INA254 80-V, High-Voltage, ±75-A Integrated Precision Shunt, Bidirectional, Zero-Drift Current-Shunt Monitor

1 Features

- Precision integrated 400-µΩ shunt resistor
  - Continuous ±75 A at 25°C
  - Continuous ±50 A from –40°C to +85°C
  - Shunt resistor tolerance: 0.5% (maximum)
  - Low drift: 10 ppm/°C (0°C to 125°C)
  - Low inductance: 2 nH
- High accuracy
  - System gain error: 0.5% (maximum)
  - System gain drift: 45 ppm/°C (maximum)
  - Input offset current: ±62.5 mA (maximum)
  - Input offset drift: 625 µA/°C (maximum)
  - DC CMRR > 120-dB
  - 90-dB AC CMRR at 50 kHz
- Enhanced PWM rejection
- Wide common-mode range: –4 V to +80 V
- Available gains: 20 mV/A, 40 mV/A, and 75 mV/A

2 Applications

- 48-V motor controls
- DC/DC converters
- Medical cordless tools
- Solenoid and actuators
- Remote I/O link control

3 Description

The INA254 is a voltage-output, current sense amplifier with a 400-µΩ integrated shunt resistor. The INA254 is designed to monitor bidirectional currents over a wide common-mode range from –4 V to +80 V, independent of the supply voltage. Three fixed gains are available: 20 mV/A, 40 mV/A, and 75 mV/A. The integration of the precision resistor with a zero-drift chopped amplifier provides calibration equivalent measurement accuracy, ultra-low temperature drift performance of ±45 ppm/°C (maximum), and an optimized Kelvin layout for the sensing resistor.

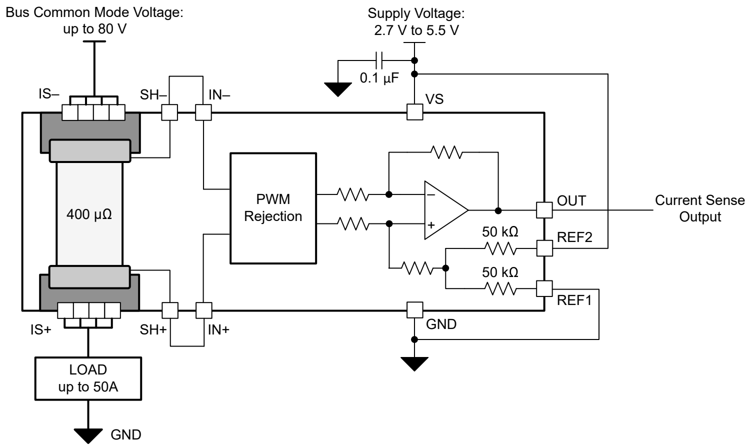
The INA254 is designed with enhanced PWM rejection circuitry to suppress large (dv/dt) signals that enable real-time continuous current measurements. The measurements are critical for in-line current measurements in a motor-drive application, and for solenoid valve control applications.

This device operates from a single 2.7-V to 5.5-V power supply, drawing a maximum of 2.4 mA of supply current. All gain versions are specified over the extended operating temperature range (–40°C to +125°C), and are available in a 24-pin HTSSOP package.

Package Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA254	HTSSOP (24)	9.50 mm × 4.40 mm

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



Typical High-Side Bidirectional Application

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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 * (June 2021) to Revision A (March 2023)	Page
• Changed data sheet status from Advanced Information to Production Data	1
• Changed *Device Information* table title to *Package Information*	1
• Moved the *Power Supply Recommendations* and *Layout* sections to the Application and Implementation section	23

5 Device Comparison

Table 5-1. Device Comparison

PRODUCT	GAIN (mV/A)
INA254A1	20
INA254A2	40
INA254A3	75

6 Pin Configuration and Functions

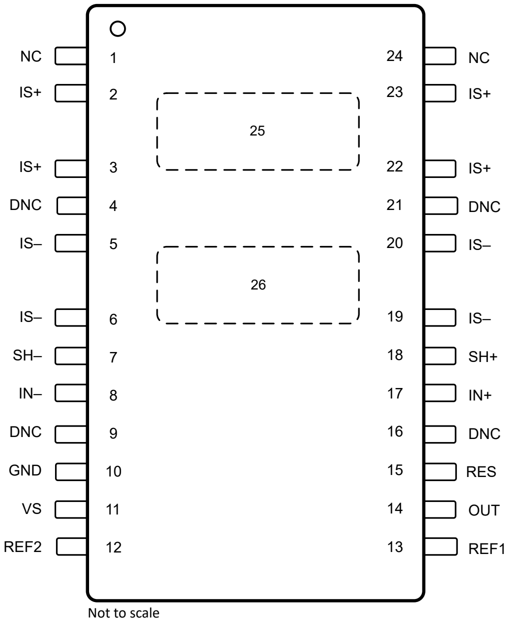


Figure 6-1. PWA Package 24-Pin HTSSOP Top View

Table 6-1. Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
DNC	4, 9, 16, 21	—	Do not connect this pin to any potential; leave this pin floating
GND	10	Ground	Device ground connection
IN+	17	Analog input	Positive input to internal amplifier. Connect to SH+ or external filter network.
IN–	8	Analog input	Negative input to internal amplifier. Connect to SH– or external filter network.
IS+	2, 3, 22, 23, 25	Analog input	Positive connection to internal shunt resistor. Connect to supply for high-side sensing or load ground for low-side sensing.
IS–	5, 6, 19, 20, 26	Analog input	Negative connection to internal shunt resistor. Connect to load for high-side sensing or system ground for low-side sensing.
NC	1, 24	—	No internal connection. Can be left floating, connected to ground or supply. Connecting to IS+ simplifies high current connections to the shunt.
OUT	14	Analog output	Current sense amplifier output.
REF1	13	Analog input	Reference voltage 1. Connect to any voltage between 0 V and VS to support bidirectional or unidirectional operation.
REF2	12	Analog input	Reference voltage 2. Connect to any voltage between 0 V and VS to support bidirectional or unidirectional operation.
RES	15	—	Reserved pin. Connect to GND.
SH+	18	Analog output	Internal shunt positive sense connection. Connect to IN+ or external filter network.
SH–	7	Analog output	Internal shunt negative sense connection. Connect to IN– or external filter network.
VS	11	Power	Device power supply connection, 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 (V_s)			6	V
Analog input current	Continuous current	–50	50	A
Analog Inputs, V_{IN+}, V_{IN-} [2]	Differential (V_{IN+}) - (V_{IN-})	–80	80	V
	Common - mode	GND – 6	90	V
Analog inputs (REF)		GND – 0.3	Vs + 0.3	V
Analog outputs (SH+, SH-)	Common - mode	GND – 6	90	V
Analog output (OUT)		GND – 0.3	Vs + 0.3	V
T_A	Operating Temperature	–55	150	°C
T_J	Junction temperature		150	°C
T_{stg}	Storage temperature	–65	150	°C

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

(2) 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 ANSI/ESDA/JEDEC JS-001, all pins(1)	±2000	V
		Charged device model (CDM), per ANSI/ESDA/JEDEC JS-002, all pins((2))	±1000	

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

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

7.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
V_{CM}	Common-mode input range	–4		80	V
V_S	Operating supply range	2.7		5.5	V
V_{REF1}, V_{REF2}	Reference voltage range	0		V_S	V
T_A	Ambient temperature	–40		125	°C

7.4 Thermal Information

THERMAL METRIC(1)		INA254 PWA (HTSSOP) 24 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	19.4	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	2.3	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance(2)	–4.0	°C/W
Ψ_{JT}	Junction-to-top characterization parameter(2)	–8.7	°C/W
Ψ_{JB}	Junction-to-board characterization parameter(2)	–4.1	°C/W

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

(2) Negative values result from board temperatures that are higher than the die temperature due to shunt heating.

7.5 Electrical Characteristics

at T_A = 25 °C, V_S = 5 V, I_{SENSE} = IS+ = 0 A, V_{CM} = 12 V, and V_{REF1} = V_{REF2} = VS / 2 (unless otherwise noted)

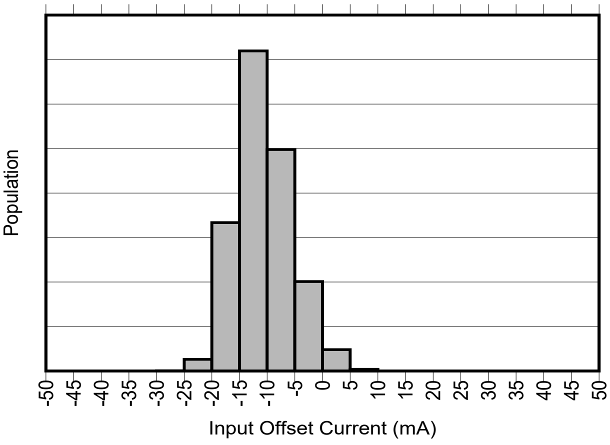
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	V_{IN+} = –4V to 80V, I_{SENSE} =0A, T_A = – 40°C to +125°C	–4		80	V
CMRR	Common-mode rejection ratio	V_{IN+} = –4V to 80V, ISENSE =0A, T_A = –40°C to +125°C		±0.5	±2.5	mA/V
		f = 50 kHz		±56		mA/V
I_{os}	Offset current, input referred	I_{SENSE} = 0 A			±62.5	mA
dI_{os}/dT	Offset current drift	I_{SENSE} = 0 A, T_A = –40°C to +125°C			±0.625	mA/°C
PSRR	Power supply rejection ratio	V_S = 2.7 V to 5.5 V, I_{SENSE} = 0 A			±25	mA/V
I_B	Input bias current	I_{B+}, I_{B-}, I_{SENSE} = 0 A		90		µA
INTEGRATED SHUNT RESISTOR						
R_{SHUNT}	Shunt resistance (IN+ to IN-)	Equivalent resistance when used with onboard amplifier	0.398	0.4	0.402	mΩ
		Used as stand-alone resistor		0.4		mΩ
	Package resistance	IS+ to IS-		1		mΩ
	Package inductance	IS+ to IS-		2		nH
	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	T_A = –40°C to +85°C			±50	A
	Shunt short time overload	I_{SENSE} = 120 A for 5 seconds		± 0.05%		%
	Shunt temperature cycle	–65°C to 150°C, 500 cycles		± 0.1		%
	Shunt resistance to solder heat	260°C solder, 10 seconds		± 0.1		%
	Shunt high temperature exposure	1000 hours, T_A = 150°C		± 0.3		%
	Shunt cold temperature storage	24 hours, T_A = –65°C		± 0.060		%
OUTPUT						
G	Gain	INA254A1		20		mV/A
		INA254A2		40		mV/A
		INA254A3		75		mV/A
	System Gain error (shunt + amplifier)	GND + 50 mV ≤ V_{OUT} ≤ V_S – 200 mV, T_A = 25°C		±0.05	±0.5	%
		T_A = –40°C to +125°C			±45	ppm/°C
	Non-Linearity Error	GND + 10 mV ≤ V_{OUT} ≤ V_S – 200 mV		±0.01		%
	Reference Divider Accuracy	$V_{OUT} = \|(V_{REF1} – V_{REF2})\| / 2$ at I_{SENSE} = 0 A, T_A = –40°C to +125°C		±0.02	±0.1	%
RVRR	Reference voltage rejection ratio (input - referred)			12.5		mA/V
	Maximum capacitive load	No sustained oscillation		1		nF
VOLTAGE OUTPUT						
	Swing to Vs Power Supply Rail	R_L = 10 kΩ to GND,T_A = –40°C to +125°C		V_S – 0.05	V_S – 0.2	V
	Swing to Ground	R_L = 10 kΩ to GND, T_A = –40°C to +125°C		V_{GND} + 1	V_{GND} + 10	mV
FREQUENCY RESPONSE						
BW	Bandwidth	All devices, -3dB Bandwidth		350		kHz
		All devices, 2% THD+N		100		kHz
	Settling time	V_{IN+}, V_{IN-} = 12 V, I_{SENSE} = 50 A Output settles to 1%		2		µs

at T_A = 25 °C, V_S = 5 V, I_{SENSE} = IS+ = 0 A, V_{CM} = 12 V, and V_{REF1} = V_{REF2} = VS / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SR	Slew Rate			2.4		V/µs
NOISE						
	Current Noise Density			100		µA/√Hz
POWER SUPPLY						
I_Q	Quiescent current			1.8	2.4	mA
		T_A = –40°C to+125°C			2.6	mA

7.6 Typical Characteristics

at T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, and V_{REF} = V_S / 2 (unless otherwise noted)



All gains

Figure 7-1. Input Offset Current Production Distribution

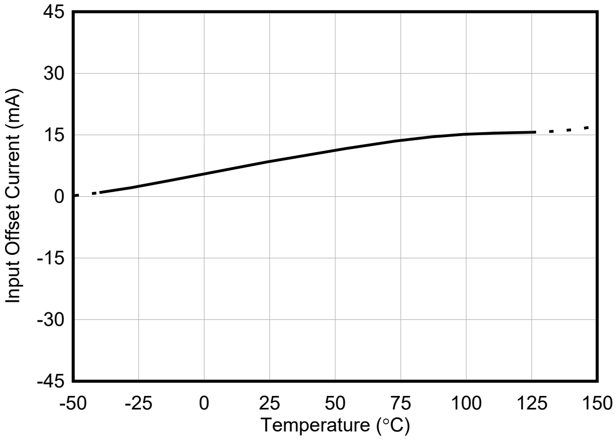
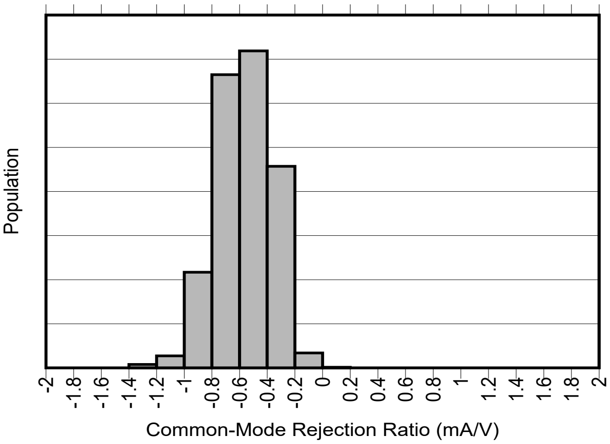


Figure 7-2. Input Offset Current vs Temperature



All gains

Figure 7-3. Common-Mode Rejection Production Distribution

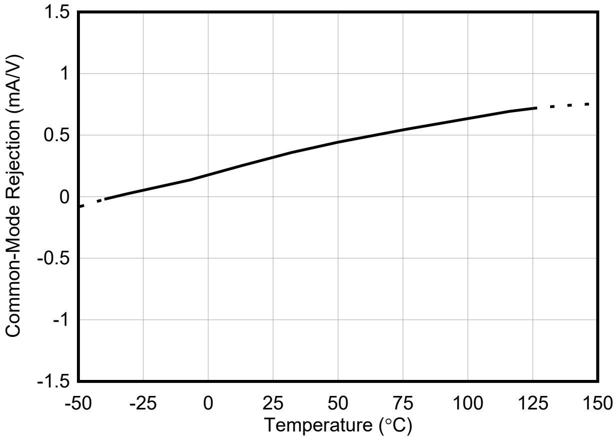


Figure 7-4. Common-Mode Rejection Ratio vs Temperature

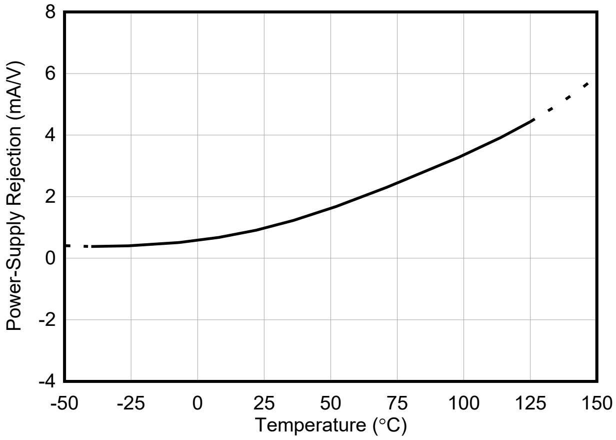


Figure 7-5. Power-Supply Rejection Ratio vs Temperature

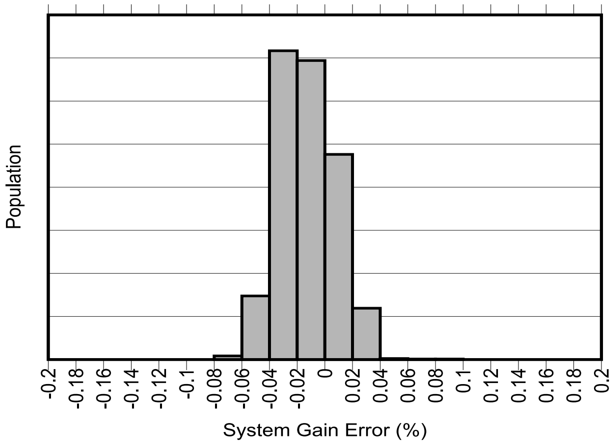


Figure 7-6. Gain Error Production Distribution (INA254A1)

7.6 Typical Characteristics (continued)

at T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, and V_{REF} = V_S / 2 (unless otherwise noted)

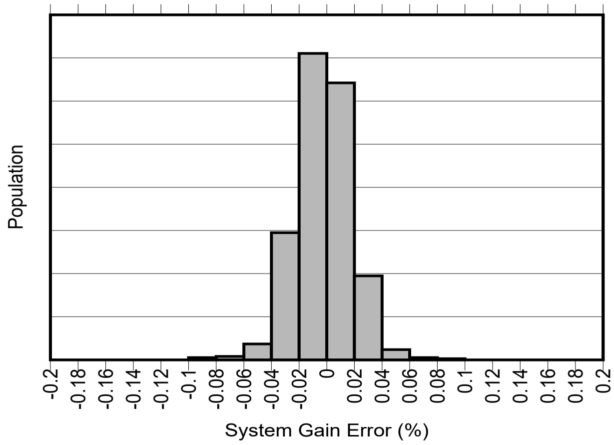


Figure 7-7. Gain Error Production Distribution (INA254A2)

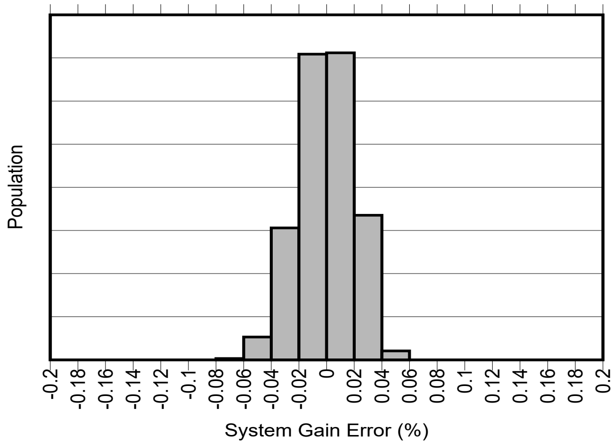


Figure 7-8. Gain Error Production Distribution (INA254A3)

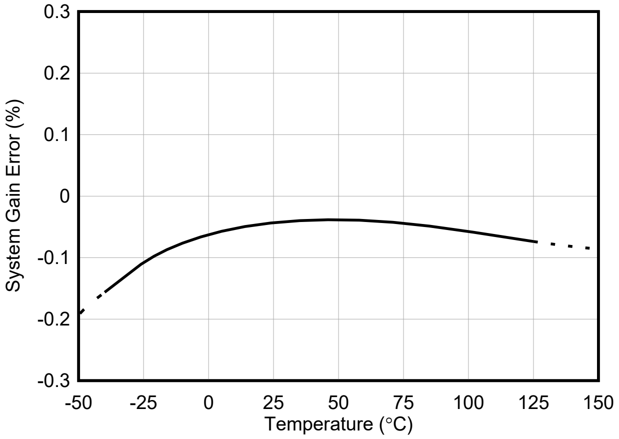
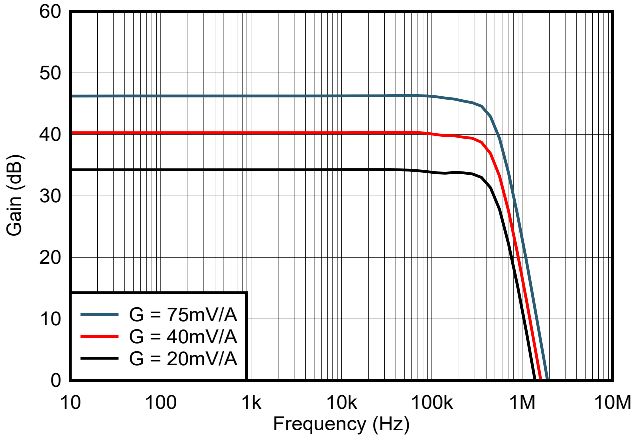


Figure 7-9. System Gain Error vs Temperature



V_{CM} = 0 V, V_{DIFF} = 10-mV_{PP} sine

Figure 7-10. Amplifier Gain Error vs Frequency

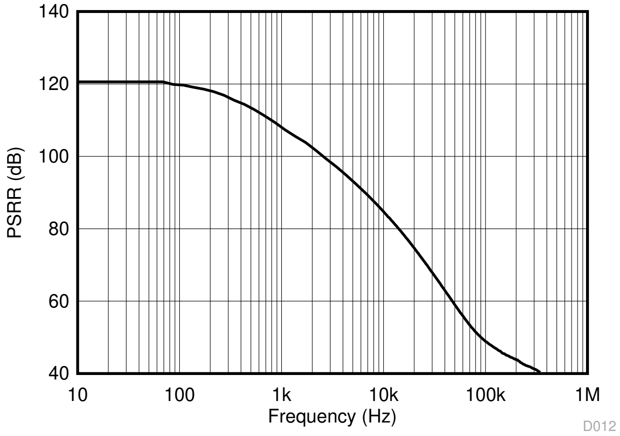


Figure 7-11. Power-Supply Rejection Ratio vs Frequency

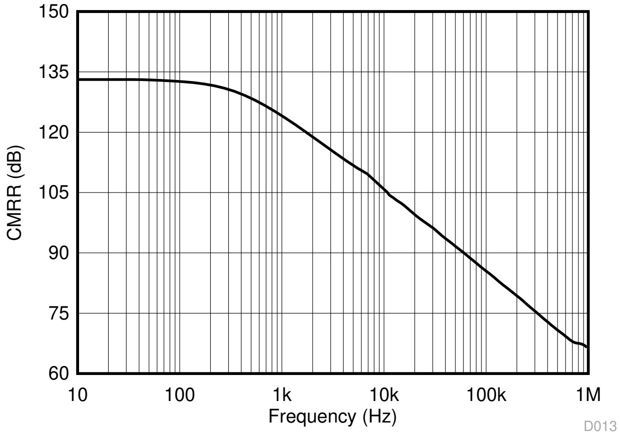


Figure 7-12. Common-Mode Rejection Ratio vs Frequency

7.6 Typical Characteristics (continued)

at T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, and V_{REF} = V_S / 2 (unless otherwise noted)

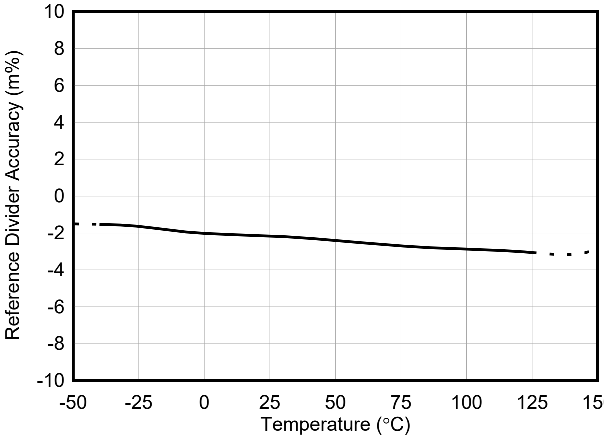
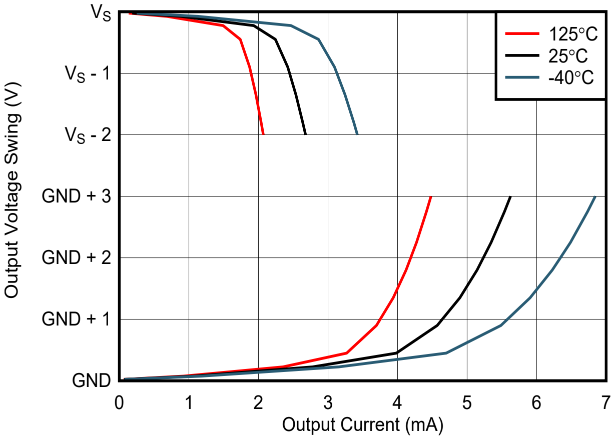


Figure 7-13. Reference Divider Accuracy vs Temperature



V_S = 5 V

Figure 7-14. Output Voltage Swing vs Output Current

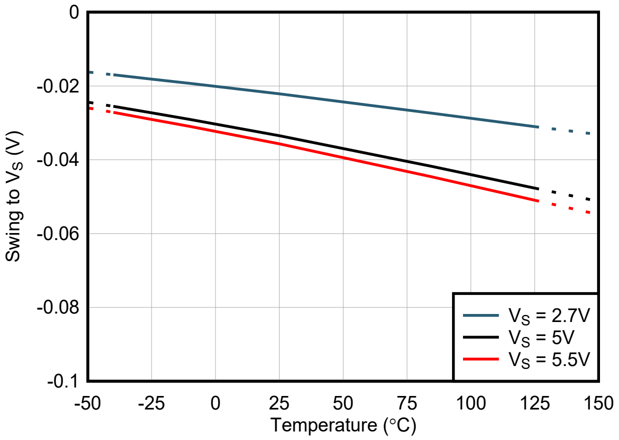


Figure 7-15. Output Voltage Swing High vs Temperature

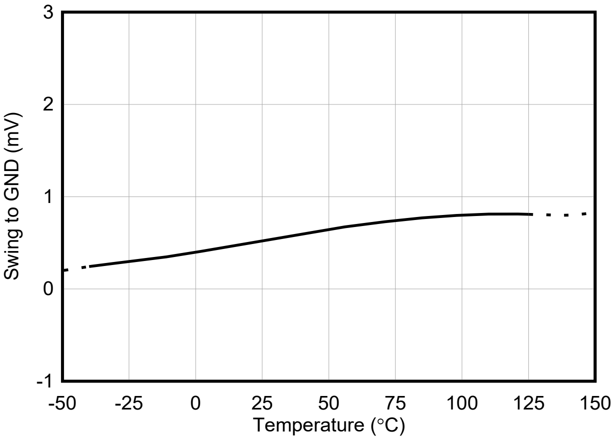


Figure 7-16. Output Voltage Swing Low vs Temperature

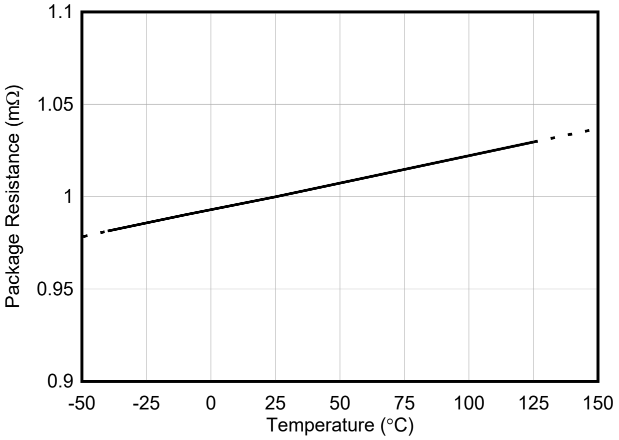
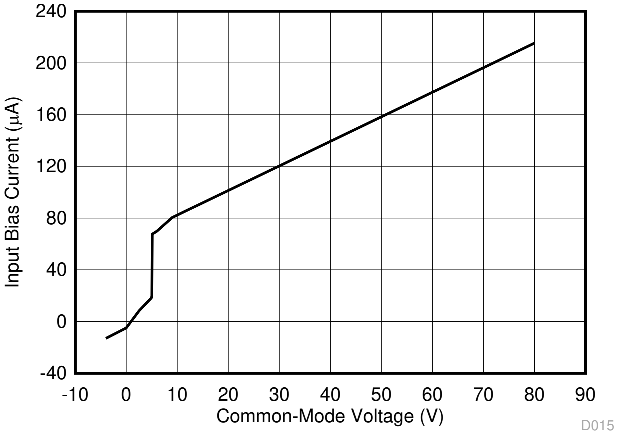


Figure 7-17. Package Resistance vs Temperature

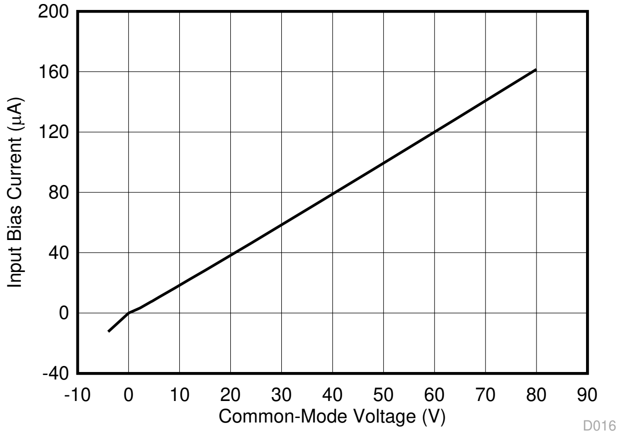


V_S = 5 V

Figure 7-18. Input Bias Current vs Common-Mode Voltage

7.6 Typical Characteristics (continued)

at T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, and V_{REF} = V_S / 2 (unless otherwise noted)



V_S = 0 V

Figure 7-19. Input Bias Current vs Common-Mode Voltage

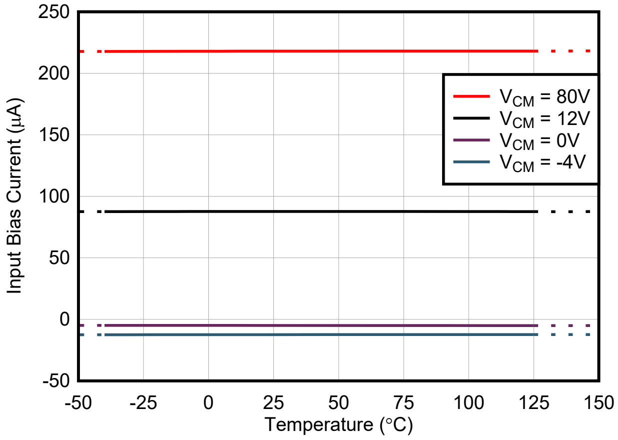


Figure 7-20. Input Bias Current vs Temperature

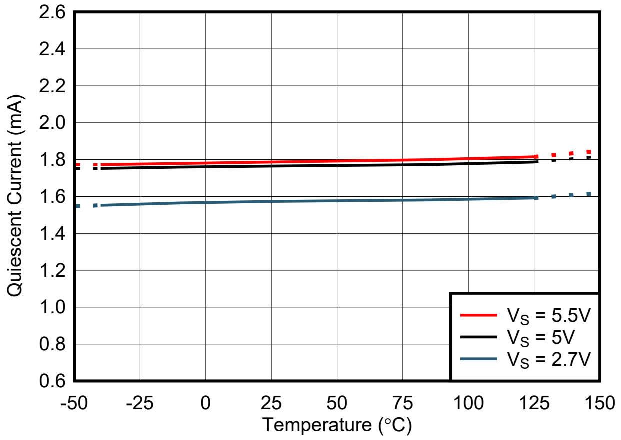


Figure 7-21. Quiescent Current vs Temperature

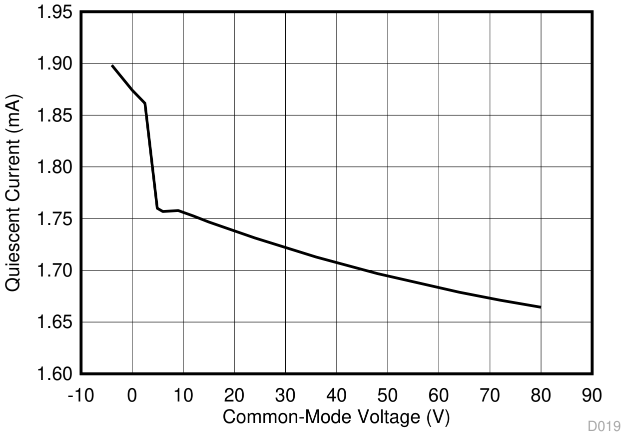


Figure 7-22. Quiescent Current vs Common-Mode Voltage

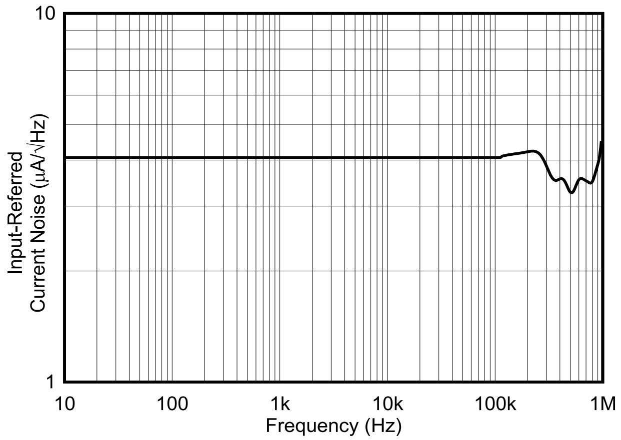


Figure 7-23. INA254A1 Input-Referred Current Noise vs Frequency

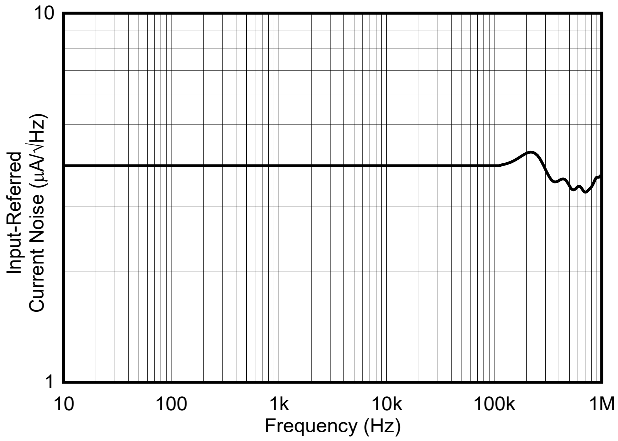


Figure 7-24. INA254A2 Input-Referred Current Noise vs Frequency

7.6 Typical Characteristics (continued)

at T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, and V_{REF} = V_S / 2 (unless otherwise noted)

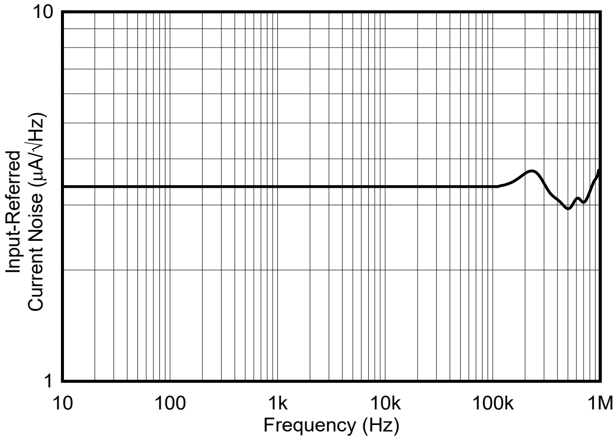


Figure 7-25. INA254A3 Input-Referred Current Noise vs Frequency

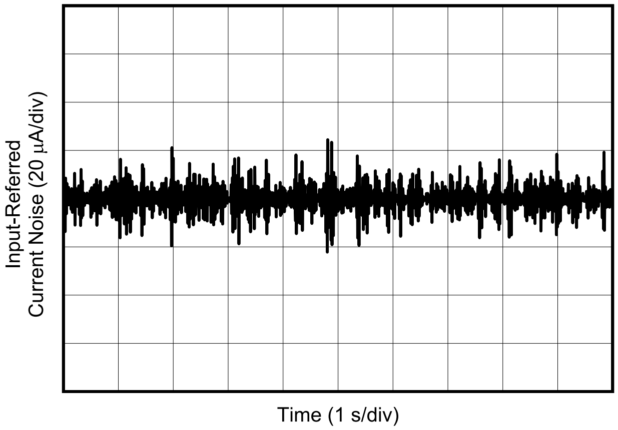
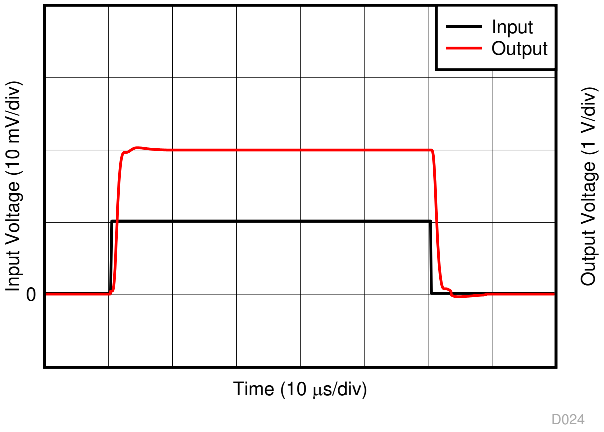
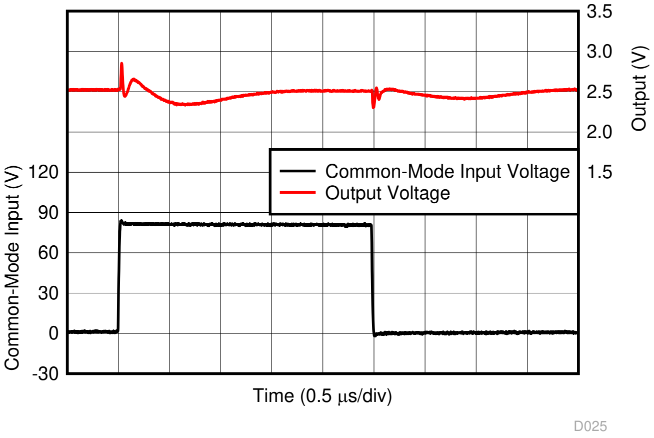


Figure 7-26. 0.1-Hz to 10-Hz Current Noise (Referred-to-Input)



V_{REF1} = V_{REF2} = 0 V, 10-mV_{PP} input step

Figure 7-27. Amplifier Step Response



V_{REF1} = V_{REF2} = 0 V

Figure 7-28. Common-Mode Transient Response

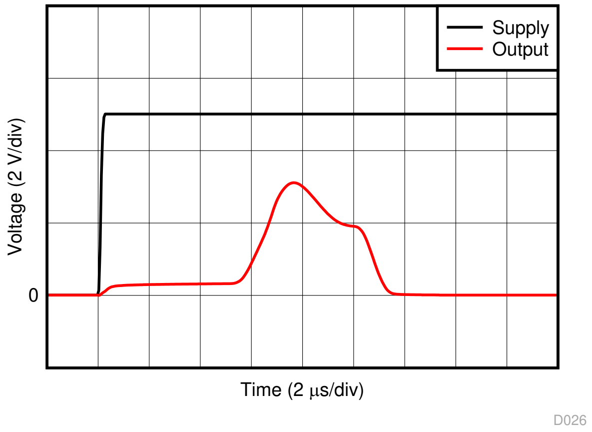
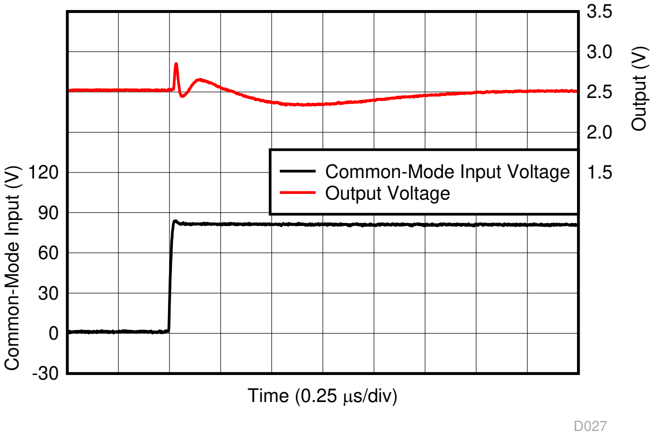


Figure 7-29. Start-Up Response

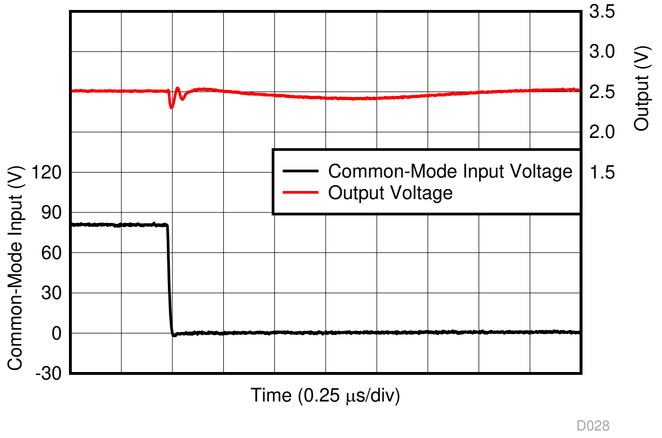


Rising Edge

Figure 7-30. Common-Mode Voltage Transient Response

7.6 Typical Characteristics (continued)

at T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, and V_{REF} = V_S / 2 (unless otherwise noted)



Falling Edge

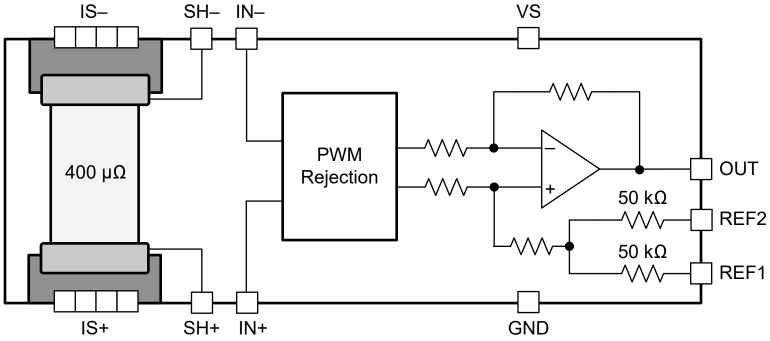
Figure 7-31. Common-Mode Voltage Transient Response

8 Detailed Description

8.1 Overview

The INA254 features a precision, 400-µΩ current-sensing resistor and supports common-mode voltages up to 80 V. The internal amplifier features a precision zero-drift topology with excellent common-mode rejection ratio (CMRR). The internal amplifier also features an enhanced pulse-width modulation (PWM) rejection current-sensing amplifier integrated into a single package. High-precision measurements are enabled by matching the shunt resistor value and the current-sensing amplifier gain, thus providing a highly-accurate, system-calibrated method for measuring current. Enhanced PWM rejection reduces the effect of common-mode transients on the output signal that are associated with PWM signals. 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.

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Integrated Shunt Resistor

The INA254 features a precise, low-drift, current-sensing resistor that provides accurate measurements over the entire specified temperature range of –40°C to +125°C. The integrated current-sensing resistor provides measurement stability over temperature, and simplifies printed circuit board (PCB) 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 input pins (IN– and IN+) to the sense pins of the shunt resistor (SH– and SH+) eliminates many instances of parasitic impedance commonly found in typical very-low sensing-resistor level measurements. Although the sense connection of the current-sensing resistor can be accessed through the SH+ and SH– pins, this resistor is not intended to be used as a stand-alone component. The INA254 is system-calibrated to make sure that the current-sensing resistor and current-sensing amplifier are both precisely matched to one another. Use of 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 INA254 has approximately 1 mΩ of package resistance. Of this total package resistance, 400 µΩ 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 1-mΩ package resistance between the IS+ and IS– pins. The heat dissipated across the package when current flows through the device ultimately determines the maximum current that can be safely handled by the package. The current consumption of the silicon is relatively low, leaving the total package resistance to carry the high load current as the primary contributor to the total power dissipation of the package. The maximum safe-operating current level is set to make sure that the heat dissipated across the package is limited so that no damage occurs to the resistor or the package, or that 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, contribute to how effectively the device dissipates heat. The internal heat is developed as a result of the current flowing through the total package resistance of 1 mΩ. Under the conditions of no air flow, a maximum ambient temperature of 85°C, and 2-oz. copper input power planes, the INA254 accommodates continuous current levels up to 50 A. Figure 8-1 shows that the current-handling capability is derated at temperatures greater than the 85°C level, with safe operation up to 30 A at a 125°C ambient temperature. With air flow and larger 2-oz. copper input power planes, the INA254 safely accommodates continuous current levels up to 50 A across the entire –40°C to +125°C temperature range.

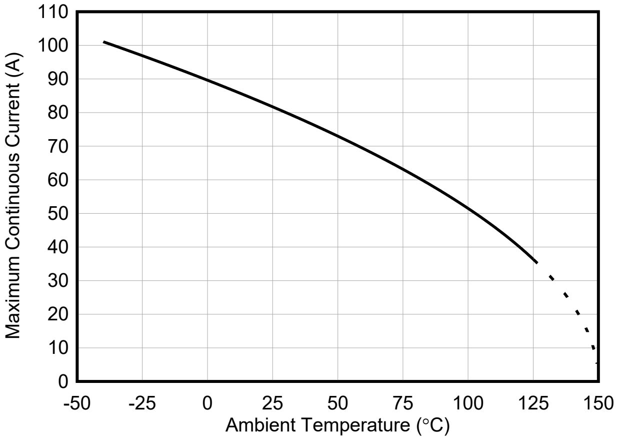


Figure 8-1. Maximum Continuous Current vs Ambient Temperature

8.3.2 Short-Circuit Duration

The INA254 features a physical shunt resistance that is able to withstand current levels higher than the continuous handling limit of 50 A without sustaining damage to the current-sensing resistor or the current-sensing amplifier, if the excursions are brief. Figure 8-2 shows the short-circuit duration curve for the INA254.

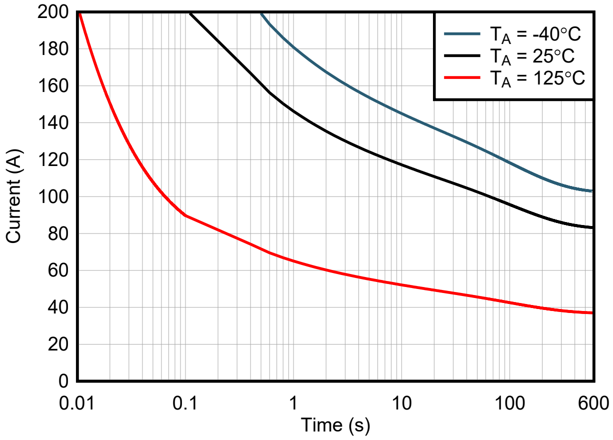


Figure 8-2. Short-Circuit Duration

8.3.3 Temperature Stability

System calibration is common for many industrial applications to eliminate initial component and system-level errors that can be present. A system-level calibration reduces the initial accuracy requirement for many of the individual components because the errors associated with these components are effectively eliminated through the calibration procedure. This calibration enables precise measurements at the temperature in which the system is calibrated. As the system temperature changes because of external ambient changes or self heating, measurement errors are reintroduced. Without accurate temperature compensation used in addition to the initial adjustment, the calibration procedure is not effective. The user must account for temperature-induced changes. One of the primary benefits of the low temperature coefficient of the INA254 (including both the integrated current-sensing resistor and current-sensing amplifier) is that the device measurement remains accurate, even when the temperature changes throughout the specified temperature range of the device.

Figure 8-3 shows the drift performance for the integrated current-sensing resistor. Use Figure 8-3 to determine the typical variance in the shunt resistor value at various temperatures. 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 INA254, the resistor does vary slightly more when operated in temperatures ranging from –40°C to 0°C than when operated from 0°C to 125°C.

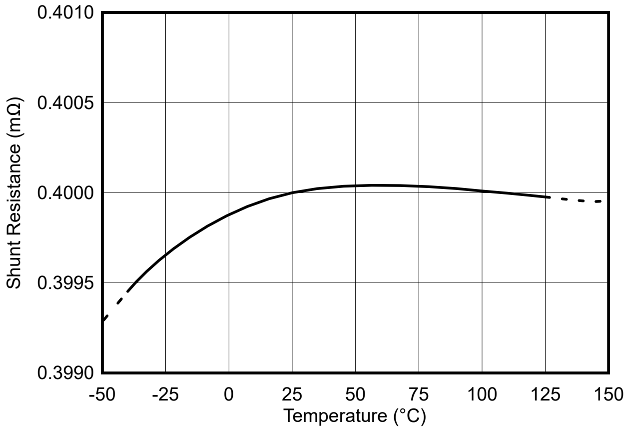


Figure 8-3. Sensing Resistor vs Temperature

An additional aspect to consider is that when current flows through the current-sensing resistor, power is dissipated 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.

8.3.4 Enhanced PWM Rejection Operation

The enhanced PWM rejection feature of the INA254 provides increased attenuation of large common-mode ΔV/Δt transients. Large ΔV/Δt common-mode transients associated with PWM signals are employed in applications such as motor or solenoid drive and switching power supplies. Traditionally, large ΔV/Δt common-mode transitions are handled strictly by increasing the amplifier signal bandwidth, which can increase chip size, complexity and ultimately cost. The INA254 is designed with high common-mode rejection techniques to reduce large ΔV/Δt transients before the system is disturbed as a result of these large signals. The high AC CMRR, in conjunction with signal bandwidth, allows the INA254 to provide minimal output transients and ringing compared with standard circuit approaches.

8.3.5 Input Signal Bandwidth

The INA254 input signal, which represents the current being measured, is accurately measured with minimal disturbance from large ΔV/Δt 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 INA254 bandwidth is defined by the –3-dB bandwidth of the current-sense amplifier inside the device. 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.

Figure 8-4 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 INA254 bandwidth.

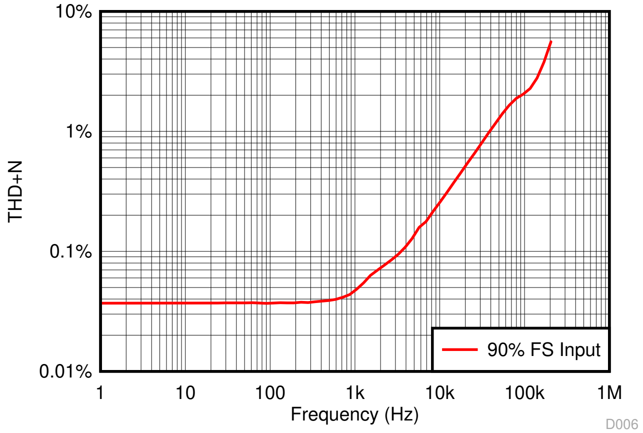


Figure 8-4. Amplifier Performance Over Frequency

For applications requiring distortion sensitive signals, Figure 8-4 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 are required to determine the acceptance criteria, and to validate the performance levels meet the system specifications.

8.4 Device Functional Modes

8.4.1 Adjusting the Output Midpoint With the Reference Pins

Figure 8-5 shows a test circuit for reference-divider accuracy. The INA254 output is configurable to allow for unidirectional or bidirectional operation.

CAUTION

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

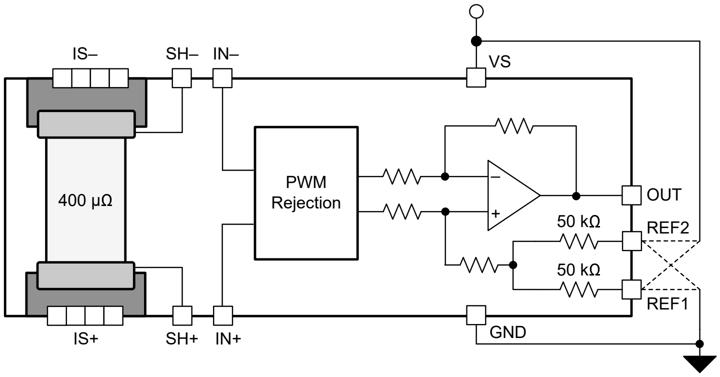


Figure 8-5. Adjusting the Output Midpoint

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). 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 internal shunt resistor.

8.4.3 Ground Referenced Output

When using the INA254 in unidirectional mode with a ground-referenced output, both reference inputs are connected to ground. Figure 8-6 shows how this configuration takes the output to ground when there is 0 A flowing across the internal shunt.

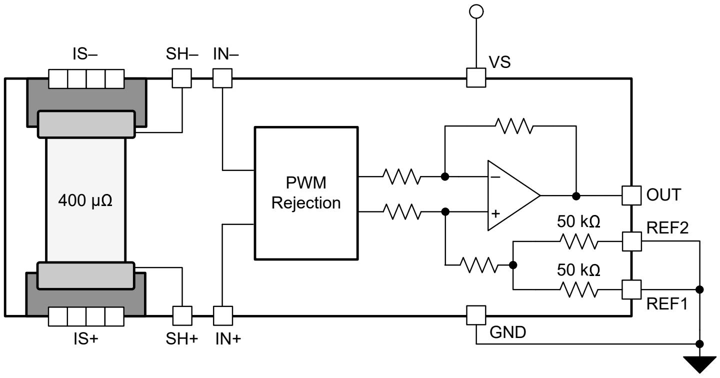


Figure 8-6. Ground-Referenced Output

8.4.4 Reference Pin Connections for Bidirectional Current Measurements

Bidirectional operation allows the INA254 to measure currents through a resistive shunt in two directions. For this case, set the output voltage 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 nonsymmetrical.

8.4.4.1 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. Figure 8-7 shows this configuration. 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.

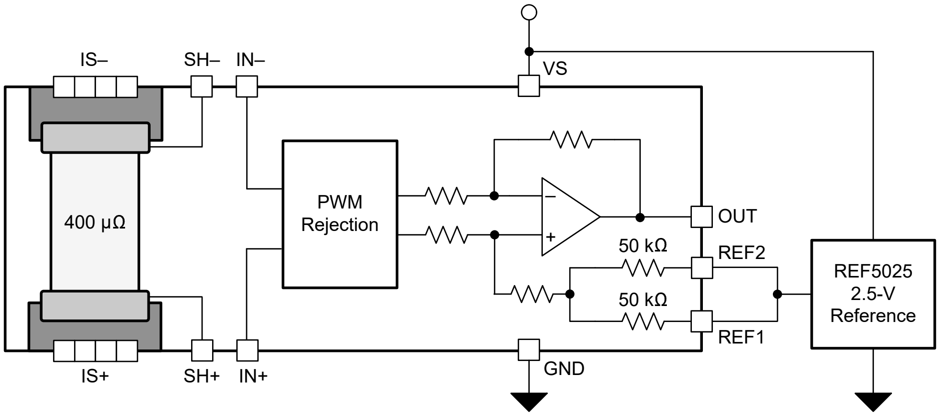


Figure 8-7. External Reference Output

8.4.5 Output Set to Mid-Supply Voltage

Figure 8-8 shows that, 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. This method creates a ratiometric offset to the supply voltage, where the output voltage remains at VS / 2 when 0 V is applied between the IN+ and IN– inputs.

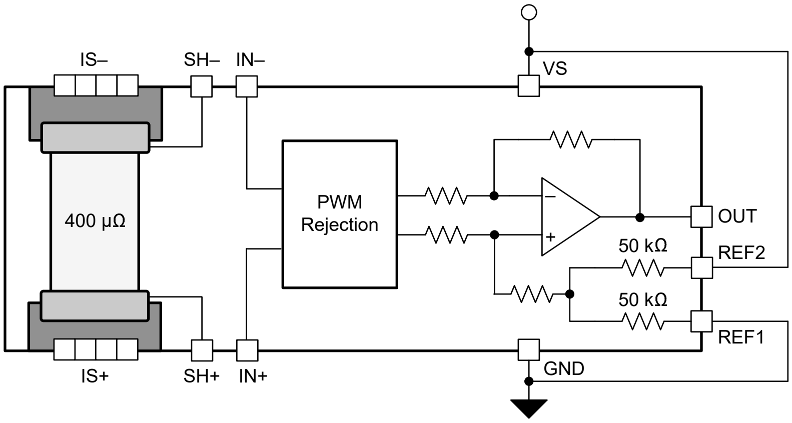


Figure 8-8. Mid-Supply Voltage Output

8.4.6 Output Set to Mid-External Reference

In this example, Figure 8-9 shows how an external reference is divided by two by connecting one REF pin to ground and the other REF pin to the reference.

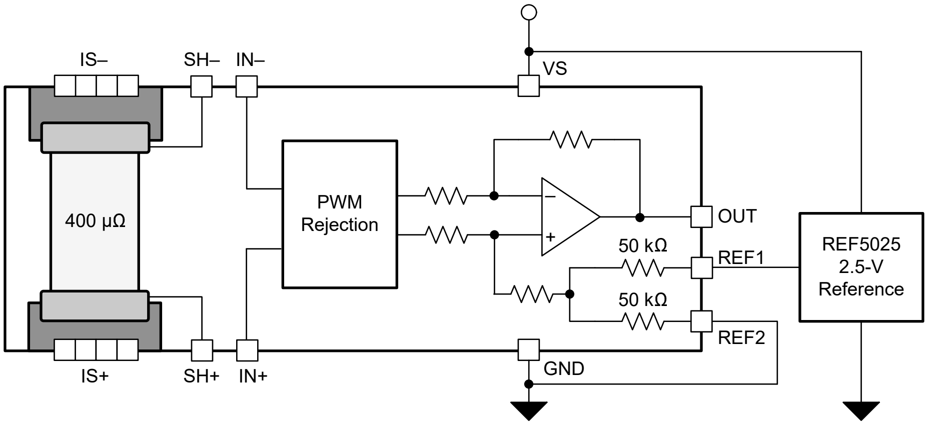


Figure 8-9. Mid-External Reference Output

8.4.7 Output Set Using Resistor Divider

The INA254 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, like in Figure 8-10, use the output as a differential signal with respect to the resistor divider voltage. For most accurate results, do not use single-ended measurements at the amplifier output because the internal impedance shifts can adversely affect device performance specifications.

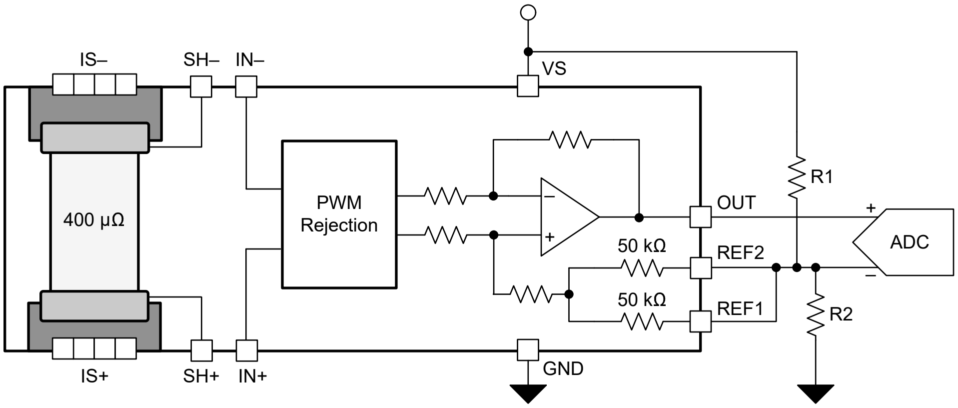


Figure 8-10. Setting the Reference Using a Resistor Divider

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

9.1 Application Information

The INA254 measures the voltage developed as current flows across the integrated low inductive current-sensing resistor. The device provides reference pins to configure operation as either unidirectional or bidirectional output swing. When using the INA254 for inline motor current sense or measuring current in an H-bridge, the device is commonly configured for bidirectional operation.

9.1.1 Input Filtering

Note

Input filters are not required for accurate measurements using the INA254. For most accurate results, do not use filters at the IN+ and IN– inputs. However, If filter components are used on the input of the amplifier, follow the guidelines in this section to minimize 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 also satisfies the filtering requirement, but carefully select the components to minimize the impact on device performance. Figure 9-1 shows a filter placed at the inputs pins.

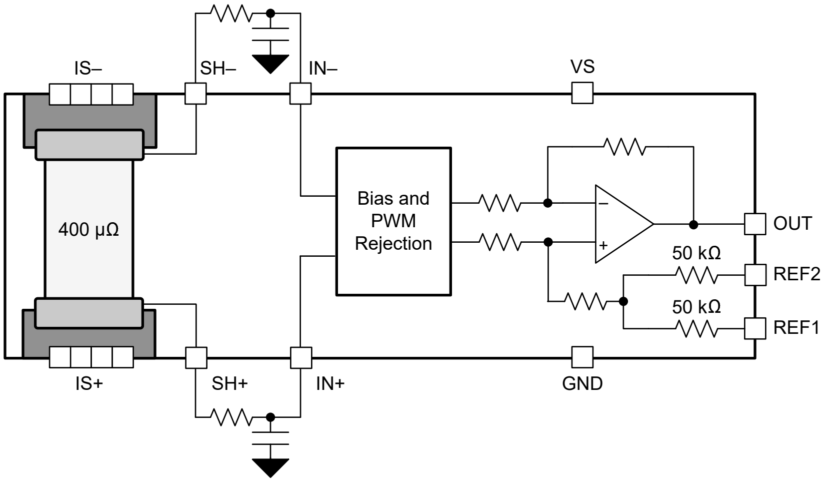


Figure 9-1. Filter at Input Pins

External series resistance provides a source of additional measurement error. Therefore, keep the value of these series resistors to 10 Ω or less to reduce loss of accuracy. The internal bias network shown in Figure 9-1 creates a mismatch in input bias currents when a differential voltage is applied between the input pins (see Figure 9-2). 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.

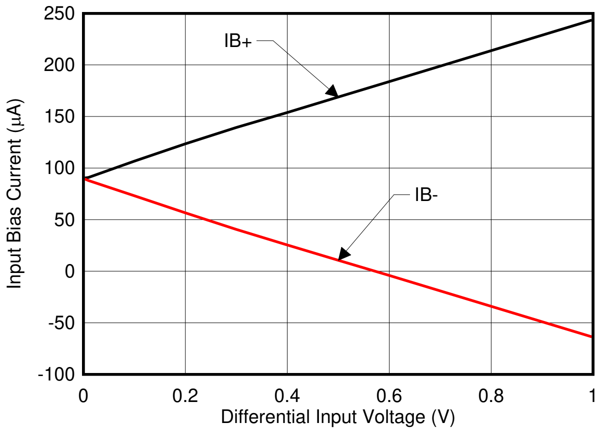


Figure 9-2. Input Bias Current vs Differential Input Voltage

Use Equation 1 to calculate the measurement error expected from the additional external filter resistors.

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

where

- Equation 2 determines the Gain Error Factor

$$\text{Gain Error Factor} = \frac{3000}{R_S + 3000} \tag{2}$$

Where:

- R_S is the external filter resistance value

Use Equation 2 to calculate the gain error factor and determine the gain error introduced by the additional external series resistance. Use Equation 1 to calculate the deviation of the shunt voltage resulting from the attenuation and imbalance created by the added external filter resistance. Table 9-1 provides the gain error factor and gain error for several resistor values.

Table 9-1. 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 INA254 offers advantages for multiple applications including the following:

- High common-mode range and excellent CMRR enables direct inline sensing
- Precision low-inductive, low-drift shunt eliminates the need for overtemperature system calibration
- Ultra-low offset and drift eliminates the necessity of calibration
- Wide supply range enables a direct interface with most microprocessors

9.2.1 Speaker Enhancements and Diagnostics Using Current Sense Amplifier

CLASS-D audio amplifiers in conjunction with the INA254 provide accurate speaker load current. Speaker load current is used to determine speaker diagnostics, and can further be expanded to measure key speaker parameters, such as speaker coil resistance and speaker real-time ambient temperature.

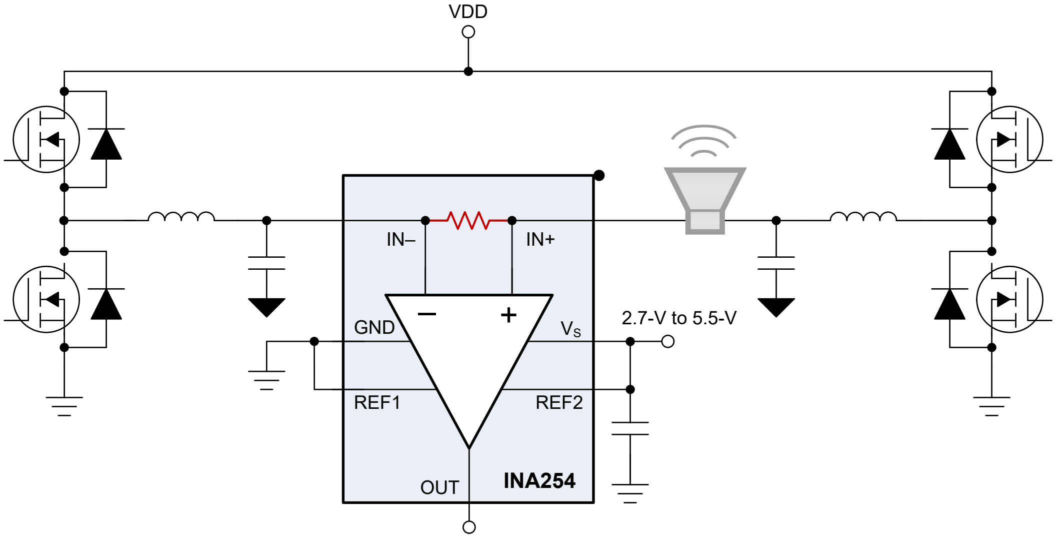


Figure 9-3. Current Sensing in a CLASS-D Subsystem

9.2.1.1 Design Requirements

Table 9-2. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Common-mode voltage	60 V
Power-supply voltage	3.3 V
Peak current	±15 A
Frequency sweep	20 Hz to 20 Khz

9.2.1.2 Detailed Design Procedure

For this application, the INA254 measures current flowing through the speaker from the CLASS-D amplifier. The integrated shunt of 400 µΩ with an inductance of only 2 nH is an excellent choice for current sensing in speaker applications where low inductance is required. The low-inductive shunt enables accurate current sensing across frequencies over the audio range of 20 Hz to 20 kHz.

The INA254 is setup to support bidirectional currents with the reference set to mid-supply as shown in Figure 8-9. When the power supply to the INA254 is set at 3.3 V and there is no current flowing in the speaker, the output of INA254 is at 1.65 V. When operating with a gain of 75 mV/A with peak-to-peak current of ±15 A, the output of the INA254 will swing from 0.525 V to 2.775 V. In this application the output can be directly connected to an ADC input that has a full scale range of 3.3 V. The INA254 has a low THD+N of 0.1% at 1 kHz that enables distortion measurement of speaker. The INA254 can measure the impedance of the speaker and accurately measure the resonance frequency and peak impedance at resonance frequency. The INA254 can accurately track changes in the impedance in real-time.

9.2.1.3 Application Curve

Figure 9-4 shows the typical example output response of a speaker with 4-Ω impedance measurement from 20 Hz to 20 kHz.

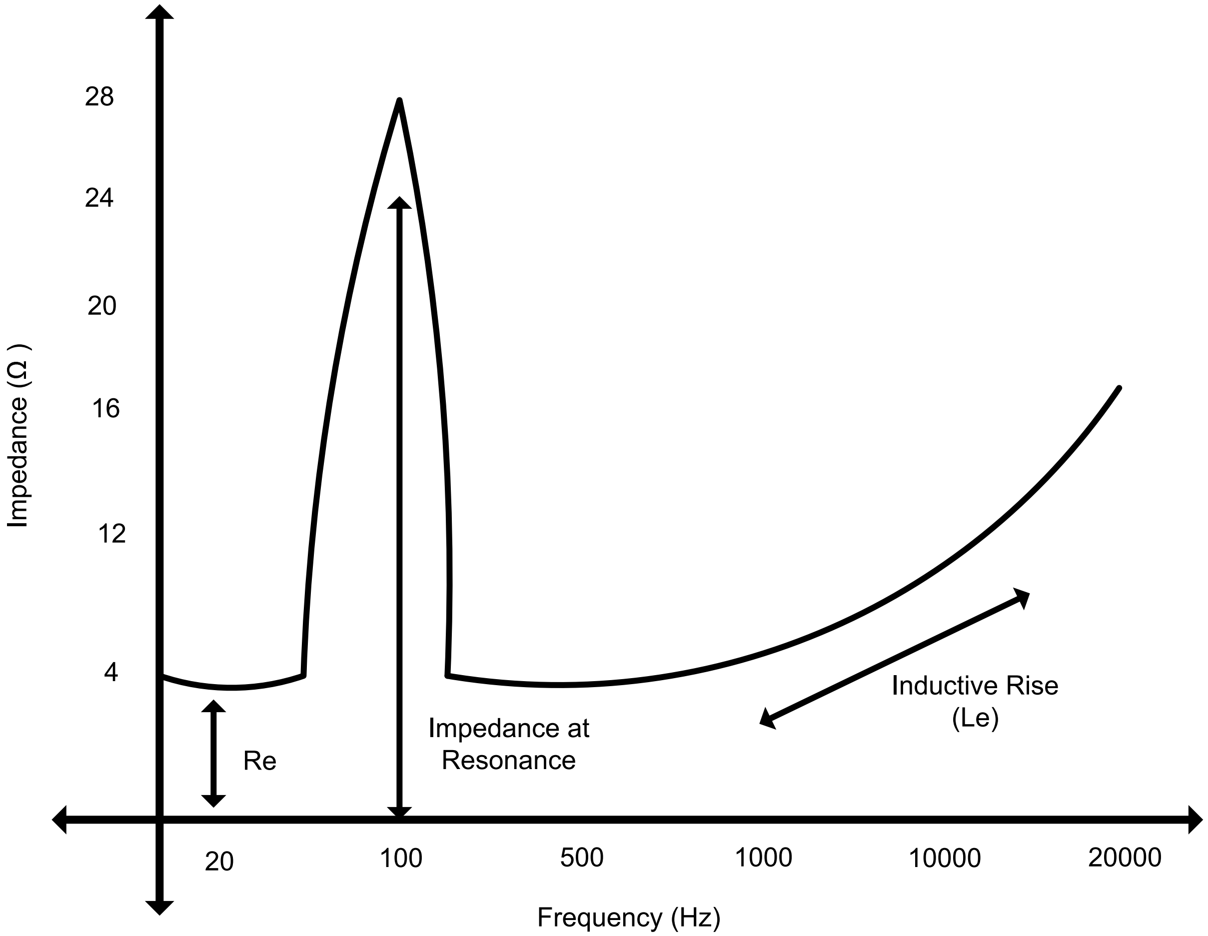


Figure 9-4. Speaker Impedance Measurement

9.3 Power Supply Recommendations

The INA254 makes accurate measurements beyond the connected power-supply voltage (VS) because the inputs (IN+ and IN–) operate anywhere between –4 V and +80 V, independent of VS. For example, the VS 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 INA254 is constrained to the supply voltage.

Place the power-supply bypass capacitor as close as possible to the supply and ground pins. The recommended value of this bypass capacitor is 0.1 μF. Additional decoupling capacitance can be added to compensate for noisy or high-impedance power supplies. If the INA254 output is set to mid-supply, then take extreme care to minimize noise on the power supply.

9.4 Layout

9.4.1 Layout Guidelines

- This device is specified for current handling of up to 50 A over the entire –40°C to +85°C temperature range using a 2-oz. copper pour for the input power plane, as well as no external airflow passing over the device.
- The primary current-handling limitation for this device 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 50 A over a wider 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. Thermal vias help spread the current and power dissipated over multiple board layers. The INA254 evaluation module (EVM) features a 2-oz. copper pour for the planes, and is capable of supporting 50 A at temperatures up to 125°C.
- The bypass capacitor should be placed close to device ground and supply pins, but can be moved farther out if needed to avoid cutting thermal planes. The recommended value of this bypass capacitor is 0.1 µF. Additional decoupling capacitance can be added to compensate for noisy or high-impedance power supplies.

9.4.2 Layout Example

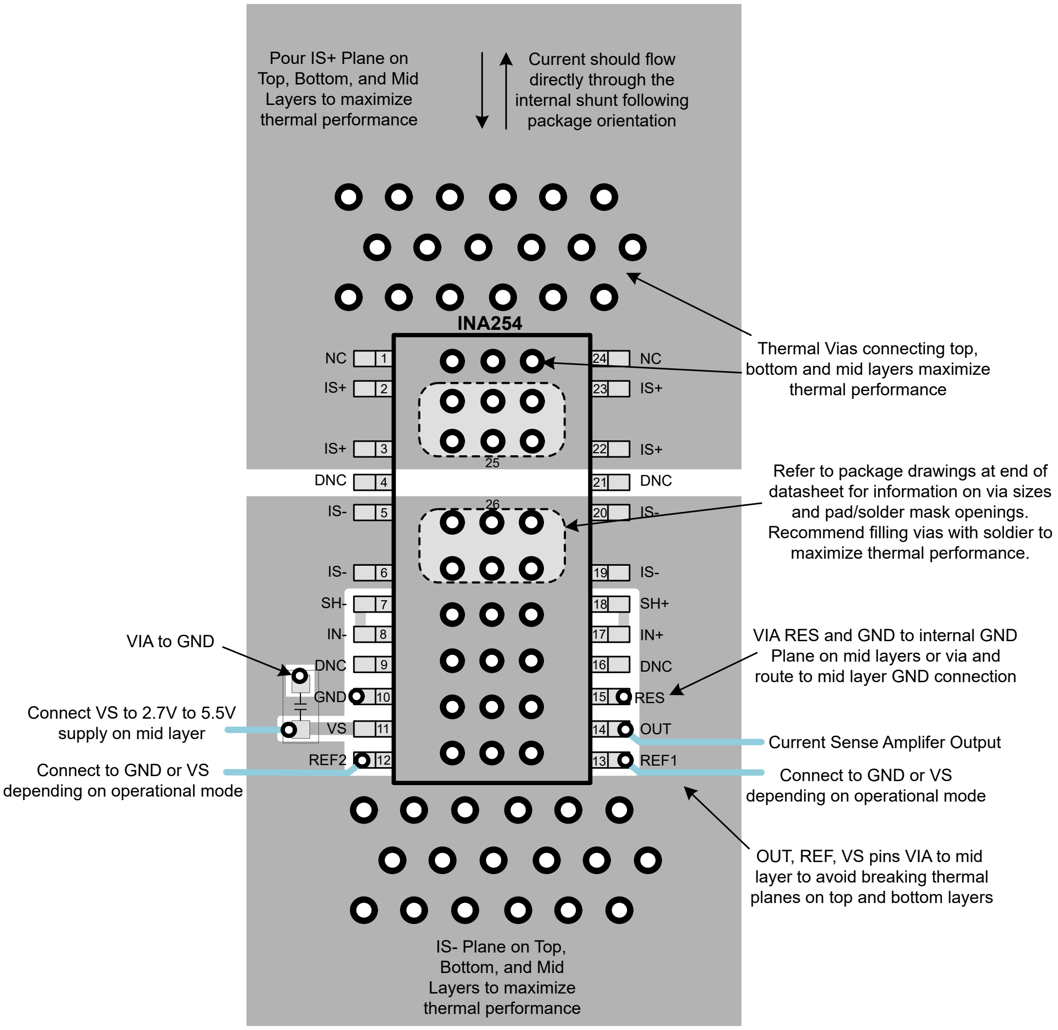


Figure 9-5. INA254 Layout Example

10 Device and Documentation Support

10.1 Device Support

10.1.1 Development Support

For development support, see the INA254 Evaluation Module (EVM).

10.2 Documentation Support

10.2.1 Related Documentation

For related documentation see the following: Texas Instruments, *INA254EVM User's Guide* (SLOU514)

10.3 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.

10.4 Support Resources

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

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

10.5 Trademarks

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10.6 Electrostatic Discharge Caution

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

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

10.7 Glossary

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

11 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.

PACKAGE OPTION ADDENDUM

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
INA254A1IPWAR	ACTIVE	HTSSOP	PWA	24	2500	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 125	IN254A1	Samples
INA254A2IPWAR	ACTIVE	HTSSOP	PWA	24	2500	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 125	IN254A2	Samples
INA254A3IPWAR	ACTIVE	HTSSOP	PWA	24	2500	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 125	IN254A3	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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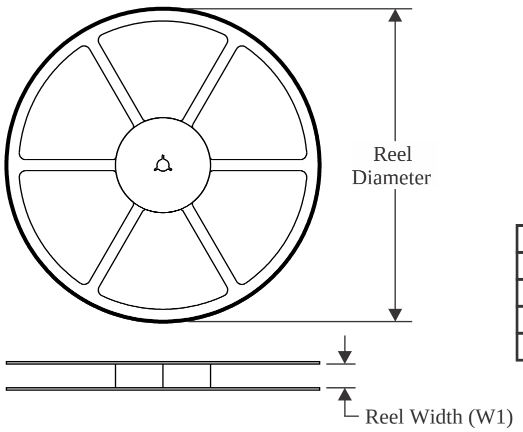
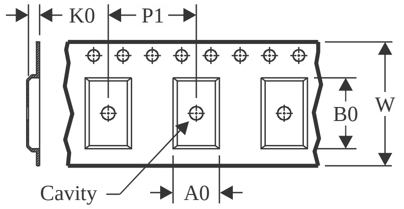
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

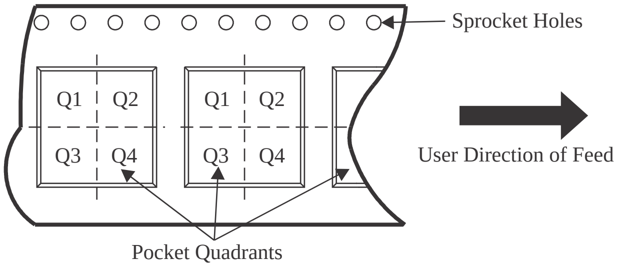


TAPE DIMENSIONS



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

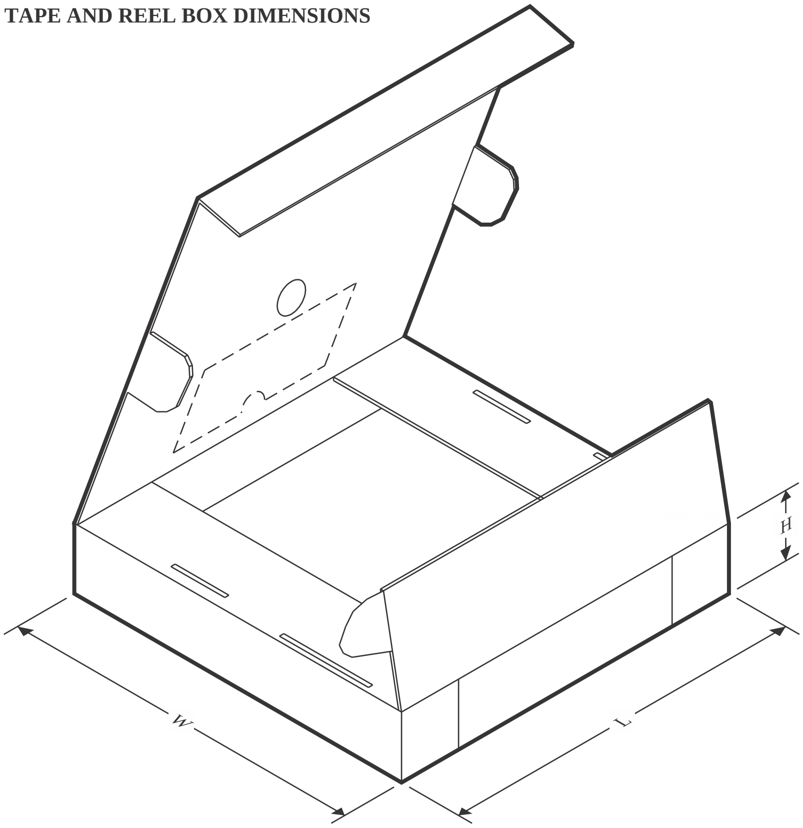
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
INA254A1IPWAR	HTSSOP	PWA	24	2500	330.0	16.4	6.9	10.2	1.8	12.0	16.0	Q1
INA254A2IPWAR	HTSSOP	PWA	24	2500	330.0	16.4	6.9	10.2	1.8	12.0	16.0	Q1
INA254A3IPWAR	HTSSOP	PWA	24	2500	330.0	16.4	6.9	10.2	1.8	12.0	16.0	Q1

TAPE AND REEL BOX DIMENSIONS



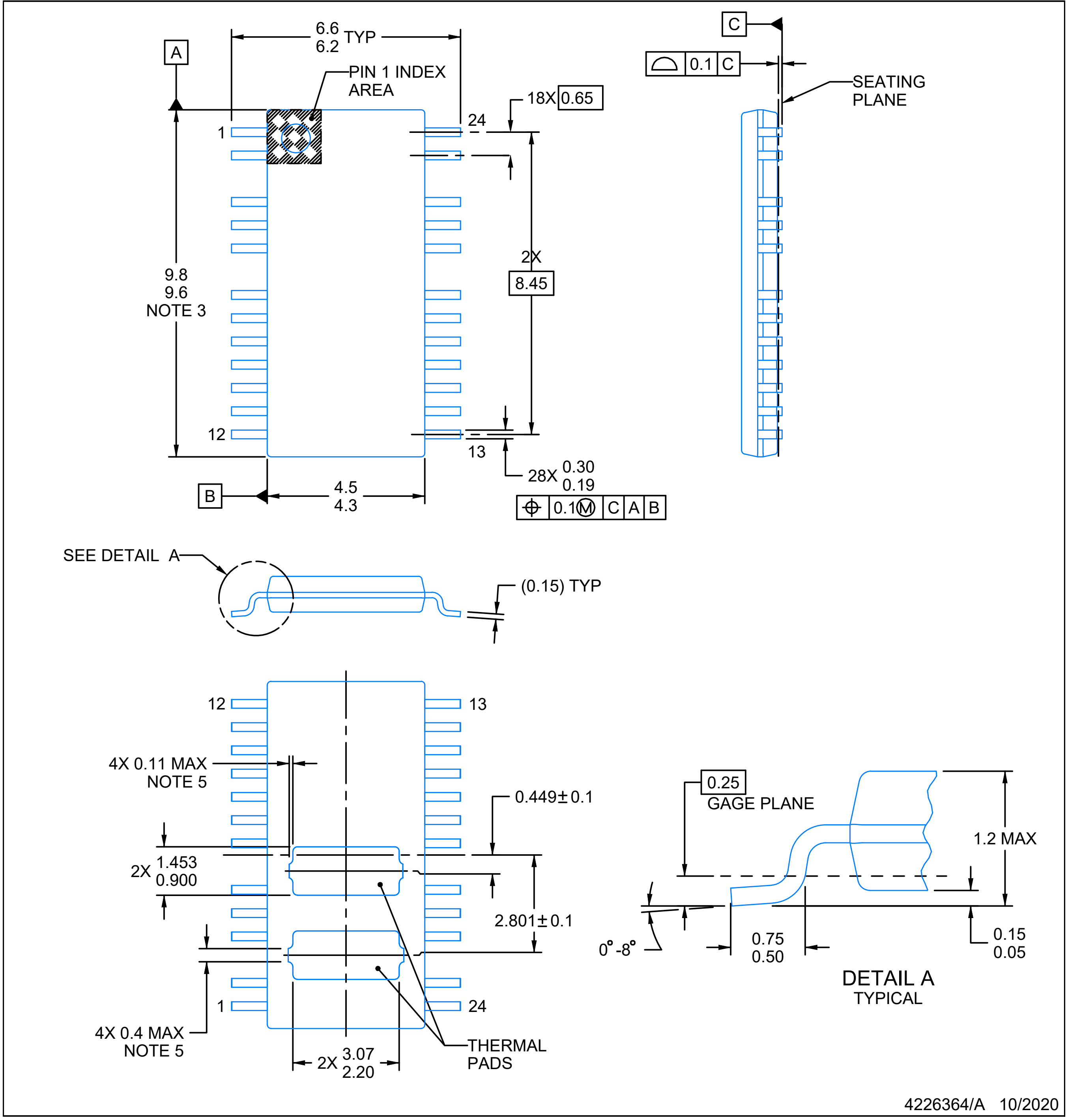
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA254A1IPWAR	HTSSOP	PWA	24	2500	350.0	350.0	43.0
INA254A2IPWAR	HTSSOP	PWA	24	2500	350.0	350.0	43.0
INA254A3IPWAR	HTSSOP	PWA	24	2500	350.0	350.0	43.0

PWA0024A

PowerPAD™ TSSOP - 1.2 mm max height

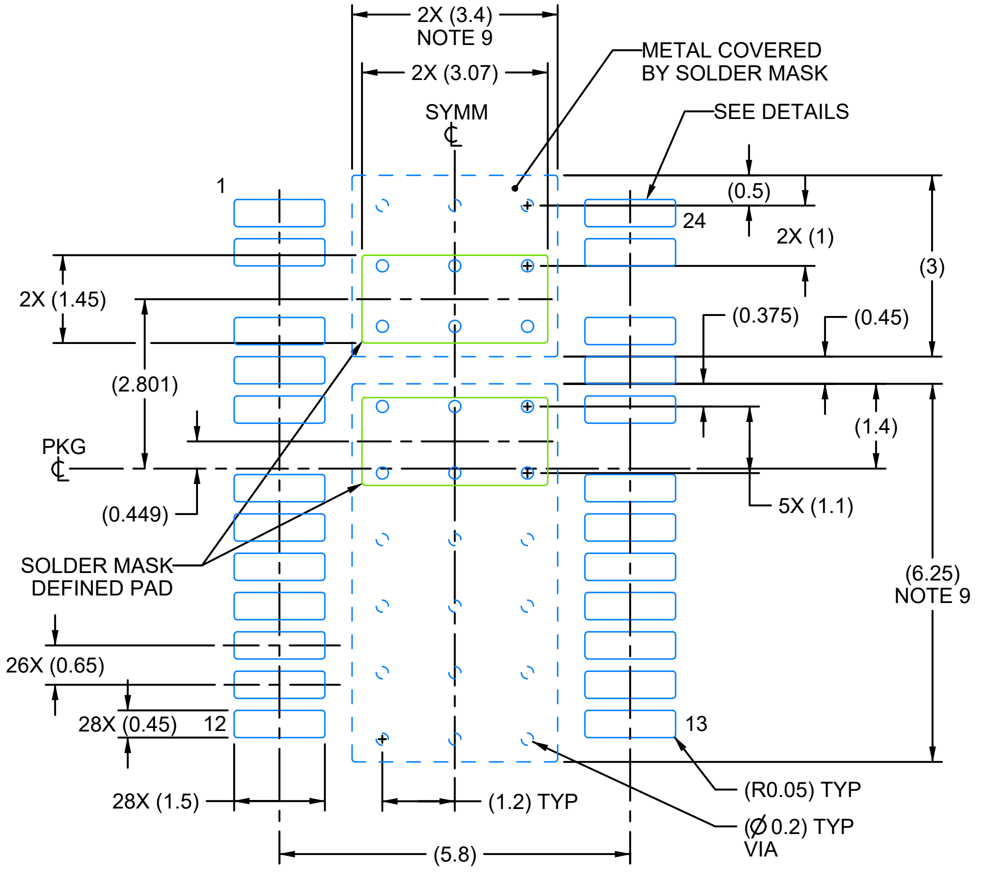
SMALL OUTLINE PACKAGE



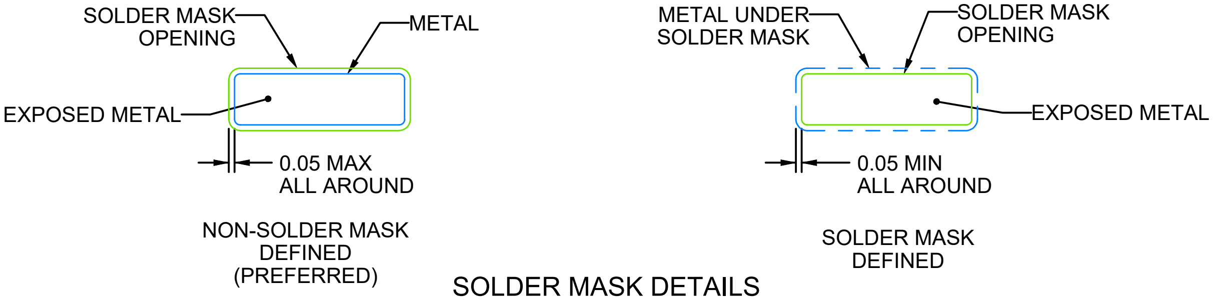
PowerPAD is a trademark of Texas Instruments.

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. Reference JEDEC registration MO-153.
5. Features may differ or may not be present.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 8X



SOLDER MASK DETAILS

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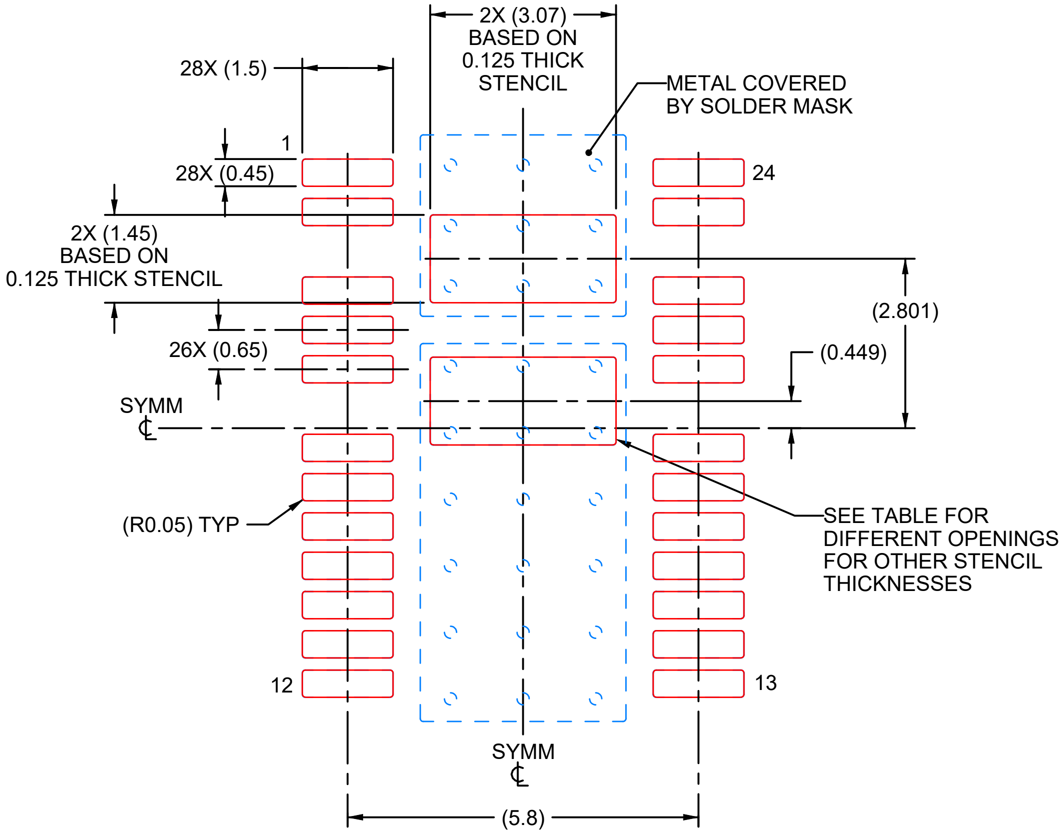
NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
8. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature numbers SLMA002 (www.ti.com/lit/slma002) and SLMA004 (www.ti.com/lit/slma004).
9. Size of metal pad may vary due to creepage requirement.
10. Vias are optional depending on application, refer to device data sheet. It is recommended that vias under paste be filled, plugged or tented.



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE: 8X

STENCIL THICKNESS	SOLDER STENCIL OPENING
0.1	3.43 X 1.62
0.125	3.07 X 1.45 (SHOWN)
0.15	2.80 X 1.33
0.175	2.59 X 1.23

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NOTES: (continued)

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

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