INA250-Q1 AEC-Q100, 36-V, Bidirectional, Precision Current Sense Amplifier With Integrated Shunt Resistor

1 Features

- Qualified for Automotive Applications
- AEC-Q100 Qualified With the Following Results:
  - Device Temperature Grade 1: –40°C to +125°C Ambient Operating Temperature Range
  - Device HBM ESD Classification Level 2
  - Device CDM ESD Classification Level C5
- Functional Safety-Capable
  - Documentation available to aid functional safety system design
- Precision Integrated Shunt Resistor:
  - Shunt Resistor: 2-mΩ
  - Shunt Resistor Tolerance: 0.1% (Maximum)
  - 15 A Continuous from –40°C to +85°C
  - 0°C to +125°C Temperature Coefficient: 10 ppm/°C
- High Accuracy:
  - Gain Error (Shunt and Amplifier): 0.3% (Maximum)
  - Offset Current: 50 mA (Maximum, INA250A2-Q1)
- Four Available Gains:
  - INA250A1-Q1: 200 mV/A
  - INA250A2-Q1: 500 mV/A
  - INA250A3-Q1: 800 mV/A
  - INA250A4-Q1: 2 V/A
- Wide Common-Mode Range: –0.1 V to 36 V
- Specified Operating Temperature: –40°C to +125°C

2 Applications

- Body Control Modules
- DC/DC Converter
- Battery Management Systems
- Engine Control Systems
- Suspension Systems

3 Description

The automotive qualified INA250-Q1 is a voltage-output, current-sensing amplifier family that integrates an internal precision shunt resistor to enable high-accuracy current measurements at common-mode voltages that may vary from 0 V to 36 V, independent of the supply voltage.

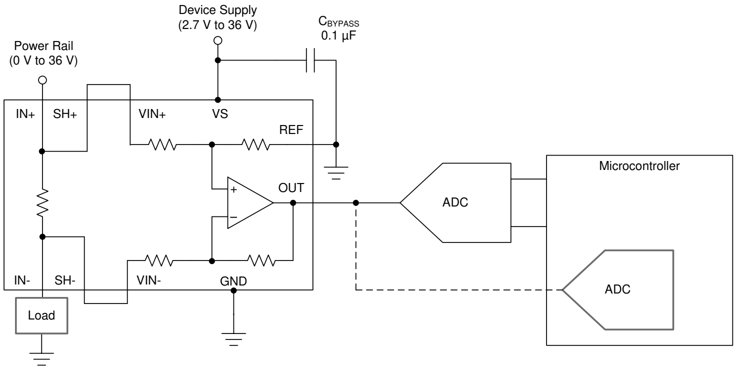
The INA250-Q1 family is available in four output voltage scales: 200 mV/A, 500 mV/A, 800 mV/A, and 2 V/A. This device is fully tested and specified for continuous currents up to 10 amps at the maximum temperature of +125°C. The INA250-Q1 device operates from a single 2.7-V to 36-V supply and draws a maximum of 300 µA of supply current. All INA250-Q1 gain versions are specified over the extended operating temperature range of –40°C to +125°C, and are available in a TSSOP-16 package.

Device Information

PART NUMBER	PACKAGE[1]	PACKAGE SIZE[2]
INA250-Q1	PW (TSSOP, 16)	5.00 mm × 6.40 mm

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

(2) The package size (length × width) is a nominal value and includes pins, where applicable.



Simplified Schematic

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4 Revision History

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

Changes from Revision B (April 2020) to Revision C (September 2023)	Page
• Changed the numbering format for tables, figures, and cross-references throughout the document	1
• Changed the *Device Information* table to *Package Information*	1
• Changed the *Shunt resistance (SH+ to SH–)* minimum value for use as stand-alone resistor from: 1.9 mΩ to 1.8 mΩ in the *Electrical Characteristics* table	6
• Changed the *Shunt resistance (SH+ to SH–)* minimum value for use as stand-alone resistor from: 2.1 mΩ to 2.2 mΩ in the *Electrical Characteristics* table	6

Changes from Revision A (November 2016) to Revision B (April 2020)	Page
• Added Functional Safety-Capable information	1

Changes from Revision * (July 2016) to Revision A (November 2016)	Page
• Document status changed from Product Preview to Production Data	1
• Changed maximum charged-device model ESD value from ±750 to ±1000	4
• Changed maximum I_B values in the *Electrical Characteristics* table from ±35 to ±40	6

5 Pin Configuration and Functions

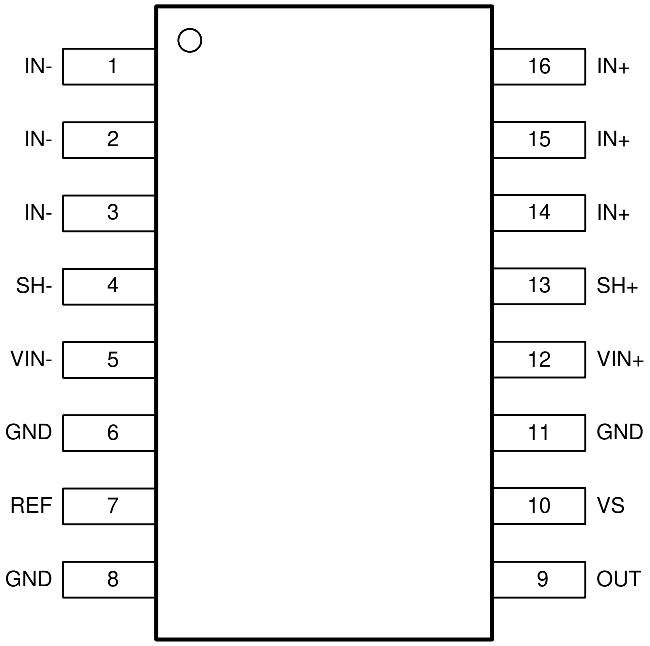


Figure 5-1. PW Package 16-Pin TSSOP Top View

Table 5-1. Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
GND	6, 8, 11	Analog	Ground
IN–	1, 2, 3	Analog input	Connect to load
IN+	14, 15, 16	Analog input	Connect to supply
OUT	9	Analog output	Output voltage
REF	7	Analog input	Reference voltage, 0 V to VS (up to 18 V)
SH–	4	Analog output	Kelvin connection to internal shunt. Connect to VIN– if no filtering is needed. See Figure 7-4 for filter recommendations.
SH+	13	Analog output	Kelvin connection to internal shunt. Connect to VIN+ if no filtering is needed. See Figure 7-4 for filter recommendations.
VIN–	5	Analog input	Voltage input from load side of shunt resistor.
VIN+	12	Analog input	Voltage input from supply side of shunt resistor.
VS	10	Analog	Device power supply, 2.7 V to 36 V

6 Specifications

6.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Supply voltage (VS)			40	V
Analog input current	Continuous current		±15	A
Analog inputs (IN+, IN–)	Common-mode	GND – 0.3	40	V
Analog inputs (VIN+, VIN–)	Common-mode	GND – 0.3	40	V
	Differential $(V_{IN+}) - (V_{IN-})$	–40	40	
Analog inputs (REF)		GND – 0.3	VS + 0.3	V
Analog outputs (SH+, SH–)	Common-mode	GND – 0.3	40	V
Analog outputs (OUT)		GND – 0.3	(VS + 0.3) up to 18	V
Temperature	Operating, T_A	–55	150	°C
	Junction, T_J		150	
	Storage, T_{stg}	–65	150	

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.

6.2 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.

6.3 Recommended Operating Conditions

		MIN	NOM	MAX	UNIT
V_{CM}	Common-mode input voltage	0		36	V
VS	Operating supply voltage	2.7		36	V
T_A	Operating free-air temperature	–40		125	°C

6.4 Thermal Information

THERMAL METRIC[1]		INA250-Q1 PW (TSSOP) 16 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	104.4	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	42.3	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	48.5	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	4.5	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	48	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	°C/W

(1) For more information about traditional and new thermal metrics, see *Semiconductor and IC Package Thermal Metrics* (SPRA953).

6.5 Electrical Characteristics

at T_A = 25°C, VS = 5 V, V_{IN+} = 12 V, V_{REF} = 2.5 V, I_{SENSE} = IN+ = 0 A, unless otherwise noted.

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range		–0.1		36	V
CMR	Common-mode rejection	INA250A1-Q1, V_{IN+} = 0 V to 36 V, T_A = –40°C to 125°C	94	102		dB
		INA250A2-Q1, V_{IN+} = 0 V to 36 V, T_A = –40°C to 125°C	97	110		
		INA250A3-Q1, V_{IN+} = 0 V to 36 V, T_A = –40°C to 125°C	106	114		
		INA250A4-Q1, V_{IN+} = 0 V to 36 V, T_A = –40°C to 125°C	108	118		
I_{OS}	Offset current, RTI(1)	INA250A1-Q1, I_{SENSE} = 0 A		±15	±100	mA
		INA250A2-Q1, I_{SENSE} = 0 A		±12.5	±50	
		INA250A3-Q1, I_{SENSE} = 0 A		±5	±30	
		INA250A4-Q1, I_{SENSE} = 0 A		±5	±20	
dI_{OS}/dT	RTI versus temperature	T_A = –40°C to 125°C		25	250	µA/°C
PSR		VS = 2.7 V to 36 V, T_A = –40°C to 125°C		±0.03	±1	mA/V
I_B	Input bias current	I_{B+}, I_{B-}, I_{SENSE} = 0 A		±28	±40	µA
V_{REF}	Reference input range(3)		0		(VS) up to 18	V
SHUNT RESISTOR(5)						
R_{SHUNT}	Shunt resistance (SH+ to SH–)	Equivalent resistance when used with onboard amplifier	1.998	2	2.002	mΩ
		Used as stand-alone resistor(7)	1.8	2	2.2	
	Package resistance	IN+ to IN–		4.5		mΩ
	Resistor temperature coefficient	T_A = –40°C to 125°C		15		ppm/°C
		T_A = –40°C to 0°C		50		
		T_A = 0°C to 125°C		10		
I_{SENSE}	Maximum continuous current(4)	T_A = –40°C to 85°C			±15	A
	Shunt short time overload	I_{SENSE} = 30 A for 5 seconds		±0.05%		
	Shunt thermal shock	–65°C to 150°C, 500 cycles		±0.1%		
	Shunt resistance to solder heat	260°C solder, 10 s		±0.1%		
	Shunt high temperature exposure	1000 hours, T_A = 150°C		±0.15%		
	Shunt cold temperature storage	24 hours, T_A = –65°C		±0.025%		

at T_A = 25°C, VS = 5 V, V_{IN+} = 12 V, V_{REF} = 2.5 V, I_{SENSE} = IN+ = 0 A, unless otherwise noted.

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
G	Gain	INA250A1-Q1		200		mV/A
		INA250A2-Q1		500		
		INA250A3-Q1		800		
		INA250A4-Q1		2		V/A
	System gain error[6]	I_{SENSE} = –10 A to 10 A, T_A = 25°C		±0.05%	±0.3%	
		I_{SENSE} = –10 A to 10 A, T_A = –40°C to 125°C			±0.75%	
		T_A = –40°C to 125°C			45	ppm/°C
	Nonlinearity error	I_{SENSE} = 0.5 A to 10 A		±0.03%		
R_O	Output impedance			1.5		Ω
	Maximum capacitive load	No sustained oscillation		1		nF
VOLTAGE OUTPUT[2]						
	Swing to VS power-supply rail	R_L = 10 kΩ to GND		(VS) – 0.1	(VS) – 0.2	V
	Swing to GND	R_L = 10 kΩ to GND		(V_{GND}) + 25	(V_{GND}) + 50	mV
FREQUENCY RESPONSE						
BW	Bandwidth	INA250A1-Q1, C_L = 10 pF		50		kHz
		INA250A2-Q1, C_L = 10 pF		50		
		INA250A3-Q1, C_L = 10 pF		35		
		INA250A4-Q1, C_L = 10 pF		11		
SR	Slew rate	C_L = 10 pF		0.2		V/µs
NOISE, RTI[1]						
	Voltage noise density	INA250A1-Q1		51		nV/√Hz
		INA250A2-Q1		35		
		INA250A3-Q1		37		
		INA250A4-Q1		27		
POWER SUPPLY						
VS	Operating voltage range		2.7		36	V
I_Q	Quiescent current	T_A = –40°C to 125°C		200	300	µA
TEMPERATURE RANGE						
	Specified range		–40		125	°C

(1) RTI = referred-to-input.
(2) See *Output Voltage Swing vs Output Current* (Figure 6-19).
(3) The supply voltage range maximum is 36 V, but the reference voltage cannot be higher than 18 V.
(4) See Figure 7-1 and the *Layout* section for additional information on the current derating and layout recommendations to improve the current handling capability of the device at higher temperatures.
(5) See the *Integrated Shunt Resistor* section for additional information regarding the integrated current-sensing resistor.
(6) System gain error includes amplifier gain error and the integrated sense resistor tolerance. System gain error does not include the stress related characteristics of the integrated sense resistor. These characteristics are described in the *Shunt Resistor* section of the *Electrical Characteristics* table.
(7) The internal shunt resistor is intended to be used with the internal amplifier and is not intended to be used as a stand-alone resistor. See the *Integrated Shunt Resistor* section for more information.

6.6 Typical Characteristics

at T_A = 25°C, VS = 5 V, V_{IN+} = 12 V, V_{REF} = 2.5 V, I_{SENSE} = IN+ = 0 A, unless otherwise noted.

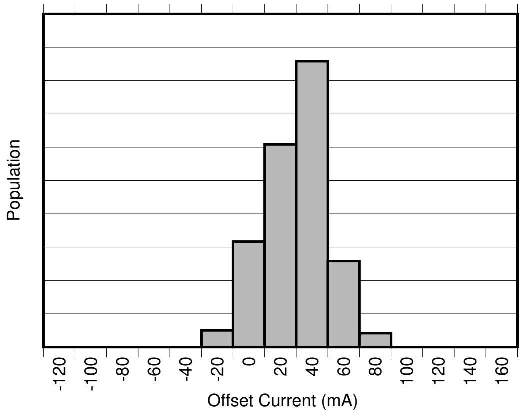


Figure 6-1. INA250A1-Q1 Input Offset Distribution

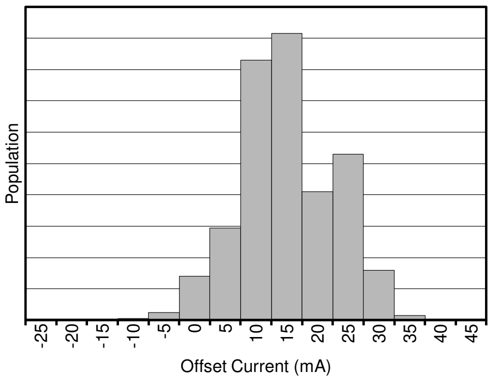


Figure 6-2. INA250A2-Q1 Input Offset Distribution

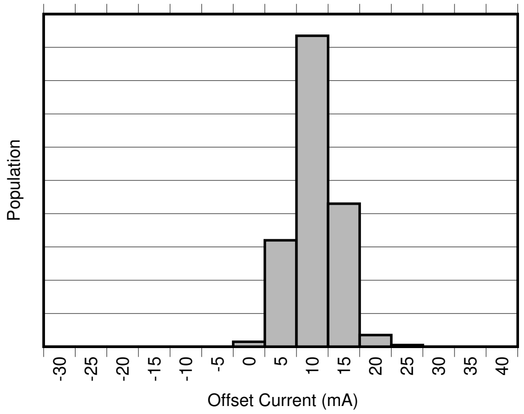


Figure 6-3. INA250A3-Q1 Input Offset Distribution

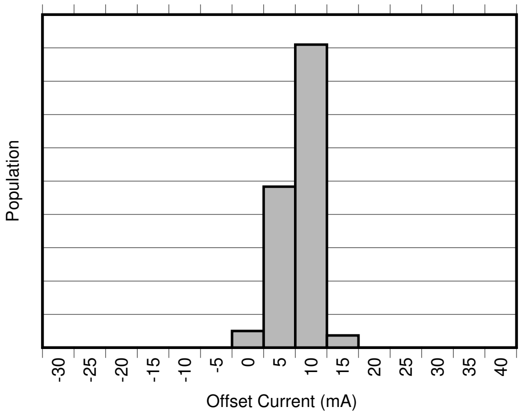


Figure 6-4. INA250A4-Q1 Input Offset Distribution

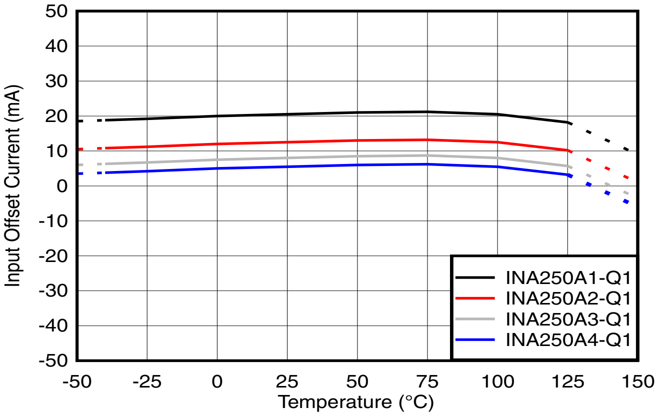


Figure 6-5. Input Offset vs Temperature

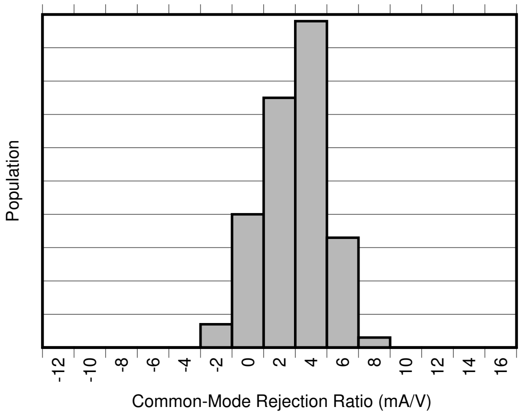


Figure 6-6. INA250A1-Q1 Common-Mode Rejection Ratio Distribution

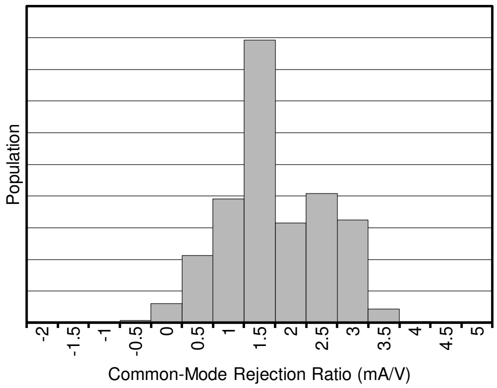


Figure 6-7. INA250A2-Q1 Common-Mode Rejection Ratio Distribution

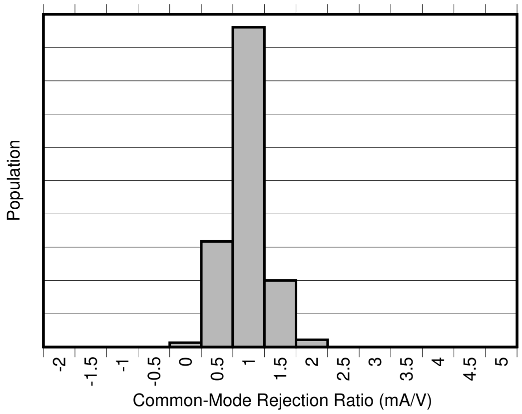


Figure 6-8. INA250A3-Q1 Common-Mode Rejection Ratio Distribution

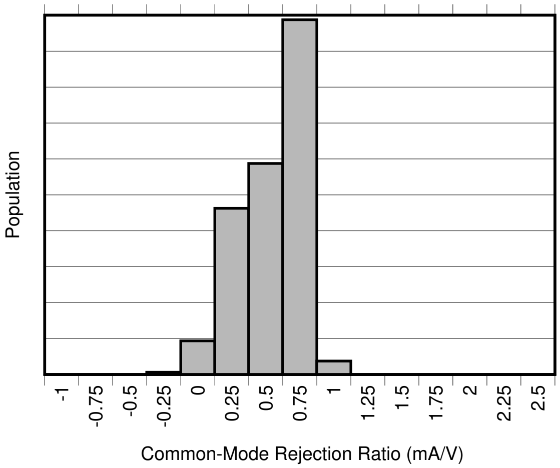


Figure 6-9. INA250A4-Q1 Common-Mode Rejection Ratio Distribution

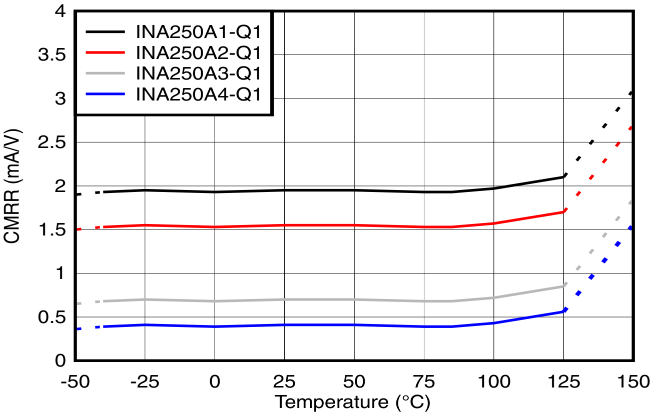


Figure 6-10. Common-Mode Rejection Ratio vs Temperature

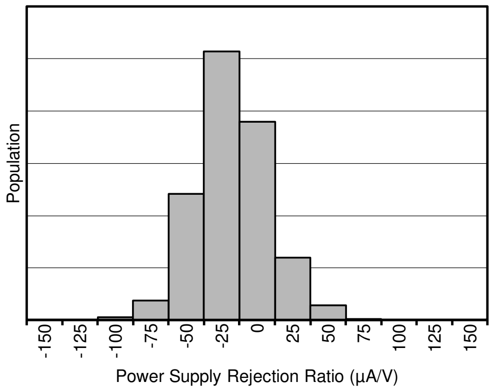


Figure 6-11. Power-Supply Rejection Ratio Distribution

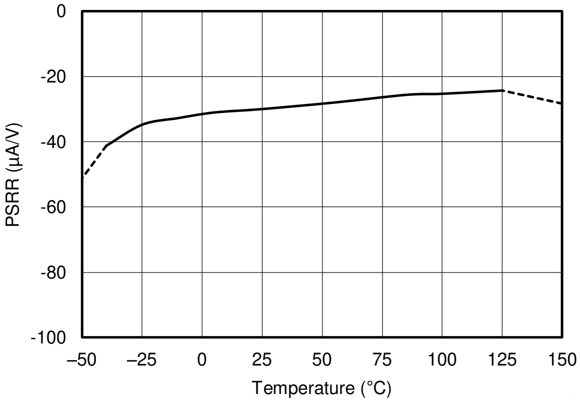


Figure 6-12. Power-Supply Rejection Ratio vs Temperature

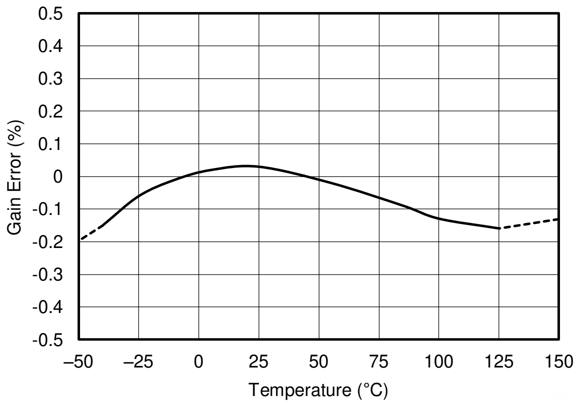
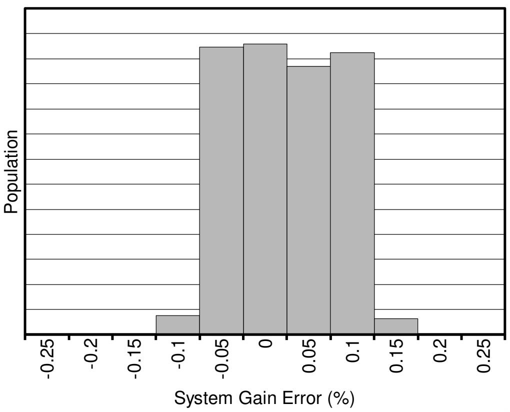


Figure 6-13. System Gain Error vs Temperature



System gain error = R_{SHUNT} error + amplifier gain error, load current = 10 A

Figure 6-14. System Gain Error Distribution

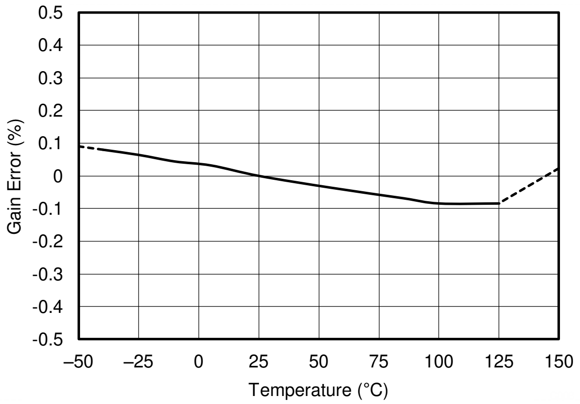
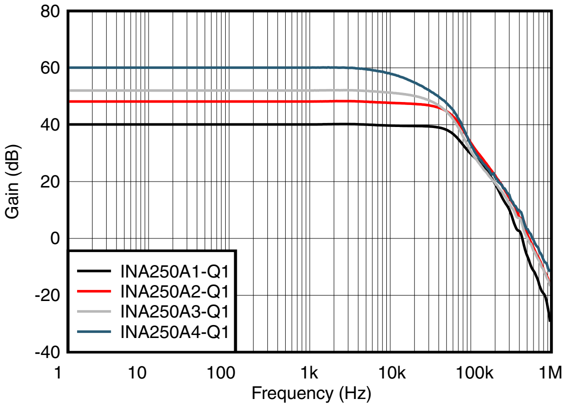
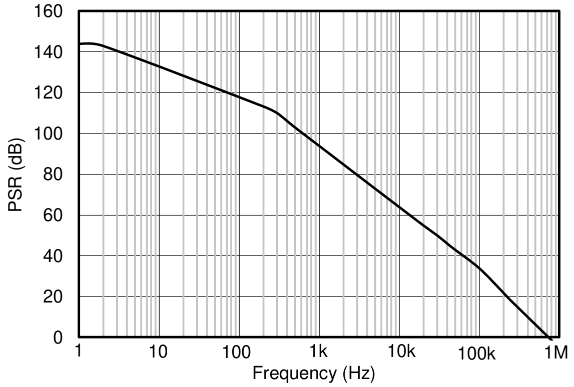


Figure 6-15. Amplifier Gain Error vs Temperature



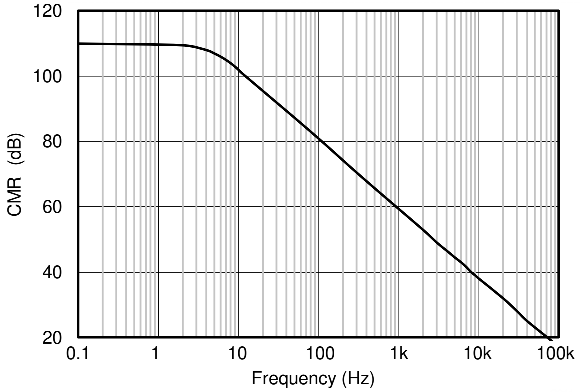
V_{CM} = 12 V, I_{SENSE} = 500 mA_{PP}

Figure 6-16. Amplifier Gain vs Frequency



V_{CM} = 12 V, V_{REF} = 2.5 V, I_{SENSE} = 0 A, VS = 5 V + 250-mV sine disturbance

Figure 6-17. Power-Supply Rejection vs Frequency



VS = 5 V, V_{REF} = 2.5 V, I_{SENSE} = 0 A, V_{CM} = 1-V sine wave

Figure 6-18. Common-Mode Rejection vs Frequency

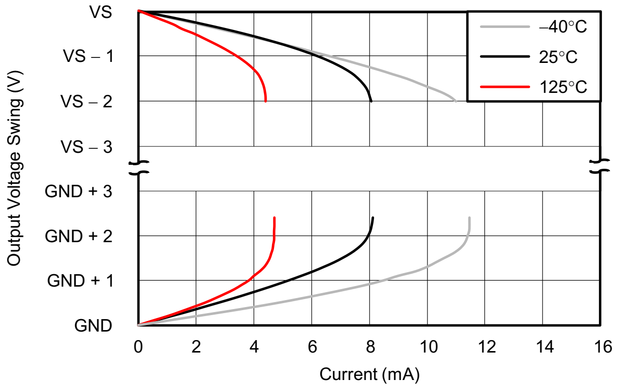
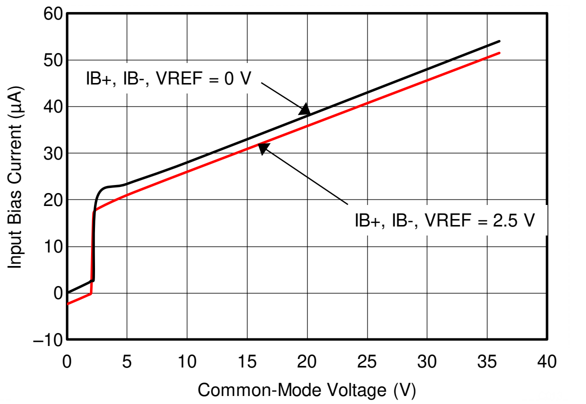
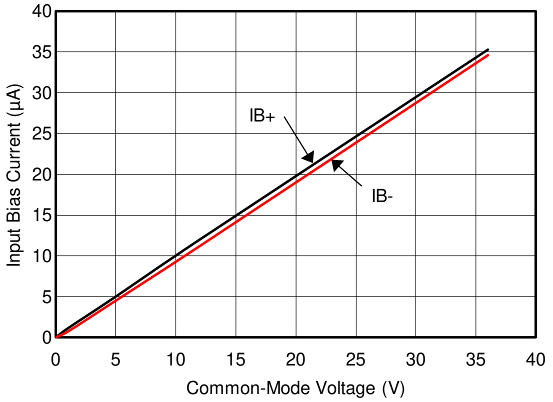


Figure 6-19. Output Voltage Swing vs Output Current



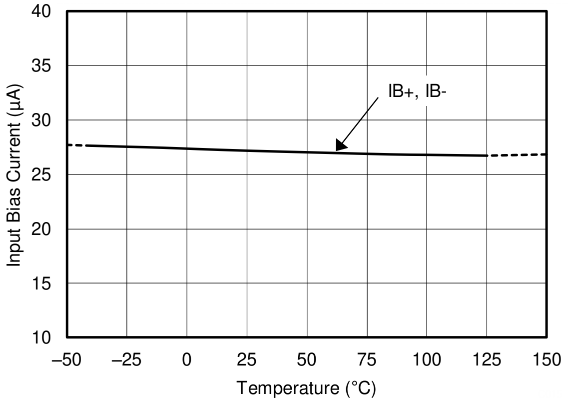
I_{SENSE} = 0 A, VS = 5 V

Figure 6-20. Input Bias Current vs Common-Mode Voltage (VS = 5 V)



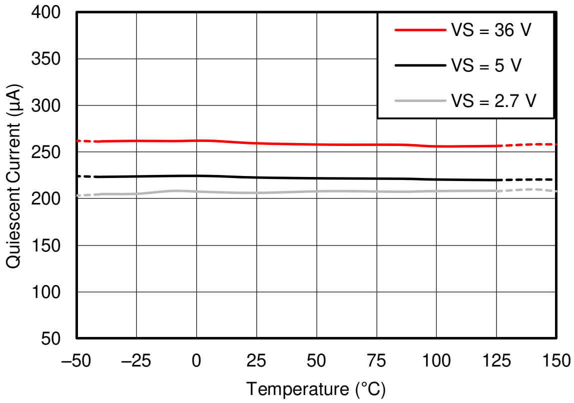
I_{SENSE} = 0 A, VS = 0 V, VREF = 0 V

Figure 6-21. Input Bias Current vs Common-Mode Voltage (VS = 0 V)



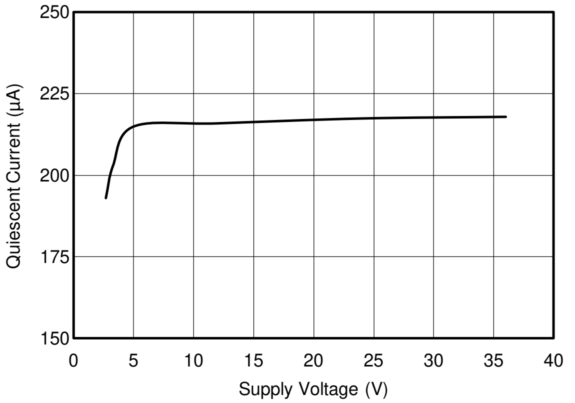
I_{SENSE} = 0 A, VS = 5 V

Figure 6-22. Input Bias Current vs Temperature



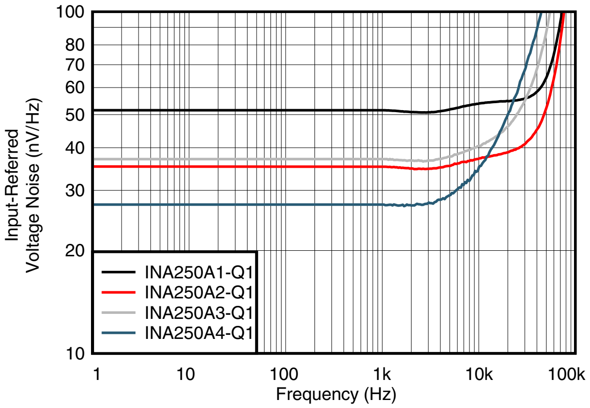
VREF = VS / 2

Figure 6-23. Quiescent Current vs Temperature



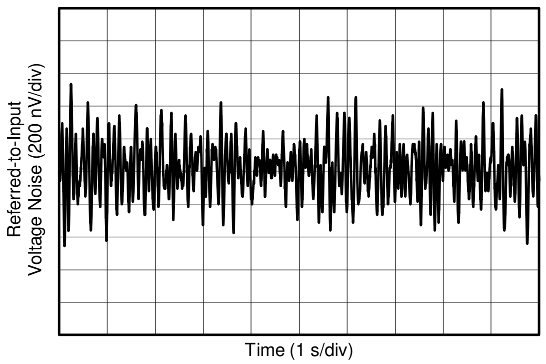
VREF = 2.5 V

Figure 6-24. Quiescent Current vs Supply Voltage



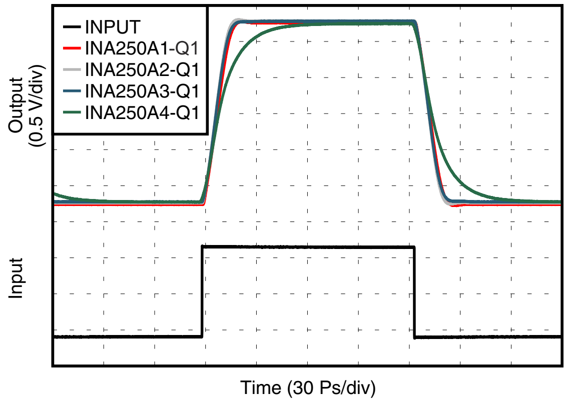
VS = 5 V, V_{REF} = 2.5 V, I_{SENSE} = 0 A

Figure 6-25. Input-Referred Voltage Noise vs Frequency



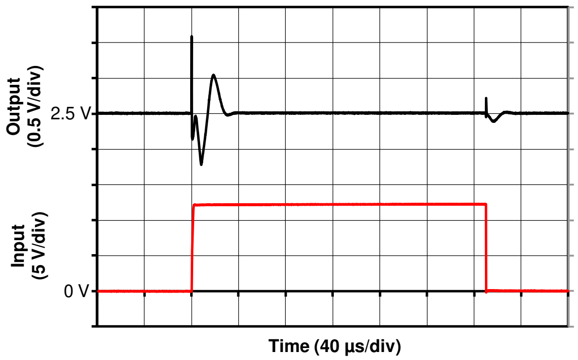
VS = 5 V, V_{CM} = 0 V, I_{SENSE} = 0 A

Figure 6-26. 0.1-Hz to 10-Hz Voltage Noise (Referred-to-Input)



Input = (VIN+) - (VIN-)

Figure 6-27. Step Response



Input = VIN+, V_{REF} = 2.5 V

Figure 6-28. Common-Mode Transient Response

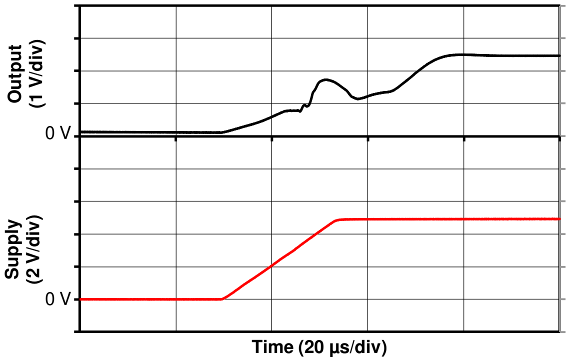


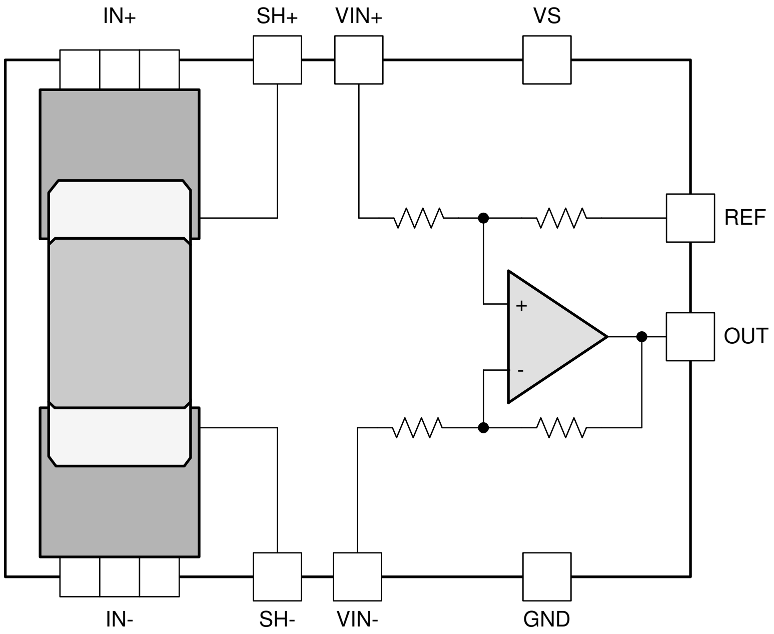
Figure 6-29. Start-Up Response

7 Detailed Description

7.1 Overview

The INA250-Q1 features a 2-mΩ, precision, current-sensing resistor and a 36-V common-mode, zero-drift topology, precision, current-sensing amplifier integrated into a single package. High precision measurements are enabled through the matching of the shunt resistor value and the current-sensing amplifier gain providing a highly-accurate, system-calibrated solution. Multiple gain versions are available to allow for the optimization of the desired full-scale output voltage based on the target current range expected in the application.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Integrated Shunt Resistor

The INA250-Q1 features a precise, low-drift, current-sensing resistor to allow for precision measurements over the entire specified temperature range of –40°C to +125°C. The integrated current-sensing resistor ensures measurement stability overtemperature and improves layout and board constraint difficulties common in high precision measurements.

The onboard current-sensing resistor is designed as a 4-wire (or Kelvin) connected resistor that enables accurate measurements through a force-sense connection. Connecting the amplifier inputs pins (VIN– and VIN+) to the sense pins of the shunt resistor (SH– and SH+) eliminates many of the parasitic impedances commonly found in typical very-low sensing-resistor level measurements. Although the sense connection of the current-sensing resistor may be accessed through the SH+ and SH– pins, this resistor is not intended to be used as a stand-alone component. The INA250-Q1 device is system-calibrated to ensure that the current-sensing resistor and current-sensing amplifier are both precisely matched to one another. Using the shunt resistor without the onboard amplifier results in a current-sensing resistor tolerance of approximately 5%. To achieve the optimized system gain specification, the onboard sensing resistor must be used with the internal current-sensing amplifier.

The INA250-Q1 has approximately 4.5-mΩ of package resistance. 2 mΩ of this total package resistance is a precisely-controlled resistance from the Kelvin-connected current-sensing resistor used by the amplifier. The power dissipation requirements of the system and package are based on the total 4.5-mΩ package resistance between the IN+ and IN– pins. The heat dissipated across the package when current flows through the device ultimately determines the maximum current that may be safely handled by the package. The current consumption of the silicon is relatively low, leaving the total package resistance carrying the high load current as the primary contributor to the total power dissipation of the package. The maximum safe-operating current level ensures that the heat dissipated across the package is limited so that the resistor and the package are not damaged, and the internal junction temperature of the silicon does not exceed a +150°C limit.

External factors (such as ambient temperature, external air flow, and PCB layout) may contribute to how effectively the heat developed from the current flowing through the total package resistance may be removed from the device. Under the conditions of no air flow, a maximum ambient temperature of +85°C, and 1-oz. copper input power planes, the INA250-Q1 device can accommodate continuous current levels up to 15 A. As shown in Figure 7-1, the current handling capability is derated at temperatures above the +85°C level with safe operation up to 10 A at a +125°C ambient temperature. With air flow and larger 2-oz. copper input power planes, the INA250-Q1 may safely accommodate continuous current levels up to 15 A over the entire –40°C to +125°C temperature range.

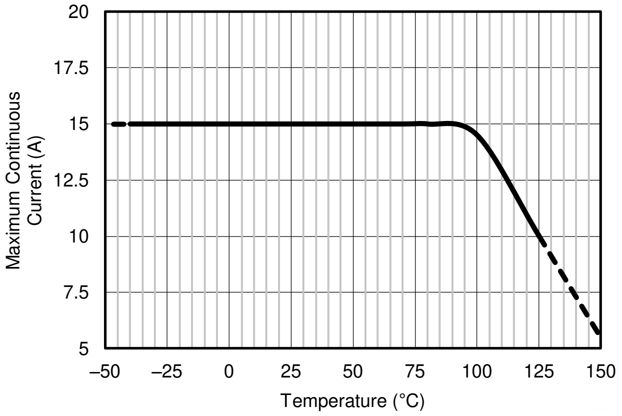


Figure 7-1. Maximum Current vs Temperature

7.3.2 Short-Circuit Duration

The INA250-Q1 features a physical shunt resistance that can withstand current levels higher than the continuous handling limit of 15 A without sustaining damage to the current-sensing resistor or the current-sensing amplifier if the excursions are brief. Figure 7-2 shows the short-circuit duration curve for the INA250-Q1.

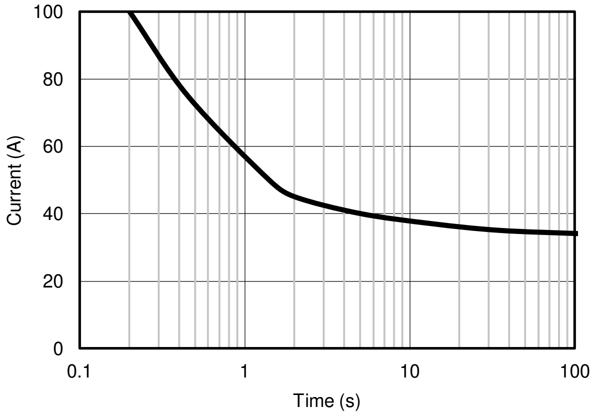


Figure 7-2. Short-Circuit Duration

7.3.3 Temperature Stability

System calibration is common for many industrial applications to eliminate initial component and system-level errors that may be present. A system-level calibration may reduce the initial accuracy requirement for many of the individual components because the calibration procedure eliminates these errors associated with the components Performing this calibration may enable precision measurements at the system calibration temperature, but as the system temperature changes as a result of external ambient changes or self heating, measurement errors are reintroduced. Without using accurate temperature compensation in addition to the initial adjustment, the calibration procedure is ineffective in accounting for these temperature-induced changes.

One of the primary benefits of the very-low-temperature coefficient of the INA250-Q1(including the integrated current-sensing resistor and current-sensing amplifier) is that the device measurement remains highly accurate, even when the temperature changes throughout the specified temperature range.

The drift performance of the integrated current-sensing resistor is shown in Figure 7-3. Although several temperature ranges are specified in the *Electrical Characteristics* table, applications operating in ranges other than those described may use Figure 7-3 to determine how much variance in the shunt resistor value may be expected. As with any resistive element, the tolerance of the component varies when exposed to different temperature conditions. For the current-sensing resistor integrated in the INA250-Q1, the resistor varies more when operating in temperatures ranging from –40°C to 0°C than when operating in ranges from 0°C to +125°C. However, even in the –40°C to 0°C temperature range, the drift is still low at 25 ppm/°C.

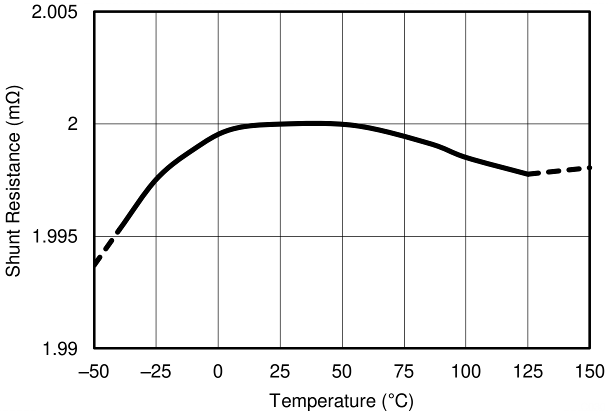


Figure 7-3. Sensing Resistor vs Temperature

An additional aspect to consider is that when current flows through the current-sensing resistor, power dissipates across this component. This dissipated power results in an increase in the internal temperature of the package, including the integrated sensing resistor. This resistor self-heating effect results in an increase of the resistor temperature helping to move the component out of the colder, wider drift temperature region.

7.4 Device Functional Modes

7.4.1 Amplifier Operation

The INA250-Q1 current-sense amplifier may be configured to measure both unidirectional and bidirectional currents through the reference voltage level applied to the reference pin (REF). The reference voltage connected to REF sets the output level that corresponds with a zero input current condition. For unidirectional operation, tie the REF pin to ground so that when the current increases, the output signal also increases upwards from this reference voltage (or ground in this case). For bidirectional currents, an external voltage source may be used as the reference voltage connected to the REF pin to bias up the output. Set the reference voltage to enable sufficient range above and below this level based on the expected current range to be measured. Positive currents result in an output signal that increases from the zero-current output level set by the reference voltage, whereas negative currents result in an output signal that decreases.

Equation 1 shows the amplifier transfer function for both unidirectional and bidirectional amplifiers:

$$V_{OUT} = (I_{LOAD} \times \text{GAIN}) + V_{REF} \tag{1}$$

where:

- I_{LOAD} is the current being measured passing through the internal shunt resistor,
- GAIN is the corresponding gain (mA/V) of the selected device, and
- V_{REF} is the voltage applied to the REF pin

As with any difference amplifier, the INA250-Q1 common-mode rejection ratio is affected by any impedance present at the REF input. This concern is not a problem when the REF pin is connected directly to a reference or power supply. When using resistive dividers from a power supply or a reference voltage, buffer the REF pin with an op amp.

7.4.2 Input Filtering

An obvious and straightforward location for filtering is at the device output; however, this location negates the advantage of the low output impedance of the output stage buffer. The input then represents the best location for implementing external filtering. Figure 7-4 shows the typical implementation of the input filter for the device.

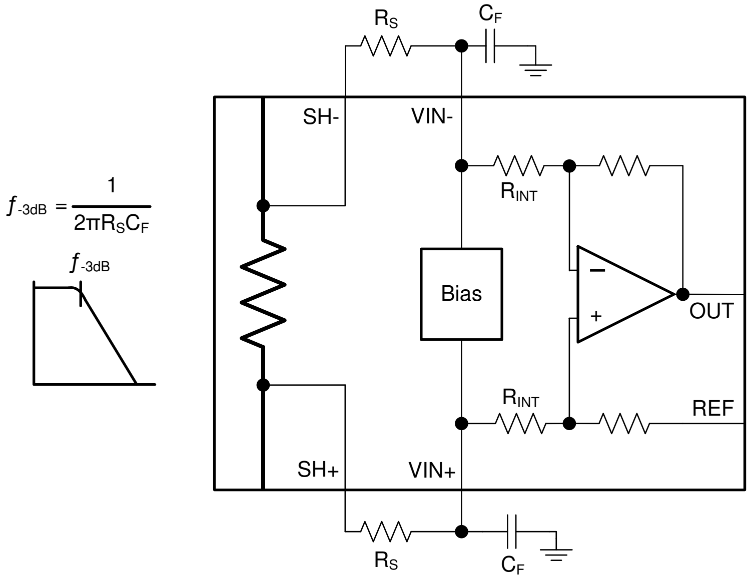


Figure 7-4. Input Filter

However, the addition of external series resistance at the input pins to the amplifier creates an additional error in the measurement. If possible, keep the value of these series resistors to 10 Ω or less to reduce the affect to accuracy. The internal bias network illustrated in Figure 7-4 at the input pins creates a mismatch in input bias currents when a differential voltage is applied between the input pins, as shown in Figure 7-5.

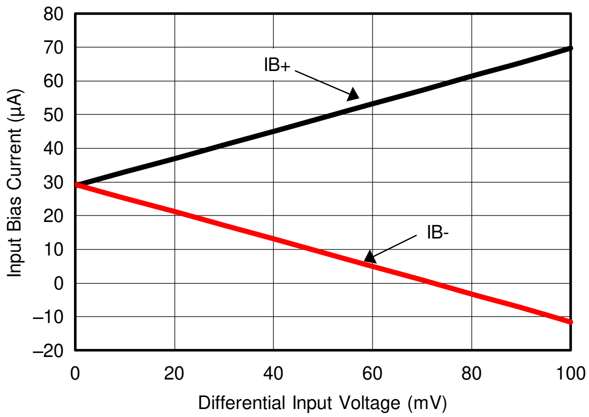


Figure 7-5. Input Bias Current vs Differential Input Voltage

7.4.2.1 Calculating Gain Error Resulting from External Filter Resistance

If additional external series filter resistors are added to the circuit, the mismatch in bias currents results in a mismatch of voltage drops across the filter resistors. This mismatch creates a differential error voltage that subtracts from the voltage developed across the Kelvin connection of the shunt resistor, thus reducing the voltage that reaches the amplifier input terminals. Without the additional series resistance, the mismatch in input bias currents has little effect on device operation as a result of the low input bias current of the amplifier and the typically low impedance of the traces between the shunt and amplifier input pins. The amount of error these external filter resistors add to the measurement may be calculated using Equation 3, where the gain error factor is calculated using Equation 2.

The amount of variance between the differential voltage present at the device input relative to the voltage developed at the shunt resistor is based both on the external series resistance value as well as the internal input resistors, R_{INT}, as shown in Figure 7-4. The reduction of the shunt voltage reaching the device input pins appears as a gain error when comparing the output voltage relative to the voltage across the shunt resistor. A factor may be calculated to determine the amount of gain error that is introduced by the addition of external series resistance. Equation 2 calculates the expected deviation from the shunt voltage compared to the expected voltage at the device input pins.

$$\text{Gain Error Factor} = \frac{(1250 \times R_{INT})}{(1250 \times R_S) + (1250 \times R_{INT}) + (R_S \times R_{INT})} \tag{2}$$

where:

- R_{INT} is the internal input resistor and
- R_S is the external series resistance

$$\text{Gain Error (\%)} = 100 - (100 \times \text{Gain Error Factor}) \tag{3}$$

With the adjustment factor equation including the device internal input resistance, this factor varies with each gain version, as shown in Table 7-1. Table 7-2 lists the gain error factor for each individual device.

Equation 3 calculates the expected gain error from the addition of the external series resistors.

Table 7-1. Input Resistance

DEVICE	GAIN	R_{INT}
INA250A1-Q1	200 mV/A	50 kΩ
INA250A2-Q1	500 mV/A	20 kΩ
INA250A3-Q1	800 mV/A	12.5 kΩ
INA250A4-Q1	2 V/A	5 kΩ

Table 7-2. Device Gain Error Factor

DEVICE	SIMPLIFIED GAIN ERROR FACTOR
INA250A1-Q1	$\frac{50,000}{(41 \bullet R_S) + 50,000}$
INA250A2-Q1	$\frac{20,000}{(17 \bullet R_S) + 20,000}$
INA250A3-Q1	$\frac{12,500}{(11 \bullet R_S) + 12,500}$
INA250A4-Q1	$\frac{1,000}{R_S + 1,000}$

For example, using an INA250A2-Q1 device and the corresponding gain error equation from Table 7-2, a series resistance of 10-Ω results in a gain error factor of 0.991. The corresponding gain error is then calculated using Equation 3, resulting in a gain error of approximately 0.84% because of the external 10-Ω series resistors.

7.4.3 Shutting Down the Device

Although the device does not have a shutdown pin, the low power consumption allows for the device to be powered from the output of a logic gate or transistor switch that may turn on and turn off the voltage connected to the device power-supply pin. However, in current-shunt monitoring applications, there is also a concern for how much current is drained from the shunt circuit in shutdown conditions. Evaluating this current drain involves considering the simplified schematic in shutdown mode, as shown in Figure 7-6.

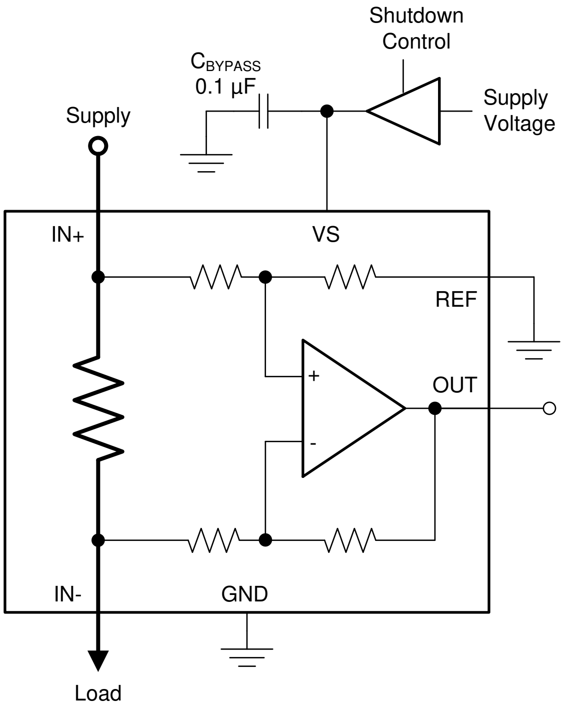


Figure 7-6. Shutting Down the Device

Note that there is typically an approximate 1-MΩ impedance (from the combination of the feedback and input resistors) from each device input to the REF pin. The amount of current flowing through these pins depends on the respective configuration. For example, if the REF pin is grounded, calculating the effect of the 1-MΩ impedance from the shunt to ground is straightforward. However, if the reference or op amp is powered when the device is shut down, the calculation is direct. Instead of assuming 1 MΩ to ground, assume 1 MΩ to the reference voltage. If the reference or op amp is also shut down, some knowledge of the reference or op amp output impedance under shutdown conditions is required. For instance, if the reference source functions similar to an open circuit when un-powered, little or no current flows through the 1-MΩ path.

7.4.4 Using the Device with Common-Mode Transients Above 36 V

With a small amount of additional circuitry, the device may be used in circuits subject to transients higher than 36 V (such as in automotive applications). Use only zener diodes or zener-type transient absorbers (sometimes referred to as *transzorbs*); any other type of transient absorber has an unacceptable time delay. Start by adding a pair of resistors, as shown in Figure 7-7, as a working impedance for the zener. Keeping these resistors as small as possible is preferable; a resistor value of 10-Ω is the most common. This value limits the effect on accuracy with the addition of these external components, as described in the *Input Filtering* section. Device interconnections between the shunt resistor and amplifier have a current handling limit of 1 A. Using a 10-Ω resistor limits the allowable transient range to 10 V above the zener clamp so the device is not damaged. Larger resistor values may be used in this protection circuit to accommodate a larger transient voltage range, which results in a larger effect on gain error. Because this circuit limits only short-term transients, many applications are satisfied with a 10-Ω resistor, along with conventional zener diodes of the lowest power rating available.

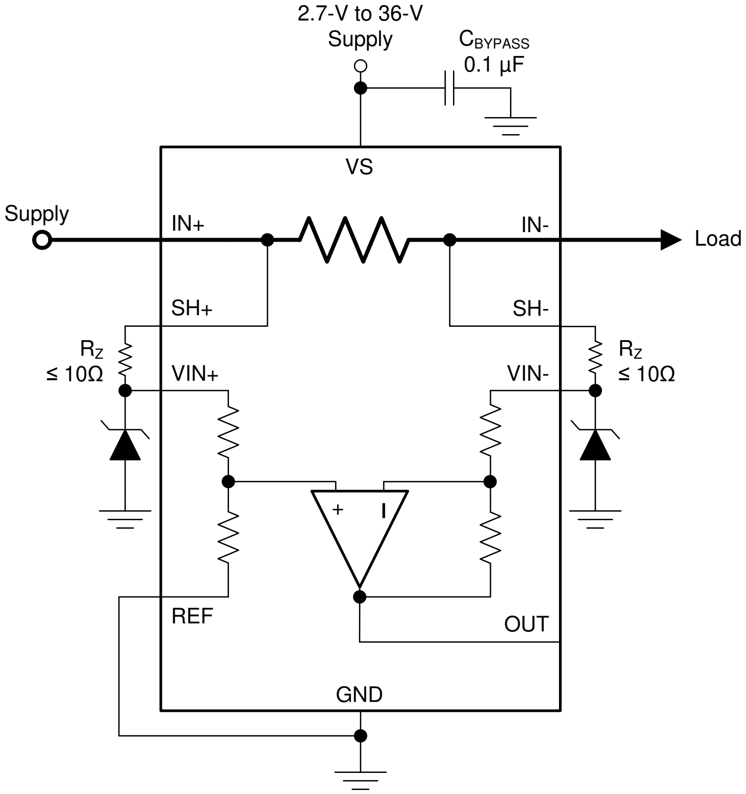


Figure 7-7. Device Transient Protection

8 Applications and Implementation

Note

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

8.1 Application Information

The INA250-Q1 measures the voltage developed across the internal current-sensing resistor when current passes through the device. The ability to drive the reference pin to adjust the functionality of the output signal offers multiple configurations, as discussed in this section.

8.2 Typical Applications

8.2.1 Current Summing

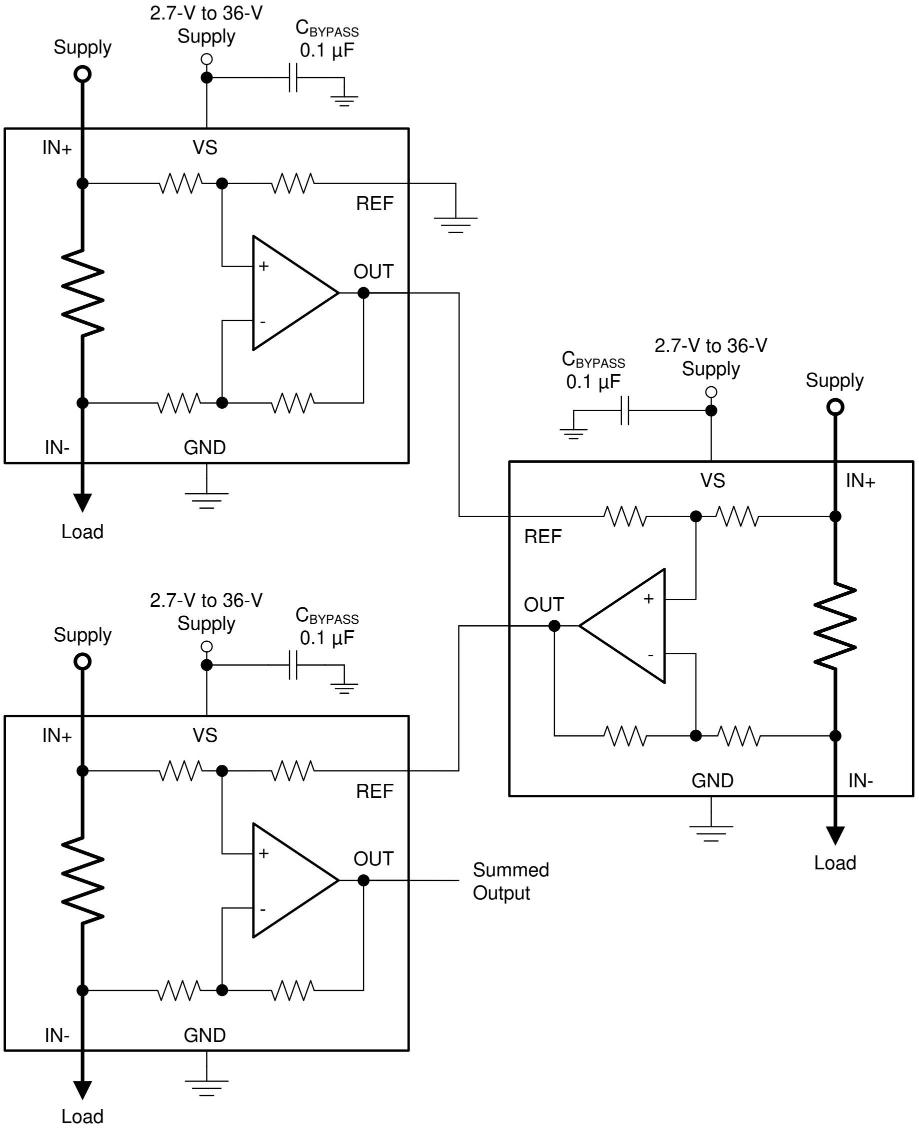


Figure 8-1. Daisy-Chain Configuration

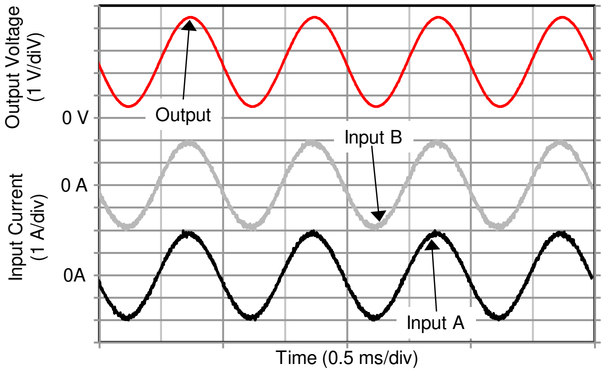
8.2.1.1 Design Requirements

Three daisy-chained devices are illustrated in Figure 8-1. The reference input of the first INA250-Q1 device sets the quiescent level on the output of all the INA250-Q1 devices in the string.

8.2.1.2 Detailed Design Procedure

The outputs of multiple INA250-Q1 devices are easily summed by connecting the output signal of one INA250-Q1 device to the reference input of a second INA250-Q1 device. Summing beyond two devices is possible by repeating this configuration, connecting the output signal of the next INA250-Q1 device to the reference pin of a subsequent INA250-Q1 in the chain. The output signal of the final INA250-Q1 device in this chain includes the current level information for all channels in the chain.

8.2.1.3 Application Curve



VS = 5 V, V_{REF} = 2.5 V

Figure 8-2. Daisy-Chain Configuration Output Response

8.2.2 Parallel Multiple INA250-Q1 Devices for Higher Current

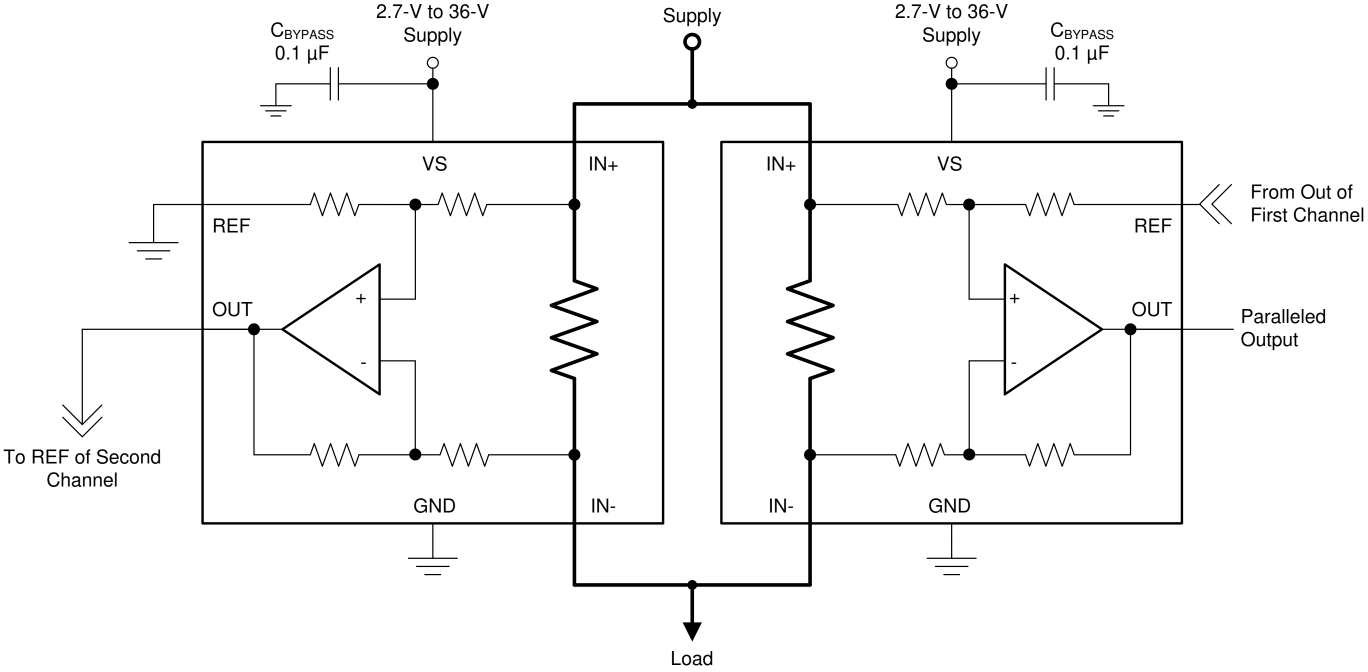


Figure 8-3. Parallel Summing Configuration

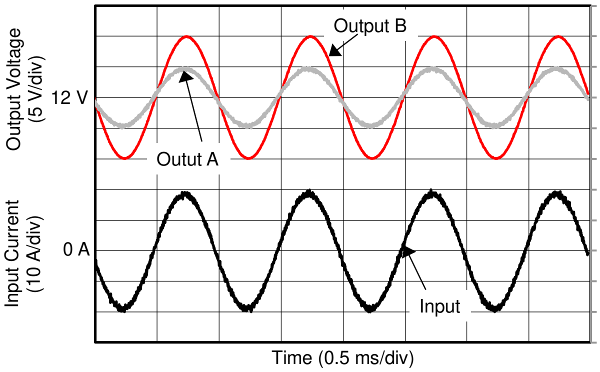
8.2.2.1 Design Requirements

The parallel connection for multiple INA250-Q1 devices may reduce the equivalent overall sense resistance, enabling monitoring of higher current levels than a single device is able to accommodate alone. This configuration also uses a summing arrangement, as described in the *Current Summing* section. A parallel summing configuration is shown in Figure 8-3.

8.2.2.2 Detailed Design Procedure

With a summing configuration, the output of the first channel is fed into the reference input of the second, adding the distributed measurements back together into a single measured value.

8.2.2.3 Application Curve



VS = 24 V, V_{REF} = 12 V

Figure 8-4. Parallel Configuration Output Response

8.2.3 Current Differencing

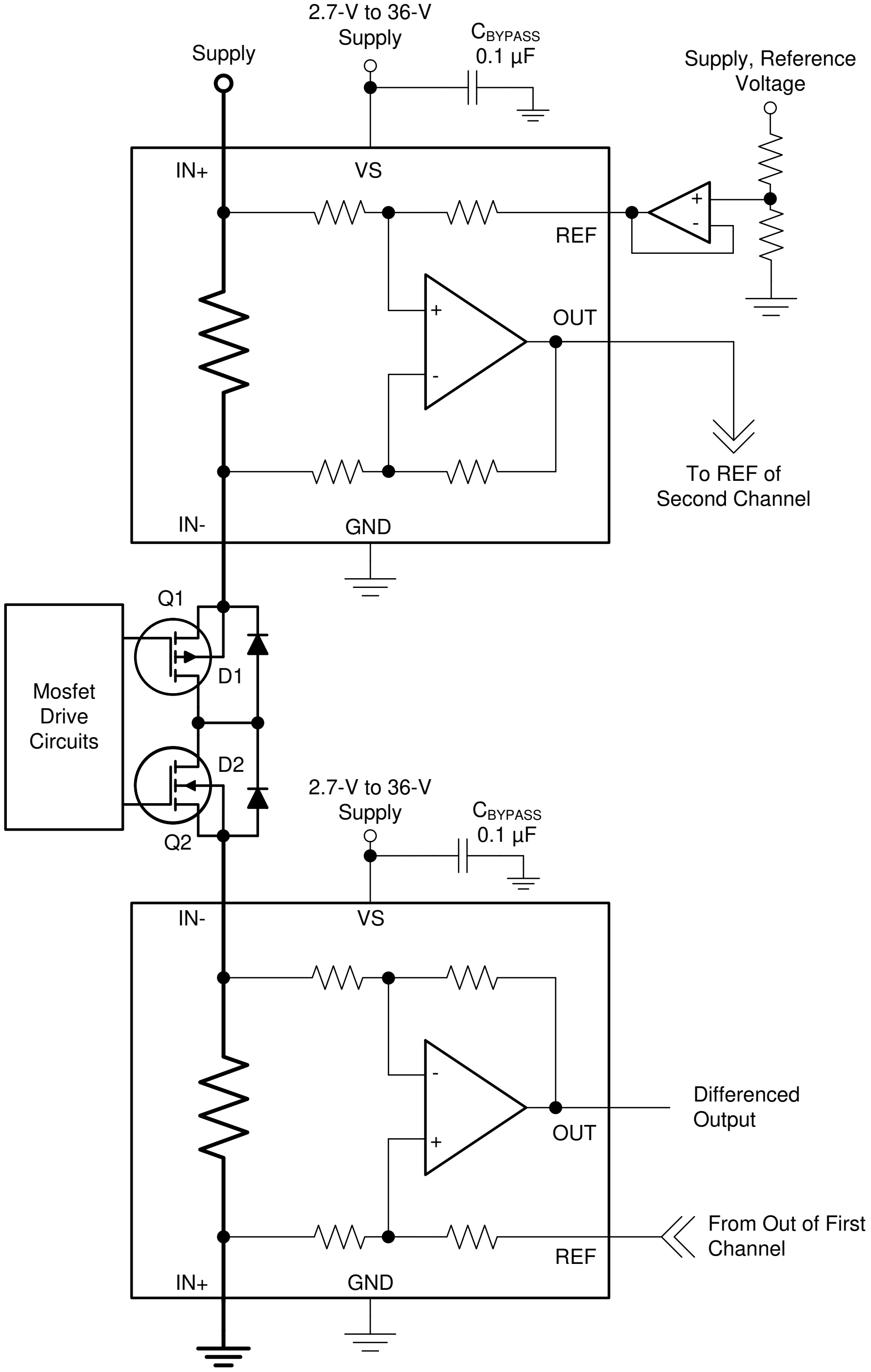


Figure 8-5. Current Differencing Configuration

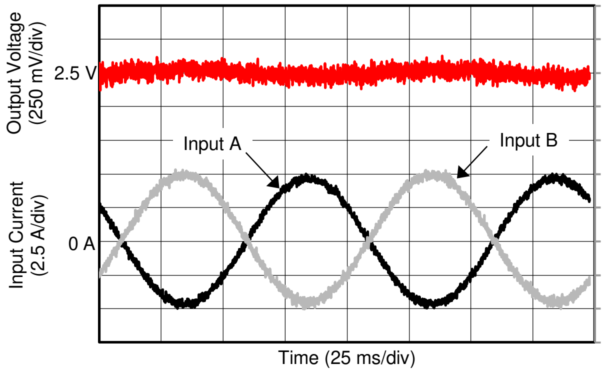
8.2.3.1 Design Requirements

Occasionally, the need may arise to confirm that the current into a load is identical to the current coming out of a load, such as when performing diagnostic testing or fault detection. This procedure requires precision current differencing. This method is the same as current summing, except that the two amplifiers have the respective inputs connected opposite of each other. Under normal operating conditions, the final output is close to the reference value and proportional to any current difference. Figure 8-5 is an example of two INA250-Q1 devices connected for current differencing.

8.2.3.2 Detailed Design Procedure

The load current may also be measured directly at the output of the first channel. Although technically this configuration is current differencing, this connection (see Figure 8-5) is intended to allow the upper (positive) sense channel to report any positive-going excursions in the overall output, and the lower (negative) sense channel to report any negative-going excursions.

8.2.3.3 Application Curve



VS = 5 V, V_{REF} = 2.5 V

Figure 8-6. Current Differencing Configuration Output Response

8.3 Power Supply Recommendations

The input circuitry of the device may accurately measure signals on common-mode voltages beyond the power-supply voltage, VS. For example, the voltage applied to the VS power-supply pin may be 5 V, whereas the load power-supply voltage being monitored (the common-mode voltage) may be as high as 36 V. Note that the device may withstand the full 0-V to 36-V range at the input pins, regardless of whether the device has power applied or not. Power-supply bypass capacitors are required for stability, and must be placed as closely as possible to the supply and ground pins of the device. A typical value for this supply bypass capacitor is 0.1 µF. Applications with noisy or high-impedance power supplies may require additional decoupling capacitors to reject power-supply noise.

8.4 Layout

8.4.1 Layout Guidelines

- The INA250-Q1 is specified for current handling of up to 10 A over the entire –40°C to +125°C temperature range using a 1-oz. copper pour for the input power plane as well as no external airflow passing over the device.
- The primary current-handling limitation for the INA250-Q1 is how much heat is dissipated inside the package. Efforts to improve heat transfer out of the package and into the surrounding environment improve the ability of the device to handle currents of up to 15 A over the entire –40°C to +125°C temperature range.
- Heat transfer improvements primarily involve larger copper power traces and planes with increased copper thickness (2 oz.) as well as providing airflow to pass over the device. The *INA250EVM* (SBOU153) is capable of supporting 15 A at temperatures up to +125°C.
- 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 µF. Additional decoupling capacitance may be added to compensate for noisy or high-impedance power supplies.

8.4.2 Layout Examples

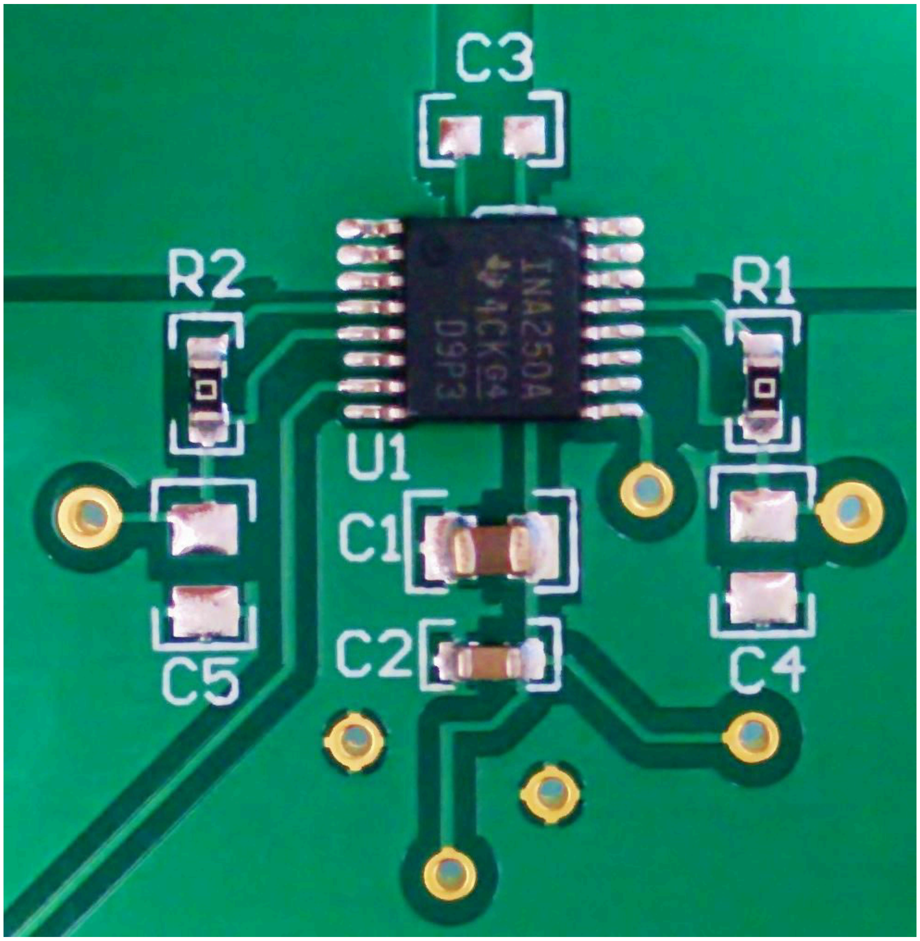


Figure 8-7. Recommended Layout

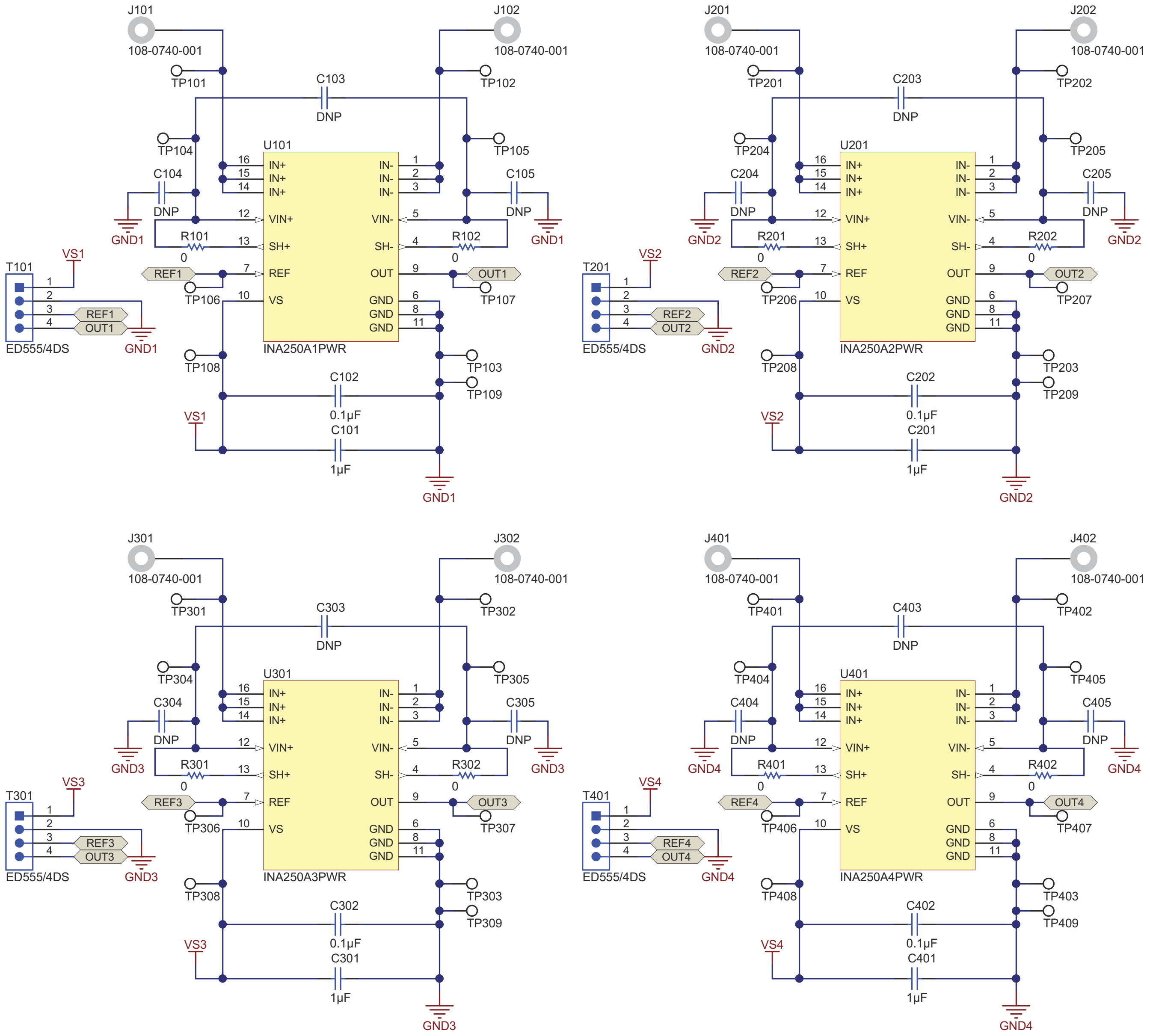


Figure 8-8. Recommended Layout Schematic

9 Device and Documentation Support

9.1 Documentation Support

9.1.1 Related Documentation

- *INA250EVM User Guide* (SBOU153).

9.2 Receiving Notification of Documentation Updates

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

9.3 Support Resources

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

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9.4 Trademarks

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9.5 Electrostatic Discharge Caution

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

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

9.6 Glossary

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

10 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
INA250A1QPWRQ1	ACTIVE	TSSOP	PW	16	2000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	Q250A1	Samples
INA250A2QPWRQ1	ACTIVE	TSSOP	PW	16	2000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	Q250A2	Samples
INA250A3QPWRQ1	ACTIVE	TSSOP	PW	16	2000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	Q250A3	Samples
INA250A4QPWRQ1	ACTIVE	TSSOP	PW	16	2000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	Q250A4	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.
OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

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

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

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

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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 INA250-Q1 :

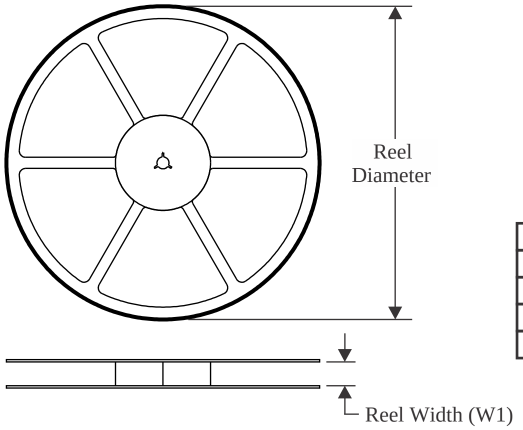
- Catalog : INA250

NOTE: Qualified Version Definitions:

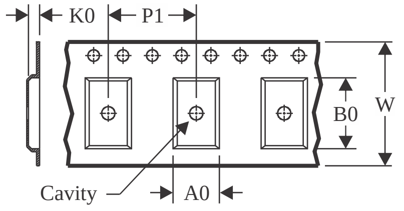
- Catalog - TI's standard catalog product

TAPE AND REEL INFORMATION

REEL DIMENSIONS

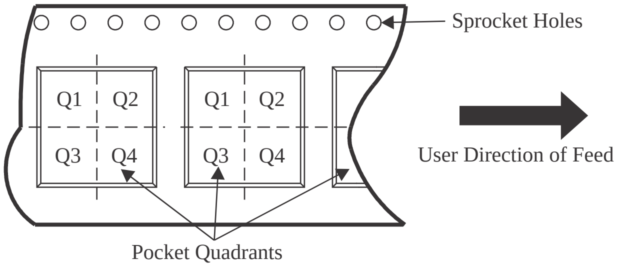


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

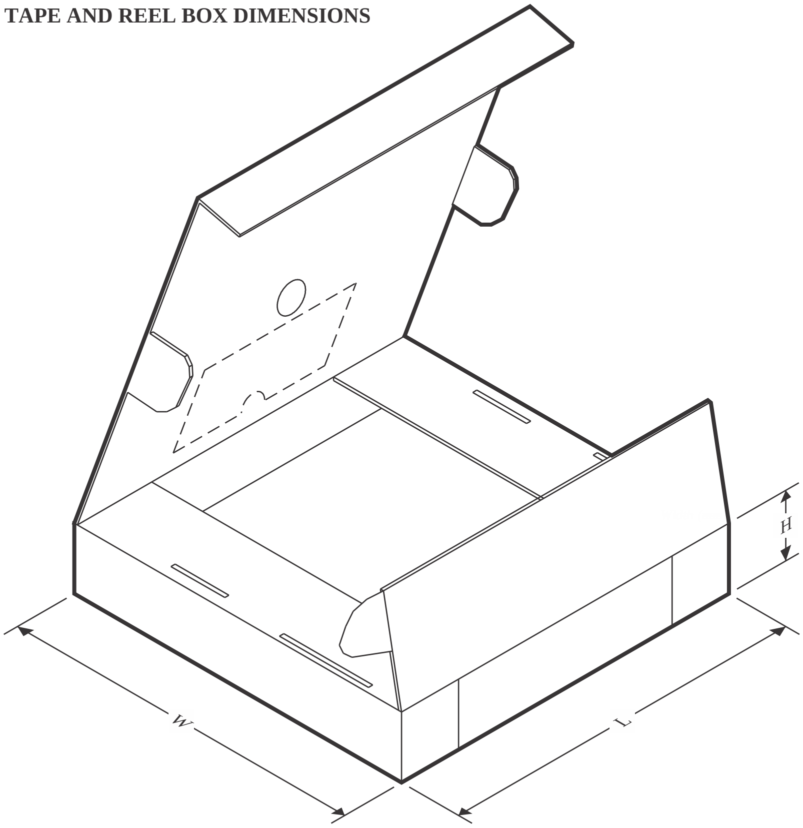
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
INA250A1QPWRQ1	TSSOP	PW	16	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
INA250A2QPWRQ1	TSSOP	PW	16	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
INA250A3QPWRQ1	TSSOP	PW	16	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
INA250A4QPWRQ1	TSSOP	PW	16	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



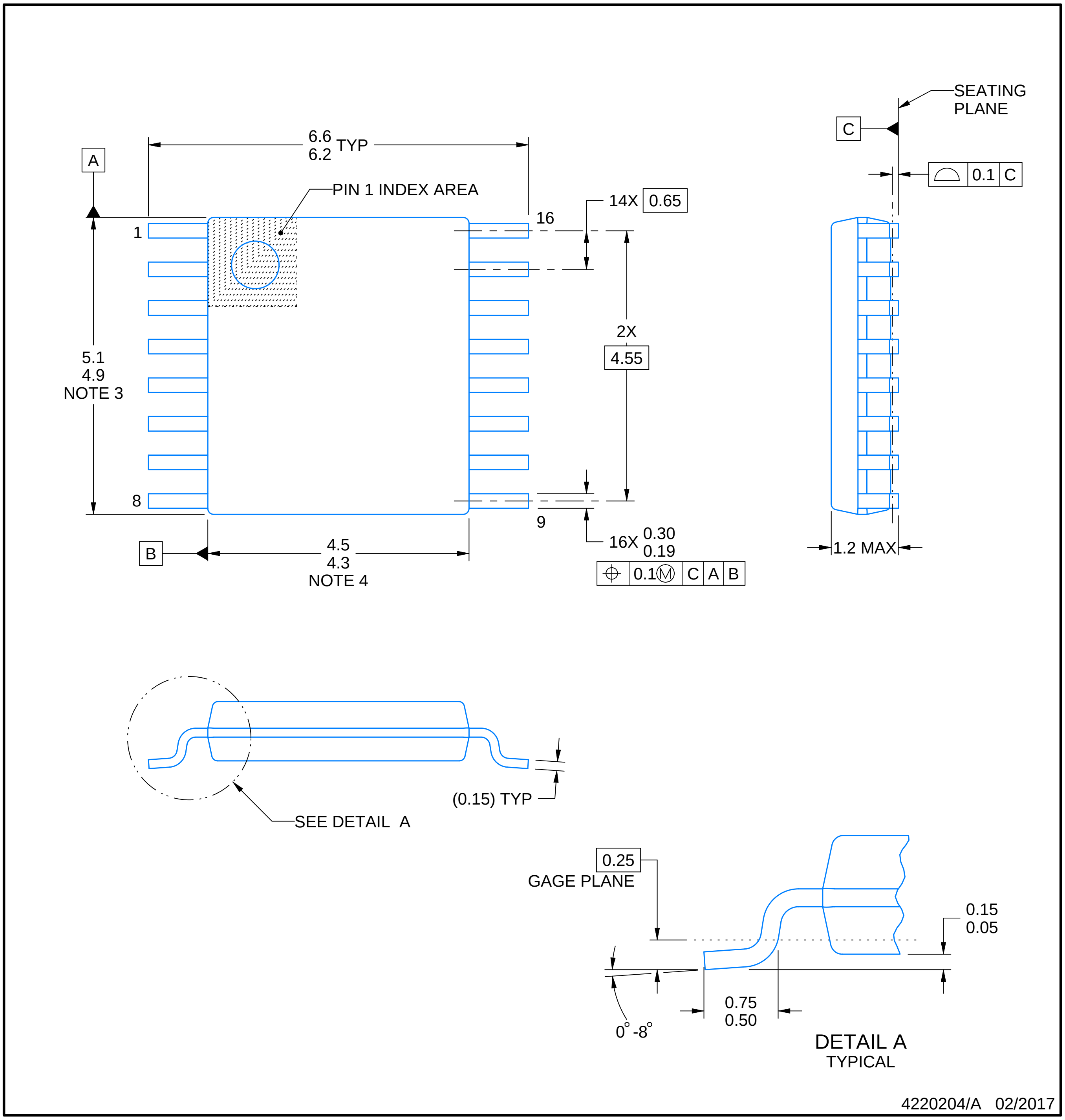
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA250A1QPWRQ1	TSSOP	PW	16	2000	356.0	356.0	35.0
INA250A2QPWRQ1	TSSOP	PW	16	2000	356.0	356.0	35.0
INA250A3QPWRQ1	TSSOP	PW	16	2000	356.0	356.0	35.0
INA250A4QPWRQ1	TSSOP	PW	16	2000	356.0	356.0	35.0

PACKAGE OUTLINE

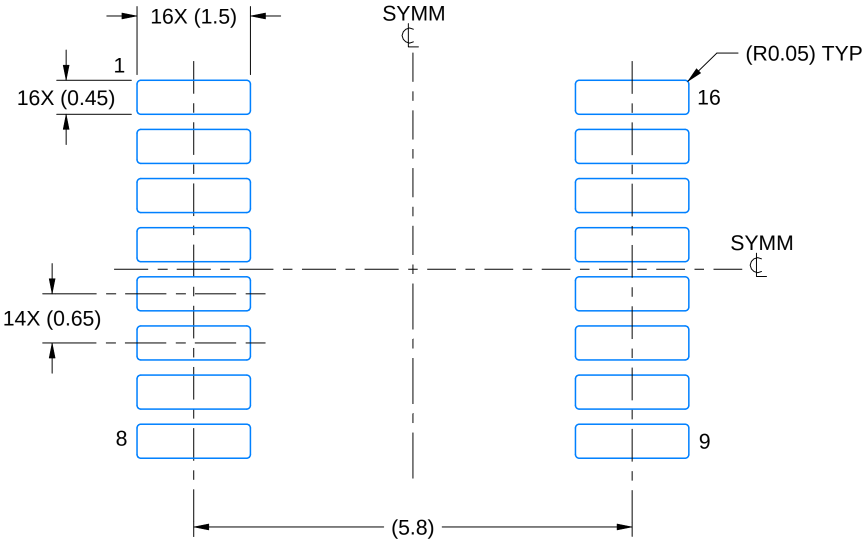
TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 10X

NON-SOLDER MASK
DEFINED
(PREFERRED)

SOLDER MASK
DEFINED

SOLDER MASK DETAILS

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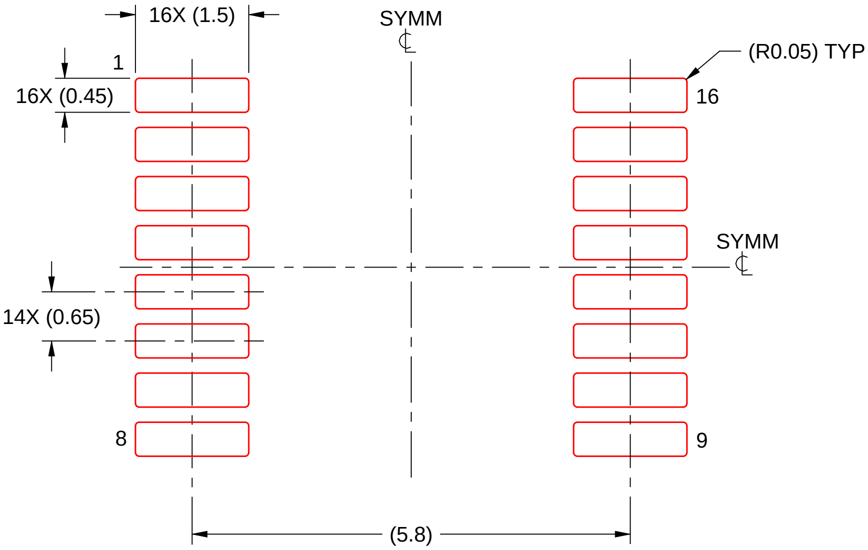
NOTES: (continued)

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



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

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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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