

INA240-SEP 同相範囲の広い、ハイサイドおよびローサイド、双方向、ゼロ・ドリフトの電流センス・アンプ、宇宙用に強化されたプラスチックに搭載

1 特長

- VID V62/18615
- 放射線耐性を強化
 - 単一イベント・ラッチアップ(SEL)耐性: 125°Cで43MeV-cm²/mgまで
 - 30krad(Si)までELDRSフリー
 - 20krad(Si)まで、すべてのウェハー・ロットについて吸収線量(TID) RLAT
- 宇宙向けに強化されたプラスチック
 - 管理されたベースライン
 - 金線
 - NiPdAuリード仕上げ
 - 単一のアセンブリ/テスト施設
 - 単一の製造施設
 - 軍用温度範囲(-55°C~125°C)で利用可能
 - 長期にわたる製品ライフ・サイクル
 - 長期にわたる製品変更通知
 - 製品のトレーサビリティ
 - モールド・コンパウンドの改良による低いガス放出
- 強化された PWM 除去
- 優れた CMRR : 132dB (標準値)
- 広い同相電圧範囲: -4V~80V
- ゲイン: 20V/V
 - ゲイン誤差: 0.2% (最大値)
 - ゲイン・ドリフト係数: 2.5ppm/°C (最大値)
- オフセット電圧: ±25μV (最大値)
- オフセット・ドリフト係数: 250nV/°C (最大値)

- 静止電流: 2.4mA (最大値)

2 アプリケーション

- 低軌道衛星用途のサポート
- 電源監視
- 過電流および低電流の検出
- 衛星テレメトリ
- モータ制御ループ

3 概要

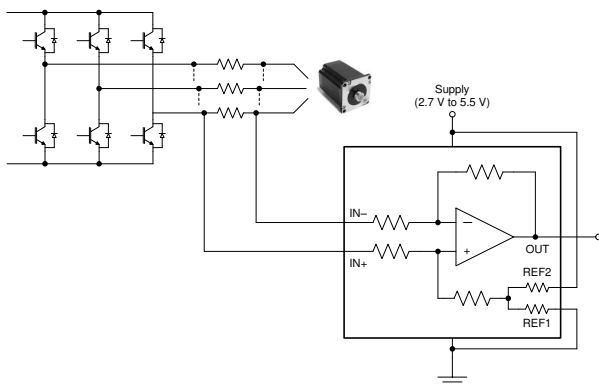
INA240-SEP デバイスは電圧出力の電流センス・アンプで、強化された PWM 除去機能により、電源電圧に依存しない -4V~80V の広い同相電圧範囲で、シャント抵抗の両端間の電圧降下を検出できます。負の同相電圧により、グランドより低い電位で動作でき、標準的なソレノイド・アプリケーションのフライバック期間に対応できます。強化されたPWM除去により、パルス幅変調(PWM)信号を使用するシステム(モータ・ドライブやソレノイド制御システムなど)において、大きな同相過渡電圧($\Delta V/\Delta t$)を高いレベルで抑制します。この機能により、大きな過渡電圧や、それに関連する出力電圧の回復リップルなしに、正確な電流を測定できます。

製品情報⁽¹⁾

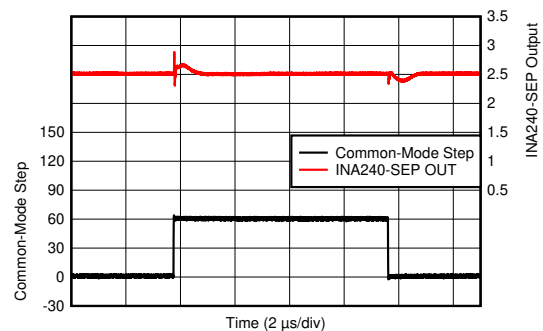
型番	パッケージ	本体サイズ(公称)
INA240PMPWTPSEP	TSSOP (8)	3.00mm×4.40mm
INA240PMPWPSEP		

(1) 提供されているすべてのパッケージについては、巻末の注文情報を参照してください。

代表的なアプリケーション



強化されたPWM除去



D004

目次

1	特長	1	8.4	Device Functional Modes.....	14
2	アプリケーション	1	9	Application and Implementation	20
3	概要	1	9.1	Application Information.....	20
4	改訂履歴	2	9.2	Typical Applications	22
5	概要 (続き)	3	9.3	Do's and Don'ts	25
6	Pin Configuration and Functions	4	10	Power Supply Recommendations	25
7	Specifications	5	10.1	Power Supply Decoupling	25
7.1	Absolute Maximum Ratings	5	11	Layout	26
7.2	ESD Ratings	5	11.1	Layout Guidelines	26
7.3	Recommended Operating Conditions.....	5	11.2	Layout Example	26
7.4	Thermal Information	5	12	デバイスおよびドキュメントのサポート	27
7.5	Electrical Characteristics.....	6	12.1	ドキュメントの更新通知を受け取る方法.....	27
7.6	Typical Characteristics	7	12.2	コミュニティ・リソース	27
8	Detailed Description	11	12.3	商標	27
8.1	Overview	11	12.4	静電気放電に関する注意事項	27
8.2	Functional Block Diagram	11	12.5	Glossary	27
8.3	Feature Description.....	11	13	メカニカル、パッケージ、および注文情報	28

4 改訂履歴

資料番号末尾の英字は改訂を表しています。その改訂履歴は英語版に準じています。

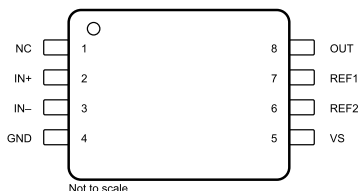
日付	リビジョン	注
2018年12月	*	初版

5 概要（続き）

このデバイスは2.7V～5.5Vの単電源で動作し、消費電流は最大2.4mAです。ゲインは 20V/V 固定です。ゼロ・ドリフト・アーキテクチャの低いオフセットにより、シャントでの最大電圧降下がわずか 10mV フルスケールで電流センシングが可能です。

6 Pin Configuration and Functions

**INA240-SEP PW Package
8-Pin TSSOP
Top View**



NC- no internal connection

Pin Functions

PIN		I/O	DESCRIPTION
NAME	PW (TSSOP)		
GND	4	Analog	Ground.
IN–	3	Analog input	Connect to load side of shunt resistor.
IN+	2	Analog input	Connect to supply side of shunt resistor.
NC	1	—	Reserved. Connect to ground.
OUT	8	Analog output	Output voltage.
REF1	7	Analog input	Reference 1 voltage. Connect to 0 V to VS; see the Adjusting the Output Midpoint With the Reference Pins section for connection options.
REF2	6	Analog input	Reference 2 voltage. Connect to 0 V to VS; see the Adjusting the Output Midpoint With the Reference Pins section for connection options.
VS	5	—	Power supply, 2.7 V to 5.5 V.

7 Specifications

7.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Supply voltage			6	V
Analog inputs, V_{IN+} , V_{IN-} ⁽²⁾	Differential ($V_{IN+} - V_{IN-}$)	–80	80	V
	Common-mode	–6	90	
REF1, REF2, NC inputs		GND – 0.3	$V_S + 0.3$	V
Output		GND – 0.3	$V_S + 0.3$	V
Operating free-air temperature, T_A		–55	150	°C
Junction temperature, T_J			150	°C
Storage temperature, T_{stg}		–65	150	°C

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

7.2 ESD Ratings

		VALUE	UNIT
$V_{(ESD)}$ Electrostatic discharge	Human-body model (HBM), per AEC Q100-002 ⁽¹⁾	±2000	V
	Charged-device model (CDM), per AEC Q100-011	±1000	

- (1) AEC Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

7.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
V_{CM}	Common-mode input voltage	–4		80	V
V_S	Operating supply voltage	2.7		5.5	V
T_A	Operating free-air temperature	–55		125	°C

7.4 Thermal Information

THERMAL METRIC ⁽¹⁾		INA240-SEP	UNIT
		PW (TSSOP)	
		8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	149.1	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	33.2	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	78.4	°C/W
ψ_{JT}	Junction-to-top characterization parameter	1.5	°C/W
ψ_{JB}	Junction-to-board characterization parameter	76.4	°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 $T_A = -55^\circ\text{C}$ to 125°C , $V_S = 5\text{ V}$, $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-}$, $V_{\text{CM}} = 12\text{ V}$, and $V_{\text{REF1}} = V_{\text{REF2}} = V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V _{CM}	Common-mode input range	V _{IN+} = −4 V to 80 V, V _{SENSE} = 0 mV T _A = −55°C to 125°C	−4		80	V
CMRR	Common-mode rejection ratio	V _{IN+} = −4 V to 80 V, V _{SENSE} = 0 mV T _A = −55°C to 125°C	120	132		dB
		f = 50 kHz		93		
V _{OS}	Offset voltage, input-referred	V _{SENSE} = 0 mV		±5	±25	μV
dV _{OS} /dT	Offset voltage drift	V _{SENSE} = 0 mV, T _A = −55°C to 125°C		±50	±250	nV/°C
PSRR	Power-supply rejection ratio	V _S = 2.7 V to 5.5 V, V _{SENSE} = 0 mV T _A = −55°C to 125°C		±1	±10	μV/V
I _B	Input bias current	I _{B+} , I _{B−} , V _{SENSE} = 0 mV		90		μA
	Reference input range		0		V _S	V
OUTPUT						
G	Gain			20		V/V
	Gain error	GND + 50 mV ≤ V _{OUT} ≤ V _S − 200 mV		±0.05%	±0.20%	
		T _A = −55°C to 125°C		±0.5	±2.5	ppm/°C
	Nonlinearity error	GND + 10 mV ≤ V _{OUT} ≤ V _S − 200 mV		±0.01%		
	Reference divider accuracy	V _{OUT} = (V _{REF1} − V _{REF2}) / 2 at V _{SENSE} = 0 mV, T _A = −55°C to 125°C		0.02%	0.1%	
RVRR	Reference voltage rejection ratio (input-referred)			20		μV/V
	Maximum capacitive load	No sustained oscillation		1		nF
VOLTAGE OUTPUT ⁽¹⁾						
	Swing to V _S power-supply rail	R _L = 10 kΩ to GND T _A = −55°C to 125°C		V _S − 0.05	V _S − 0.2	V
	Swing to GND	R _L = 10 kΩ to GND, V _{SENSE} = 0 mV V _{REF1} = V _{REF2} = 0 V T _A = −55°C to 125°C		V _{GND} + 1	V _{GND} + 10	mV
FREQUENCY RESPONSE						
BW	Bandwidth	All gains, −3-dB bandwidth		400		kHz
		All gains, 2% THD+N ⁽²⁾		100		
	Settling time - output settles to 0.5% of final value			9.6		μs
SR	Slew rate			2		V/μs
NOISE (INPUT REFERRED)						
	Voltage noise density			40		nV/√Hz
POWER SUPPLY						
V _S	Operating voltage range	T _A = −55°C to 125°C	2.7		5.5	V
I _Q	Quiescent current	V _{SENSE} = 0 mV		1.8	2.4	mA
		I _Q vs temperature, T _A = −55°C to 125°C			2.6	
TEMPERATURE RANGE						
	Specified range		−55		125	°C

(1) See [Figure 10](#).

(2) See the [Input Signal Bandwidth](#) section for more details.

7.6 Typical Characteristics

at $T_A = -55^{\circ}\text{C}$ to 125°C , $V_S = 5\text{ V}$, $V_{CM} = 12\text{ V}$, and $V_{REF} = V_S / 2$ (unless otherwise noted)

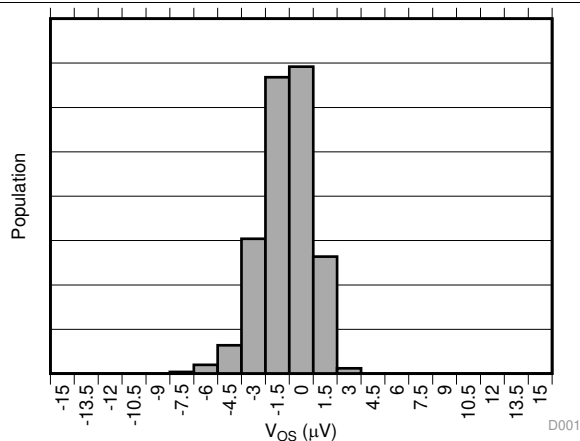


Figure 1. Input Offset Voltage Production Distribution

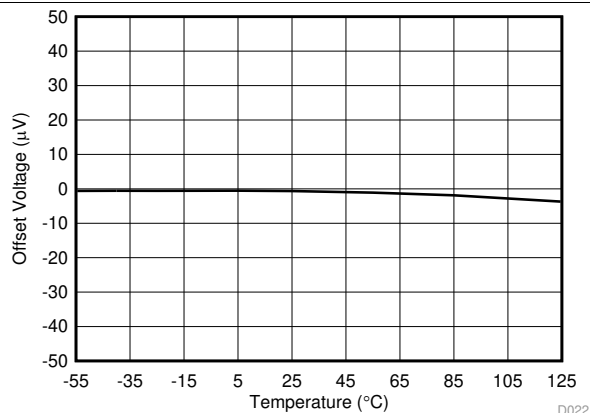


Figure 2. Offset Voltage vs Temperature

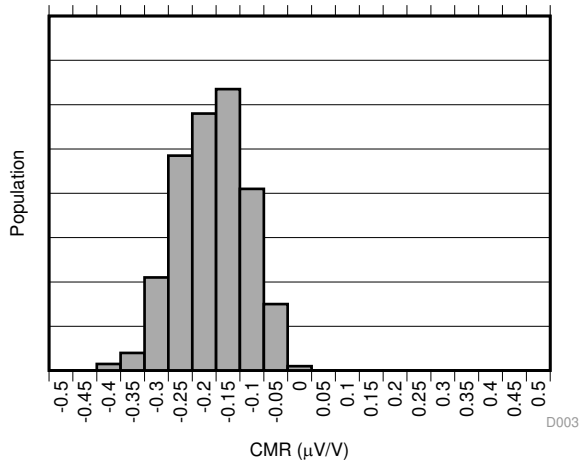


Figure 3. Common-Mode Rejection Production Distribution

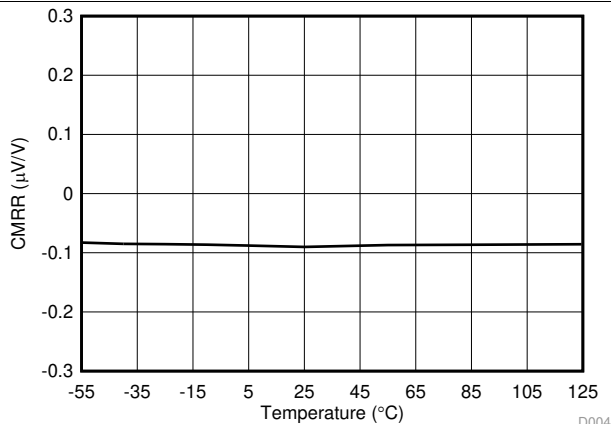


Figure 4. Common-Mode Rejection Ratio vs Temperature

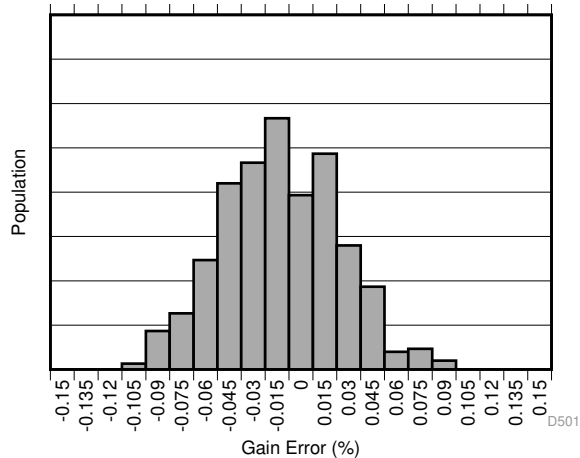


Figure 5. Gain Error Production Distribution

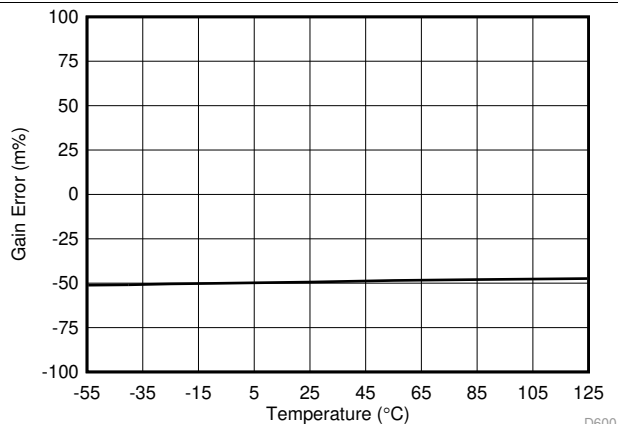


Figure 6. Gain Error vs Temperature

Typical Characteristics (continued)

at $T_A = -55^\circ\text{C}$ to 125°C , $V_S = 5\text{ V}$, $V_{CM} = 12\text{ V}$, and $V_{REF} = V_S / 2$ (unless otherwise noted)

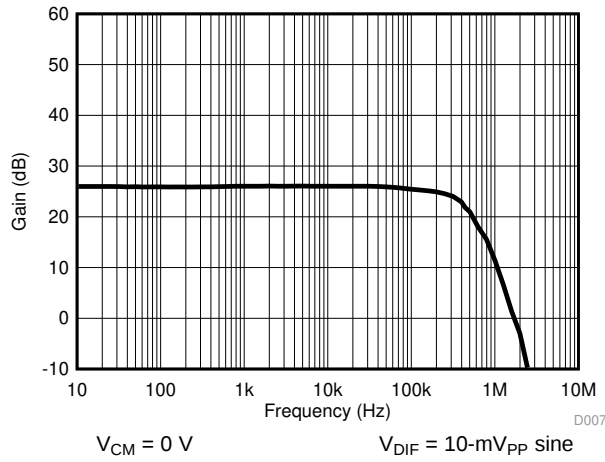


Figure 7. Gain vs Frequency

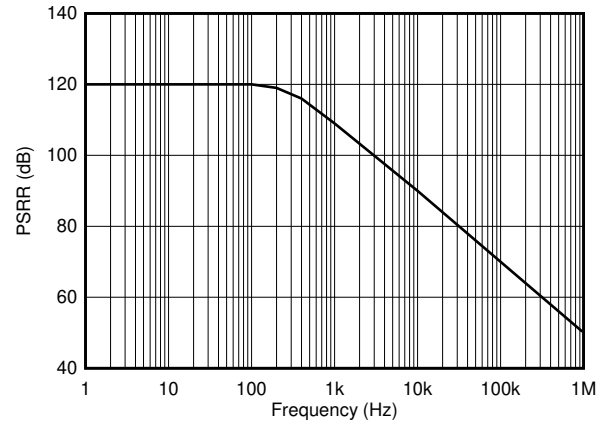


Figure 8. Power-Supply Rejection Ratio vs Frequency

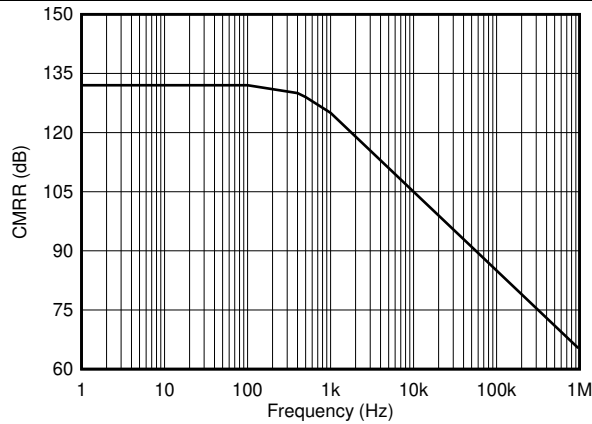


Figure 9. Common-Mode Rejection Ratio vs Frequency

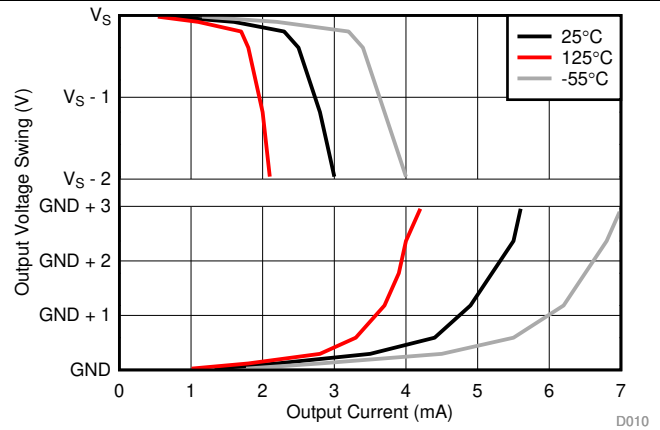


Figure 10. Output Voltage Swing vs Output Current

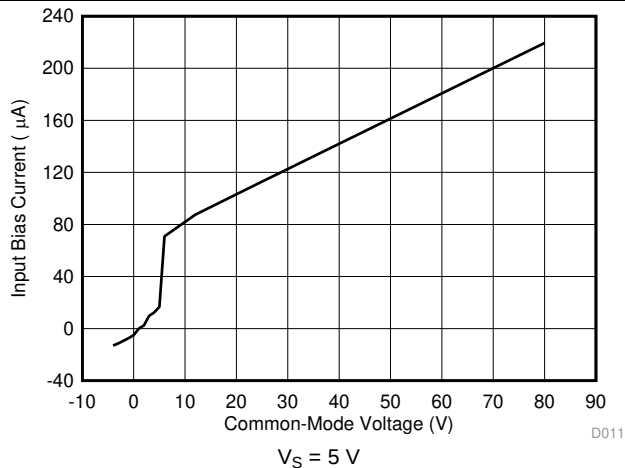


Figure 11. Input Bias Current vs Common-Mode Voltage

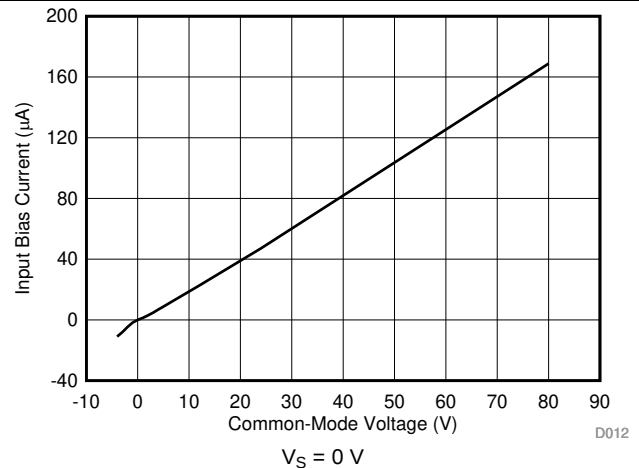


Figure 12. Input Bias Current vs Common-Mode Voltage

Typical Characteristics (continued)

at $T_A = -55^{\circ}\text{C}$ to 125°C , $V_S = 5\text{ V}$, $V_{CM} = 12\text{ V}$, and $V_{REF} = V_S / 2$ (unless otherwise noted)

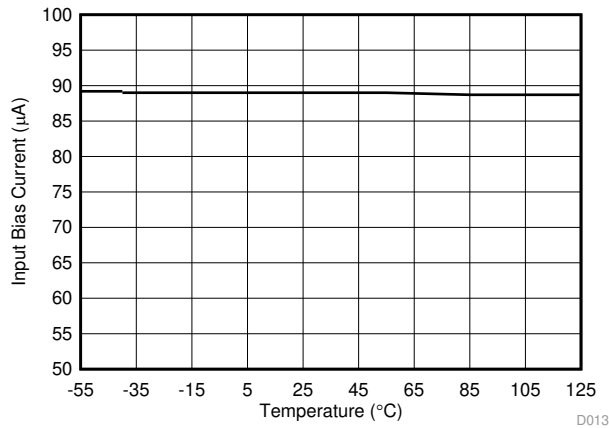


Figure 13. Input Bias Current vs Temperature

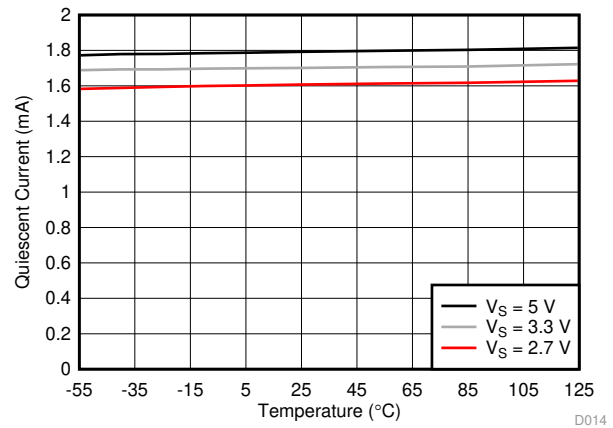


Figure 14. Quiescent Current vs Temperature

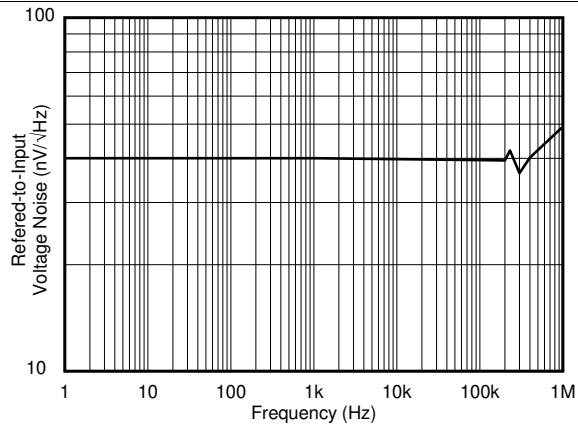
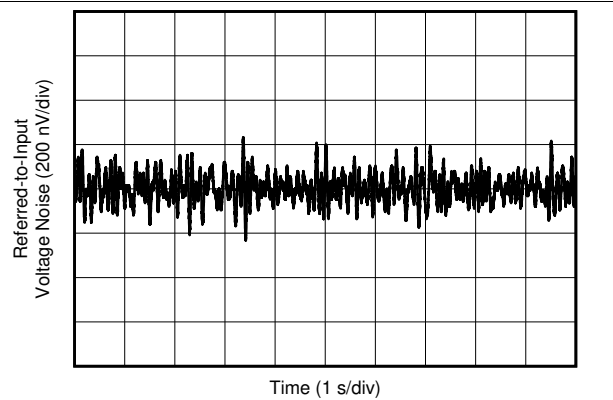


Figure 15. Input-Referred Voltage Noise vs Frequency



$V_S = \pm 2.5\text{ V}$ $V_{CM} = 0\text{ V}$ $V_{DIF} = 0\text{ V}$
 $V_{REF1} = V_{REF2} = 0\text{ V}$ Input referred

Figure 16. 0.1-Hz to 10-Hz Voltage Noise

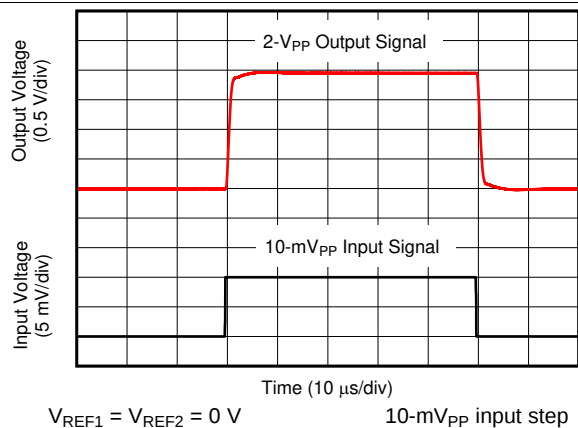


Figure 17. Step Response

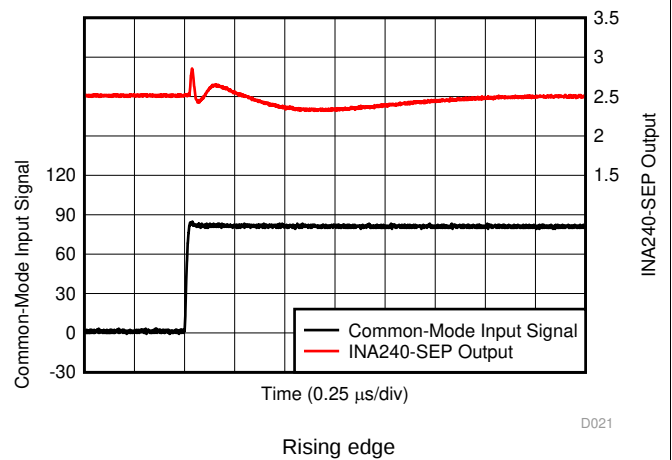
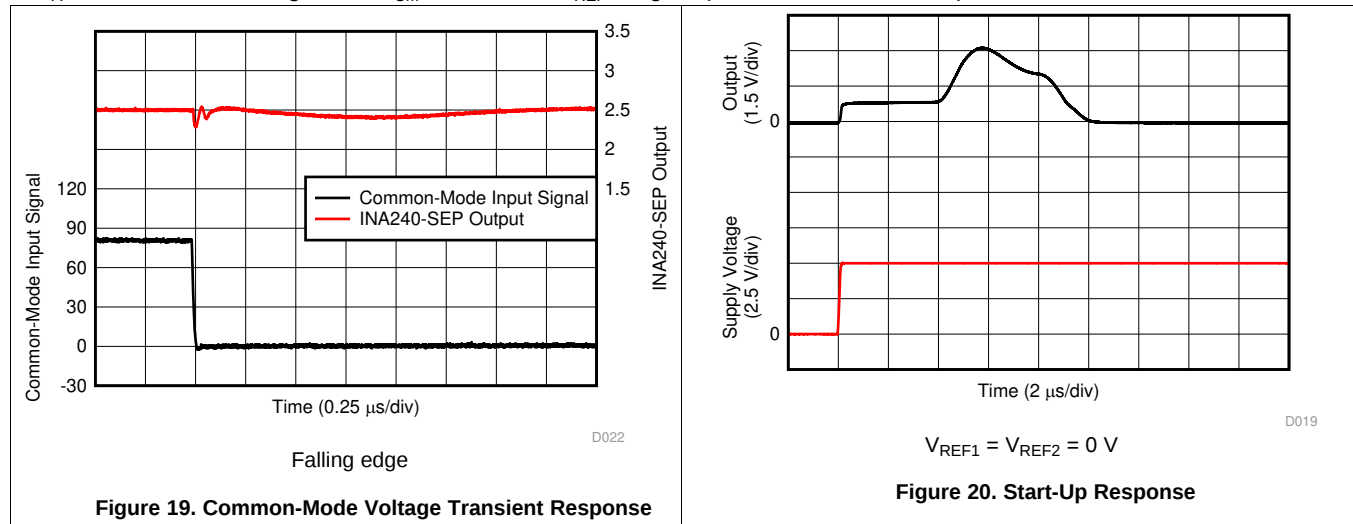


Figure 18. Common-Mode Voltage Transient Response

Typical Characteristics (continued)

at $T_A = -55^\circ\text{C}$ to 125°C , $V_S = 5\text{ V}$, $V_{CM} = 12\text{ V}$, and $V_{REF} = V_S / 2$ (unless otherwise noted)

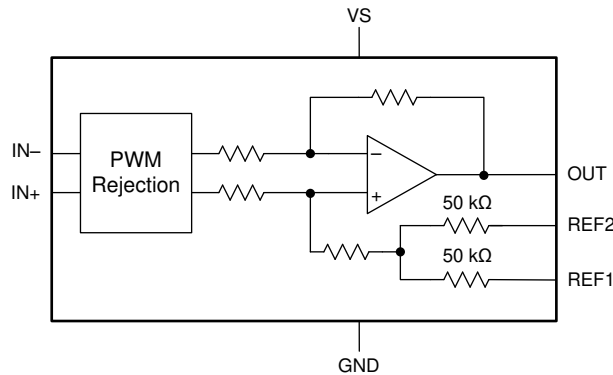


8 Detailed Description

8.1 Overview

The INA240-SEP is a current-sense amplifier that offers a wide common-mode range, precision, zero-drift topology, excellent common-mode rejection ratio (CMRR), and features enhanced pulse width modulation (PWM) rejection. Enhanced PWM rejection reduces the effect of common-mode transients on the output signal that are associated with PWM signals.

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Amplifier Input Signal

The INA240-SEP is designed to handle large common-mode transients over a wide voltage range. Input signals from current measurement applications for linear and PWM applications can be connected to the amplifier to provide a highly accurate output, with minimal common-mode transient artifacts.

8.3.1.1 Enhanced PWM Rejection Operation

The enhanced PWM rejection feature of the INA240-SEP provides increased attenuation of large common-mode $\Delta V/\Delta t$ transients. Large $\Delta V/\Delta t$ common-mode transients associated with PWM signals are employed in applications such as motor or solenoid drive and switching power supplies. Traditionally, large $\Delta V/\Delta t$ common-mode transitions are handled strictly by increasing the amplifier signal bandwidth, which can increase chip size, complexity and ultimately cost. The INA240-SEP is designed with high common-mode rejection techniques to reduce large $\Delta V/\Delta t$ transients before the system is disturbed as a result of these large signals. The high AC CMRR, in conjunction with signal bandwidth, allows the INA240-SEP to provide minimal output transients and ringing compared with standard circuit approaches.

8.3.1.2 Input Signal Bandwidth

The INA240-SEP input signal, which represents the current being measured, is accurately measured with minimal disturbance from large $\Delta V/\Delta t$ common-mode transients as previously described. For PWM signals typically associated with motors, solenoids, and other switching applications, the current being monitored varies at a significantly slower rate than the faster PWM frequency.

The INA240-SEP bandwidth is defined by the –3-dB bandwidth of the current-sense amplifier inside the device; see the [Electrical Characteristics](#) table. The device bandwidth provides fast throughput and fast response required for the rapid detection and processing of overcurrent events. Without the higher bandwidth, protection circuitry may not have adequate response time and damage may occur to the monitored application or circuit.

Feature Description (continued)

Figure 21 shows the performance profile of the device over frequency. Harmonic distortion increases at the upper end of the amplifier bandwidth with no adverse change in detection of overcurrent events. However, increased distortion at the highest frequencies must be considered when the measured current bandwidth begins to approach the INA240-SEP bandwidth.

For applications requiring distortion sensitive signals, Figure 21 provides information to show that there is an optimal frequency performance range for the amplifier. The full amplifier bandwidth is always available for fast overcurrent events at the same time that the lower frequency signals are amplified at a low distortion level. The output signal accuracy is reduced for frequencies closer to the maximum bandwidth. Individual requirements determine the acceptable limits of distortion for high-frequency, current-sensing applications. Testing and evaluation in the end application or circuit is required to determine the acceptance criteria and to validate the performance levels meet the system specifications.

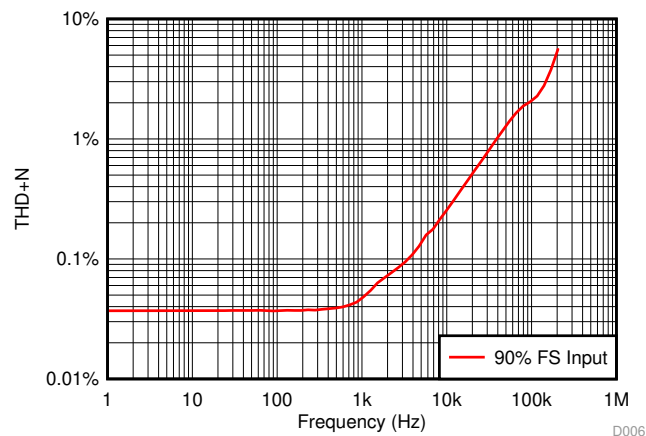


Figure 21. Performance Over Frequency

8.3.2 Selecting the Sense Resistor (R_{SENSE})

The INA240-SEP determines the current magnitude from measuring the differential voltage developed across a resistor. This resistor is referred to as a *current-sensing* resistor or a *current-shunt* resistor. The flexible design of the device allows a wide input signal range across this current-sensing resistor.

The current-sensing resistor is ideally chosen solely based on the full-scale current to be measured, the full-scale input range of the circuitry following the device. The minimum current-sensing resistor is a design-based decision in order to maximize the input range of the signal chain circuitry. Full-scale output signals that are not maximized to the full input range of the system circuitry limit the ability of the system to exercise the full dynamic range of system control.

Two important factors to consider when finalizing the current-sensing resistor value are: the required current measurement accuracy and the maximum power dissipation across the resistor. A larger resistor voltage provides for a more accurate measurement, but increases the power dissipation in the resistor. The increased power dissipation generates heat, which reduces the sense resistor accuracy because of the temperature coefficient. The voltage signal measurement uncertainty is reduced when the input signal gets larger because any fixed errors become a smaller percentage of the measured signal. The design trade-off to improve measurement accuracy increases the current-sensing resistor value. The increased resistance value results in an increased power dissipation in the system which can additionally decrease the overall system accuracy. Based on these relationships, the measurement accuracy is inversely proportional to both the resistance value and power dissipation contributed by the current-shunt selection.

Table 1 shows an example of the different results obtained from using two different gain versions of the INA240-SEP. From the table data, the higher gain device allows a smaller current-shunt resistor and decreased power dissipation in the element. The [Calculating Total Error](#) section provides information on the error calculations that must be considered in addition to the gain and current-shunt value when designing with the INA240-SEP.

Feature Description (continued)

Table 1. R_{SENSE} Selection and Power Dissipation⁽¹⁾

PARAMETER		EQUATION	RESULTS
Gain		—	20 V/V
V_{DIFF}	Ideal maximum differential input voltage	$V_{\text{DIFF}} = V_{\text{OUT}} / \text{Gain}$	150 mV
R_{SENSE}	Current-sense resistor value	$R_{\text{SENSE}} = V_{\text{DIFF}} / I_{\text{MAX}}$	15 m Ω
P_{RSENSE}	Current-sense resistor power dissipation	$R_{\text{SENSE}} \times I_{\text{MAX}}^2$	1.5 W

(1) Full-scale current = 10 A, and full-scale output voltage = 3 V.

8.4 Device Functional Modes

8.4.1 Adjusting the Output Midpoint With the Reference Pins

Figure 22 shows a test circuit for reference-divider accuracy. The INA240-SEP output is configurable to allow for unidirectional or bidirectional operation.

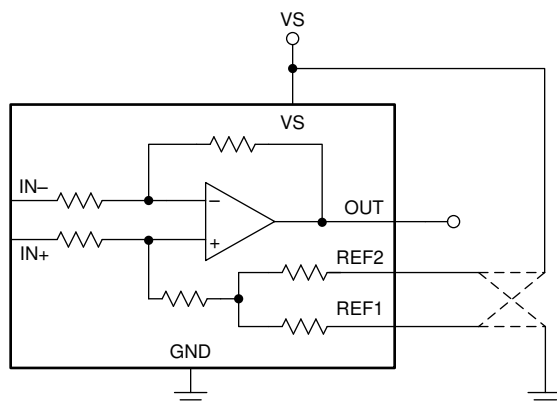


Figure 22. Test Circuit For Reference Divider Accuracy

NOTE

Do not connect the REF1 pin or the REF2 pin to any voltage source lower than GND or higher than V_S .

The output voltage is set by applying a voltage or voltages to the reference voltage inputs, REF1 and REF2. The reference inputs are connected to an internal gain network. There is no operational difference between the two reference pins.

8.4.2 Reference Pin Connections for Unidirectional Current Measurements

Unidirectional operation allows current measurements through a resistive shunt in one direction. For unidirectional operation, connect the device reference pins together and then to the negative rail (see the [Ground Referenced Output](#) section) or the positive rail (see the [VS Referenced Output](#) section). The required differential input polarity depends on the output voltage setting. The amplifier output moves away from the referenced rail proportional to the current passing through the external shunt resistor. If the amplifier reference pins are connected to the positive rail, then the input polarity must be negative to move the amplifier output down (towards ground). If the amplifier reference pins are connected at ground, then the input polarity must be positive to move the amplifier output up (towards supply).

The following sections describe how to configure the output for unidirectional operation cases.

8.4.2.1 Ground Referenced Output

When using the INA240-SEP in a unidirectional mode with a ground referenced output, both reference inputs are connected to ground; this configuration takes the output to ground when there is a 0-V differential at the input (as [Figure 23](#) shows).

Device Functional Modes (continued)

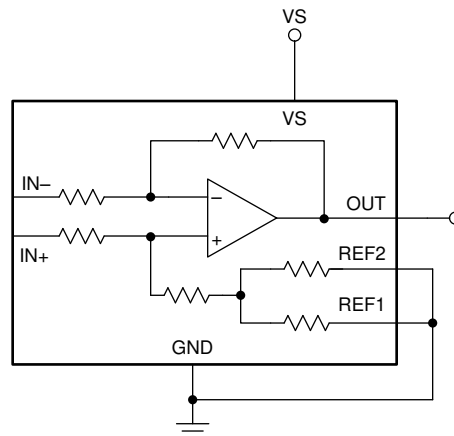


Figure 23. Ground Referenced Output

8.4.2.2 VS Referenced Output

Unidirectional mode with a VS referenced output is configured by connecting both reference pins to the positive supply. Use this configuration for circuits that require power-up and stabilization of the amplifier output signal and other control circuitry before power is applied to the load (as shown in Figure 24).

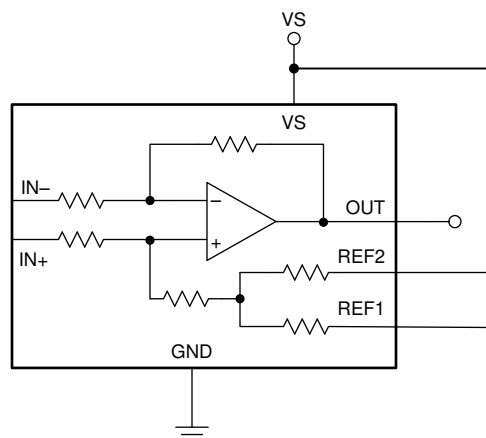


Figure 24. VS Referenced Output

8.4.3 Reference Pin Connections for Bidirectional Current Measurements

Bidirectional operation allows the INA240-SEP to measure currents through a resistive shunt in two directions. For this operation case, the output voltage can be set anywhere within the reference input limits. A common configuration is to set the reference inputs at half-scale for equal range in both directions. However, the reference inputs can be set to a voltage other than half-scale when the bidirectional current is non-symmetrical.

8.4.3.1 Output Set to External Reference Voltage

Connecting both pins together and then to a reference voltage results in an output voltage equal to the reference voltage for the condition of shorted input pins or a 0-V differential input; this configuration is shown in Figure 25. The output voltage decreases below the reference voltage when the IN+ pin is negative relative to the IN- pin and increases when the IN+ pin is positive relative to the IN- pin. This technique is the most accurate way to bias the output to a precise voltage.

Device Functional Modes (continued)

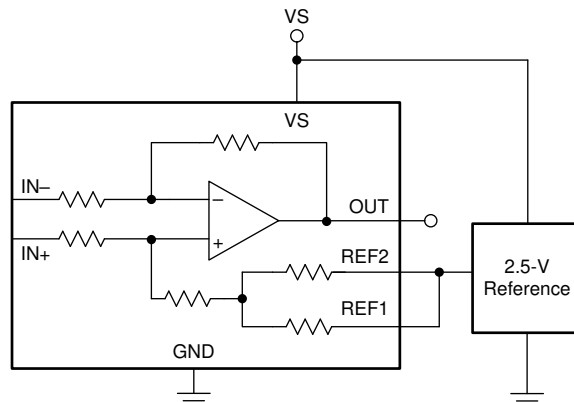


Figure 25. External Reference Output

8.4.3.2 Output Set to Midsupply Voltage

By connecting one reference pin to VS and the other to the GND pin, the output is set at half of the supply when there is no differential input, as shown in [Figure 26](#). This method creates a ratiometric offset to the supply voltage, where the output voltage remains at $VS / 2$ for 0 V applied to the inputs.

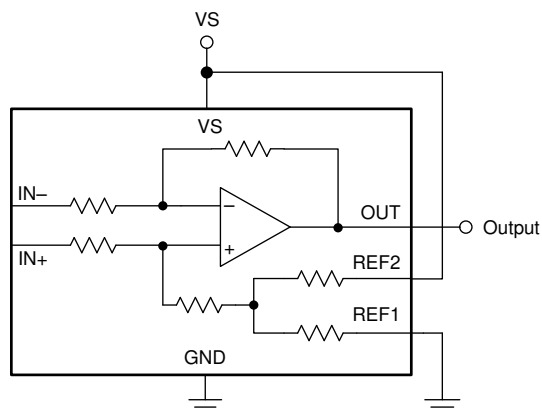


Figure 26. Midsupply Voltage Output

Device Functional Modes (continued)

8.4.3.3 Output Set to Mid-External Reference

In this case, an external reference is divided by two by connecting one REF pin to ground and the other REF pin to the reference, as shown in Figure 27.

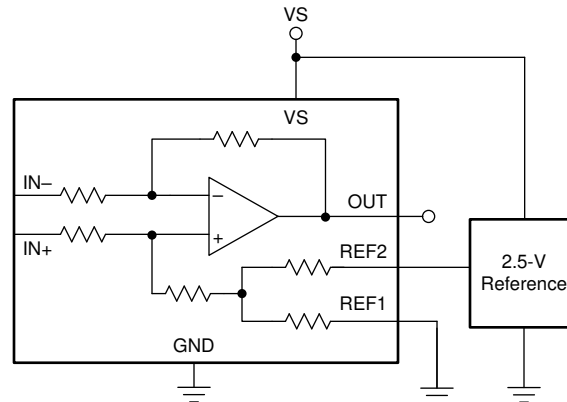


Figure 27. Mid-External Reference Output

8.4.3.4 Output Set Using Resistor Divider

The INA240-SEP REF1 and REF2 pins allow for the midpoint of the output voltage to be adjusted for system circuitry connections to analog to digital converters (ADCs) or other amplifiers. The REF pins are designed to be connected directly to supply, ground, or a low-impedance reference voltage. The REF pins can be connected together and biased using a resistor divider to achieve a custom output voltage. If the amplifier is used in this configuration, as shown in Figure 28, use the output as a differential signal with respect to the resistor divider voltage. Use of the amplifier output as a single-ended signal in this configuration is not recommended because the internal impedance shifts can adversely affect device performance specifications.

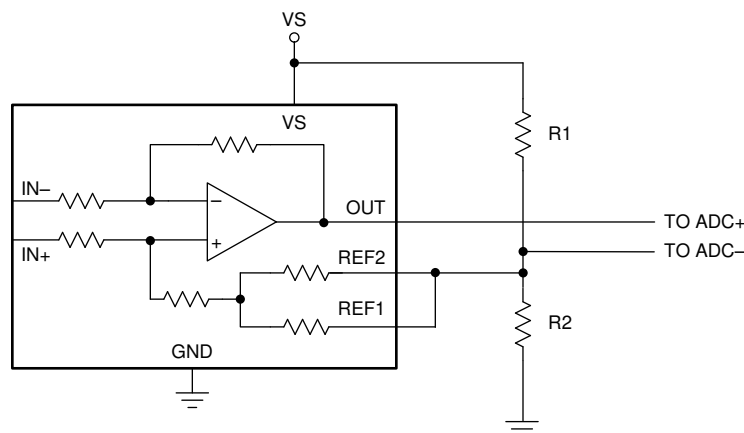


Figure 28. Setting the Reference Using a Resistor Divider

8.4.4 Calculating Total Error

The INA240-SEP electrical specifications (see the [Electrical Characteristics](#) table) include typical individual error terms (such as gain error, offset error, and nonlinearity error). Total error, including all of these individual error components, is not specified in the [Electrical Characteristics](#) table. In order to accurately calculate the expected error of the device, the device operating conditions must first be known. Some current-shunt monitors specify a total error in the product data sheet. However, this total error term is accurate under only one particular set of operating conditions. Specifying the total error at this point has limited value because any deviation from these specific operating conditions no longer yields the same total error value. This section discusses the individual error sources and how the device total error value can be calculated from the combination of these errors for specific conditions.

Device Functional Modes (continued)

Two examples are provided in [Table 2](#) and [Table 3](#) that detail how different operating conditions can affect the total error calculations. Typical and maximum calculations are shown as well to provide the user more information on how much error variance is present from device to device.

8.4.4.1 Error Sources

The typical error sources that have the largest effect on the total error of the device are gain error, nonlinearity, common-mode rejection ratio, and input offset voltage error. For the INA240-SEP, an additional error source (referred to as the *reference voltage rejection ratio*) is also included in the total error value.

Device Functional Modes (continued)

8.4.4.2 Reference Voltage Rejection Ratio Error

Reference voltage rejection ratio refers to the amount of error induced by applying a reference voltage to the INA240-SEP that deviates from the mid-point of the device supply voltage.

8.4.4.2.1 Total Error Example 1

Table 2. Total Error Calculation: Example 1⁽¹⁾

TERM	SYMBOL	EQUATION	TYPICAL VALUE
Initial input offset voltage	V_{OS}	—	5 μ V
Added input offset voltage because of common-mode voltage	V_{OS_CM}	$\frac{1}{10^{\left(\frac{CMRR_{dB}}{20}\right)}} \times (V_{CM} - 12V)$	0 μ V
Added input offset voltage because of reference voltage	V_{OS_REF}	$RVRR \times V_S / 2 - V_{REF} $	0 μ V
Total input offset voltage	V_{OS_Total}	$\sqrt{(V_{OS})^2 + (V_{OS_CM})^2 + (V_{OS_REF})^2}$	5 μ V
Error from input offset voltage	Error_ V_{OS}	$\frac{V_{OS_Total}}{V_{SENSE}} \times 100$	0.05%
Gain error	Error_ Gain	—	0.05%
Nonlinearity error	Error_ Lin	—	0.01%
Total error	—	$\sqrt{(\text{Error_}V_{OS})^2 + (\text{Error_Gain})^2 + (\text{Error_Lin})^2}$	0.07%

(1) The data for Table 2 was taken with the INA240-SEP, $V_S = 5$ V, $V_{CM} = 12$ V, $V_{REF1} = V_{REF2} = V_S / 2$, and $V_{SENSE} = 10$ mV.

8.4.4.2.2 Total Error Example 2

Table 3. Total Error Calculation: Example 2⁽¹⁾

TERM	SYMBOL	EQUATION	TYPICAL VALUE
Initial input offset voltage	V_{OS}	—	5 μ V
Added input offset voltage because of common-mode voltage	V_{OS_CM}	$\frac{1}{10^{\left(\frac{CMRR_{dB}}{20}\right)}} \times (V_{CM} - 12V)$	12.1 μ V
Added input offset voltage because of reference voltage	V_{OS_REF}	$RVRR \times V_S / 2 - V_{REF} $	5 μ V
Total input offset voltage	V_{OS_Total}	$\sqrt{(V_{OS})^2 + (V_{OS_CM})^2 + (V_{OS_REF})^2}$	14 μ V
Error from input offset voltage	Error_ V_{OS}	$\frac{V_{OS_Total}}{V_{SENSE}} \times 100$	0.14%
Gain error	Error_ Gain	—	0.05%
Nonlinearity error	Error_ Lin	—	0.01%
Total error	—	$\sqrt{(\text{Error_}V_{OS})^2 + (\text{Error_Gain})^2 + (\text{Error_Lin})^2}$	0.15%

(1) The data for Table 3 was taken with the INA240-SEP, $V_S = 5$ V, $V_{CM} = 60$ V, $V_{REF1} = V_{REF2} = 0$ V, and $V_{SENSE} = 10$ mV.

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

The INA240-SEP measures the voltage developed as current flows across the current-sensing resistor. The device provides reference pins to configure operation as either unidirectional or bidirectional output swing. When using the INA240-SEP for inline motor current sense, the device is commonly configured for bidirectional operation.

9.1.1 Input Filtering

NOTE

Input filters are not required for accurate measurements using the INA240-SEP, and use of filters in this location is not recommended. If filter components are used on the input of the amplifier, follow the guidelines in this section to minimize the effects on performance.

Based strictly on user design requirements, external filtering of the current signal may be desired. The initial location that can be considered for the filter is at the output of the current amplifier. Although placing the filter at the output satisfies the filtering requirements, this location changes the low output impedance measured by any circuitry connected to the output voltage pin. The other location for filter placement is at the current amplifier input pins. This location satisfies the filtering requirement also, however the components must be carefully selected to minimally impact device performance. [Figure 29](#) shows a filter placed at the inputs pins.

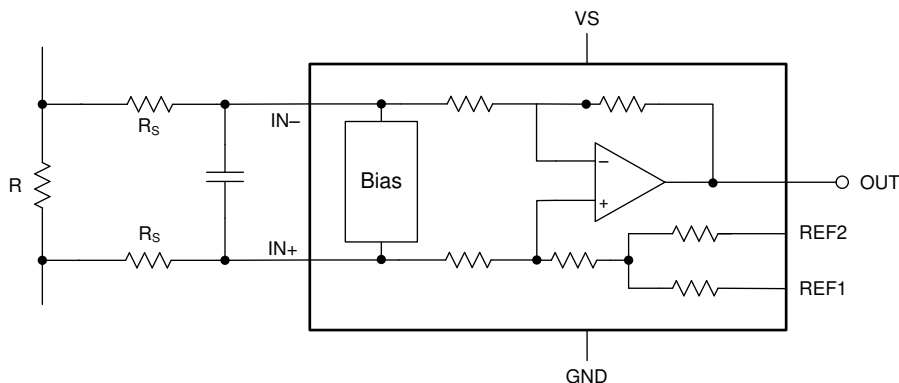


Figure 29. Filter at Input Pins

External series resistance provide a source of additional measurement error, so keep the value of these series resistors to 10 Ω or less to reduce loss of accuracy. The internal bias network shown in [Figure 29](#) creates a mismatch in input bias currents (see [Figure 30](#)) when a differential voltage is applied between the input pins. If additional external series filter resistors are added to the circuit, a mismatch is created in the voltage drop across the filter resistors. This voltage is a differential error voltage in the shunt resistor voltage. In addition to the absolute resistor value, mismatch resulting from resistor tolerance can significantly impact the error because this value is calculated based on the actual measured resistance.

Application Information (continued)

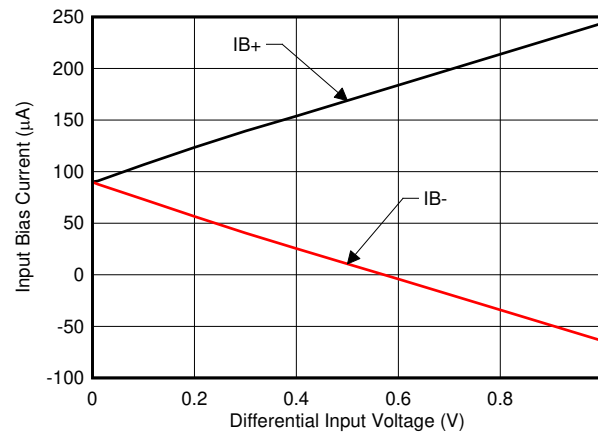


Figure 30. Input Bias Current vs Differential Input Voltage

The measurement error expected from the additional external filter resistors can be calculated using [Equation 1](#), where the gain error factor is calculated using [Equation 2](#).

$$\text{Gain Error (\%)} = 100 - (100 \times \text{Gain Error Factor}) \quad (1)$$

The gain error factor, shown in [Equation 1](#), can be calculated to determine the gain error introduced by the additional external series resistance. [Equation 1](#) calculates the deviation of the shunt voltage resulting from the attenuation and imbalance created by the added external filter resistance. [Table 4](#) provides the gain error factor and gain error for several resistor values.

$$\text{Gain Error Factor} = \frac{3000}{R_S + 3000}$$

Where:

- R_S is the external filter resistance value (2)

Table 4. Gain Error Factor and Gain Error For External Input Resistors

EXTERNAL RESISTANCE (Ω)	GAIN ERROR FACTOR	GAIN ERROR (%)
5	0.998	0.17
10	0.997	0.33
100	0.968	3.23

9.2 Typical Applications

The INA240-SEP offers advantages for multiple applications including the following:

- High common-mode range and excellent CMRR enables direct inline sensing
- Ultra-low offset and drift eliminates the necessity of calibration
- Wide supply range enables a direct interface with most microprocessors

Two specific applications are provided and include more detailed information.

9.2.1 Inline Motor Current-Sense Application

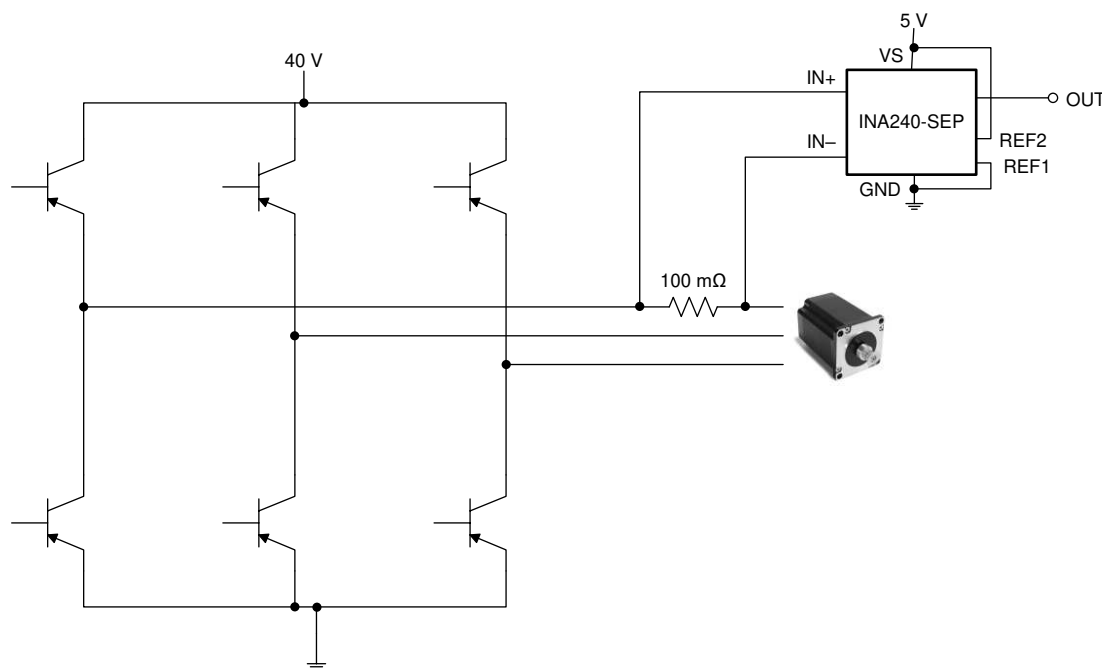


Figure 31. Inline Motor Application Circuit

9.2.1.1 Design Requirements

Inline current sensing has many advantages in motor control, from torque ripple reduction to real-time motor health monitoring. However, the full-scale PWM voltage requirements for inline current measurements provide challenges to accurately measure the current. Switching frequencies in the 50-kHz to 100-kHz range create higher $\Delta V/\Delta t$ signal transitions that must be addressed to obtain accurate inline current measurements.

With a superior common-mode rejection capability, high precision, and a high common-mode specification, the INA240-SEP provides performance for a wide range of common-mode voltages.

9.2.1.2 Detailed Design Procedure

For this application, the INA240-SEP measures current in the drive circuitry of a 36-V, 4000-RPM motor.

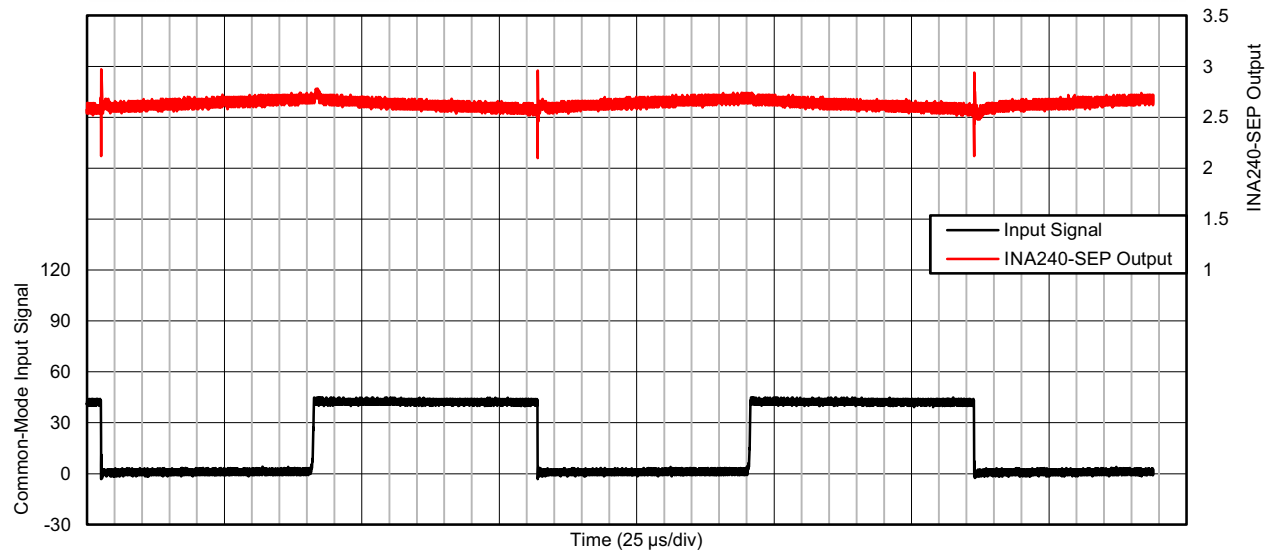
To demonstrate the performance of the device, the INA240-SEP with a gain of 20 V/V was selected for this design and powered from a 5-V supply.

Using the information in the [Adjusting the Output Midpoint With the Reference Pins](#) section, the reference point is set to midscale by splitting the supply with REF1 connected to ground and REF2 connected to supply. This configuration allows for bipolar current measurements. Alternatively, the reference pins can be tied together and driven with an external precision reference.

The current-sensing resistor is sized so that the output of the INA240-SEP is not saturated. A value of 100-mΩ was selected to maintain the analog input within the device limits.

Typical Applications (continued)

9.2.1.3 Application Curve



C005

Figure 32. Inline Motor Current-Sense Input and Output Signals

Typical Applications (continued)

9.2.2 Solenoid Drive Current-Sense Application

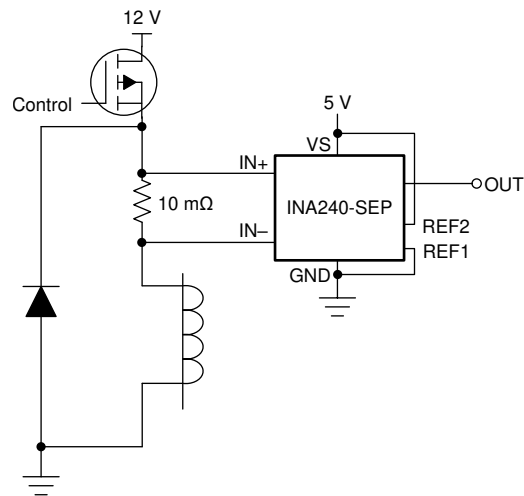


Figure 33. Solenoid Drive Application Circuit

9.2.2.1 Design Requirements

Challenges exist in solenoid drive current sensing that are similar to those in motor inline current sensing. In certain topologies, the current-sensing amplifier is exposed to the full-scale PWM voltage between ground and supply. The INA240-SEP is well suited for this type of application.

9.2.2.2 Detailed Design Procedure

For this application, the INA240-SEP measures current in the driver circuit of a 24-V, 500-mA water valve.

Using the information in the [Adjusting the Output Midpoint With the Reference Pins](#) section, the reference point is set to midscale by splitting the supply with REF1 connected to ground and REF2 connected to supply. Alternatively, the reference pins can be tied together and driven with an external precision reference.

A value of 10 mΩ was selected to maintain the analog input within the device limits.

9.2.2.3 Application Curve

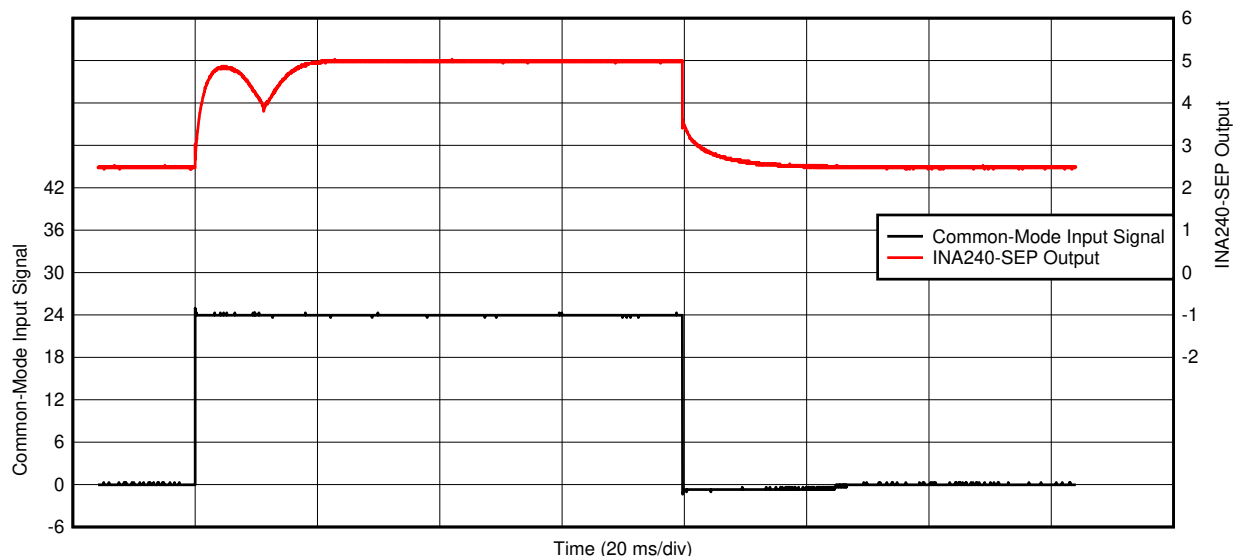


Figure 34. Solenoid Drive Current Sense Input and Output Signals

D020

9.3 Do's and Don'ts

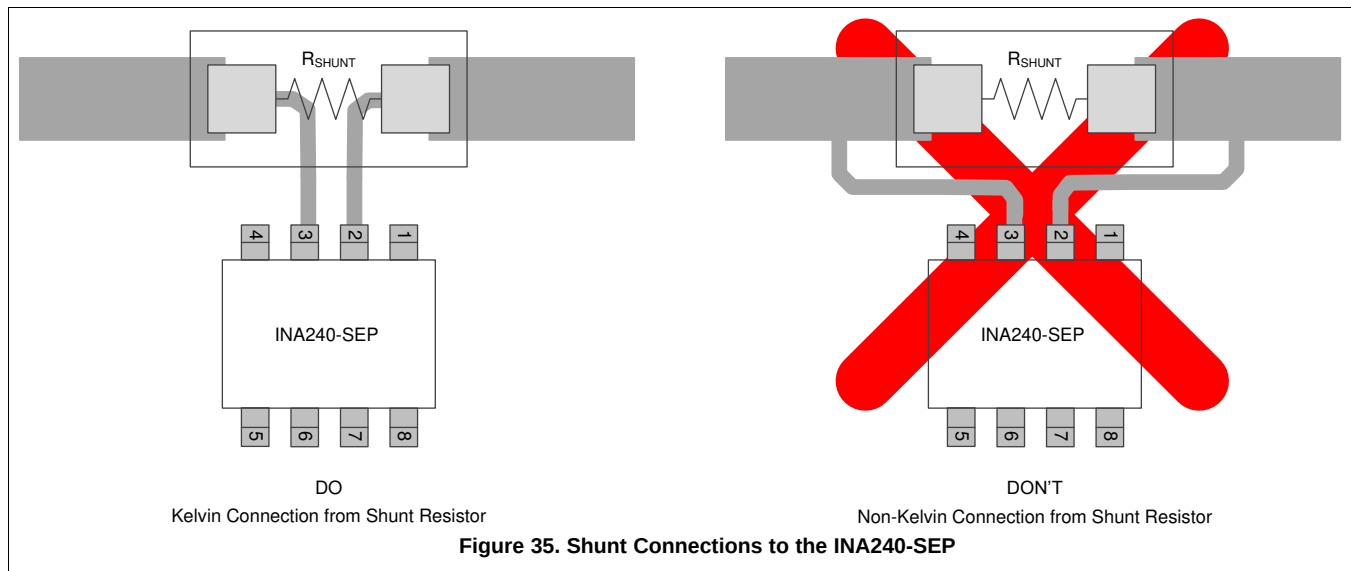
9.3.1 High-Precision Applications

For high-precision applications, verify accuracy and stability of the amplifier by:

- Providing a precision reference connected to REF1 and REF2
- Optimizing the layout of the power and sensing path of the sense resistor (see the [Layout](#) section)
- Providing adequate bypass capacitance on the supply pin (see the [Power Supply Decoupling](#) section)

9.3.2 Kelvin Connection from the Current-Sense Resistor

To provide accurate current measurements, verify the routing between the current-sense resistor and the amplifier uses a Kelvin connection. Use the information provided in [Figure 35](#) and the [Connection to the Current-Sense Resistor](#) section during device layout.



10 Power Supply Recommendations

The INA240-SEP makes accurate measurements beyond the connected power-supply voltage (V_S) because the inputs (IN+ and IN–) operate anywhere between -4 V and 80 V independent of V_S . For example, the V_S power supply equals 5 V and the common-mode voltage of the measured shunt can be as high as 80 V.

Although the common-mode voltage of the input can be beyond the supply voltage, the output voltage range of the INA240-SEP series is constrained to the supply voltage.

10.1 Power Supply Decoupling

Place the power-supply bypass capacitor as close as possible to the supply and ground pins. TI recommends a bypass capacitor value of $0.1 \mu\text{F}$. Additional decoupling capacitance can be added to compensate for noisy or high-impedance power supplies.

11 Layout

11.1 Layout Guidelines

11.1.1 Connection to the Current-Sense Resistor

Poor routing of the current-sensing resistor can result in additional resistance between the input pins of the amplifier. Any additional high-current carrying impedance can cause significant measurement errors because the current resistor has a very-low-ohmic value. Use a Kelvin or 4-wire connection to connect to the device input pins. This connection technique ensures that only the current-sensing resistor impedance is detected between the input pins.

11.2 Layout Example

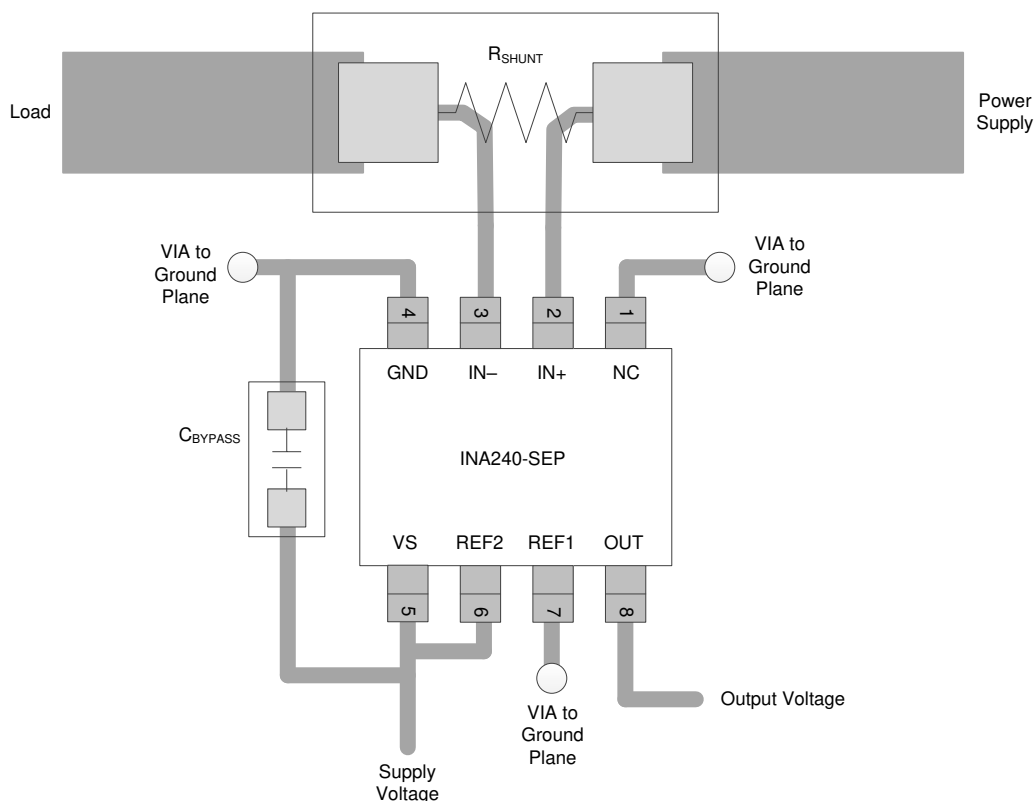


Figure 36. Recommended TSSOP Package Layout

12 デバイスおよびドキュメントのサポート

12.1 ドキュメントの更新通知を受け取る方法

ドキュメントの更新についての通知を受け取るには、ti.comのデバイス製品フォルダを開いてください。右上の「アラートを受け取る」をクリックして登録すると、変更されたすべての製品情報に関するダイジェストを毎週受け取れます。変更の詳細については、修正されたドキュメントに含まれている改訂履歴をご覧ください。

12.2 コミュニティ・リソース

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設計サポート TIの設計サポート 役に立つE2Eフォーラムや、設計サポート・ツールをすばやく見つけることができます。技術サポート用の連絡先情報も参照できます。

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静電気放電はわずかな性能の低下から完全なデバイスの故障に至るまで、様々な損傷を与えます。高精度の集積回路は、損傷に対して敏感であり、極めてわずかなパラメータの変化により、デバイスに規定された仕様に適合しなくなる場合があります。

12.5 Glossary

SLYZ022 — *TI Glossary*.

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

13 メカニカル、パッケージ、および注文情報

以降のページには、メカニカル、パッケージ、および注文に関する情報が記載されています。この情報は、そのデバイスについて利用可能な最新のデータです。このデータは予告なく変更されることがあり、ドキュメントが改訂される場合もあります。本データシートのブラウザ版を使用されている場合は、画面左側の説明をご覧ください。

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
INA240PMPWPSEP	ACTIVE	TSSOP	PW	8	150	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-55 to 125	240SEP	Samples
INA240PMPWTPSEP	ACTIVE	TSSOP	PW	8	250	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-55 to 125	240SEP	Samples
V62/18615-01XE	ACTIVE	TSSOP	PW	8	250	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-55 to 125	240SEP	Samples
V62/18615-01XE-T	ACTIVE	TSSOP	PW	8	150	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-55 to 125	240SEP	Samples

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

ACTIVE: Product device recommended for new designs.

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

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

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

OBSELETE: TI has discontinued the production of the device.

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

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

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

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

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

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

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

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continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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

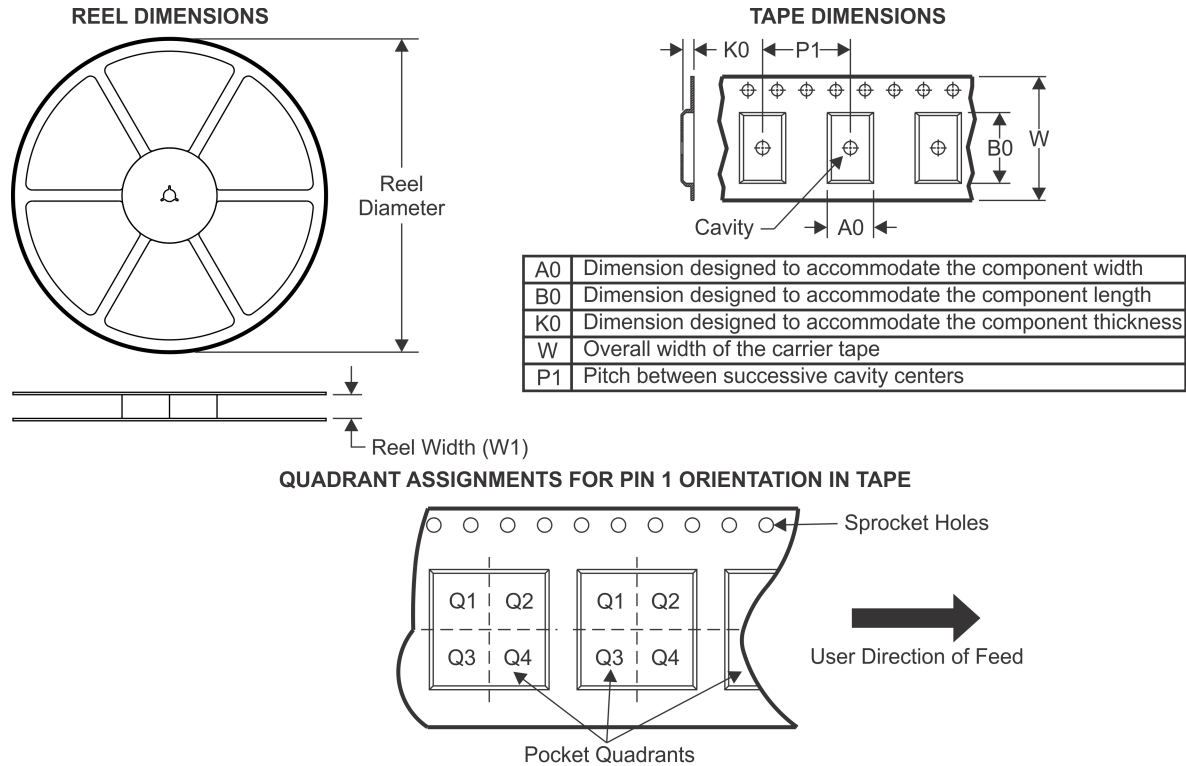
OTHER QUALIFIED VERSIONS OF INA240-SEP :

- Automotive : [INA240-Q1](#)

NOTE: Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

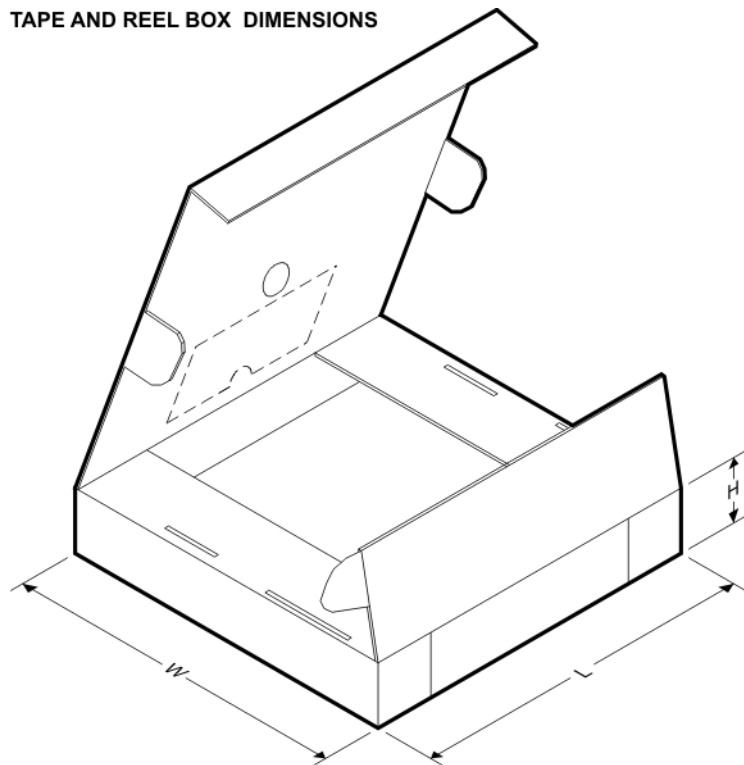
TAPE AND REEL INFORMATION



*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
INA240PMPWTPSEP	TSSOP	PW	8	250	180.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1

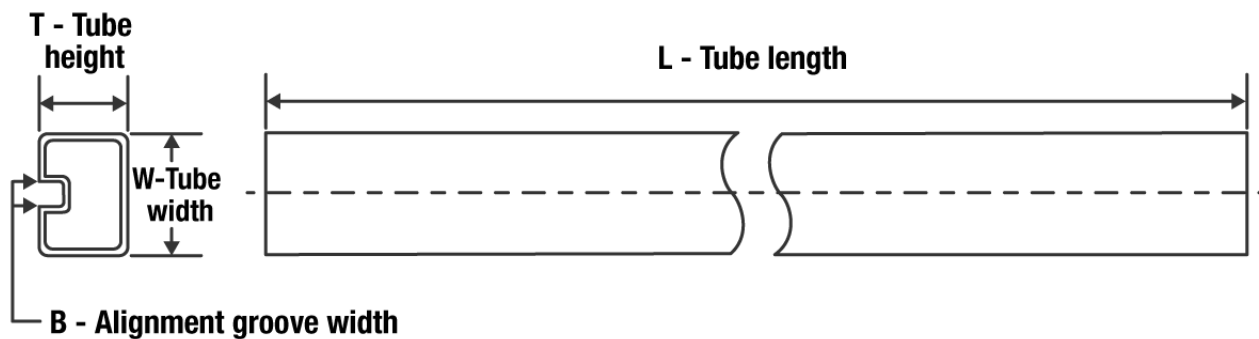
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA240PMPWTPSEP	TSSOP	PW	8	250	210.0	185.0	35.0

TUBE



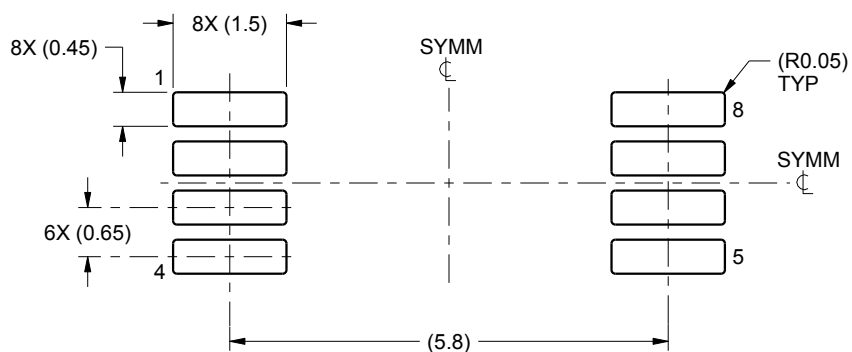
*All dimensions are nominal

Device	Package Name	Package Type	Pins	SPQ	L (mm)	W (mm)	T (μm)	B (mm)
INA240PMPWPSEP	PW	TSSOP	8	150	530	10.2	3600	3.5
V62/18615-01XE-T	PW	TSSOP	8	150	530	10.2	3600	3.5

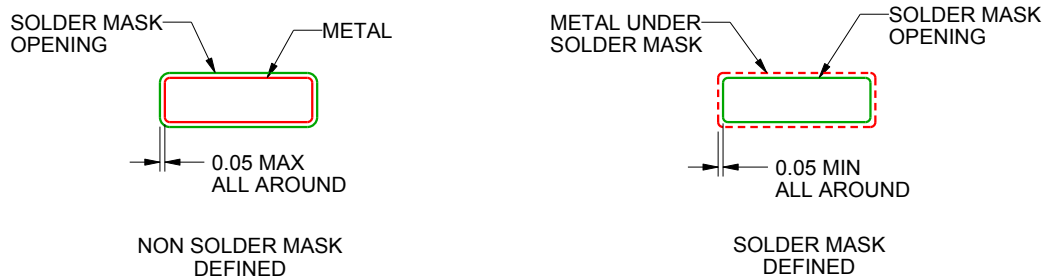
PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE
SCALE:10X



SOLDER MASK DETAILS
NOT TO SCALE

4221848/A 02/2015

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

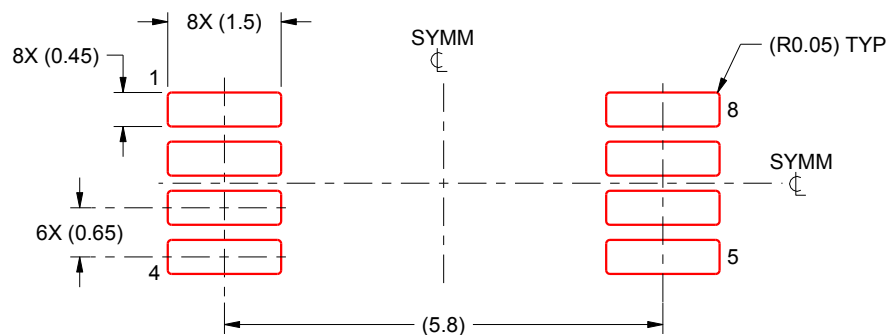
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:10X

4221848/A 02/2015

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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