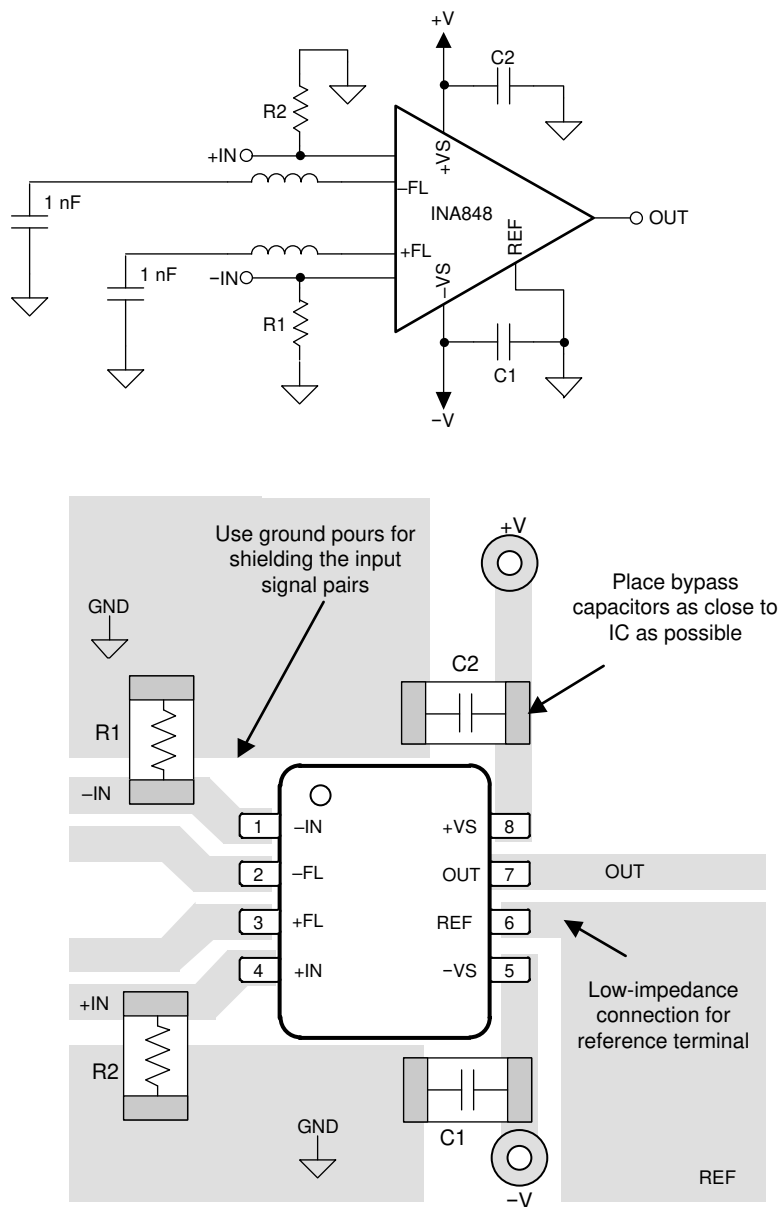
## 11 Layout

### 11.1 Layout Guidelines

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

- Take care to make sure that both input paths are well-matched for source impedance and capacitance to avoid converting common-mode signals into differential signals.
- Noise propagates into analog circuitry through the power pins of the circuit as a whole and of the device. Bypass capacitors reduce the coupled noise by providing low-impedance power sources local to the analog circuitry.
  - Connect low-ESR, 0.1- $\mu$ F ceramic bypass capacitors between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from +VS to ground is applicable for single-supply applications.
- To reduce parasitic coupling, run the input traces as far away from the supply or output traces as possible. If these traces cannot be kept separate, crossing the sensitive trace perpendicular is much better than in parallel with the noisy trace.
- Place the external components (filter components, load) as close to the device as possible.
- Use ground layer to minimize the parasitic inductance of the board.
- Keep the traces as short as possible.

## 11.2 Layout Example



**Figure 11-1. Example Schematic and Associated PCB Layout**  
(inductors and capacitors shown on FL pins are optional)



## 12 Device and Documentation Support

### 12.1 Documentation Support

#### 12.1.1 Related Documentation

For related documentation see the following:

- Texas Instruments, [REF50xx Low-Noise, Very Low Drift, Precision Voltage Reference](#)
- Texas Instruments, [OPA191 Low-Power, Precision, 36-V, e-trim CMOS Amplifier](#)
- Texas Instruments, [TINA-TI software folder](#)
- Texas Instruments, [INA Common-Mode Range Calculator](#)

#### 12.2 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.

#### 12.3 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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#### 12.5 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.

#### 12.6 Glossary

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

## 13 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
INA848ID	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	INA848	<a href="#">Samples</a>
INA848IDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	Call TI	Call TI	-40 to 125	INA848	<a href="#">Samples</a>

(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.

**OBsolete:** 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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**TAPE AND REEL INFORMATION**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
INA848IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA848IDR	SOIC	D	8	2500	853.0	449.0	35.0



**D0008A**

# PACKAGE OUTLINE

**SOIC - 1.75 mm max height**

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

## 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.

**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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