

INA299-Q1 AEC-Q100, -2V to 80V, Bi-directional, 650kHz, High-Precision Current Sense Amplifier

1 Features

- AEC-Q100 qualified for automotive applications:
 - Temperature grade 1: -40°C to $+125^{\circ}\text{C}$, T_A
- Functional Safety-Capable
 - Documentation available to aid functional safety system design
- Wide common-mode voltage:
 - Operational voltage: -2V to $+80\text{V}$
 - Survival voltage: -12V to $+85\text{V}$
- Bidirectional operation
- High small signal bandwidth: 650kHz (20V/V Gain)
- Slew rate: $2.5\text{V}/\mu\text{s}$
- Step response settling time to 1%: $6.5\mu\text{s}$
- High CMRR: 120dB
- Gain error (maximum) : $\pm 0.25\%$, $\pm 10\text{ppm}/^{\circ}\text{C}$ drift
- Offset voltage (maximum): $\pm 150\mu\text{V}$, $\pm 0.5\mu\text{V}/^{\circ}\text{C}$ drift
- Operates from 2.7V to 12V supply
- Operational current: $650\mu\text{A}$
- Available gains:
 - INA299A1-Q1: 20V/V
 - INA299A2-Q1: 50V/V
 - INA299A3-Q1: 100V/V
- Package options: SOT23-6 (DBV)

2 Applications

- eTurbo/charger
- Electric power steering (EPS)
- Starter/generator
- Regenerative braking
- Brake system

3 Description

The INA299-Q1 is a precise, bidirectional current sense amplifier that can measure voltage drops across shunt resistors over a wide common-mode range from -2V to 80V , independent of the supply voltage. The high-precision current measurement is achieved through a combination of low offset voltage ($\pm 150\mu\text{V}$, maximum), small gain error ($\pm 0.25\%$, maximum) and a high DC CMRR (typical 120dB). The INA299-Q1 is not only designed for high voltage, bidirectional DC current measurements, but also for high-speed applications (such as transient detection and fast overcurrent protection) with a high signal bandwidth of 650kHz and fast settling time.

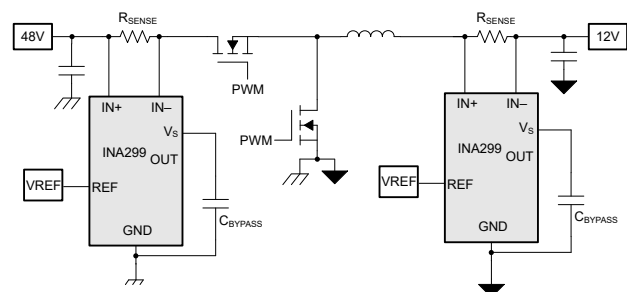
The INA299-Q1 operates from a single 2.7V to 12V supply, drawing $650\mu\text{A}$ of supply current. The INA299-Q1 is available in three gain options: 20V/V, 50V/V, 100V/V. Multiple gain options allow for optimization between available shunt resistor values and wide output dynamic range requirements.

The INA299-Q1 is specified over operating temperature range of -40°C to $+125^{\circ}\text{C}$ and is offered in a 6-pin SOT-23 package.

Package Information

PART NUMBER	PACKAGE ⁽¹⁾	PACKAGE SIZE ⁽²⁾
INA299-Q1	DBV (SOT-23, 6)	2.90mm × 2.80mm

- For all available packages, see the package option addendum at the end of the data sheet.
- The package size (length × width) is a nominal value and includes pins, where applicable.



Typical Application - DC/DC Converter



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4 Pin Configuration and Functions

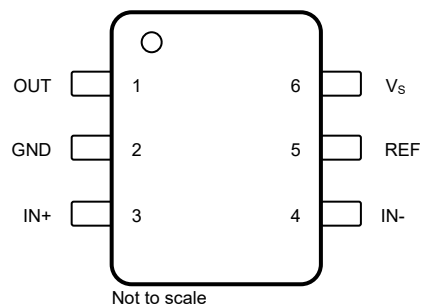


Figure 4-1. INA299-Q1 : DBV Package 6-Pin SOT-23 Top View

Table 4-1. Pin Functions: DBV Package

PIN		TYPE	DESCRIPTION
NAME	NO.		
GND	2	Ground	Ground
IN+	3	Input	Current-sense amplifier positive input. For high-side applications, connect to bus-voltage side of sense resistor. For low-side applications, connect to load side of sense resistor.
IN–	4	Input	Current-sense amplifier negative input. For high-side applications, connect to load side of sense resistor. For low-side applications, connect to ground side of sense resistor.
OUT	1	Output	Output voltage
REF	5	Input	Reference voltage. Connect to voltage potential from 0V to V_S ; see Adjusting the Output With the Reference Pin for connection options.
V_S	6	Power	Power supply, 2.7V to 12V

5 Specifications

5.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Supply Voltage (V _S)	(V _S – GND)	–0.3	13.2	V
Analog Inputs, V _{IN+} , V _{IN–} ⁽²⁾	Differential (V _{IN+}) – (V _{IN–})	–6	6	V
Analog Inputs, V _{IN+} , V _{IN–} ⁽²⁾	Common - mode	–12	85	V
REF		GND – 0.3	V _S + 0.3	V
Output		GND – 0.3	V _S + 0.3	V
T _A	Operating temperature	–55	150	°C
T _J	Junction temperature		150	°C
T _{stg}	Storage temperature	–65	150	°C

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

5.2 ESD Ratings

			VALUE	UNIT
V _(ESD)	Electrostatic discharge	Human body model (HBM), per AEC Q100-002 ⁽¹⁾ HBM ESD classification level 2	±2000	V
		Charged device model (CDM), per AEC Q100-011 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.

5.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
V _{CM}	Common-mode input range	–2	48	80	V
V _S	Operating supply range	2.7	5	12	V
V _{SENSE}	Differential sense input range	0		V _S / G	V
T _A	Ambient temperature	–40		125	°C

5.4 Thermal Information

THERMAL METRIC ⁽¹⁾		INA299-Q1	UNIT
		DBV (SOT-23)	
		6 PINS	
R _{θJA}	Junction-to-ambient thermal resistance	158.8	°C/W
R _{θJC(top)}	Junction-to-case (top) thermal resistance	76.9	°C/W
R _{θJB}	Junction-to-board thermal resistance	41.4	°C/W
Ψ _{JT}	Junction-to-top characterization parameter	17.3	°C/W
Ψ _{JB}	Junction-to-board characterization parameter	41.1	°C/W

THERMAL METRIC ⁽¹⁾		INA299-Q1	UNIT
		DBV (SOT-23)	
		6 PINS	
$R_{\theta JC(bot)}$	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 note.

5.5 Electrical Characteristics

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$, $V_{REF} = V_S / 2$, $V_{SENSE} = 0\text{V}$, $V_{CM} = V_{IN-} = 48\text{V}$, (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range ⁽¹⁾	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$	-2		80	V
CMRR	Common-mode rejection ratio, input referred	$2.5\text{V} < V_{CM} < 80\text{V}$,	110	120		dB
		$0\text{V} < V_{CM} < 80\text{V}$,	80	90		
		$-2\text{V} < V_{CM} \leq 2.5\text{V}$,	65			
		$f = 50\text{kHz}$, $V_{CM} = 12\text{V}$		65		
V_{os}	Offset voltage, input referred	$V_{CM} = 2.5\text{V}$	-150		150	μV
		$V_{CM} = 2.5\text{V}$, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$	-200		200	
dV_{os}/dT	Offset voltage drift	$V_{CM} = 2.5\text{V}$			± 0.5	$\mu\text{V}/^\circ\text{C}$
PSRR	Power supply rejection ratio, input referred	$V_{CM} = 2.5\text{V}$, $2.7\text{V} \leq V_S \leq 12\text{V}$, $V_{REF} = 1\text{V}$, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			± 6	$\mu\text{V}/\text{V}$
I_B	Input bias current	I_{B+} , I_{B-} , $V_{CM} = 2.5\text{V}$, $V_{SENSE} = 0\text{V}$		13	± 21	μA
		I_{B+} , I_{B-} , $V_{CM} = 2.5\text{V}$, $V_{SENSE} = 0\text{V}$, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			± 28	
	Reference input range		0		V_S	V
RVRR	Reference voltage rejection ratio, input referred	$V_{REF} = 0.5\text{V}$ to 4.5V , $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		± 5	± 20	$\mu\text{V}/\text{V}$
OUTPUT						
G	Gain	INA299A1-Q1		20		V/V
		INA299A2-Q1		50		
		INA299A3-Q1		100		
G_{ERR}	Gain error	$V_{CM} = 2.5\text{V}$, $(\text{GND} + 50\text{mV}) < V_{OUT} < (V_S - 200\text{mV})$			± 0.25	%
	Gain error drift	$V_{CM} = 2.5\text{V}$, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$, $(\text{GND} + 50\text{mV}) < V_{OUT} < (V_S - 200\text{mV})$			10	$\text{ppm}/^\circ\text{C}$
NL_{ERR}	Nonlinearity error	$V_{OUT} = 0.5\text{V}$ to 4.5V , $V_{CM} = 12\text{V}$		0.01		%
	Maximum capacitive load	No sustained oscillations, no isolation resistor		500		pF
VOLTAGE OUTPUT						
	Swing to V_S (Power supply rail)	$V_{CM} = 2.5\text{V}$, $R_L = 10\text{k}\Omega$ to GND	4.9			V
	Swing to ground	$V_{CM} = 2.5\text{V}$, $R_L = 10\text{k}\Omega$ to GND			80	mV
FREQUENCY RESPONSE						
BW	Bandwidth	INA299A1-Q1		650		kHz
		INA299A2-Q1		500		
		INA299A3-Q1		400		

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$, $V_{\text{REF}} = V_S / 2$, $V_{\text{SENSE}} = 0\text{V}$, $V_{\text{CM}} = V_{\text{IN-}} = 48\text{V}$, (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
	Settling time	$V_{\text{OUT}} = 0.5\text{V}$ to 4.5V step, Output settles to 1%		6.5		μs
		$V_{\text{OUT}} = 0.5\text{V}$ to 4.5V step, Output settles to 5%		3		
SR	Slew rate	INA299A1-Q1, $V_{\text{SENSE}} = \pm 100\text{mV}$, INA299A2-Q1, $V_{\text{SENSE}} = \pm 40\text{mV}$, INA299A3-Q1, $V_{\text{SENSE}} = \pm 20\text{mV}$,		2.5		$\text{V}/\mu\text{s}$
NOISE						
V_{en}	Voltage noise density	$f > 10\text{kHz}$		117		$\text{nV}/\sqrt{\text{Hz}}$
POWER SUPPLY						
I_Q	Quiescent current	$V_{\text{CM}} = 2.5\text{V}$		450	600	μA
		$V_{\text{CM}} = 2.5\text{V}$, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			650	μA
		$V_{\text{CM}} = -2\text{V}$		950	1100	μA
		$V_{\text{CM}} = -2\text{V}$, $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			1200	μA
T_A	Specified Range		-40		125	$^\circ\text{C}$

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

5.6 Typical Characteristics

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$, $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-} = 0\text{V}$, $V_{\text{CM}} = V_{\text{IN}-} = 48\text{V}$, and $V_{\text{REF}} = V_S / 2$ (unless otherwise noted)

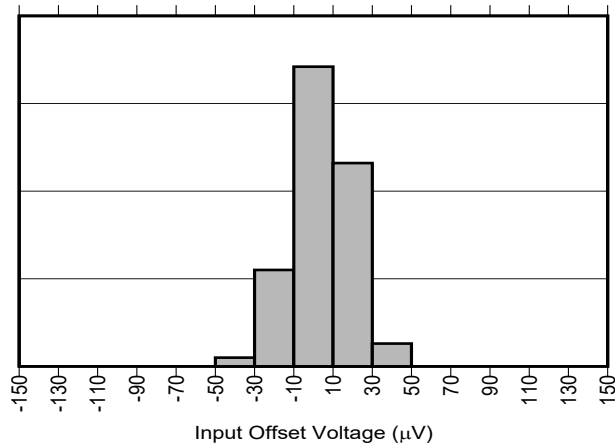


Figure 5-1. INA299-Q1 Input Offset Voltage Production Distribution

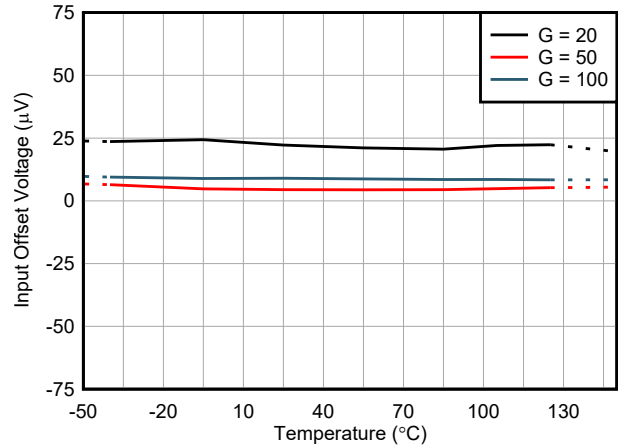


Figure 5-2. Input Offset Voltage vs Temperature

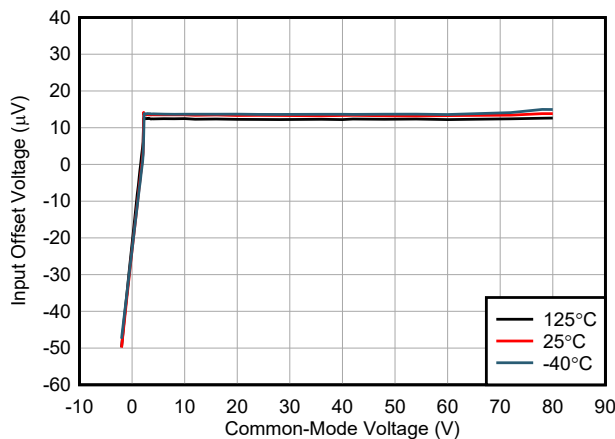


Figure 5-3. Input Offset Voltage vs Common-Mode Voltage

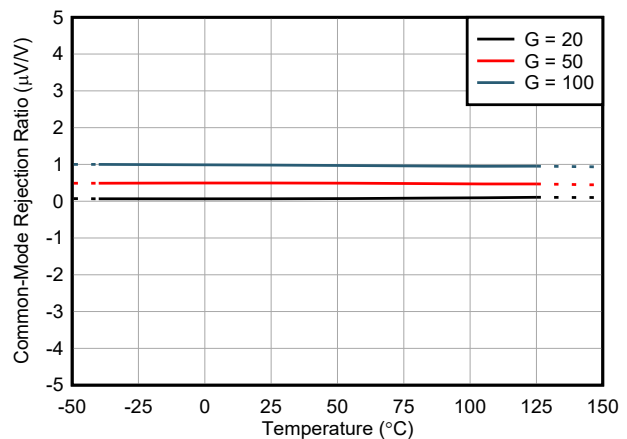


Figure 5-4. Common-Mode Rejection Ratio vs Temperature

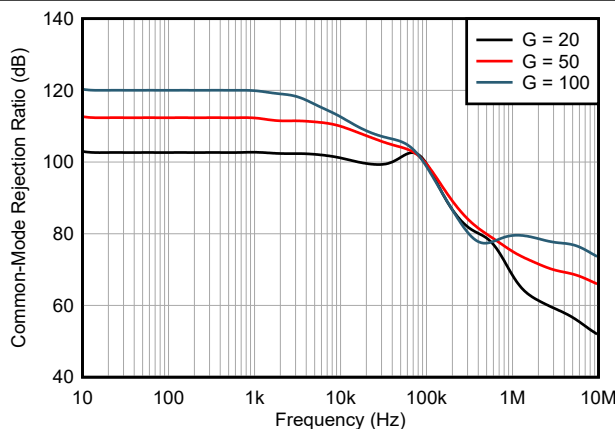


Figure 5-5. Common-Mode Rejection Ratio vs Frequency

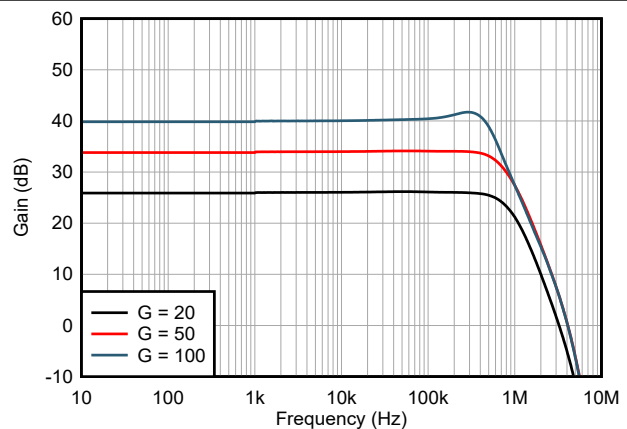


Figure 5-6. Gain vs Frequency

5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$, $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-} = 0\text{V}$, $V_{\text{CM}} = V_{\text{IN}-} = 48\text{V}$, and $V_{\text{REF}} = V_S / 2$ (unless otherwise noted)

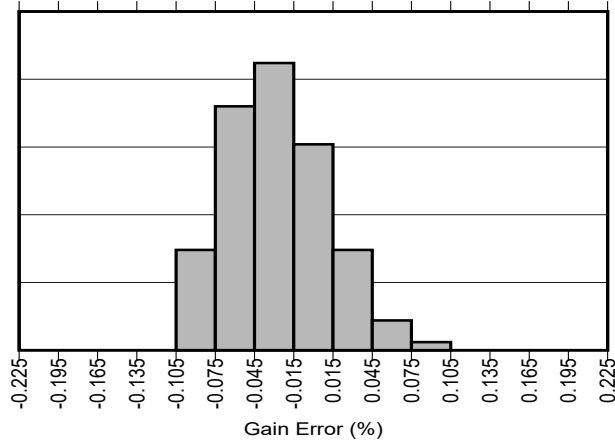


Figure 5-7. INA299-Q1 Gain Error Production Distribution

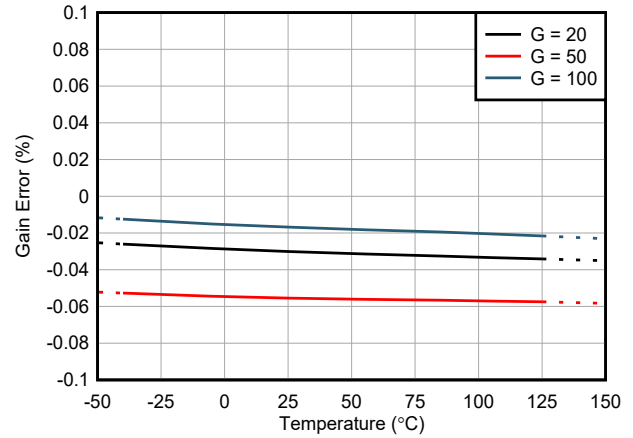


Figure 5-8. Gain Error vs Temperature

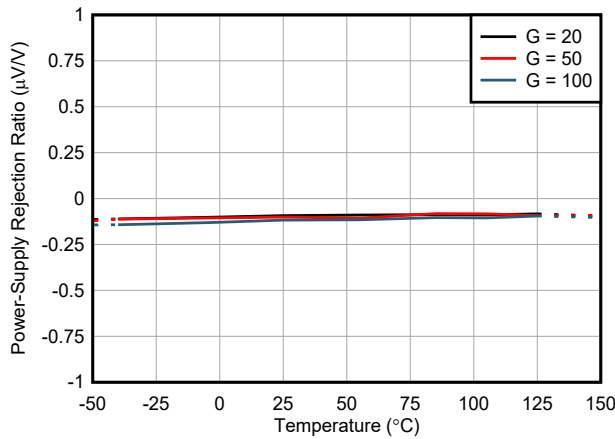


Figure 5-9. Power-Supply Rejection Ratio vs Temperature

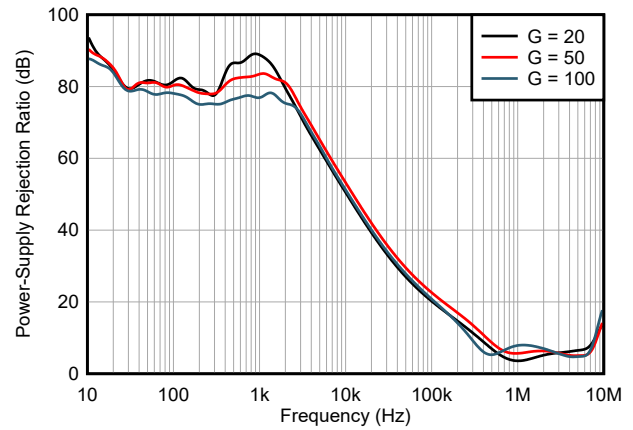


Figure 5-10. Power-Supply Rejection Ratio vs Frequency

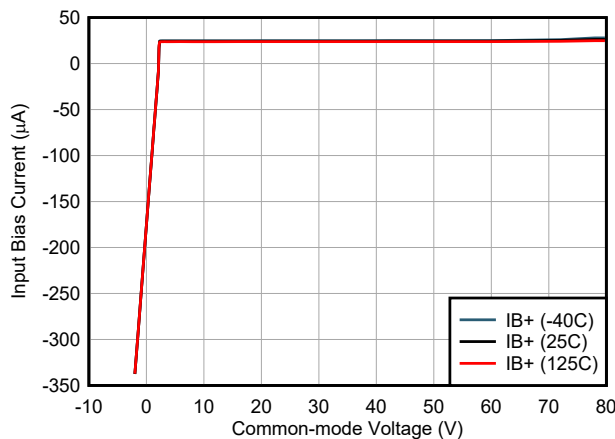


Figure 5-11. Input Bias Current vs Common-Mode Voltage

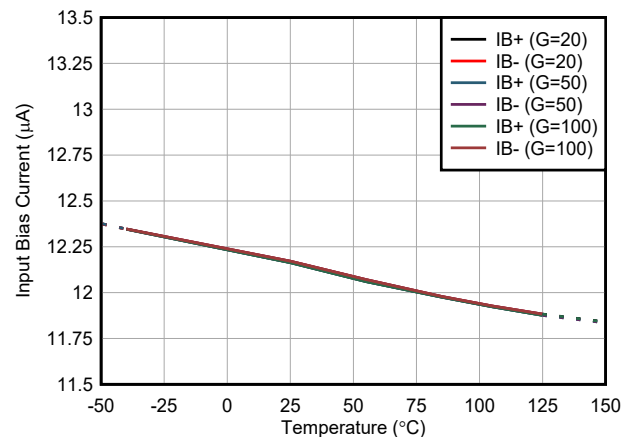


Figure 5-12. Input Bias Current vs Temperature

5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$, $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-} = 0\text{V}$, $V_{\text{CM}} = V_{\text{IN}-} = 48\text{V}$, and $V_{\text{REF}} = V_S / 2$ (unless otherwise noted)

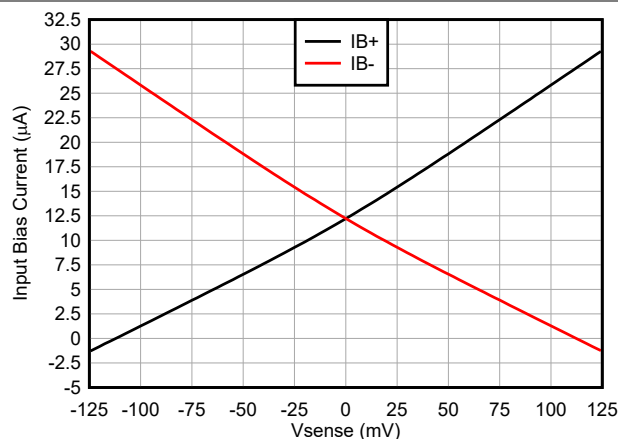


Figure 5-13. INA299-Q1 Gain = 20V/V, Input Bias Current vs V_{SENSE}

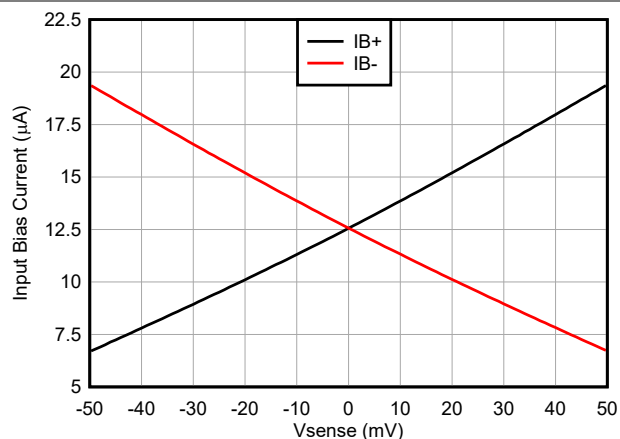


Figure 5-14. INA299-Q1 Gain = 50V/V, Input Bias Current vs V_{SENSE}

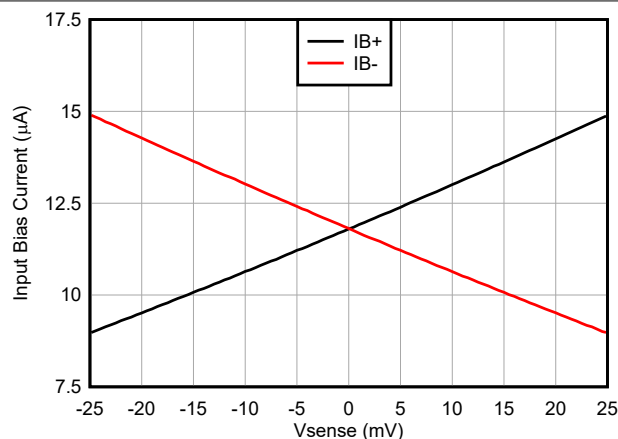


Figure 5-15. INA299-Q1 Gain = 100V/V Input Bias Current vs V_{SENSE}

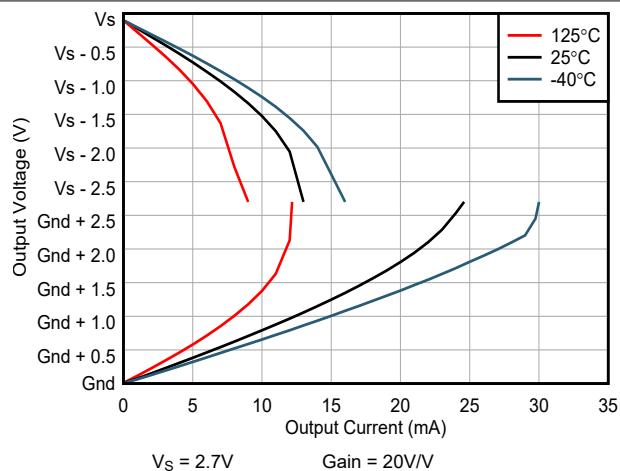


Figure 5-16. Output Voltage vs Output Current

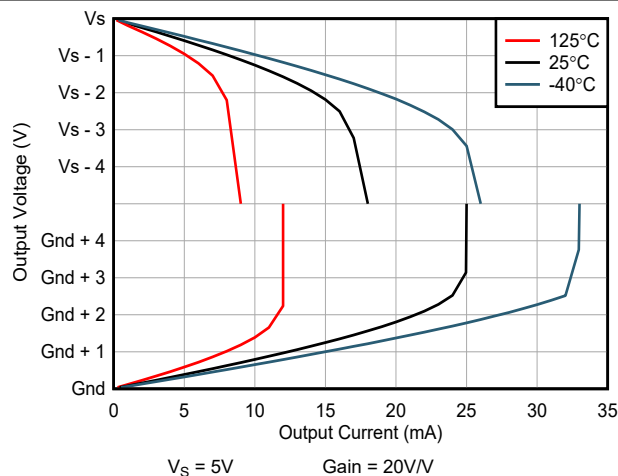


Figure 5-17. Output Voltage vs Output Current

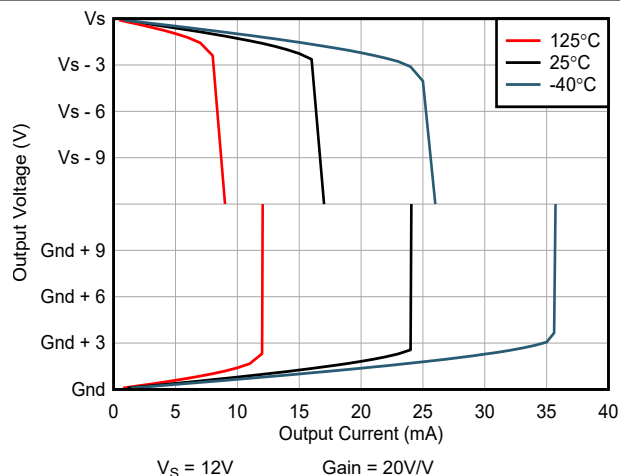


Figure 5-18. Output Voltage vs Output Current

5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$, $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-} = 0\text{V}$, $V_{\text{CM}} = V_{\text{IN}-} = 48\text{V}$, and $V_{\text{REF}} = V_S / 2$ (unless otherwise noted)

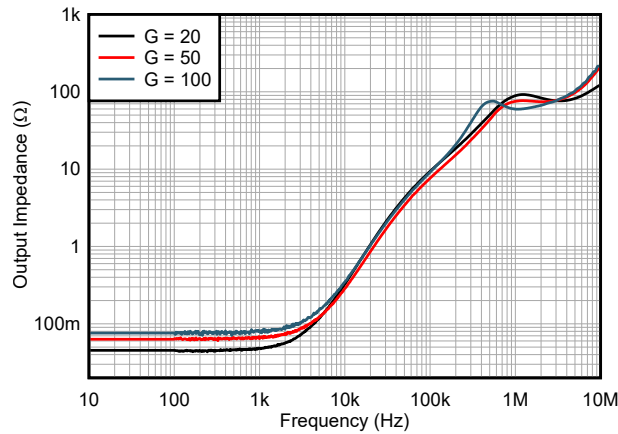


Figure 5-19. Output Impedance vs Frequency

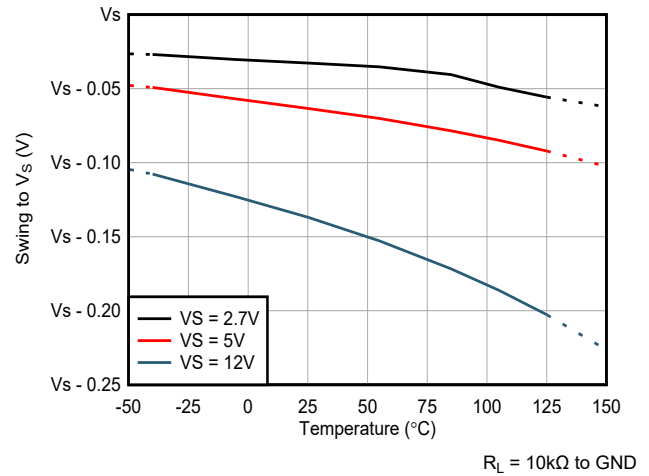


Figure 5-20. Swing to Supply vs Temperature

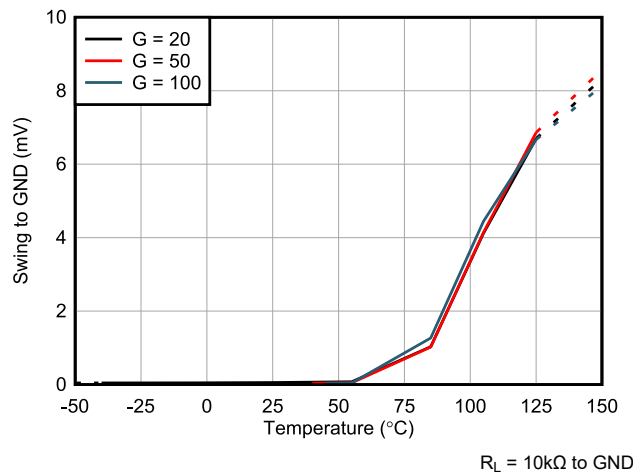


Figure 5-21. Swing to GND vs Temperature

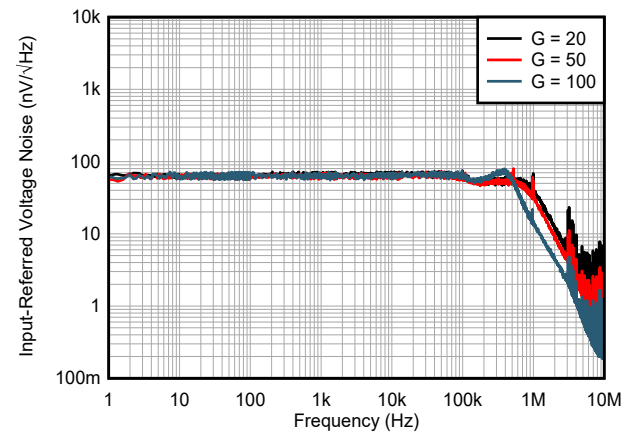


Figure 5-22. Input Referred Noise vs Frequency

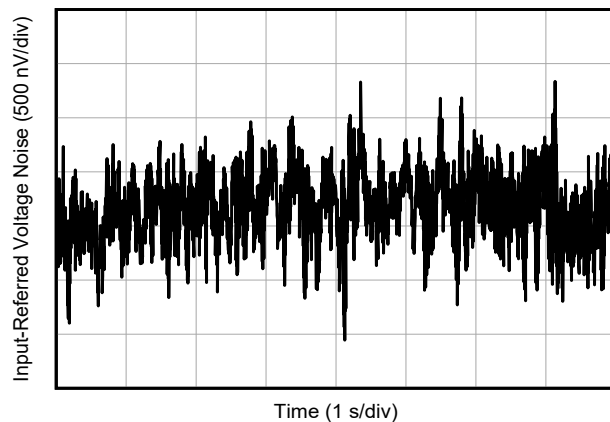


Figure 5-23. 0.1Hz to 10Hz Voltage Noise

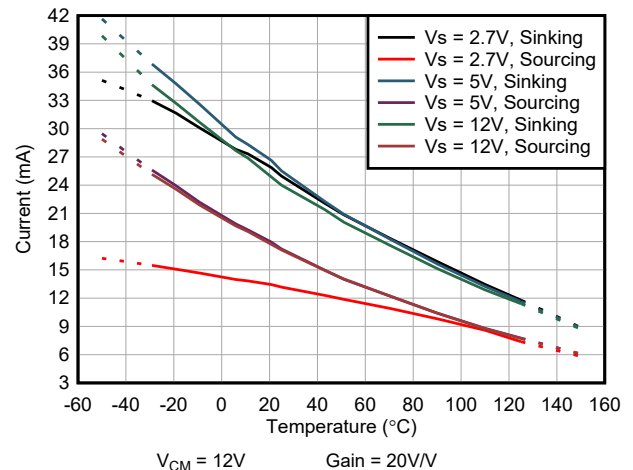


Figure 5-24. Short-Circuit Current vs Temperature

5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$, $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-} = 0\text{V}$, $V_{\text{CM}} = V_{\text{IN}-} = 48\text{V}$, and $V_{\text{REF}} = V_S / 2$ (unless otherwise noted)

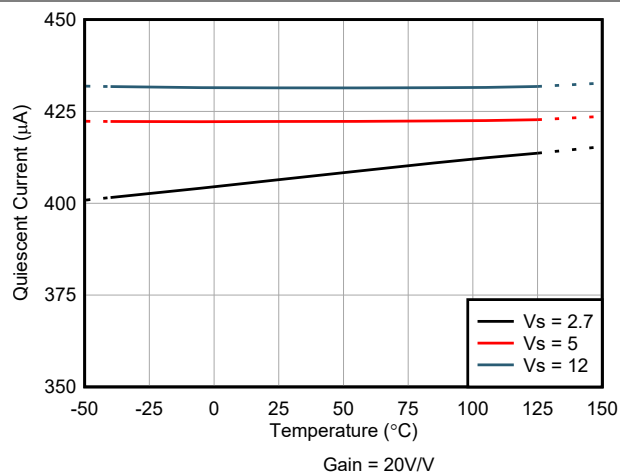


Figure 5-25. Quiescent Current vs Temperature

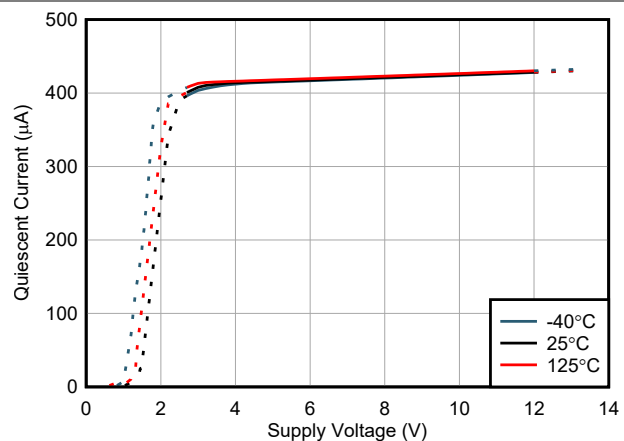


Figure 5-26. Quiescent Current vs Supply Voltage

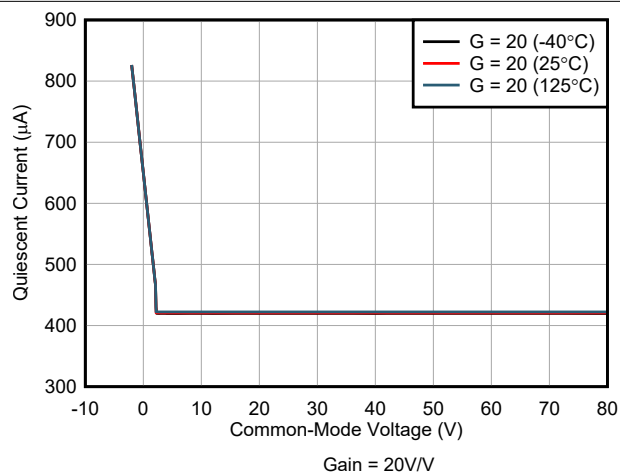


Figure 5-27. Quiescent Current vs Common-Mode Voltage

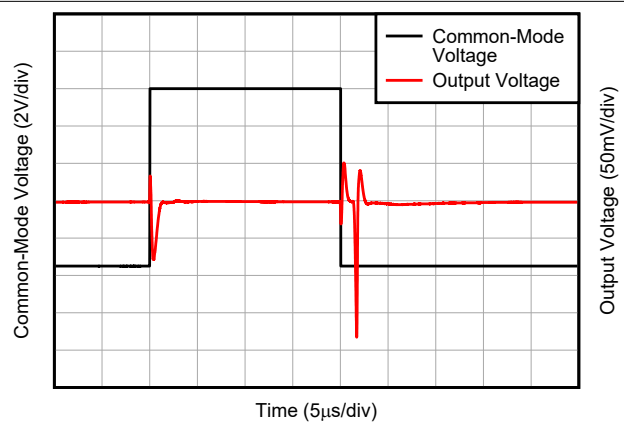


Figure 5-28. Common-Mode Voltage Fast Transient Pulse

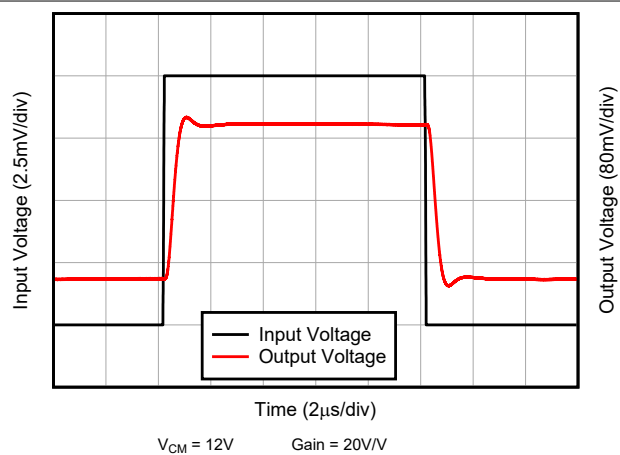


Figure 5-29. Small Step Response

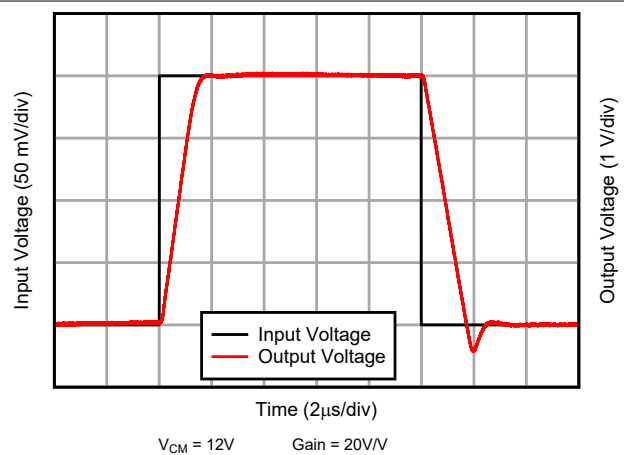
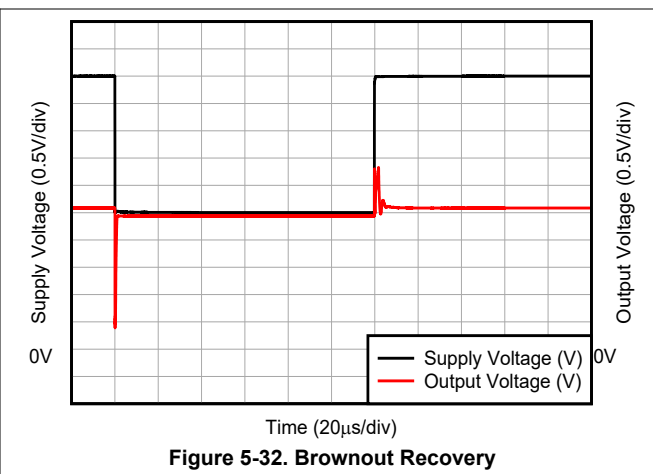
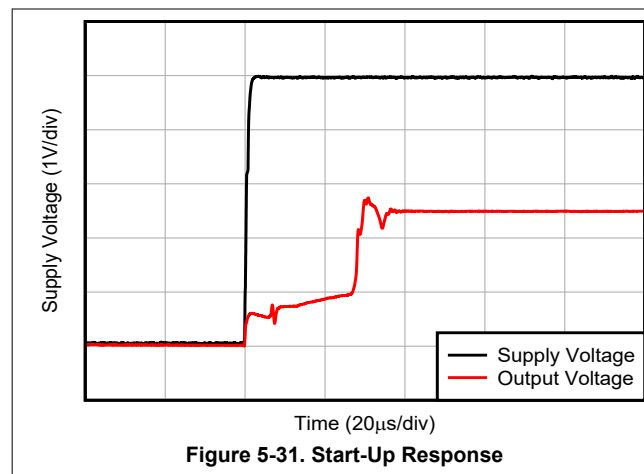


Figure 5-30. Large Step Response

5.6 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$, $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-} = 0\text{V}$, $V_{\text{CM}} = V_{\text{IN}-} = 48\text{V}$, and $V_{\text{REF}} = V_S / 2$ (unless otherwise noted)

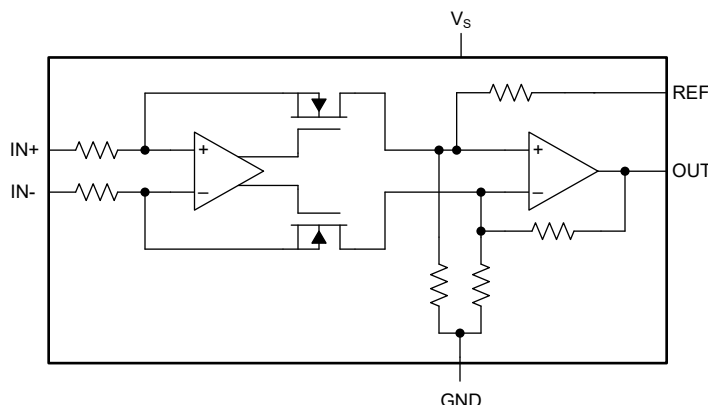


6 Detailed Description

6.1 Overview

The INA299-Q1 is a high-side or low-side bidirectional, high-bandwidth current-sense amplifier that offers a wide common-mode range, precision zero-drift topology, good common-mode rejection ratio (CMRR) and fast slew rate. Different gain versions are available to optimize the output dynamic range based on the application. The INA299-Q1 is designed using an architecture that enables low bias currents of 13 μ A with a specified common-mode voltage range from –2V to 80V with signal bandwidths up to 650kHz.

6.2 Functional Block Diagram



6.3 Feature Description

6.3.1 Amplifier Input Common-Mode Signal

The INA299-Q1 supports large input common-mode voltages from –2V to +80V. The internal topology of the INA299-Q1 allows the common-mode range to exceed the power-supply voltage (V_S). This allows for the INA299-Q1 to be used for low-side or high-side current-sensing applications that extend beyond the supply range of 2.7V to 12V.

6.3.2 Low Input Bias Current

The INA299-Q1 inputs draw 13 μ A (typical) bias current per input pin at common-mode voltages as high as 80V, which enables precision current sensing on applications that require lower current leakage. The input bias current is proportional to the common-mode voltage at –2V to 2.5V, after that the input bias current of the INA299-Q1 remains constant over the entire common-mode voltage range.

6.3.3 Low V_{SENSE} Operation

The INA299-Q1 features high performance operation across the entire valid V_{SENSE} range. The zero-drift input architecture of the INA299-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.

6.3.4 Wide Fixed Gain Output

The INA299-Q1 maximum gain error is $\pm 0.25\%$ at room temperature, with a maximum drift of ± 10 ppm/°C over the full temperature range of –40°C to +125°C. The INA299-Q1 is available in multiple gain options of 20V/V, 50V/V, and 100V/V which the system designer must select based on the desired signal-to-noise ratio and other system requirements, such as the dynamic current range and full-scale output voltage target.

6.3.5 Wide Supply Range

The INA299-Q1 operates with a wide supply range from 2.7V to 12V. While the input common-mode voltage range of the INA299-Q1 is independent of the supply voltage, the output voltage is bound by the supply voltage

applied to the device. The output voltage can range from as low as 80mV to as high as 100mV below the supply voltage.

6.4 Device Functional Modes

6.4.1 Adjusting the Output With the Reference Pin

Figure 6-1 shows the reference pin driven at the divided supply voltage to bias the output at the same voltage when differential input voltage is 0V. The INA299-Q1 output is configurable to allow for unidirectional or bidirectional operation.

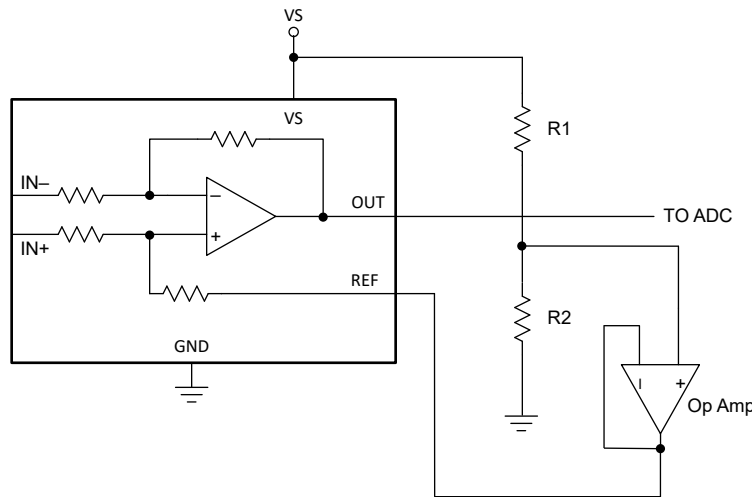


Figure 6-1. Reference Pin Adjusting the Output

The output voltage is set by applying a voltage to the reference input pin, REF. REF is connected to a precisely matched internal gain network. When REF is connected to buffered divided supply voltage, the output is set at the mid-point voltage when current-sense input voltage is 0V as shown in Equation 1. In most bidirectional applications REF is driven to mid supply to set the output voltage to mid-supply.

$$V_{OUT} = G \times (V_{IN+} - V_{IN-}) + V_{REF} \quad (1)$$

6.4.2 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 pin to the negative rail (see the [Ground Referenced Output](#) section) or the positive rail (see the [VS Referenced Output](#) section). The required differential input polarity depends on the reference input setting. The amplifier output moves away from the referenced rail proportional to the current passing through the external shunt resistor. If the amplifier reference pin is connected to the positive rail, then the input polarity must be negative to move the amplifier output down (towards ground). If the amplifier reference pin is connected to ground, then the input polarity must be positive to move the amplifier output up (towards supply).

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

6.4.2.1 Ground Referenced Output

When using the INA299-Q1 in a unidirectional mode with a ground referenced output, the reference input is connected to ground. This configuration takes the output to ground when there is a 0V differential at the input (see [Figure 6-2](#)).

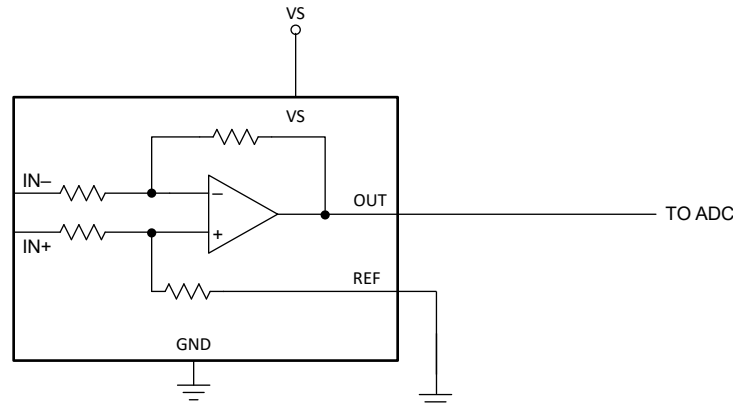


Figure 6-2. Ground Referenced Output

6.4.2.2 VS Referenced Output

Unidirectional mode with a VS referenced output is configured by connecting the reference pin to the positive supply. Use this configuration for circuits that has negative current magnitude. This configuration takes the output to the supply when there is a 0V differential at the input (see [Figure 6-3](#)).

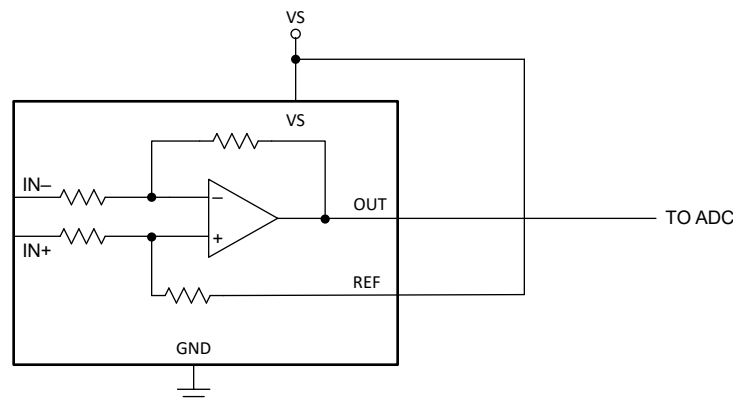


Figure 6-3. VS Referenced Output

6.4.3 Reference Pin Connections for Bidirectional Current Measurements

The INA299-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 INA299-Q1 can operate in either a unidirectional or bidirectional mode based on the voltage potential placed on the reference pin.

The linear range of the output stage is limited to how close the output voltage can approach ground as well the supply voltage as described in the [Specifications](#). The value of the current-sensing resistor along with the current range to be measured, optimum gain option, as well as the voltage applied to the reference pin must be selected to keep the INA299-Q1 within the linear region of operation.

6.4.3.1 Output Set to External Reference Voltage

Connecting the reference pin to an external reference voltage results in an output voltage equal to the reference voltage for the condition of shorted input pins or a 0V differential input. [Figure 6-4](#) 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.

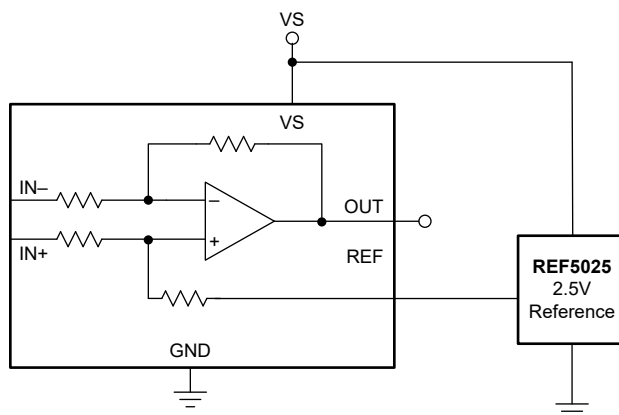


Figure 6-4. External Reference Output

6.4.3.2 Output Set to Mid-Supply Voltage

Figure 6-5 shows by connecting the reference pin to equally divide supply voltage VS sets the output at half of the supply voltage when there is no differential input. This method creates a ratiometric offset to the supply voltage, where the output voltage remains at $VS / 2$ for 0V applied to the inputs.

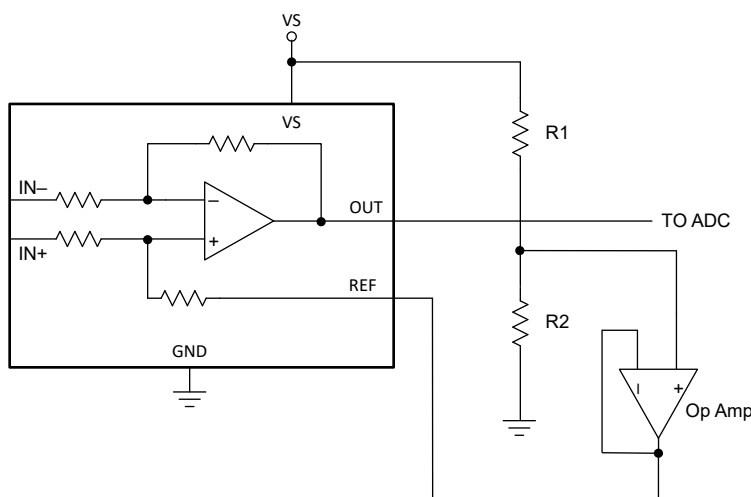


Figure 6-5. Mid-Supply Voltage Output

7 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.

7.1 Application Information

The INA299-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 INA299-Q1 make it usable over a wide range of voltage rails while still maintaining an accurate current measurement.

7.1.1 R_{SENSE} and Device Gain Selection

The accuracy of any current-sense amplifier is maximized by choosing the largest current-sense resistor value possible. A larger value 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 value can be in a given application because of the physical dimensions of the package, package construction, and maximum power dissipation. Equation 2 gives the maximum value for the current-sense resistor for a given power dissipation budget:

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

where:

- PD_{MAX} is the maximum allowable power dissipation in R_{SENSE} .
- I_{MAX} is the maximum current that flows 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 verify that the current-sense signal is properly passed to the output, both positive and negative output swing limitations must be examined. Equation 3 provides the maximum values of R_{SENSE} and GAIN to keep the device from exceeding the positive swing limitation.

$$I_{MAX} \times R_{SENSE} \times GAIN < V_{SP} \quad (3)$$

where:

- I_{MAX} is the maximum current that flows through R_{SENSE} .
- GAIN is the gain of the current-sense amplifier.
- V_{SP} is the positive output swing of the device as specified in the [Specifications](#).

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 selecting a lower gain device is possible 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 4 provides the limit on the minimum value of the sense resistor.

$$I_{MIN} \times R_{SENSE} \times GAIN > V_{SN} \quad (4)$$

where:

- I_{MIN} is the minimum current that flows through R_{SENSE} .
- GAIN is the gain of the current-sense amplifier.
- V_{SN} is the negative output swing of the device as specified in the [Specifications](#).

Table 7-1 shows an example of the different results obtained from using five different gain versions of the INA299-Q1. From the table data, the highest gain device allows a smaller current-shunt resistor and decreased power dissipation in the element.

Table 7-1. R_{SENSE} Selection and Power Dissipation ⁽¹⁾

PARAMETER		EQUATION	RESULTS AT $V_S = 5V$		
			A1 DEVICES	A2 DEVICES	A3 DEVICES
G	Gain		20V/V	50V/V	100V/V
V_{SENSE}	Ideal differential input voltage	$V_{SENSE} = V_{OUT} / G$	250mV	100mV	50mV
R_{SENSE}	Current sense resistor value	$R_{SENSE} = V_{SENSE} / I_{MAX}$	25mΩ	10mΩ	5mΩ
P_{SENSE}	Current-sense resistor power dissipation	$R_{SENSE} \times I_{MAX}^2$	2.5W	1W	0.5W

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

7.2 Typical Application

The INA299-Q1 is a bidirectional, current-sense amplifier capable of measuring currents through a resistive shunt with common-mode voltages from $-2V$ to $+80V$.

7.2.1 High-side Current Sensing in Motor Application

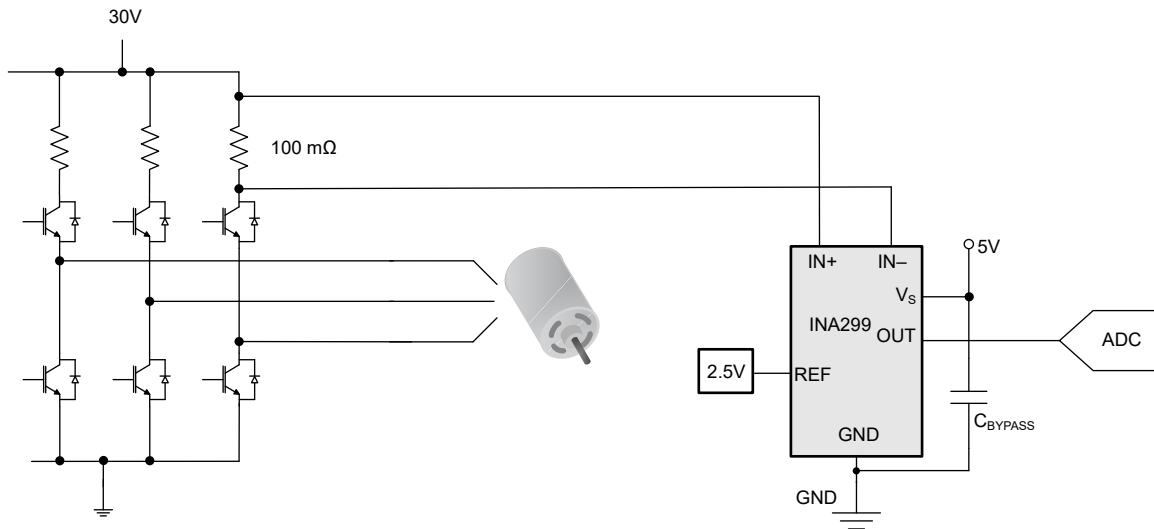


Figure 7-1. High-Side Motor Current-Sense Application Circuit

7.2.1.1 Design Requirements

In this example application, the common-mode voltage ranges from 0V to 30V. The maximum sense current is 0.5A, and a 5V supply is available for the INA299-Q1. Following the design guidelines from [R_{SENSE} and Device Gain Selection](#), a R_{SENSE} of 100mΩ and a gain of 50V/V are selected to provide good output dynamic range. Table 7-2 lists the design setup for this application.

Table 7-2. Design Parameters

DESIGN PARAMETERS	EXAMPLE VALUE
Power supply voltage	5V
Common mode voltage range	30V
Maximum sense current	0.5A
R_{SENSE} resistor	100mΩ

Table 7-2. Design Parameters (continued)

DESIGN PARAMETERS	EXAMPLE VALUE
Gain option	50V/V

7.2.1.2 Detailed Design Procedure

The INA299-Q1 is designed to measure a typical high-side current in motor application. The INA299-Q1 measures current across the 100mΩ shunt that is placed at supply in series with half-bridge driving a motor. The INA299-Q1 measures the differential voltage across the shunt resistor, and the signal is internally amplified with a gain of 50V/V. The output of the INA299-Q1 is connected to the analog-to-digital converter (ADC) of an MCU to digitize the current measurements.

Measuring current on the motor can provide indication of failure. Measuring high-side current also indicates if there are any ground faults on the motor or the FETs that can be damaged in an application. The INA299-Q1, with high bandwidth and slew rate, can be used to detect fast overcurrent conditions to prevent the motor damage from short-to-ground faults.

7.2.1.3 Application Curve

Figure 7-2 shows the current response of a motor.

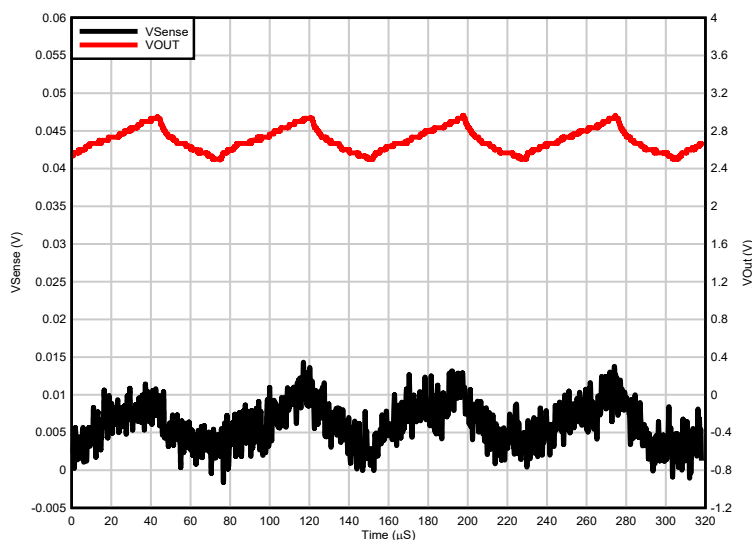


Figure 7-2. High-Side Motor Current Measurement

7.3 Power Supply Recommendations

The INA299-Q1 makes accurate measurements beyond the connected power-supply voltage (V_S) because the inputs (IN+ and IN–) can operate anywhere between –2V and +80V independent of V_S . For example, with the V_S power supply equal to 5V, the common-mode voltage of the measured shunt can be as high as +80V.

7.3.1 Power Supply Decoupling

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

7.4 Layout

7.4.1 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.

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

- Place the power-supply bypass capacitor as close to the device power supply and ground pins as possible. The recommended value of this bypass capacitor is 0.1 μ F. Additional decoupling capacitance can be added to compensate for noisy or high-impedance power supplies.

7.4.2 Layout Examples

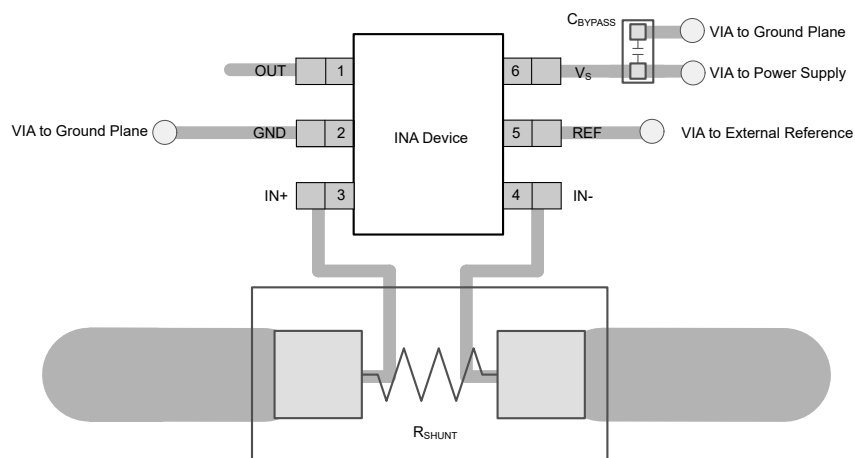


Figure 7-3. INA299-Q1 SOT-23 6-pin (DBV) Package Recommended Layout

8 Device and Documentation Support

8.1 Documentation Support

8.1.1 Related Documentation

For related documentation see the following: Texas Instruments,

- Texas Instruments, [INA299xEVM](#), EVM User's Guide

8.2 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.

8.3 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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8.5 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.

8.6 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

9 Revision History

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

DATE	REVISION	NOTES
July 2025	*	Initial Release

10 Mechanical, Packaging, and Orderable Information

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

PACKAGING INFORMATION

Orderable 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)
INA299A1QDBVRQ1	Active	Production	SOT-23 (DBV) 6	3000 LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	3NCF
INA299A2QDBVRQ1	Active	Production	SOT-23 (DBV) 6	3000 LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	3NEF
INA299A3QDBVRQ1	Active	Production	SOT-23 (DBV) 6	3000 LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	3NDF

⁽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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OTHER QUALIFIED VERSIONS OF INA299-Q1 :

- Catalog : [INA299](#)

NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product

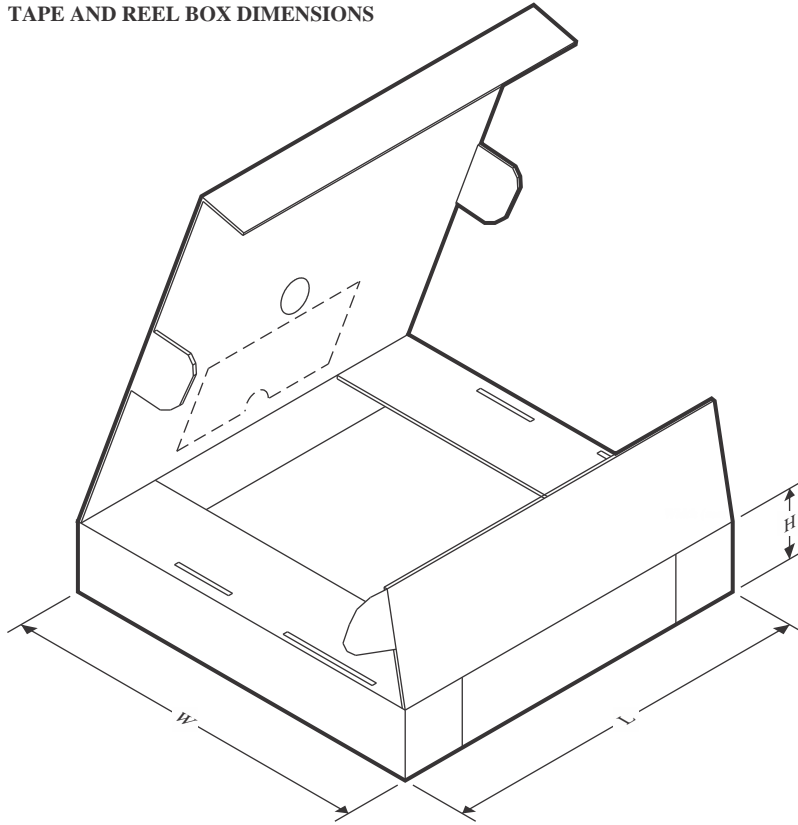
TAPE AND REEL INFORMATION



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
INA299A1QDBVRQ1	SOT-23	DBV	6	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA299A2QDBVRQ1	SOT-23	DBV	6	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA299A3QDBVRQ1	SOT-23	DBV	6	3000	180.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3

TAPE AND REEL BOX DIMENSIONS

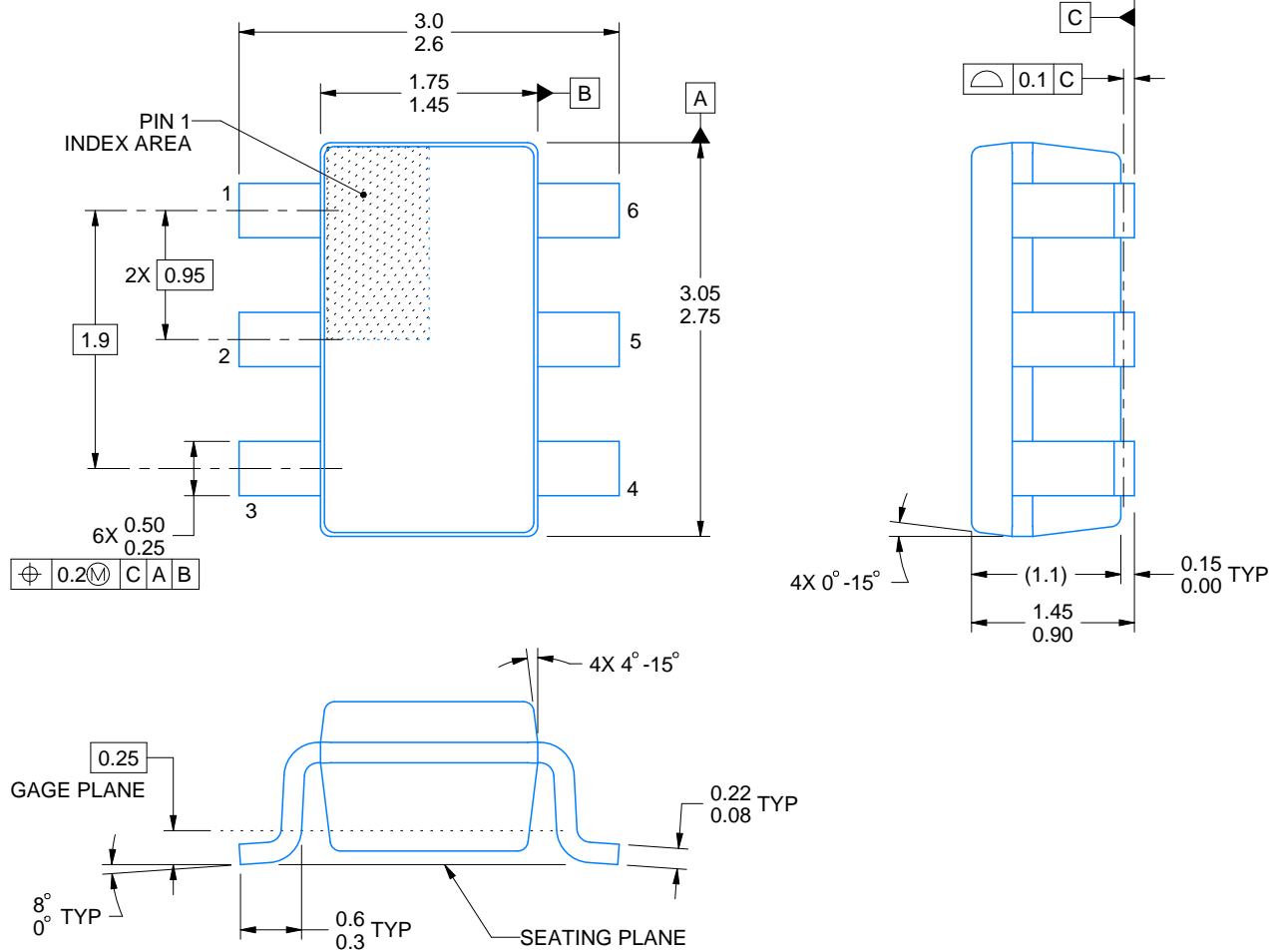


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA299A1QDBVRQ1	SOT-23	DBV	6	3000	210.0	185.0	35.0
INA299A2QDBVRQ1	SOT-23	DBV	6	3000	210.0	185.0	35.0
INA299A3QDBVRQ1	SOT-23	DBV	6	3000	210.0	185.0	35.0

DBV0006A**PACKAGE OUTLINE****SOT-23 - 1.45 mm max height**

SMALL OUTLINE TRANSISTOR



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NOTES:

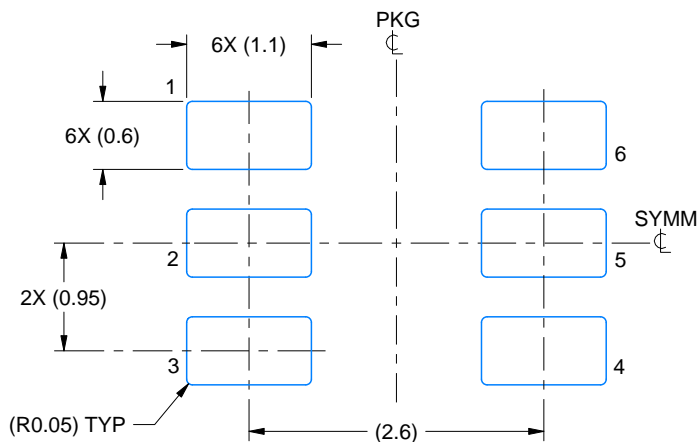
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.25 per side.
4. Leads 1,2,3 may be wider than leads 4,5,6 for package orientation.
5. Reference JEDEC MO-178.

EXAMPLE BOARD LAYOUT

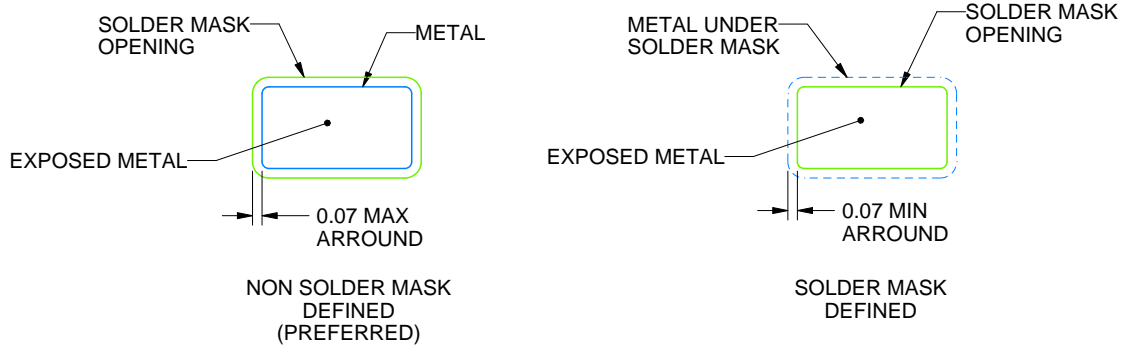
DBV0006A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



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.

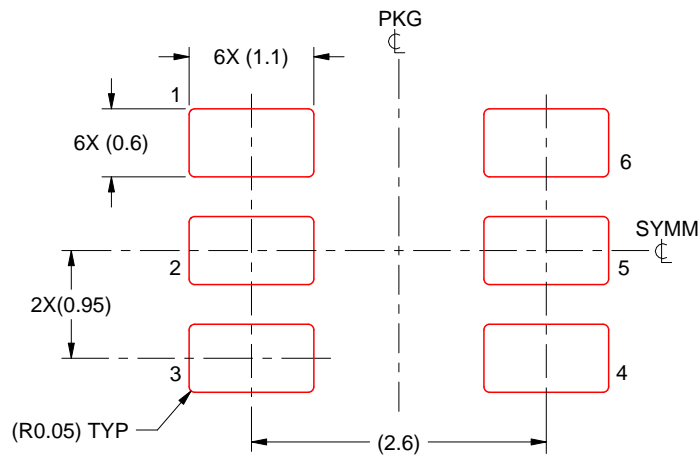
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

DBV0006A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



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

4214840/G 08/2024

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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