TEXAS INSTRUMENTS
INA302-Q1, INA303-Q1
SBOS977A – MARCH 2019 – REVISED MAY 2021

INA30x-Q1 AEC-Q100, 36-V, Bidirectional, 550-kHz, 4V/µs, High-Precision Current Sense Amplifier With Dual Window Comparator

1 Features

- AEC-Q100 qualified for automotive applications
  - Temperature grade 1: –40°C ≤ T_A ≤ +125°C
  - HBM ESD classification level 2
  - CDM ESD classification level C6
- Functional Safety-Capable
  - Documentation available to aid functional safety system design
- Wide common-mode input range: –0.1 V to +36 V
- Dual comparator outputs:
  - INA302-Q1: Two independent overlimit alerts
  - INA303-Q1: Window comparator
  - Threshold levels set individually
  - Comparator 1 alert response: 1 µs
  - Comparator 2 adjustable delay: 2 µs to 10 s
  - Open-drain outputs with independent latch control modes
- High accuracy amplifier:
  - Offset voltage: 30 µV (max, A3 version)
  - Offset voltage drift: 0.5 µV/°C (max)
  - Gain error: 0.15% (max, A3 version)
  - Gain error drift: 10 ppm/°C
- Available amplifier gains:
  - INA302A1-Q1, INA303A1-Q1: 20 V/V
  - INA302A2-Q1, INA303A2-Q1: 50 V/V
  - INA302A3-Q1, INA303A3-Q1: 100 V/V

2 Applications

- System fault detection
- Motor control and protection
- Pump control and protection
- DC/DC converters
- Body control module

3 Description

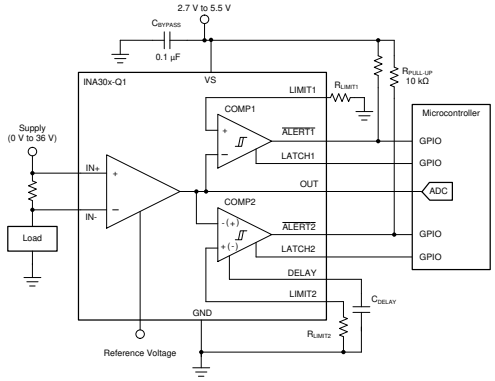
The INA302-Q1 and INA303-Q1 (INA30x-Q1) devices feature a high common-mode, bidirectional, current-sensing amplifier and two high-speed comparators to detect out-of-range current conditions. The INA302-Q1 comparators are configured to detect and respond to overcurrent conditions. The INA303-Q1 comparators are configured to respond to both overcurrent and undercurrent conditions in a windowed configuration. These devices feature an adjustable limit threshold range for each comparator set using an external limit-setting resistor. These current-shunt monitors can measure differential voltage signals on common-mode voltages that can vary from –0.1 V up to +36 V, independent of the supply. In addition, these devices will survive with common-mode voltages as high as 40 V.

The open-drain alert outputs can be configured to operate in either a transparent mode (output status follows the input state), or in a latched mode (alert output is cleared when the latch is reset). The alert response time for comparator 1 is under 1 µs, and the alert response for comparator 2 is set through an external capacitor ranging from 2 µs to 10 s.

These devices operate from a single 2.7-V to 5.5-V supply, drawing a maximum supply current of 950 µA. The devices are specified over the extended operating temperature range of –40°C to +125°C, and are available in a 14-pin TSSOP package.

Device Information

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA302-Q1	TSSOP (14)	4.40 mm × 5.00 mm
INA303-Q1		



Typical Application

Table of Contents

4 Revision History

Changes from Revision * (March 2019) to Revision A (May 2021)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document	1
• Added Functional Safety bullets	1

5 Pin Configuration and Functions

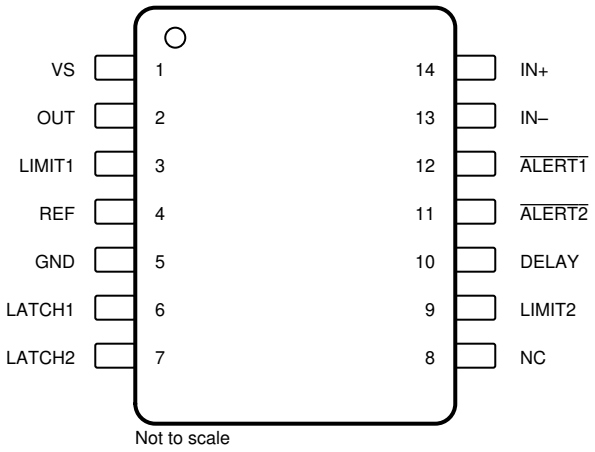


Figure 5-1. PW Package 14-Pin TSSOP Top View

Table 5-1. Pin Functions

PIN		TYPE	DESCRIPTION
NO.	NAME		
1	VS	Analog	Power supply, 2.7 V to 5.5 V
2	OUT	Analog output	Output voltage
3	LIMIT1	Analog input	$\overline{\text{ALERT1}}$ threshold limit input; see the *Setting Alert Thresholds* section for details on setting the limit threshold
4	REF	Analog input	Reference voltage, 0 V to VS
5	GND	Analog	Ground
6	LATCH1	Digital input	Transparent or latch mode selection input
7	LATCH2	Digital input	Transparent or latch mode selection input
8	NC	—	No internal connection
9	LIMIT2	Analog input	$\overline{\text{ALERT2}}$ threshold limit input; see the *Setting Alert Thresholds* section for details on setting the limit threshold
10	DELAY	Analog input	Delay timing input; see the *Alert Outputs* section for details on setting the delayed alert response for comparator 2
11	$\overline{\text{ALERT2}}$	Analog output	Open-drain output; active-low. This pin is an overlimit alert for the INA302-Q1 and an underlimit alert for the INA303-Q1.
12	$\overline{\text{ALERT1}}$	Analog output	Open-drain output, active-low overlimit alert
13	IN–	Analog input	Connect to load side of the current-sensing resistor
14	IN+	Analog input	Connect to supply side of the current-sensing resistor

6 Specifications

6.1 Absolute Maximum Ratings

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

			MIN	MAX	UNIT
V_S	Supply voltage			6	V
	Analog inputs (IN+, IN–)	Differential (V_{IN+}) – ($V_{IN–}$)(2)	–40	40	V
		Common-mode(3)	GND – 0.3	40	
	Analog input	LIMIT1, LIMIT2, DELAY, REF	GND – 0.3	(V_S) + 0.3	V
	Analog output	OUT	GND – 0.3	(V_S) + 0.3	V
	Digital input	LATCH1, LATCH2	GND – 0.3	(V_S) + 0.3	V
	Digital output	$\overline{\text{ALERT1}}$, $\overline{\text{ALERT2}}$	GND – 0.3	6	V
T_J	Junction temperature			150	°C
T_{stg}	Storage temperature		–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) V_{IN+} and $V_{IN–}$ are the voltages at the IN+ and IN– pins, respectively.
(3) Input voltage can exceed the voltage shown without causing damage to the device if the current at that pin is limited to 5 mA.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)	±3000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101(2)	±1500	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
V_{CM}	Common-mode input voltage	–0.1	12	36	V
V_S	Operating supply voltage	2.7	5	5.5	V
T_A	Operating free-air temperature	–40		125	°C

6.4 Thermal Information

THERMAL METRIC(1)		INA30x-Q1 PW (TSSOP) 14 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	110.2	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	35.1	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	53.2	°C/W
ψ_{JT}	Junction-to-top characterization parameter	2.3	°C/W
ψ_{JB}	Junction-to-board characterization parameter	52.4	°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_{SENSE} = 0 V, V_{REF} = V_S / 2, V_S = 5 V, V_{IN+} = 12 V, V_{LIMIT1} = 3 V, and V_{LIMIT2} = 3 V (INA302-Q1) or 2 V (INA303-Q1) (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{IN}	Differential input voltage range	V_{IN} = V_{IN+} – $V_{IN–}$, V_{REF} = V_S / 2, A1 versions	0		±125	mV
		V_{IN} = V_{IN+} – $V_{IN–}$, V_{REF} = V_S / 2, A2 versions	0		±50	
		V_{IN} = V_{IN+} – $V_{IN–}$, V_{REF} = V_S / 2, A3 versions	0		±25	
CMRR	Common-mode rejection ratio	V_{IN+} = 0 V to 36 V, T_A = –40°C to +125°C, A1 versions	100	114		dB
		V_{IN+} = 0 V to 36 V, T_A = –40°C to +125°C, A2 versions	106	118		
		V_{IN+} = 0 V to 36 V, T_A = –40°C to +125°C, A3 versions	110	120		
V_{OS}	Offset voltage, RTI[1]	A1 versions		±15	±80	µV
		A2 versions		±10	±50	
		A3 versions		±5	±30	
dV_{OS}/dT	Offset voltage drift, RTI[1]	T_A= –40°C to +125°C		0.02	0.25	µV/°C
PSRR	Power-supply rejection ratio	V_S = 2.7 V to 5.5 V, V_{IN+} = 12 V, T_A = –40°C to +125°C		±0.3	±5	µV/V
I_B	Input bias current	I_{B+}, $I_{B–}$		115		µA
I_{OS}	Input offset current	V_{SENSE} = 0 mV		±0.01		µA
OUTPUT						
G	Gain	A1 versions		20		V/V
		A2 versions		50		
		A3 versions		100		
	Gain error	V_{OUT} = 0.5 V to V_S – 0.5 V, A1 versions		±0.02%	±0.075%	
		V_{OUT} = 0.5 V to V_S – 0.5 V, A2 versions		±0.05%	±0.1%	
		V_{OUT} = 0.5 V to V_S – 0.5 V, A3 versions		±0.1%	±0.15%	
		T_A= –40°C to +125°C		3	10	ppm/°C
	Nonlinearity error	V_{OUT} = 0.5 V to V_S – 0.5 V		±0.01%		
	Maximum capacitive load	No sustained oscillation		500		pF
VOLTAGE OUTPUT						
	Swing to V_S power-supply rail	R_L = 10 kΩ to GND, T_A = –40°C to +125°C		V_S – 0.05	V_S – 0.1	V
	Swing to GND	R_L = 10 kΩ to GND, T_A = –40°C to +125°C		V_{GND} + 15	V_{GND} + 30	mV
FREQUENCY RESPONSE						
BW	Bandwidth	A1 versions, C_{OUT} = 500 pF		550		kHz
		A2 versions, C_{OUT} = 500 pF		440		
		A3 versions, C_{OUT} = 500 pF		400		
SR	Slew rate			4		V/µs
NOISE, RTI[1]						
	Voltage noise density			30		nV/√Hz

at T_A = 25°C, V_{SENSE} = 0 V, V_{REF} = V_S / 2, V_S = 5 V, V_{IN+} = 12 V, V_{LIMIT1} = 3 V, and V_{LIMIT2} = 3 V (INA302-Q1) or 2 V (INA303-Q1) (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
COMPARATOR						
t_p	Total alert propagation delay	Comparator 1, input overdrive = 1 mV		0.6	1	µs
		Comparator 2, input overdrive = 1 mV, delay = 100 kΩ to V_S		1.25	2	
	Slew-rate-limited t_p	Comparator 1, V_{OUT} step = 0.5 V to 4.5 V, V_{LIMIT} = 4 V		1	1.5	µs
		Comparator 2 (INA302-Q1), V_{OUT} step = 0.5 V to 4.5 V, V_{LIMIT} = 4 V, delay = 100 kΩ to V_S		1.5	2.5	
		Comparator 2 (INA303-Q1), V_{OUT} step = 4.5 V to 0.5 V, V_{LIMIT} = 1 V, delay = 100 kΩ to V_S		1.5	2.5	
I_{LIMIT1}	Limit threshold output current, comparator 1	T_A = 25°C, V_{LIMIT1} < V_S – 0.6 V	79.2	80	80.8	µA
		T_A = –40°C to +125°C, V_{LIMIT1} < V_S – 0.6 V	78.4		81.6	
I_{LIMIT2}	Limit threshold output current, comparator 2	T_A = 25°C, V_{LIMIT2} < V_S – 0.6 V	79.7	80	80.4	µA
		T_A = –40°C to +125°C, V_{LIMIT2} < V_S – 0.6 V	79.2		80.8	
V_{OS}	Offset voltage, both comparators	A1 versions		0.5	3.5	mV
		A2 versions		0.5	3.5	
		A3 versions		0.5	4.0	
HYS	Hysteresis	comparator 1, comparator 2		100		mV
	Internal programmable delay error	T_A = –40°C to +125°C			4%	
V_{TH}	Delay threshold voltage	T_A = –40°C to +125°C	1.21	1.22	1.23	V
I_D	Delay charging current	T_A = –40°C to +125°C, V_{DELAY} = 0.6 V	4.85	5	5.15	µA
R_D	Delay discharge resistance			70		Ω
V_{IH}	LATCH1, LATCH2 high-level input voltage	T_A = –40°C to +125°C	1.4		6	V
V_{IL}	LATCH1, LATCH2 low-level input voltage	T_A = –40°C to +125°C	0		0.4	V
V_{OL}	Alert low-level output voltage	I_{OL} = 3 mA, T_A = –40°C to +125°C		70	400	mV
	$\overline{ALERT1}$, $\overline{ALERT2}$ pin leakage input current	V_{OH} = 3.3 V		0.1	1	µA
	LATCH1, LATCH2 digital leakage input current	0 V ≤ V_{LATCH1} , V_{LATCH2} ≤ V_S		1		µA
POWER SUPPLY						
I_Q	Quiescent current	T_A = 25°C		850	950	µA
		T_A = –40°C to +125°C			1150	

(1) RTI = referred-to-input.

6.6 Typical Characteristics

at T_A = 25°C, V_{REF} = V_S / 2, V_{SENSE} = 0 V, V_S = 5 V, V_{IN+} = 12 V, and $\overline{ALERT1}$, $\overline{ALERT2}$ pullup resistors = 10 kΩ (unless otherwise noted)

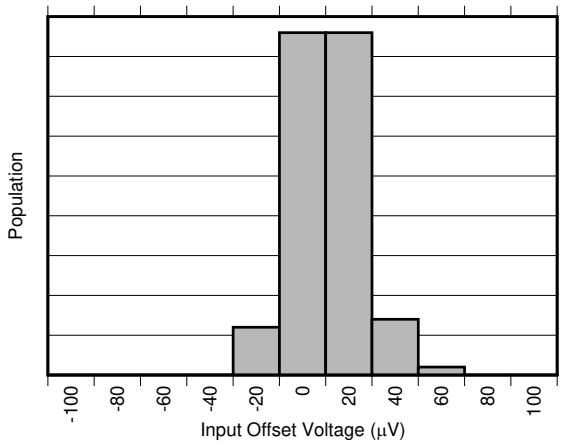


Figure 6-1. Input Offset Voltage Distribution (INA30xA1-Q1)

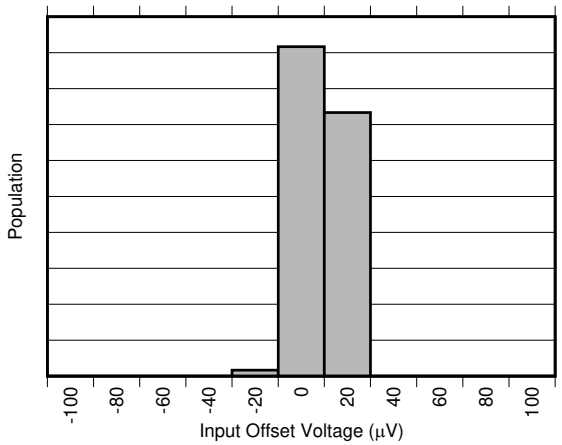


Figure 6-2. Input Offset Voltage Distribution (INA30xA2-Q1)

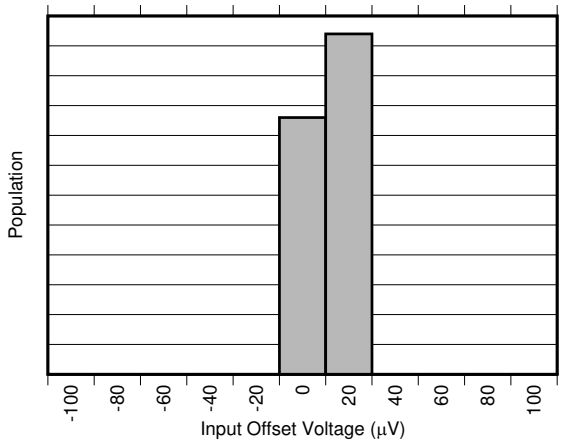


Figure 6-3. Input Offset Voltage Distribution (INA30xA3-Q1)

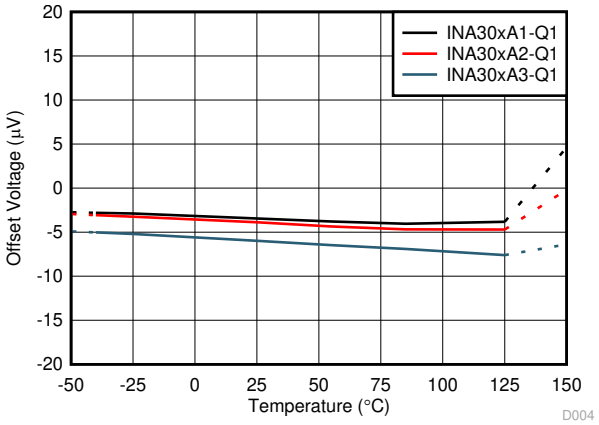


Figure 6-4. Input Offset Voltage vs. Temperature

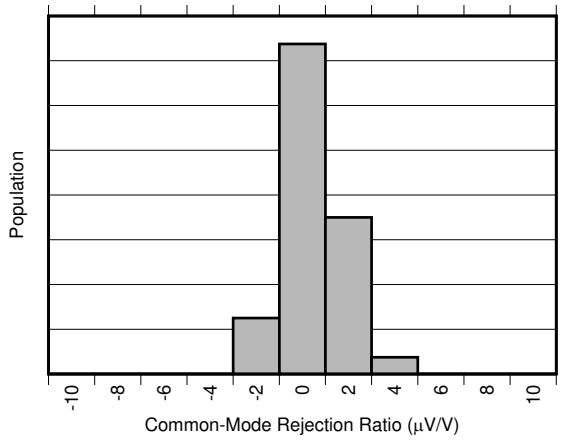


Figure 6-5. CMRR Distribution (INA30xA1-Q1)

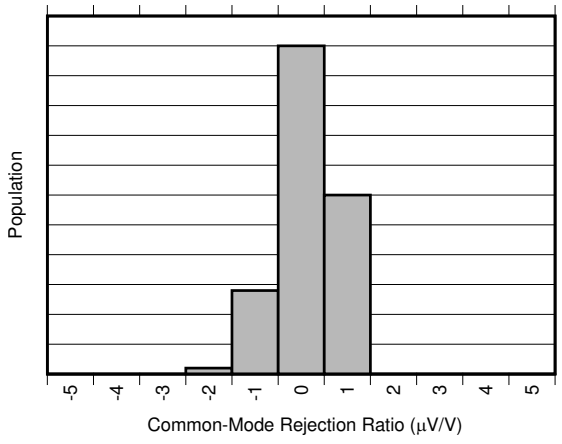


Figure 6-6. CMRR Distribution (INA30xA2-Q1)

6.6 Typical Characteristics (continued)

at T_A = 25°C, V_{REF} = V_S / 2, V_{SENSE} = 0 V, V_S = 5 V, V_{IN+} = 12 V, and $\overline{ALERT1}$, $\overline{ALERT2}$ pullup resistors = 10 kΩ (unless otherwise noted)

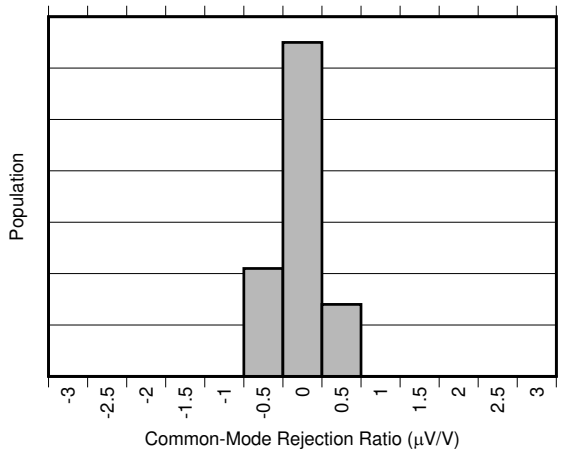


Figure 6-7. CMRR Distribution (INA30xA3-Q1)

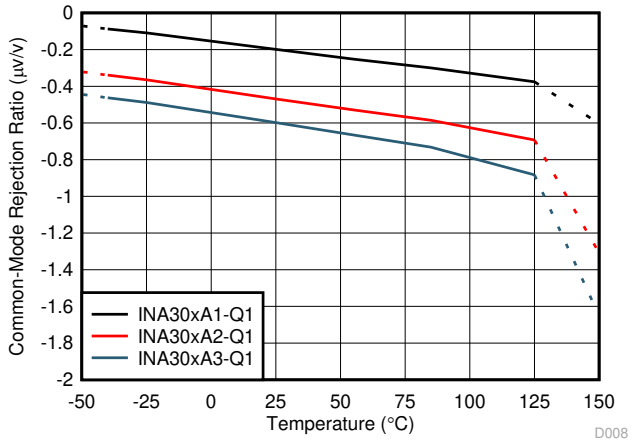


Figure 6-8. CMRR vs. Temperature

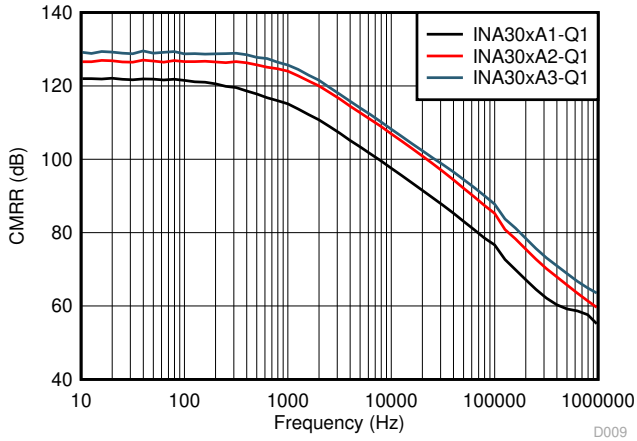


Figure 6-9. CMRR vs. Frequency

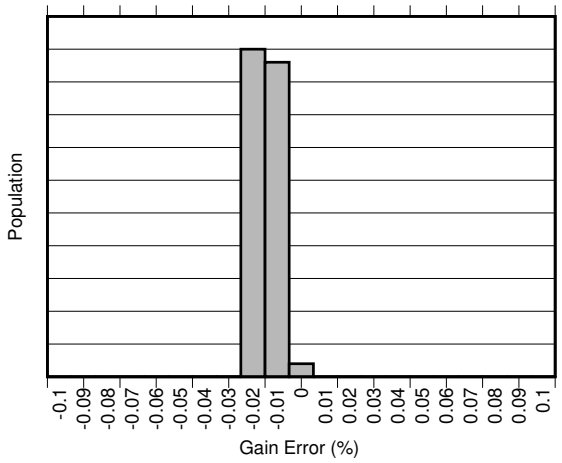


Figure 6-10. Gain Error Distribution (INA30xA1-Q1)

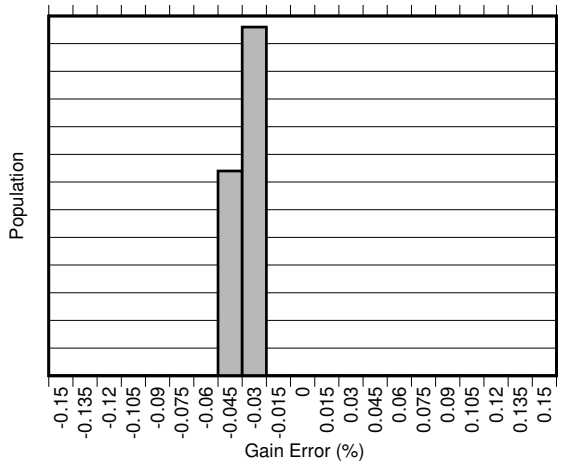


Figure 6-11. Gain Error Distribution (INA30xA2-Q1)

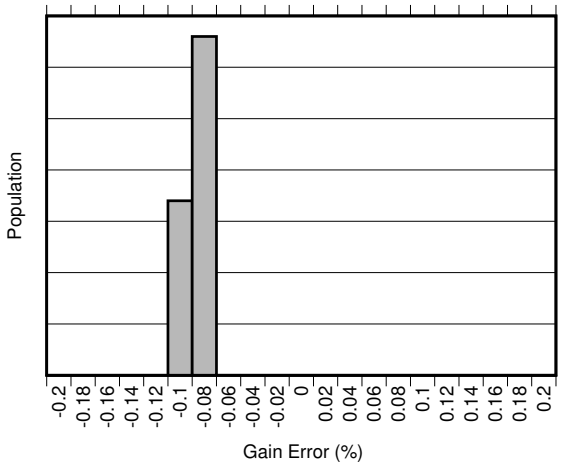


Figure 6-12. Gain Error Distribution (INA30xA3-Q1)

6.6 Typical Characteristics (continued)

at T_A = 25°C, V_{REF} = V_S / 2, V_{SENSE} = 0 V, V_S = 5 V, V_{IN+} = 12 V, and $\overline{ALERT1}$, $\overline{ALERT2}$ pullup resistors = 10 kΩ (unless otherwise noted)

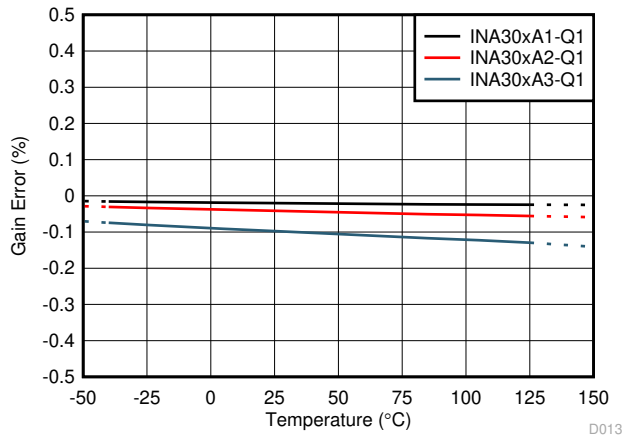


Figure 6-13. Gain Error vs. Temperature

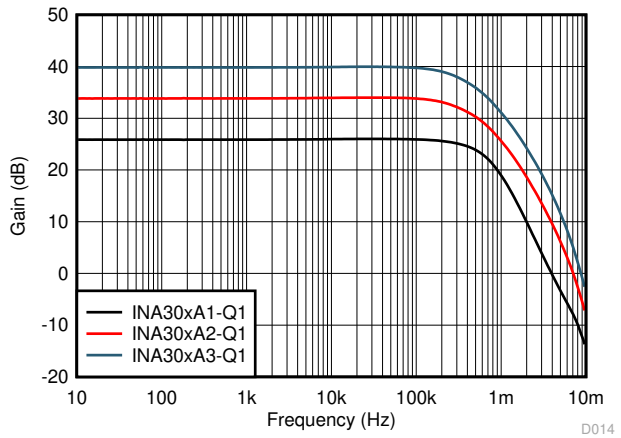


Figure 6-14. Gain vs. Frequency

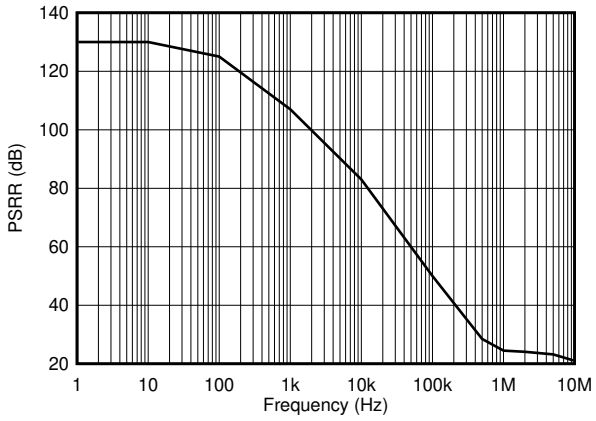


Figure 6-15. PSRR vs. Frequency

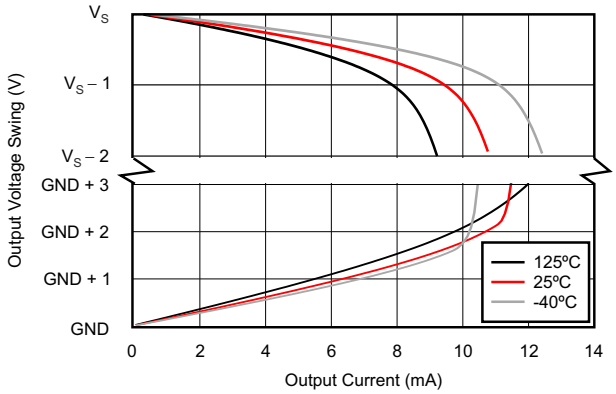
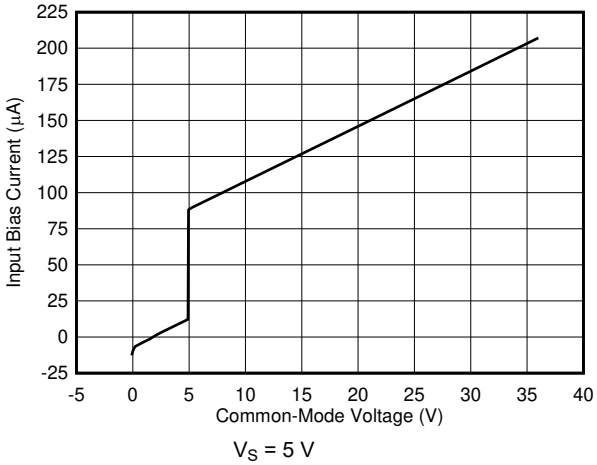
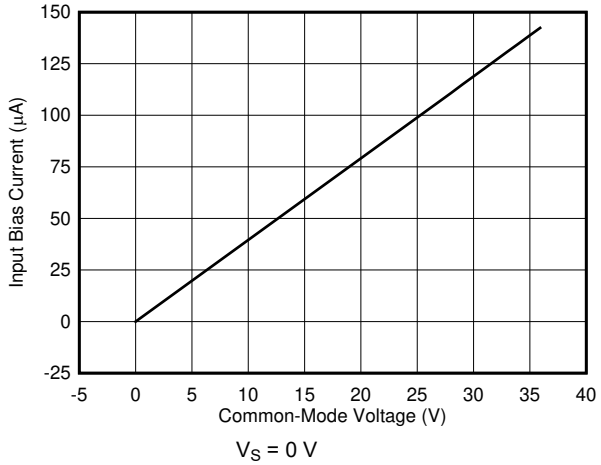


Figure 6-16. Output Voltage Swing vs. Output Current



V_S = 5 V

Figure 6-17. Input Bias Current vs. Common-Mode Voltage



V_S = 0 V

Figure 6-18. Input Bias Current vs. Common-Mode Voltage

6.6 Typical Characteristics (continued)

at T_A = 25°C, V_{REF} = V_S / 2, V_{SENSE} = 0 V, V_S = 5 V, V_{IN+} = 12 V, and $\overline{ALERT1}$, $\overline{ALERT2}$ pullup resistors = 10 kΩ (unless otherwise noted)

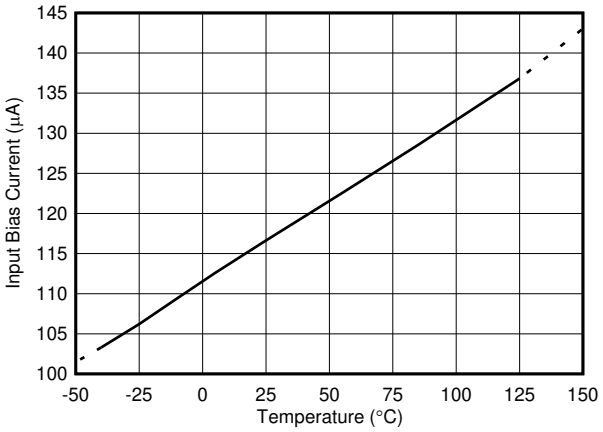


Figure 6-19. Input Bias Current vs. Temperature

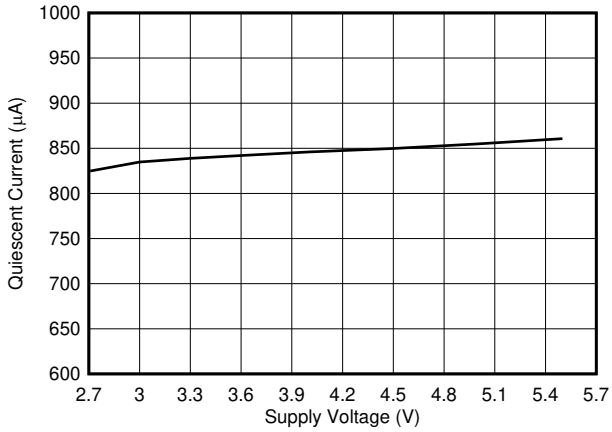


Figure 6-20. Quiescent Current vs. Supply Voltage

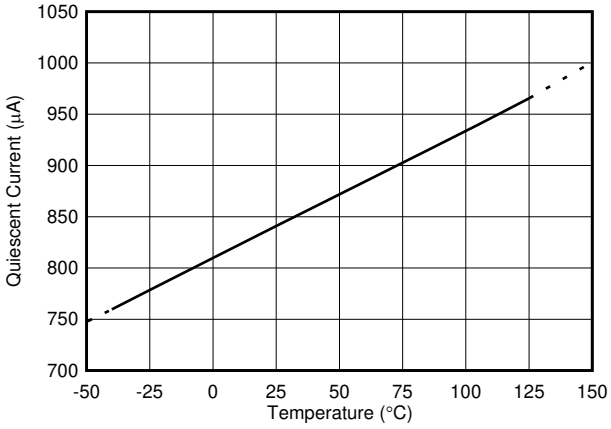


Figure 6-21. Quiescent Current vs. Temperature

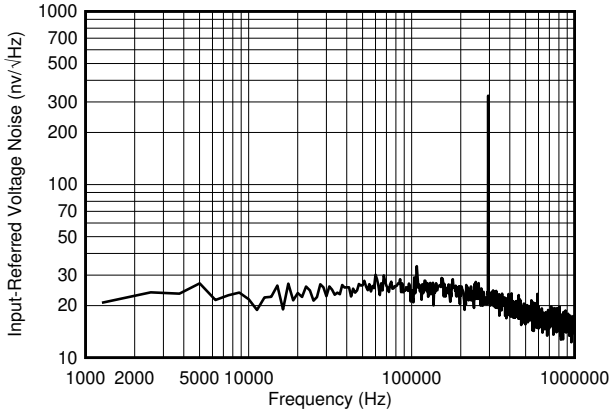


Figure 6-22. Input-Referred Voltage Noise vs. Frequency

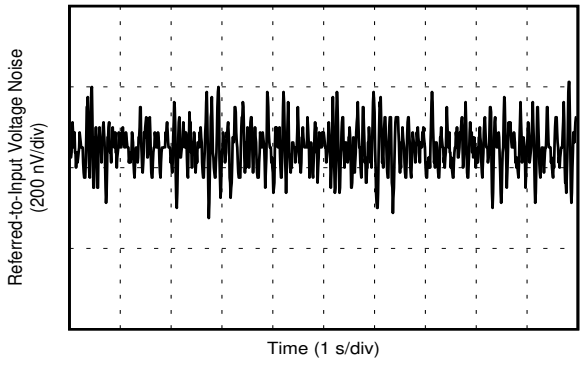
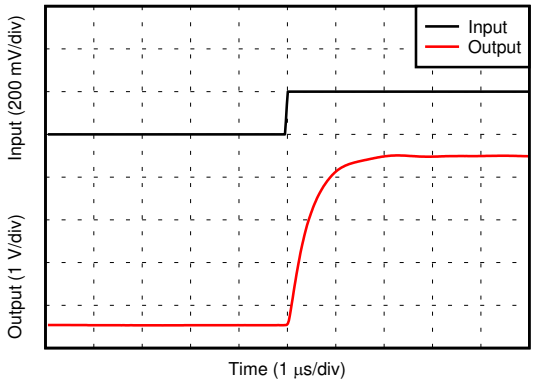


Figure 6-23. 0.1-Hz to 10-Hz Voltage Noise (Referred to Input)



4-V_{PP} output step

Figure 6-24. Voltage Output Rising Step Response

6.6 Typical Characteristics (continued)

at T_A = 25°C, V_{REF} = V_S / 2, V_{SENSE} = 0 V, V_S = 5 V, V_{IN+} = 12 V, and $\overline{ALERT1}$, $\overline{ALERT2}$ pullup resistors = 10 kΩ (unless otherwise noted)

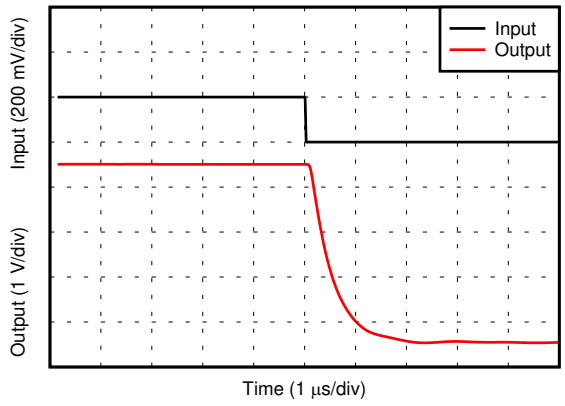


Figure 6-25. Voltage Output Falling Step Response

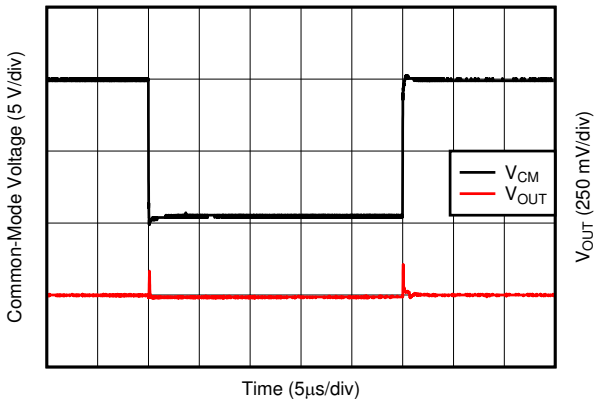


Figure 6-26. Common-Mode Voltage Transient Response

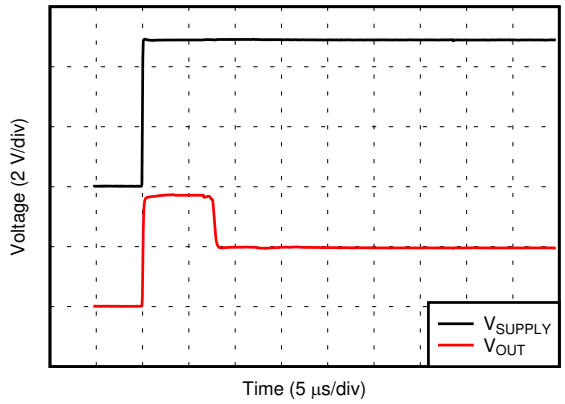


Figure 6-27. Start-Up Response

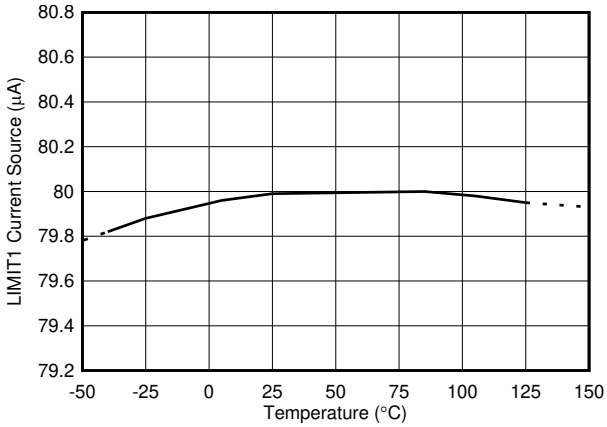


Figure 6-28. LIMIT1 Current Source vs. Temperature

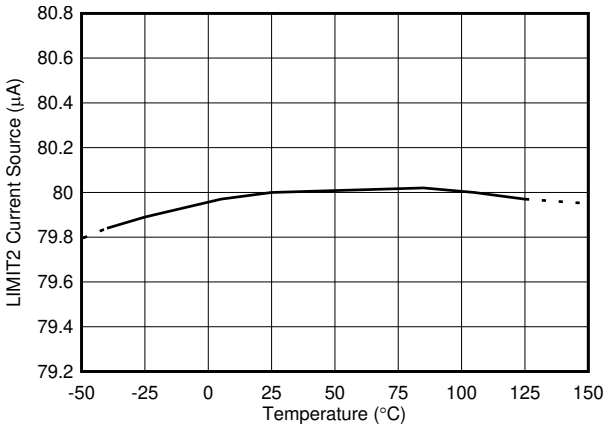


Figure 6-29. LIMIT2 Current Source vs. Temperature

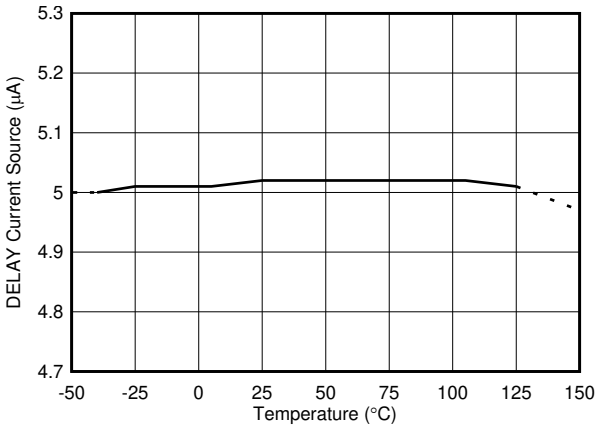


Figure 6-30. DELAY Current vs. Temperature

6.6 Typical Characteristics (continued)

at T_A = 25°C, V_{REF} = V_S / 2, V_{SENSE} = 0 V, V_S = 5 V, V_{IN+} = 12 V, and $\overline{ALERT1}$, $\overline{ALERT2}$ pullup resistors = 10 kΩ (unless otherwise noted)

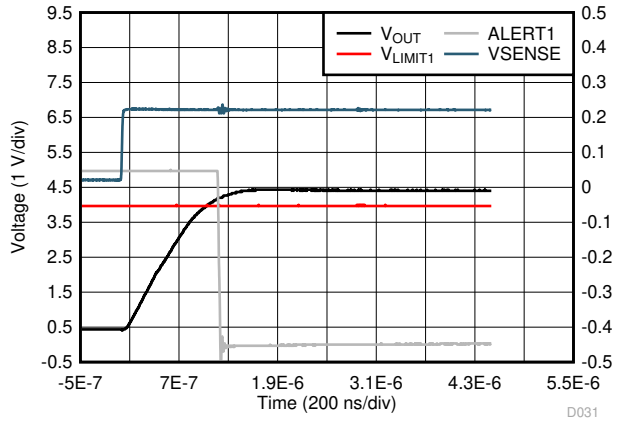
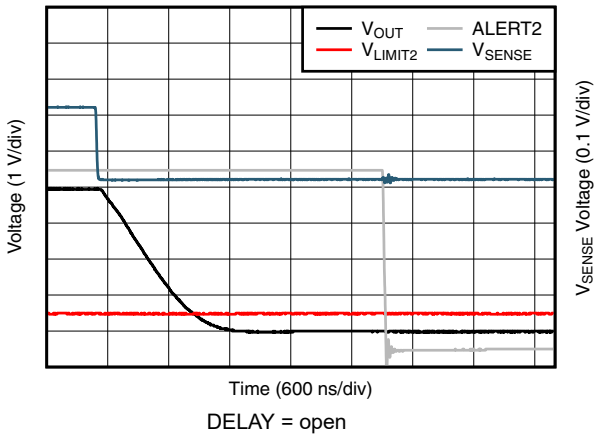
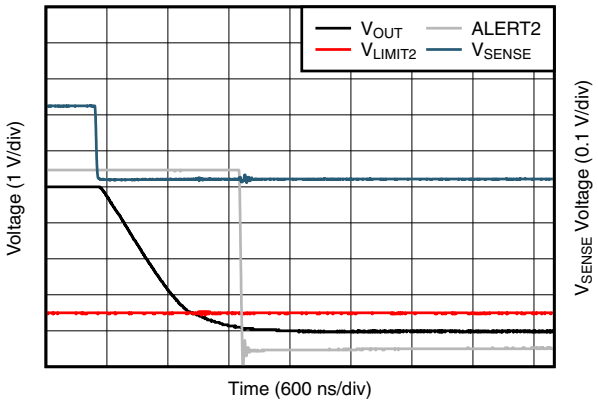


Figure 6-31. Comparator 1 Total Propagation Delay (INA30x-Q1)



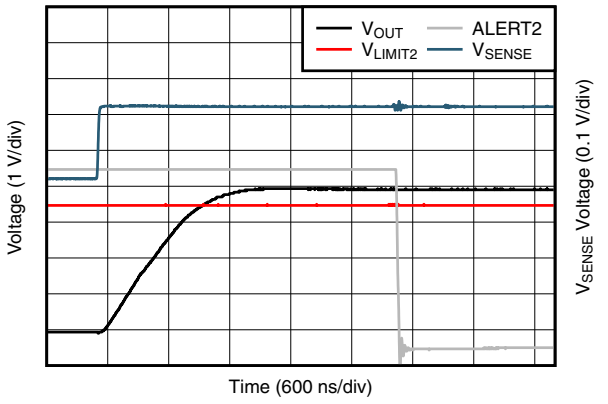
DELAY = open

Figure 6-32. Comparator 2 Total Propagation Delay (INA303-Q1)



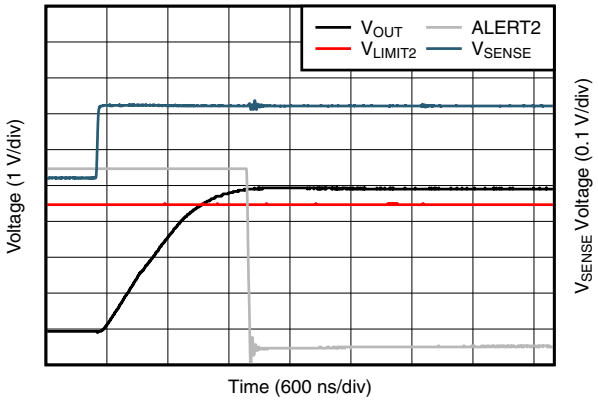
DELAY = 100 kΩ to V_S

Figure 6-33. Comparator 2 Total Propagation Delay (INA303-Q1)



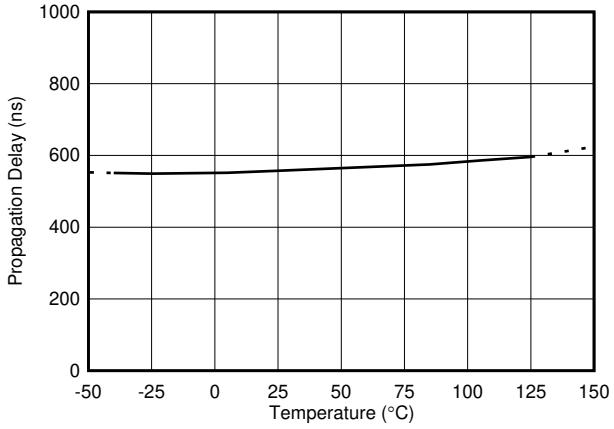
DELAY = open

Figure 6-34. Comparator 2 Total Propagation Delay (INA302-Q1)



DELAY = 100 kΩ to V_S

Figure 6-35. Comparator 2 Total Propagation Delay (INA302-Q1)



V_{OD} = 1 mV

Figure 6-36. Comparator 1 Propagation Delay vs. Temperature

6.6 Typical Characteristics (continued)

at T_A = 25°C, V_{REF} = V_S / 2, V_{SENSE} = 0 V, V_S = 5 V, V_{IN+} = 12 V, and $\overline{ALERT1}$, $\overline{ALERT2}$ pullup resistors = 10 kΩ (unless otherwise noted)

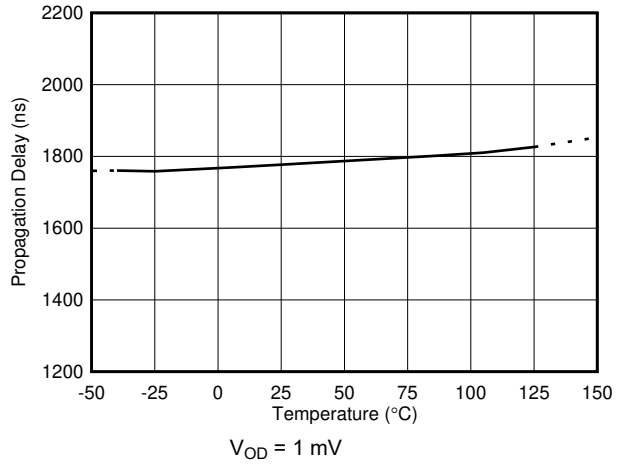


Figure 6-37. Comparator 2 Propagation Delay vs. Temperature

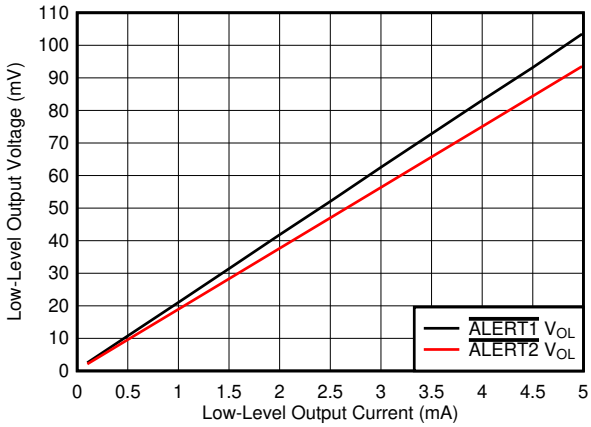


Figure 6-38. Comparator Alert V_{OL} vs. I_{OL}

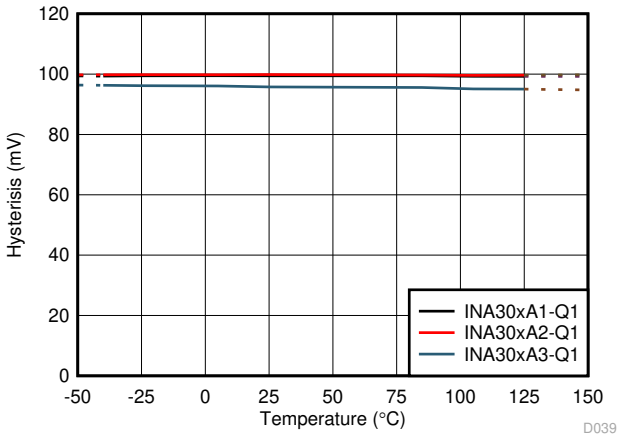


Figure 6-39. Comparator 1 Hysteresis vs. Temperature

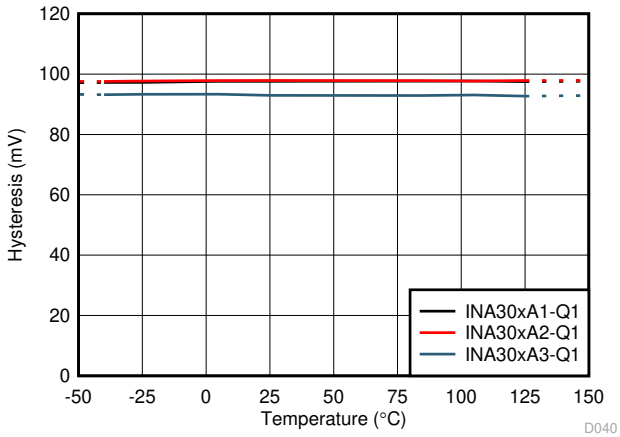


Figure 6-40. Comparator 2 Hysteresis vs. Temperature

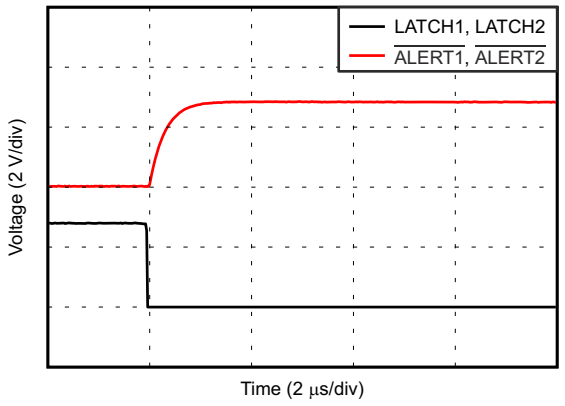


Figure 6-41. Comparator Latch Response

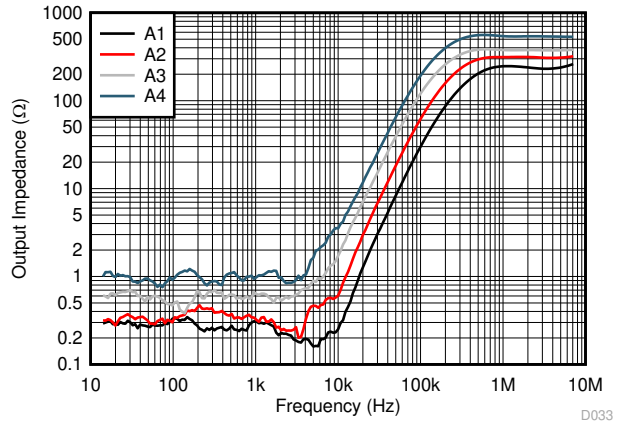


Figure 6-42. Output Impedance vs. Frequency

7 Detailed Description

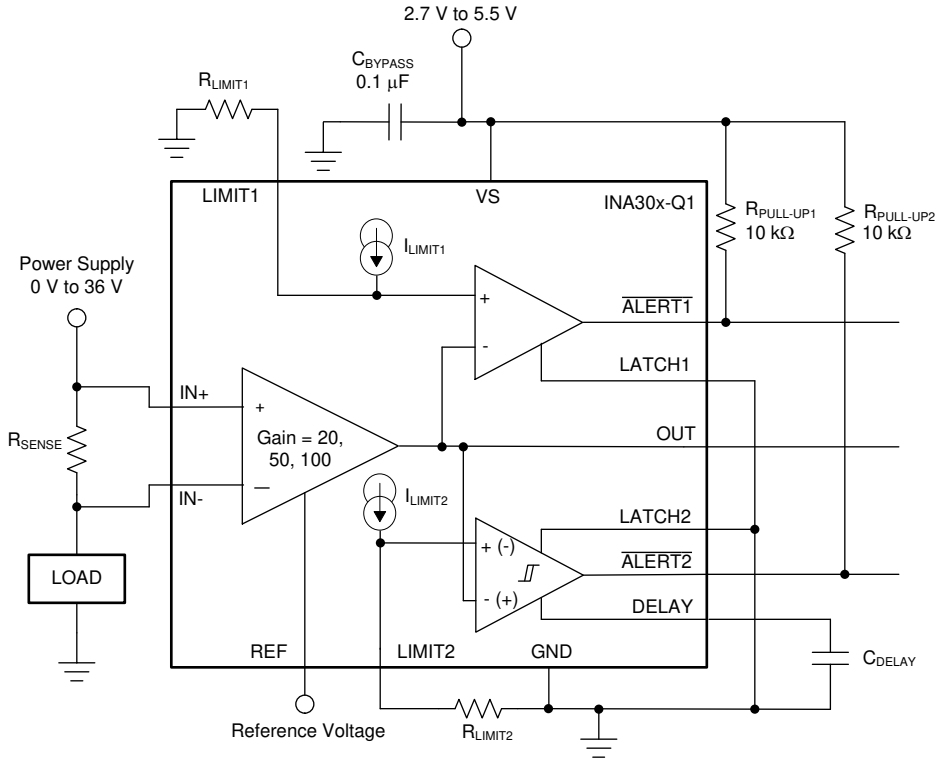
7.1 Overview

The INA30x-Q1 feature a zero-drift, 36-V, common-mode, bidirectional, current-sensing amplifier, and two high-speed comparators that can detect multiple out-of-range current conditions. These specially designed, current-sensing amplifiers can be used in both low-side or high-side applications where common-mode voltages far exceed the supply voltage of the device. Currents are measured by accurately sensing voltages developed across current-sensing resistors (also known as *current-shunt resistors*). Current can be measured on input voltage rails as high as 36 V, and the device can be powered from supply voltages as low as 2.7 V.

The zero-drift topology enables high-precision measurements with maximum input offset voltages as low as 30 µV (max) with a temperature contribution of only 0.25 µV/°C (max) over the full temperature range of –40°C to +125°C. The low total offset voltage of the INA302-Q1 enables smaller current-sense resistor values to be used, improving power-efficiency without sacrificing measurement accuracy resulting from the smaller input signal.

Both devices use a single external resistor to set each out-of-range threshold. The INA302-Q1 allows for two overcurrent thresholds, and the INA303-Q1 allows for both an undercurrent and overcurrent threshold. The response time of the $\overline{\text{ALERT1}}$ threshold is fixed and is less than 1 µs. The response time of the $\overline{\text{ALERT2}}$ threshold can be set with an external capacitor. The combination of a precision current-sense amplifier with onboard comparators creates a highly-accurate solution that is capable of fast detection of multiple out-of-range conditions. The ability to detect when currents are out-of-range allows the system to take corrective actions to prevent potential component or system-wide damage.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Bidirectional Current Sensing

The INA30x-Q1 sense current flow through a sense resistor in both directions. The bidirectional current-sensing capability is achieved by applying a voltage at the REF pin to offset the output voltage. A positive differential voltage sensed at the inputs results in an output voltage that is greater than the applied reference voltage. Likewise, a negative differential voltage at the inputs results in output voltage that is less than the applied reference voltage. The equation for the output voltage of the current-sense amplifier is shown in Equation 1.

$$V_{OUT} = (I_{LOAD} \times R_{SENSE} \times GAIN) + V_{REF} \quad (1)$$

where

- I_{LOAD} is the load current to be monitored.
- R_{SENSE} is the current-sense resistor.
- GAIN is the gain option of the device selected.
- V_{REF} is the voltage applied to the REF pin.

7.3.2 Out-of-Range Detection

The INA303-Q1 detects when negative currents are out-of-range by setting a voltage at the LIMIT2 pin that is less than the applied reference voltage. The limit voltage is set with an external resistor or externally driven by a voltage source or digital-to-analog converter (DAC); see the *Setting Alert Thresholds* section for additional information. A typical application using the INA303-Q1 to detect negative overcurrent conditions is illustrated in the *Typical Application* section.

7.3.3 Alert Outputs

Both $\overline{\text{ALERTx}}$ pins are active-low, open-drain outputs that pull low when the sensed current is detected to be out of range. Both open-drain $\overline{\text{ALERTx}}$ pins require an external pullup resistor to an external supply. The external supply for the pullup voltage can exceed the supply voltage, V_S, but is restricted from operating at greater than 5.5 V. The pullup resistance is selected based on the capacitive load and required rise time; however, a 10-kΩ resistor value is typically sufficient for most applications. The response time of the $\overline{\text{ALERT1}}$ output to an out-of-range event is less than 1 µs, and the response time of the $\overline{\text{ALERT2}}$ output is proportional to the value of the external C_{DELAY} capacitor. The equation to calculate the delay time for the $\overline{\text{ALERT2}}$ output is given in Equation 2:

$$t_{DELAY} = \begin{cases} 1.5\ \mu s & \text{If DELAY is connected to VS with 100 k}\Omega \\ \dfrac{C_{DELAY} \times V_{TH}}{I_D} + 2.5\ \mu s & \text{If } C_{DELAY} \geq 47\ \text{pF} \end{cases} \quad (2)$$

where

- C_{DELAY} is the external delay capacitor.
- V_{TH} is the delay threshold voltage.
- I_D is the DELAY pin current for comparator 2.

For example, if a delay time of 10 µs is desired, the calculated value for C_{DELAY} is 30.7 pF. The closest standard capacitor value to the calculated value is 30 pF. If a delay time greater than 2.5 µs on the $\overline{\text{ALERT2}}$ output is not needed, the C_{DELAY} capacitor can be omitted. To achieve minimum delay on the $\overline{\text{ALERT2}}$ output, connect a 100-kΩ resistor from the DELAY pin to the VS pin. Both comparators in the INA30x-Q1 have hysteresis to avoid oscillations in the $\overline{\text{ALERTx}}$ outputs. The effect hysteresis has on the comparator behavior is described in the *Hysteresis* section.

Figure 7-1 shows the alert output response of the internal comparators for the INA302-Q1. When the output voltage of the current-sense amplifier is less than the voltage developed on either limit pin, both $\overline{\text{ALERTx}}$ outputs are in the default high state. When the current sense amplifier output is greater than the threshold voltage set by the LIMIT2 pin, the $\overline{\text{ALERT2}}$ output pulls low after a delay time set by the external delay capacitor. The lower overcurrent threshold is commonly referred to as the *overcurrent warning threshold*. If the current continues to rise until the current-sense amplifier output voltage exceeds the threshold voltage set at the LIMIT1 pin, then the $\overline{\text{ALERT1}}$ output becomes active and immediately pulls low. The low voltage on $\overline{\text{ALERT1}}$ indicates that the measured signal at the amplifier input has exceeded the programmed threshold level, indicating an overcurrent condition has occurred. The upper threshold is commonly referred to as the *fault* or *system critical threshold*. Systems often initiate protection procedures (such as a system shutdown) when the current exceeds this threshold.

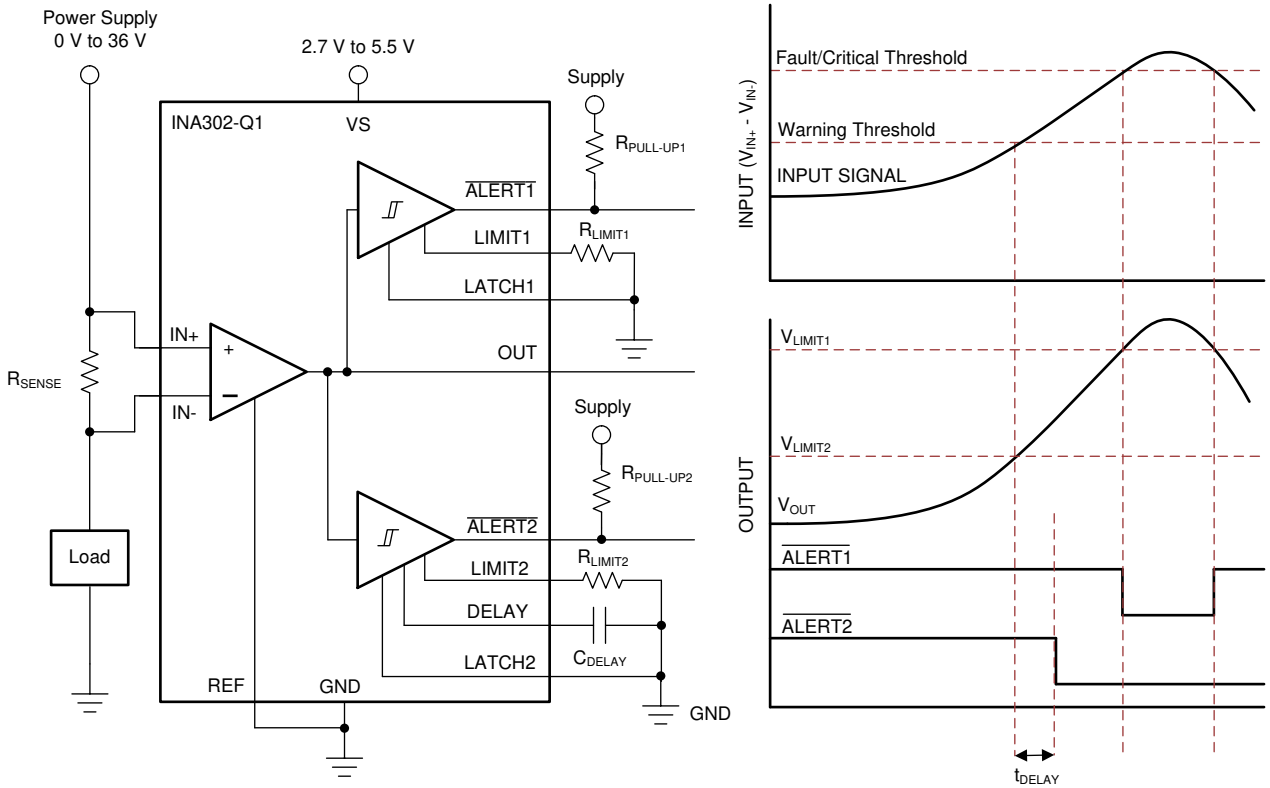


Figure 7-1. Out-of-Range Alert Responses for the INA302-Q1

Figure 7-2 shows the alert output response of the internal comparators for the INA303-Q1. Both $\overline{\text{ALERT}}$x outputs are in the default high state when the output voltage of the current-sense amplifier is less than the voltage developed at the LIMIT1 pin and is greater than the voltage developed at the LIMIT2 pin. The $\overline{\text{ALERT1}}$ output becomes active and pulls low when the current-sense amplifier output voltage exceeds the threshold voltage set at the LIMIT1 pin. The low voltage on $\overline{\text{ALERT1}}$ indicates that the measured signal at the amplifier input has exceeded the programmed threshold level, indicating an overcurrent or out-of-range condition has occurred. When the current-sense amplifier output is less than the threshold voltage set by the LIMIT2 pin, the $\overline{\text{ALERT2}}$ output pulls low after the delay time set by the external delay capacitor expires. The delay time for the $\overline{\text{ALERT2}}$ output is proportional to the value of the external C_{DELAY} capacitor, and is calculated by Equation 2.

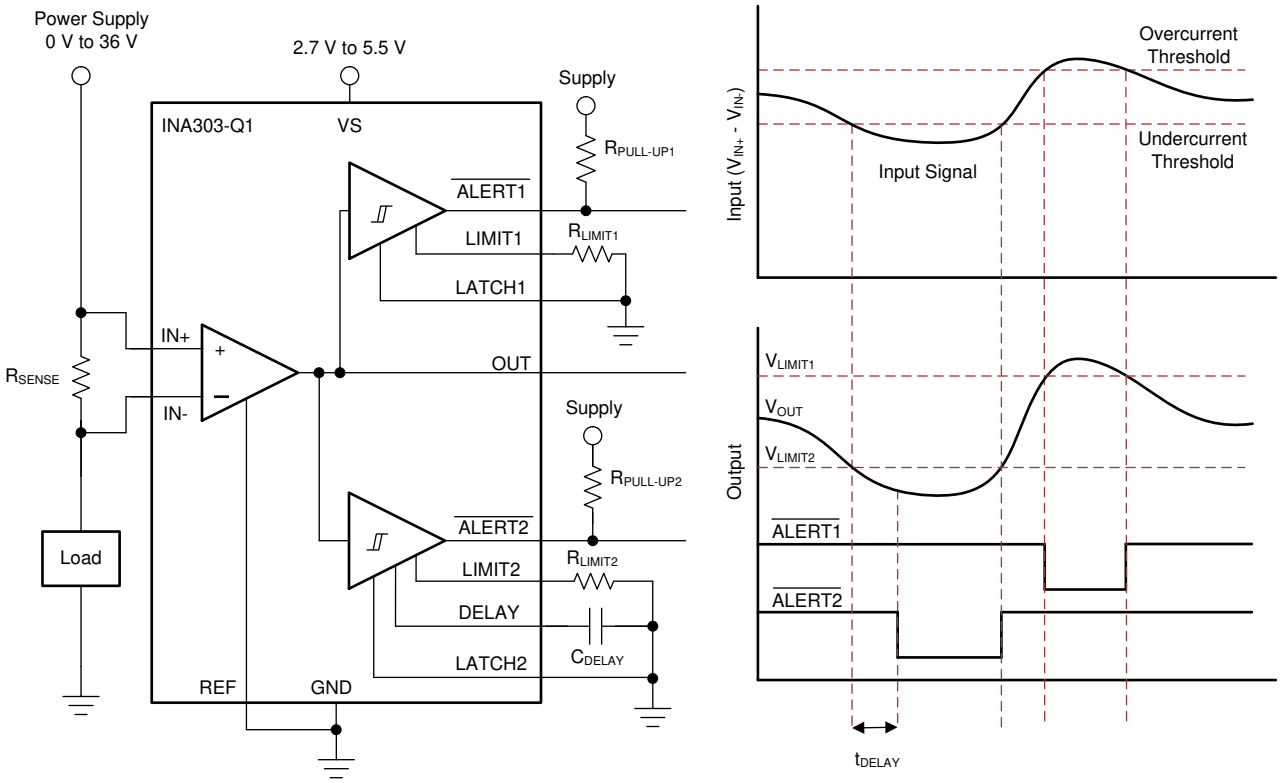


Figure 7-2. Out-of-Range Alert Responses for the INA303-Q1

Figure 7-3 shows the alert output response of the INA303-Q1 when the two $\overline{\text{ALERT}}$x pins are connected together. When configured in this manner, the INA303-Q1 can provide a single signal to indicate when the sensed current is operating either outside the normal operating bands or within a normal operational window. Both $\overline{\text{ALERT1}}$ and $\overline{\text{ALERT2}}$ outputs behave the same in regard to the alert mode. The difference with $\overline{\text{ALERT2}}$ is that the transition of the output state is delayed by the time set by the external delay capacitor. If the overcurrent or undercurrent event is not present when the delay time expires, $\overline{\text{ALERT2}}$ does not respond.

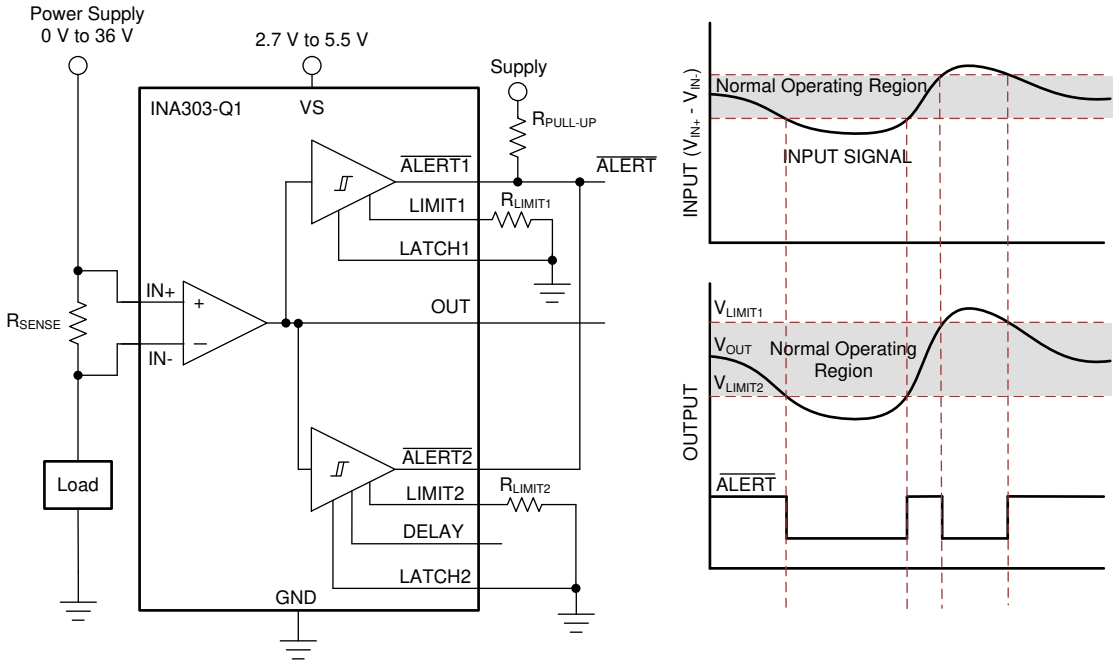


Figure 7-3. Current Window Comparator Implementation With the INA303-Q1

7.3.3.1 Setting Alert Thresholds

The INA30x-Q1 family of devices determines if an out-of-range event is present by comparing the amplifier output voltage to the voltage at the corresponding LIMITx pin. The threshold voltage for the LIMITx pins can be set using a single external resistor or by connecting an external voltage source to each pin. The INA302-Q1 allows setting limits for two overcurrent conditions. Generally, the lower overcurrent threshold is referred to as a *warning limit* and the higher overcurrent threshold is referred to as the *critical* or *fault limit*. The INA303-Q1 allows setting thresholds to detect both undercurrent and overcurrent limit conditions.

7.3.3.1.1 Resistor-Controlled Current Limit

The typical approach to set the limit threshold voltage is to connect resistors from the two LIMITx pins to ground. The voltage developed across the R_{LIMIT1}, R_{LIMIT2} resistors represents the desired fault current value at which the corresponding $\overline{ALERTx}$ pin becomes active. The values for the R_{LIMIT1}, R_{LIMIT2} resistors are calculated using Equation 3:

$$R_{LIMIT} = \frac{(I_{TRIP} \times R_{SENSE} \times GAIN) + V_{REF}}{I_{LIMIT}} \quad (3)$$

where

- I_{TRIP} is the desired out-of-range current threshold.
- R_{SENSE} is the current-sensing resistor.
- GAIN is the gain option of the device selected.
- V_{REF} is the voltage applied to the REF pin.
- I_{LIMIT} is the limit threshold output current for the selected comparator, typically 80 µA.

Note

When solving for the value of R_{LIMIT}, the voltage at the corresponding LIMITx pin as determined by the product of R_{LIMIT} and I_{LIMIT} must not exceed the compliance voltage of V_S – 0.6 V.

7.3.3.1.1.1 Resistor-Controlled Current Limit: Example

For example, if the current level indicating an out-of-range condition (I_{TRIP}) is 20 A and the current-sense resistor value (R_{SENSE}) is 10 mΩ, then the input threshold signal is 200 mV. The INA302A1-Q1 has a gain of 20, so the resulting output voltage at the 20-A input condition is 4 V at the output of the current-sense amplifier when the REF pin is grounded. The value for R_{LIMIT} is selected to allow the device to detect this 20-A threshold, indicating that an overcurrent event has occurred. When the INA302-Q1 detects this out-of-range condition, the $\overline{ALERTx}$ pin asserts and pulls low. For this example, the value of R_{LIMIT} to detect a 4-V level is calculated to be 50 kΩ.

7.3.3.1.2 Voltage-Source-Controlled Current Limit

The second method for setting the out-of-range threshold is to directly drive the LIMITx pins with a programmable DAC or other external voltage source. The benefit of this method is the ability to adjust the current-limit threshold to account for different threshold voltages used for different system operating conditions. For example, this method can be used in a system with one current-limit threshold level that must be monitored during a power-up sequence, but different threshold levels must be monitored during other system operating modes.

The voltage applied at the LIMITx pins sets the threshold voltage for out-of-range detection. The value of the voltage for a given desired current trip point is calculated using Equation 4:

$$V_{SOURCE} = (I_{TRIP} \times R_{SENSE} \times GAIN) + V_{REF} \quad (4)$$

where

- I_{TRIP} is the desired out-of-range current threshold.
- R_{SENSE} is the current-sensing resistor.
- GAIN is the gain option of the device selected.
- V_{REF} is the voltage applied to the REF pin.

Note

The maximum voltage that can be applied to the LIMIT2 pin is V_S – 0.6 V and the maximum voltage that can be applied to the LIMIT1 pin must not exceed V_S.

7.3.3.2 Hysteresis

The hysteresis included in the comparators of the INA30x-Q1 reduces the possibility of oscillations in the alert outputs when the measured signal level is near the overlimit threshold level. For overrange events, the corresponding $\overline{\text{ALERTx}}$ pin is asserted when the output voltage (V_{OUT}) exceeds the threshold set at either LIMITx pin. The output voltage must drop to less than the LIMITx pin threshold voltage by the hysteresis value in order for the $\overline{\text{ALERTx}}$ pin to deassert and return to the nominal high state. Likewise for underrange events, the corresponding $\overline{\text{ALERTx}}$ pin is also pulled low when the output voltage drops to less than the threshold set by either LIMITx pin. The $\overline{\text{ALERTx}}$ pin is released when the output voltage of the current-sense amplifier rises to greater than the set threshold plus hysteresis. Hysteresis functionality for both overrange and underrange events is shown in Figure 7-4 and Figure 7-5 for the INA302-Q1 and INA303-Q1, respectively.

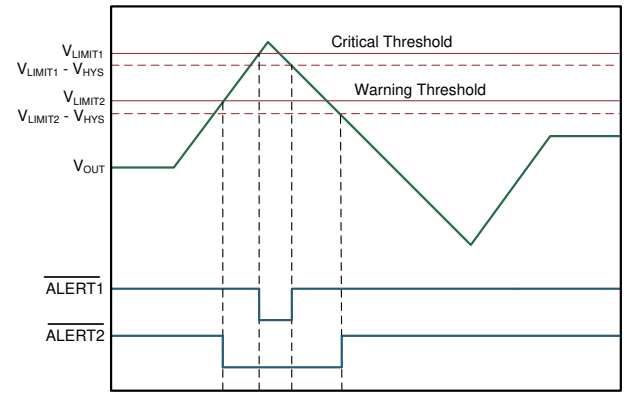


Figure 7-4. Comparator Hysteresis Behavior (INA302-Q1)

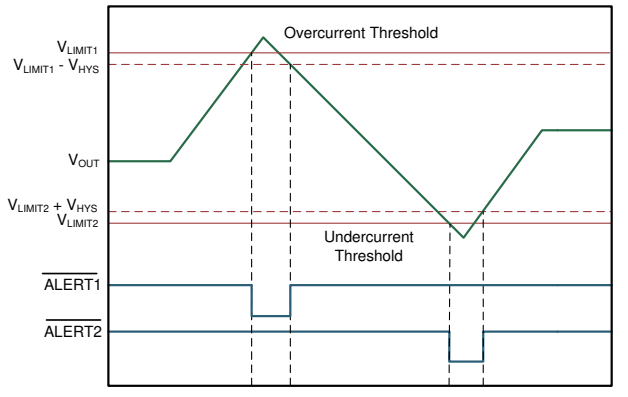


Figure 7-5. Comparator Hysteresis Behavior (INA303-Q1)

7.4 Device Functional Modes

7.4.1 Alert Operating Modes

Each comparator has two output operating modes: transparent and latched. These modes determine how the $\overline{\text{ALERTx}}$ pins respond when an out-of-range condition is removed. The device is placed into either transparent or latched state based on the voltage applied to the corresponding LATCHx pin, as shown in Table 7-1.

Table 7-1. Output Mode Settings

OUTPUT MODE	LATCHx PINS SETTINGS
$\overline{\text{ALERTx}}$ transparent mode	LATCHx = low
$\overline{\text{ALERTx}}$ latch mode	LATCHx = high

7.4.1.1 Transparent Output Mode

The comparators are set to transparent output mode when the corresponding LATCHx pin is pulled low. When set to transparent mode, the output of the comparators changes and follows the input signal with respect to the programmed alert threshold. For example, when the amplifier output violates the set limit value, the $\overline{\text{ALERTx}}$ output pin is pulled low. As soon as the differential input signal drops to less than the alert threshold, the output returns to the default high output state. A common implementation using the device in transparent mode is to connect the $\overline{\text{ALERTx}}$ pins to a hardware interrupt input on a microcontroller. The $\overline{\text{ALERTx}}$ pin is pulled low as soon as an out-of-range condition is detected, thus notifying the microcontroller. The microcontroller immediately reacts to the alert and takes action to address the overcurrent condition. In transparent output mode, there is no need to latch the state of the alert output because the microcontroller responds as soon as the out-of-range condition occurs.

7.4.1.2 Latch Output Mode

The comparators are set to latch output mode when the corresponding LATCHx pin is pulled high. Some applications do not continuously monitor the state of the $\overline{\text{ALERTx}}$ pins as described in the *Transparent Output Mode* section. For example, if the device is set to transparent output mode in an application that only polls the state of the $\overline{\text{ALERTx}}$ pins periodically, then the transition of the $\overline{\text{ALERTx}}$ pins can be missed when the out-of-range condition is not present during one of these periodic polling events. Latch output mode allows the output of the comparators to latch the output of the range condition so that the transition of the $\overline{\text{ALERTx}}$ pins is not missed when the status of the comparator $\overline{\text{ALERTx}}$ pins is polled.

The difference between latch mode and transparent mode is how the alert output responds when an overcurrent condition is removed. In transparent mode (LATCH1, LATCH2 = low), when the differential input signal drops to within normal operating range, the $\overline{\text{ALERTx}}$ pin returns to the default high setting to indicate that the overcurrent event has ended.

In latch mode (LATCHx = high), when an out-of-range condition is detected and the corresponding $\overline{\text{ALERTx}}$ pin is pulled low; the $\overline{\text{ALERTx}}$ pin does not return to the default high state when the out-of-range condition is removed. In order to clear the alert, the corresponding LATCHx pin must be pulled low for at least 100 ns. Pulling the LATCHx pins low allows the corresponding $\overline{\text{ALERTx}}$ pin to return to the default high level, provided the out-of-range condition is no longer present. If the out-of-range condition is still present when the LATCHx pins are pulled low, then the corresponding $\overline{\text{ALERTx}}$ pin remains low. The $\overline{\text{ALERTx}}$ pins can be cleared (reset to high) by toggling the corresponding LATCHx pin when the alert condition is detected by the system controller.

The latch and transparent modes are illustrated in Figure 7-6. As illustrated in this figure, at time t_1, the current-sense amplifier exceeds the limit threshold. During this time the LATCH1 pin is toggled with no affect to the $\overline{\text{ALERT1}}$ output. The state of the LATCH1 pin only matters when the output of the current-sense amplifier returns to the normal operating region, as shown at t_2. At this time the LATCH1 pin is high and the overcurrent condition is latched on the $\overline{\text{ALERT1}}$ output. As shown in the time interval between t_2 and t_3, the latch condition is cleared when the LATCHx pin is pulled low. At time t_4, the LATCH1 pin is already pulled low when the amplifier output drops below the limit threshold for the second time. The device is set to transparent mode at this point and the $\overline{\text{ALERT1}}$ pin is pulled back high as soon as the output of the current-sense amplifier drops below the alert threshold.

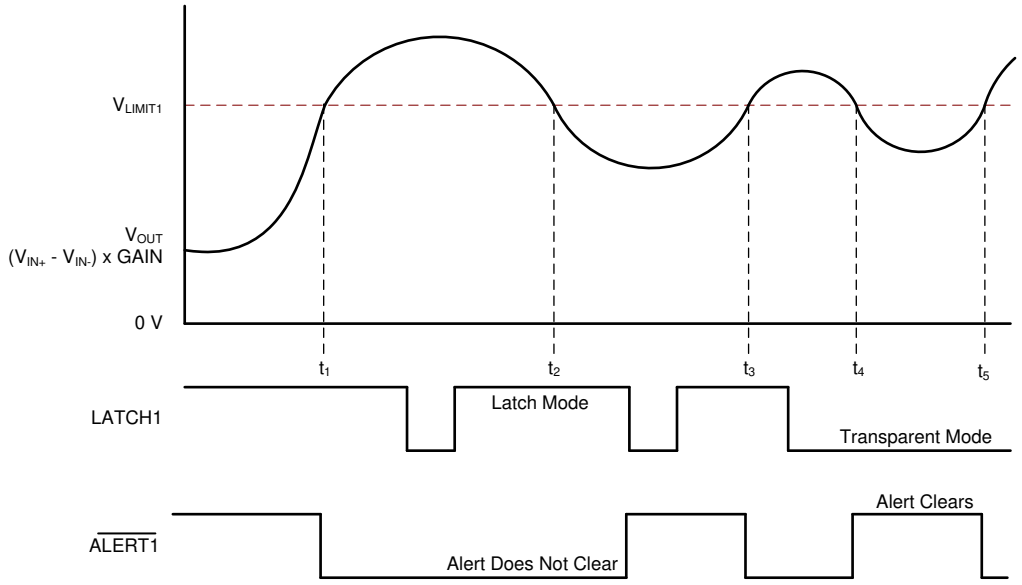


Figure 7-6. Transparent vs. Latch Mode

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

8.1.1 Selecting a Current-Sensing Resistor (R_{SENSE})

Selecting the value of this current-sensing resistor is based primarily on two factors: the required accuracy of the current measurement and the allowable power dissipation across the current-sensing resistor. Larger voltages developed across this resistor allow for more accurate measurements to be made. Amplifiers have fixed internal errors that are largely dominated by the inherent input offset voltage. When the input signal decreases, these fixed internal amplifier errors become a larger portion of the measurement and increase the uncertainty in the measurement accuracy. When the input signal increases, the measurement uncertainty is reduced because the fixed errors are a smaller percentage of the signal being measured. Therefore, the use of larger-value, current-sensing resistors inherently improves measurement accuracy.

However, a system design trade-off must be evaluated through the use of larger input signals for improving measurement accuracy. Increasing the current-sense resistor value results in an increase in power dissipation across the current-sensing resistor. Increasing the value of the current-shunt resistor increases the differential voltage developed across the resistor when current passes through the component. This increase in voltage across the resistor increases the power that the resistor must be able to dissipate. Decreasing the value of the current-shunt resistor value reduces the power dissipation requirements of the resistor, but increases the measurement errors resulting from the decreased input signal. Selecting the optimal value for the shunt resistor requires factoring both the accuracy requirement for the specific application and the allowable power dissipation of this component.

An increasing number of very low ohmic-value resistors are becoming more widely available with values reaching down to 200 µΩ or lower, with power dissipations of up to 5 W that enable large currents to be accurately monitored with sensing resistors.

8.1.1.1 Selecting a Current-Sensing Resistor: Example

In this example, the trade-offs involved in selecting a current-sensing resistor are discussed. This example requires 2.5% accuracy for detecting a 10-A overcurrent event where only 250 mW is allowed for the dissipation across the current-sensing resistor at the full-scale current level. Although the maximum power dissipation is defined as 250 mW, a lower dissipation is preferred to improve system efficiency. Some initial assumptions are made that are used in this example: the limit-setting resistor (R_{LIMIT}) is a 1% component, and the maximum tolerance specification for the internal threshold setting current source (1%) is used. Given the total error budget of 2.5%, up to 0.5% of error can be attributed to the measurement error of the device under these conditions.

As shown in Table 8-1, the maximum value calculated for the current-sensing resistor with these requirements is 2.5 mΩ. Although this value satisfies the maximum power dissipation requirement of 250 mW, headroom is available from the 2.5% maximum total overcurrent detection error to reduce the value of the current-sensing resistor and to further reduce power dissipation. Selecting a 1.5-mΩ, current-sensing resistor value offers a good tradeoff for reducing the power dissipation in this scenario by approximately 40% and stays within the accuracy region.

Table 8-1. Calculating the Current-Sensing Resistor, R_{SENSE}

PARAMETER		EQUATION	VALUE	UNIT
DESIGN TARGETS				
I_{MAX}	Maximum current		10	A
P_{D_MAX}	Maximum allowable power dissipation		250	mW
	Allowable current threshold accuracy		2.5%	
DEVICE PARAMETERS				
V_{OS}	Offset voltage		30	µV
E_G	Gain error		0.15%	
CALCULATIONS				
R_{SENSE_MAX}	Maximum allowable R_{SENSE}	P_{D_MAX} / I_{MAX}^2	2.5	mΩ
V_{OS_ERROR}	Initial offset voltage error	$(V_{OS} / (R_{SENSE\_MAX} \times I_{MAX}) \times 100$	0.12%	
$ERROR_{TOTAL}$	Total measurement error	$\sqrt{(V_{OS\_ERROR}^2 + E_G^2)}$	0.19%	
$ERROR_{INITIAL}$	Initial threshold error	I_{LIMIT} tolerance + R_{LIMIT} tolerance	2%	
$ERROR_{AVAILABLE}$	Maximum allowable measurement error	Maximum error – $ERROR_{INITIAL}$	1%	
$V_{OS\_ERROR\_MAX}$	Maximum allowable offset error	$\sqrt{(ERROR_{AVAILABLE}^2 - E_G^2)}$	0.48%	
V_{DIFF_MIN}	Minimum differential voltage	$V_{OS} / V_{OS\_ERROR\_MAX\ (1\%)}$	6.3	mV
R_{SENSE_MIN}	Minimum sense resistor value	V_{DIFF_MIN} / I_{MAX}	0.63	mΩ
P_{D_MIN}	Lowest-possible power dissipation	$R_{SENSE\_MIN} \times I_{MAX}^2$	63	mW

8.1.2 Input Filtering

The integrated comparators in the INA30x-Q1 are very accurate at detecting out-of-range events because of the low offset voltage; however, noise present at the input of the current-sense amplifier and noise internal to the device can make the offset appear larger than specified. The most obvious effect that external noise can have on the operation of a comparator is to cause a false alert condition. If a comparator detects a large noise transient coupled into the signal, the device can easily falsely interpret this transient as an overrange condition.

External filtering helps reduce the amount of noise that reaches the comparator and reduce the likelihood of a false alert from occurring because of external noise. The trade-off to adding this noise filter is that the alert response time is increased because the input signal and the noise are filtered. Figure 8-1 shows the implementation of an input filter for the device.

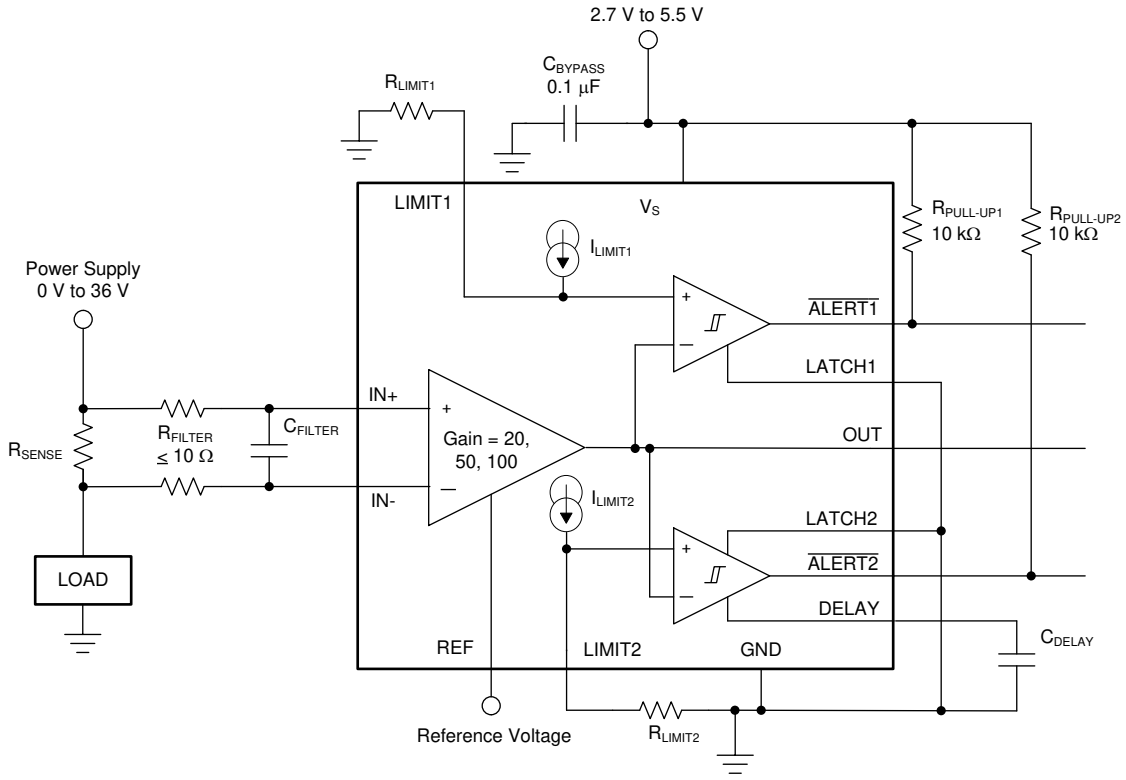


Figure 8-1. Input Filter Implementation

Limiting the amount of input resistance used in this filter is important because this resistance can have a significant effect on the input signal that reaches the device input pins by adversely affecting the gain error of the device. A typical system implementation involves placing the current-sensing resistor very near the device so the traces are very short and the trace impedance is very small. This layout helps reduce coupling of additional noise into the measurement. Under these conditions, the characteristics of the input bias currents have minimal effect on device performance.

As shown in Figure 8-2, the input bias currents increase in opposite directions when the differential input voltage increases. This increase results from the design of the device that allows common-mode input voltages to far exceed the device supply voltage range. When input filter resistors are placed in series with the unequal input bias currents, unequal voltage drops are developed across the input resistors. The difference between these two drops appears as an added signal that (in this case) subtracts from the voltage developed across the current-sensing resistor, thus reducing the signal that reaches the device input pins. Smaller-value input resistors reduce this effect of signal attenuation to allow for a more accurate measurement.

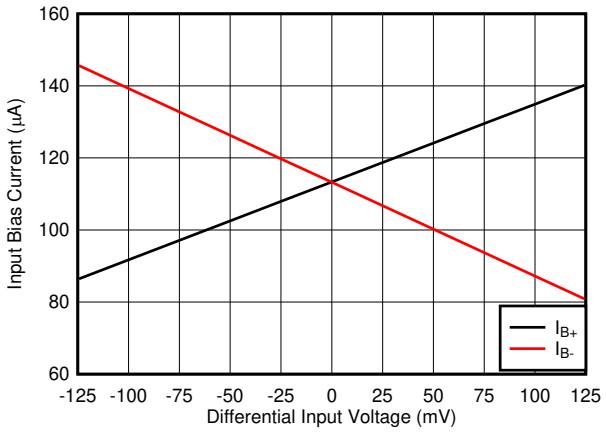
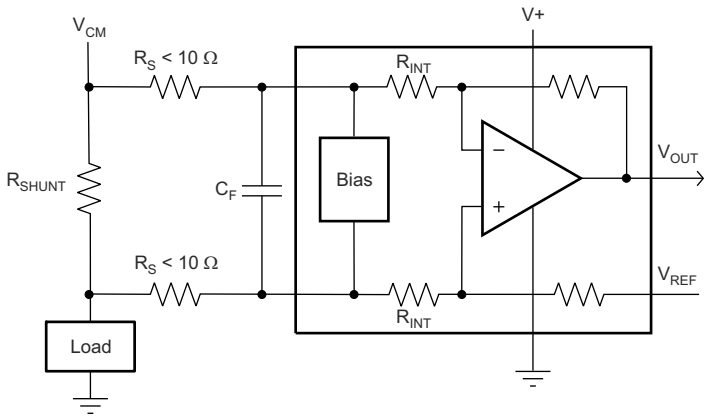


Figure 8-2. Input Bias Current vs Differential Input Voltage

The internal bias network present at the input pins shown in Figure 8-3 is responsible for the mismatch in input bias currents that is shown in Figure 8-2. If additional external series filter resistors are added to the circuit, the mismatch in bias currents results in a mismatch of voltage drops across the filter resistors. This mismatch creates a differential error voltage that subtracts from the voltage developed at the shunt resistor. This error results in a voltage at the device input pins that is different than the voltage developed across the shunt resistor. Without the additional series resistance, the mismatch in input bias currents has little effect on device operation. The amount of error these external filter resistors add to the measurement is calculated using Equation 6, where the gain error factor is calculated using Equation 5.



Comparators omitted for simplicity.

Figure 8-3. Filter at Input Pins

The amount of variance in the differential voltage present at the device input relative to the voltage developed at the shunt resistor is based both on the external series resistance value as well as the internal input resistors, R3 and R4 (or R_{INT} as illustrated in Figure 8-3). The reduction of the shunt voltage reaching the device input pins appears as a gain error when comparing the output voltage relative to the voltage across the shunt resistor. A factor can be calculated to determine the amount of gain error that is introduced by the addition of external series resistance. The equation used to calculate the expected deviation from the shunt voltage to what is measured at the device input pins is given in Equation 5:

$$\text{Gain Error Factor} = \frac{(1250 \times R_{INT})}{(1250 \times R_S) + (1250 \times R_{INT}) + (R_S \times R_{INT})} \quad (5)$$

where

- R_{INT} is the internal input resistor (R3 and R4).
- R_S is the external series resistance.

With the adjustment factor from Equation 5, including the device internal input resistance, this factor varies with each gain version, as shown in Table 8-2. Each individual device gain error factor is shown in Table 8-3.

Table 8-2. Input Resistance

PRODUCT	GAIN	R_{INT} (kΩ)
INA30xA1-Q1	20	12.5
INA30xA2-Q1	50	5
INA30xA3-Q1	100	2.5

Table 8-3. Device Gain Error Factor

PRODUCT	SIMPLIFIED GAIN ERROR FACTOR
INA30xA1-Q1	$\frac{12,500}{(11 \times R_S) + 12,500}$
INA30xA2-Q1	$\frac{1000}{R_S + 1000}$
INA30xA3-Q1	$\frac{2500}{(3 \times R_S) + 2500}$

The gain error that is expected from the addition of the external series resistors is then calculated based on Equation 6:

$$\text{Gain Error (\%)} = 100 - (100 \times \text{Gain Error Factor}) \quad (6)$$

For example, using an INA302A2-Q1 and the corresponding gain error equation from Table 8-3, a series resistance of 10 Ω results in a gain error factor of 0.99. The corresponding gain error is then calculated using Equation 6, resulting in a gain error of approximately 1% solely because of the external 10-Ω series resistors.

8.1.3 Using the INA30x-Q1 With Common-Mode Transients Greater Than 36 V

With a small amount of additional circuitry, these devices can be used in circuits subject to transients higher than 36 V. Use only zener diodes or zener-type transient absorbers (sometimes referred to as *transzorbs*). Any other type of transient absorber has an unacceptable time delay. Start by adding a pair of resistors as a working impedance for the zener diode, as shown in Figure 8-4. Keep these resistors as small as possible, preferably 10 Ω or less. Larger values can be used with an additional induced error resulting from a reduced signal that actually reaches the device input pins. Many applications are satisfied with a 10-Ω resistor along with conventional zener diodes of the lowest power rating available because this circuit limits only short-term transients. This combination uses the least amount of board space. These diodes can be found in packages as small as SOT-523 or SOD-523.

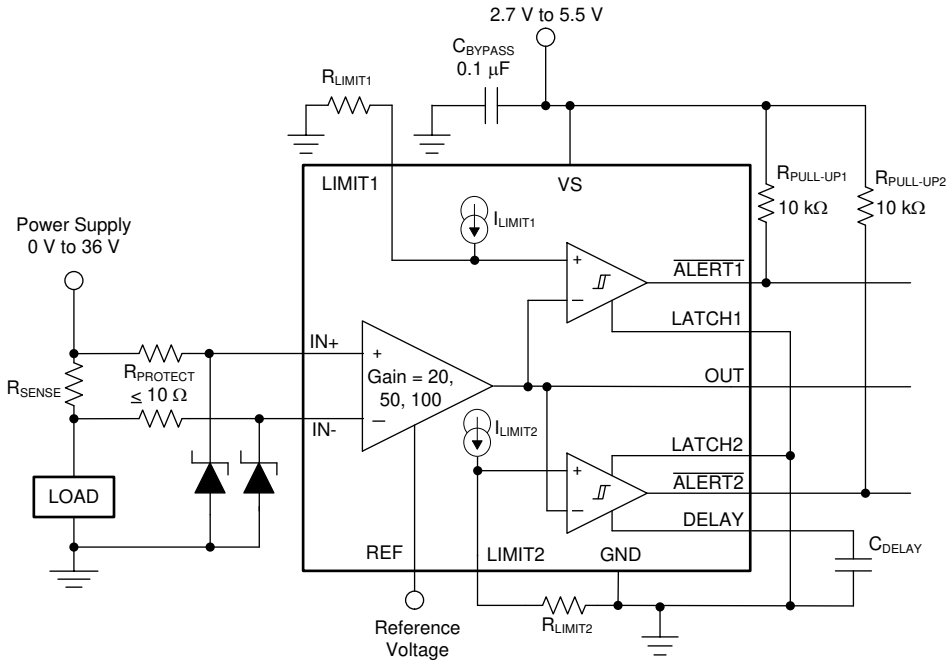


Figure 8-4. Transient Protection

8.2 Typical Application

The INA30x-Q1 are designed to be easily configured for detecting multiple out-of-range current conditions in an application. These devices are capable of monitoring and providing overcurrent detection of bidirectional currents. By using the REF pin of the INA303-Q1, both positive and negative overcurrent events can be detected.

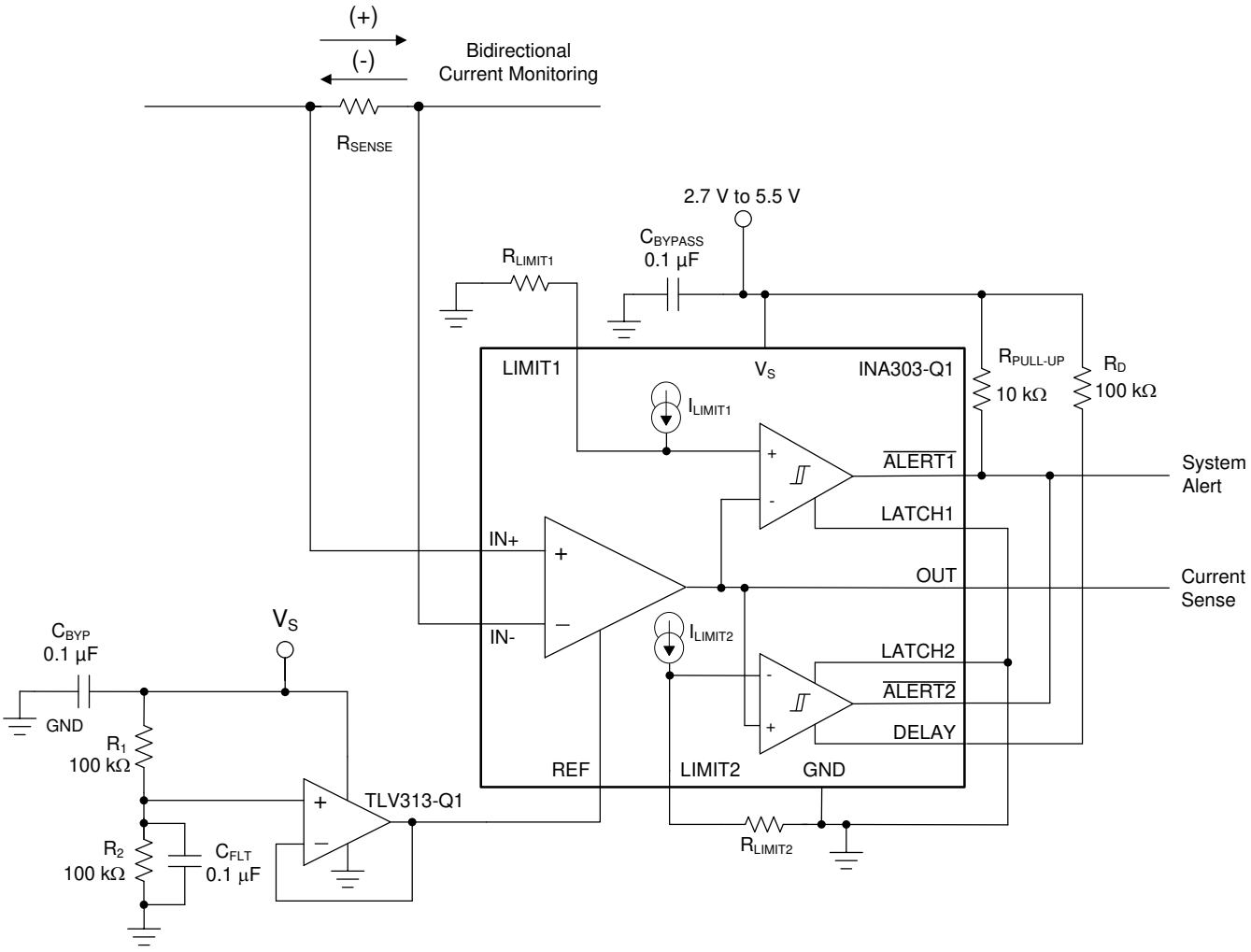


Figure 8-5. Bidirectional Application

8.2.1 Design Requirements

To allow for bidirectional monitoring, the INA303-Q1 requires a voltage applied to the REF pin. A voltage that is half of the supply voltage is usually preferred to allow for maximum output swing in both the positive and negative current direction. To reduce the errors in the reference voltage, drive the REF pin with a low-impedance source (such as an op amp or external reference). A low-value resistor divider can be used at the expense of quiescent current and accuracy. For this design, a single alert output is preferred, so both $\overline{\text{ALERT1}}$ and $\overline{\text{ALERT2}}$ are connected together and use a single pullup resistor.

8.2.2 Detailed Design Procedure

To achieve bidirectional monitoring, drive the reference pin halfway between the supply with a resistor divider buffered by an op amp, as shown in Table 8-4. To reduce the current draw from the supply, use 100-kΩ resistors to create the divide-by-two voltage divider. The TLV313-Q1 is selected to buffer the voltage divider because this device can operate from a single-supply rail with low I_Q and offset voltage. To minimize the response time of the $\overline{\text{ALERT2}}$ output, a 100-kΩ pullup resistor was added from the DELAY pin to the VS pin. Select values for R_{SENSE}, R_{LIMIT2}, and R_{LIMIT1} based on the desired current-sense levels and trip thresholds using the information in the *Resistor-Controlled Current Limit* and *Selecting a Current-Sensing Resistor (R_{SENSE})* sections. For this example, the values of R_{LIMIT1} and R_{LIMIT2} were selected so that the positive and negative overcurrent thresholds are the same. Table 8-4 shows the alert output of the INA303-Q1 application circuit with the capability to detect both positive and negative overcurrent conditions.

Table 8-4. Bidirectional Overcurrent Output Status

OVERCURRENT PROTECTION (OCP) STATUS	OUTPUT
Positive overcurrent detection (OCP+)	0
Negative overcurrent detection (OCP–)	0
Normal operation (no OCP)	1

8.2.3 Application Curve

Figure 8-6 shows the INA303-Q1 device being used in a bidirectional configuration to detect both negative and positive overcurrent events.

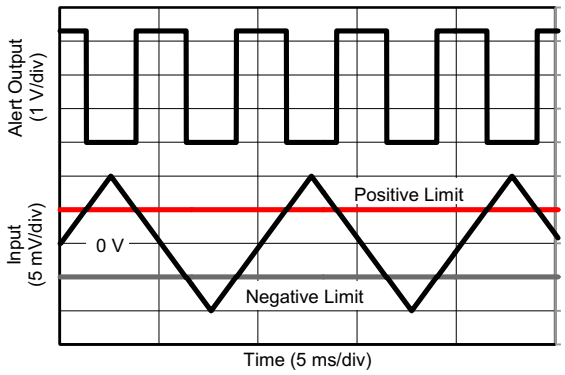


Figure 8-6. Bidirectional Application Curve

9 Power Supply Recommendations

The device input circuitry accurately measures signals on common-mode voltages beyond the power-supply voltage, V_S. For example, the voltage applied to the V_S power-supply pin can be 5 V, whereas the load power-supply voltage being monitored (V_{CM}) can be as high as 36 V. At power-up, for applications where the common-mode voltage (V_{CM}) slew rate is greater than 6 V/µs with a final common-mode voltage greater than 20 V, the V_S supply is recommended to be present before V_{CM}. If the use case requires V_{CM} to be present before V_S with V_{CM} under these same slewing conditions, then a 331-Ω resistor must be added between the V_S supply and the VS pin bypass capacitor.

Power-supply bypass capacitors are required for stability, and must be placed as close as possible to the supply and ground pins of the device. A typical value for this supply bypass capacitor is 0.1 µF. Applications with noisy or high-impedance power supplies may require additional decoupling capacitors to reject power-supply noise.

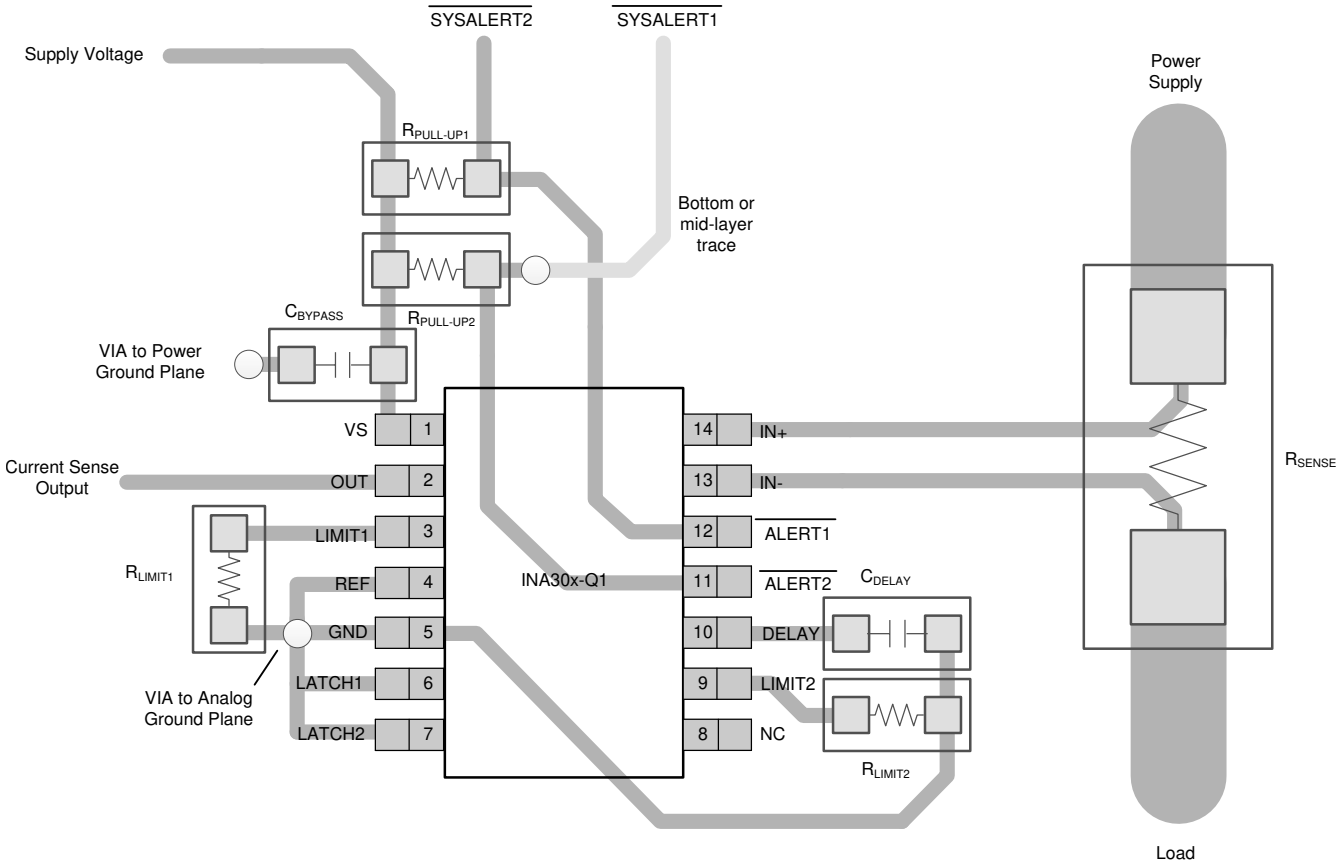
During slow power-up events, current flow through the sense resistor or voltage applied to the REF pin can result in the output voltage momentarily exceeding the voltage at the LIMITx pins, resulting in an erroneous indication of an out-of-range event on the $\overline{\text{ALERT}}$x output. When powering the device with a slow ramping power rail where an input signal is already present, all alert indications should be disregarded until the supply voltage has reached the final value.

10 Layout

10.1 Layout Guidelines

- Apply connections to the current-sense resistor, R_{SENSE}, on the inside of the resistor pads to avoid additional voltage losses incurred by the high current traces to the resistor. Route the traces from the current-sense resistor symmetrically and side-by-side back to the input of the INA to minimize common-mode errors and noise pickup.
- Place the power-supply bypass capacitor as closely as possible to the supply and ground pins. The recommended value of this bypass capacitor is 0.1 µF. Additional decoupling capacitance can be added to compensate for noisy or high-impedance power supplies.
- Make the connection of R_{LIMIT} to the ground pin as direct as possible to limit additional capacitance on this node. Routing this connection must be limited to the same plane if possible to avoid vias to internal planes. If the routing can not be made on the same plane and must pass through vias, make sure that a path is routed from R_{LIMIT} back to the ground pin, and that R_{LIMIT} is not simply connected directly to a ground plane.
- Routing to the delay capacitor must be short and direct. Keep the routing trace from the DELAY pin to the delay capacitor away from the $\overline{\text{ALERT2}}$ trace (or any other noisy signals) to minimize any coupling effects. If no delay capacitor is used do not have any connection to the DELAY pin. Long trace lengths on the DELAY pin can cause noise to couple to the device, resulting in false trips.
- Pull up the open-drain output pins to the supply voltage rail; a 10-kΩ pullup resistor is recommended.

10.2 Layout Example



Connect the limit resistors and delay capacitors directly to the GND pin; leave the DELAY pin unconnected or connected to VS through a pullup resistor if no delay is needed.

Figure 10-1. Recommended Layout

11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation

For related documentation see the following:

- Texas Instruments, *TLVx313-Q1 Low Power Rail-to-Rail In/Out 750-µV Typical Offset Op Amps* data sheet
- Texas Instruments, *Monitoring Current for Multiple Out-of-Range Conditions* application report

11.2 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.

11.3 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.

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

11.4 Related Links

Table 11-1 lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to order now.

Table 11-1. Related Links

PARTS	PRODUCT FOLDER	ORDER NOW	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
INA302-Q1	Click here	Click here	Click here	Click here	Click here
INA303-Q1	Click here	Click here	Click here	Click here	Click here

11.5 Trademarks

TI E2E™ is a trademark of Texas Instruments.
All trademarks are the property of their respective owners.

11.6 Electrostatic Discharge Caution

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

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

11.7 Glossary

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

12 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)
INA302A1QPWRQ1	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I302A1Q
INA302A1QPWRQ1.B	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I302A1Q
INA302A2QPWRQ1	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I302A2Q
INA302A2QPWRQ1.B	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I302A2Q
INA302A3QPWRQ1	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I302A3Q
INA302A3QPWRQ1.B	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I302A3Q
INA303A1QPWRQ1	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I303A1Q
INA303A1QPWRQ1.B	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I303A1Q
INA303A2QPWRQ1	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I303A2Q
INA303A2QPWRQ1.B	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I303A2Q
INA303A3QPWRQ1	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I303A3Q
INA303A3QPWRQ1.B	Active	Production	TSSOP (PW) | 14	2000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	I303A3Q

(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.

OTHER QUALIFIED VERSIONS OF INA302-Q1, INA303-Q1 :

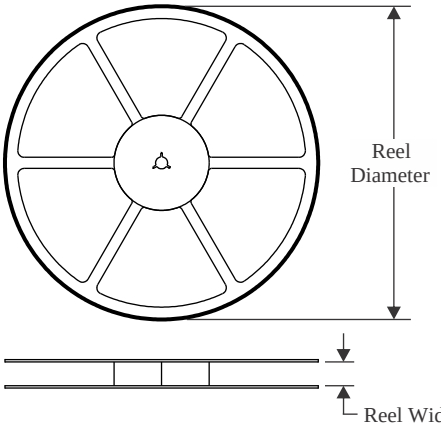
- Catalog : INA302, INA303

NOTE: Qualified Version Definitions:

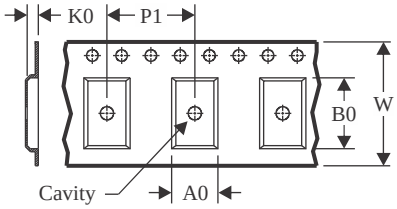
- Catalog - TI's standard catalog product

TAPE AND REEL INFORMATION

REEL DIMENSIONS

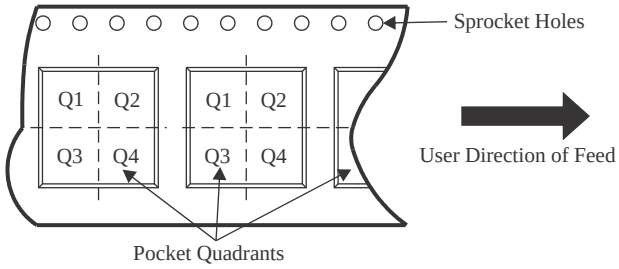


TAPE DIMENSIONS



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

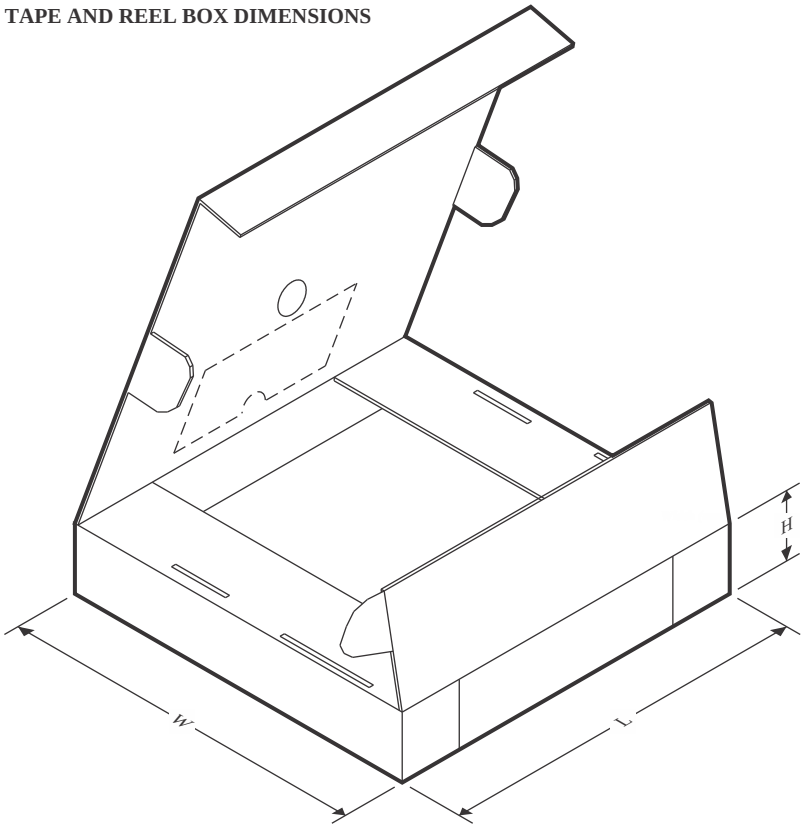
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
INA302A1QPWRQ1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
INA302A2QPWRQ1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
INA302A3QPWRQ1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
INA303A1QPWRQ1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
INA303A2QPWRQ1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
INA303A3QPWRQ1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

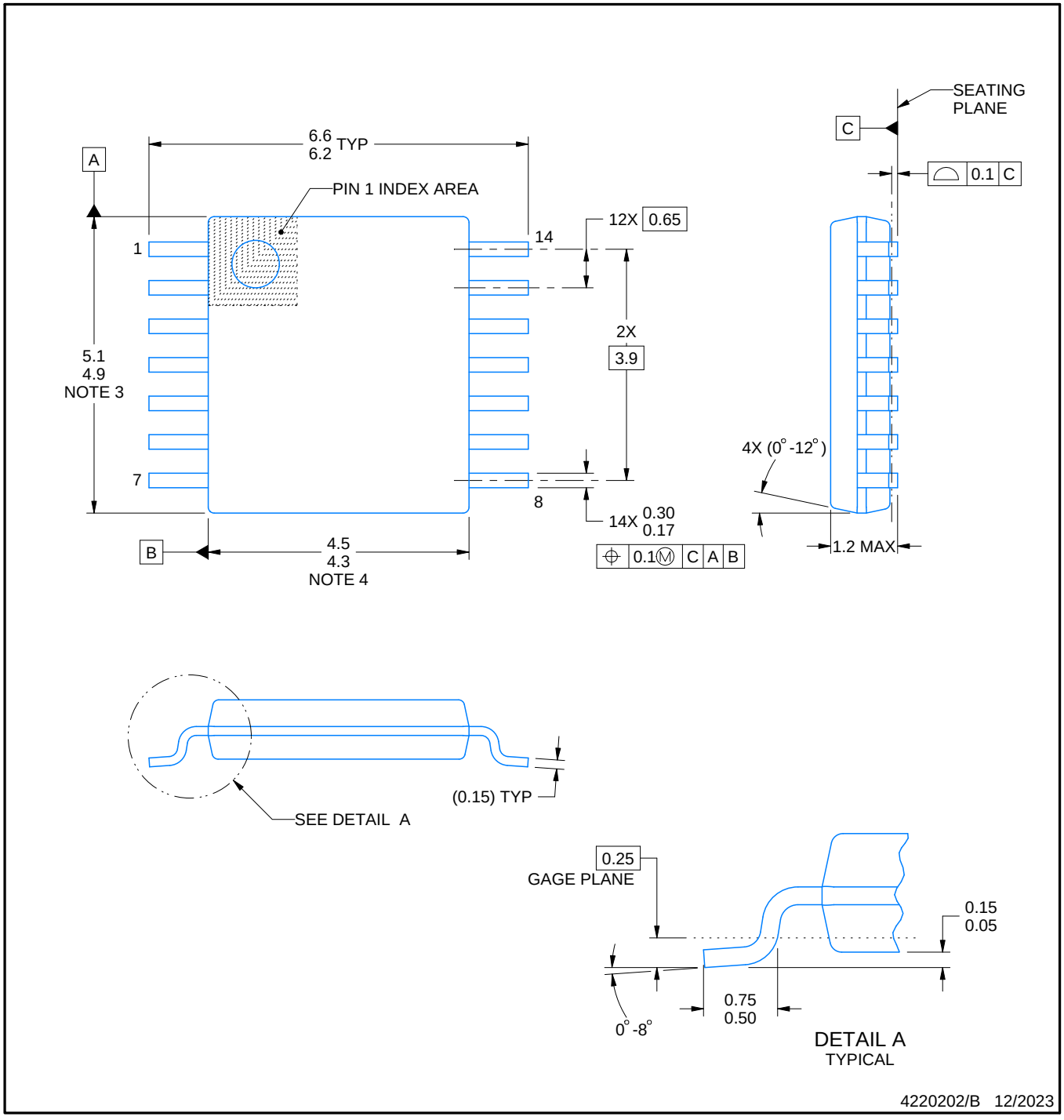
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA302A1QPWRQ1	TSSOP	PW	14	2000	356.0	356.0	35.0
INA302A2QPWRQ1	TSSOP	PW	14	2000	356.0	356.0	35.0
INA302A3QPWRQ1	TSSOP	PW	14	2000	356.0	356.0	35.0
INA303A1QPWRQ1	TSSOP	PW	14	2000	356.0	356.0	35.0
INA303A2QPWRQ1	TSSOP	PW	14	2000	356.0	356.0	35.0
INA303A3QPWRQ1	TSSOP	PW	14	2000	356.0	356.0	35.0

PACKAGE OUTLINE

PW0014A

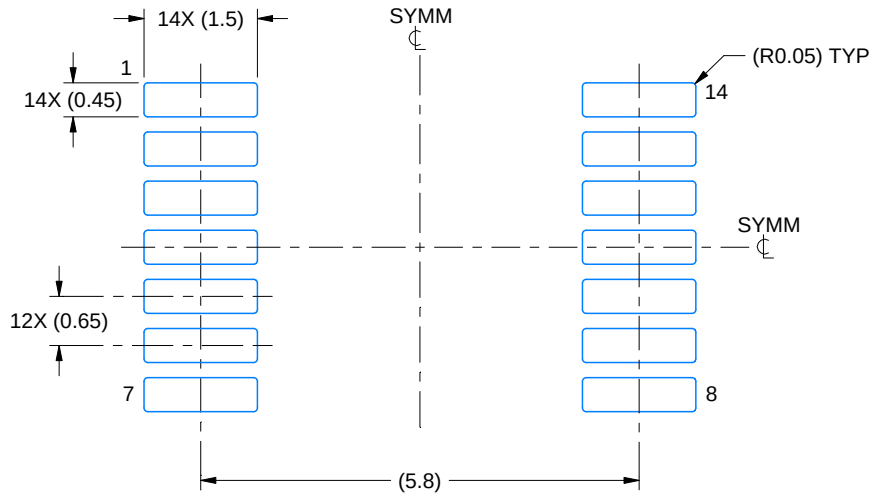
TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE

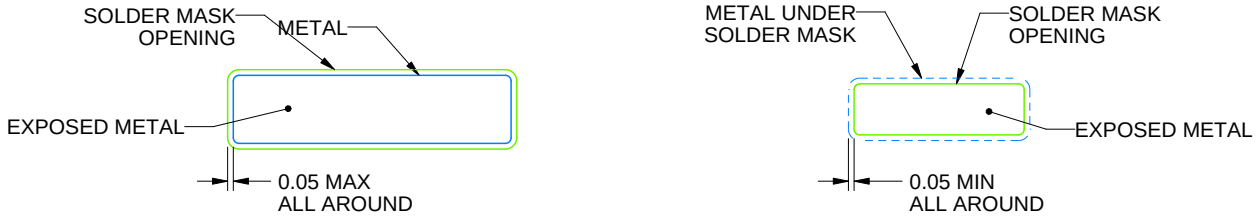


NOTES:

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



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 10X

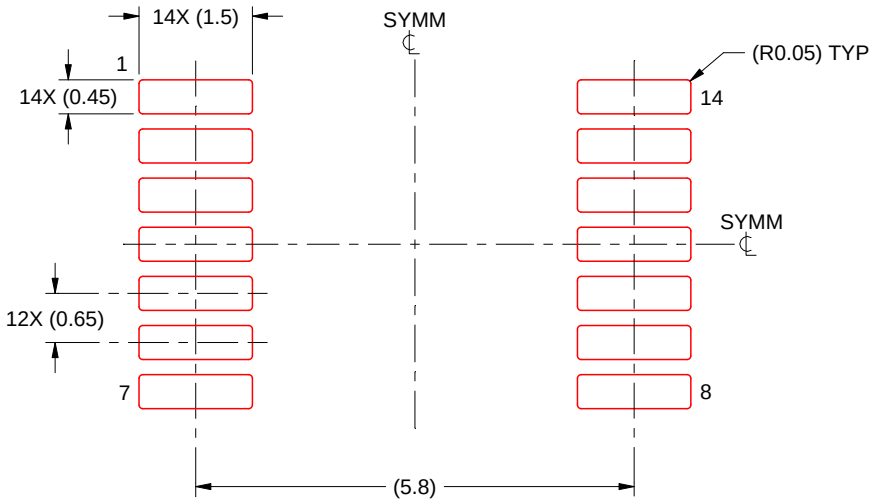


SOLDER MASK DETAILS

4220202/B 12/2023

NOTES: (continued)

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



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

4220202/B 12/2023

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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