

## INA828 50 $\mu$ V 偏移、7nV/ $\sqrt{\text{Hz}}$ 噪声低功耗精密仪表放大器

### 1 特性

- 精密仪表放大器演变：
  - 第二代：INA828
  - 第一代：INA128
- 低失调电压：最大值为 50 $\mu$ V
- 增益漂移：5ppm/ $^{\circ}\text{C}$  ( $G = 1$ )，50ppm/ $^{\circ}\text{C}$  ( $G > 1$ )
- 噪声：7nV/ $\sqrt{\text{Hz}}$
- 带宽：2MHz ( $G = 1$ )、260kHz ( $G = 100$ )
- 与 1nF 电容负载一起工作时保持稳定
- 输入保护电压高达  $\pm 40\text{V}$
- 共模抑制：
  - 最小值为 110dB ( $G = 10$ )
- 电源抑制：最小值为 100dB ( $G = 1$ )
- 电源电流：最大值为 650  $\mu\text{A}$
- 电源范围：
  - 单电源：4.5V 至 36V
  - 双电源： $\pm 2.25\text{V}$  至  $\pm 18\text{V}$
- 额定温度范围： $-40^{\circ}\text{C}$  至  $+125^{\circ}\text{C}$
- 封装：8 引脚 SOIC

### 2 应用

- 工业过程控制
- 断路器
- 电池检测仪
- 心电图 (ECG) 放大器
- 电力自动化
- 医疗仪表
- 便携式仪表

### 3 说明

INA828 是一款高精度仪表放大器，此放大器提供低功耗并且可在极宽的单电源或双电源范围内工作。可通过单个外部电阻器在 1 到 1000 范围内设置增益。由于采用新的超  $\beta$  输入晶体管（这些晶体管可提供极低的输入失调电压、失调电压漂移、输入偏置电流以及输入电压和电流噪声），该器件可提供出色的精度。附加电路可以为输入提供高达  $\pm 40\text{V}$  的过压保护。

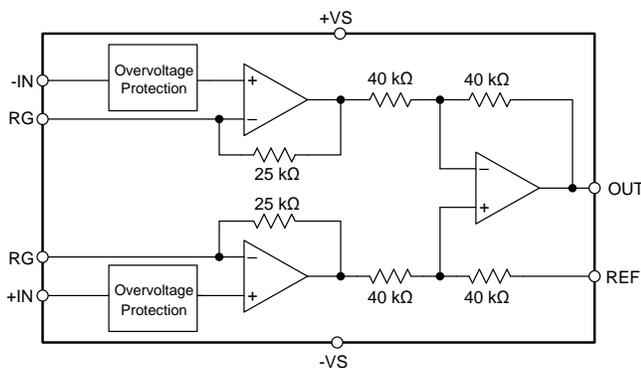
INA828 经过优化，可提供出色的共模抑制比。当  $G = 1$  时，整个输入共模范围内共模抑制比超过 90dB。该器件非常适用于通过 5V 单电源和高达  $\pm 18\text{V}$  的双电源供电的低电压运行。最后，INA828 采用 8 引脚 SOIC 封装，额定温度范围为  $-40^{\circ}\text{C}$  至  $+125^{\circ}\text{C}$ 。

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

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA828	SOIC (8)	4.90mm x 3.91mm

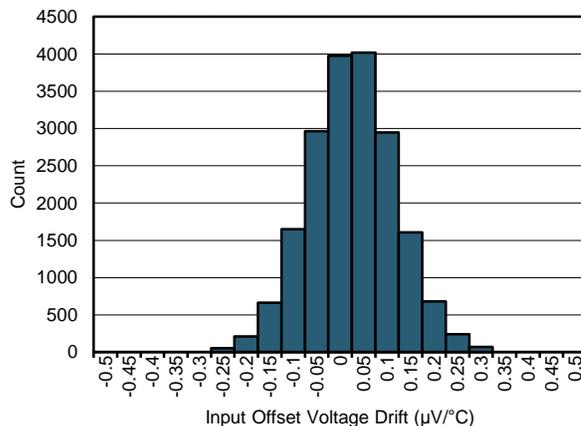
(1) 如需了解所有可用封装，请参阅产品说明书末尾的可订购产品附录。

INA828 简化内部原理图



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输入失调电压漂移的典型分布



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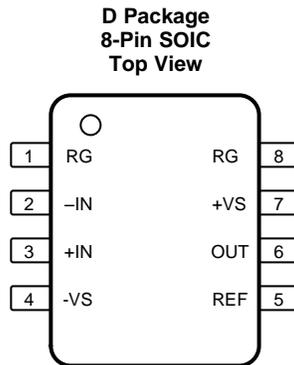
## 4 修订历史记录

### Changes from Original (August 2017) to Revision A

**Page**

- |   |   |          |
|---|---|----------|
| • | Changed MAX value for G = 1 in "GE" row from "±0.020%" to "±0.025%" ..... | <b>5</b> |
|---|---|----------|

## 5 Pin Configuration and Functions



**Pin Functions**

PIN		I/O	DESCRIPTION
NAME	NO.		
RG	1	—	Gain setting pin. Place a gain resistor between pin 1 and pin 8.
	8		
-IN	2	I	Negative (inverting) input
+IN	3	I	Positive (noninverting) input
-VS	4	—	Negative supply
REF	5	I	Reference input. This pin must be driven by a low impedance source.
OUT	6	O	Output
+VS	7	—	Positive supply

## 6 Specifications

### 6.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Supply voltage		-18	18	V
Signal input pins	Voltage	-40	40	V
	REF pin	-18	18	
Output short-circuit <sup>(2)</sup>		Continuous		
Temperature	Operating, T <sub>A</sub>	-50	150	°C
	Junction, T <sub>J</sub>		175	
	Storage, T <sub>stg</sub>	-65	150	

- (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) Short-circuit to V<sub>S</sub> / 2.

### 6.2 ESD Ratings

		VALUE	UNIT
V <sub>(ESD)</sub> Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>	±1500	V
	Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup>	±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.

### 6.3 Recommended Operating Conditions

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

		MIN	MAX	UNIT
Supply voltage	Single supply	4.5	36	V
	Dual supply	±2.25	±18	
Specified temperature		-40	125	°C
Operating temperature		-50	150	°C

### 6.4 Thermal Information

THERMAL METRIC <sup>(1)</sup>		INA828	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.

## 6.5 Electrical 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  $G = 1$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>INPUT</b>						
$V_{\text{OSI}}$	Input stage offset voltage <sup>(1)(2)</sup>	$G = 100$ , RTI		20	50	$\mu\text{V}$
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$ <sup>(3)</sup>			90	$\mu\text{V}$
		vs temperature, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				0.5
$V_{\text{OSO}}$	Output stage offset voltage <sup>(1)(2)</sup>	$G = 1$ , RTI		50	250	$\mu\text{V}$
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$ <sup>(3)</sup>			500	$\mu\text{V}$
		vs temperature, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				5
PSRR	Power-supply rejection ratio	$G = 1$ , RTI	110	120		dB
		$G = 10$ , RTI	114	130		
		$G = 100$ , RTI	130	135		
		$G = 1000$ , RTI	136	140		
$Z_{\text{id}}$	Differential impedance			100    1		$\text{G}\Omega$    pF
$Z_{\text{ic}}$	Common-mode impedance			100    10		$\text{G}\Omega$    pF
	RFI filter, -3-dB frequency			53		MHz
$V_{\text{CM}}$	Operating input range <sup>(4)</sup>	$V_S = \pm 2.25\text{ V}$ to $\pm 18\text{ V}$ , $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$	(V-) + 2		(V+) - 2	V
			See Figure 48 to Figure 51			
	Input overvoltage range	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			$\pm 40$	V
CMRR	Common-mode rejection ratio	At dc to 60 Hz, RTI, $V_{\text{CM}} = (V-) + 2\text{ V}$ to $(V+) - 2\text{ V}$ , $G = 1$	90	100		dB
		At dc to 60 Hz, RTI, $V_{\text{CM}} = (V-) + 2\text{ V}$ to $(V+) - 2\text{ V}$ , $G = 10$	110	120		
		At dc to 60 Hz, RTI, $V_{\text{CM}} = (V-) + 2\text{ V}$ to $(V+) - 2\text{ V}$ , $G = 100$	130	140		
		At dc to 60 Hz, RTI, $V_{\text{CM}} = (V-) + 2\text{ V}$ to $(V+) - 2\text{ V}$ , $G = 1000$	140	145		
<b>BIAS CURRENT</b>						
$I_{\text{B}}$	Input bias current	$V_{\text{CM}} = V_S / 2$		0.15	0.6	nA
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			2	
$I_{\text{OS}}$	Input offset current	$V_{\text{CM}} = V_S / 2$		0.15	0.6	nA
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			2	
<b>NOISE VOLTAGE</b>						
$e_{\text{NI}}$	Input stage voltage noise <sup>(5)</sup>	$f = 1\text{ kHz}$ , $G = 100$ , $R_S = 0\ \Omega$		7		$\text{nV}/\sqrt{\text{Hz}}$
		$f_{\text{B}} = 0.1\text{ Hz}$ to $10\text{ Hz}$ , $G = 100$ , $R_S = 0\ \Omega$		0.14		$\mu\text{V}_{\text{PP}}$
$e_{\text{NO}}$	Output stage voltage noise <sup>(5)</sup>	$f = 1\text{ kHz}$ , $R_S = 0\ \Omega$		90		$\text{nV}/\sqrt{\text{Hz}}$
		$f_{\text{B}} = 0.1\text{ Hz}$ to $10\text{ Hz}$ , $R_S = 0\ \Omega$		7.7		$\mu\text{V}_{\text{PP}}$
$I_{\text{n}}$	Noise current	$f = 1\text{ kHz}$		170		$\text{fA}/\sqrt{\text{Hz}}$
		$f_{\text{B}} = 0.1\text{ Hz}$ to $10\text{ Hz}$ , $G = 100$		4.7		$\text{pA}_{\text{PP}}$
<b>GAIN</b>						
G	Gain equation			$1 + (50\text{ k}\Omega / R_G)$		V/V
		Range of gain		1	1000	V/V
GE	Gain error	$G = 1$ , $V_O = \pm 10\text{ V}$		$\pm 0.005\%$	$\pm 0.025\%$	
		$G = 10$ , $V_O = \pm 10\text{ V}$		$\pm 0.025\%$	$\pm 0.15\%$	
		$G = 100$ , $V_O = \pm 10\text{ V}$		$\pm 0.025\%$	$\pm 0.15\%$	
		$G = 1000$ , $V_O = \pm 10\text{ V}$		$\pm 0.05\%$		
	Gain vs temperature <sup>(6)</sup>	$G = 1$ , $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			$\pm 5$	ppm/ $^\circ\text{C}$
		$G > 1$ , $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			$\pm 50$	

(1) Total offset, referred-to-input (RTI):  $V_{\text{OS}} = (V_{\text{OSI}}) + (V_{\text{OSO}} / G)$ .

(2) Offset drifts are uncorrelated. Input-referred offset drift is calculated using:  $\Delta V_{\text{OS(RTI)}} = \sqrt{[\Delta V_{\text{OSI}}]^2 + (\Delta V_{\text{OSO}} / G)^2}$ 

(3) Specified by characterization.

(4) Input voltage range of the INA828 input stage. The input range depends on the common-mode voltage, differential voltage, gain, and reference voltage. See *Typical Characteristic curves* Figure 48 through Figure 51 for more information.

(5) Total RTI voltage noise is equal to:  $e_{\text{N(RTI)}} = \sqrt{e_{\text{NI}}^2 + (e_{\text{NO}} / G)^2}$ 

(6) The values specified for  $G > 1$  do not include the effects of the external gain-setting resistor,  $R_G$ .

**Electrical Characteristics (continued)**

 at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Gain nonlinearity	$G = 1$ to 10, $V_O = -10\text{ V}$ to $+10\text{ V}$ , $R_L = 10\text{ k}\Omega$		1	10	ppm
	$G = 100$ , $V_O = -10\text{ V}$ to $+10\text{ V}$ , $R_L = 10\text{ k}\Omega$			15	
	$G = 1000$ , $V_O = -10\text{ V}$ to $+10\text{ V}$ , $R_L = 10\text{ k}\Omega$			20	
	$G = 1$ to 100, $V_O = -10\text{ V}$ to $+10\text{ V}$ , $R_L = 2\text{ k}\Omega$			30	
<b>OUTPUT</b>					
Voltage swing		$(V-) + 0.15$		$(V+) - 0.15$	V
Load capacitance stability			1000		pF
$Z_O$ Closed-loop output impedance	$f = 10\text{ kHz}$		1.3		$\Omega$
$I_{SC}$ Short-circuit current	Continuous to $V_S / 2$		$\pm 18$		mA
<b>FREQUENCY RESPONSE</b>					
BW Bandwidth, $-3\text{ dB}$	$G = 1$		2.0		MHz
	$G = 10$		640		kHz
	$G = 100$		260		
	$G = 1000$		33		
SR Slew rate	$G = 1$ , $V_O = \pm 10\text{ V}$		1.2		V/ $\mu\text{s}$
$t_S$ Settling time	0.01%, $G = 1$ to 100, $V_{STEP} = 10\text{ V}$		12		$\mu\text{s}$
	0.01%, $G = 1000$ , $V_{STEP} = 10\text{ V}$		40		
	0.001%, $G = 1$ to 100, $V_{STEP} = 10\text{ V}$		16		
	0.001%, $G = 1000$ , $V_{STEP} = 10\text{ V}$		50		
<b>REFERENCE INPUT</b>					
$R_{IN}$ Input impedance			40		k $\Omega$
Voltage range		$(V-)$		$(V+)$	V
Gain to output			1		V/V
Reference gain error			0.01%		
<b>POWER SUPPLY</b>					
$V_S$ Power-supply voltage	Single supply	4.5		36	V
	Dual supply	$\pm 2.25$		$\pm 18$	
$I_Q$ Quiescent current	$V_{IN} = 0\text{ V}$		600	650	$\mu\text{A}$
	vs temperature, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			850	

### 6.6 Typical Characteristics

At  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

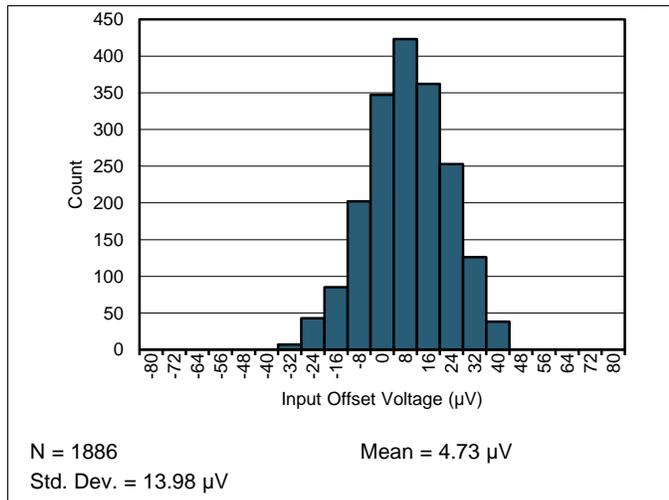


图 1. Typical Distribution of Input Offset Voltage

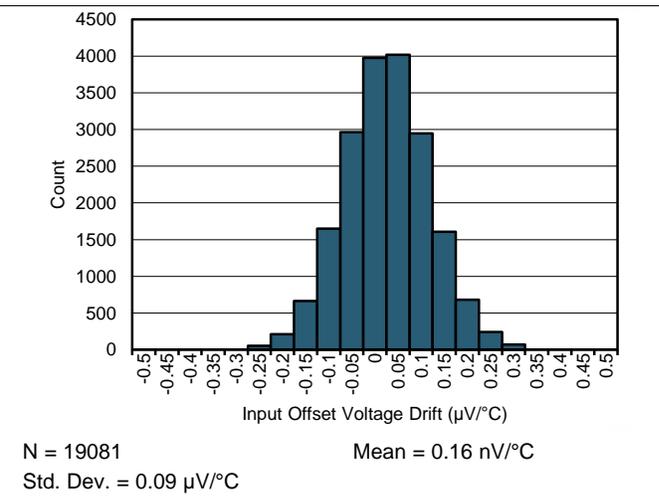


图 2. Typical Distribution of Input Offset Voltage Drift

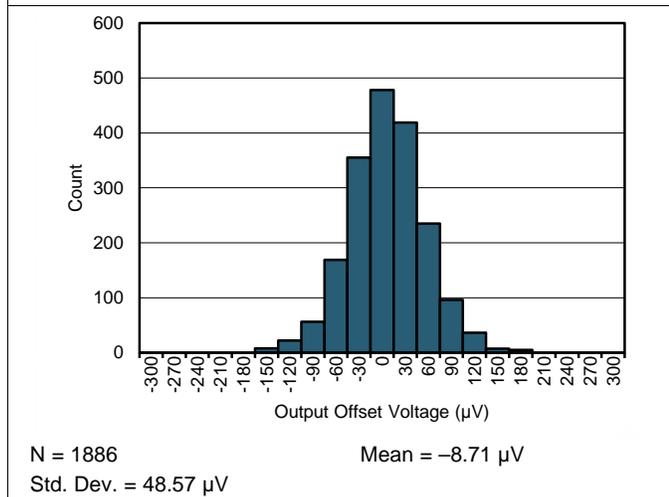


图 3. Typical Distribution of Output Offset Voltage

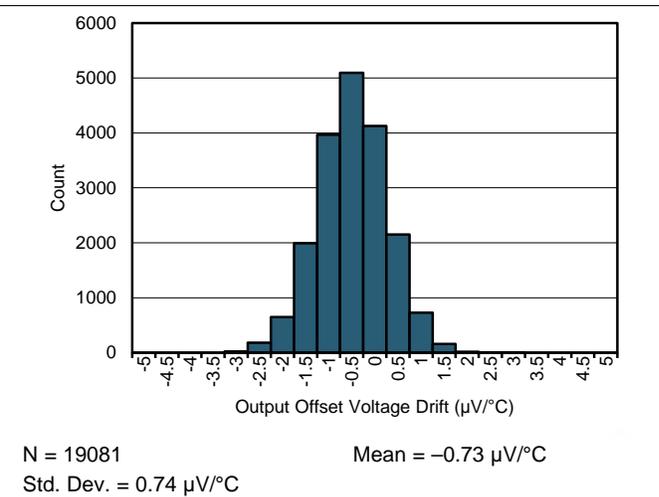


图 4. Typical Distribution of Output Offset Voltage Drift

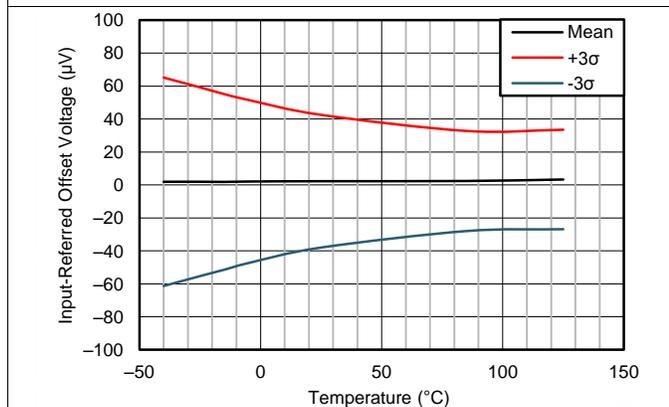


图 5. Input-Referred Offset Voltage vs Temperature

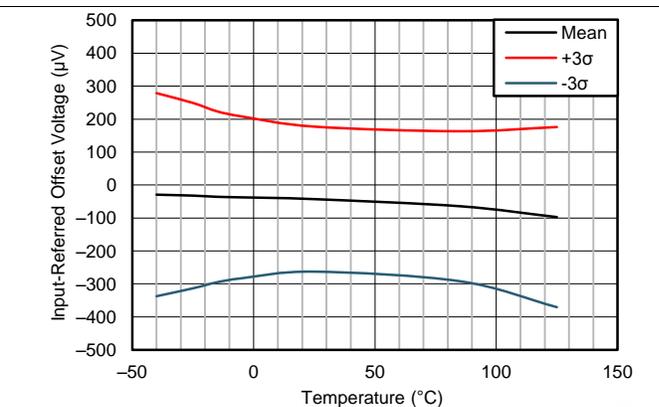
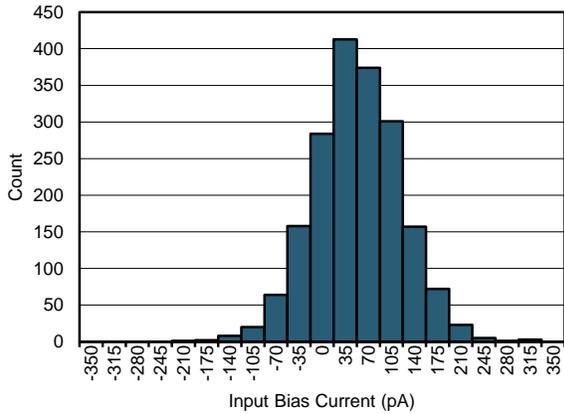


图 6. Input-Referred Offset Voltage vs Temperature

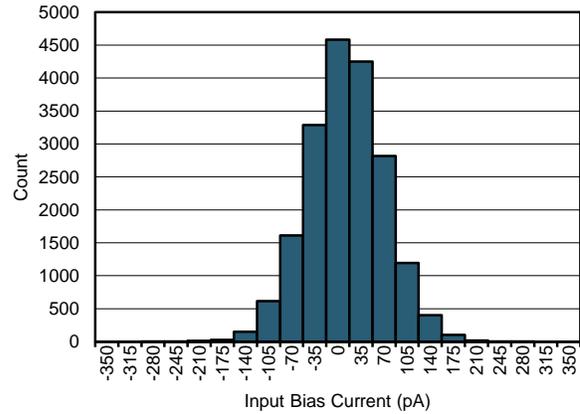
Typical Characteristics (接下页)

At  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)



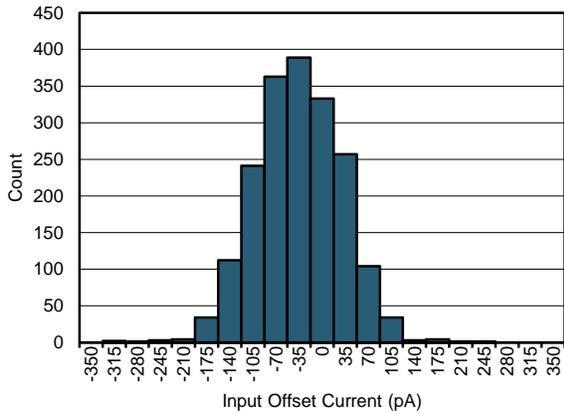
N = 1886  
Std. Dev. = 65.31 pA  
Mean = 36.25 pA

图 7. Typical Distribution of Input Bias Current (25°C)



N = 19081  
Std. Dev. = 57.46 pA  
Mean = -5.32 pA

图 8. Typical Distribution of Input Bias Current (90°C)



N = 1886  
Std. Dev. = 63.86 pA  
Mean = -52.64 pA

图 9. Typical Distribution of Input Offset Current

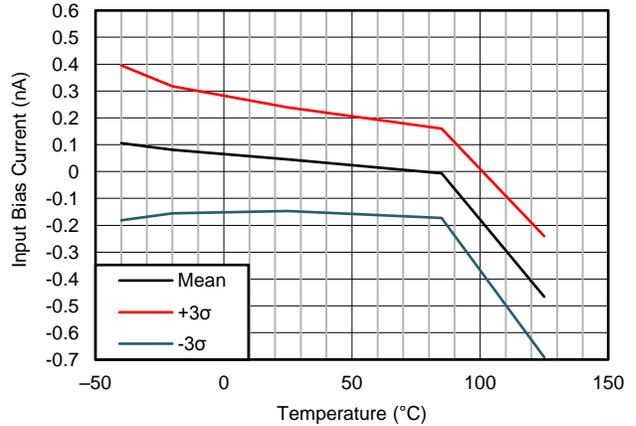


图 10. Input Bias Current vs Temperature

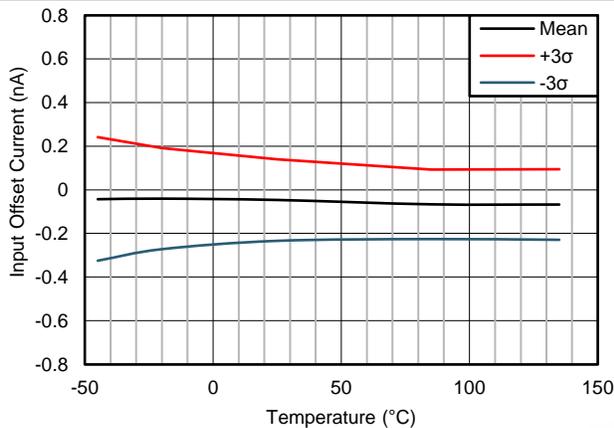
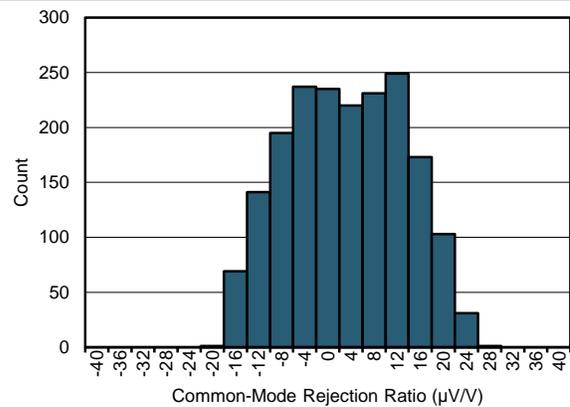


图 11. Input Offset Current vs Temperature

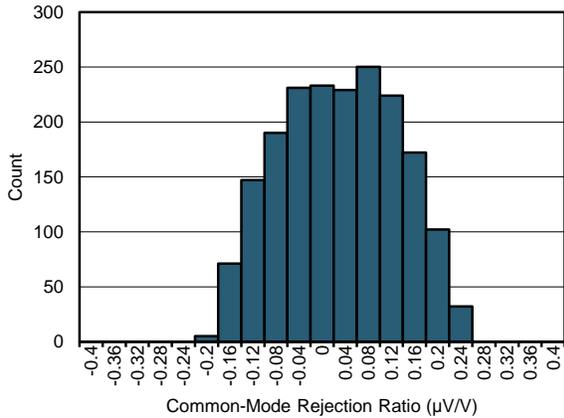


N = 1886  
Std. Dev. = 10.04  $\mu\text{V/V}$   
Mean = 1.18  $\mu\text{V/V}$

图 12. Typical CMRR Distribution (G = 1)

Typical Characteristics (接下页)

At  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)



N = 1886  
Std. Dev. = 0.1  $\mu\text{V/V}$

Mean = 0.01  $\mu\text{V/V}$

图 13. Typical CMRR Distribution (G = 100)

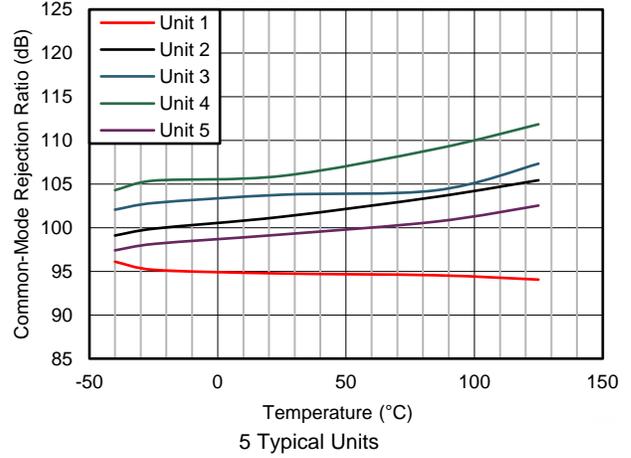


图 14. CMRR vs Temperature (G = 1)

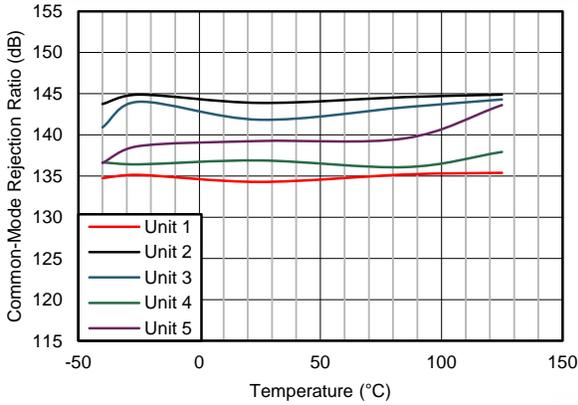


图 15. CMRR vs Temperature (G = 100)

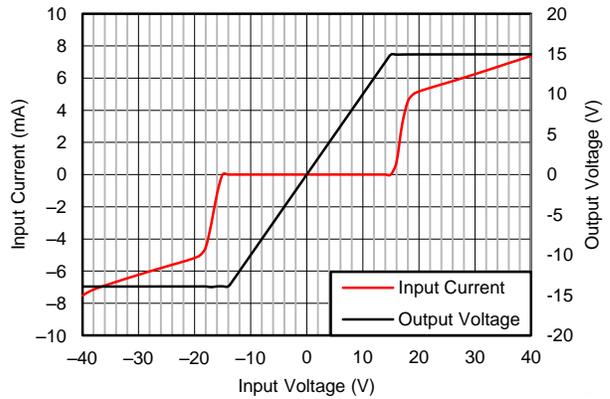


图 16. Input Current vs Input Overvoltage

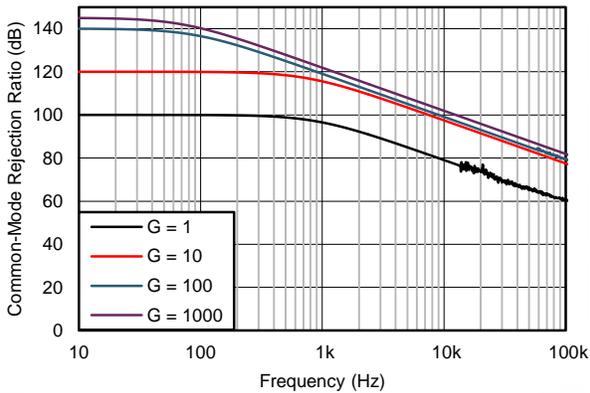


图 17. CMRR vs Frequency (RTI)

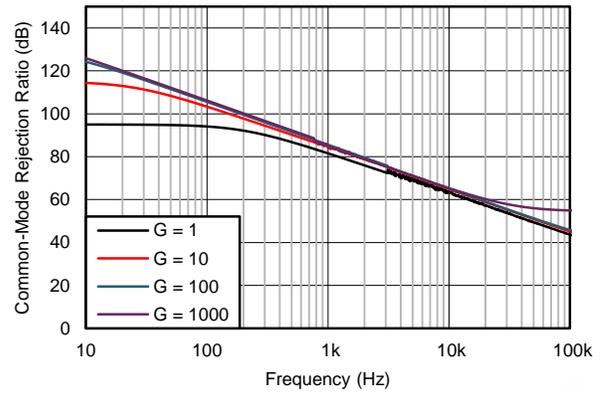
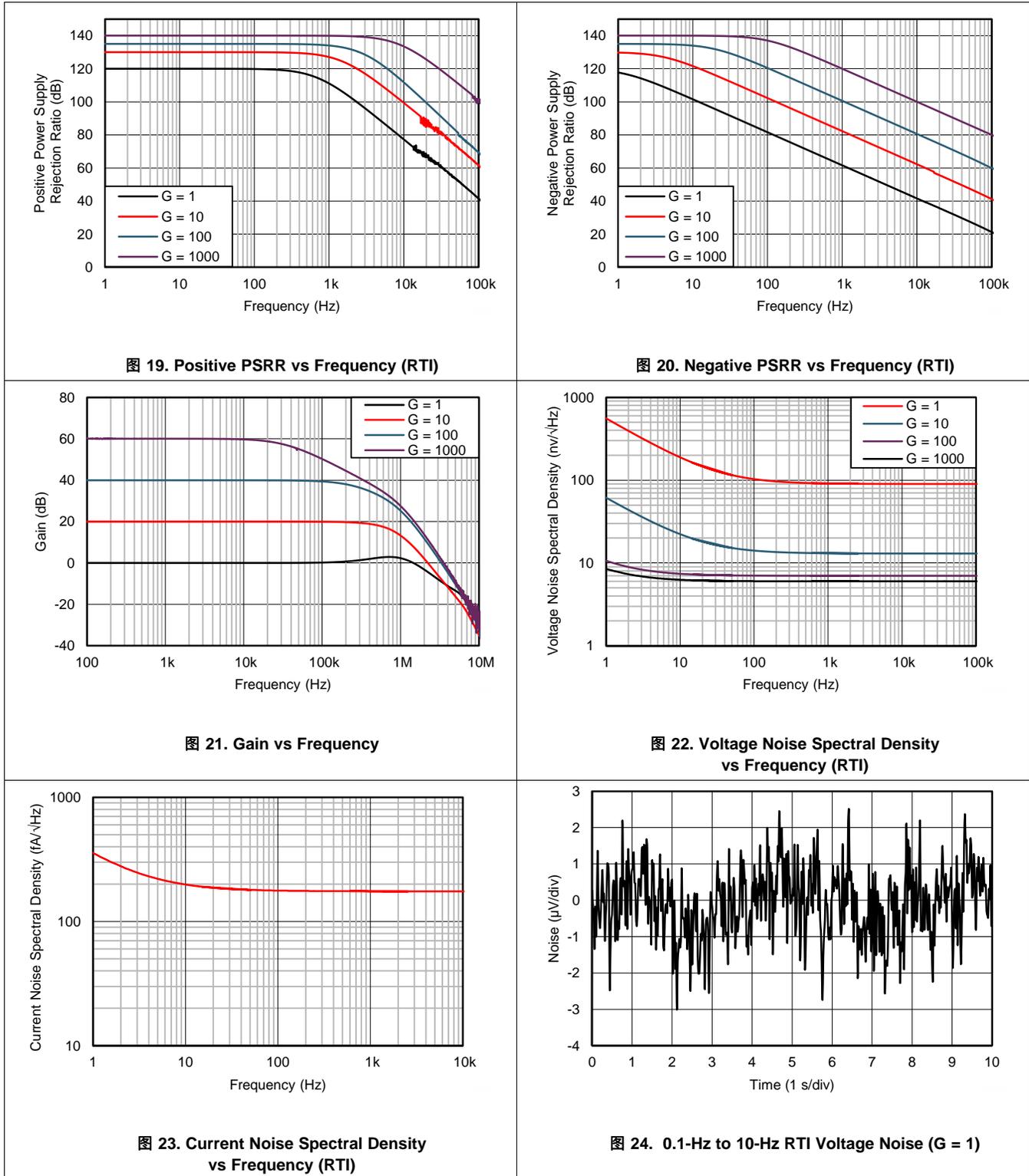


图 18. CMRR vs Frequency (RTI, 1-k $\Omega$  Source Imbalance)

Typical Characteristics (接下页)

At  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)



Typical Characteristics (接下页)

At  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

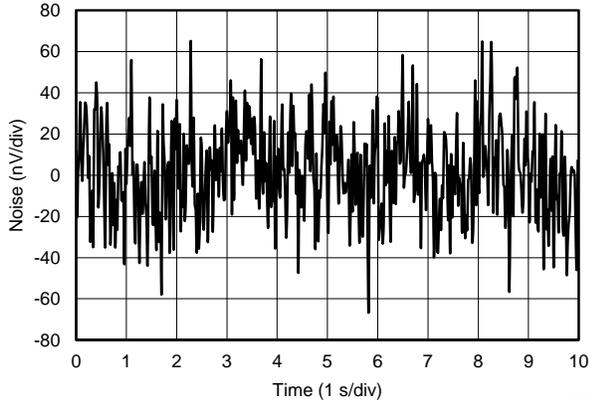


图 25. 0.1-Hz to 10-Hz RTI Voltage Noise ( $G = 1000$ )

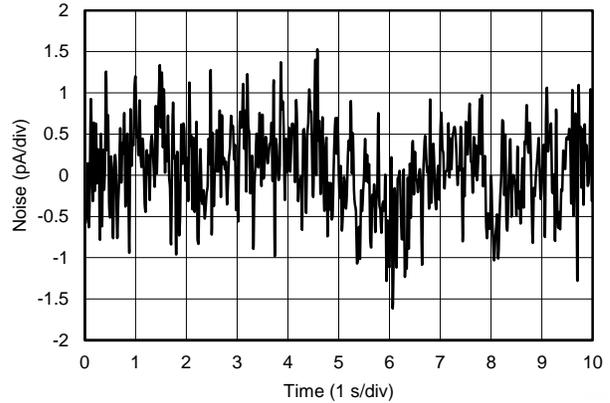


图 26. 0.1-Hz to 10-Hz RTI Current Noise

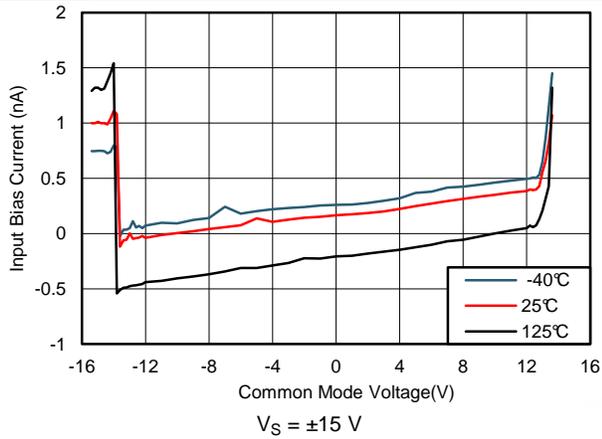


图 27. Input Bias Current vs Common-Mode Voltage

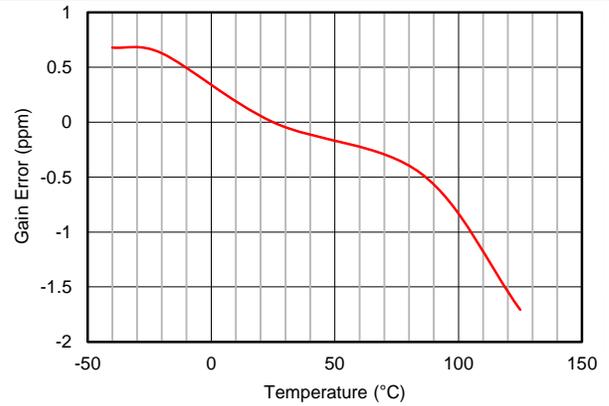


图 28. Gain Error vs Temperature ( $G = 1$ )

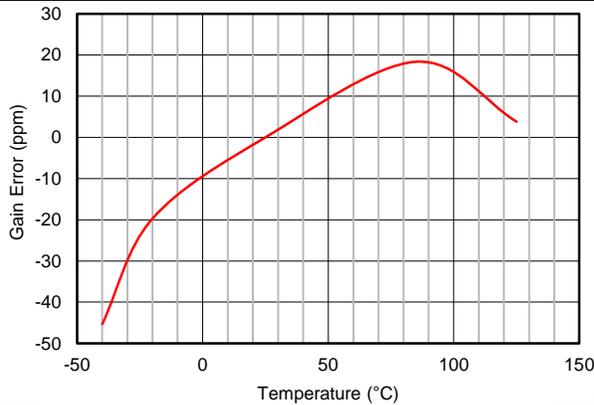


图 29. Gain Error vs Temperature ( $G = 100$ )

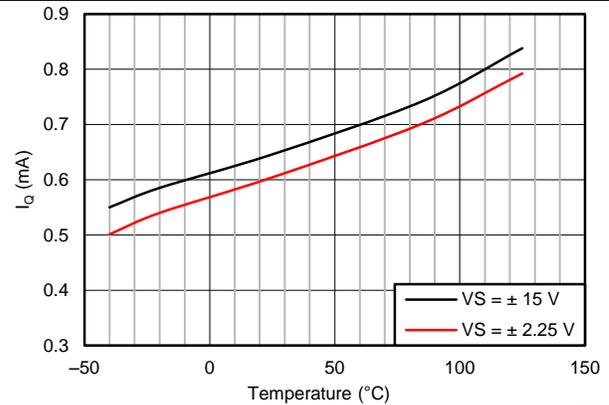


图 30. Supply Current vs Temperature

Typical Characteristics (接下页)

At  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

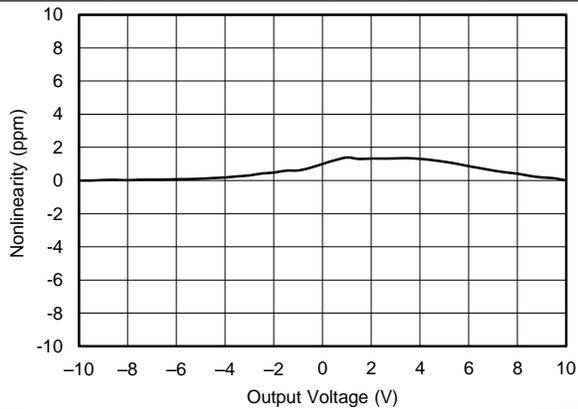


图 31. Gain Nonlinearity (G = 1)

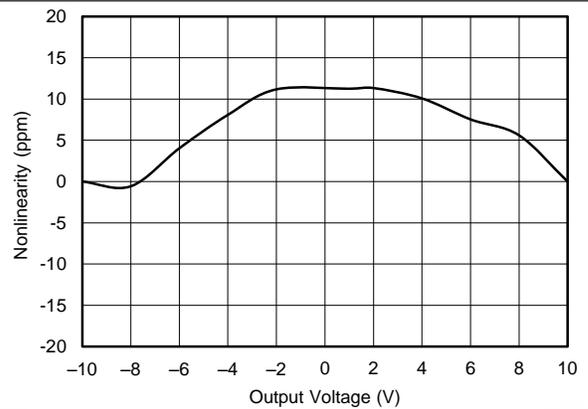


图 32. Gain Nonlinearity (G = 100)

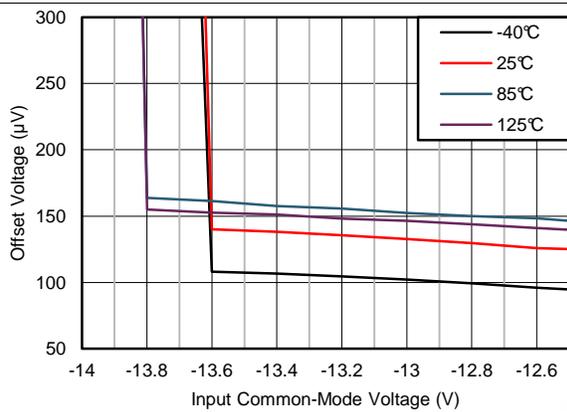


图 33. Offset Voltage vs Negative Common-Mode Voltage

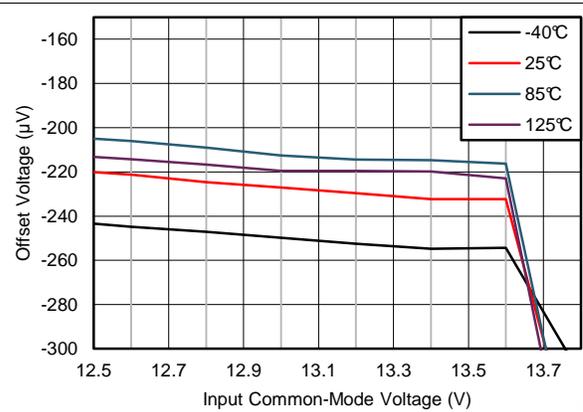


图 34. Offset Voltage vs Positive Common-Mode Voltage

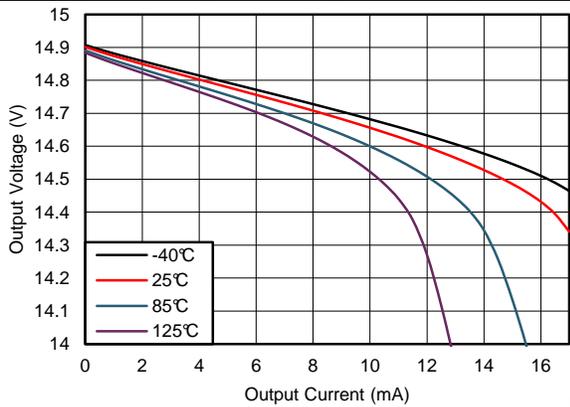


图 35. Positive Output Voltage Swing vs Output Current

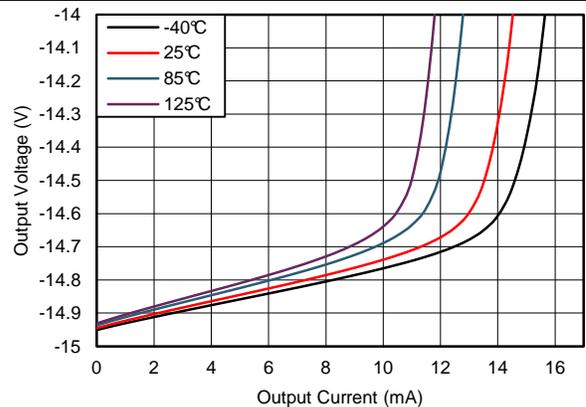


图 36. Negative Output Voltage Swing vs Output Current

Typical Characteristics (接下页)

At  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

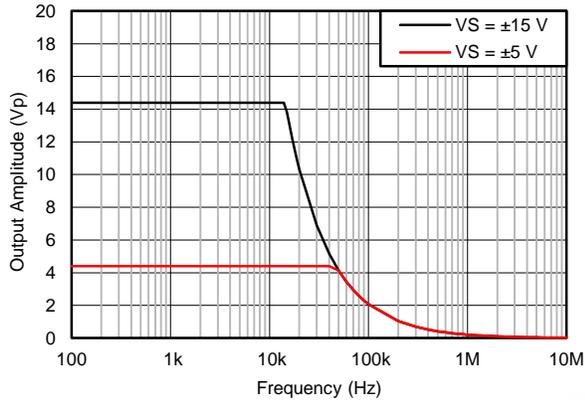
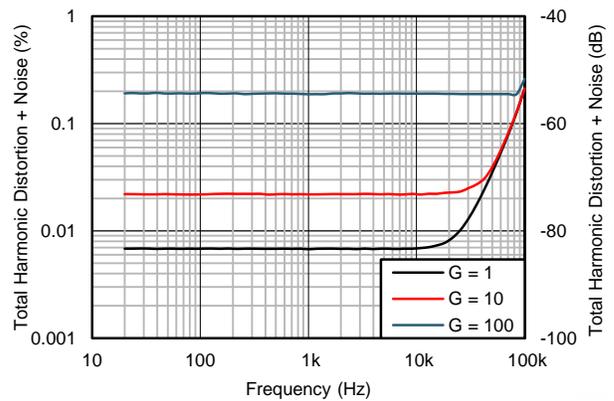


图 37. Large-Signal Frequency Response



500-kHz Measurement bandwidth  
1- $V_{RMS}$  Output voltage  
100-k $\Omega$  Load

图 38. THD+N vs Frequency

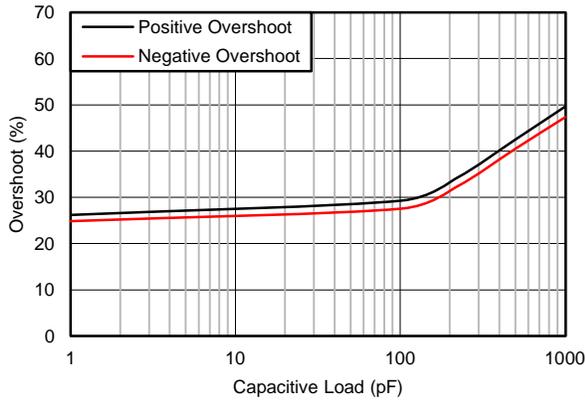
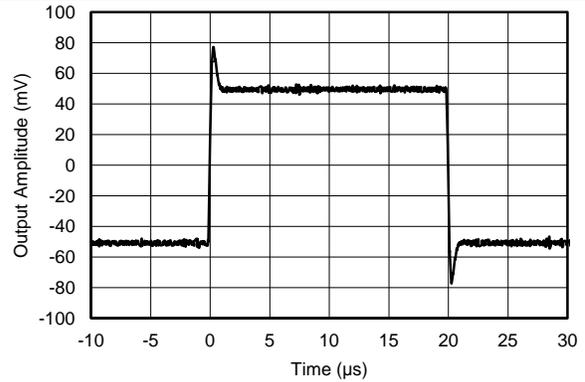
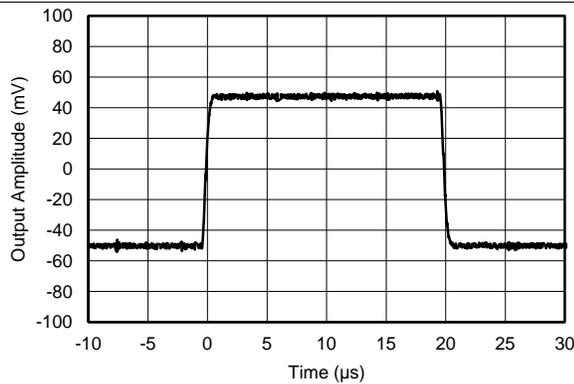


图 39. Overshoot vs Capacitive Loads



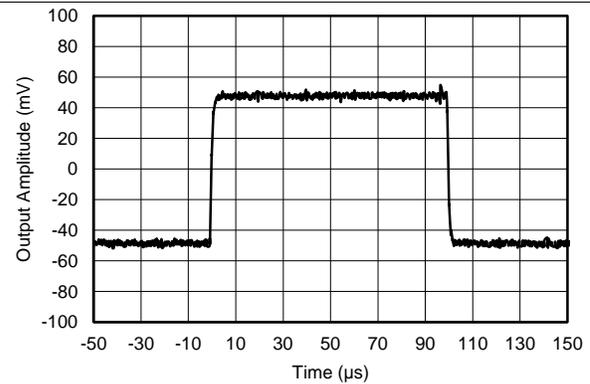
$G = 1$ ,  $R_L = 10\text{ k}\Omega$ ,  $C_L = 100\text{ pF}$

图 40. Small-Signal Response



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

图 41. Small-Signal Response

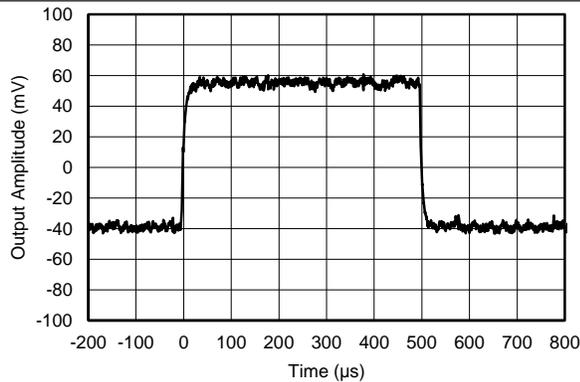


$G = 100$ ,  $R_L = 10\text{ k}\Omega$ ,  $C_L = 100\text{ pF}$

图 42. Small-Signal Response

Typical Characteristics (接下页)

At  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)



$G = 1000$ ,  $R_L = 10\text{ k}\Omega$ ,  $C_L = 100\text{ pF}$

图 43. Small-Signal Response

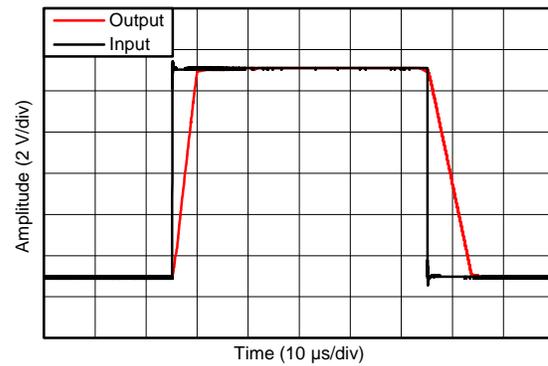


图 44. Large Signal Step Response

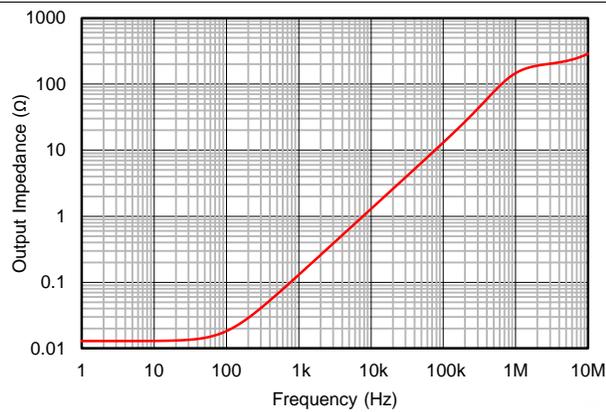


图 45. Closed-Loop Output Impedance

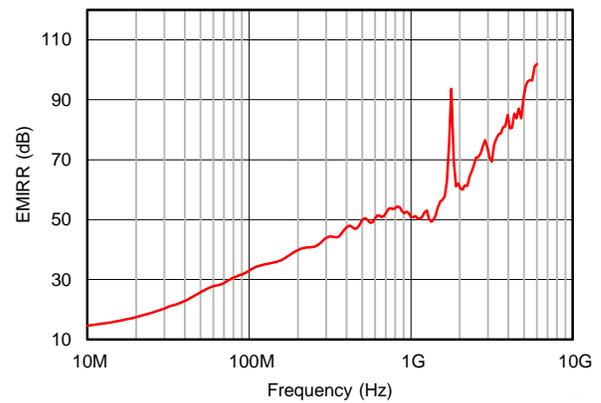


图 46. Differential-Mode EMI Rejection Ratio

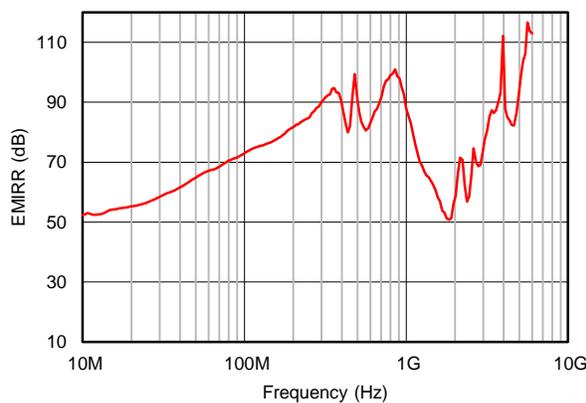
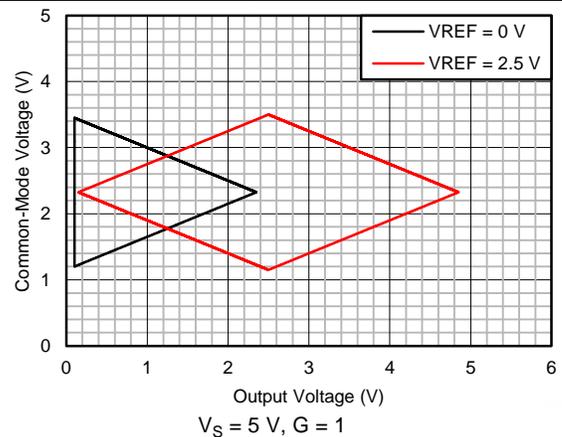


图 47. Common-Mode EMI Rejection Ratio



$V_S = 5\text{ V}$ ,  $G = 1$

图 48. Input Common-Mode Voltage vs Output Voltage

Typical Characteristics (接下页)

At  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

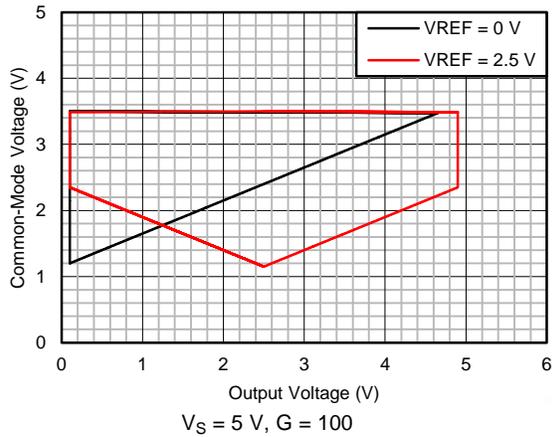


图 49. Input Common-Mode Voltage vs Output Voltage

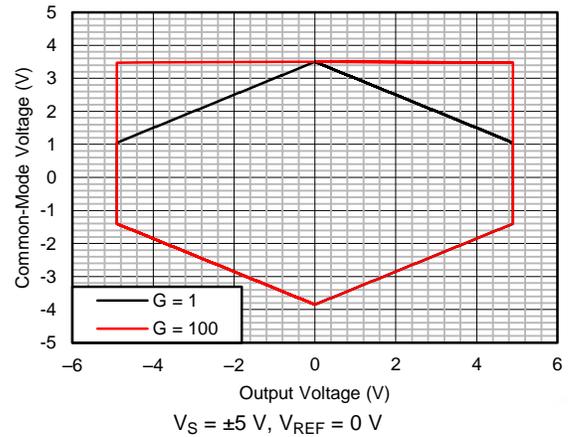


图 50. Input Common-Mode Voltage vs Output Voltage

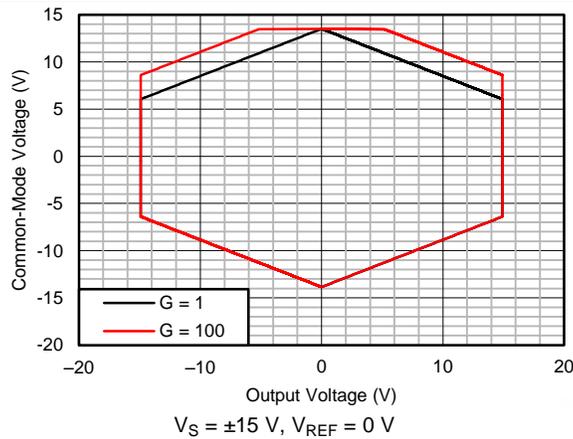


图 51. Input Common-Mode Voltage vs Output Voltage

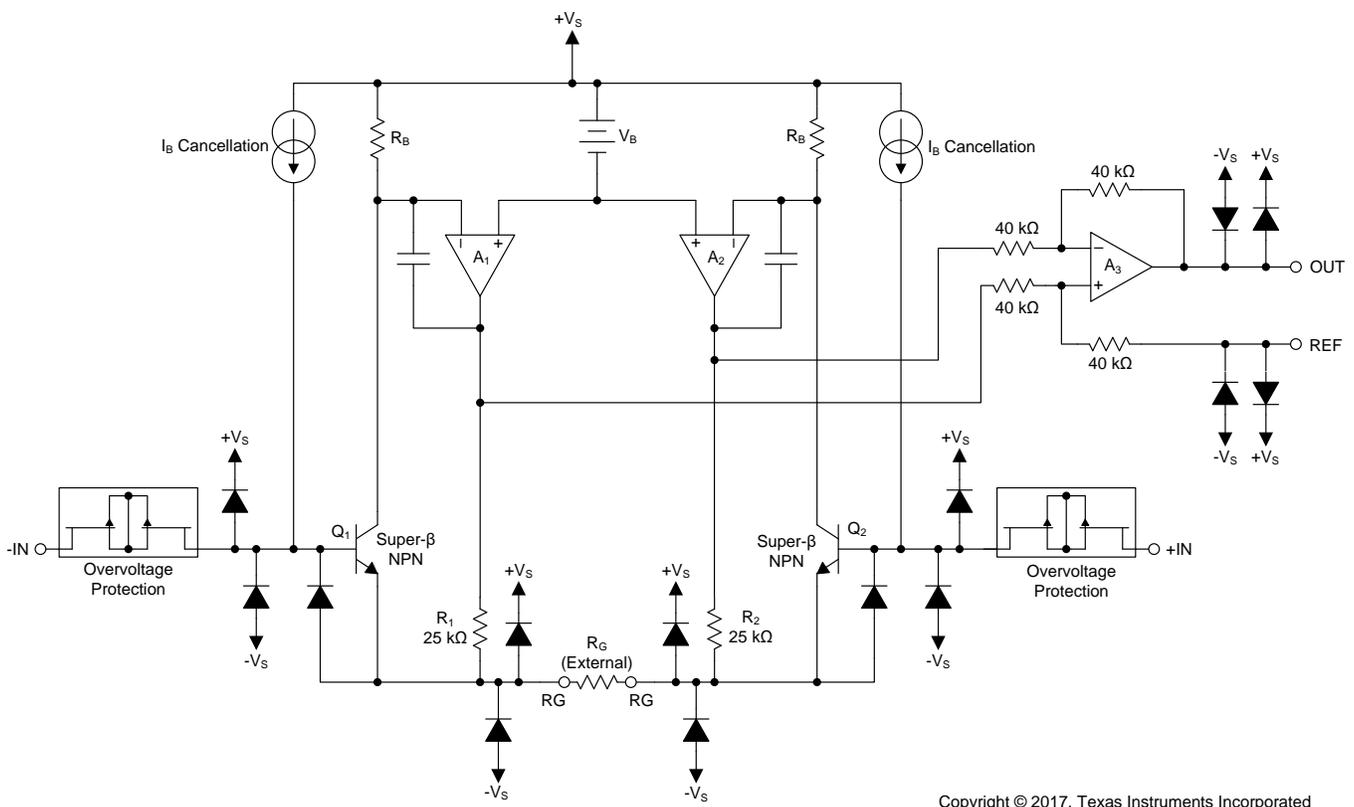
## 7 Detailed Description

### 7.1 Overview

The INA828 is a monolithic precision instrumentation amplifier incorporating a current-feedback input stage and a 4-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 terminal. 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.

Each input is protected by two field-effect transistors (FETs) that provide a low series resistance under normal signal conditions, and preserve excellent noise performance. When excessive voltage is applied, these transistors limit input current to approximately 8 mA.

### 7.2 Functional Block Diagram



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### 7.3 Feature Description

#### 7.3.1 Setting the Gain

图 52 shows that the gain of the INA828 is set by a single external resistor,  $R_G$ , connected between the RG pins (pins 1 and 8).

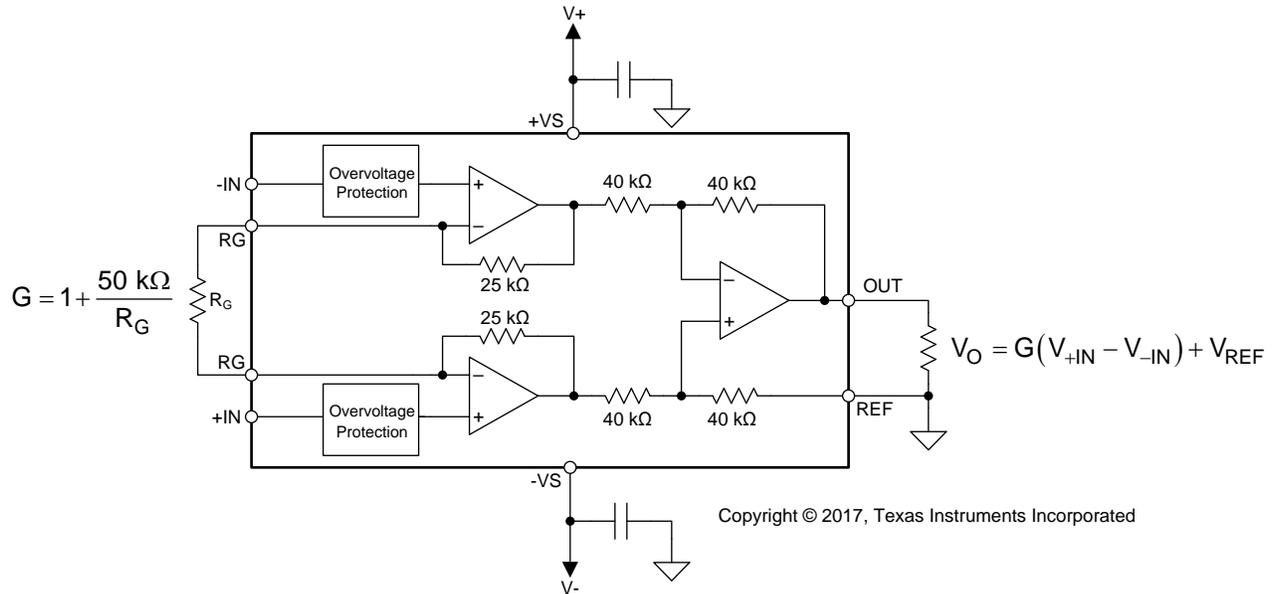


图 52. Simplified Diagram of the INA828 With Gain and Output Equations

The value of  $R_G$  is selected according to:

$$G = 1 + \frac{50 \text{ k}\Omega}{R_G} \tag{1}$$

表 1 lists several commonly-used gains and resistor values. The 50-k $\Omega$  term in 公式 1 comes from the sum of the two internal 25-k $\Omega$  feedback resistors. These on-chip resistors are laser-trimmed to accurate absolute values. The accuracy and temperature coefficients of these resistors are included in the gain accuracy and drift specifications of the INA828.

表 1. Commonly-Used Gains and Resistor Values

DESIRED GAIN	$R_G$ ( $\Omega$ )	NEAREST 1% $R_G$ ( $\Omega$ )
1	NC	NC
2	50 k	49.9 k
5	12.5 k	12.4 k
10	5.556 k	5.49 k
20	2.632 k	2.61 k
50	1.02 k	1.02 k
100	505.1	511
200	251.3	249
500	100.2	100
1000	50.05	49.9

### 7.3.1.1 Gain Drift

The stability and temperature drift of the external gain setting resistor,  $R_G$ , also affects gain. The contribution of  $R_G$  to gain accuracy and drift can be determined from 公式 1.

The best gain drift of 5 ppm/°C (maximum) can be achieved when the INA828 uses  $G = 1$  without  $R_G$  connected. In this case, gain drift is limited only by the slight mismatch of the temperature coefficient of the integrated 40-kΩ resistors in the differential amplifier ( $A_3$ ). At gains greater than 1, gain drift increases as a result of the individual drift of the 25-kΩ resistors in the feedback of  $A_1$  and  $A_2$ , relative to the drift of the external gain resistor  $R_G$ . The low temperature coefficient of the internal feedback resistors significantly improves the overall temperature stability of applications using gains greater than 1 V/V over alternate solutions.

Low resistor values required for high gain can make wiring resistance important. Sockets add to the wiring resistance and contribute additional gain error (such as a possible unstable gain error) at gains of approximately 100 or greater. To assure stability, avoid parasitic capacitance of more than a few picofarads at  $R_G$  connections. Careful matching of any parasitics on both  $R_G$  pins maintains optimal CMRR over frequency; see *Typical Characteristics*, 图 17.

### 7.3.2 EMI Rejection

Texas Instruments developed a method to accurately measure the immunity of an amplifier over a broad frequency spectrum, extending from 10 MHz to 6 GHz. This method uses an EMI rejection ratio (EMIRR) to quantify the ability of the INA828 to reject EMI. The offset resulting from an input EMI signal can be calculated using 公式 2:

$$\Delta V_{OS} = \left( \frac{V_{RF\_PEAK}^2}{100 \text{ mV}_P} \right) \cdot 10^{-\left( \frac{EMIRR \text{ (dB)}}{20} \right)}$$

where

- $V_{RF\_PEAK}$  is the peak amplitude of the input EMI signal. (2)

图 53 and 图 54 show the INA828 EMIRR graph for both differential and common-mode EMI rejection across this frequency range. 表 2 shows the EMIRR values for the INA828 at frequencies commonly encountered in real-world applications. Applications listed in 表 2 can be centered on or operated near the particular frequency shown. Depending on the end-system requirements, additional EMI filters may be required near the signal inputs of the system, as well as incorporating known good practices such as using short traces, low-pass filters, and damping resistors combined with parallel and shielded signal routing.

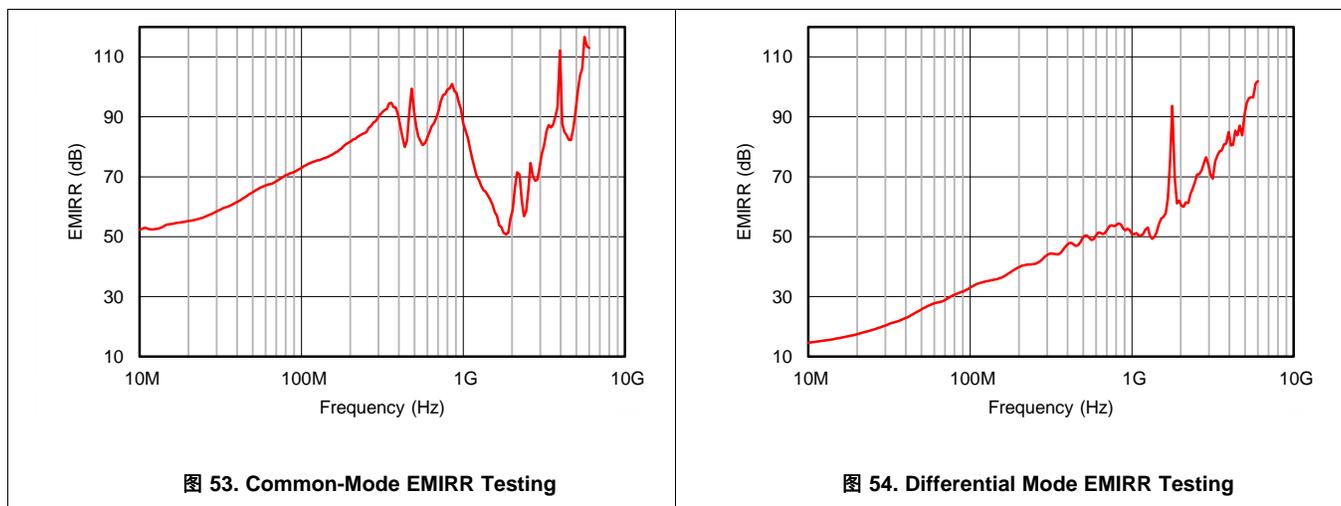
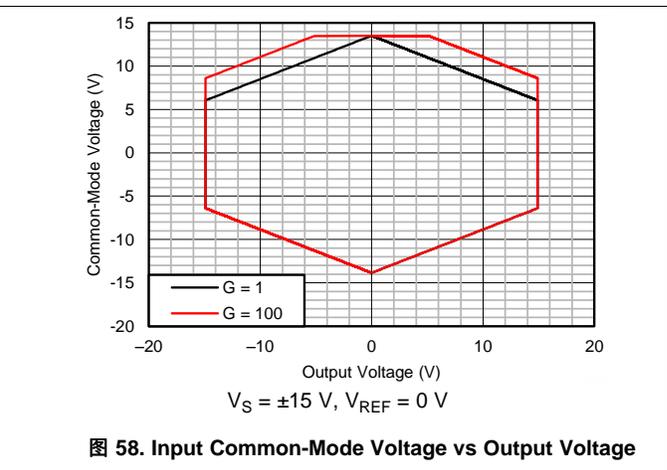
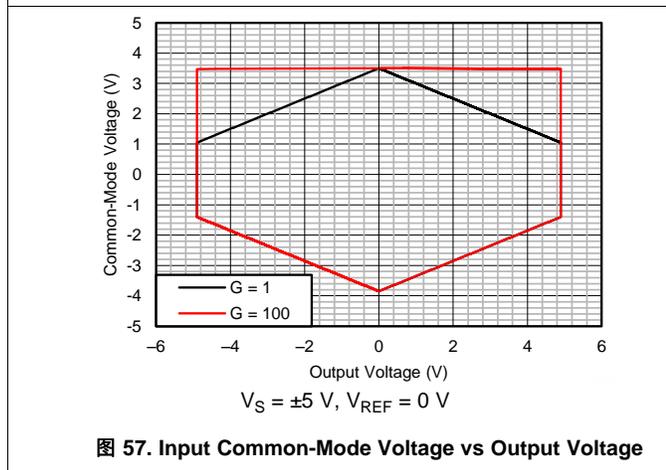
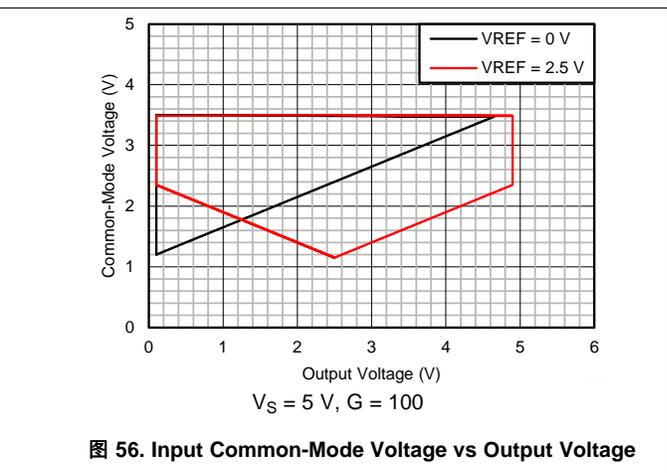
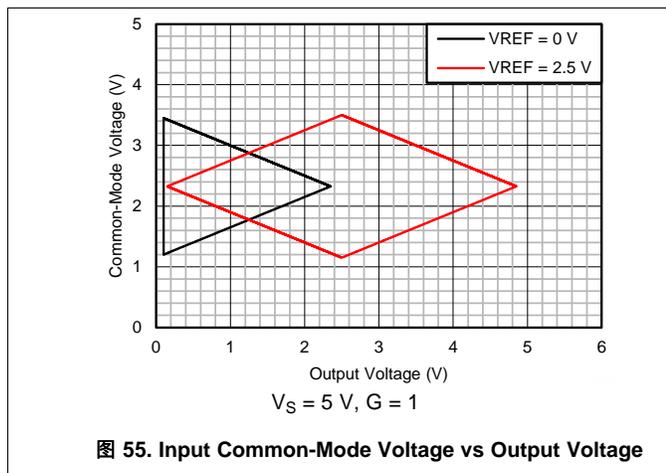


表 2. INA828 EMIRR for Frequencies of Interest

FREQUENCY	APPLICATION OR ALLOCATION	DIFFERENTIAL EMIRR	COMMON-MODE EMIRR
400 MHz	Mobile radio, mobile satellite, space operation, weather, radar, ultrahigh-frequency (UHF) applications	48 dB	87 dB
900 MHz	Global system for mobile communications (GSM) applications, radio communication, navigation, GPS (up to 1.6 GHz), GSM, aeronautical mobile, UHF applications	52 dB	98 dB
1.8 GHz	GSM applications, mobile personal communications, broadband, satellite, L-band (1 GHz to 2 GHz)	94 dB	51 dB
2.4 GHz	802.11b, 802.11g, 802.11n, Bluetooth®, mobile personal communications, industrial, scientific and medical (ISM) radio band, amateur radio and satellite, S-band (2 GHz to 4 GHz)	66 dB	57 dB
3.6 GHz	Radiolocation, aero communication and navigation, satellite, mobile, S-band	79 dB	87 dB
5 GHz	802.11a, 802.11n, aero communication and navigation, mobile communication, space and satellite operation, C-band (4 GHz to 8 GHz)	90 dB	92 dB

### 7.3.3 Input Common-Mode Range

The linear input voltage range of the INA828 input circuitry extends within 2 Volts of both power supplies and maintains excellent common-mode rejection throughout this range. The common-mode range for the most common operating conditions are shown in 图 55, 图 56, and 图 51. The common-mode range for other operating conditions is best calculated using the *INA common-mode range calculating tool*. The INA828 device can operate over a wide range of power supplies and VREF configurations, thus providing a comprehensive guide to common-mode range limits for all possible conditions is impractical.



### 7.3.4 Input Protection

The inputs of the INA828 device are individually protected for voltages up to  $\pm 40$  V. For example, a condition of  $-40$  V on one input and  $40$  V on the other input does not cause damage. Internal circuitry on each input provides low series impedance under normal signal conditions. If the input is overloaded, the protection circuitry limits the input current to a value of approximately  $8$  mA.

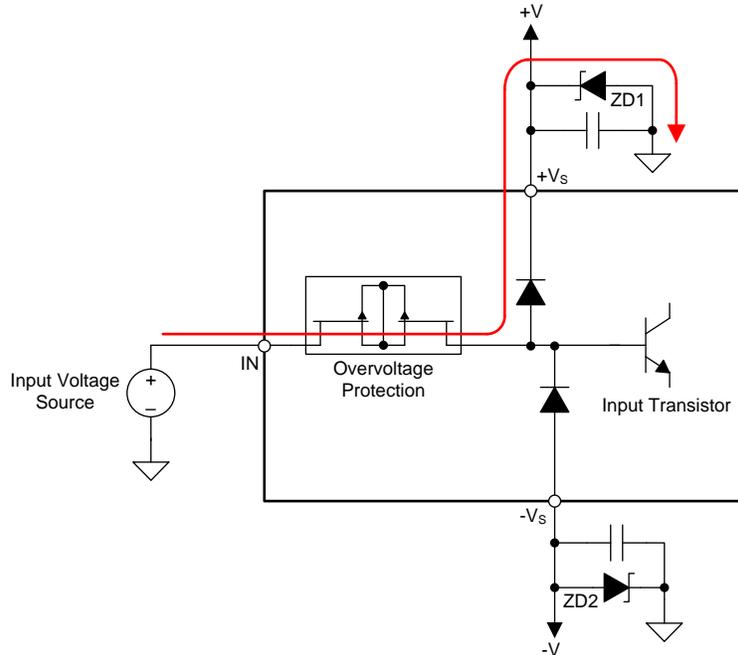


图 59. Input Current Path During an Overvoltage Condition

During an input overvoltage condition, current flows through the input protection diodes into the power supplies, see 图 59. If the power supplies are unable to sink current, then Zener diode clamps (ZD1 and ZD2 in 图 59) must be placed on the power supplies to provide a current pathway to ground. 图 60 illustrates the input current for input voltages from  $-40$  V to  $+40$  V when the INA828 is powered by  $\pm 15$ -V supplies.

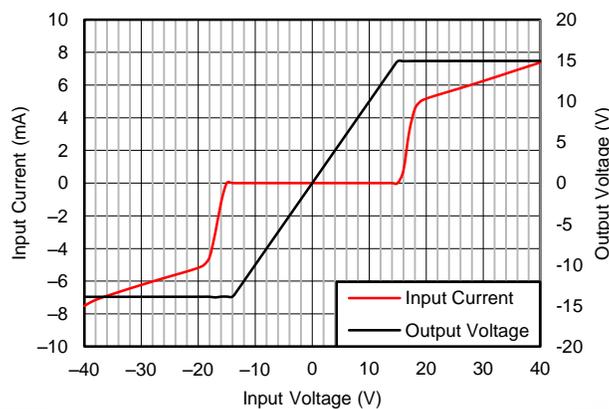


图 60. Input Current vs Input Overvoltage

### 7.3.5 Operating Voltage

The INA828 operates over a power-supply range of 4.5 V to 36 V ( $\pm 2.25$  V to  $\pm 18$  V).

#### 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 the *Typical Characteristics* section of this data sheet.

### 7.4 Device Functional Modes

The INA828 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 INA828 is 36 V ( $\pm 18$  V).

## 8 Application and Implementation

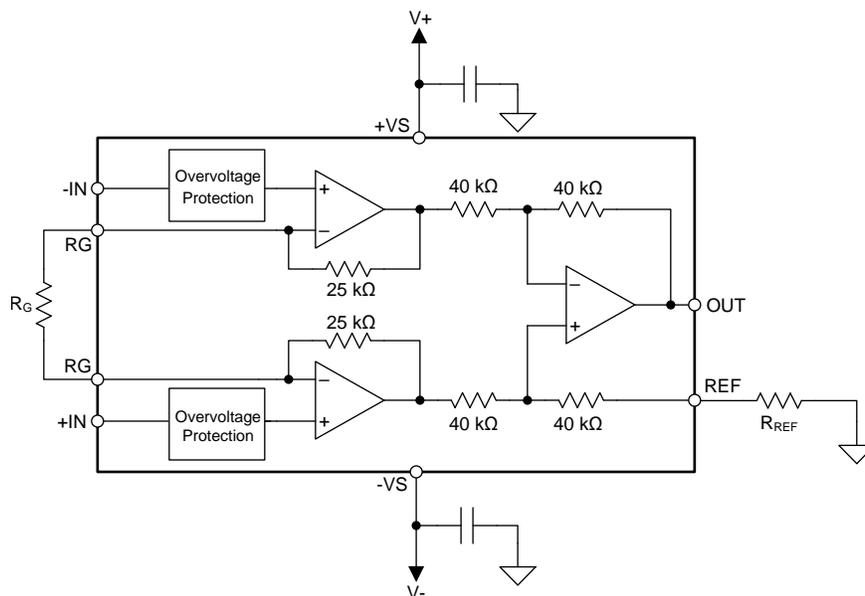
### 注

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

### 8.1 Reference Terminal

The output voltage of the INA828 is developed with respect to the voltage on the reference terminal, REF. Often, in dual-supply operation, the reference pin (pin 6) is connected to the low-impedance system ground. In single-supply operation, offsetting the output signal to a precise mid-supply level is useful (for example, 2.5 V in a 5-V supply environment). To accomplish this level shift, a voltage source must be connected to the REF pin to level-shift the output so that the INA828 can drive a single-supply ADC.

The voltage source applied to the reference terminal must have a low output impedance. As illustrated in [图 61](#), any resistance at the reference terminal (shown as  $R_{REF}$  in [图 61](#)) is in series with one of the internal 40-k $\Omega$  resistors.



**图 61. Parasitic Resistance Shown at the Reference Terminal**

The parasitic resistance at the reference terminal,  $R_{REF}$ , creates an imbalance in the 4 resistors of the internal difference amplifier, resulting in degraded common-mode rejection ratio (CMRR). [图 62](#) shows the degradation in CMRR of the INA828 for increasing resistance at the reference terminal. For the best performance, keep the source impedance to the REF terminal,  $R_{REF}$ , below 5  $\Omega$ .

Reference Terminal (接下页)

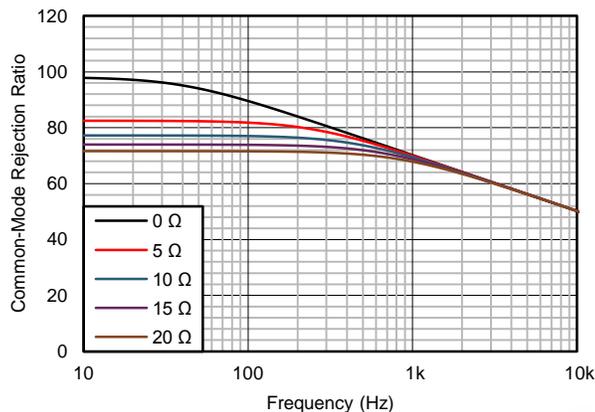
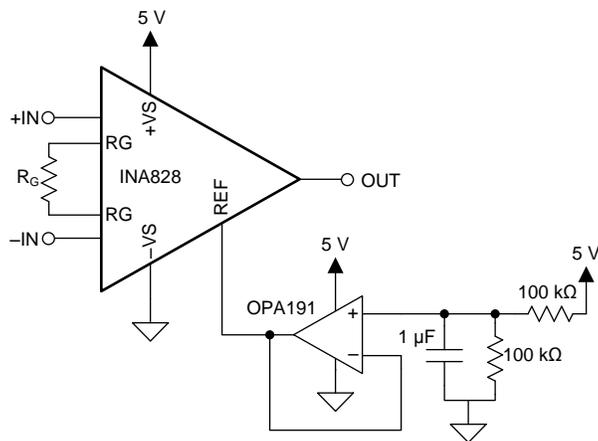


图 62. The Effect of Increasing Resistance at the Reference Terminal

Voltage reference ICs are an excellent option for providing a low-impedance voltage source for the reference terminal. However, if a resistor voltage divider is used to generate a reference voltage, it must be buffered by an op amp as shown in 图 63 to avoid CMRR degradation.



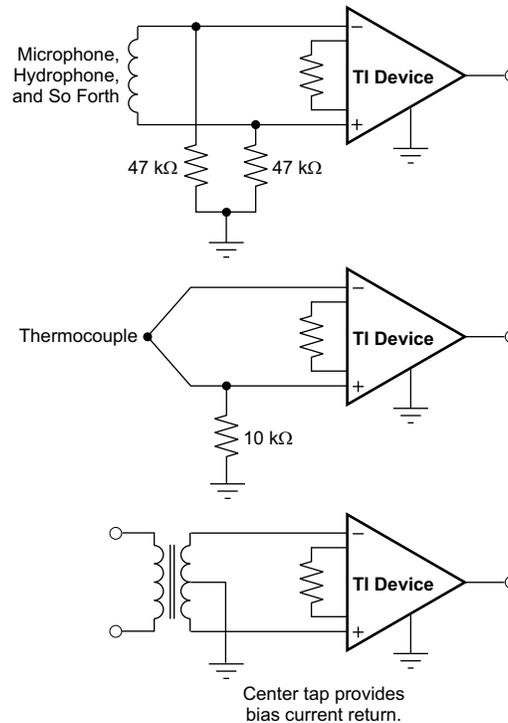
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图 63. Using an Op Amp to Buffer Reference Voltages

## 8.2 Input Bias Current Return Path

The input impedance of the INA828 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 150 pA. High input impedance means that this input bias current changes very little with varying input voltage.

Input circuitry must provide a path for this input bias current for proper operation. 图 64 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 INA828, and the input amplifiers saturate. If the differential source resistance is low, the bias current return path can be connected to one input (as shown in the thermocouple example in 图 64). 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.



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**图 64. Providing an Input Common-Mode Current Path**

### 8.3 PCB Assembly Effects on Precision

The printed-circuit board (PCB) assembly process, including reflow soldering, imparts thermal stresses on the INA828 which can degrade the precision of the device and must be considered in the development of very-high-precision systems. Baking the PCBs after the assembly process can restore the precision of the device to pre-assembly values. 图 65, 图 66, and 图 67 illustrate the effect of reflow soldering on the typical distribution of input offset voltage of the INA828. 图 65 shows the distribution of input offset voltage for a set of INA828 devices prior to the PCB assembly process. Exposing the INA828 to a JEDEC-standard thermal profile for reflow soldering produces the histogram shown in 图 66 on another set of INA828 devices. The standard deviation of input offset voltage has almost doubled due to the thermal stress imparted to the INA828 from the reflow process. However, baking INA828 units for 30 minutes at 125°C after the reflow soldering process produced the distribution given in 图 67. The post-reflow bake restored the standard deviation of the input offset voltage to pre-assembly levels.

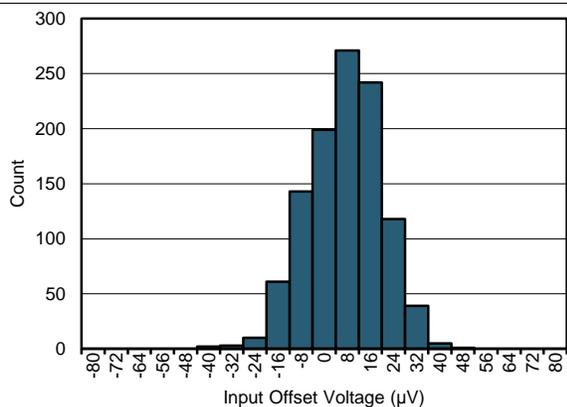


图 65. Typical Distribution of INA828 Input Offset Voltage Prior to Reflow Soldering

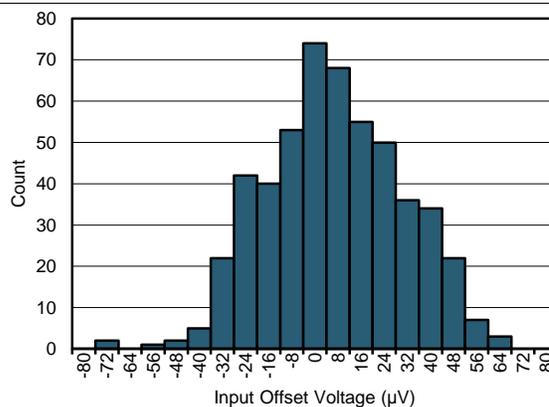


图 66. Typical Distribution of INA828 Input Offset Voltage After Reflow Soldering

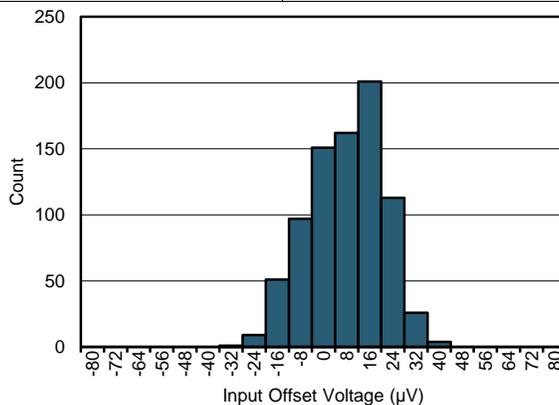
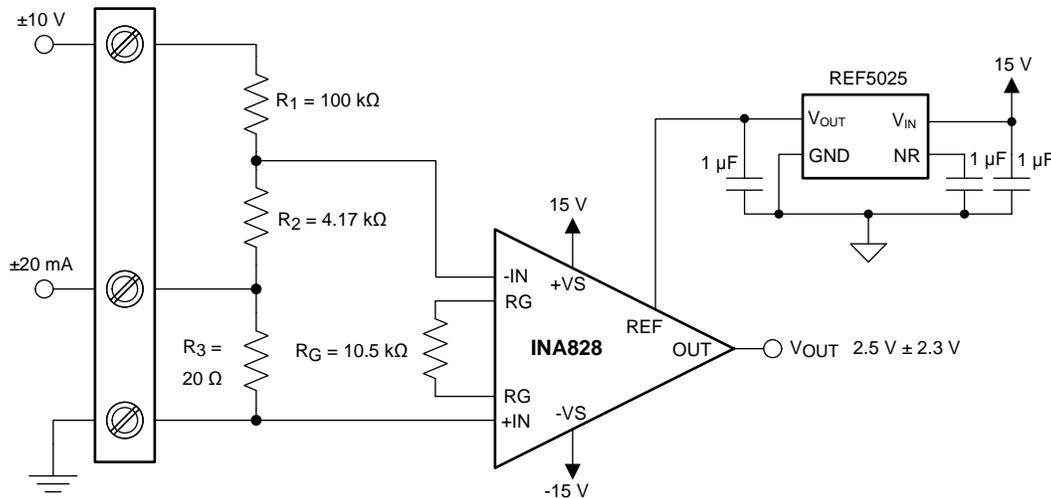


图 67. Typical Distribution of Post-Reflow INA828 Units Baked at 125°C for 30 Minutes

## 8.4 Typical Application

图 68 shows a three-terminal programmable-logic controller (PLC) design for the INA828. This PLC reference design accepts inputs of  $\pm 10\text{ V}$  or  $\pm 20\text{ mA}$ . The output is a single-ended voltage of  $2.5\text{ V} \pm 2.3\text{ V}$  (or  $200\text{ mV}$  to  $4.8\text{ V}$ ). Many PLCs typically have these input and output ranges.



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图 68. PLC Input ( $\pm 10\text{ V}$ ,  $4\text{ mA}$  to  $20\text{ mA}$ )

### 8.4.1 Design Requirements

For this application, the design requirements are:

- $4\text{-mA}$  to  $20\text{-mA}$  input with less than  $20\text{-}\Omega$  burden
- $\pm 20\text{-mA}$  input with less than  $20\text{-}\Omega$  burden
- $\pm 10\text{-V}$  input with impedance of approximately  $100\text{ k}\Omega$
- Maximum  $4\text{-mA}$  to  $20\text{-mA}$  or  $\pm 20\text{-mA}$  burden voltage equal to  $\pm 0.4\text{ V}$
- Output range within  $0\text{ V}$  to  $5\text{ V}$

### 8.4.2 Detailed Design Procedure

There are two modes of operation for the circuit shown in 图 68: current input and voltage input. This design requires  $R_1 \gg R_2 \gg R_3$ . Given this relationship, 公式 3 calculates the current input mode transfer function.

$$V_{\text{OUT-I}} = V_{\text{D}} \times G + V_{\text{REF}} = -(I_{\text{IN}} \times R_3) \times G + V_{\text{REF}}$$

where

- $G$  represents the gain of the instrumentation amplifier
- $V_{\text{D}}$  represents the differential voltage at the INA828 inputs
- $V_{\text{REF}}$  is the voltage at the INA828 REF pin
- $I_{\text{IN}}$  is the input current

(3)

公式 4 shows the transfer function for the voltage input mode.

$$V_{\text{OUT-V}} = V_{\text{D}} \times G + V_{\text{REF}} = -\left[V_{\text{IN}} \times \frac{R_2}{R_1 + R_2}\right] \times G + V_{\text{REF}}$$

where

- $V_{\text{IN}}$  is the input voltage

(4)

$R_1$  sets the input impedance of the voltage input mode. The minimum typical input impedance is  $100\text{ k}\Omega$ .  $100\text{ k}\Omega$  is selected for  $R_1$  because increasing the  $R_1$  value also increases noise. The value of  $R_3$  must be extremely small compared to  $R_1$  and  $R_2$ .  $20\text{ }\Omega$  for  $R_3$  is selected because that resistance value is much smaller than  $R_1$  and yields an input voltage of  $\pm 400\text{ mV}$  when operated in current mode ( $\pm 20\text{ mA}$ ).

**Typical Application (接下页)**

Use 公式 5 to calculate  $R_2$  given  $V_D = \pm 400\text{ mV}$ ,  $V_{IN} = \pm 10\text{ V}$ , and  $R_1 = 100\text{ k}\Omega$ .

$$V_D = V_{IN} \times \frac{R_2}{R_1 + R_2} \rightarrow R_2 = \frac{R_1 \times V_D}{V_{IN} - V_D} = 4.167\text{ k}\Omega \tag{5}$$

The value obtained from 公式 5 is not a standard 0.1% value, so 4.17 kΩ is selected.  $R_1$  and  $R_2$  also use 0.1% tolerance resistors to minimize error.

Use 公式 6 to calculate the ideal gain of the instrumentation amplifier.

$$G = \frac{V_{OUT} - V_{REF}}{V_D} = \frac{4.8\text{ V} - 2.5\text{ V}}{400\text{ mV}} = 5.75 \frac{\text{V}}{\text{V}} \tag{6}$$

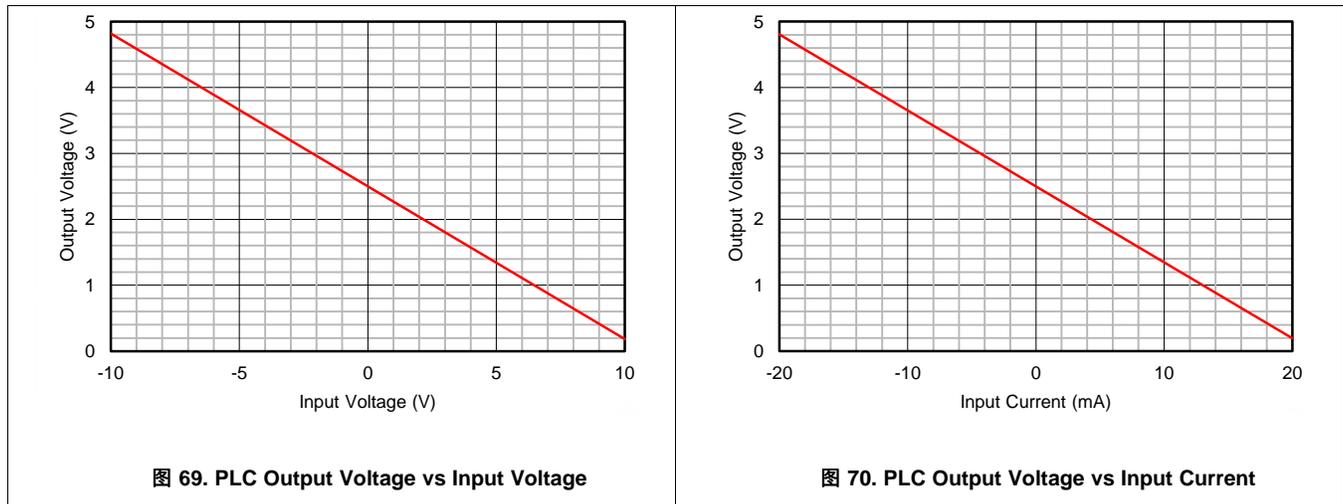
公式 7 calculates the gain-setting resistor value using the INA828 gain equation, 公式 1.

$$R_G = \frac{50\text{ k}\Omega}{G - 1} = \frac{50\text{ k}\Omega}{5.75 - 1} = 10.5\text{ k}\Omega \tag{7}$$

10.5 kΩ is a standard 0.1% resistor value that can be used in this design.

**8.4.3 Application Curves**

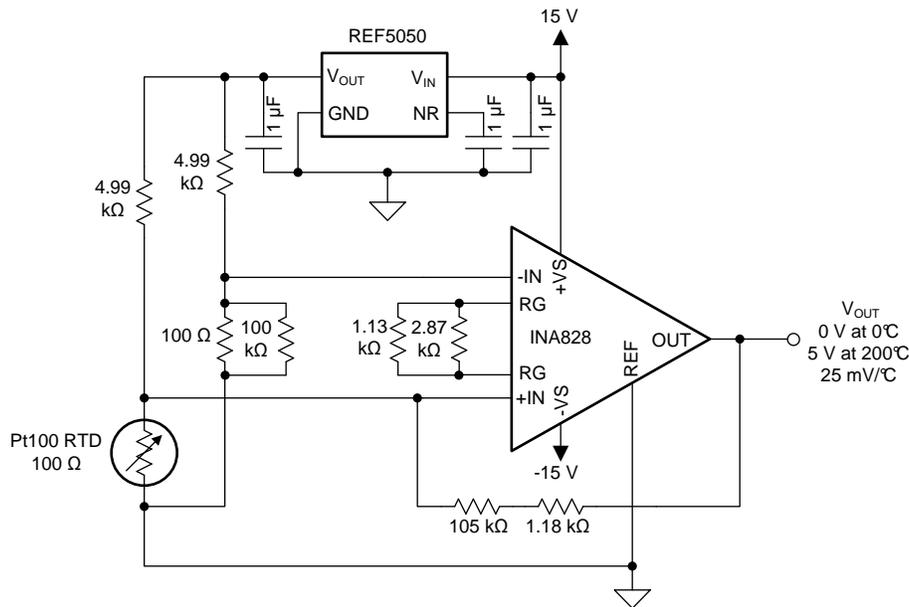
图 69 and 图 70 show typical characteristic curves for the circuit in 图 68.



## 8.5 Other Application Examples

### 8.5.1 Resistance Temperature Detector Interface

图 71 illustrates a 3-wire interface circuit for resistance temperature detectors (RTDs). The circuit incorporates analog linearization and has an output voltage range from 0 to 5 V. The linearization technique employed is described in *Analog linearization of resistance temperature detectors*. Series and parallel combinations of standard 1% resistor values are used to achieve less than 0.02°C of error over a 200°C temperature span.



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图 71. A 3-Wire Interface for RTDs With Analog Linearization

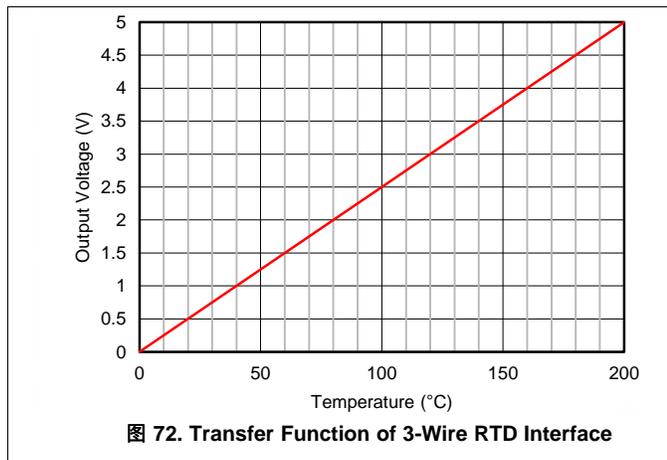


图 72. Transfer Function of 3-Wire RTD Interface

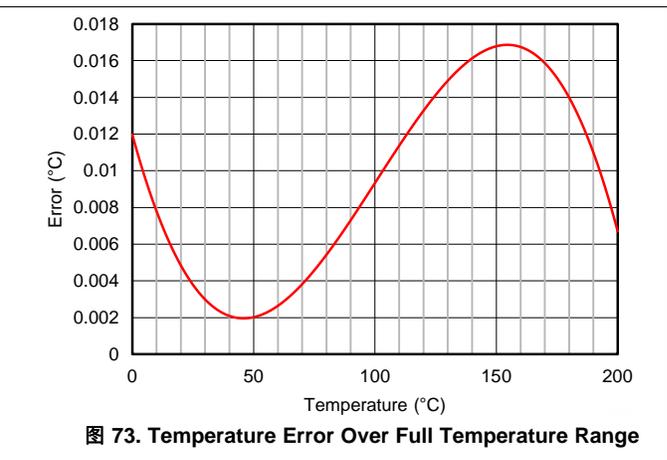


图 73. Temperature Error Over Full Temperature Range

## 9 Power Supply Recommendations

The nominal performance of the INA828 is specified with a supply voltage of  $\pm 15$  V and mid-supply reference voltage. The device can also be operated using power supplies from  $\pm 1.5$  V (3 V) to  $\pm 18$  V (36 V) and non mid-supply reference voltages with excellent performance. Parameters that can vary significantly with operating voltage and reference voltage are illustrated in the [Typical Characteristics](#) section.

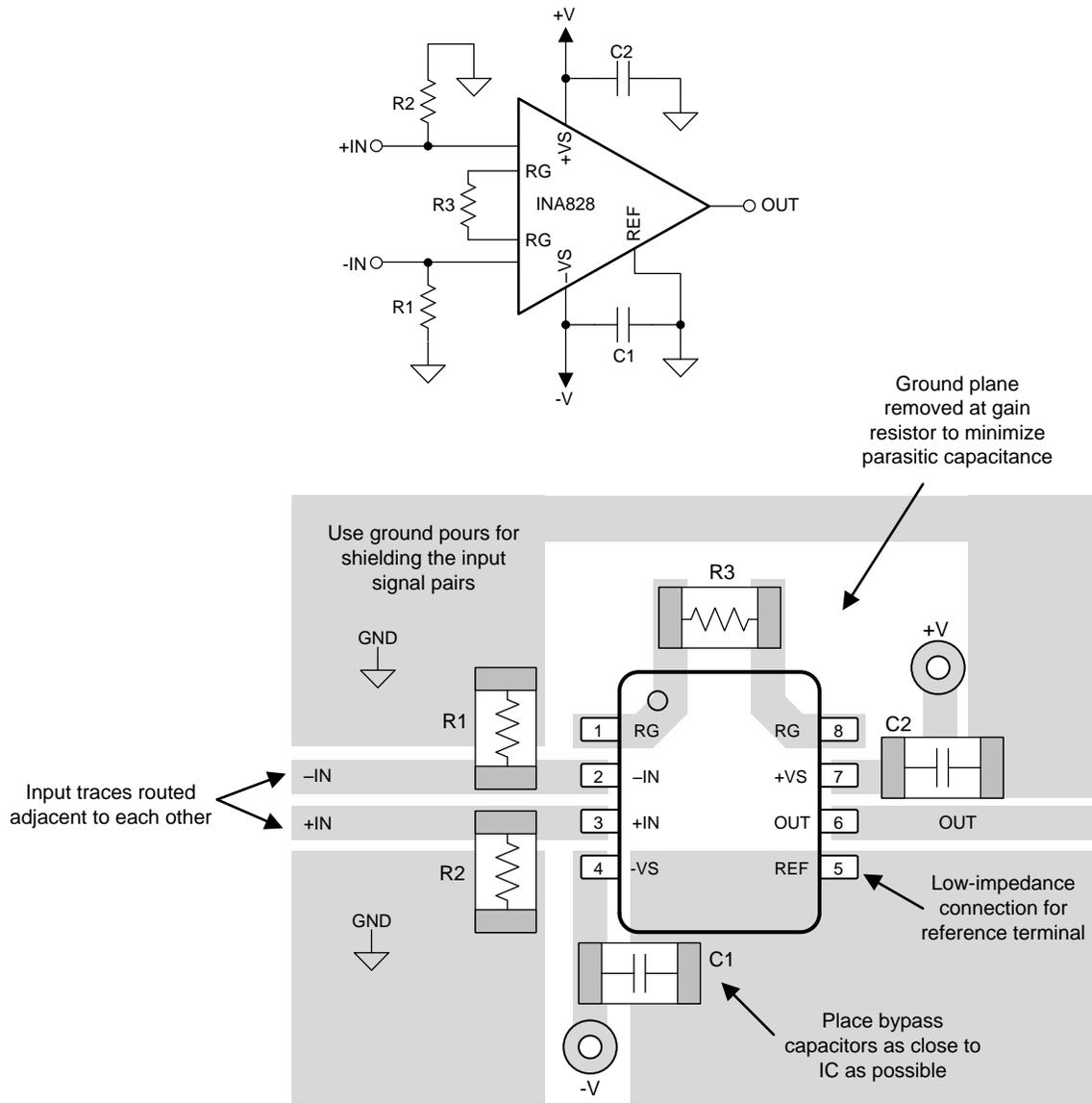
## 10 Layout

### 10.1 Layout Guidelines

Attention to good layout practices is always recommended. For best operational performance of the device, use good PCB layout practices, including:

- Care must be taken to assure that both input paths are well-matched for source impedance and capacitance to avoid converting common-mode signals into differential signals. In addition, parasitic capacitance at the gain-setting pins can also affect CMRR over frequency. For example, in applications that implement gain switching using switches or PhotoMOS<sup>®</sup> relays to change the value of  $R_G$ , select the component so that the switch capacitance is as small as possible.
- Noise can propagate into analog circuitry through the power pins of the circuit as a whole and of the device itself. Bypass capacitors are used to 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  $V+$  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 as close to the device as possible. As illustrated in [图 74](#), keeping  $R_G$  close to the pins minimizes parasitic capacitance.
- Keep the traces as short as possible.

## 10.2 Layout Example



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图 74. Example Schematic and Associated PCB Layout

## 11 器件和文档支持

### 11.1 Documentation Support

#### 11.1.1 Related Documentation

For related documentation see the following:

- [《REF50xx 低噪声、极低漂移、高精度电压基准》](#)
- [OPA191 低功耗精密 36V e-trim CMOS 放大器](#)
- [TINA-TI 软件文件夹](#)
- [INA 共模范围计算器](#)

#### 11.2 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. 有关更改的详细信息，请查看任何已修订文档中包含的修订历史记录。

#### 11.3 Community Resources

下列链接提供到 TI 社区资源的连接。链接的内容由各个分销商“按照原样”提供。这些内容并不构成 TI 技术规范，并且不一定反映 TI 的观点；请参阅 TI 的 [《使用条款》](#)。

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**设计支持** *TI 参考设计支持* 可帮助您快速查找有帮助的 E2E 论坛、设计支持工具以及技术支持的联系信息。

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ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

#### 11.6 Glossary

[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

## 12 机械、封装和可订购信息

以下页面包含机械、封装和可订购信息。这些信息是指定器件的最新可用数据。数据如有变更，恕不另行通知和修订此文档。如欲获取此数据表的浏览器版本，请参阅左侧的导航。

**PACKAGING INFORMATION**

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
INA828ID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	INA828	<a href="#">Samples</a>
INA828IDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	INA828	<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.

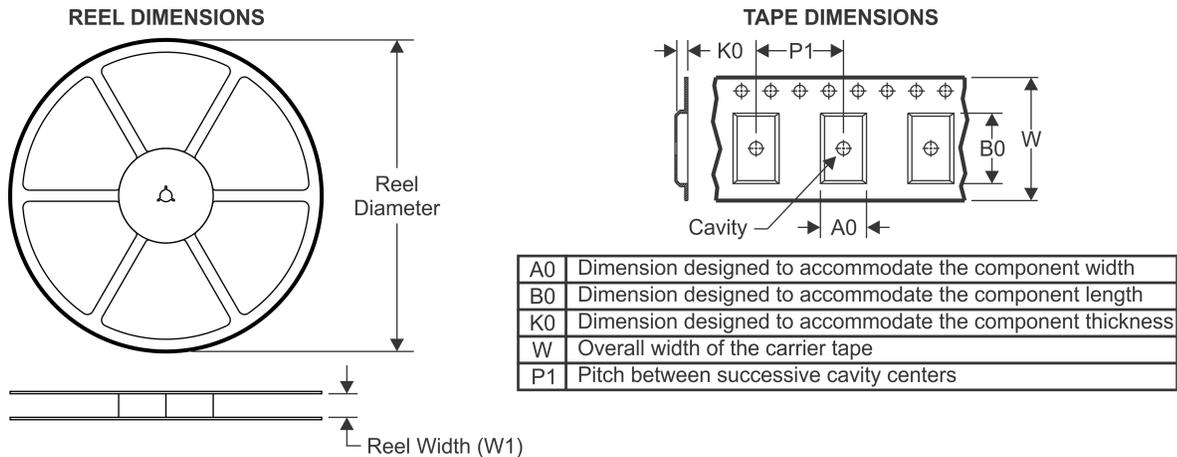
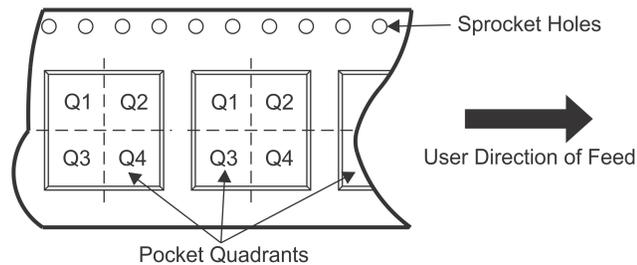
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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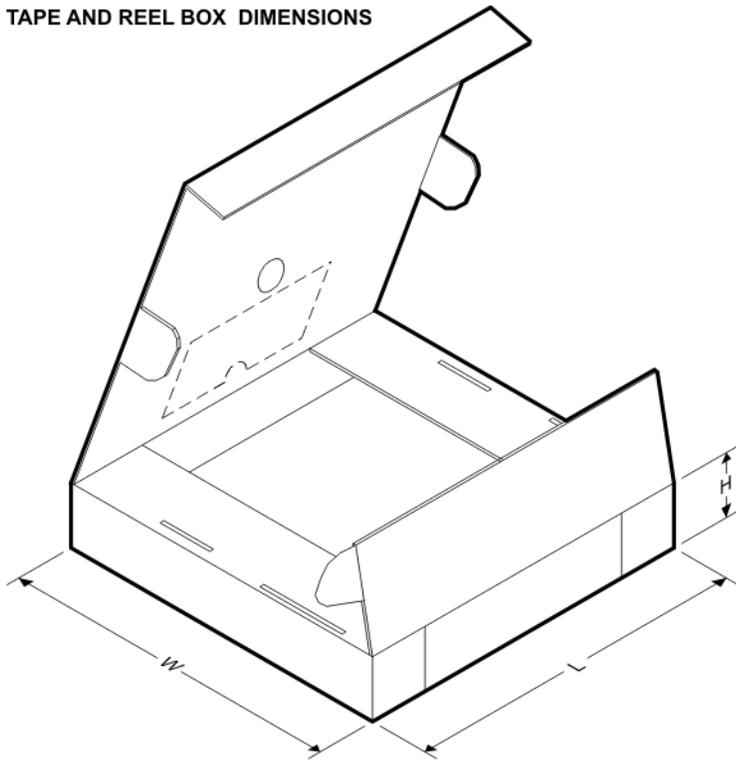


**TAPE AND REEL INFORMATION**

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**


\*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
INA828IDR	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)
INA828IDR	SOIC	D	8	2500	367.0	367.0	35.0

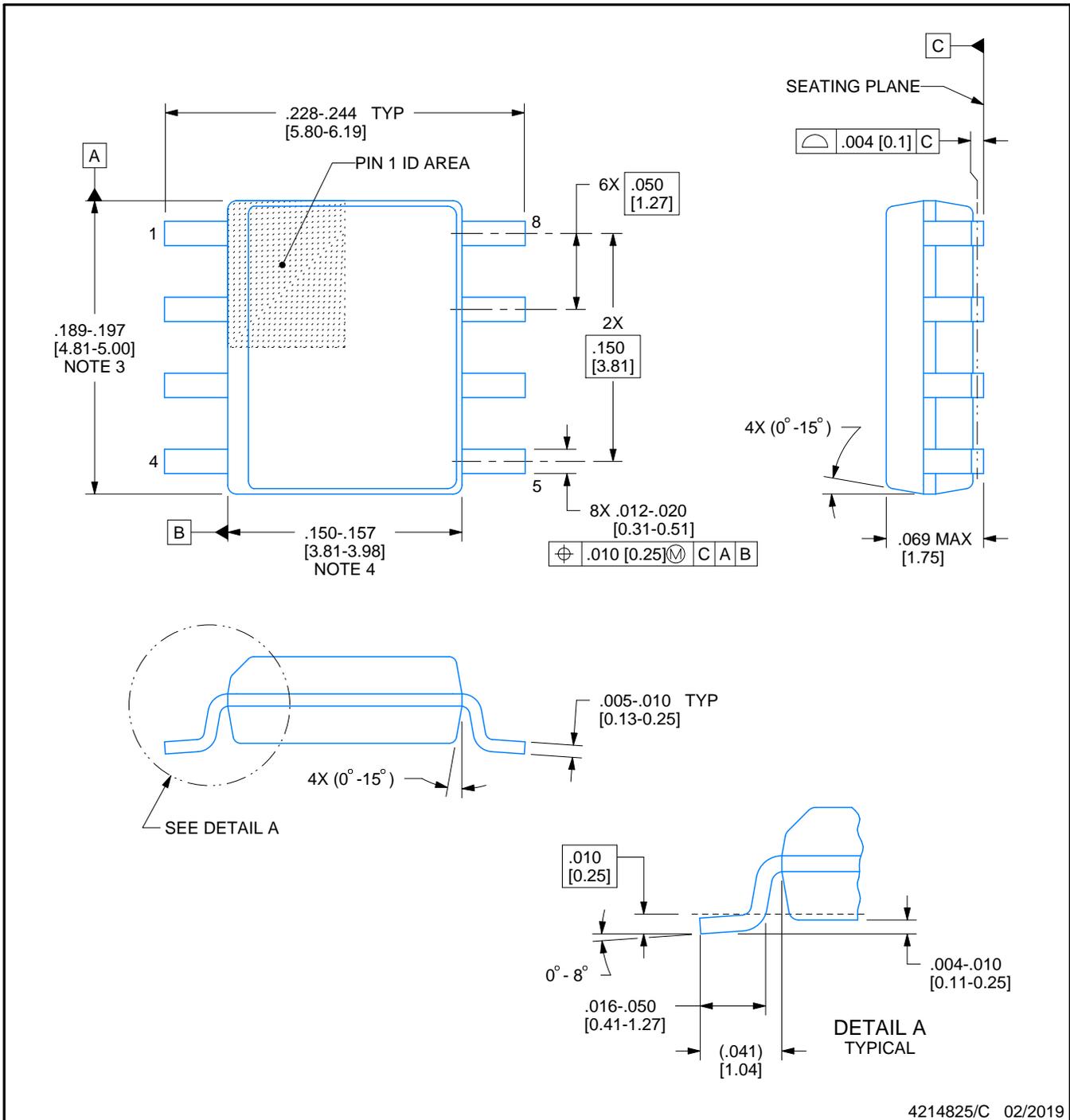


D0008A

# PACKAGE OUTLINE

## SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

### NOTES:

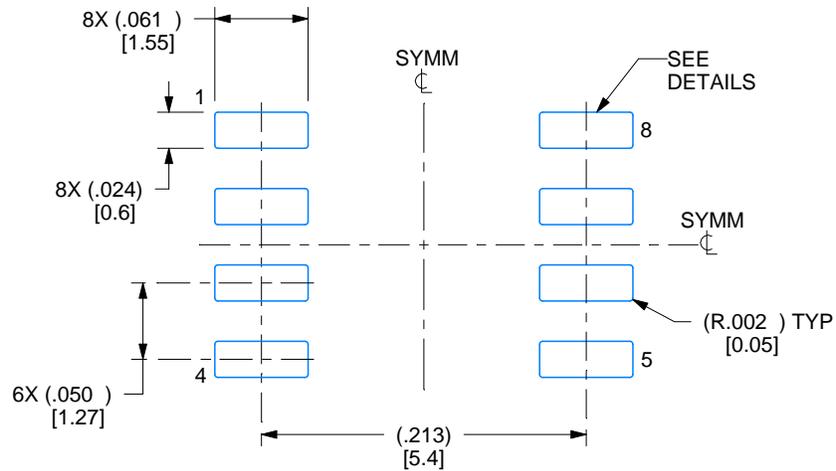
- Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
- This drawing is subject to change without notice.
- This dimension does not include mold flash, protrusions, or gate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

# EXAMPLE BOARD LAYOUT

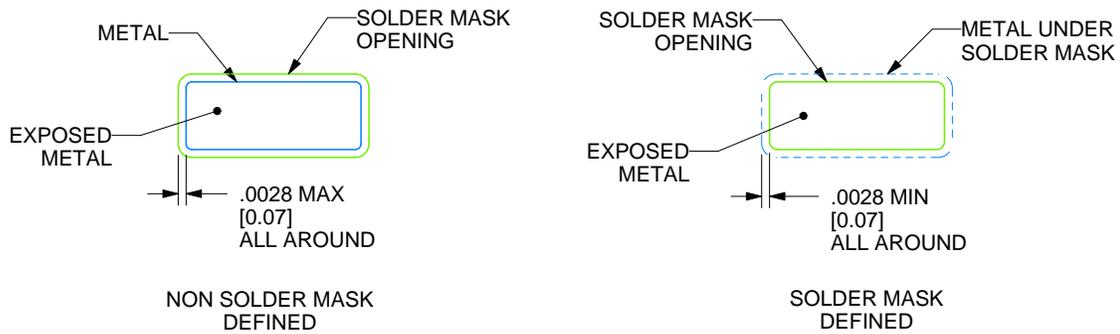
D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:8X



SOLDER MASK DETAILS

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NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

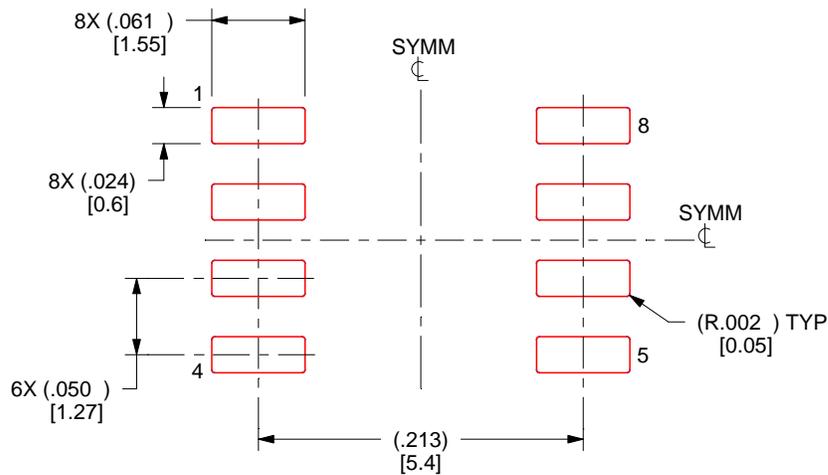
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

# 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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