INA293-Q1, AEC-Q100, –4 V to 110 V, 1.3-MHz, Ultra-Precise Current Sense Amplifier

1 Features

- AEC-Q100 qualified for automotive applications
  - Temperature grade 1: –40 °C to +125 °C, T_A
- Functional Safety-Capable
  - Documentation available to aid functional safety system design
- Wide common-mode voltage:
  - Operational voltage: −4 V to +110 V
  - Survival voltage: −20 V to +120 V
- Excellent CMRR:
  - 160-dB DC-CMRR
  - 85-dB AC-CMRR at 50 kHz
- Accuracy:
  - Gain:
    - Gain error: ±0.15% (maximum)
    - Gain drift: ±10 ppm/ °C (maximum)
  - Offset:
    - Offset voltage: ±15 µV (typical)
    - Offset drift: ±0.05 µV/ °C (typical)
- Available gains:
  - INA293A1-Q1, INA293B1-Q1 : 20 V/V
  - INA293A2-Q1, INA293B2-Q1 : 50 V/V
  - INA293A3-Q1, INA293B3-Q1 : 100 V/V
  - INA293A4-Q1, INA293B4-Q1 : 200 V/V
  - INA293A5-Q1, INA293B5-Q1 : 500 V/V
- High bandwidth: 1.3 MHz
- Slew rate: 2.5 V/µs
- Quiescent current: 1.5 mA

2 Applications

- 48-V automotive
- Solenoid control
- 48-V DC/DC converter
- Valve control

3 Description

The INA293-Q1 is a ultra-precise current sense amplifier that can measure voltage drops across shunt resistors over a wide common-mode range from –4 V to 110 V. The negative common-mode voltage allows the device to operate below ground, thus accommodating precise measurement of recirculating currents in half-bridge applications. The combination of a low offset voltage, small gain error and high DC CMRR enables highly accurate current measurement. The INA293-Q1 is not only designed for DC current measurement, but also for high-speed applications (ex. Fast over-current protection) with a high bandwidth of 1.3 MHz and an 85-dB AC CMRR (at 50 kHz).

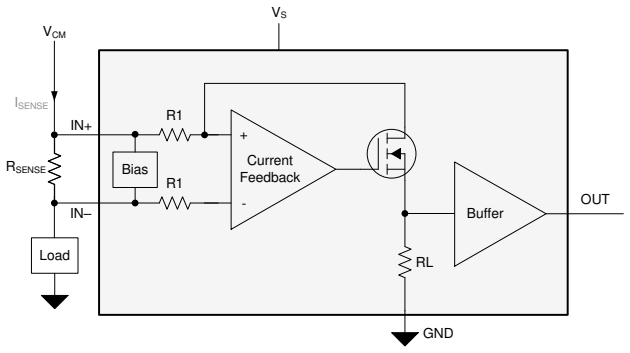
The INA293-Q1 operates from a single 2.7-V to 20-V supply, drawing 1.5 mA of supply current. The INA293-Q1 is available with five gain options: 20 V/V, 50 V/V, 100 V/V, 200 V/V, and 500 V/V. These gain options address wide dynamic range current-sensing applications.

The INA293-Q1 is specified over an operating temperature range of −40 °C to +125 °C and is offered in a space-saving SOT-23 package with two pin-out variants.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA293-Q1	SOT-23 (5)	2.90 mm × 1.60 mm

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



Functional Block Diagram

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 Revision B (June 2021) to Revision C (August 2022) **Page**

- Changed Equation 5 17
- Moved the *Power Supply Recommendations* and *Layout* sections to the *Application and Implementation* section....19

Changes from Revision A (September 2020) to Revision B (June 2021) **Page**

- Changed data sheet title from: INA293-Q1, AEC-Q100, –4-V to 110-V, 1-MHz, High-Precision Current Sense Amplifier to: INA293-Q1, AEC-Q100, –4-V to 110-V, 1.3-MHz, High-Precision Current Sense Amplifier....1

Changes from Revision * (May 2019) to Revision A (September 2020) **Page**

- Changed data sheet title....1
- Changed data sheet status from Advanced Information to Production Data....1
- Updated the numbering format for tables, figures, and cross-references throughout the document....1
- Added functional safety-capable bullets to the *Features* section....1
- Changed 'high-precise' to 'ultra-precise' in *Description* section....1

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5 Pin Configuration and Functions

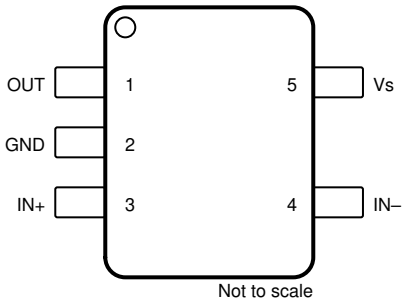


Figure 5-1. INA293A-Q1: DBV Package 5-Pin SOT-23 Top View

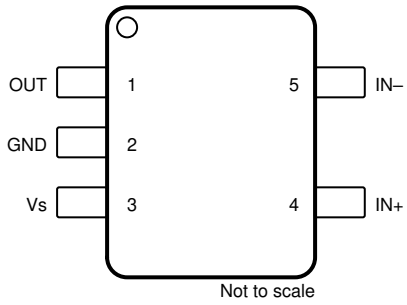


Figure 5-2. INA293B-Q1: DBV Package 5-Pin SOT-23 Top View

Table 5-1. Pin Functions

PIN			TYPE	DESCRIPTION
NAME	INA293A-Q1	INA293B-Q1		
GND	2	2	Ground	Ground
OUT	1	1	Output	Output voltage
Vs	5	3	Power	Power supply
IN+	3	4	Input	Shunt resistor positive sense input
IN–	4	5	Input	Shunt resistor negative sense input

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6 Specifications

6.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Supply Voltage (V_S)		–0.3	22	V
Analog Inputs, V_{IN+}, $V_{IN–}$ (2)	Differential (V_{IN+}) – ($V_{IN–}$), INA293A5-Q1, INA293B5-Q1	–6	6	V
	Differential (V_{IN+}) – ($V_{IN–}$), All others	–12	12	
	Common - mode	–20	120	
Output		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) Stresses beyond those listed under *Absolute Maximum Rating* 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 Condition*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) VIN+ and VIN– are the voltages at the IN+ and IN– pins, respectively.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per AEC Q100-002, all pins(1) HBM ESD Classification Level 2	±2000	V
		Charged device model (CDM), per AEC Q100-011, all pins CDM ESD Classification Level C6	±1000	

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

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6.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
V_{CM}	Common-mode input range	–4	48	110	V
V_S	Operating supply range	2.7	5	20	V
V_{SENSE}	Differential sense input range	0		V_S / G	V
T_A	Ambient temperature	–40		125	°C

6.4 Thermal Information

THERMAL METRIC(1)		INA293-Q1 DBV (SOT-23) 5 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	184.7	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	105.6	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	47.2	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	21.5	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	46.9	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	°C/W

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

6.5 Electrical Characteristics

at T_A = 25 °C, V_S = 5 V, V_{SENSE} = V_{IN+} - V_{IN-} = 0.5 V / Gain, V_{CM} = V_{IN-} = 48 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range(1)	T_A = -40°C to +125°C	–4		110	V
CMRR	Common-mode rejection ratio, input referred	-4 V ≤ V_{CM} ≤ 110 V, T_A = -40°C to +125°C	140	160		dB
		f = 50 kHz		85		dB
V_{os}	Offset voltage, input referred	INA293x1-Q1		±30	±150	µV
		INA293x2-Q1		±15	±80	
		INA293x3-Q1		±10	±50	
		INA293x4-Q1		±5	±30	
		INA293x5-Q1		±2	±20	
dV_{os}/dT	Offset voltage drift	T_A = -40°C to +125°C, INA293x1-Q1, INA293x2-Q1, INA293x3-Q1		±0.05	±0.5	µV/°C
		T_A = -40°C to +125°C, INA293x4-Q1, INA293x5-Q1		±0.025	±0.25	
PSRR	Power supply rejection ratio, input referred	INA293x1-Q1, 2.7 V ≤ V_S ≤ 20 V, T_A = -40°C to +125°C		±1	±8	µV/V
		INA293x2-Q1, INA293x3-Q1, 2.7 V ≤ V_S ≤ 20 V, T_A = -40°C to +125°C		±0.3	±3	
		INA293x4-Q1, INA293x5-Q1, 2.7 V ≤ V_S ≤ 20 V, T_A = -40°C to +125°C		±0.1	±1	
I_B	Input bias current	I_{B+}, V_{SENSE} = 0 V	10	20	30	uA
		I_{B-}, V_{SENSE} = 0 V	10	20	30	uA

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6.5 Electrical Characteristics (continued)

at T_A = 25 °C, V_S = 5 V, V_{SENSE} = V_{IN+} - V_{IN-} = 0.5 V / Gain, V_{CM} = V_{IN-} = 48 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
G	Gain	INA293x1-Q1		20		V/V
		INA293x2-Q1		50		V/V
		INA293x3-Q1		100		V/V
		INA293x4-Q1		200		V/V
		INA293x5-Q1		500		V/V
G_{ERR}	Gain error	GND + 50 mV ≤ V_{OUT} ≤ V_S – 200 mV		±0.02	±0.15	%
		T_A = -40°C to +125°C		±1	±10	ppm/°C
NL_{ERR}	Nonlinearity error			0.01		%
	Maximum capacitive load	No sustained oscillations, no isolation resistor		500		pF
VOLTAGE OUTPUT						
	Swing to Vs (Power supply rail)	R_{LOAD} = 10 kΩ, T_A = -40°C to +125°C		Vs – 0.07	Vs – 0.15	V
	Swing to ground	R_{LOAD} = 10 kΩ, V_{SENSE} = 0 V, T_A = -40°C to +125°C		0.005	0.02	V
FREQUENCY RESPONSE						
BW	Bandwidth	INA293x1-Q1, C_{LOAD} = 5 pF, V_{SENSE} = 200 mV		1300		kHz
		INA293x2-Q1, C_{LOAD} = 5 pF, V_{SENSE} = 80 mV		1300		
		INA293x3-Q1, C_{LOAD} = 5 pF, V_{SENSE} = 40 mV		1000		
		INA293x4-Q1, C_{LOAD} = 5 pF, V_{SENSE} = 20 mV		900		
		INA293x5-Q1, C_{LOAD} = 5 pF, V_{SENSE} = 8 mV		900		
SR	Slew rate	Rising edge		2.5		V/µs
	Settling time	V_{OUT} = 4 V ± 0.1 V step, Output settles to 0.5%		10		µs
		V_{OUT} = 4 V ± 0.1 V step, Output settles to 1%		5		
		V_{OUT} = 4 V ± 0.1 V step, Output settles to 5%		1		
NOISE						
Ven	Voltage noise density			50		nV/√Hz
POWER SUPPLY						
Vs	Supply voltage	T_A = –40°C to +125°C	2.7		20	V
I_Q	Quiescent current			1.5	2	mA
		T_A = -40°C to +125°C			2.25	mA

(1) Common-mode voltage at both V_{IN+} and V_{IN-} must not exceed the specified common-mode input range.

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6.6 Typical Characteristics

All specifications at T_A = 25 °C, V_S = 5 V, V_{SENSE} = V_{IN+} – V_{IN-} = 0.5 V / Gain, V_{CM} = $V_{IN–}$ = 48 V, unless otherwise noted.

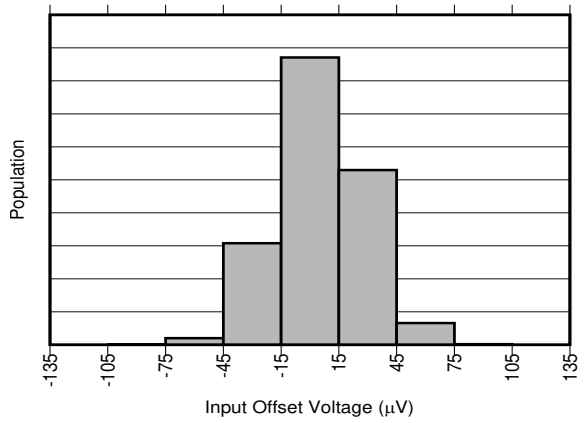


Figure 6-1. INA293x1 Input Offset Production Distribution

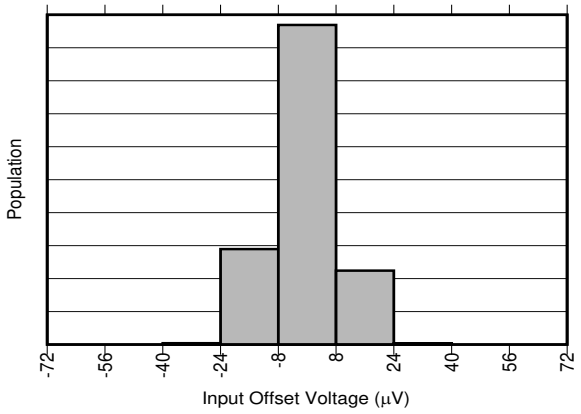


Figure 6-2. INA293x2 Input Offset Production Distribution

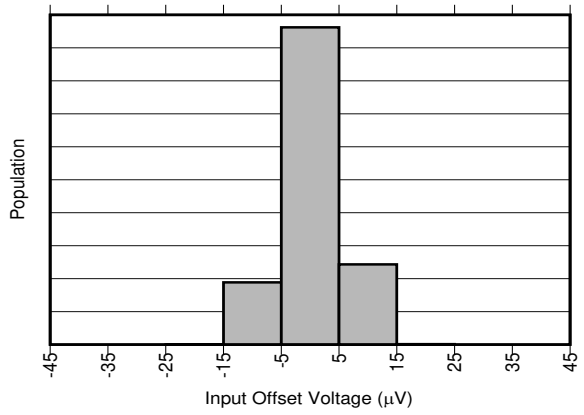


Figure 6-3. INA293x3 Input Offset Production Distribution

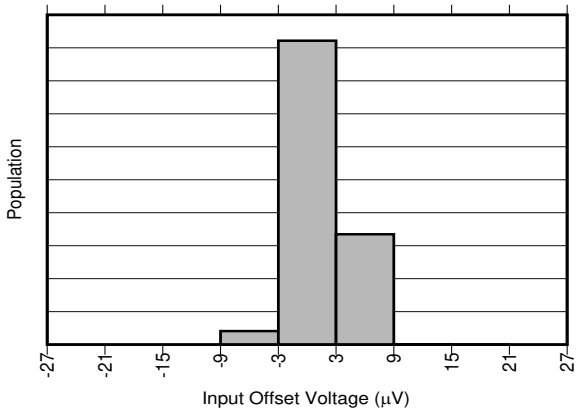


Figure 6-4. INA293x4 Input Offset Production Distribution

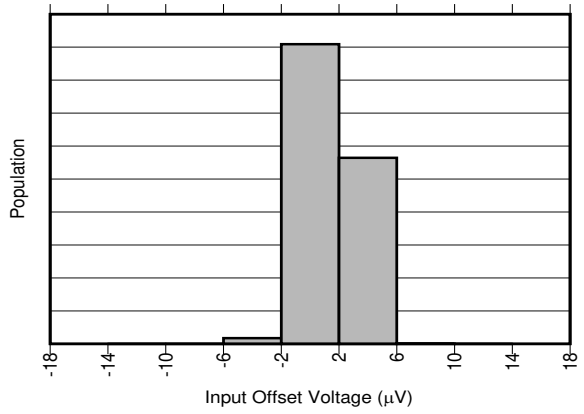


Figure 6-5. INA293x5 Input Offset Production Distribution

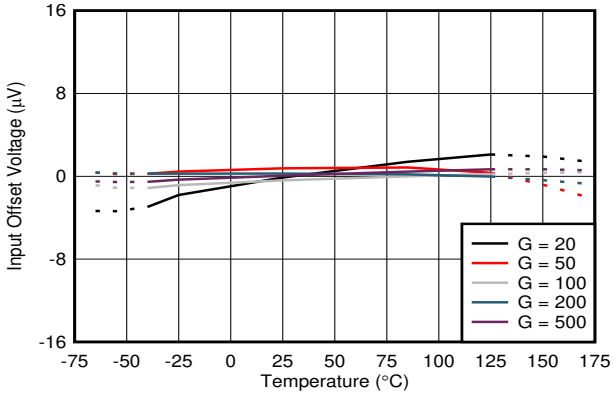


Figure 6-6. Input Offset Voltage vs Temperature

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6.6 Typical Characteristics (continued)

All specifications at T_A = 25 °C, V_S = 5 V, V_{SENSE} = V_{IN+} – V_{IN-} = 0.5 V / Gain, V_{CM} = $V_{IN–}$ = 48 V, unless otherwise noted.

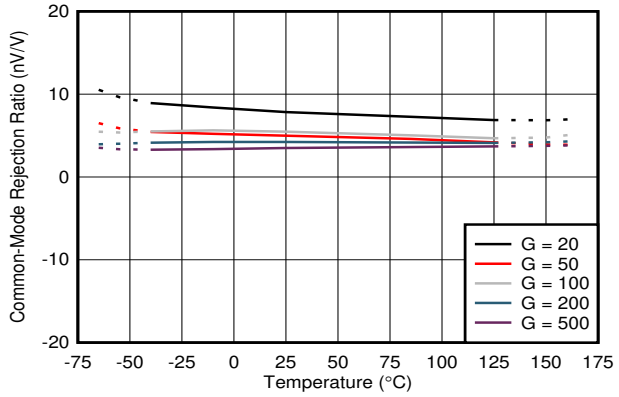


Figure 6-7. Common-Mode Rejection Ratio vs Temperature

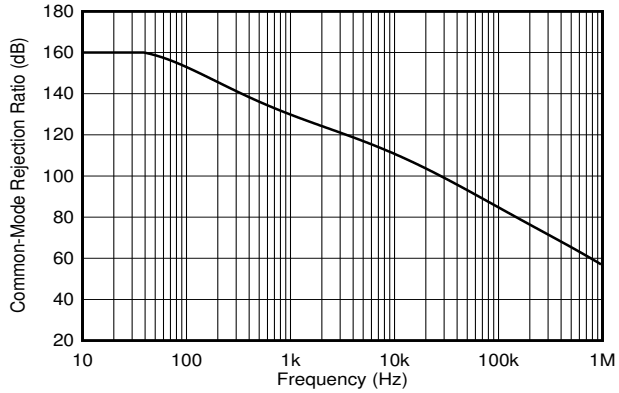


Figure 6-8. Common-Mode Rejection Ratio vs Frequency

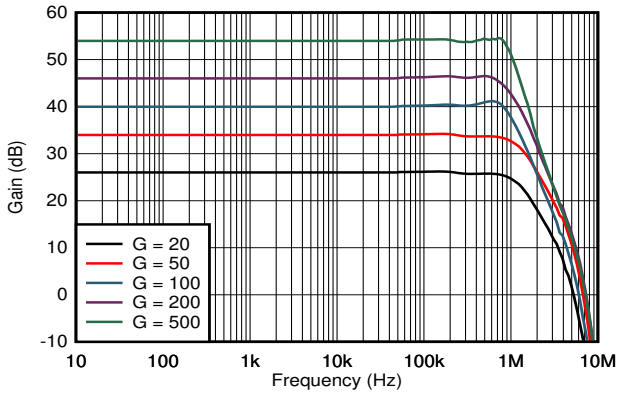


Figure 6-9. Gain vs Frequency

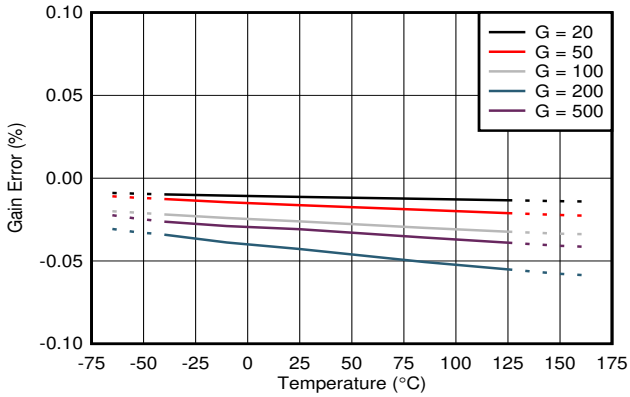


Figure 6-10. Gain Error vs Temperature

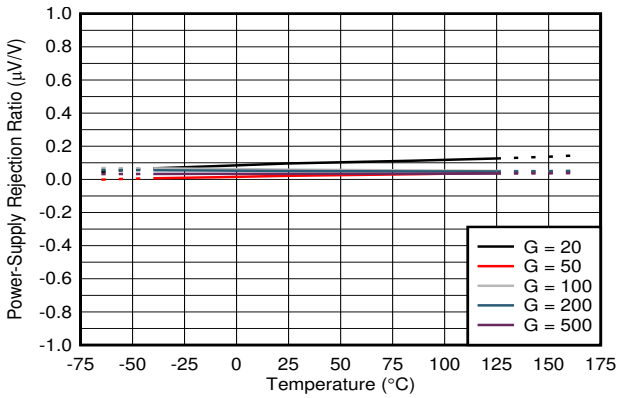


Figure 6-11. Power-Supply Rejection Ratio vs Temperature

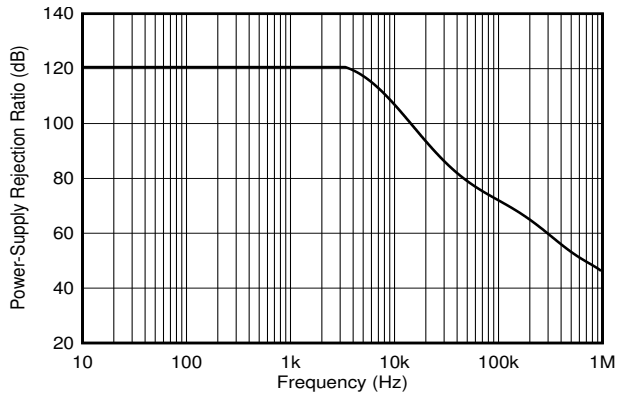
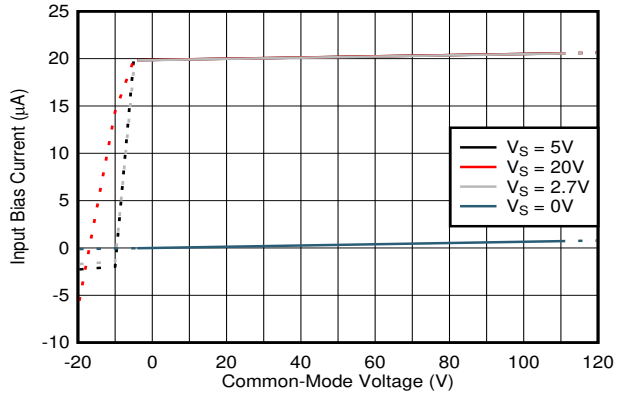


Figure 6-12. Power-Supply Rejection Ratio vs Frequency

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6.6 Typical Characteristics (continued)

All specifications at T_A = 25 °C, V_S = 5 V, V_{SENSE} = V_{IN+} – V_{IN-} = 0.5 V / Gain, V_{CM} = $V_{IN–}$ = 48 V, unless otherwise noted.



V_{SENSE} = 0 V

Figure 6-13. Input Bias Current vs Common-Mode Voltage

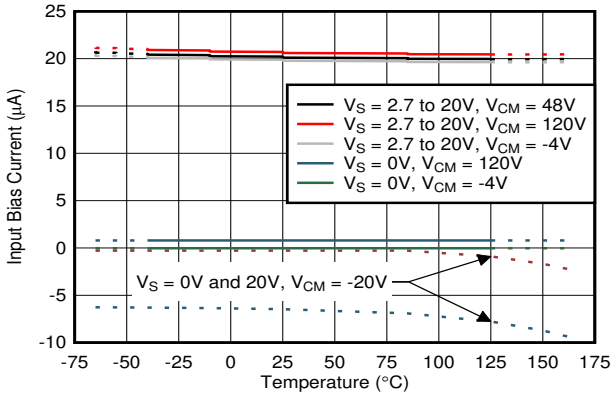


Figure 6-14. Input Bias Current vs Temperature

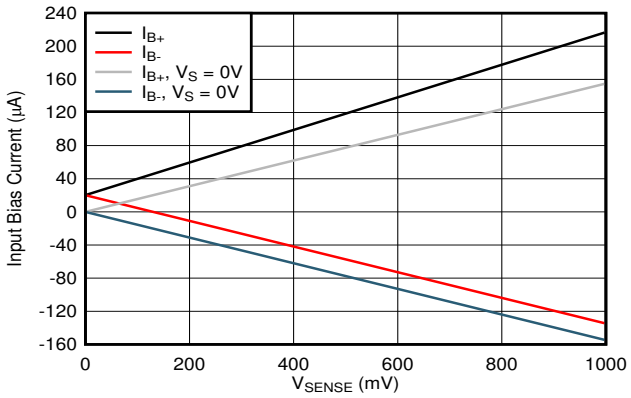


Figure 6-15. INA293x1Q Input Bias Current vs V_{SENSE}

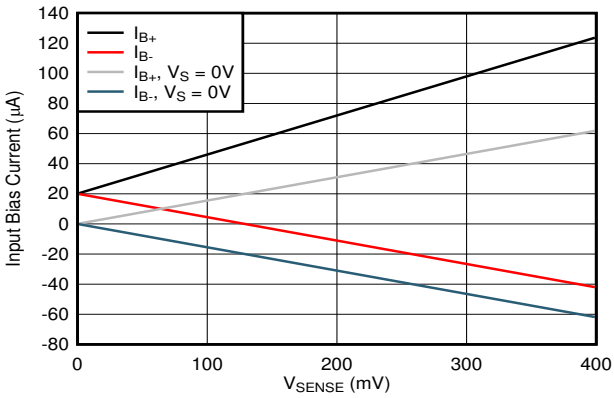


Figure 6-16. INA293x2Q, INA293x3Q Input Bias Current vs V_{SENSE}

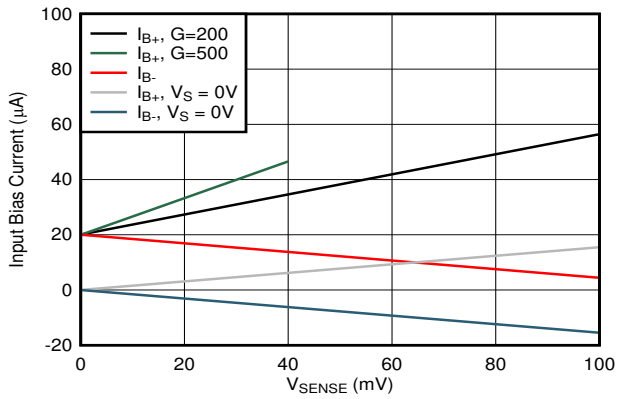
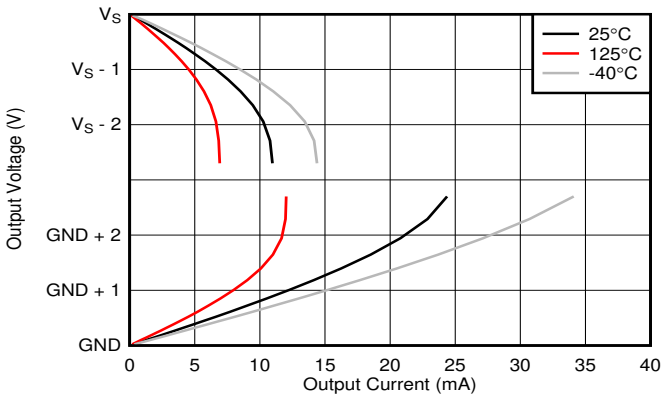


Figure 6-17. INA293x4Q, INA293x5Q Input Bias Current vs V_{SENSE}

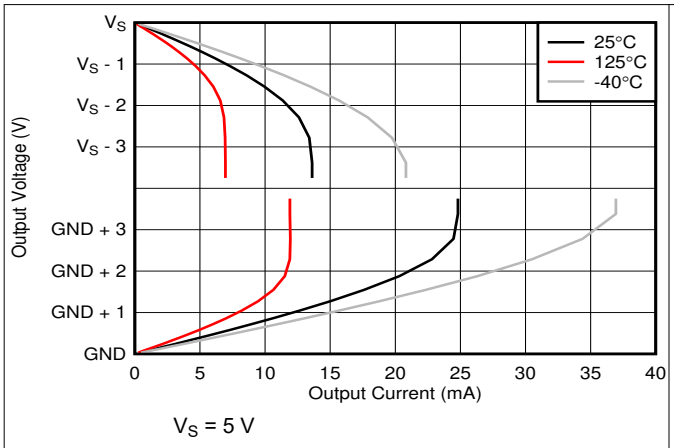


V_S = 2.7 V

Figure 6-18. Output Voltage vs Output Current

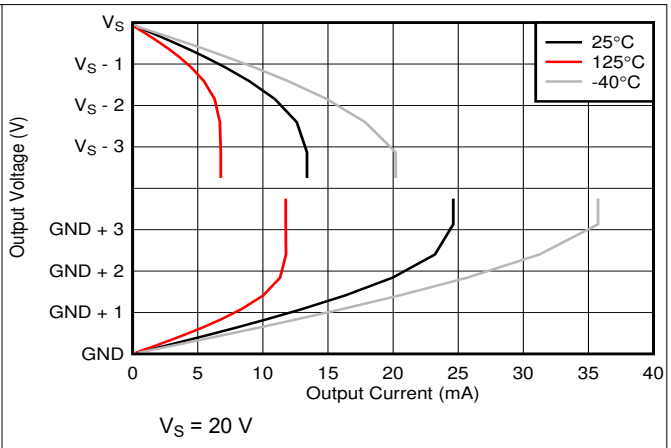
6.6 Typical Characteristics (continued)

All specifications at T_A = 25 °C, V_S = 5 V, V_{SENSE} = V_{IN+} – V_{IN-} = 0.5 V / Gain, V_{CM} = $V_{IN–}$ = 48 V, unless otherwise noted.



V_S = 5 V

Figure 6-19. Output Voltage vs Output Current



V_S = 20 V

Figure 6-20. Output Voltage vs Output Current

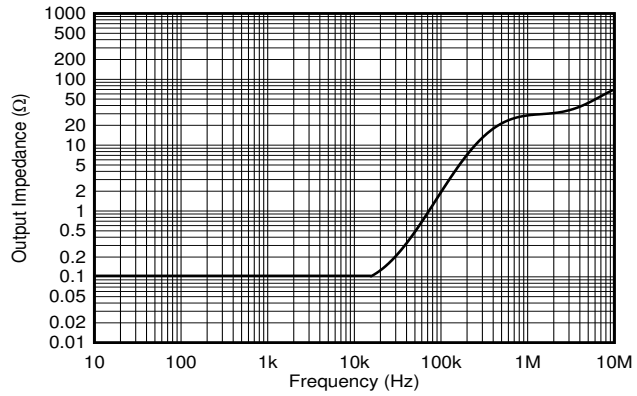


Figure 6-21. Output Impedance vs Frequency

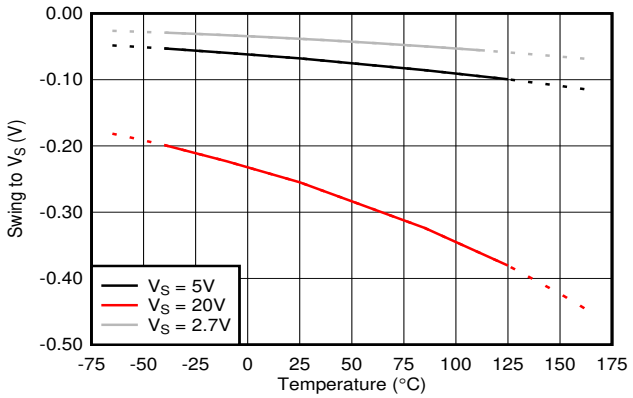


Figure 6-22. Swing to Supply vs Temperature

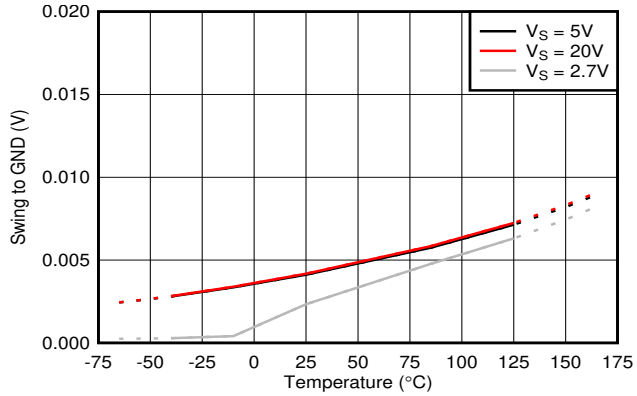


Figure 6-23. Swing to GND vs Temperature

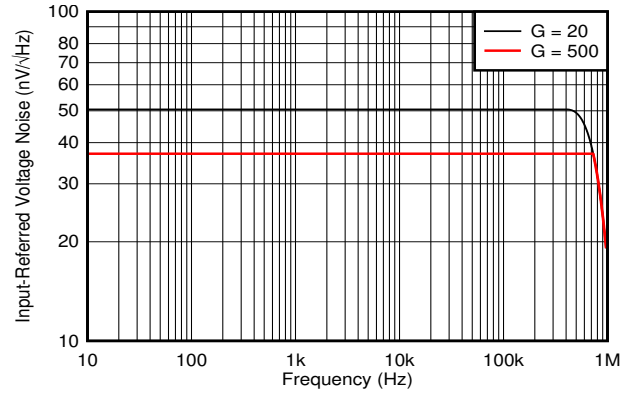


Figure 6-24. Input Referred Noise vs Frequency

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6.6 Typical Characteristics (continued)

All specifications at T_A = 25 °C, V_S = 5 V, V_{SENSE} = V_{IN+} – V_{IN-} = 0.5 V / Gain, V_{CM} = $V_{IN–}$ = 48 V, unless otherwise noted.

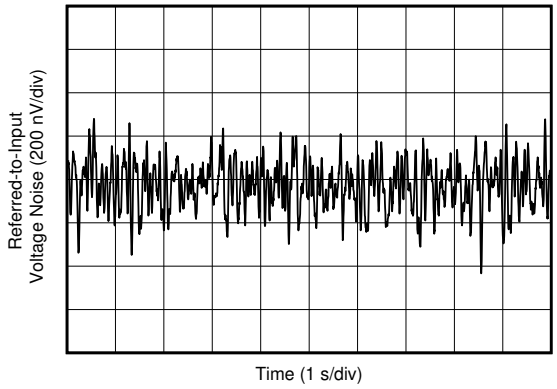


Figure 6-25. Input Referred Noise

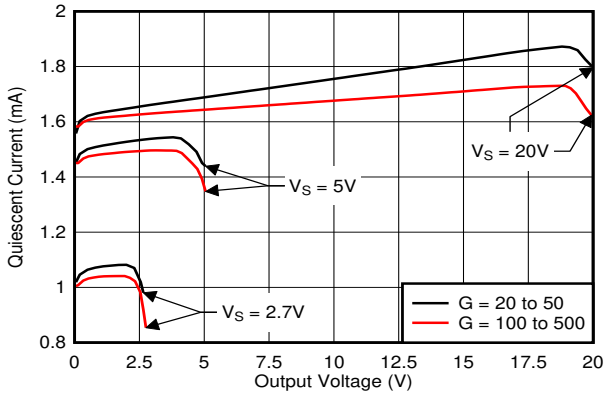


Figure 6-26. Quiescent Current vs Output Voltage

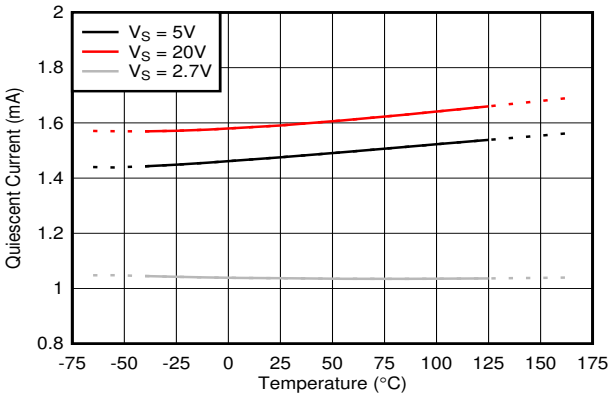


Figure 6-27. Quiescent Current vs Temperature

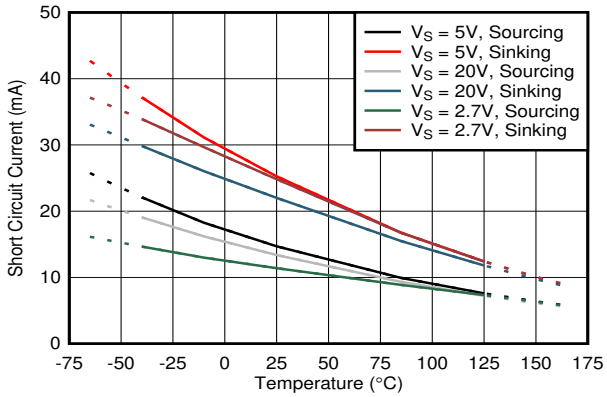


Figure 6-28. Short-Circuit Current vs Temperature

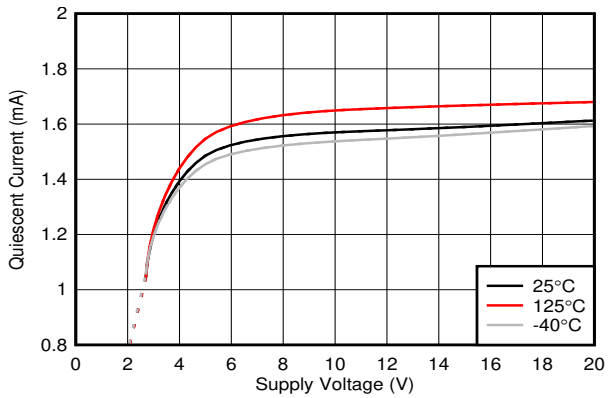


Figure 6-29. Quiescent Current vs Supply Voltage

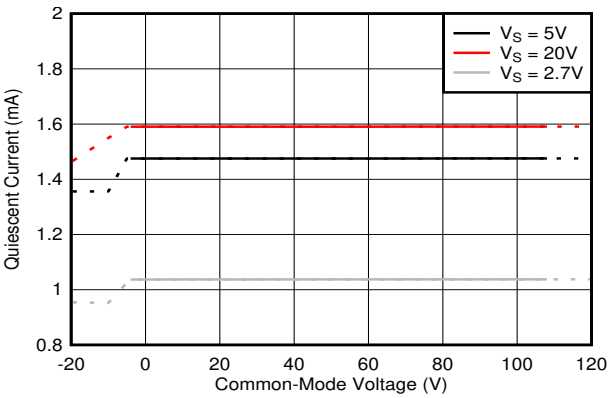


Figure 6-30. Quiescent Current vs Common-Mode Voltage

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6.6 Typical Characteristics (continued)

All specifications at T_A = 25 °C, V_S = 5 V, V_{SENSE} = V_{IN+} – V_{IN-} = 0.5 V / Gain, V_{CM} = $V_{IN–}$ = 48 V, unless otherwise noted.

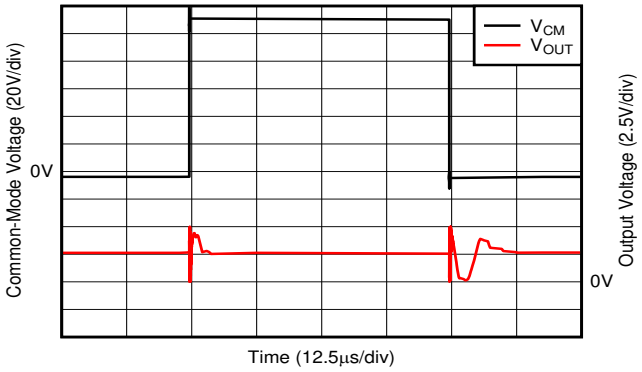


Figure 6-31. Common-Mode Voltage Fast Transient Pulse

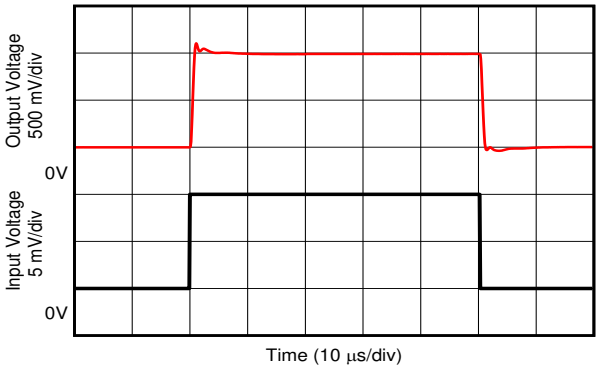


Figure 6-32. INA293x3 Step Response

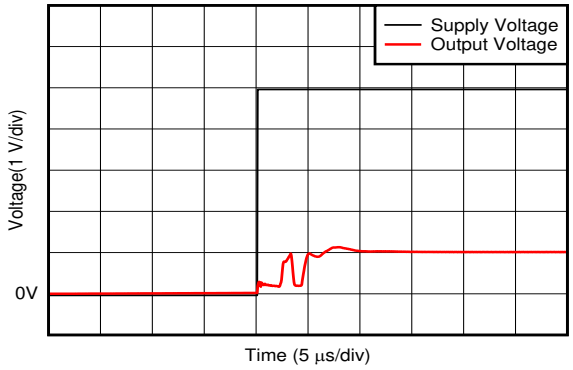


Figure 6-33. Start-Up Response

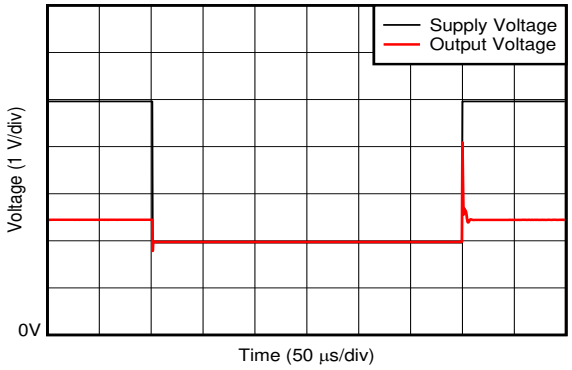


Figure 6-34. Supply Transient Response

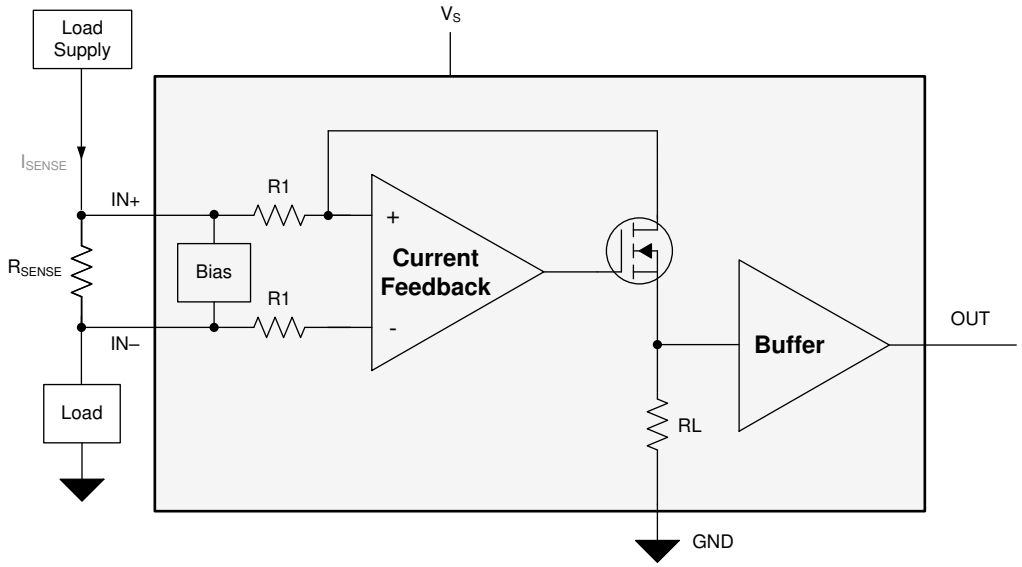
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7 Detailed Description

7.1 Overview

The INA293-Q1 is a high- or low-side current-sense amplifier that offers a wide common-mode range, precision zero-drift topology, excellent common-mode rejection ratio (CMRR), high bandwidth and fast slew rate. Different gain versions are available to optimize the output dynamic range based on the application. The INA293-Q1 is designed using a transconductance architecture with a current-feedback amplifier that enables low bias currents of 20 µA with a common-mode voltage of 110 V.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Amplifier Input Common-Mode Signal

The INA293-Q1 supports large input common-mode voltages from –4 V to +110 V. Because of the internal topology, the common-mode range is not restricted by the power-supply voltage (V_S). This allows for the INA293-Q1 to be used for both low and high side current-sensing applications.

7.3.1.1 Input-Signal Bandwidth

The INA293-Q1 –3-dB bandwidth is gain dependent, with several gain options of 20 V/V, 50 V/V, 100 V/V, 200 V/V, and 500 V/V. The unique multistage design enables the amplifier to achieve high bandwidth at all gains. This high bandwidth provides the throughput and fast response that is required for the rapid detection and processing of overcurrent events.

The bandwidth of the device also depends on the applied V_{SENSE} voltage. Figure 7-1 shows the bandwidth performance profile of the device over frequency as output voltage increases for each gain variation. As shown in Figure 7-1, the device exhibits the highest bandwidth with higher V_{SENSE} voltages, and the bandwidth is higher with lower device gain options. Individual requirements determine the acceptable limits of error for high frequency current-sensing applications. Testing and evaluation in the end application or circuit is required to determine the acceptance criteria, and to validate that the performance levels meet the system specifications.

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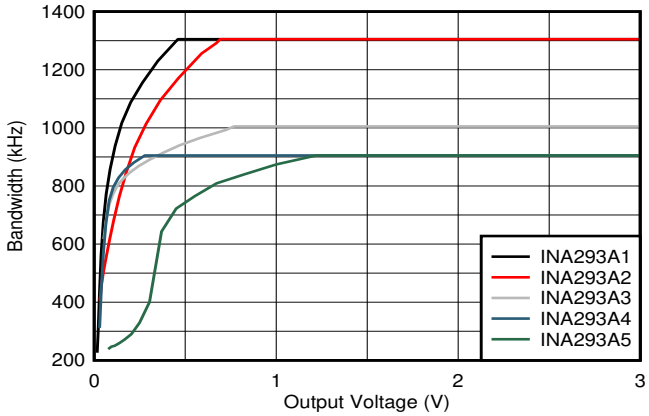


Figure 7-1. Bandwidth vs Output Voltage

7.3.1.2 Low Input Bias Current

The INA293-Q1 inputs draw a 20-µA (typical) bias current at a common-mode voltage as high as 110 V, which enables precision current sensing on applications that require lower current leakage.

7.3.1.3 Low V_{SENSE} Operation

The INA293-Q1 operates with high performance across the entire valid V_{SENSE} range. The zero-drift input architecture of the INA293-Q1 provides the low offset voltage and low offset drift needed to measure low V_{SENSE} levels accurately across the wide operating temperature of –40 °C to +125 °C. Low V_{SENSE} operation is particularly beneficial when using low ohmic shunts for low current measurements, as power losses across the shunt are significantly reduced.

7.3.1.4 Wide Fixed Gain Output

The INA293-Q1 gain error is < 0.15% at room temperature, with a maximum drift of 10 ppm/°C over the full temperature range of –40°C to +125°C. The INA293-Q1 is available in multiple gain options of 20 V/V, 50 V/V, 100 V/V, 200 V/V, and 500 V/V, which the system designer should select based on their desired signal-to-noise ratio and other system requirements.

The INA293-Q1 closed-loop gain is set by a precision, low drift internal resistor network. The ratio of these resistors are excellently matched, while the absolute values may vary significantly. Adding additional resistance around the INA293-Q1 to change the effective gain is not recommended, however, because of this variation. The typical values of the gain resistors are described in Table 7-1.

Table 7-1. Fixed Gain Resistor

GAIN	R1	RL
20 (V/V)	25 kΩ	500 kΩ
50 (V/V)	10 kΩ	500 kΩ
100 (V/V)	10 kΩ	1000 kΩ
200 (V/V)	5 kΩ	1000 kΩ
500 (V/V)	2 kΩ	1000 kΩ

7.3.1.5 Wide Supply Range

The INA293-Q1 operates with a wide supply range from 2.7 V to 20 V. The output stage supports a wide output range while INA293-Q1x1 (gain of 20 V/V) at a supply voltage of 20 V allows a maximum acceptable differential input of 1 V. When paired with the small input offset voltage of the INA293-Q1, systems with very wide dynamic range of current measurement can be supported.

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7.4 Device Functional Modes

7.4.1 Unidirectional Operation

The INA293-Q1 measures the differential voltage developed by current flowing through a resistor, commonly referred to as a current-sensing resistor or a current-shunt resistor. The INA293-Q1 operates in unidirectional mode only, meaning it only senses current sourced from a power supply to a system load as shown in Figure 7-2.

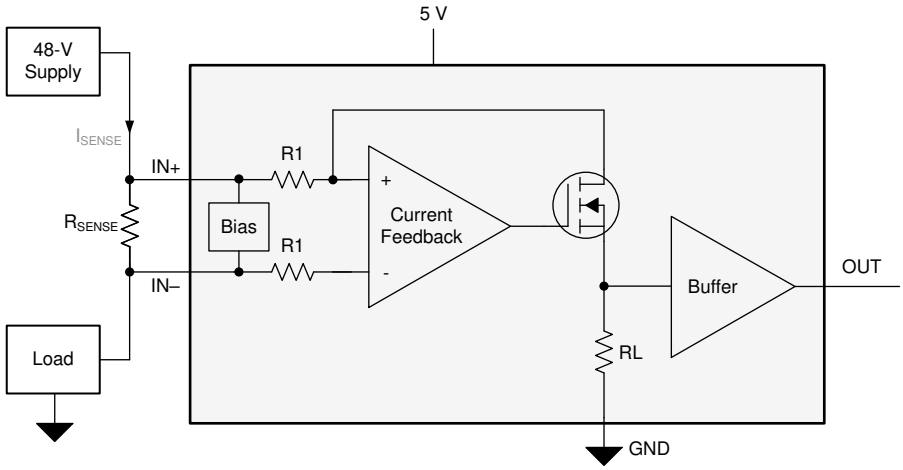


Figure 7-2. Unidirectional Application

The linear range of the output stage is limited to how close the output voltage can approach ground under zero-input conditions. The zero current output voltage of the INA293-Q1 is very small, with a maximum of GND + 20 mV. Make sure to apply a differential input voltage of (20 mV / Gain) or greater to keep the INA293-Q1 output in the linear region of operation.

7.4.2 High Signal Throughput

With a bandwidth of 1.3 MHz at a gain of 20 V/V and a slew rate of 2.5 V/µs, the INA293-Q1 is specifically designed for detecting and protecting applications from fast inrush currents. As shown in Table 7-2, the INA293-Q1 responds in less than 2 µs for a system measuring a 75-A threshold on a 2-mΩ shunt.

Table 7-2. Response Time

PARAMETER		EQUATION	INA293-Q1 AT V_S = 5 V
G	Gain		20 V/V
I_{MAX}	Maximum current		100 A
$I_{Threshold}$	Threshold current		75 A
R_{SENSE}	Current sense resistor value		2 mΩ
V_{OUT_MAX}	Output voltage at maximum current	$V_{OUT_MAX} = I_{MAX} \times R_{SENSE} \times G$	4 V
V_{OUT_THR}	Output voltage at threshold current	$V_{OUT_THR} = I_{THR} \times R_{SENSE} \times G$	3 V
SR	Slew rate		2.5 V/µs
	Output response time	$T_{response} = V_{OUT_THR} / SR$	< 2 µs

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8 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.

8.1 Application Information

The INA293-Q1 amplifies the voltage developed across a current-sensing resistor as current flows through the resistor to the load. The wide input common-mode voltage range and high common-mode rejection of the INA293-Q1 make it usable over a wide range of voltage rails while still maintaining an accurate current measurement.

8.1.1 R_{SENSE} and Device Gain Selection

The accuracy of any current-sense amplifier is maximized by choosing the current-sense resistor to be as large as possible. A large sense resistor maximizes the differential input signal for a given amount of current flow and reduces the error contribution of the offset voltage. However, there are practical limits as to how large the current-sense resistor can be in a given application because of the resistor size and maximum allowable power dissipation. Equation 1 gives the maximum value for the current-sense resistor for a given power dissipation budget:

$$R_{SENSE} < \frac{PD_{MAX}}{I_{MAX}^2} \quad (1)$$

where:

- PD_{MAX} is the maximum allowable power dissipation in R_{SENSE}.
- I_{MAX} is the maximum current that will flow through R_{SENSE}.

An additional limitation on the size of the current-sense resistor and device gain is due to the power-supply voltage, V_S, and device swing-to-rail limitations. To make sure that the current-sense signal is properly passed to the output, both positive and negative output swing limitations must be examined. Equation 2 provides the maximum values of R_{SENSE} and GAIN to keep the device from exceeding the positive swing limitation.

$$I_{MAX} \times R_{SENSE} \times GAIN < V_{SP} \quad (2)$$

where:

- I_{MAX} is the maximum current that will flow through R_{SENSE}.
- GAIN is the gain of the current-sense amplifier.
- V_{SP} is the positive output swing as specified in the data sheet.

To avoid positive output swing limitations when selecting the value of R_{SENSE}, there is always a trade-off between the value of the sense resistor and the gain of the device under consideration. If the sense resistor selected for the maximum power dissipation is too large, then it is possible to select a lower-gain device in order to avoid positive swing limitations.

The negative swing limitation places a limit on how small the sense resistor value can be for a given application. Equation 3 provides the limit on the minimum value of the sense resistor.

$$I_{MIN} \times R_{SENSE} \times GAIN > V_{SN} \quad (3)$$

where:

- I_{MIN} is the minimum current that will flow through R_{SENSE}.

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- GAIN is the gain of the current-sense amplifier.
- V_{SN} is the negative output swing of the device.

Table 8-1 shows an example of the different results obtained from using five different gain versions of the INA293-Q1. From the table data, the highest gain device allows a smaller current-shunt resistor and decreased power dissipation in the element.

Table 8-1. R_{SENSE} Selection and Power Dissipation(1)

PARAMETER		EQUATION	RESULTS AT V_S = 5 V				
			A1, B1 DEVICES	A2, B2 DEVICES	A3, B3 DEVICES	A4, B4 DEVICES	A5, B5 DEVICES
G	Gain		20 V/V	50 V/V	100 V/V	200 V/V	500 V/V
V_{DIFF}	Ideal differential input voltage	$V_{DIFF} = V_{OUT} / G$	250 mV	100 mV	50 mV	25 mV	10 mV
R_{SENSE}	Current sense resistor value	$R_{SENSE} = V_{DIFF} / I_{MAX}$	25 mΩ	10 mΩ	5 mΩ	2.5 mΩ	1 mΩ
P_{SENSE}	Current-sense resistor power dissipation	$R_{SENSE} \times I_{MAX}2$	2.5 W	1 W	0.5W	0.25 W	0.1 W

(1) Design example with 10-A full-scale current with maximum output voltage set to 5 V.

8.1.2 Input Filtering

Note

Input filters are not required for accurate measurements using the INA293-Q1, and use of filters in this location is not recommended. If filter components are used on the input of the amplifier, follow the guidelines in this section to minimize the effects on performance.

Based strictly on user design requirements, external filtering of the current signal may be desired. The initial location that can be considered for the filter is at the output of the current sense 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 sense amplifier input pins. This location satisfies the filtering requirement also, however the components must be carefully selected to minimally impact device performance. Figure 8-1 shows a filter placed at the input pins.

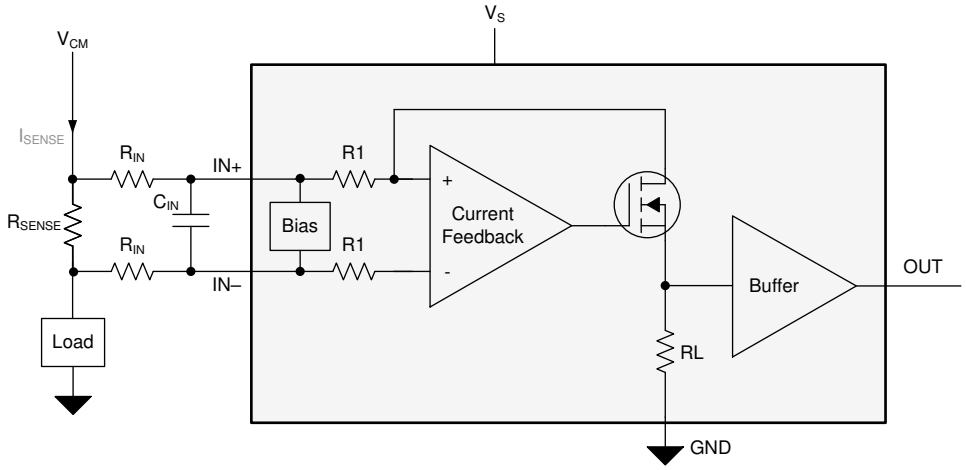


Figure 8-1. Filter at Input Pins

External series resistance provides a source of additional measurement error, so keep the value of these series resistors to 10 Ω or less to reduce loss of accuracy. The internal bias network shown in Figure 8-1 creates a mismatch in input bias currents (see Figure 6-15, Figure 6-16 and Figure 6-17) when a differential voltage is applied between the input pins. If additional external series filter resistors are added to the circuit, a mismatch is created in the voltage drop across the filter resistors. This voltage is a differential error voltage in the shunt resistor voltage. In addition to the absolute resistor value, mismatch resulting from resistor tolerance can significantly impact the error because this value is calculated based on the actual measured resistance.

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The measurement error expected from the additional external filter resistors can be calculated using Equation 4, where the gain error factor is calculated using Equation 5.

$$\text{Gain Error (\%)} = 100 - (100 \times \text{Gain Error Factor}) \quad (4)$$

The gain error factor, shown in Equation 4, can be calculated to determine the gain error introduced by the additional external series resistance. Equation 4 calculates the deviation of the shunt voltage, resulting from the attenuation and imbalance created by the added external filter resistance. Table 8-2 provides the gain error factor and gain error for several resistor values.

$$\text{Gain Error Factor} = \frac{R_B \times R1}{(R_B \times R1) + (R_B \times R_{IN}) + (2 \times R_{IN} \times R1)} \quad (5)$$

Where:

- R_{IN} is the external filter resistance value.
- R1 is the INA293-Q1 input resistance value specified in Table 7-1.
- R_B in the internal bias resistance, which is 6600 Ω ± 20%.

Table 8-2. Example Gain Error Factor and Gain Error for 10-Ω External Filter Input Resistors

DEVICE (GAIN)	GAIN ERROR FACTOR	GAIN ERROR (%)
INA293-Q1x1 (20)	0.997108386	-0.289161432
INA293-Q1x2 (50)	0.996512207	-0.348779273
INA293-Q1x3 (100)	0.996512207	-0.348779273
INA293-Q1x4 (200)	0.995520159	-0.447984072
INA293-Q1x5 (500)	0.992555831	-0.744416873

8.2 Typical Application

The INA293-Q1 is a unidirectional, current-sense amplifier capable of measuring currents through a resistive shunt with shunt common-mode voltages from –4 V to +110 V.

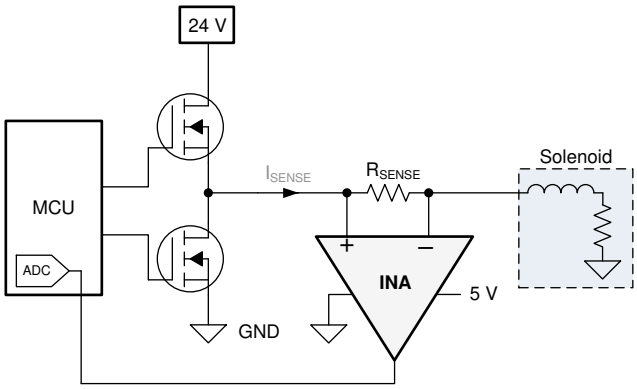


Figure 8-2. Current Sensing in a Solenoid Application

8.2.1 Design Requirements

In this example application, the common-mode voltage ranges from 0 V to 24 V. The maximum sense current is 1.5 A, and a 5-V supply is available for the INA293-Q1. Following the design guidelines from the *R_{SENSE} and Device Gain Selection* section, a R_{SENSE} of 50 mΩ and a gain of 50 V/V are selected to provide good output dynamic range. Table 8-3 lists the design setup for this application.

Table 8-3. Design Parameters

DESIGN PARAMETERS	EXAMPLE VALUE
Power supply voltage	5 V

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Table 8-3. Design Parameters (continued)

DESIGN PARAMETERS	EXAMPLE VALUE
Common-mode voltage range	0 V to 24 V
Maximum sense current	1.5 A
R_{SENSE} resistor	50 mΩ
Gain option	50 V/V

8.2.2 Detailed Design Procedure

The INA293-Q1 is designed to measure current in a typical solenoid application. The INA293-Q1 measures current across the 50-mΩ shunt that is placed at the output of the half-bridge. The INA293-Q1 measures the differential voltage across the shunt resistor, and the signal is internally amplified with a gain of 50 V/V. The output of the INA293-Q1 is connected to the analog-to-digital converter (ADC) of an MCU to digitize the current measurements.

Solenoid loads are highly inductive and are often prone to failure. Solenoids are often used for position control, precise fluid control, and fluid regulation. Measuring real-time current on the solenoid continuously can indicate premature failure of the solenoid which can lead to a faulty control loop in the system. Measuring high-side current also indicates if there are any ground faults on the solenoid or the FETs that can be damaged in an application. The INA293-Q1, with high bandwidth and slew rate, can be used to detect fast overcurrent conditions to prevent the solenoid damage from short-to-ground faults.

8.2.2.1 Overload Recovery With Negative V_{SENSE}

The INA293-Q1 is a unidirectional current sense amplifier that is meant to operate with a positive differential input voltage (V_{SENSE}). If negative V_{SENSE} is applied, the device is placed in an overload condition and requires time to recover once V_{SENSE} returns positive. The required overload recovery time increases with more negative V_{SENSE}.

8.2.3 Application Curve

Figure 8-3 shows the output response of a solenoid.

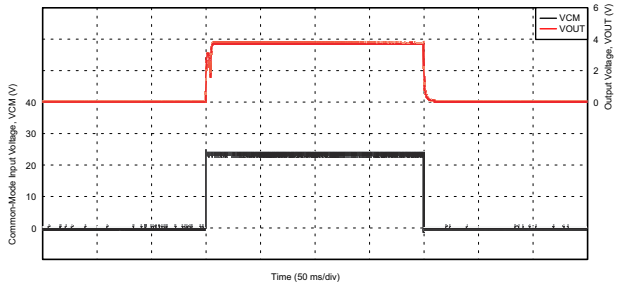


Figure 8-3. Solenoid Control Current Response

8.3 Power Supply Recommendations

The INA293-Q1 power supply can be 5 V, whereas the input common-mode voltage can vary between –4 V to 110 V. The output voltage range of the OUT pin, however, is limited by the voltage on the power-supply pin.

8.4 Layout

8.4.1 Layout Guidelines

Attention to good layout practices is always recommended.

- Connect the input pins to the sensing resistor using a Kelvin or 4-wire connection. This connection technique makes sure that only the current-sensing resistor impedance is detected between the input pins. Poor routing of the current-sensing resistor commonly results in additional resistance present between the input pins.

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Given the very low ohmic value of the current resistor, any additional high-current carrying impedance can cause significant measurement errors.

- Place the power-supply bypass capacitor as close as possible to the device power 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.

8.4.2 Layout Example

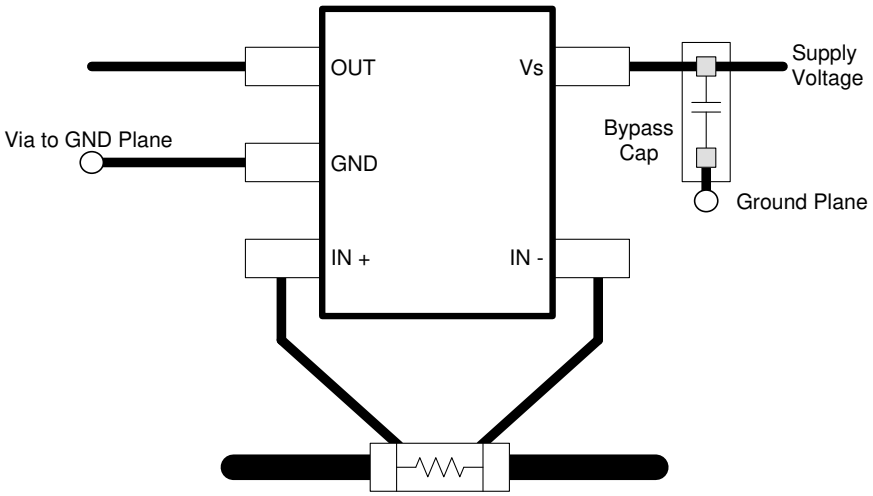


Figure 8-4. INA293A-Q1 Recommended Layout

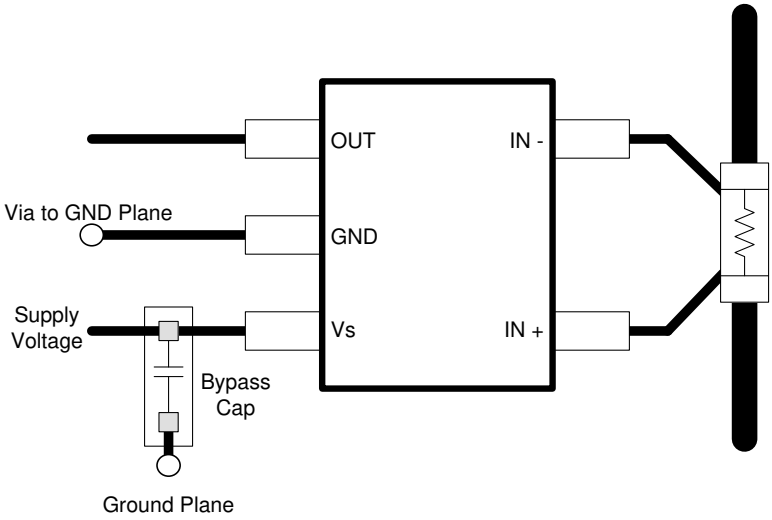


Figure 8-5. INA293B-Q1 Recommended Layout

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9 Device and Documentation Support

9.1 Documentation Support

9.1.1 Related Documentation

For related documentation see the following: Texas Instruments, *INA293EVM* user's guide.

9.2 Receiving Notification of Documentation Updates

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

9.3 Support Resources

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

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9.5 Electrostatic Discharge Caution



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

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

9.6 Glossary

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

10 Mechanical, Packaging, and Orderable Information

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

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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)
INA293A1QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1UZC
INA293A1QDBVRQ1.B	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1UZC
INA293A2QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V1C
INA293A2QDBVRQ1.B	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V1C
INA293A3QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V2C
INA293A3QDBVRQ1.B	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V2C
INA293A4QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V3C
INA293A4QDBVRQ1.B	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V3C
INA293A5QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V4C
INA293A5QDBVRQ1.B	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V4C
INA293B1QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V5C
INA293B1QDBVRQ1.B	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V5C
INA293B2QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V6C
INA293B2QDBVRQ1.B	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V6C
INA293B3QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V7C
INA293B3QDBVRQ1.B	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V7C
INA293B4QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V8C
INA293B4QDBVRQ1.B	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V8C
INA293B5QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V9C
INA293B5QDBVRQ1.B	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1V9C

(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 INA293-Q1 :

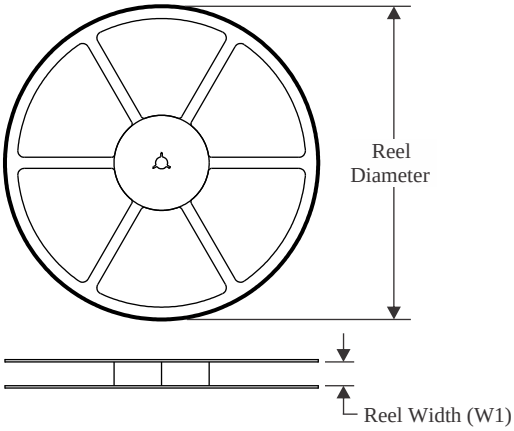
- Catalog : INA293

NOTE: Qualified Version Definitions:

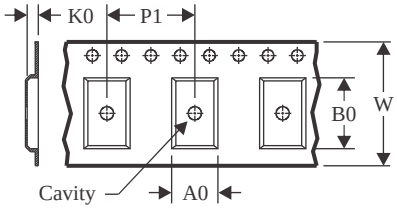
- Catalog - TI's standard catalog product

TAPE AND REEL INFORMATION

REEL DIMENSIONS

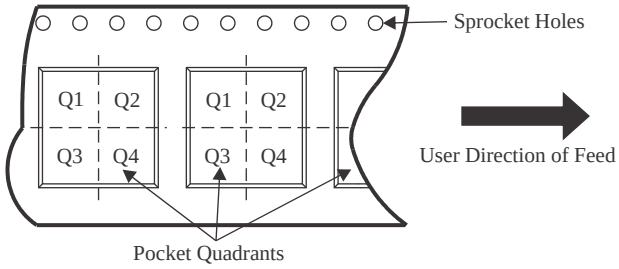


TAPE DIMENSIONS



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

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE

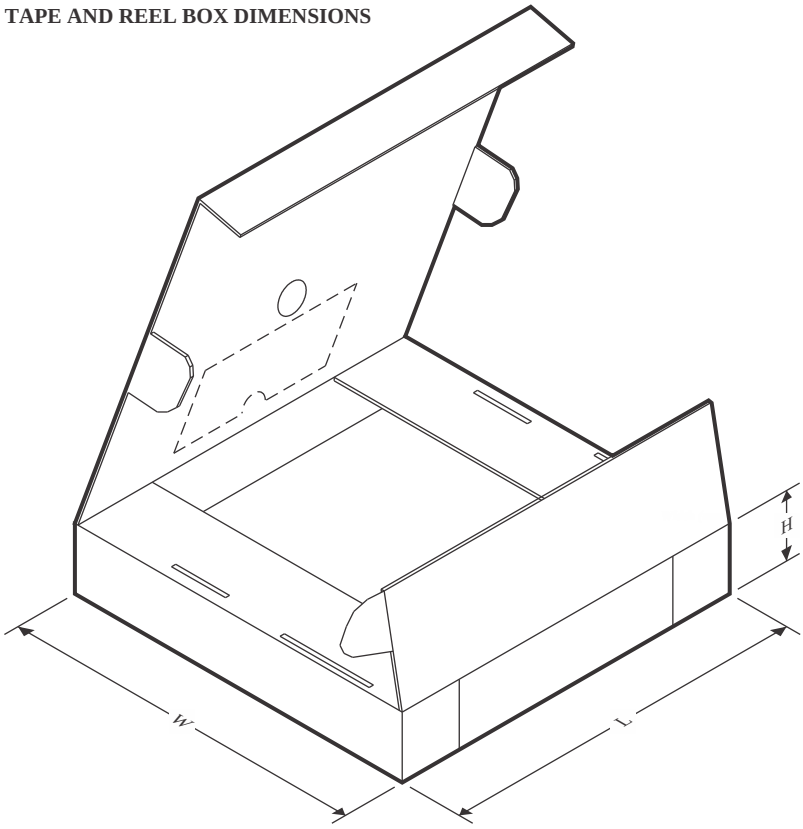


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
INA293A1QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
INA293A1QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA293A2QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
INA293A2QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA293A3QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA293A3QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
INA293A4QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
INA293A4QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA293A5QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
INA293A5QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA293B1QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA293B1QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
INA293B2QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA293B2QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
INA293B3QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
INA293B3QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3

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
INA293B4QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA293B4QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
INA293B5QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
INA293B5QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA293A1QDBVRQ1	SOT-23	DBV	5	3000	183.0	183.0	20.0
INA293A1QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0
INA293A2QDBVRQ1	SOT-23	DBV	5	3000	183.0	183.0	20.0
INA293A2QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0
INA293A3QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0
INA293A3QDBVRQ1	SOT-23	DBV	5	3000	183.0	183.0	20.0
INA293A4QDBVRQ1	SOT-23	DBV	5	3000	183.0	183.0	20.0
INA293A4QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0
INA293A5QDBVRQ1	SOT-23	DBV	5	3000	183.0	183.0	20.0
INA293A5QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0
INA293B1QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0
INA293B1QDBVRQ1	SOT-23	DBV	5	3000	183.0	183.0	20.0
INA293B2QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0
INA293B2QDBVRQ1	SOT-23	DBV	5	3000	183.0	183.0	20.0
INA293B3QDBVRQ1	SOT-23	DBV	5	3000	183.0	183.0	20.0
INA293B3QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0
INA293B4QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0
INA293B4QDBVRQ1	SOT-23	DBV	5	3000	183.0	183.0	20.0

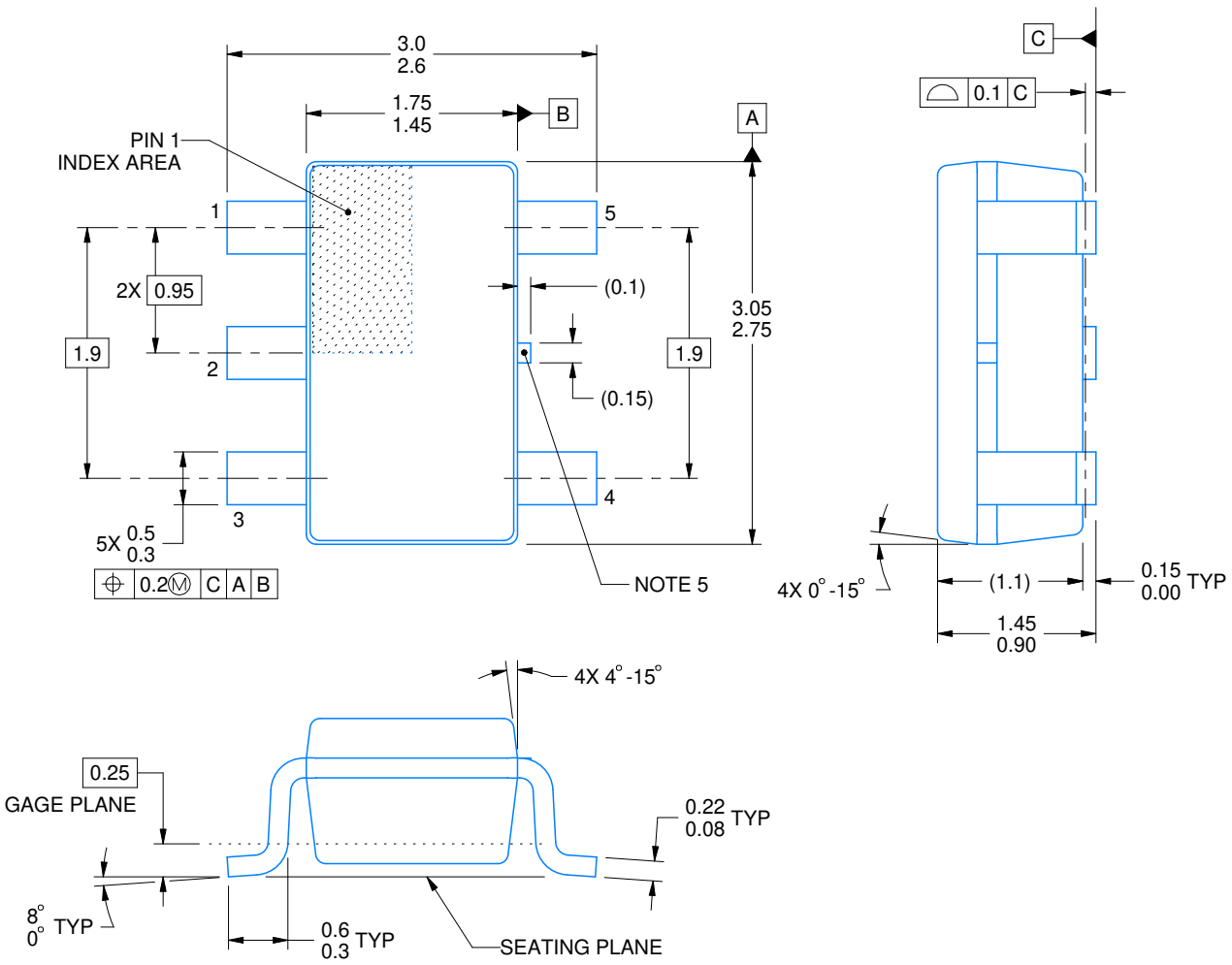
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA293B5QDBVRQ1	SOT-23	DBV	5	3000	183.0	183.0	20.0
INA293B5QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0

PACKAGE OUTLINE

DBV0005A

SOT-23 - 1.45 mm max height

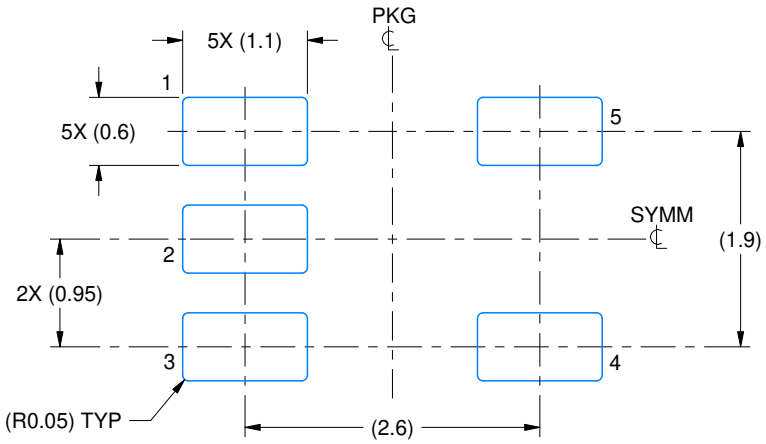
SMALL OUTLINE TRANSISTOR



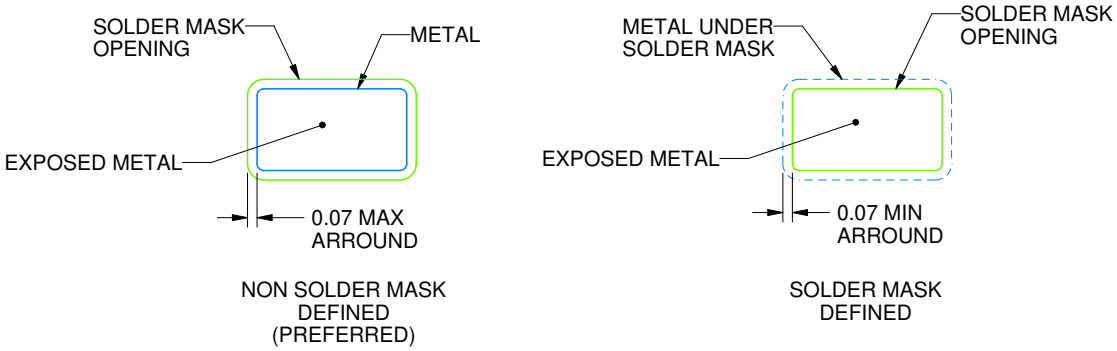
4214839/K 08/2024

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. Refernce JEDEC MO-178.
4. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25 mm per side.
5. Support pin may differ or may not be present.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:15X

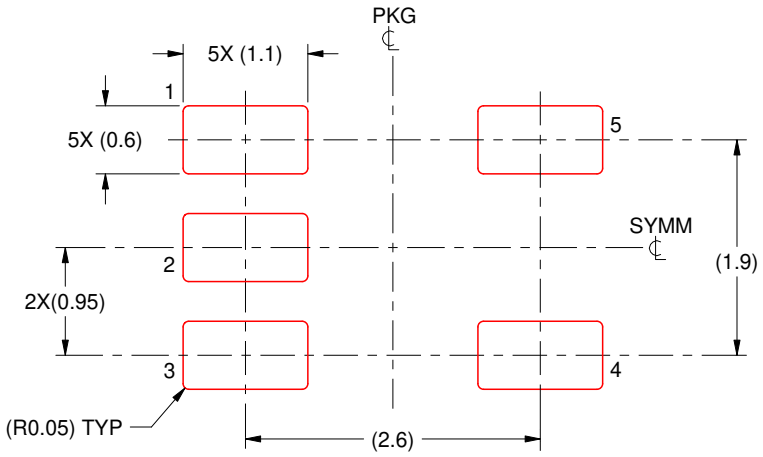


SOLDER MASK DETAILS

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NOTES: (continued)

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



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:15X

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NOTES: (continued)

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

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