INA253 High Voltage, Bidirectional, Zero-Drift, Current-Shunt Monitor With Integrated, 2-mΩ, Precision, Low Inductive Shunt Resistor

1 Features

- Precision Integrated Shunt Resistor
  - Shunt Resistor: 2 mΩ
  - Shunt Inductance: 3 nH
  - Shunt Resistor Tolerance: 0.1% (Max)
  - ±15 A Continuous from –40°C to +85°C
  - 0°C to 125°C Temperature Coefficient: 10 ppm/°C
- High Bandwidth: 350 kHz
- Enhanced PWM rejection
- Excellent CMRR
  - > 120-dB DC CMRR
  - 90-dB AC CMRR at 50 kHz
- Accuracy:
  - Gain:
    - Gain Error: 0.4% (Max)
    - Gain Drift: 45 ppm/°C (Max)
  - Offset:
    - Offset Current: ±15 mA (Max)
    - Offset Drift: 125 µA/°C (Max)
- Wide Common-Mode Range: –4 V to +80 V
- Available Gains: 100 mV/A, 200 mV/A, and 400 mV/A
- Quiescent Current: 2.4 mA (Max)

2 Applications

- Solenoid and Valve Controls
- Transmission control
- Motor Controls
- Actuator Controls
- DC/DC Converters
- Remote I/O Link Control

3 Description

The INA253 is a voltage-output, current sense amplifier with an integrated shunt resistor of 2 mΩ. The INA253 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: 100 mV/A, 200 mV/A, and 400 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 15 ppm/°C, and an optimized Kelvin layout for the sensing resistor.

The INA253 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.

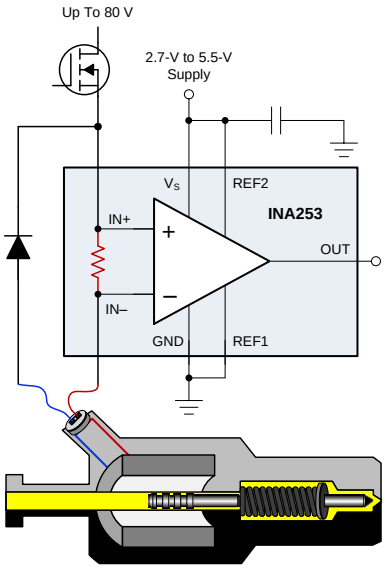
This device operates from a single 2.7-V to 5.5-V power supply, drawing a maximum of 3 mA of supply current. All gain versions are specified over the extended operating temperature range (–40°C to +125°C), and are available in a 20-pin TSSOP package.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA253	TSSOP (20)	6.50 mm × 4.40 mm

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

Typical Application



An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.

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4 Revision History

Changes from Original (July 2018) to Revision A **Page**

- Changed device status from advanced information to production data (active) ... 1

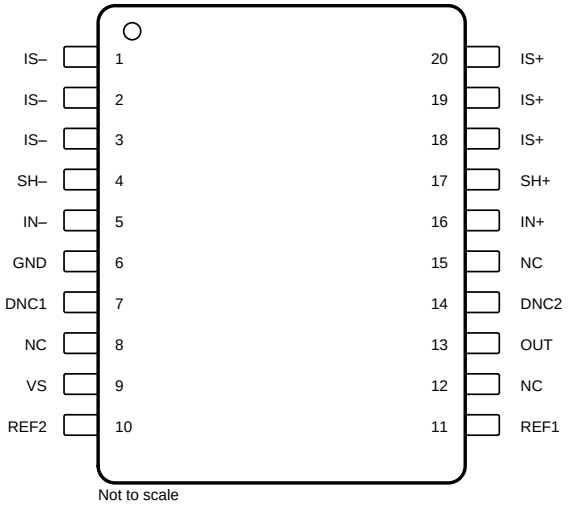
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5 Device Comparison Table

PRODUCT	GAIN (mV/A)
INA253A1	100
INA253A2	200
INA253A3	400

6 Pin Configuration and Functions

PW Package
20-Pin TSSOP
Top View



Not to scale

Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
1	IS–	Analog input	Connect to load
2	IS–	Analog input	Connect to load
3	IS–	Analog input	Connect to load
4	SH–	Analog output	Kelvin connection to internal shunt. Connect to IN– if no filtering is needed
5	IN–	Analog input	Voltage input from load side of shunt resistor
6	GND	—	Ground
7	DNC1	—	Do not connect this pin to any potential; leave this pin floating.
8	NC	—	No connect
9	VS	Analog	Power supply, 2.7 V to 5.5 V
10	REF2	Analog input	Reference voltage 2, 0 V to VS
11	REF1	Analog input	Reference voltage 1, 0 V to VS
12	NC	—	No connect
13	OUT	Analog	Output voltage
14	DNC2	—	Do not connect this pin to any potential; leave this pin floating.
15	NC	Analog	Reserved; connect this pin to ground
16	IN+	Analog input	Voltage input from supply side of shunt resistor
17	SH+	Analog output	Kelvin connection to internal shunt. Connect to IN+ if no filtering is needed
18	IS+	Analog input	Connect to supply
19	IS+	Analog input	Connect to supply
20	IS+	Analog input	Connect to supply

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7 Specifications

7.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Supply voltage			6	V
Shunt input current (I_{SENSE})	Continuous		±15	A
Analog inputs (IS+, IS–)	Common-mode	GND – 6	90	V
Analog inputs (V_{IN+},$V_{IN–}$)	Differential (V_{IN+}) – ($V_{IN–}$)	–80	80	V
	Common-mode	GND – 6	90	
Analog inputs (REF1, REF2, NC)		GND – 0.3	V_S + 0.3	V
Analog outputs (SH+, SH–)	Common-mode	GND – 6	90	V
Analog output (OUT)		GND – 0.3	V_S + 0.3	V
Temperature	Operating, T_A	–55	150	°C
	Junction, T_J		150	
	Storage, T_{stg}	–65	150	°C

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

7.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)	±2000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101(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 voltage	–4		80	V
V_S	Operating supply voltage	2.7		5.5	V
T_A	Operating free-air temperature	–40		125	°C

7.4 Thermal Information

THERMAL METRIC(1)		INA253 PW (TSSOP) 20 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	110.6	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	54.1	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	87.5	°C/W
ψ_{JT}	Junction-to-top characterization parameter	114.1	°C/W
ψ_{JB}	Junction-to-board characterization parameter	87.5	°C/W

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

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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} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	V_{IN+} = –4 V to +80 V, I_{SENSE} = 0 A, T_A = –40°C to +125°C	–4		80	V
CMR	Common-mode rejection	V_{IN+} = –4 V to +80 V, I_{SENSE} = 0 A, T_A = –40°C to +125°C		±125	±500	µA/V
		f = 50 kHz		±13		mA/V
I_{OS}	Offset current, input-referred	I_{SENSE} = 0 A		±2.5	±15	mA
dI_{OS}/dT	Offset current drift	I_{SENSE} = 0 A, T_A = –40°C to +125°C		25	125	µA/°C
PSRR	Power-supply rejection ratio	V_S = 2.7 V to 5.5 V, I_{SENSE} = 0 A		±0.5	±5	mA/V
I_B	Input bias current	I_{B+}, $I_{B–}$, I_{SENSE} = 0 A		90		µA
	Reference input range		0		V_S	V
SHUNT RESISTOR						
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(1)	1.9	2	2.1	
	Package resistance	IS+ to IS–		4.5		mΩ
	Package inductance	IS+ to IS–		3		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		ppm/°C
I_{SENSE}	Maximum continuous current(2)	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 seconds		±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%		
OUTPUT						
G	Gain	INA253A1		100		mV/A
		INA253A2		200		
		INA253A3		400		mV/A
	System gain error(3)	GND + 50 mV ≤ V_{OUT} ≤ V_S – 200 mV, T_A = 25°C		±0.05%	±0.4%	
		T_A = –40°C to +125°C			±45	ppm/°C
	Nonlinearity error	GND + 10 mV ≤ V_{OUT} ≤ V_S – 200 mV		±0.01%		
	Reference divider accuracy	V_{OUT} = |(V_{REF1} – V_{REF2})| / 2 at I_{SENSE} = 0 A, T_A = –40°C to +125°C		0.02%	0.1%	
RVRR	Reference voltage rejection ratio (input-referred)	INA253A2		2.5		mA/V
		INA253A1, INA253A3		1		
	Maximum capacitive load	No sustained oscillation		1		nF
VOLTAGE OUTPUT						
	Swing to V_S 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 GND	R_L = 10 kΩ to GND, I_{SENSE} = 0 A, V_{REF1} = V_{REF2} = 0 V, T_A = –40°C to +125°C		V_{GND} + 1	V_{GND} + 10	mV

(1) 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.
(2) See *Maximum Continuous Current* for additional information on the current derating and review *layout* recommendations to improve the current handling capability of the device at higher temperatures.
(3) 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.

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Electrical Characteristics (continued)

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

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
FREQUENCY RESPONSE						
BW	Bandwidth(4)	All gains, –3-dB bandwidth		350		kHz
		All gains, 2% THD+N(4)		100		kHz
	Output settling time	Settles to 0.5% of final value		10		µs
SR	Slew rate			2.4		V/µs
NOISE (Input Referred)						
	Voltage noise density			40		nV/√Hz
POWER SUPPLY						
V_S	Operating voltage range	T_A = –40°C to +125°C	2.7		5.5	V
I_Q	Quiescent current	I_{SENSE} = 0 A		1.8	2.4	mA
		I_Q vs temperature, T_A = –40°C to +125°C			2.6	

(4) See *Bandwidth* section for more details.

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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)

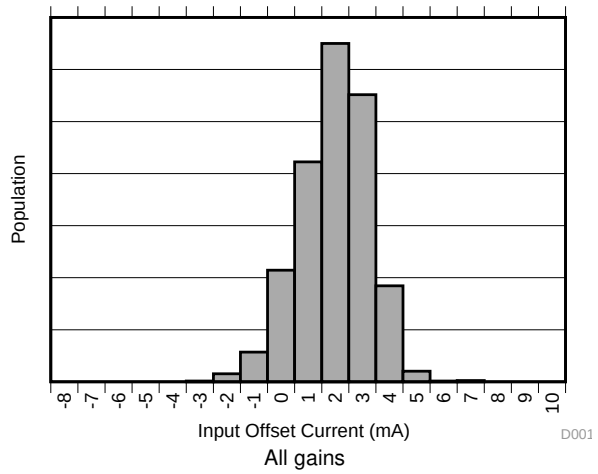


Figure 1. Input Offset Voltage Production Distribution

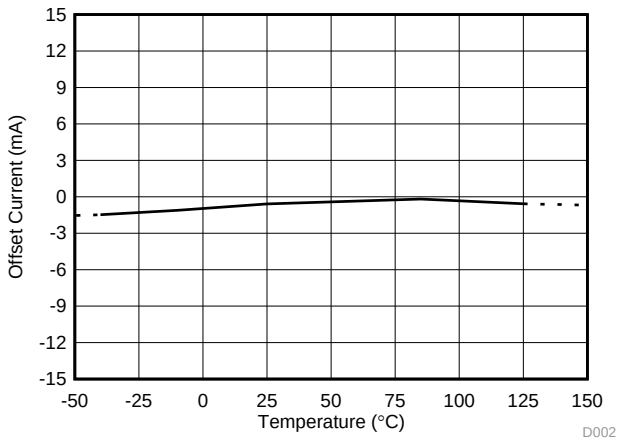


Figure 2. Input Offset Current vs Temperature

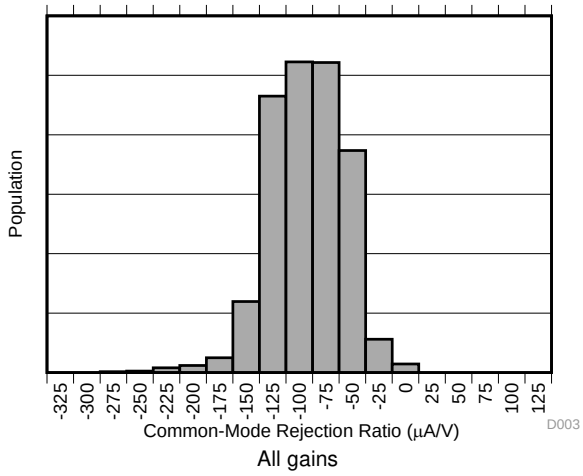


Figure 3. Common-Mode Rejection Production Distribution

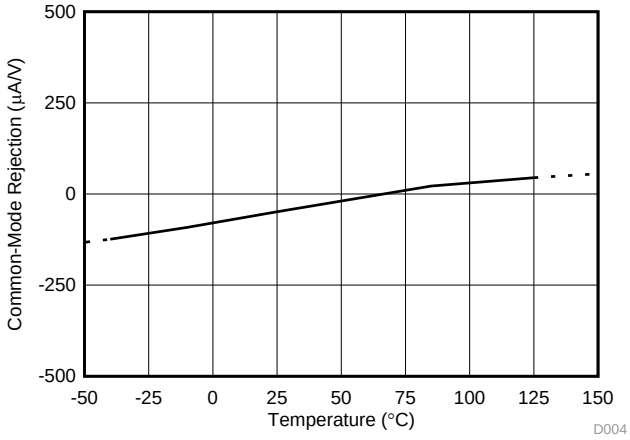


Figure 4. Common-Mode Rejection Ratio vs Temperature

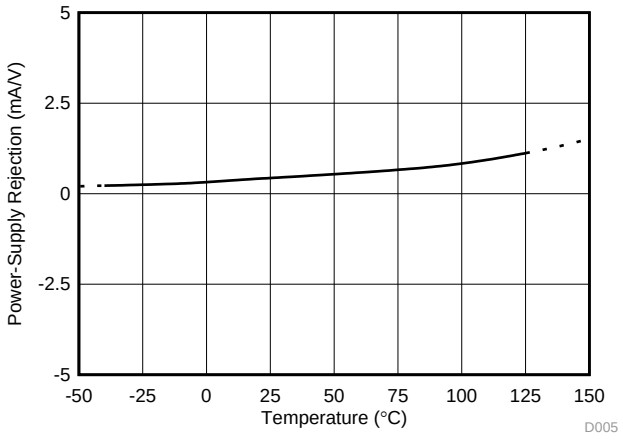


Figure 5. Power-Supply Rejection Ratio vs Temperature

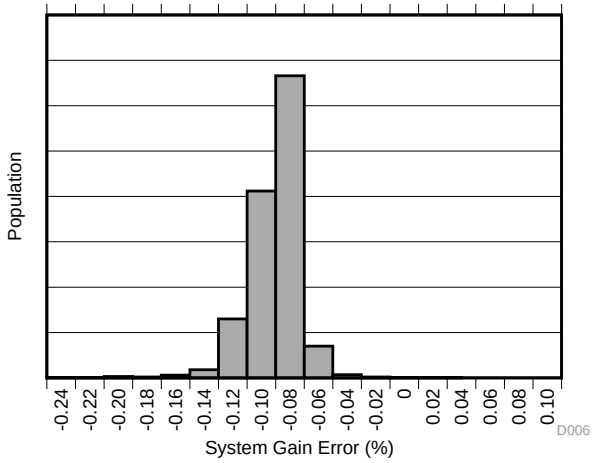


Figure 6. Gain Error Production Distribution (INA253A1)

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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)

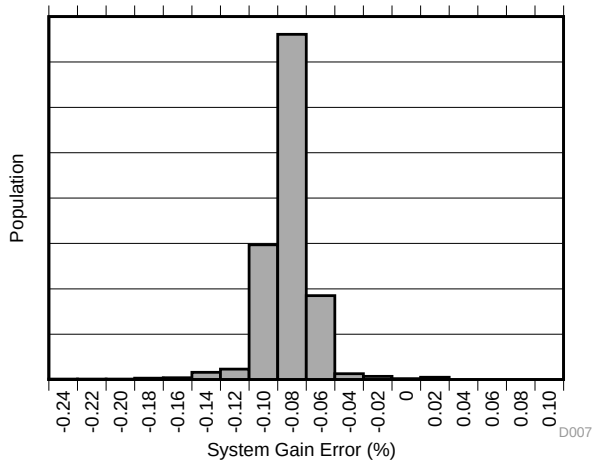


Figure 7. Gain Error Production Distribution (INA253A2)

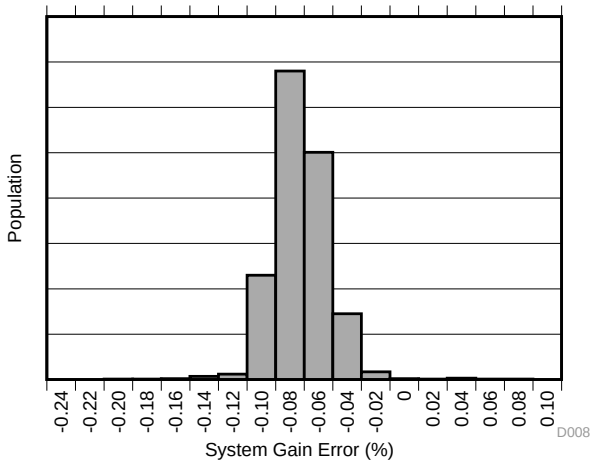


Figure 8. Gain Error Production Distribution (INA253A3)

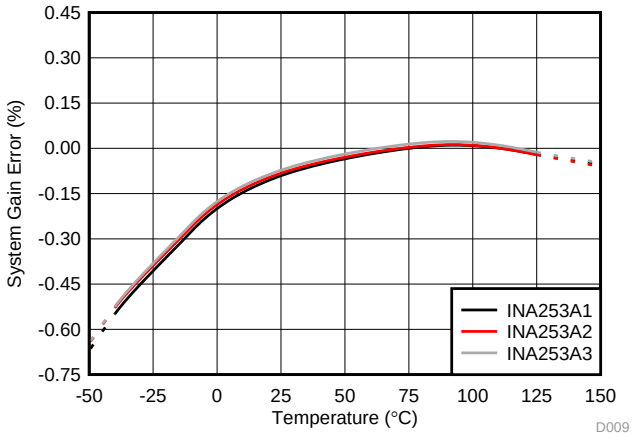


Figure 9. System Gain Error vs Temperature

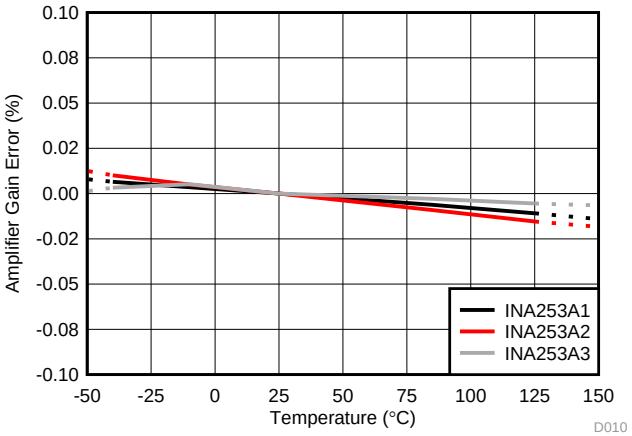
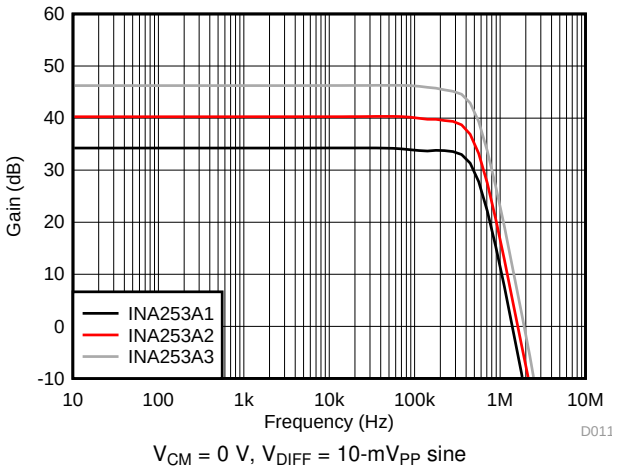


Figure 10. Amplifier Gain Error vs Temperature



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

Figure 11. Amplifier Gain Error vs Frequency

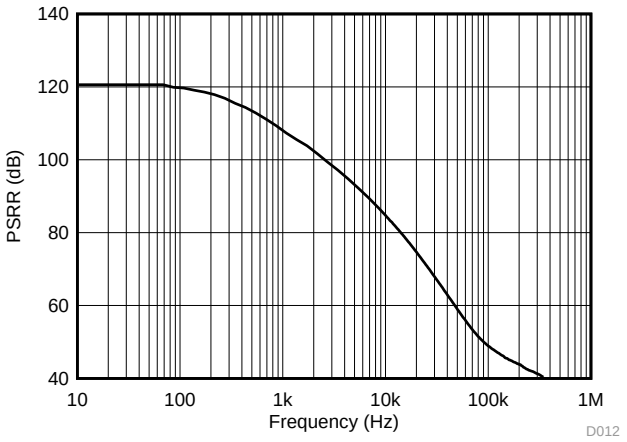


Figure 12. Power-Supply Rejection Ratio vs Frequency

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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)

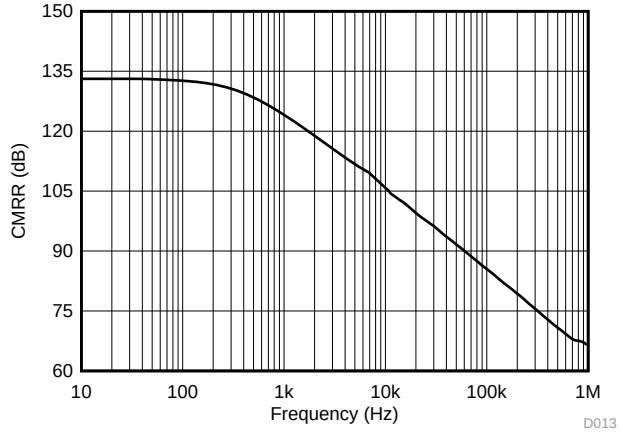
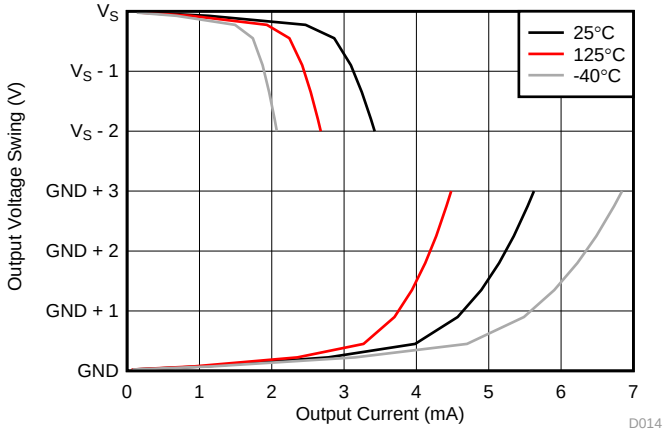
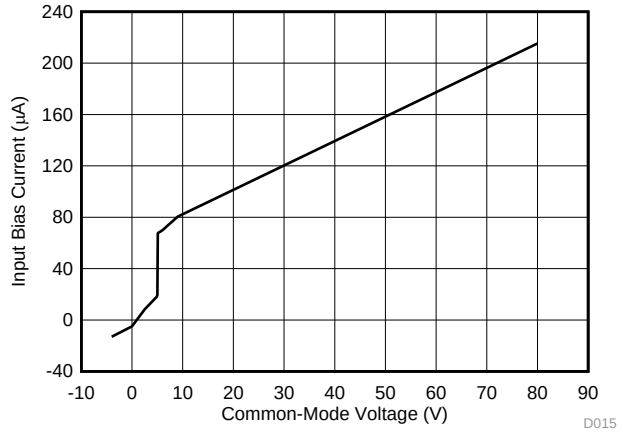


Figure 13. Common-Mode Rejection Ratio vs Frequency



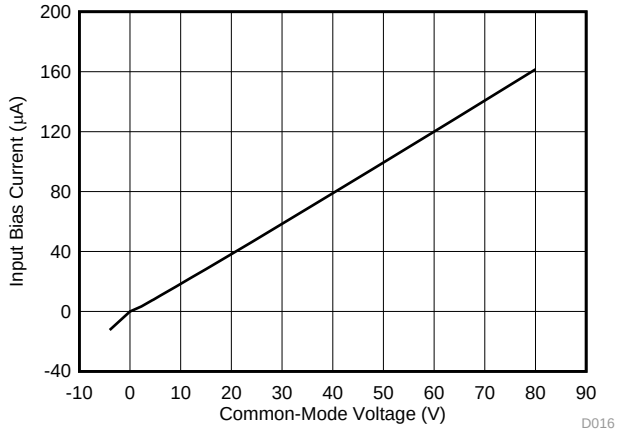
V_S = 5 V

Figure 14. Output Voltage Swing vs Output Current



V_S = 5 V

Figure 15. Input Bias Current vs Common-Mode Voltage



V_S = 0 V

Figure 16. Input Bias Current vs Common-Mode Voltage

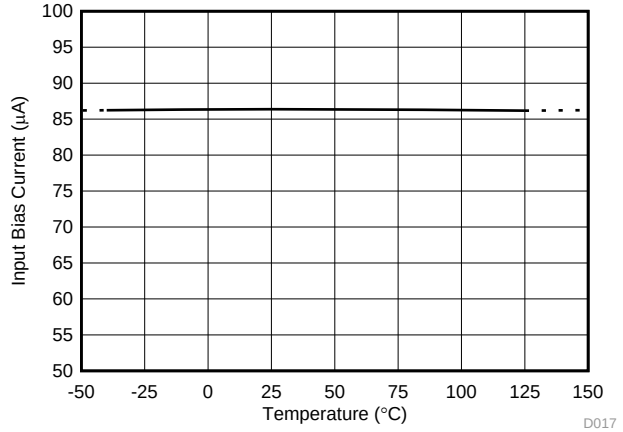


Figure 17. Input Bias Current vs Temperature

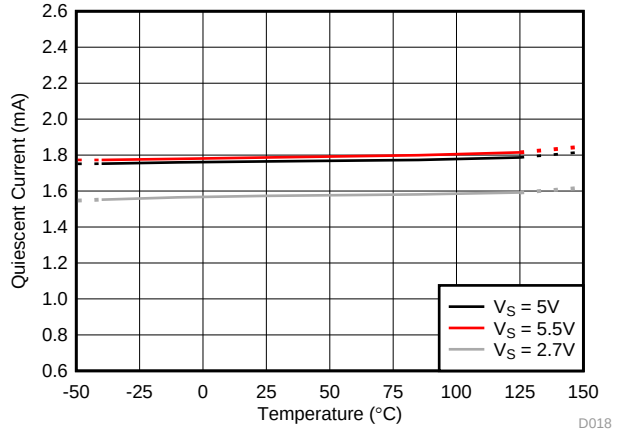


Figure 18. Quiescent Current vs Temperature

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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)

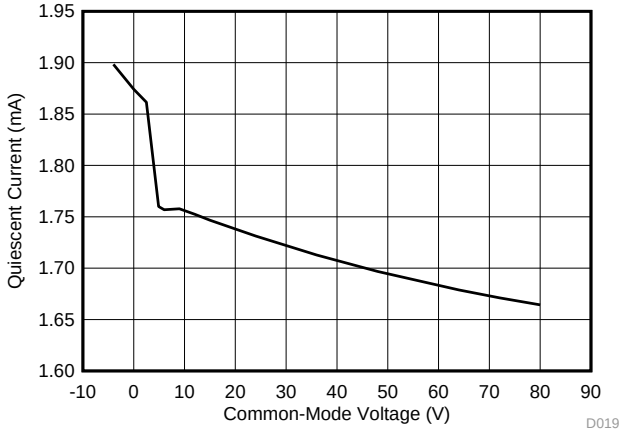


Figure 19. Quiescent Current vs Common-mode Voltage

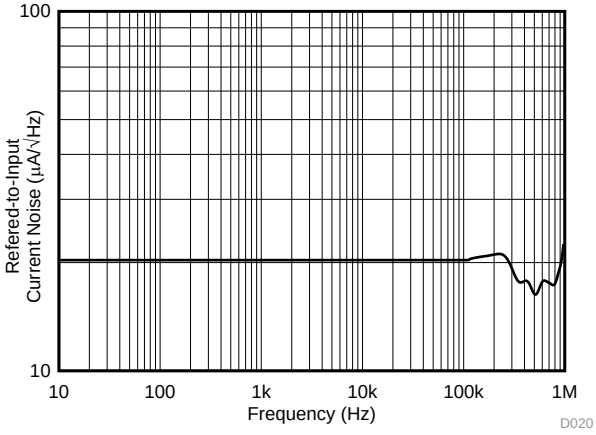


Figure 20. INA253A1 Input-Referred Voltage Noise vs Frequency

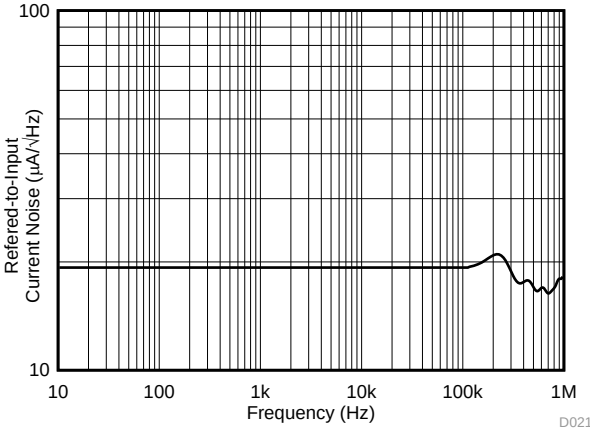


Figure 21. INA253A2 Input-Referred Voltage Noise vs Frequency

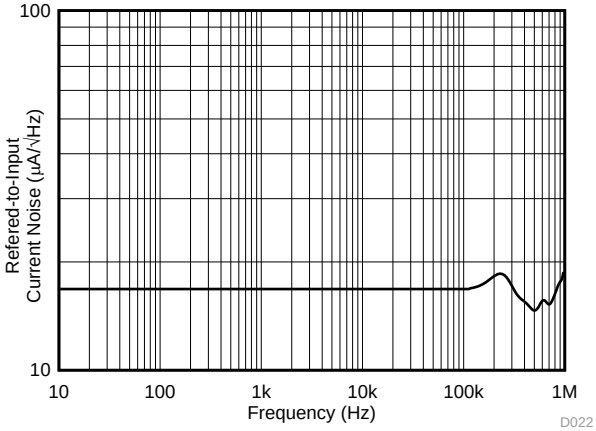


Figure 22. INA253A3 Input-Referred Voltage Noise vs Frequency

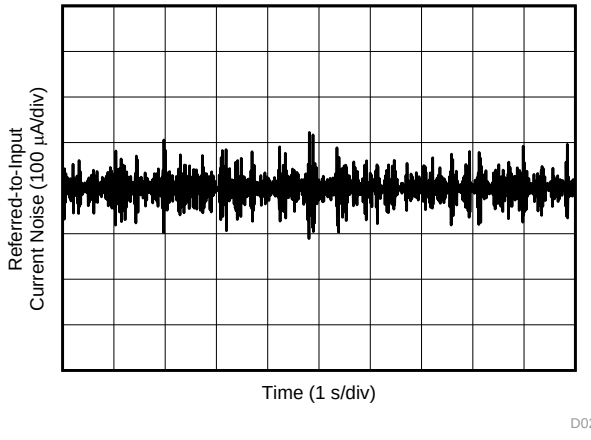
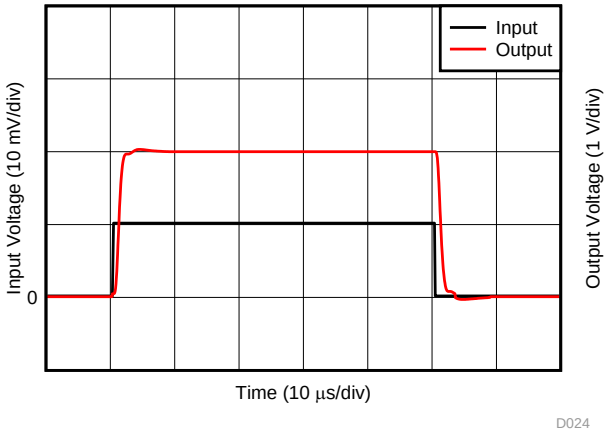


Figure 23. 0.1-Hz to 10-Hz Voltage Noise (Referred-to-Input)



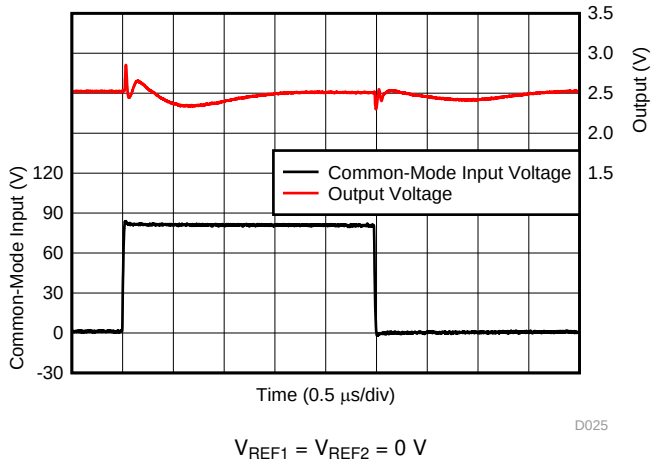
V_{REF1} = V_{REF2} = 0 V, 10-mV_{PP} input step

Figure 24. Amplifier Step Response

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

Figure 25. Common-Mode Transient Response

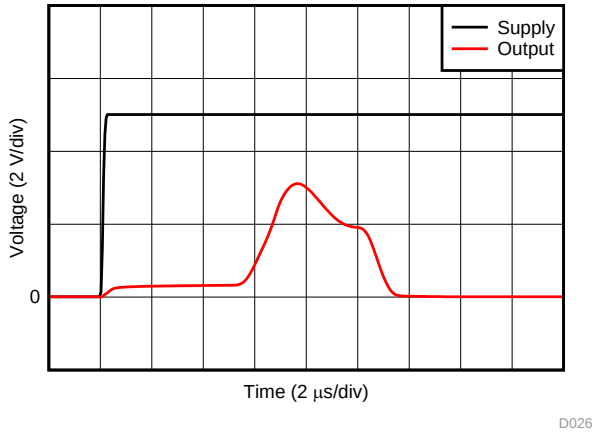
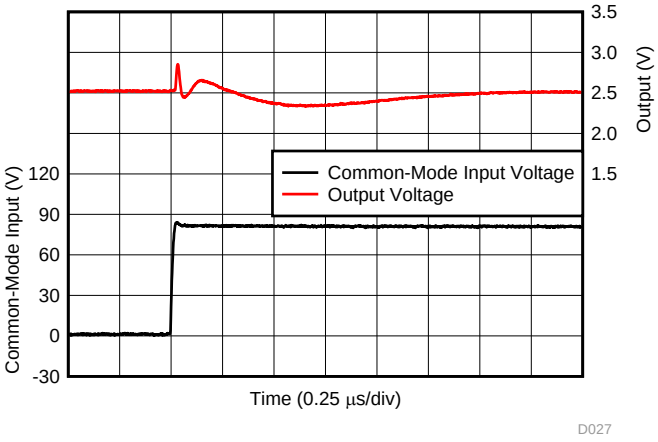
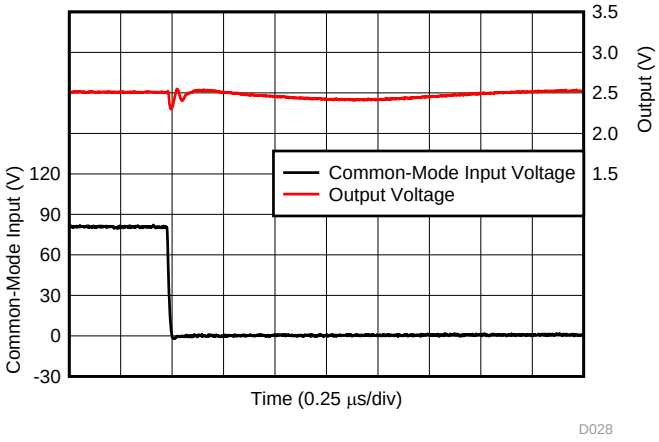


Figure 26. Start-Up Response



Rising Edge

Figure 27. Common-Mode Voltage Transient Response



Falling Edge

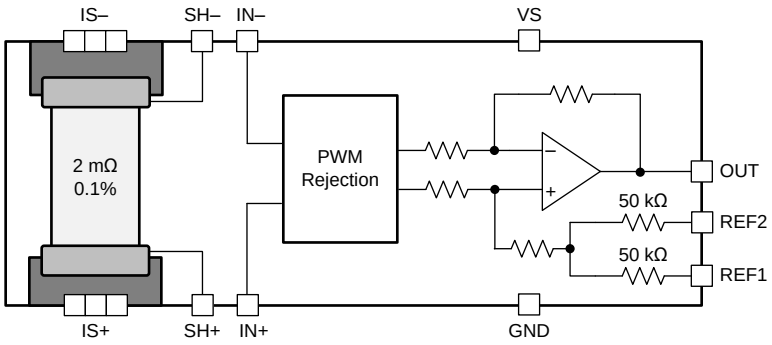
Figure 28. Common-Mode Voltage Transient Response

8 Detailed Description

8.1 Overview

The INA253 features a precision, 2-mΩ 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 INA253 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 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 can be accessed through the SH+ and SH– pins, this resistor is not intended to be used as a stand-alone component. The INA253 is system-calibrated to makes 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 INA253 has approximately 4.5 mΩ of package resistance. Of this total package resistance, 2 mΩ 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 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.

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Feature Description (continued)

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 4.5 mΩ. Under the conditions of no air flow, a maximum ambient temperature of 85°C, and 1-oz. copper input power planes, the INA253 accommodates continuous current levels up to 15 A. Figure 29 shows that the current-handling capability is derated at temperatures greater than 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 INA253 safely accommodates continuous current levels up to 15 A across the entire –40°C to +125°C temperature range.

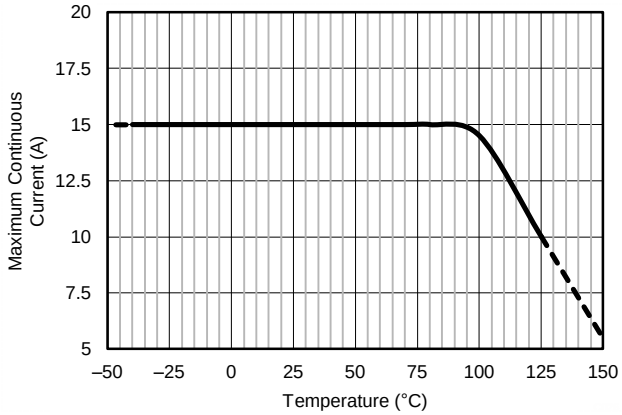


Figure 29. Maximum Continuous Current vs Temperature

8.3.2 Short-Circuit Duration

The INA253 features a physical shunt resistance that is able to 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 30 shows the short-circuit duration curve for the INA253.

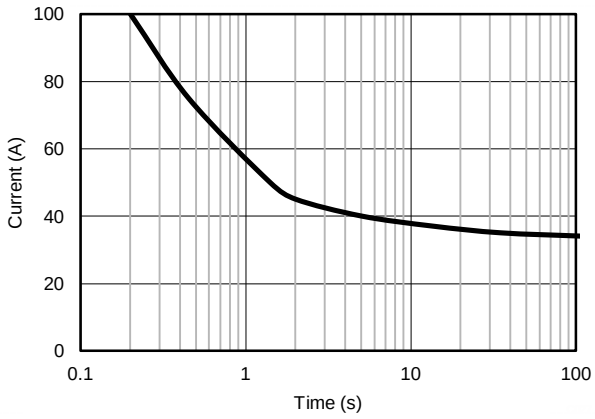


Figure 30. Short-Circuit Duration

Feature Description (continued)

8.3.3 Temperature Stability

System calibration is common for many industrial applications in order 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 INA253 (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 31 shows the drift performance for the integrated current-sensing resistor. Use Figure 31 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 INA253, 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. Even in the –40°C to 0°C temperature range, the drift is still low at 25 ppm/°C.

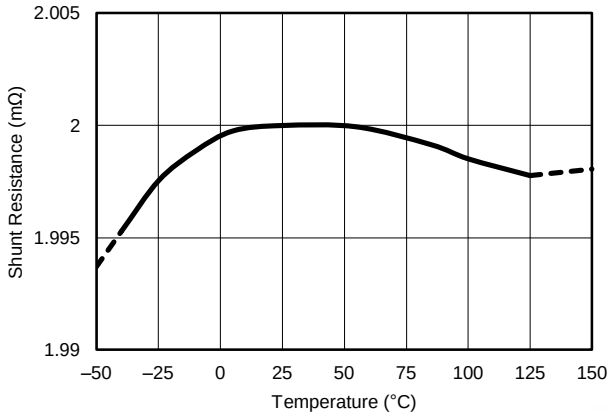


Figure 31. Sensing Resistor vs Temperature

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 INA253 provides increased attenuation of large common-mode $\Delta V/\Delta t$ transients. Large $\Delta V/\Delta t$ common-mode transients associated with PWM signals are employed in applications such as motor or solenoid drive and switching power supplies. Traditionally, large $\Delta V/\Delta t$ common-mode transitions are handled strictly by increasing the amplifier signal bandwidth, which can increase chip size, complexity and ultimately cost. The INA253 is designed with high common-mode rejection techniques to reduce large $\Delta V/\Delta t$ transients before the system is disturbed as a result of these large signals. The high ac CMRR, in conjunction with signal bandwidth, allows the INA253 to provide minimal output transients and ringing compared with standard circuit approaches.

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Feature Description (continued)

8.3.5 Input Signal Bandwidth

The INA253 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 INA253 bandwidth is defined by the –3-dB bandwidth of the current-sense amplifier inside the device; see the *Electrical Characteristics* for more information. 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 32 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 INA253 bandwidth.

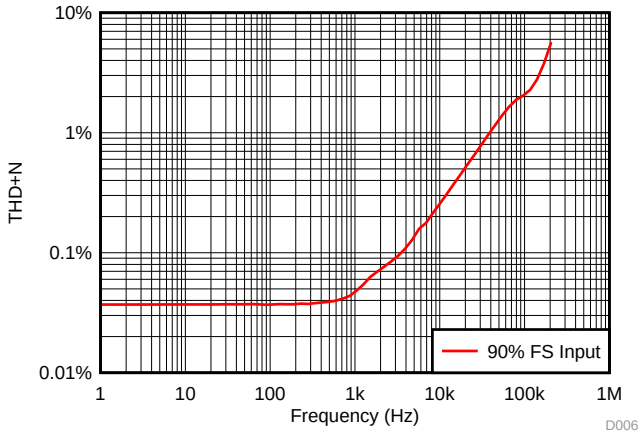


Figure 32. Amplifier Performance Over Frequency

For applications requiring distortion sensitive signals, Figure 32 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.

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8.4 Device Functional Modes

8.4.1 Adjusting the Output Midpoint With the Reference Pins

Figure 33 shows a test circuit for reference-divider accuracy. The INA253 output is configurable to allow for unidirectional or bidirectional operation.w

CAUTION

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

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

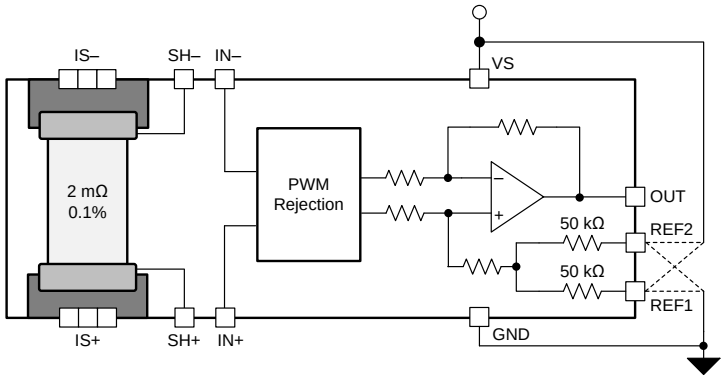


Figure 33. Adjusting the Output Midpoint

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 INA253 in unidirectional mode with a ground-referenced output, both reference inputs are connected to ground. Figure 34 shows how this configuration takes the output to ground when there is 0-A flowing across the internal shunt.

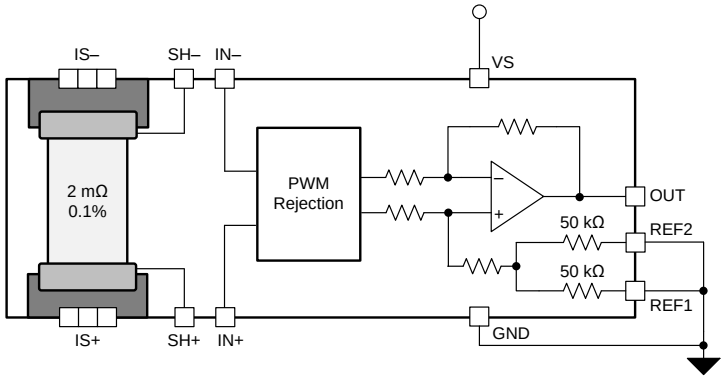


Figure 34. Ground-Referenced Output

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Device Functional Modes (continued)

8.4.4 Reference Pin Connections for Bidirectional Current Measurements

Bidirectional operation allows the INA253 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 35 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.

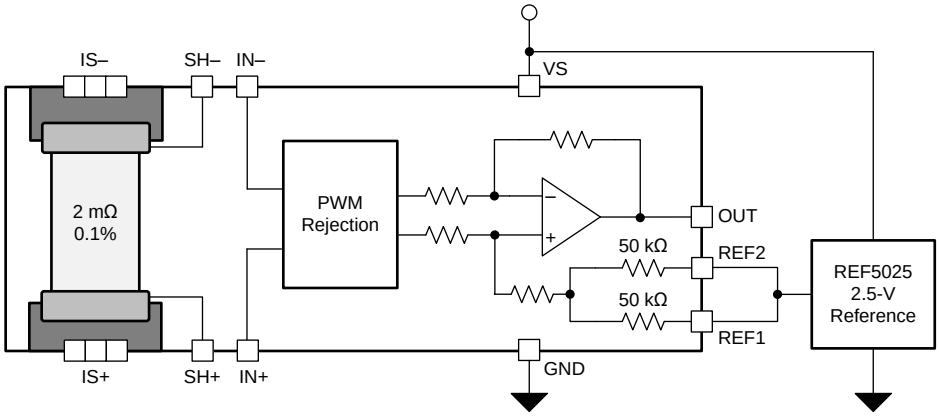


Figure 35. External Reference Output

8.4.5 Output Set to Mid-Supply Voltage

Figure 36 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.

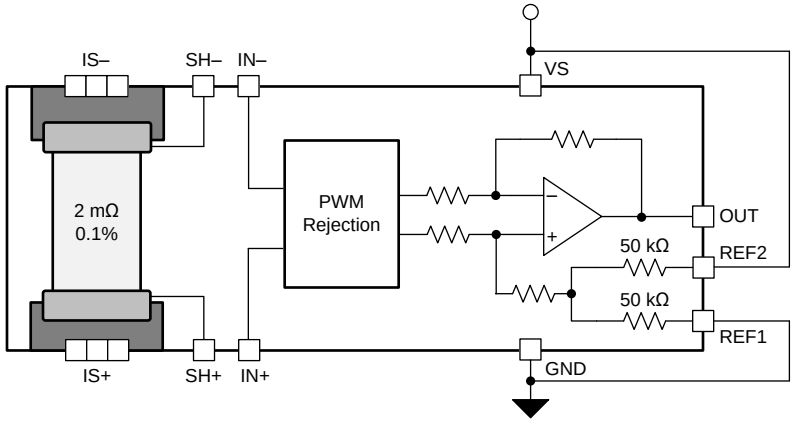


Figure 36. Mid-Supply Voltage Output

Device Functional Modes (continued)

8.4.6 Output Set to Mid-External Reference

In this example, an external reference is divided by two by connecting one REF pin to ground and the other REF pin to the reference, as shown in Figure 37.

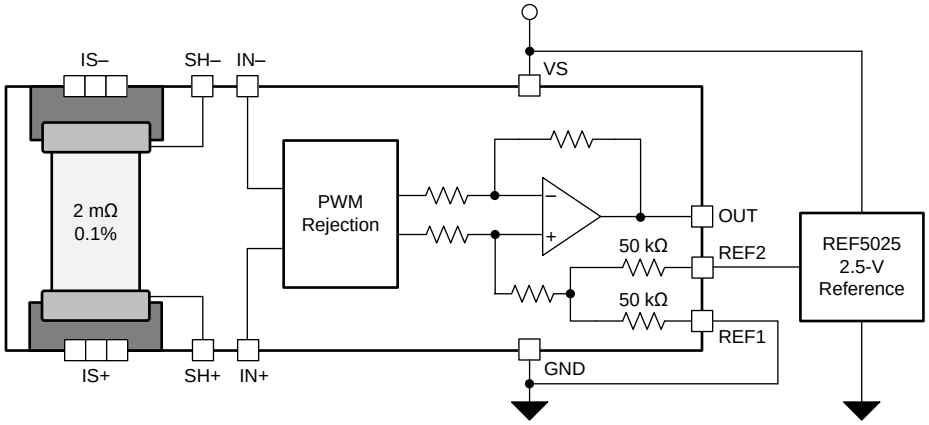


Figure 37. Mid-External Reference Output

8.4.7 Output Set Using Resistor Divide

The INA253 REF1 and REF2 pins allow for the midpoint of the output voltage to be adjusted for system circuitry connections to analog to digital converters (ADCs) or other amplifiers. The REF pins are designed to be connected directly to supply, ground, or a low-impedance reference voltage. The REF pins can be connected together and biased using a resistor divider to achieve a custom output voltage. If the amplifier is used in this configuration, as shown in Figure 38, 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.

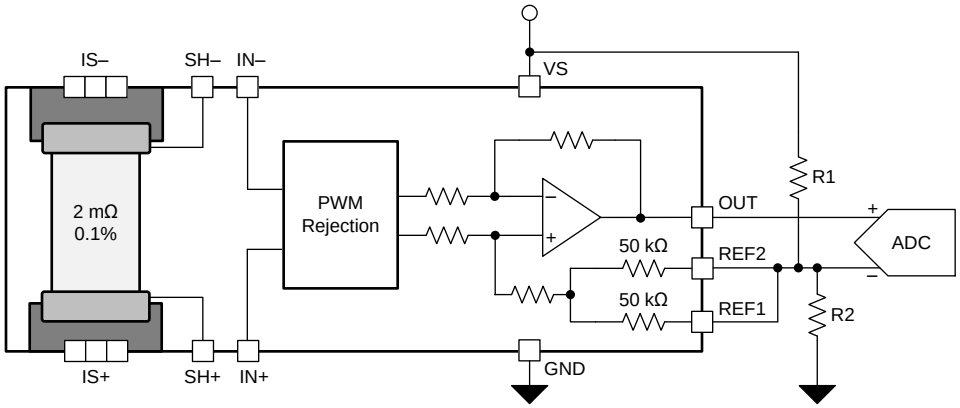


Figure 38. Setting the Reference Using a Resistor Divider

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9 Application and Implementation

NOTE

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

9.1 Application Information

The INA253 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 INA253 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 INA253. 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 39 shows a filter placed at the inputs pins.

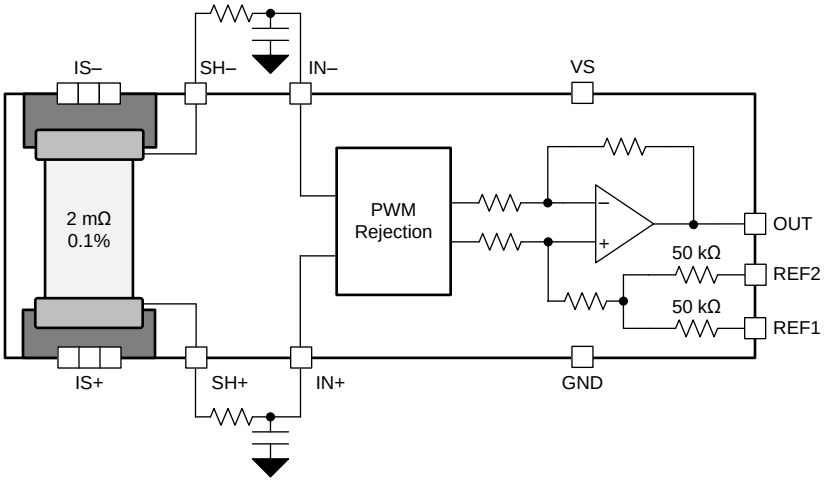


Figure 39. Filter at Input Pins

External series resistance provides a source of additional measurement error. Therefore, keep the value of these series resistors to 10-Ω or less in order to reduce loss of accuracy. The internal bias network shown in Figure 39 creates a mismatch in input bias currents when a differential voltage is applied between the input pins (see Figure 40). 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.

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Application Information (continued)

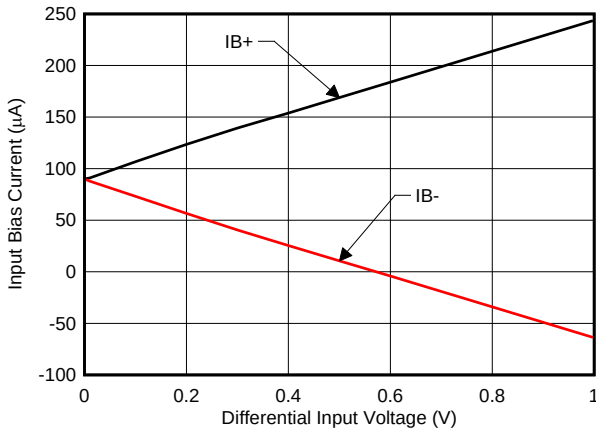


Figure 40. Input Bias Current vs Differential Input Voltage

Calculate the measurement error expected from the additional external filter resistors using Equation 1.

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

where

- Gain Error Factor is calculated using Equation 2.

$$\text{Gain Error Factor} = \frac{3000}{R_S + 3000} \quad (2)$$

Where:

- R_S is the external filter resistance value

Calculate the gain error factor, shown in Equation 2, in order to determine the gain error introduced by the additional external series resistance. Equation 1 calculates the deviation of the shunt voltage resulting from the attenuation and imbalance created by the added external filter resistance. Table 1 provides the gain error factor and gain error for several resistor values.

Table 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

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9.2 Typical Applications

The INA253 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 High-Side, High-Drive, Solenoid Current-Sense Application

Challenges exist in solenoid drive current sensing that are similar to those in motor inline current sensing. In certain topologies, the current-sensing amplifier is exposed to the full-scale PWM voltage between ground and supply. The INA253 is an excellent choice for this type of application. The 2-mΩ integrated shunt with a total system accuracy of 0.2% with a total system drift of 25 ppm/°C provides system accuracy across temperature eliminating the need for tri temperature system calibration.

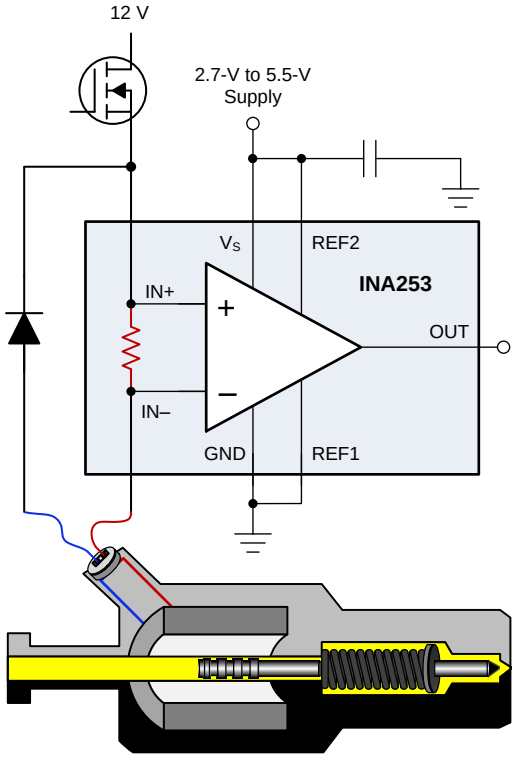


Figure 41. Solenoid Drive Application Circuit

9.2.1.1 Design Requirements

For this application, the INA253 measures current in the driver circuit of a 12-V, 500-mA hydraulic valve.

Table 2. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Common-mode voltage	12 V
Maximum sense current	500 mA
Power-supply voltage	3.3 V

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9.2.1.2 Detailed Design Procedure

To demonstrate the performance of the device, the INA253, with a gain of 400mV/A, is selected for this design and powered from a 5-V supply.

Using the information in the *Output Set to Mid-Supply Voltage* section, the reference point is set to midscale by splitting the supply with REF1 connected to ground and REF2 connected to supply. Alternatively, the reference pins can be tied together and driven with an external precision reference.

9.2.1.3 Application Curve

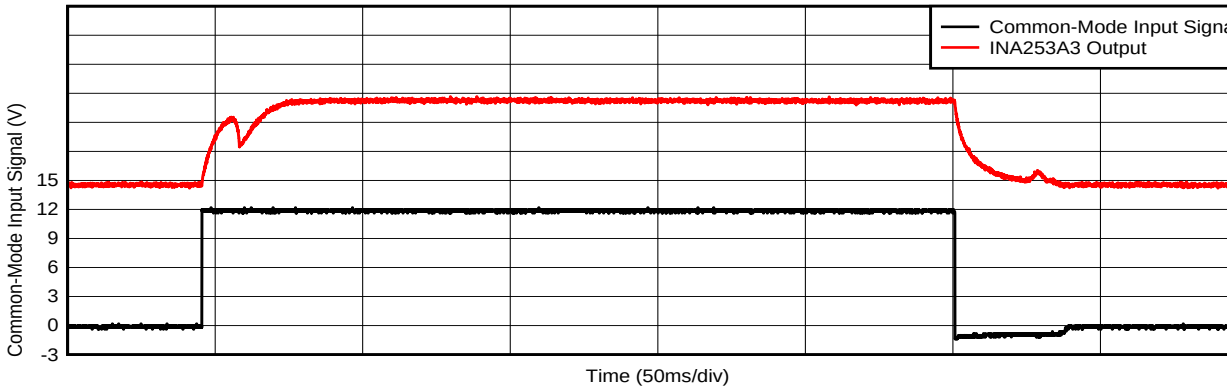


Figure 42. Solenoid Drive Current Sense Input and Output Signals

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9.2.2 Speaker Enhancements and Diagnostics Using Current Sense Amplifier

CLASS-D audio amplifiers in conjunction with the INA253 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.

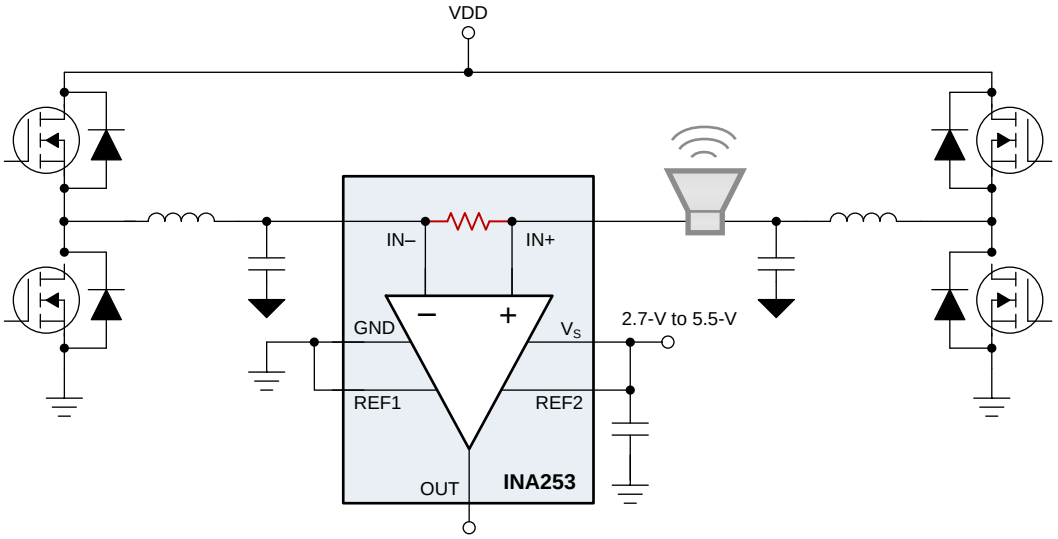


Figure 43. Current Sensing in a CLASS-D Subsystem

9.2.2.1 Design Requirements

Table 3. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Common-mode voltage	24 V
Power-supply voltage	5 V
Maximum rms current	5 A
Frequency sweep	20 Hz to 20 Khz

9.2.2.2 Detailed Design Procedure

For this application, the INA253 measures current flowing through the speaker from the CLASS-D amplifier. The integrated shunt of 2 mΩ with an inductance of only 3 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 INA253 is setup in a bidirectional with the reference set to mid-supply as shown in Figure 37. The power supply to INA253 is setup at 5 V. The output of INA253 is set at 2.5 V. The INA253 with a gain of 100 mV/A, the INA253 output for a peak to peak of 10-A current the output of the INA253 will swing from 3.5 V to 1.5 V. The output can be directly connected to ADC input that has a full scale range of 5 V. The INA253 has a low THD+N of 0.1% at 1 kHz that enables distortion measurement of speaker. The INA253 can measure the impedance of the speaker and accurately measure the resonance frequency and peak impedance at resonance frequency. The INA253 can accurately track changes in impedance real time.

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9.2.2.3 Application Curve

A typical example output response of speaker of 4-Ω impedance measurement from 20 Hz to 20 kHz is as shown in Figure 44.

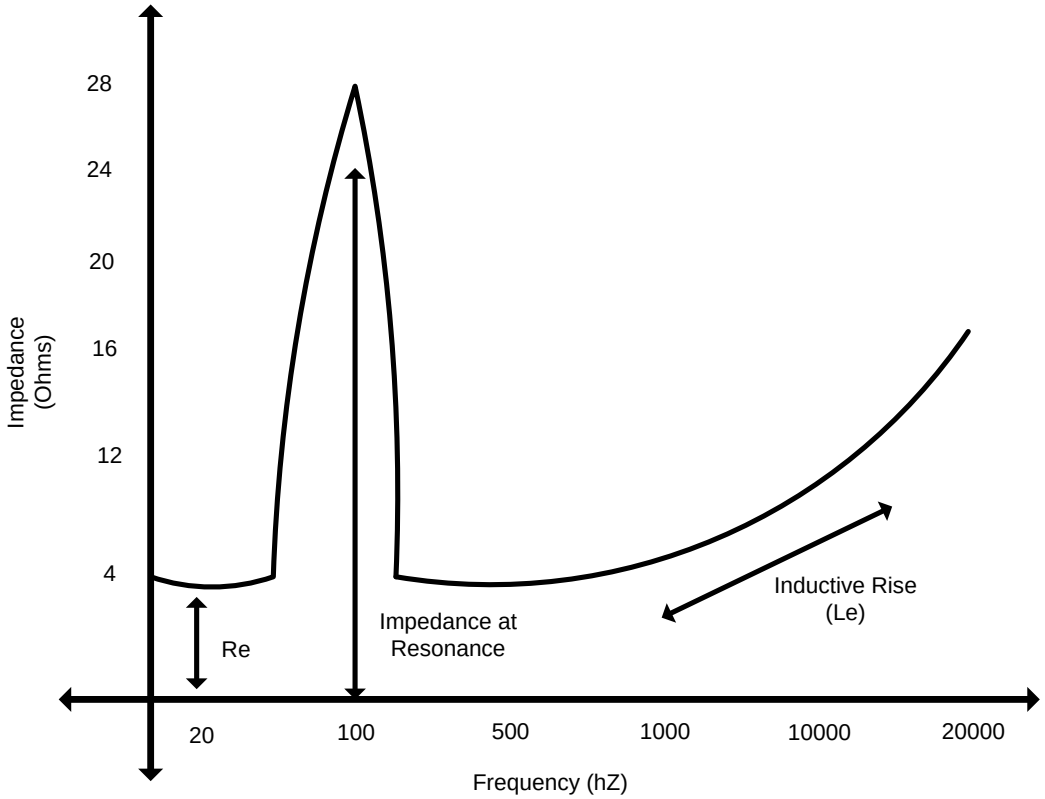


Figure 44. Speaker Impedance Measurement

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9.2.3 Current Sensing for Remote I/Os in PLC

In industrial remote IOs, there is often one power supply for several ports, as shown in Figure 45. For example, an IO-Link master has one power supply of 24 V 5 A, but eight IO-Link ports, where each port can deliver up to 1 A. The IO-Link master must measure the total current to make sure in order to not overload the power supply. To prevent from overloading the system, each port is only turned on if sufficient headroom in the total system current is available. Figure 45 shows the block diagram of such a system. This is example is implemented on TI reference design TIDA-010016. The INA253 is an excellent choice for this design because this device is simple to use, and delivers high accuracy over a wide temperature range. The integrated 2-mΩ shunt has a low voltage drop .and therefore low power dissipation.

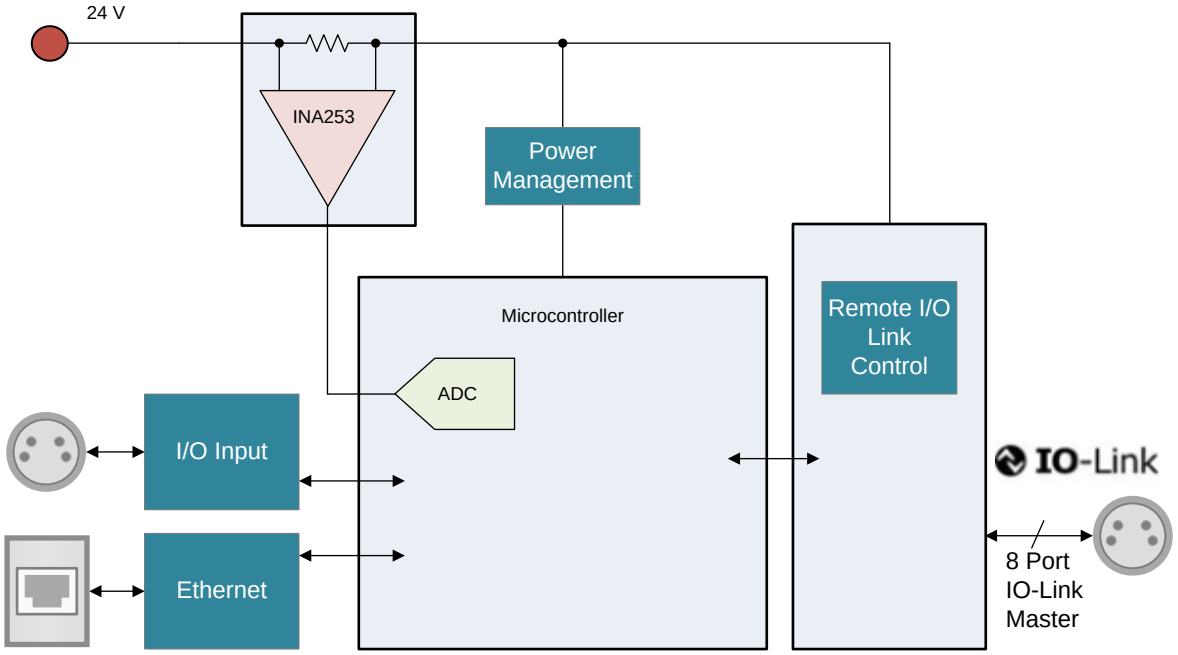


Figure 45. Current Sensing in Remote I/O

9.2.3.1 Design Requirements

Table 4. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Common-mode voltage	24 V
Maximum current	9 A
ADC input voltage	1.8 V
Supply voltage	3.3 V

In this design, the current flow is unidirectional; therfore, the REF inputs must be tied to GND. Because of the given ADC input range and current, the 200-mV/A version is chosen.

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9.2.3.2 Application Curve

A typical response of INA253 in a remote I/O application is shown in Figure 46. The common-mode voltage steps from 0 V to 24 V, and the current output across the 24 V power supply is measured using the INA253.

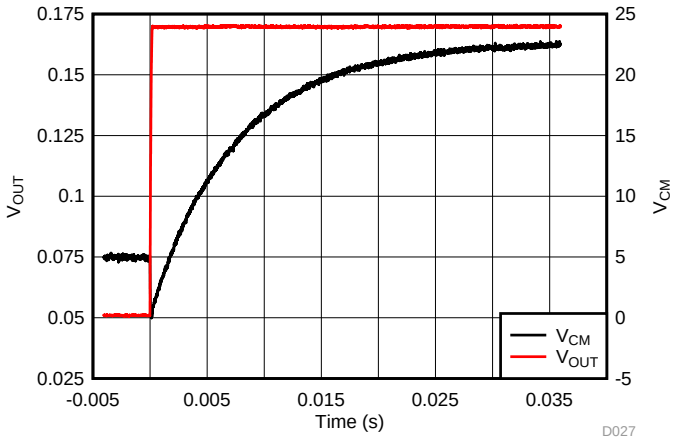


Figure 46. INA253 Current Sense Output Response in Remote I/O

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10 Power Supply Recommendations

The INA253 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 INA253 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 INA253 output is set to mid-supply, then take extreme care to minimize noise on the power supply.

11 Layout

11.1 Layout Guidelines

- This device 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 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 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 INA253 evaluation module (EVM) features a 2-oz copper pour for the planes, and 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. 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.

11.2 Layout Example

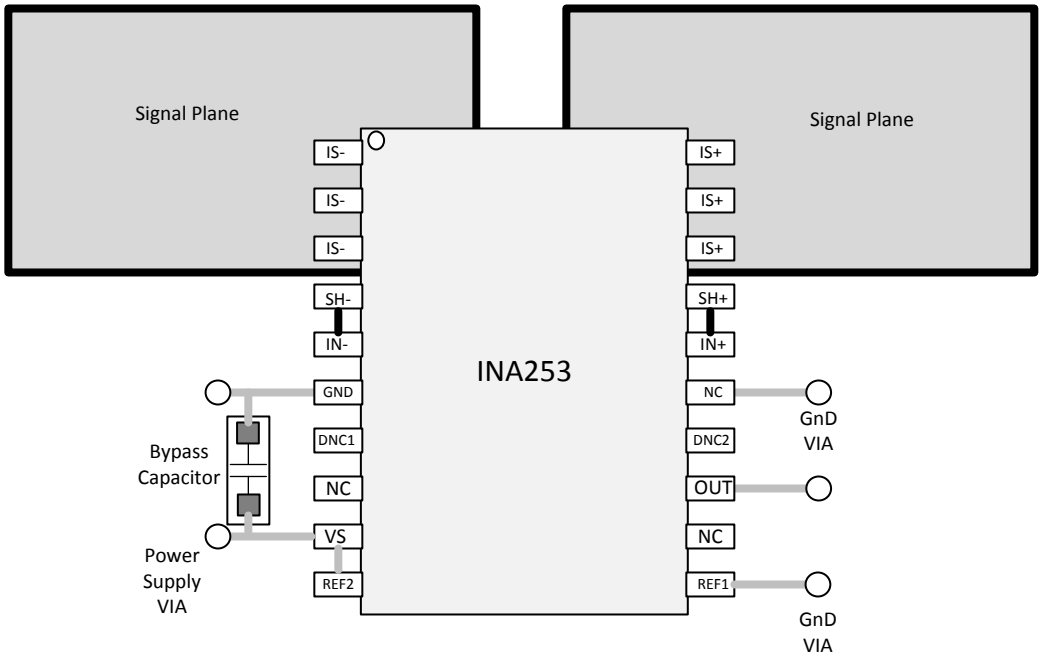


Figure 47. INA253 Layout Example

12 Device and Documentation Support

12.1 Device Support

12.1.1 Development Support

INA253 Evaluation Module (EVM)

12.2 Related Documentation

For related documentation see the following: *INA253EVM User's Guide*

12.3 Receiving Notification of Documentation Updates

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

12.4 Community Resources

The following links connect to TI community resources. Linked contents are 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.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

12.5 Trademarks

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12.6 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.

12.7 Glossary

SLYZ022 — *TI Glossary*.

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

13 Mechanical, Packaging, and Orderable Information

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

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PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
INA253A1IPW	Obsolete	Production	TSSOP (PW) | 20	-	-	Call TI	Call TI	-40 to 125	I253A1
INA253A1IPWR	Active	Production	TSSOP (PW) | 20	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I253A1
INA253A1IPWR.A	Active	Production	TSSOP (PW) | 20	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I253A1
INA253A2IPWR	Active	Production	TSSOP (PW) | 20	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I253A2
INA253A2IPWR.A	Active	Production	TSSOP (PW) | 20	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I253A2
INA253A3IPW	Obsolete	Production	TSSOP (PW) | 20	-	-	Call TI	Call TI	-40 to 125	I253A3
INA253A3IPWR	Active	Production	TSSOP (PW) | 20	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I253A3
INA253A3IPWR.A	Active	Production	TSSOP (PW) | 20	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I253A3
INA253A3IPWRG4	Active	Production	TSSOP (PW) | 20	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I253A3
INA253A3IPWRG4.A	Active	Production	TSSOP (PW) | 20	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I253A3

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts 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.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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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 INA253 :

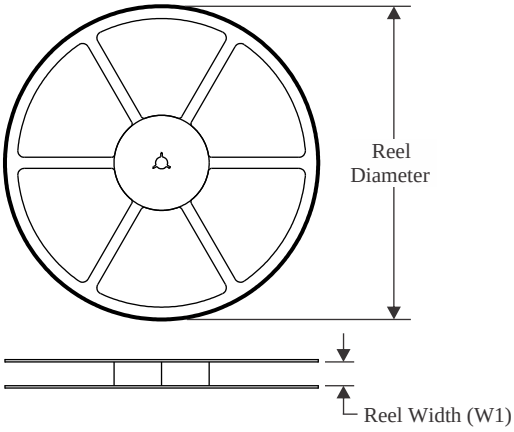
- Automotive : INA253-Q1

NOTE: Qualified Version Definitions:

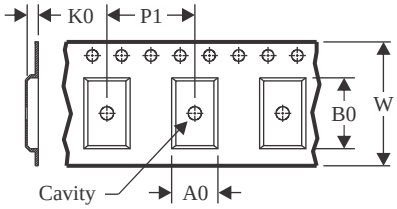
- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

TAPE AND REEL INFORMATION

REEL DIMENSIONS

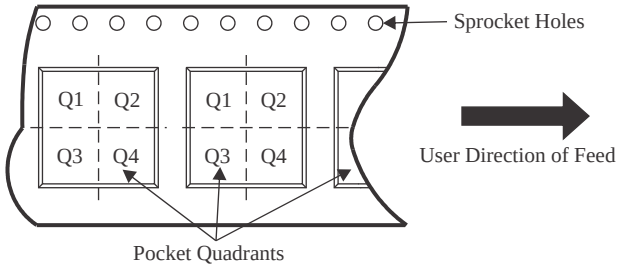


TAPE DIMENSIONS



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

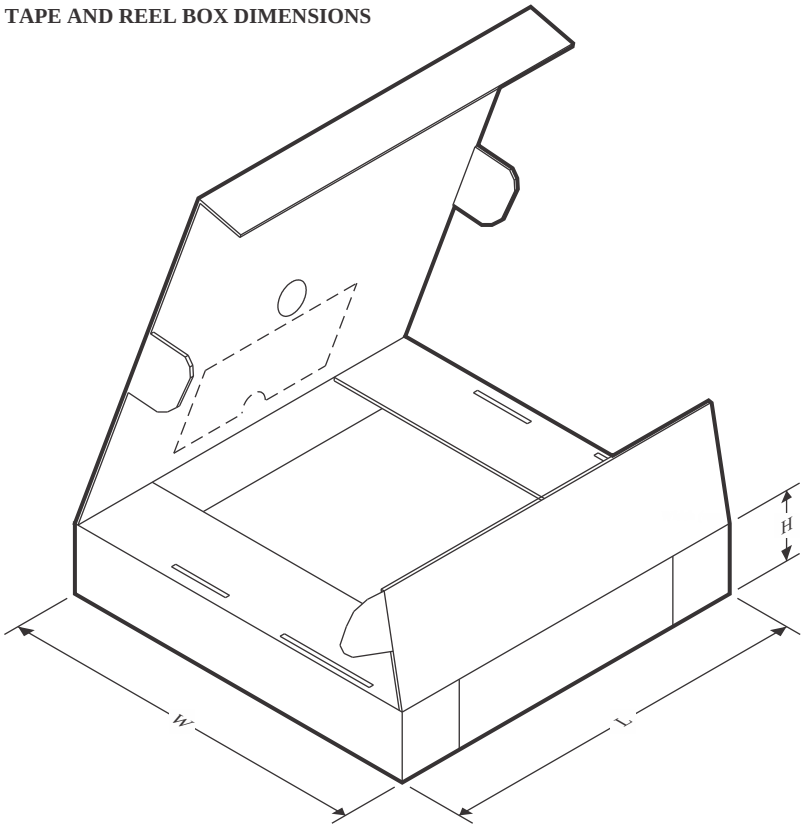
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
INA253A1IPWR	TSSOP	PW	20	2000	330.0	16.4	6.95	7.0	1.4	8.0	16.0	Q1
INA253A2IPWR	TSSOP	PW	20	2000	330.0	16.4	6.95	7.0	1.4	8.0	16.0	Q1
INA253A3IPWR	TSSOP	PW	20	2000	330.0	16.4	6.95	7.0	1.4	8.0	16.0	Q1
INA253A3IPWRG4	TSSOP	PW	20	2000	330.0	16.4	6.95	7.0	1.4	8.0	16.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

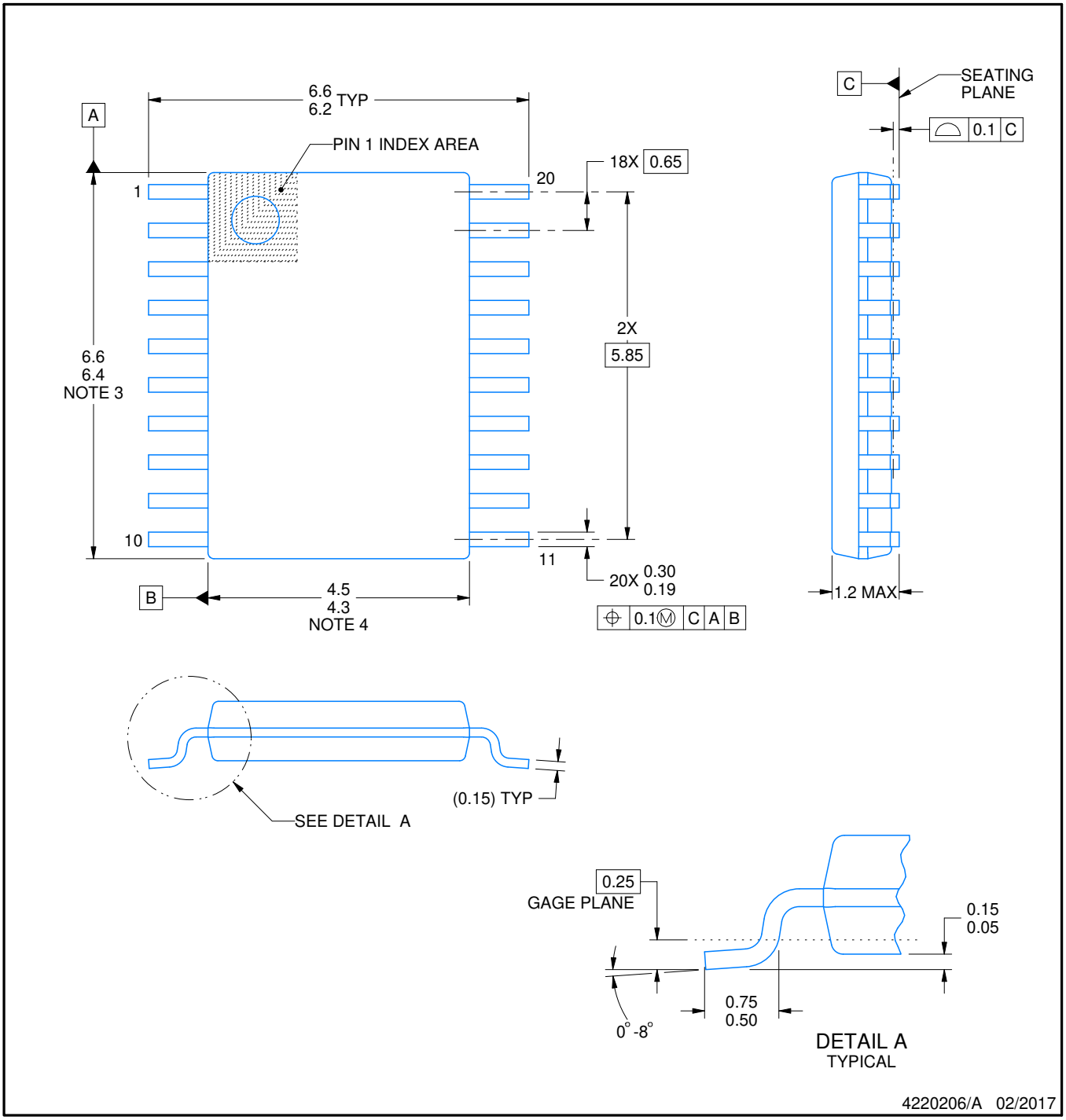
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA253A1IPWR	TSSOP	PW	20	2000	353.0	353.0	32.0
INA253A2IPWR	TSSOP	PW	20	2000	353.0	353.0	32.0
INA253A3IPWR	TSSOP	PW	20	2000	353.0	353.0	32.0
INA253A3IPWRG4	TSSOP	PW	20	2000	353.0	353.0	32.0

PACKAGE OUTLINE

PW0020A

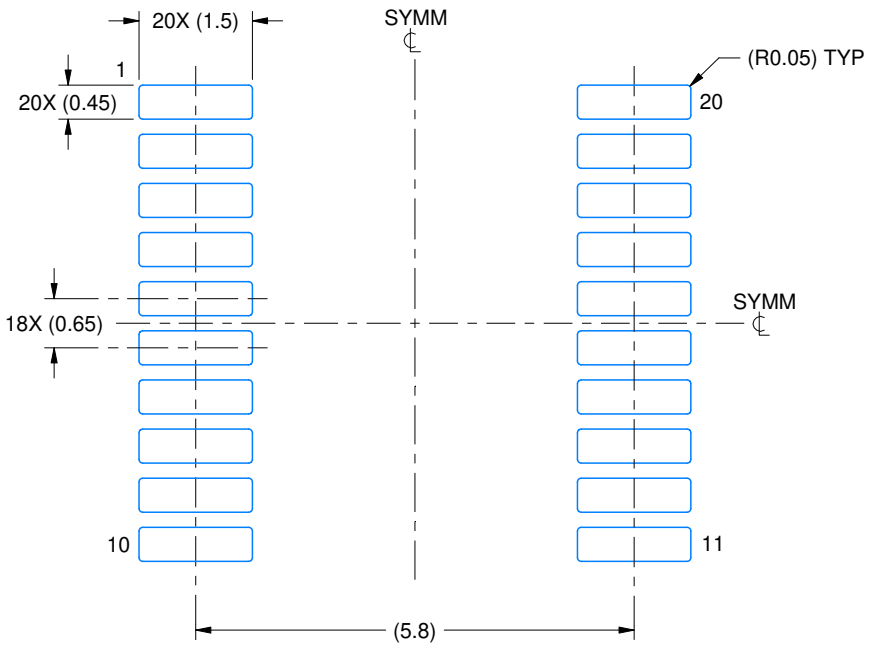
TSSOP - 1.2 mm max height

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

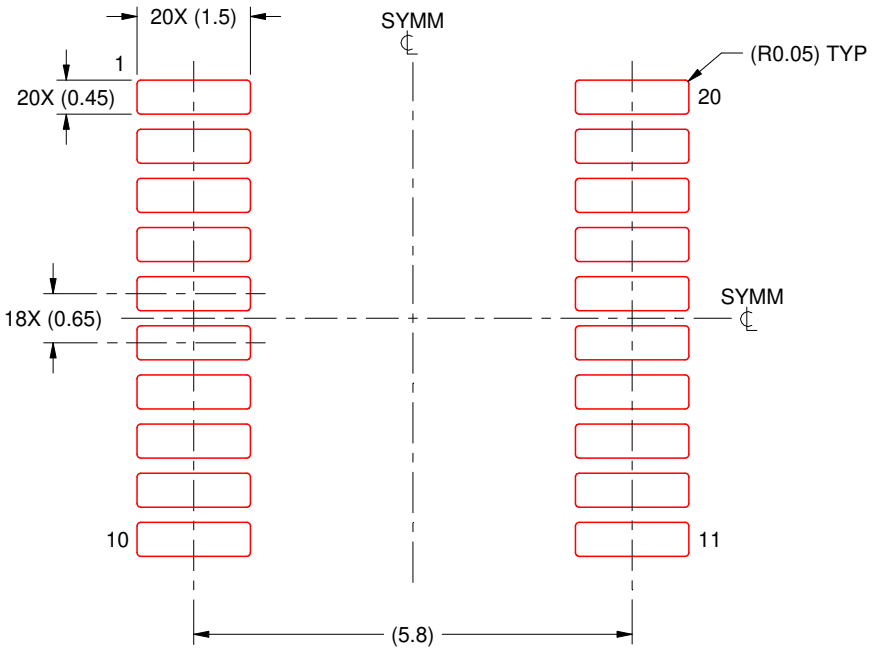


SOLDER MASK DETAILS

4220206/A 02/2017

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

4220206/A 02/2017

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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