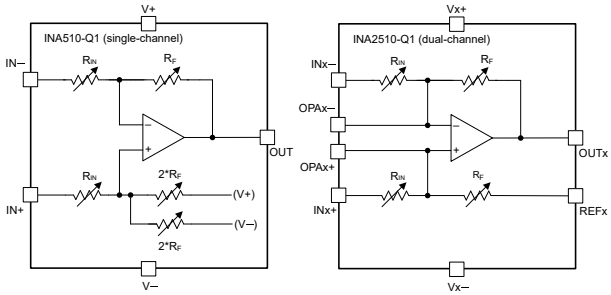
INAx510-Q1 Automotive, Fast Settling, Wide-Bandwidth Difference Amplifier for Level Translation and Differential to Single-Ended Conversion

1 Features

- AEC-Q100 qualified for automotive applications
  - Specified temperature range: –40°C to 125°C
- Differential to single-ended converter
- High speed ADC driver, 18MHz (typical)
- Four gains (G = 0.5, 0.75, 1 and 1.5)
- Good precision performance
  - CMRR: 92dB G = 1 (typical)
  - Gain error: ±0.02% (typical)
  - Offset voltage: ±0.5mV (typical)
- Excellent temperature drift
  - Gain drift: ±0.5ppm/°C (typical)
  - Offset drift: ±1.2µV/°C (typical)
- Dual channel for added space savings
- Drives 70pF with <25% overshoot (typical)
- Supply range: 1.7V (±0.85V) to 5.5V (±2.75V)
- Functional Safety Capable
  - Documentation available to aid functional safety system design

2 Applications

- Hybrid, electic and powertrain systems
- String inverter
- EV charging station power module
- Battery energy storage system
- Power delivery
- Industrial AC-DC



NOTE: The difference amplifier reference is internally connected to mid-supply on the INA510M-Q1 single-channel variant. The INA2510E-Q1 dual-channel variant provides external access to the reference inputs.

INAx510-Q1 Simplified Internal Schematics

3 Description

The INA510-Q1 is a wide-bandwidth difference amplifier that offers four gain options for simultaneous level translation and differential-to-single-ended conversion applications. The device can level-translate the differential output signal from an ASIC and match the differential output signal to the full-scale input range of a single-ended ADC while satisfying the settling time requirements.

The device boasts a 18MHz closed-loop bandwidth across all gain options for faster settling performance within the ADC sampling window. The INAx510-Q1 achieves a typical CMRR of 92dB and a maximum gain error of ±0.05% referred to the output in the G = 1 configuration.

The INAx510-Q1 enables excellent performance while saving BOM costs and board space by removing the need for precise, low-drift external resistors. The device provides excellent temperature drift performance, made possible by precision-matched integrated resistors, and achieves a maximum gain drift of 2.5ppm/°C and a maximum referred offset drift of 5µV/°C.

The wide-bandwidth and precision performance make the INAx510-Q1 an excellent choice for replacing discrete difference amplifier implementations built with commodity amplifiers and resistors. The device is offered in single-channel and dual-channel versions, in the 5-pin SOT-23 and 16-pin SOT-23 packages, respectively.

Package Information

PART NUMBER(1)	REFERENCE VARIANT	PACKAGE(2)	PACKAGE SIZE(4)
INA510-Q1 (single channel)	Internal to Mid-supply (M)	DBV (SOT-23, 5)	2.9mm × 2.8mm
INA2510-Q1 (dual channel) (3)	External (E)	DYY (SOT-23, 16)(3)	4.2mm × 3.26mm

(1) See Device Comparison
(2) For more information, see Section 11
(3) This package is preview only.
(4) The package size (length × width) is a nominal value and includes pins, where applicable

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4 Device Comparison Table

DEVICE	NO. OF CHANNELS	REFERENCE VERSION	GAIN VERSION	PACKAGE	LEADS
INA510M-Q1	1	Internal to Mid-rail (M)	INA510M05 G = 0.50V/V	SOT-23 DBV	5
			INA510M07 G = 0.75V/V	SOT-23 DBV	5
			INA510M10 G = 1V/V	SOT-23 DBV	5
			INA510M15 G = 1.5V/V	SOT-23 DBV	5
INA2510E-Q1	2	External (E)	INA2510E05 G = 0.50V/V	SOT-23 DYY	16
			INA2510E07 G = 0.75V/V	SOT-23 DYY	16
			INA2510E10 G = 1V/V	SOT-23 DYY	16
			INA2510E15 G = 1.5V/V	SOT-23 DYY	16

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5 Pin Configuration and Functions

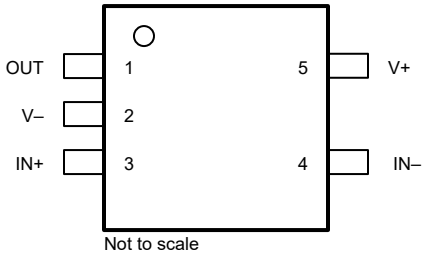

Figure 5-1. INA510-Q1 DBV Package, 5-Pin SOT-23 (Top View)

Table 5-1. Pin Functions

PIN		TYPE[1]	DESCRIPTION
NAME	DBV (SOT-23, 5)		
IN–	4	I	Negative (inverting) input
IN+	3	I	Positive (noninverting) input
OUT	1	O	Output
V–	2	—	Negative supply
V+	5	—	Positive supply

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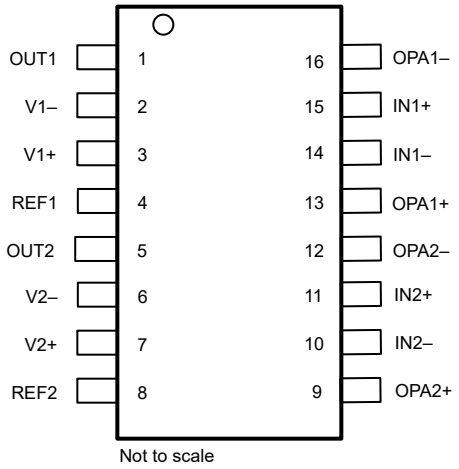

Figure 5-2. INA2510-Q1 DYY Package, 16-Pin SOT-23 (Top View)

Table 5-2. Pin Functions

PIN		TYPE[(1)]	DESCRIPTION
NAME	DYY (SOT-23, 16)		
IN1–	14	I	Negative (inverting) input channel 1
IN1+	15	I	Positive (noninverting) input channel 1
OUT1	1	O	Output channel 1
REF1	4	I	Reference input channel 1
V1–	2	—	Negative supply channel 1
V1+	3	—	Positive supply channel 1
OPA1–	16	I	Op-amp inverting input channel 1
OPA1+	13	I	Op-amp noninverting input channel 1
IN2–	10	I	Negative (inverting) input channel 2
IN2+	11	I	Positive (noninverting) input channel 2
OUT2	5	O	Output channel 2
REF2	4	I	Reference input channel 2
V2–	6	—	Negative supply channel 2
V2+	7	—	Positive supply channel 2
OPA2–	12	I	Op-amp inverting input channel 2
OPA2+	9	I	Op-amp noninverting input channel 2

(1) I = input, O = output

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6 Specifications

6.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Supply pins (V+, V–)	Single Supply, V_S = (V+) – (V–)		6	V
	Dual Supply		±3	V
Signal input pins (IN+, IN–, REFx, OPAPx, OPANx)	Voltage	(V–) – 0.3	(V–) + 6	V
Signal input pins	Current	–10	10	mA
Output short-circuit[2]		Continuous		
Operating Temperature, T_A		–55	150	°C
Junction Temperature, T_J			150	
Storage Temperature, T_{stg}		–65	150	

(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) Short-circuit to V_S / 2.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001[1]	±2000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101[2]	±1000	

(1) JEDEC document JEP155 states that 500V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250V 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	MAX	UNIT
Supply voltage V_S = (V+) – (V–)	Single-supply	1.7	5.5	V
	Dual-supply	±0.85	±2.75	
C_{BYP}	Bypass capacitor on the power supply pins [1]	0.1		µF
T_A	Operating temperature	–40	125	°C

(1) For C_{BYP}, use low-ESR ceramic capacitors between each supply pin and ground. Only one C_{BYP} is sufficient for single supply operation. Ensure that C_{BYP} is placed as close to the device as possible and the supply trace routes through C_{BYP} before reaching the supply pin.

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6.4 Thermal Information

THERMAL METRIC[1]		INA510-Q1 DBV (SOT-23) 5 PINS	INA2510-Q1 DYY (SOT-23) 16 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	187.1	120.0	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	107.4	56.8	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	57.5	51.3	°C/W
ψ_{JT}	Junction-to-top characterization parameter	33.5	2.6	°C/W
ψ_{JB}	Junction-to-board characterization parameter	57.1	50.9	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	N/A	°C/W

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

6.5 Electrical Characteristics - INAx510-Q1, G = 0.50

For V_S = (V+) – (V–) = 1.7V to 5.5V (±0.85V to ±2.75V) at T_A = 25°C, V_{REF} = [(V+) + (V–)] / 2, G = 0.5, R_L = 10kΩ connected to V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V and V_{OUT} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OFFSET							
V_{OSO}	Offset voltage, RTO[3]	V_S = 5.5V	T_A = 25°C		±0.3	±2.0	mV
	Offset voltage over T, RTO[3]	V_S = 5.5V	T_A = –40°C to 125°C			±2.0	mV
	Offset temp drift, RTO[3][1]	V_S = 5.5V	T_A = –40°C to 125°C		±1.2	5	µV/°C
PSRR	Power-supply rejection ratio, RTO[3]	V_S = 1.7V to 5.5V	T_A = 25°C		40	230	µV/V
INPUT IMPEDANCE							
R_{IN-DM}	Differential Resistance	R_{IN-DM} = 2*R_{IN}			10		kΩ
R_{IN-CM}	Common-mode Resistance	R_{IN-CM} = 0.5*(R_{IN} + R_F)			3.75		kΩ
INPUT VOLTAGE							
V_{CM}	Input Common-Mode Range	3V ≤ V_S ≤ 5.5V, V_{REF} = V_S / 2		(V–) – 0.2		(V–) + 6	V
V_{CM}	Input Common-Mode Range	1.7V ≤ V_S < 3V, V_{REF} = V_S / 2		(V–) – 0.2		3*(V+) – 2*V_{REF}	V
CMRR DC	Common-mode rejection ratio, RTO[3]	V_{CM} = [(V–) – 0.2V]to[(V–) + 6V], High CMRR region	V_S = 5.5V, V_{REF} = V_S / 2	79	92		dB
CMRR DC	Common-mode rejection ratio, RTO[3]	V_{CM} = [(V–) – 0.2]to[3*(V+) – 2*V_{REF}], Rail-to-Rail CMRR region	V_S = 3V, V_{REF} = V_S / 2	67	82		dB
NOISE VOLTAGE							
e_{NI}	Input voltage noise density		f = 1kHz		34		nV/√Hz
			f = 10kHz		30		
E_{NI}	Input voltage noise	f_B = 0.1Hz to 10Hz			6.5		$µV_{PP}$
GAIN							
GE	Gain error[2]	V_{REF} = V_S / 2, Vs = 5.5V	V_O = (V–) + 0.1V to (V+) – 0.1V		±0.02	±0.05	%
	Gain drift vs temperature[2]	V_{REF} = V_S / 2, Vs = 5.5V	T_A = –40°C to 125°C			±2.5	ppm/°C
OUTPUT							
V_{OH}	Positive rail headroom	R_L = 10kΩ to V_S / 2			12	25	mV
V_{OL}	Negative rail headroom	R_L = 10kΩ to V_S / 2			18	35	mV
C_L Drive	Load capacitance drive	V_O = 100mV step, Overshoot < 25%			70		pF
Z_O	Closed-loop output impedance	f = 10kHz			0.010		Ω
I_{SC}	Short-circuit current	V_S = 5.5V, Sourcing			50		mA
		V_S = 5.5V, Sinking			-40		mA
FREQUENCY RESPONSE							
BW	Bandwidth, –3dB	V_{IN} = 100mV_{pk-pk}			18		MHz
THD + N	Total harmonic distortion + noise	V_S = 5.5V, V_{CM} = 2.75V, V_O = 2V_{PP}, R_L = 10kΩ f = 1kHz, 80kHz measurement BW			0.001		%
THD + N	Total harmonic distortion + noise	V_S = 5.5V, V_{CM} = 2.75V, V_O = 4V_{PP}, R_L = 10kΩ f = 10kHz, 80kHz measurement BW			0.001		%
EMIRR	Electro-magnetic interference rejection ratio	f = 400MHz, V_{IN_EMIRR} = 630mV_{PP}, Common-Mode			67.5		dB
SR	Slew rate	Rising, V_S = 5V, V_O = 2V step			24		V/µs
		Falling, V_S = 5V, V_O = 2V step			32		

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6.5 Electrical Characteristics - INAx510-Q1, G = 0.50 (continued)

For V_S = (V+) – (V–) = 1.7V to 5.5V (±0.85V to ±2.75V) at T_A = 25°C, V_{REF} = [(V+) + (V–)] / 2, G = 0.5, R_L = 10kΩ connected to V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V and V_{OUT} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
t_S	Settling time	To 0.1%, V_S = 5.5V, V_{STEP} = 2V, C_L = 10pF			0.39		µs
		To 0.01%, V_S = 5.5V, V_{STEP} = 2V, C_L = 10pF			0.59		
	Overload recovery	V_{STEP} = V_S / G			0.05		µs
REFERENCE INPUT							
REF - V_{IN}	Input voltage range	V_S = 5.5V, External Reference (E Version)		(V–)		(V+)	V
REF - G	Reference gain to output	V_S = 5.5V, External Reference (E Version)			1		V/V
REF - GE	Reference gain error(2)	V_S = 5.5V, External Reference (E Version)			±0.02	±0.1	%
POWER SUPPLY							
V_S	Power-supply voltage	Dual-supply		±0.85		±2.75	V
I_Q	Quiescent current	V_S = 1.7V			1.6		mA
		V_S = 3.3V			1.8	2.5	
		V_S = 5.5V			2.2	3.0	
		V_S = 5.5V	T_A = –40°C to 125°C			3.2	

(1) Offset drifts are uncorrelated.
(2) Minimum and maximum values are specified by characterization.
(3) RTO stands for Referred to Output

6.6 Electrical Characteristics - INAx510-Q1, G = 0.75

For V_S = (V+) – (V–) = 1.7V to 5.5V (±0.85V to ±2.75V) at T_A = 25°C, V_{REF} = [(V+) + (V–)] / 2, G = 0.75, R_L = 10kΩ connected to V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V and V_{OUT} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OFFSET							
V_{OSO}	Offset voltage, RTO[3]	V_S = 5.5V	T_A = 25°C		±0.35	±2.2	mV
	Offset voltage over T, RTO[3]	V_S = 5.5V	T_A = –40°C to 125°C			±2.2	mV
	Offset temp drift, RTO[3][1]	V_S = 5.5V	T_A = –40°C to 125°C		±1.2	5	µV/°C
PSRR	Power-supply rejection ratio, RTO[3]	V_S = 1.7V to 5.5V	T_A = 25°C		45	250	µV/V
INPUT IMPEDANCE							
R_{IN-DM}	Differential Resistance	R_{IN-DM} = 2*R_{IN}			6.67		kΩ
R_{IN-CM}	Common-mode Resistance	R_{IN-CM} = 0.5*(R_{IN} + R_F)			2.92		kΩ
INPUT VOLTAGE							
V_{CM}	Input common-mode Range	3.6V < V_S ≤ 5.5V, V_{REF} = V_S / 2		(V–) – 0.2		(V–) + 6	V
V_{CM}	Input common-mode Range	1.7V ≤ V_S ≤ 3.6V, V_{REF} = V_S / 2		(V–) – 0.2		2.33*(V+) – 1.33*V_{REF}	V
CMRR DC	Common-mode rejection ratio, RTO[3]	V_{CM} = [(V–) – 0.2]to [(V–) + 6], High CMRR region	V_S = 5.5V, V_{REF} = V_S / 2	77	92		dB
CMRR DC	Common-mode rejection ratio, RTO[3]	V_{CM} = [(V–) – 0.2]to[2.33*(V+) – 1.33*V_{REF}], Rail-to-Rail CMRR region	V_S = 3V, V_{REF} = V_S / 2	64	85		dB
NOISE VOLTAGE							
e_{NI}	Input voltage noise density		f = 1kHz		25		nV/√Hz
			f = 10kHz		21		
E_{NI}	Input voltage noise	f_B = 0.1Hz to 10Hz			5.0		$µV_{PP}$
GAIN							
GE	Gain error[2]	V_{REF} = V_S / 2, Vs = 5.5V	V_O = (V–) + 0.1V to (V+) – 0.1V		±0.02	±0.05	%
	Gain drift vs temperature[2]	V_{REF} = V_S / 2, Vs = 5.5V	T_A = –40°C to 125°C			±2.5	ppm/°C
OUTPUT							
V_{OH}	Positive rail headroom	R_L = 10kΩ to V_S / 2			14	25	mV
V_{OL}	Negative rail headroom	R_L = 10kΩ to V_S / 2			20	35	mV
C_L Drive	Load capacitance drive	V_O = 100mV step, Overshoot < 25%			70		pF
Z_O	Closed-loop output impedance	f = 10kHz			0.010		Ω
I_{SC}	Short-circuit current	V_S = 5.5V, Sourcing			50		mA
		V_S = 5.5V, Sinking			-40		mA
FREQUENCY RESPONSE							
BW	Bandwidth, –3dB	V_{IN} = 100mV_{pk-pk}			18		MHz
THD + N	Total harmonic distortion + noise	V_S = 5.5V, V_{CM} = 2.75V, V_O = 2V_{PP}, R_L = 10kΩ f = 1kHz, 80kHz measurement BW			0.001		%
THD + N	Total harmonic distortion + noise	V_S = 5.5V, V_{CM} = 2.75V, V_O = 4V_{PP}, R_L = 10kΩ f = 10kHz, 80kHz measurement BW			0.001		%
EMIRR	Electro-magnetic interference rejection ratio	f = 400MHz, V_{IN_EMIRR} = 630mV_{PP}, Common-Mode			70		dB

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6.6 Electrical Characteristics - INAx510-Q1, G = 0.75 (continued)

For V_S = (V+) – (V–) = 1.7V to 5.5V (±0.85V to ±2.75V) at T_A = 25°C, V_{REF} = [(V+) + (V–)] / 2, G = 0.75, R_L = 10kΩ connected to V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V and V_{OUT} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
SR	Slew rate	Rising, V_S = 5V, V_O = 2V step			24		V/µs
		Falling, V_S = 5V, V_O = 2V step			32		
t_S	Settling time	To 0.1%, V_S = 5.5V, V_{STEP} = 2V, C_L = 10pF			0.41		µs
		To 0.01%, V_S = 5.5V, V_{STEP} = 2V, C_L = 10pF			0.42		
	Overload recovery	V_{STEP} = V_S / G			0.05		µs
REFERENCE INPUT							
REF - V_{IN}	Input voltage range	V_S = 5.5V, External Reference (E Version)		(V–)		(V+)	V
REF - G	Reference gain to output	V_S = 5.5V, External Reference (E Version)			1		V/V
REF - GE	Reference gain error(2)	V_S = 5.5V, External Reference (E Version)			±0.02	±0.1	%
POWER SUPPLY							
V_S	Power-supply voltage	Dual-supply		±0.85		±2.75	V
I_Q	Quiescent current	V_S = 1.7V			1.6		mA
		V_S = 3.3V			1.8	2.5	
		V_S = 5.5V			2.2	3.0	
		V_S = 5.5V	T_A = –40°C to 125°C			3.2	

(1) Offset drifts are uncorrelated.
(2) Minimum and maximum values are specified by characterization.
(3) RTO stands for Referred to Output

6.7 Electrical Characteristics - INAx510-Q1, G = 1

For V_S = (V+) – (V–) = 1.7V to 5.5V (±0.85V to ±2.75V) at T_A = 25°C, V_{REF} = [(V+) + (V–)] / 2, G = 1, R_L = 10kΩ connected to V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V and V_{OUT} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OFFSET							
V_{OSO}	Offset voltage, RTO[3]	V_S = 5.5V	T_A = 25°C		±0.4	±2.6	mV
	Offset voltage over T, RTO[3]	V_S = 5.5V	T_A = –40°C to 125°C			±2.6	mV
	Offset temp drift, RTO[3][1]	V_S = 5.5V	T_A = –40°C to 125°C		±1.2	5	µV/°C
PSRR	Power-supply rejection ratio, RTO[3]	V_S = 1.7V to 5.5V	T_A = 25°C		50	310	µV/V
INPUT IMPEDANCE							
R_{IN-DM}	Differential Resistance	R_{IN-DM} = 2*R_{IN}			10		kΩ
R_{IN-CM}	Common-mode Resistance	R_{IN-CM} = 0.5*(R_{IN} + R_F)			5		kΩ
INPUT VOLTAGE							
V_{CM}	Input common-mode Range	4V < V_S ≤ 5.5V, V_{REF} = V_S / 2		(V–) – 0.2		(V–) + 6	V
V_{CM}	Input common-mode Range	1.7V ≤ V_S ≤ 4V, V_{REF} = V_S / 2		(V–) – 0.2		2*(V+) – V_{REF}	V
CMRR DC	Common-mode rejection ratio, RTO[3]	V_{CM} = [(V–) – 0.2]to [(V–) + 6], High CMRR region	V_S = 5.5V, V_{REF} = V_S / 2	75	92		dB
CMRR DC	Common-mode rejection ratio, RTO[3]	V_{CM} = [(V–) – 0.2]to[2*(V+) – V_{REF}], Rail-to-Rail CMRR region	V_S = 3V, V_{REF} = V_S / 2	63	85		dB
NOISE VOLTAGE							
e_{NI}	Input voltage noise density		f = 1kHz		25		nV/√Hz
			f = 10kHz		21		
E_{NI}	Input voltage noise	f_B = 0.1Hz to 10Hz			4.5		$µV_{PP}$
GAIN							
GE	Gain error[2]	V_{REF} = V_S / 2, Vs = 5.5V	V_O = (V–) + 0.1V to (V+) – 0.1V		±0.02	±0.05	%
	Gain drift vs temperature[2]		T_A = –40°C to 125°C			±2.5	ppm/°C
OUTPUT							
V_{OH}	Positive rail headroom	R_L = 10kΩ to V_S / 2			9	25	mV
V_{OL}	Negative rail headroom	R_L = 10kΩ to V_S / 2			10	35	mV
C_L Drive	Load capacitance drive	V_O = 100mV step, Overshoot < 25%			70		pF
Z_O	Closed-loop output impedance	f = 10kHz			0.010		Ω
I_{SC}	Short-circuit current	V_S = 5.5V, Sourcing			50		mA
		V_S = 5.5V, Sinking			-40		mA
FREQUENCY RESPONSE							
BW	Bandwidth, –3dB	V_{IN} = 100mV_{pk-pk}			18		MHz
THD + N	Total harmonic distortion + noise	V_S = 5.5V, V_{CM} = 2.75V, V_O = 2V_{PP}, R_L = 10kΩ f = 1kHz, 80kHz measurement BW			0.001		%
THD + N	Total harmonic distortion + noise	V_S = 5.5V, V_{CM} = 2.75V, V_O = 4V_{PP}, R_L = 10kΩ f = 10kHz, 80kHz measurement BW			0.001		%
EMIRR	Electro-magnetic interference rejection ratio	f = 400MHz, V_{IN_EMIRR} = 630mV_{PP}, Common-Mode			85		dB
SR	Slew rate	Rising, V_S = 5V, V_O = 2V step			30		V/µs
		Falling, V_S = 5V, V_O = 2V step			38		

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6.7 Electrical Characteristics - INAx510-Q1, G = 1 (continued)

For V_S = (V+) – (V–) = 1.7V to 5.5V (±0.85V to ±2.75V) at T_A = 25°C, V_{REF} = [(V+) + (V–)] / 2, G = 1, R_L = 10kΩ connected to V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V and V_{OUT} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
t_S	Settling time	To 0.1%, V_S = 5.5V, V_{STEP} = 2V, C_L = 10pF			0.34		µs
		To 0.01%, V_S = 5.5V, V_{STEP} = 2V, C_L = 10pF			0.37		
	Overload recovery	V_{STEP} = V_S / G			0.04		µs
REFERENCE INPUT							
REF - V_{IN}	Input voltage range	V_S = 5.5V, External Reference (E Version)		(V–)		(V+)	V
REF - G	Reference gain to output	V_S = 5.5V, External Reference (E Version)			1		V/V
REF - GE	Reference gain error(2)	V_S = 5.5V, External Reference (E Version)			±0.02	±0.1	%
POWER SUPPLY							
V_S	Power-supply voltage	Dual-supply		±0.85		±2.75	V
I_Q	Quiescent current	V_S = 1.7V			1.6		mA
		V_S = 3.3V			1.7	2.5	
		V_S = 5.5V			2.0	2.8	
		V_S = 5.5V	T_A = –40°C to 125°C			3.0	

(1) Offset drifts are uncorrelated.
(2) Minimum and maximum values are specified by characterization.
(3) RTO stands for Referred to Output

6.8 Electrical Characteristics - INAx510-Q1, G = 1.5

For V_S = (V+) – (V–) = 1.7V to 5.5V (±0.85V to ±2.75V) at T_A = 25°C, V_{REF} = [(V+) + (V–)] / 2, G = 1.5, R_L = 10kΩ connected to V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V and V_{OUT} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OFFSET							
V_{OSO}	Offset voltage, RTO[3]	V_S = 5.5V	T_A = 25°C		±0.5	±3.2	mV
	Offset voltage over T, RTO[3]	V_S = 5.5V	T_A = –40°C to 125°C			±3.2	mV
	Offset temp drift, RTO[3][1]	V_S = 5.5V	T_A = –40°C to 125°C		±1.2	5	µV/°C
PSRR	Power-supply rejection ratio, RTO[3]	V_S = 1.7V to 5.5V	T_A = 25°C		65	310	µV/V
INPUT IMPEDANCE							
R_{IN-DM}	Differential Resistance	R_{IN-DM} = 2*R_{IN}			6.67		kΩ
R_{IN-CM}	Common-mode Resistance	R_{IN-CM} = 0.5*(R_{IN} + R_F)			4.17		kΩ
INPUT VOLTAGE							
V_{CM}	Input common-mode Range	4.5V < V_S ≤ 5.5V, V_{REF} = V_S / 2		(V–) – 0.2		(V–) + 6	V
V_{CM}	Input common-mode Range	1.7 < V_S ≤ 4.5V, V_{REF} = V_S / 2		(V–) – 0.2		1.67*(V+) – 0.67V_{REF}	V
CMRR DC	Common-mode rejection ratio, RTO[3]	V_{CM} = [(V–) – 0.2]to[1.67*(V+) – 0.67*V_{REF} – 1.85V], High CMRR region	V_S = 5.5V, V_{REF} = V_S / 2	74	88		dB
CMRR DC	Common-mode rejection ratio, RTO[3]	V_{CM} = [(V–) – 0.2]to[1.67*(V+) – 0.67V_{REF}], Rail-to-Rail CMRR region	V_S = 3V, V_{REF} = V_S / 2	60	81		dB
NOISE VOLTAGE							
e_{NI}	Input voltage noise density		f = 1kHz		19		nV/√Hz
			f = 10kHz		16		
E_{NI}	Input voltage noise	f_B = 0.1Hz to 10Hz			3.5		$µV_{PP}$
GAIN							
GE	Gain error[2]	V_{REF} = V_S / 2, Vs = 5.5V	V_O = (V–) + 0.1V to (V+) – 0.1V		±0.02	±0.05	%
	Gain drift vs temperature[2]	V_{REF} = V_S / 2, Vs = 5.5V	T_A = –40°C to 125°C			±2.5	ppm/°C
OUTPUT							
V_{OH}	Positive rail headroom	R_L = 10kΩ to V_S / 2			8	25	mV
V_{OL}	Negative rail headroom	R_L = 10kΩ to V_S / 2			10	35	mV
C_L Drive	Load capacitance drive	V_O = 100mV step, Overshoot < 25%			70		pF
Z_O	Closed-loop output impedance	f = 10kHz			0.010		Ω
I_{SC}	Short-circuit current	V_S = 5.5V, Sourcing			50		mA
		V_S = 5.5V, Sinking			-40		mA
FREQUENCY RESPONSE							
BW	Bandwidth, –3dB	V_{IN} = 100mV_{pk-pk}			18		MHz
THD + N	Total harmonic distortion + noise	V_S = 5.5V, V_{CM} = 2.75V, V_O = 2V_{PP}, R_L = 10kΩ f = 1kHz, 80kHz measurement BW			0.001		%
THD + N	Total harmonic distortion + noise	V_S = 5.5V, V_{CM} = 2.75V, V_O = 4V_{PP}, R_L = 10kΩ f = 10kHz, 80kHz measurement BW			0.001		%
EMIRR	Electro-magnetic interference rejection ratio	f = 400MHz, V_{IN_EMIRR} = 630mV_{PP}, Common-Mode			80		dB

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6.8 Electrical Characteristics - INAx510-Q1, G = 1.5 (continued)

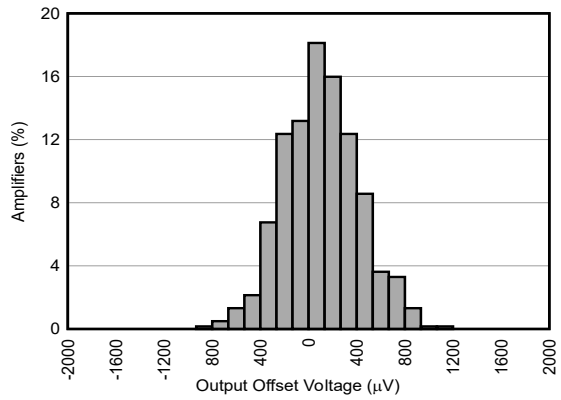
For V_S = (V+) – (V–) = 1.7V to 5.5V (±0.85V to ±2.75V) at T_A = 25°C, V_{REF} = [(V+) + (V–)] / 2, G = 1.5, R_L = 10kΩ connected to V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V and V_{OUT} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
SR	Slew rate	Rising, V_S = 5V, V_O = 2V step			30		V/µs
		Falling, V_S = 5V, V_O = 2V step			38		
t_S	Settling time	To 0.1%, V_S = 5.5V, V_{STEP} = 2V, C_L = 10pF			0.34		µs
		To 0.01%, V_S = 5.5V, V_{STEP} = 2V, C_L = 10pF			0.37		
	Overload recovery	V_{STEP} = V_S / G			0.04		µs
REFERENCE INPUT							
REF - V_{IN}	Input voltage range	V_S = 5.5V, External Reference (E Version)		(V–)		(V+)	V
REF - G	Reference gain to output	V_S = 5.5V, External Reference (E Version)			1		V/V
REF - GE	Reference gain error(2)	V_S = 5.5V, External Reference (E Version)			±0.02	±0.1	%
POWER SUPPLY							
V_S	Power-supply voltage	Dual-supply		±0.85		±2.75	V
I_Q	Quiescent current	V_S = 1.7V			1.6		mA
		V_S = 3.3V			1.7	2.5	
		V_S = 5.5V			2.0	2.8	
		V_S = 5.5V	T_A = –40°C to 125°C			3.0	

(1) Offset drifts are uncorrelated.
(2) Minimum and maximum values are specified by characterization.
(3) RTO stands for Referred to Output

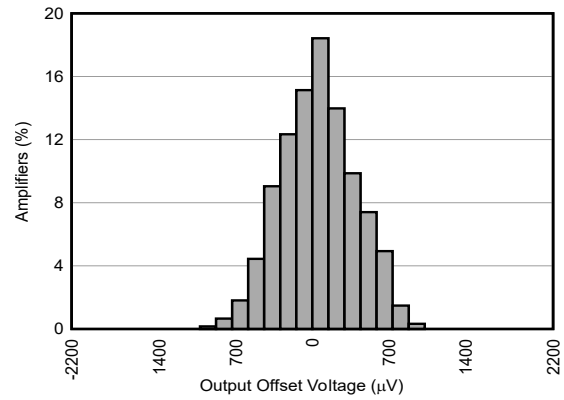
6.9 Typical Characteristics

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)



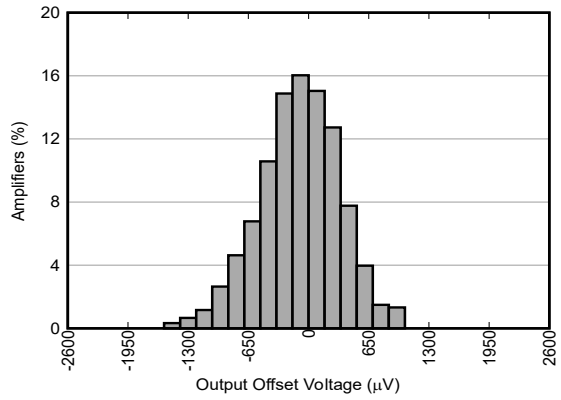
G = 0.5V/V N = 607 µ = 110µV σ = 311µV

Figure 6-1. Distribution of Output Referred Offset Voltage



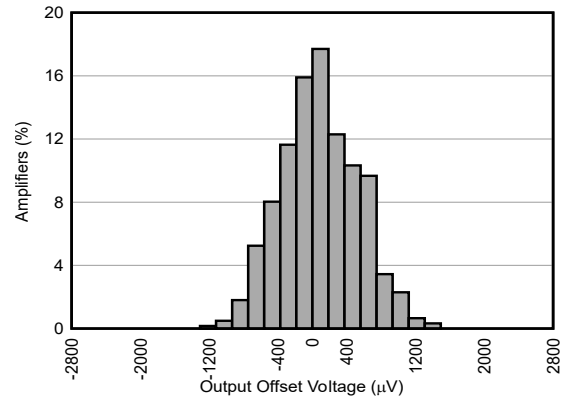
G = 0.75V/V N = 608 µ = 50µV σ = 337µV

Figure 6-2. Distribution of Output Referred Offset Voltage



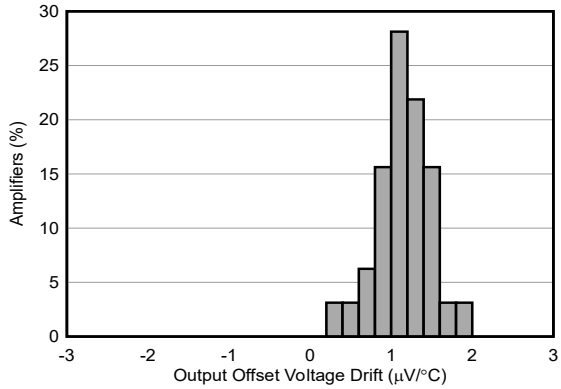
G = 1V/V N = 605 µ = -70µV σ = 432µV

Figure 6-3. Distribution of Output Referred Offset Voltage



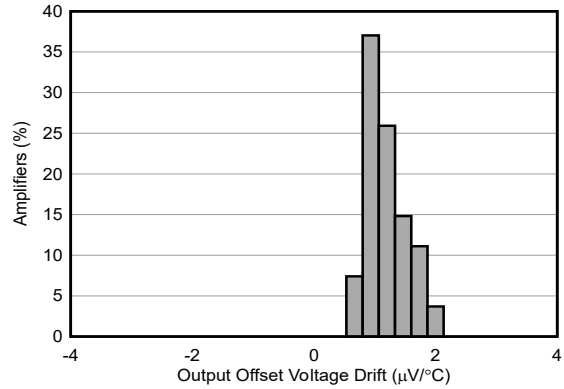
G = 1.5V/V N = 610 µ = 78µV σ = 447µV

Figure 6-4. Distribution of Output Referred Offset Voltage



G = 0.5V/V N = 30 µ =1.17µV/°C σ = 0.33µV/°C

Figure 6-5. Distribution of Output Referred Offset Voltage Drift



G = 0.75V/V N = 30 µ =1.12µV/°C σ = 0.33µV/°C

Figure 6-6. Distribution of Output Referred Offset Voltage Drift

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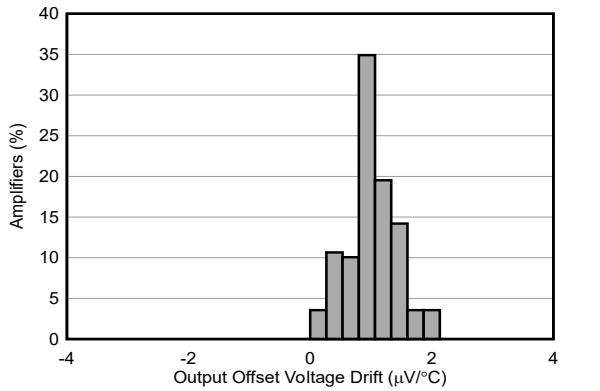
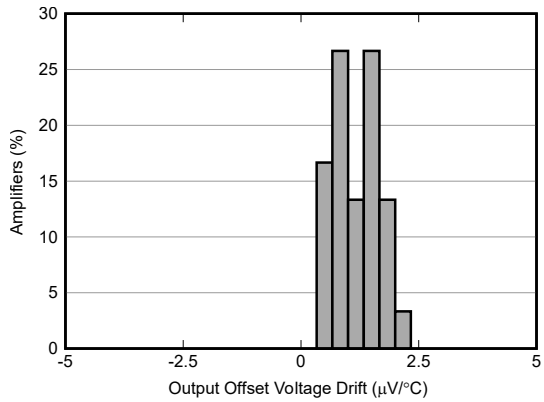
6.9 Typical Characteristics (continued)

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)



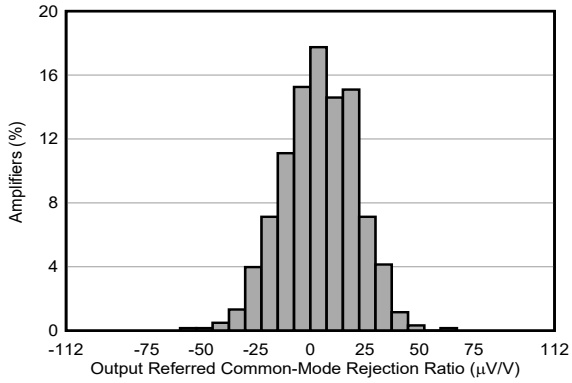
G = 1V/V N = 30 μ =0.96μV/°C σ = 0.40μV/°C

Figure 6-7. Distribution of Output Referred Offset Voltage Drift



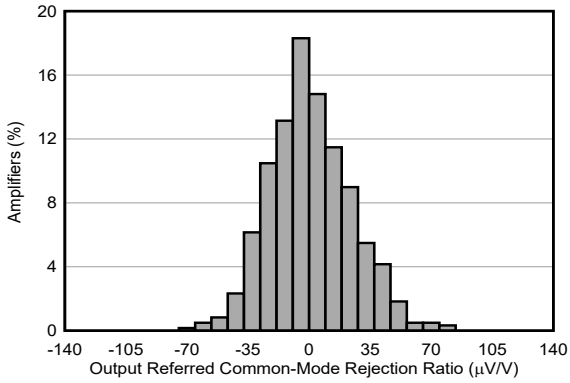
G = 1.5V/V N = 30 μ =1.21μV/°C σ = 0.46μV/°C

Figure 6-8. Distribution of Output Referred Offset Voltage Drift



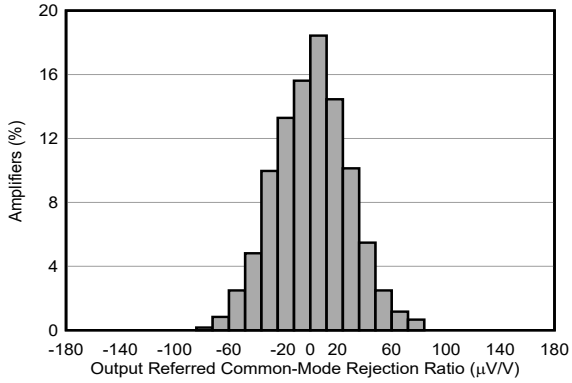
G = 0.5V/V N = 603 μ =4.3μV/V σ = 16.7μV/V

Figure 6-9. Distribution of Output Referred Common-Mode Rejection Ratio



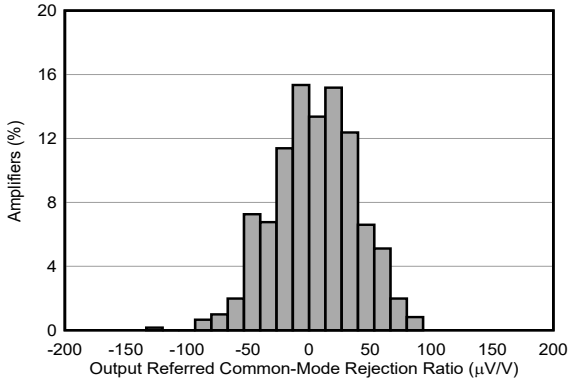
G = 0.75V/V N = 601 μ =-0.9μV/V σ = 23.5μV/V

Figure 6-10. Distribution of Output Referred Common-Mode Rejection Ratio



G = 1V/V N = 602 μ =1.8μV/V σ = 27.3μV/V

Figure 6-11. Distribution of Output Referred Common-Mode Rejection Ratio

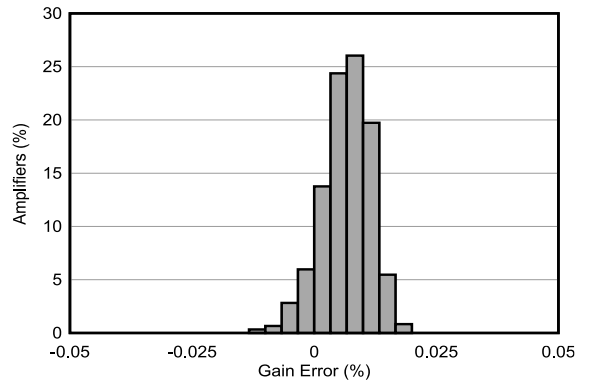


G = 1.5V/V N = 606 μ =4.9μV/V σ = 33.7μV/V

Figure 6-12. Distribution of Output Referred Common-Mode Rejection Ratio

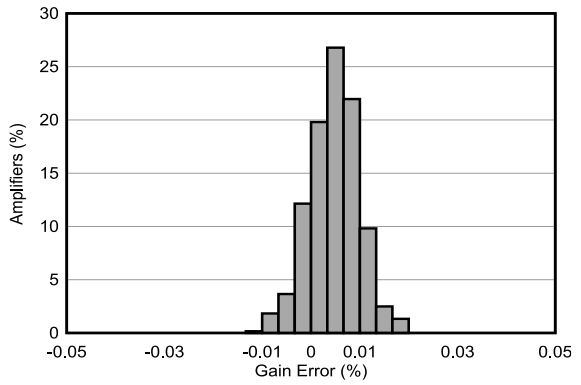
6.9 Typical Characteristics (continued)

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)



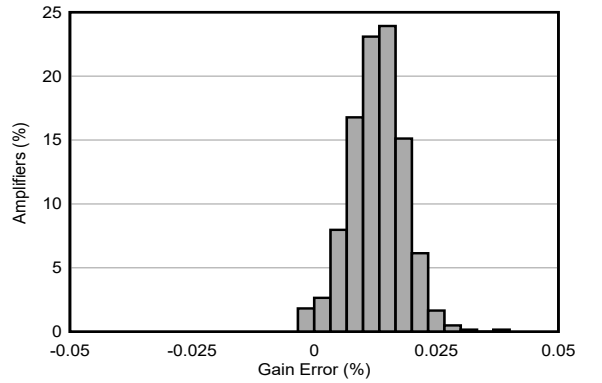
G = 0.5V/V N = 603 μ =0.007% σ = 0.005%

Figure 6-13. Distribution of Gain Error



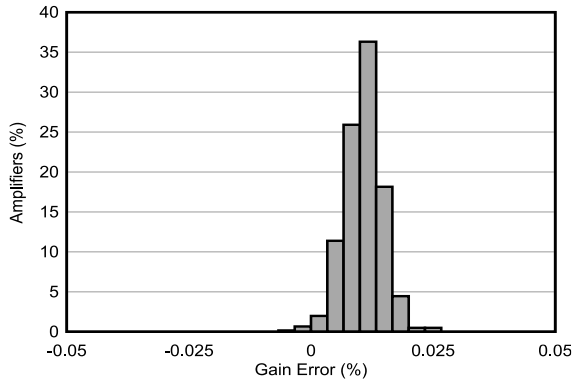
G = 0.75V/V N = 601 μ =0.005% σ = 0.005%

Figure 6-14. Distribution of Gain Error



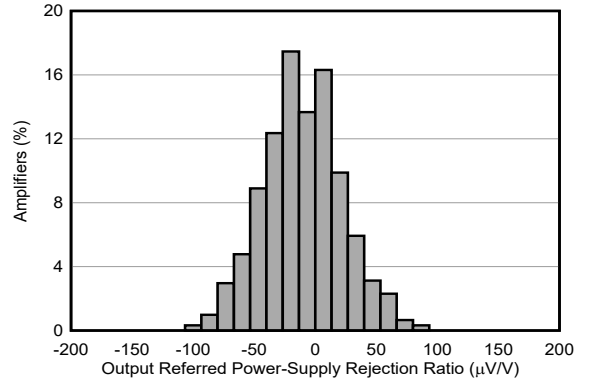
G = 1V/V N = 602 μ =0.013% σ = 0.006%

Figure 6-15. Distribution of Gain Error



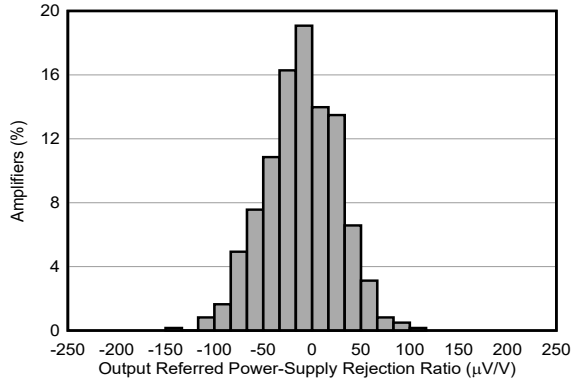
G = 1.5V/V N = 606 μ =0.011% σ = 0.004%

Figure 6-16. Distribution of Gain Error



G = 0.5V/V N = 607 μ = -10.4μV/V σ = 32.4μV/V

Figure 6-17. Distribution of Output Referred Power Supply Rejection Ratio



G = 0.75V/V N = 608 μ = -9.1μV/V σ = 37.1μV/V

Figure 6-18. Distribution of Output Referred Power Supply Rejection Ratio

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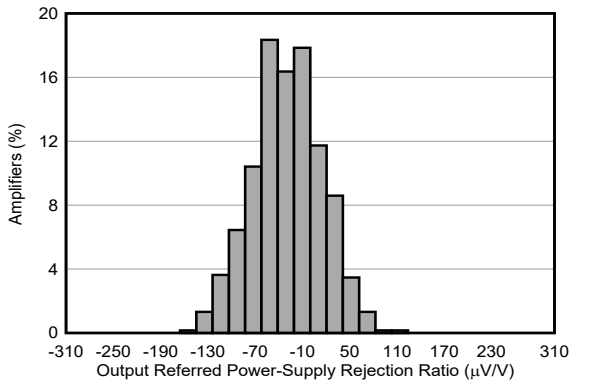
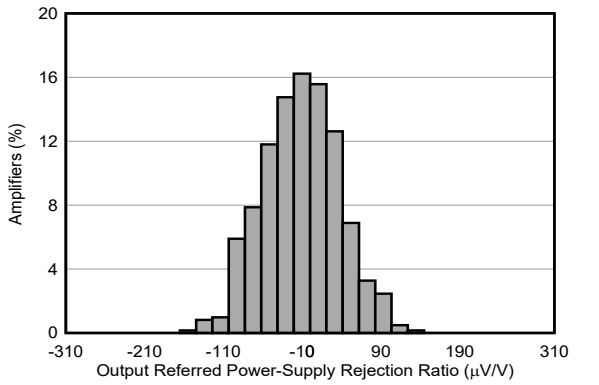
6.9 Typical Characteristics (continued)

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)



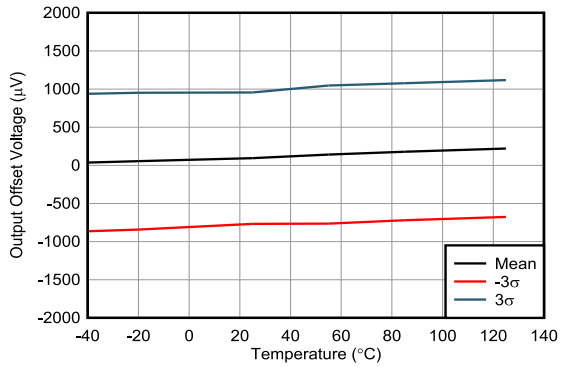
G = 1V/V N = 605 µ = -31.6µV/V σ = 44.3µV/V

Figure 6-19. Distribution of Output Referred Power Supply Rejection Ratio



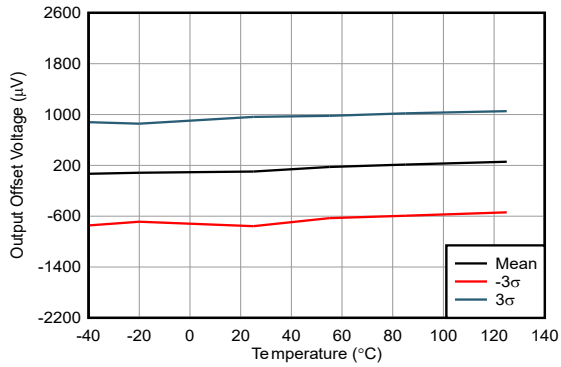
G = 1.5V/V N = 610 µ = -9.9µV/V σ = 48.7µV/V

Figure 6-20. Distribution of Output Referred Power Supply Rejection Ratio



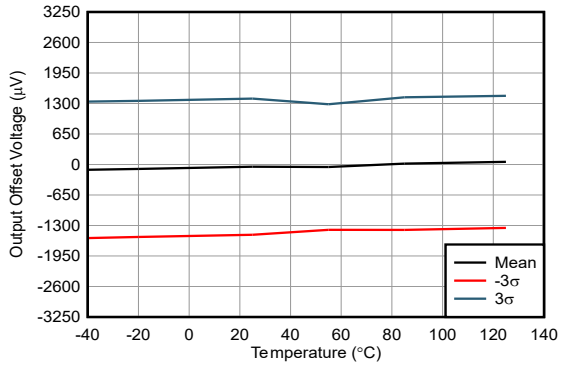
G = 0.5V/V

Figure 6-21. Output Referred Offset Voltage vs Temperature



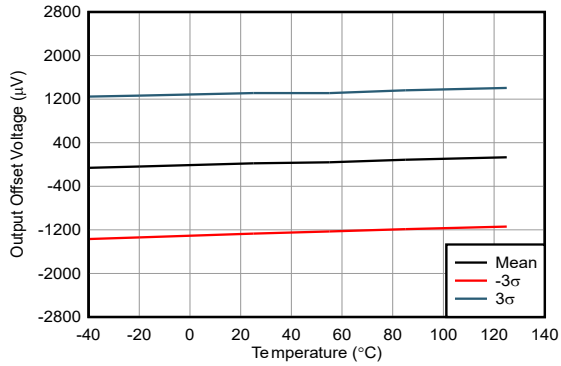
G = 0.75V/V

Figure 6-22. Output Referred Offset Voltage vs Temperature



G = 1V/V

Figure 6-23. Output Referred Offset Voltage vs Temperature

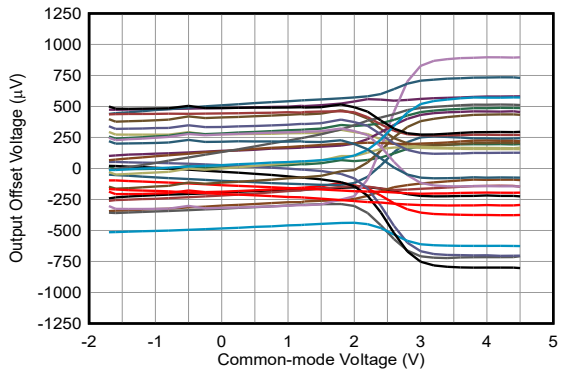


G = 1.5V/V

Figure 6-24. Output Referred Offset Voltage vs Temperature

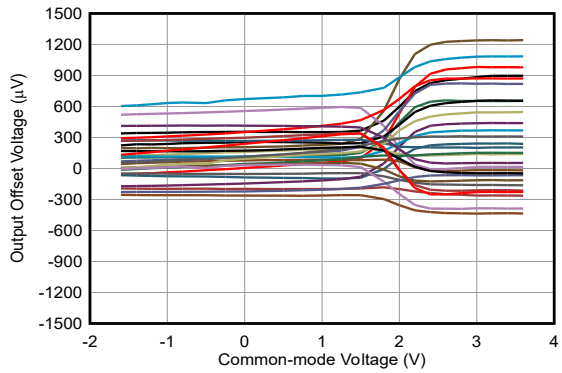
6.9 Typical Characteristics (continued)

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)



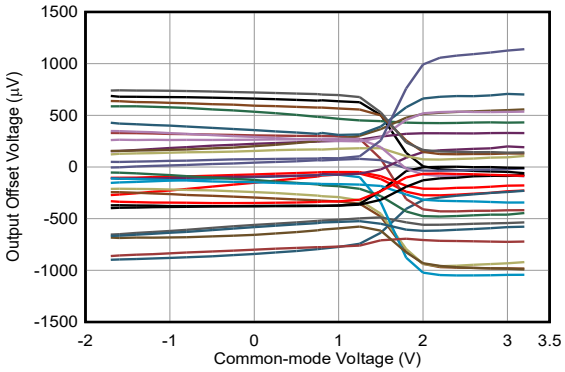
G = 0.5V/V Vs = ±1.5V N = 30

Figure 6-25. Output Referred Offset Voltage vs Common-Mode Voltage



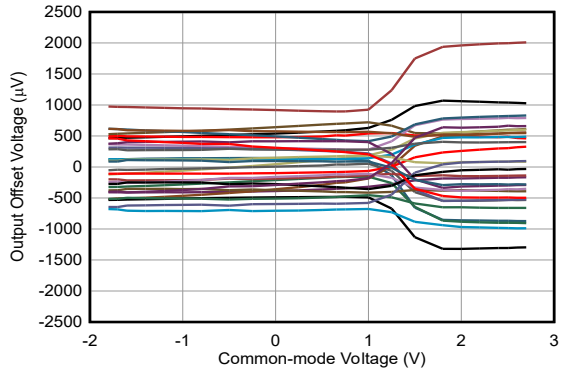
G = 0.75V/V Vs = ±1.5V N = 30

Figure 6-26. Output Referred Offset Voltage vs Common-Mode Voltage



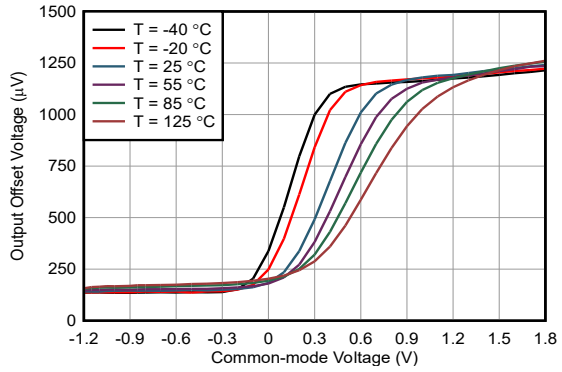
G = 1V/V Vs = ±1.5V N = 30

Figure 6-27. Output Referred Offset Voltage vs Common-Mode Voltage



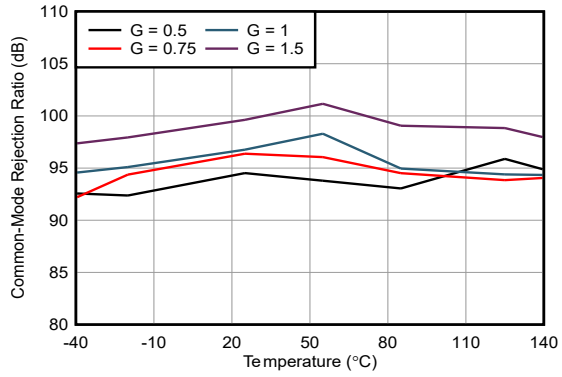
G = 1.5V/V Vs = ±1.5V N = 30

Figure 6-28. Output Referred Offset Voltage vs Common-Mode Voltage



G = 1V/V Vs = ±0.85V

Figure 6-29. Output Referred Offset Voltage vs Common-Mode and Temperature



Vs = ±2.75V

Figure 6-30. Output Referred Common-Mode Rejection Ratio vs Temperature

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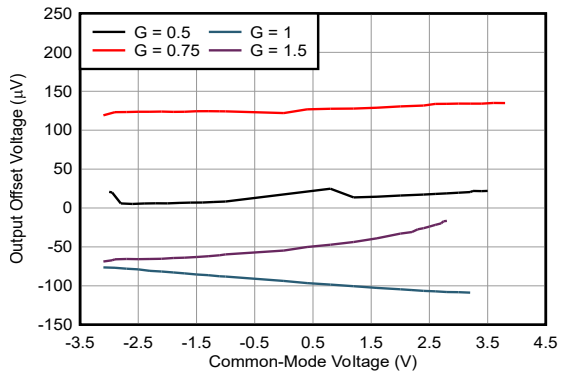
6.9 Typical Characteristics (continued)

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)



Vs = ±2.75V

Figure 6-31. Output Referred Offset Voltage vs Common-Mode

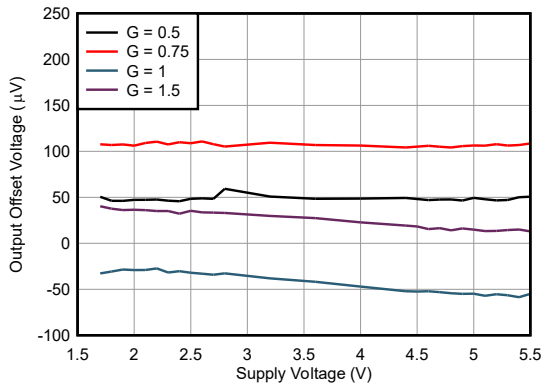


Figure 6-32. Output Referred Offset Voltage vs Supply

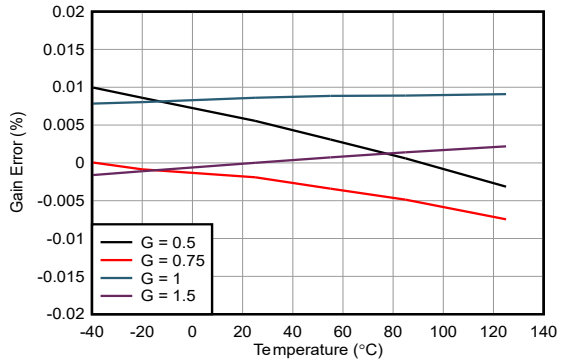


Figure 6-33. Gain Error vs Temperature

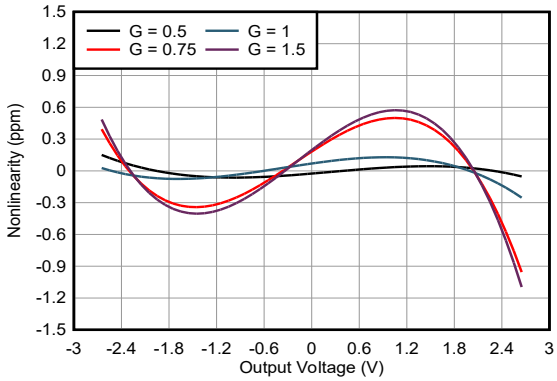
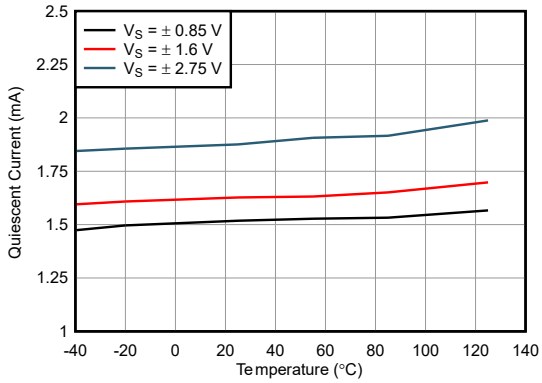
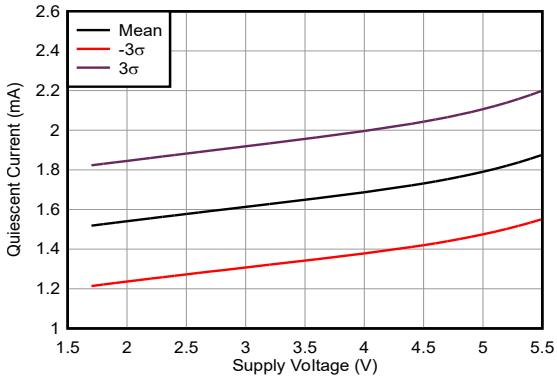


Figure 6-34. Gain Nonlinearity



G = 1V/V

Figure 6-35. Quiescent Current vs Temperature



G = 1V/V

Figure 6-36. Quiescent Current vs Supply

6.9 Typical Characteristics (continued)

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)

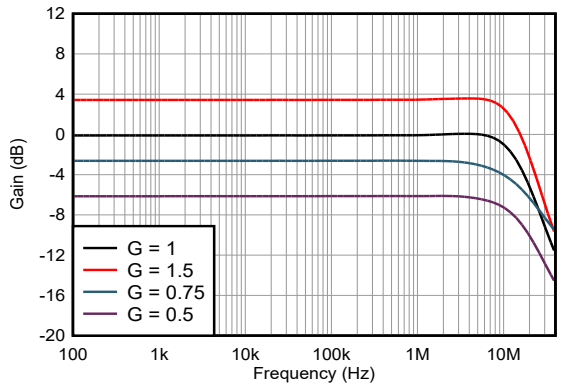


Figure 6-37. Closed Loop Gain vs Frequency

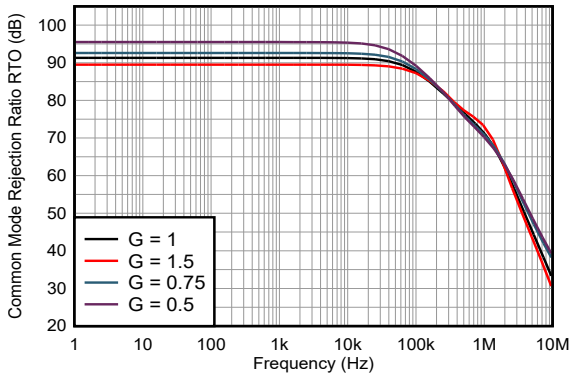


Figure 6-38. Output Referred Common-Mode Rejection Ratio vs Frequency

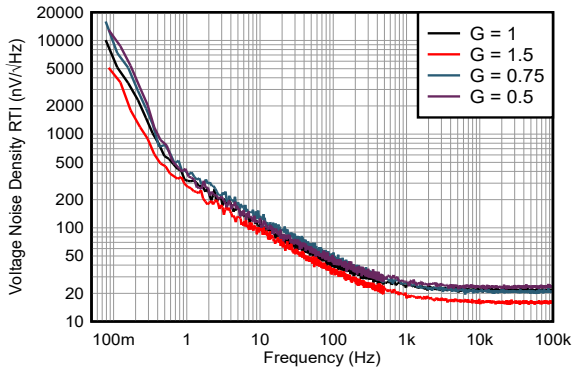
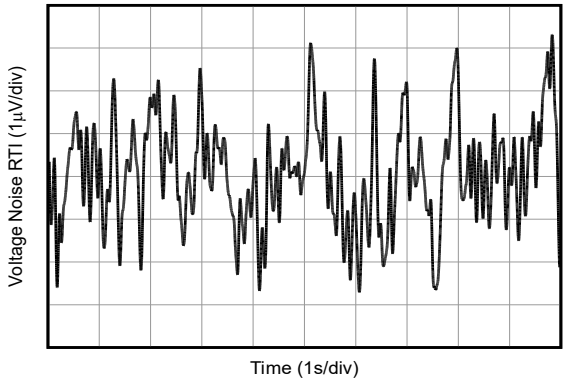
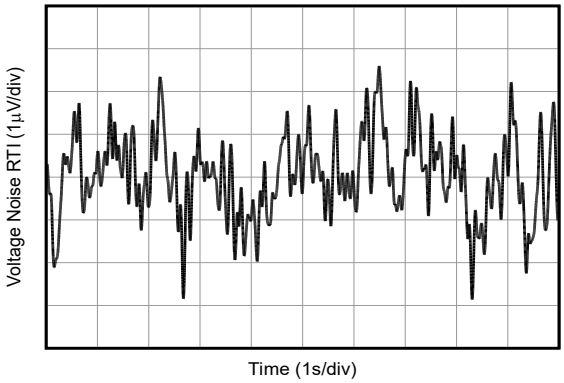


Figure 6-39. Input Referred Voltage Noise Spectral Density



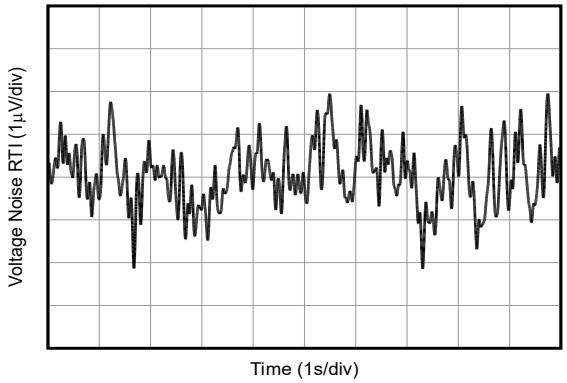
G = 0.5V/V Vs = ±2.75V

Figure 6-40. Input Referred 0.1Hz to 10Hz Voltage Noise in Time Domain



G = 0.75V/V Vs = ±2.75V

Figure 6-41. Input Referred 0.1Hz to 10Hz Voltage Noise in Time Domain



G = 1V/V Vs = ±2.75V

Figure 6-42. Input Referred 0.1Hz to 10Hz Voltage Noise in Time Domain

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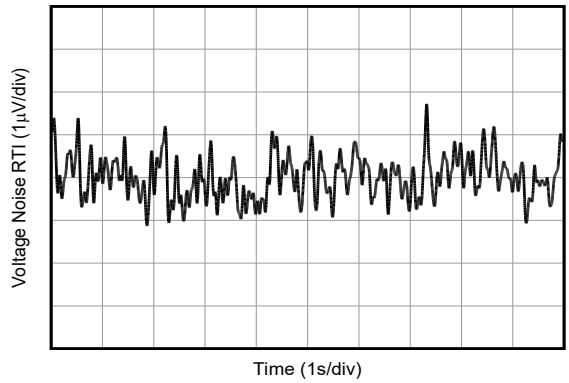
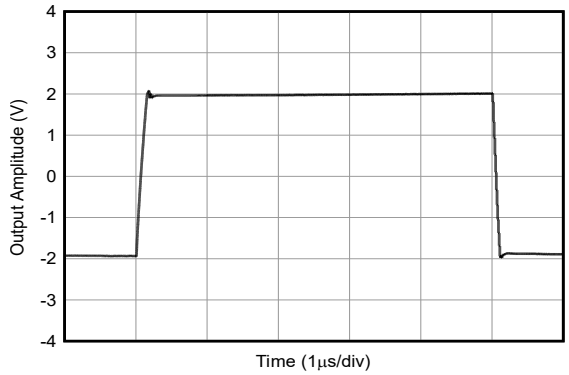
6.9 Typical Characteristics (continued)

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)



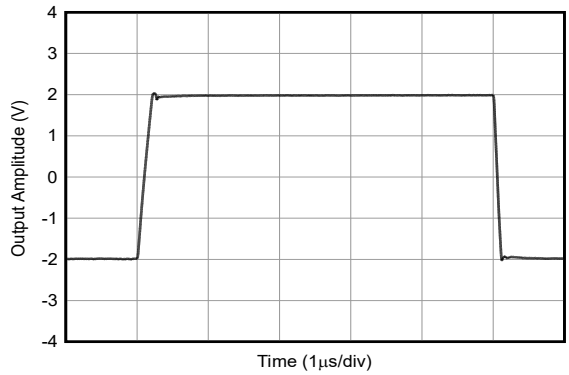
G = 1.5V/V Vs = ±2.75V

Figure 6-43. Input Referred 0.1Hz to 10Hz Voltage Noise in Time Domain



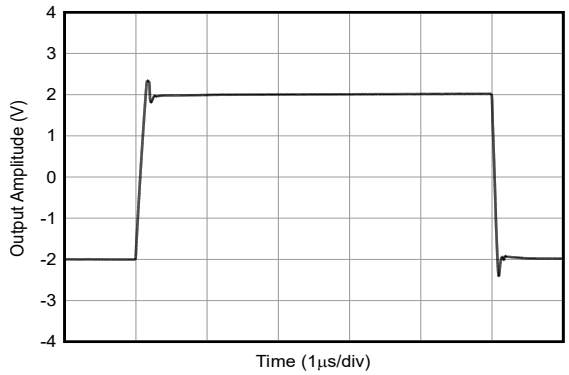
G = 0.5V/V Vs = ±2.75V C_L = 10pF

Figure 6-44. Large-Signal Step Response



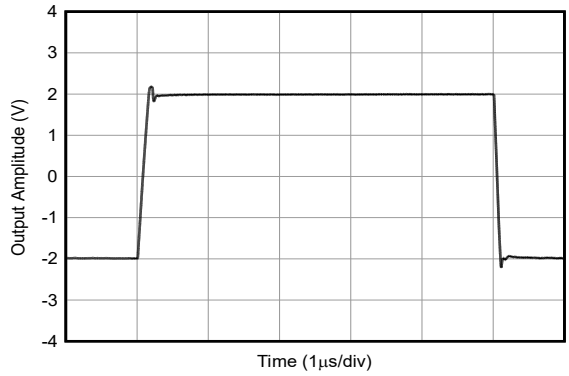
G = 0.75V/V Vs = ±2.75V C_L = 10pF

Figure 6-45. Large-Signal Step Response



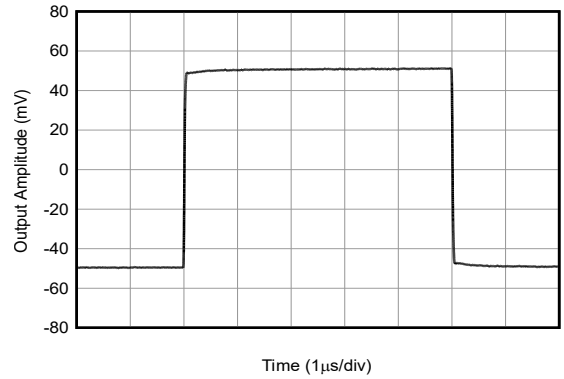
G = 1V/V Vs = ±2.75V C_L = 10pF

Figure 6-46. Large-Signal Step Response



G = 1.5V/V Vs = ±2.75V C_L = 10pF

Figure 6-47. Large-Signal Step Response

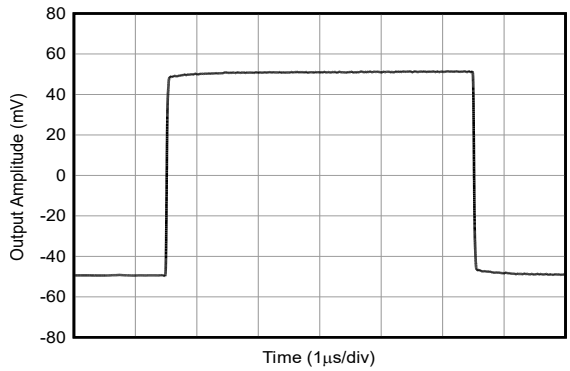


G = 0.5V/V Vs = ±2.75V C_L = 10pF

Figure 6-48. Small-Signal Step Response

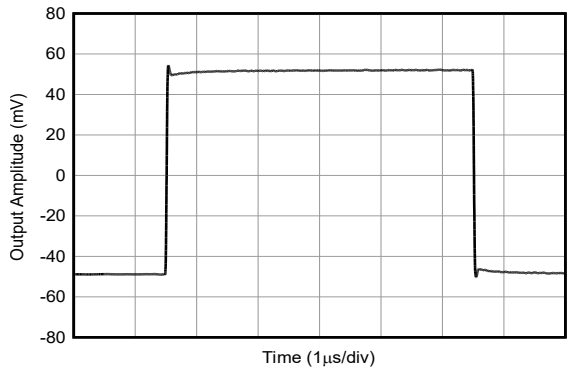
6.9 Typical Characteristics (continued)

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)



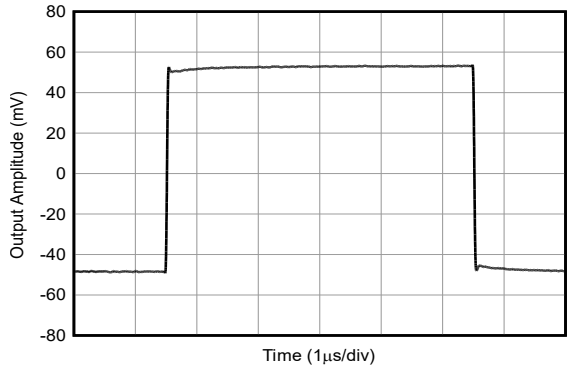
G = 0.75V/V Vs = ±2.75V C_L = 10pF

Figure 6-49. Small-Signal Step Response



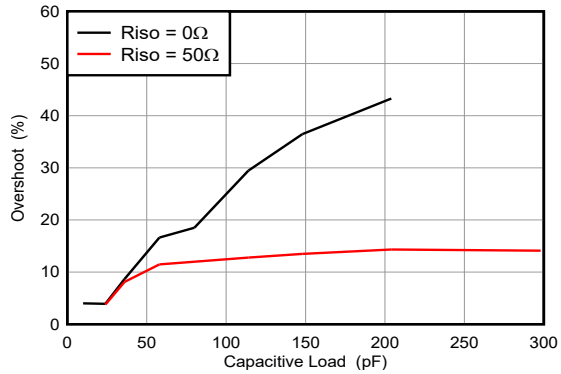
G = 1V/V Vs = ±2.75V C_L = 10pF

Figure 6-50. Small-Signal Step Response



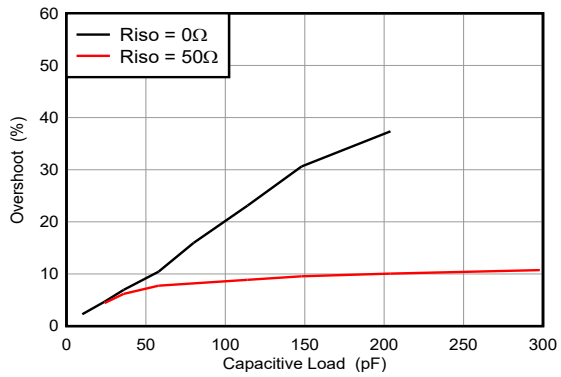
G = 1.5V/V Vs = ±2.75V C_L = 10pF

Figure 6-51. Small-Signal Step Response



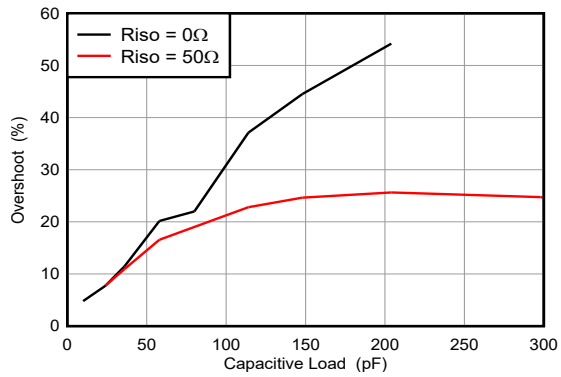
G = 0.5V/V Vs = ±2.75V

Figure 6-52. Small-Signal Overshoot vs Capacitive Load



G = 0.75V/V Vs = ±2.75V

Figure 6-53. Small-Signal Overshoot vs Capacitive Load



G = 1V/V Vs = ±2.75V

Figure 6-54. Small-Signal Overshoot vs Capacitive Load

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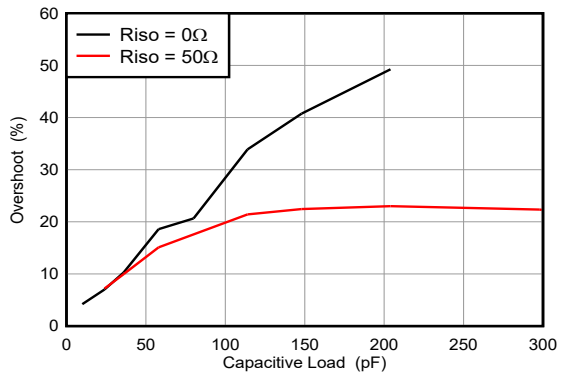
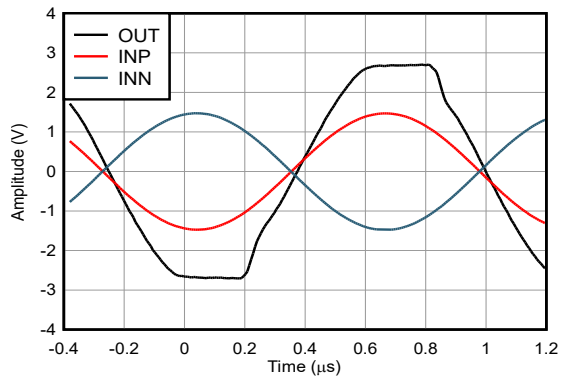
6.9 Typical Characteristics (continued)

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)



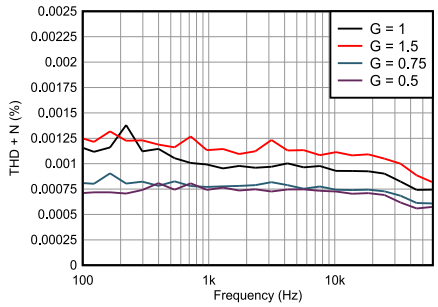
G = 1.5V/V Vs = ±2.75V

Figure 6-55. Small-Signal Overshoot vs Capacitive Load



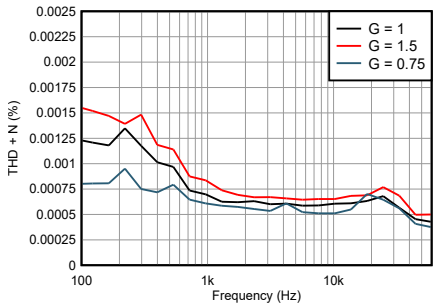
Vs = ±2.75V G = 1V/V V_{IN} = 6V_{PP}

Figure 6-56. Over-Load Recovery



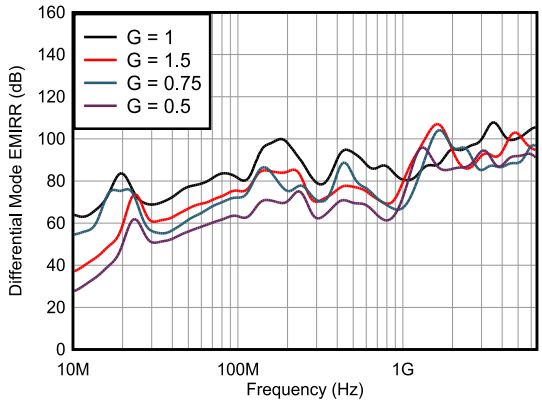
V_O = 2V_{PP} Vs = ±2.75V R_L = 10kΩ

Figure 6-57. THD + N Ratio vs Frequency



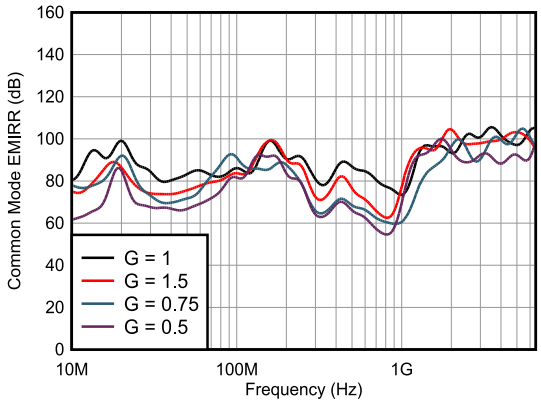
V_O = 4V_{PP} Vs = ±2.75V R_L = 10kΩ

Figure 6-58. THD + N Ratio vs Frequency



V_{EMI} = 630mV_{PP} Vs = ±2.75V

Figure 6-59. Differential-Mode EMIRR vs Frequency

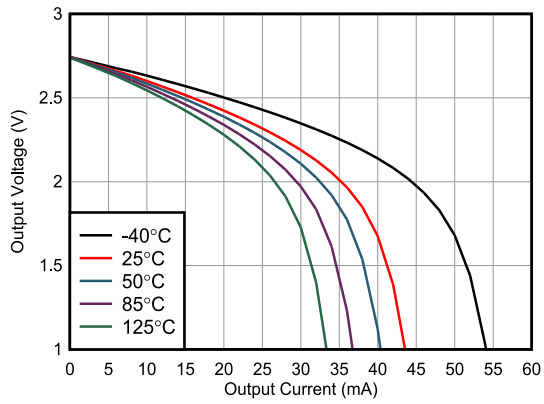


V_{EMI} = 630mV_{PP} Vs = ±2.75V

Figure 6-60. Common-Mode EMIRR vs Frequency

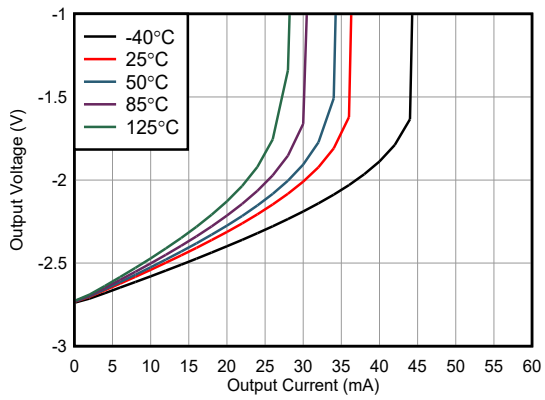
6.9 Typical Characteristics (continued)

at T_A = 25°C, V_S = (V+) – (V–) = 5.5V, V_{IN} = (V_{IN+} – $V_{IN–}$) = 0V, R_L = 10kΩ, C_L = 10pF, V_{REF} = V_S / 2, V_{CM} = (V_{IN+} + $V_{IN–}$) / 2 = V_S / 2, V_{OUT} = V_S / 2 and G = 1 (unless otherwise noted)



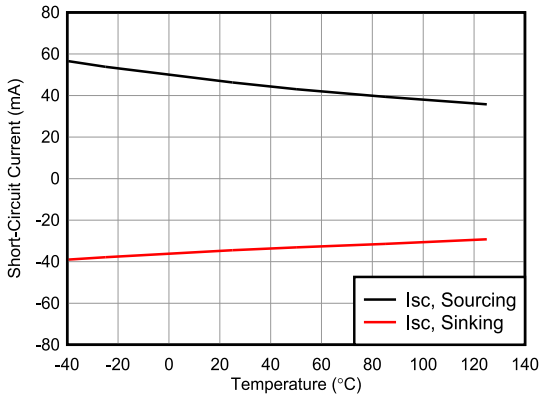
G = 1V/V Vs = ±2.75V

Figure 6-61. Output Voltage vs Output Current (Sourcing)



G = 1V/V Vs = ±2.75V

Figure 6-62. Output Voltage vs Output Current (Sinking)



G = 1V/V Vs = ±2.75V

Figure 6-63. Short-circuit Current vs Temperature

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7 Detailed Description

7.1 Overview

The INA510-Q1 is a cost-effective, integrated difference amplifier qualified for automotive applications. Designed to outperform discrete implementations using commodity amplifiers and resistors, the device delivers improved performance and a smaller design size. The integrated difference amplifier incorporates a wide-bandwidth operational amplifier with 18MHz closed-loop bandwidth across all gain options, along with four precision-matched integrated resistors. The device is well-designed for 12-bit systems. With system-level calibration of offset and gain error, accuracy can be further improved to support 14-bit and 16-bit systems.

The INA510-Q1 is offered in four gain options: the INAx510x05 provides a gain of 0.50V/V, the INAx510x07 provides a gain of 0.75V/V, the INAx510x10 provides a gain of 1V/V, and the INAx510x15 provides a gain of 1.50V/V. Optimized for voltage sensing applications, the INA510-Q1 offers a minimum common-mode rejection ratio (CMRR) of 74dB and a maximum gain error of ±0.05%. All errors, including offset, offset drift, and CMRR, are referred to the output to enable straightforward calculation of signal-to-noise ratio (SNR) and effective number of bits (ENOB) close to the analog-to-digital converter (ADC). The combination of wide bandwidth, improved DC accuracy, and low drift, advantages over a discrete implementation , makes the INA510-Q1 a well-designed front-end driver for 12-bit microcontroller ADC applications supporting sampling rates up to 1MSPS.

The INA510-Q1 gain options are designed for scaling, precision signal-level translation, and differential-to-single-ended conversion applications that interface a wide variety of differential and single-ended signals into single-ended input ADCs. This makes the device well-designed for automotive end equipment interfacing differential-output sensors with single-ended ADCs, such as inductive and magnetic position sensors, which convert both the SIN and COS signals into single-ended signals prior to the MCU/ADC to remove common-mode noise.

When routing signals differentially for common-mode noise immunity, the INA510-Q1 is useful for converting the differential signal back to single-ended signal for easy interface to single-ended ADCs while rejecting common-mode noise. The wide bandwidth of the integrated difference amplifier allows direct drive mid-speed (≤1MSPS) 12-bit resolution, single-ended input ADCs.

In space-constrained automotive applications, the device offers a significant advantage over discrete implementations by integrating the difference amplifier resistors and reducing de board space. The device is available in industry-standard packages, including the 5-pin SOT-23 (single) and 16-pin SOT-23 (dual).

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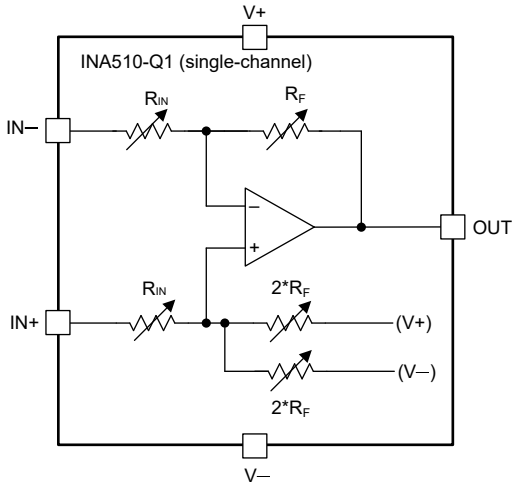
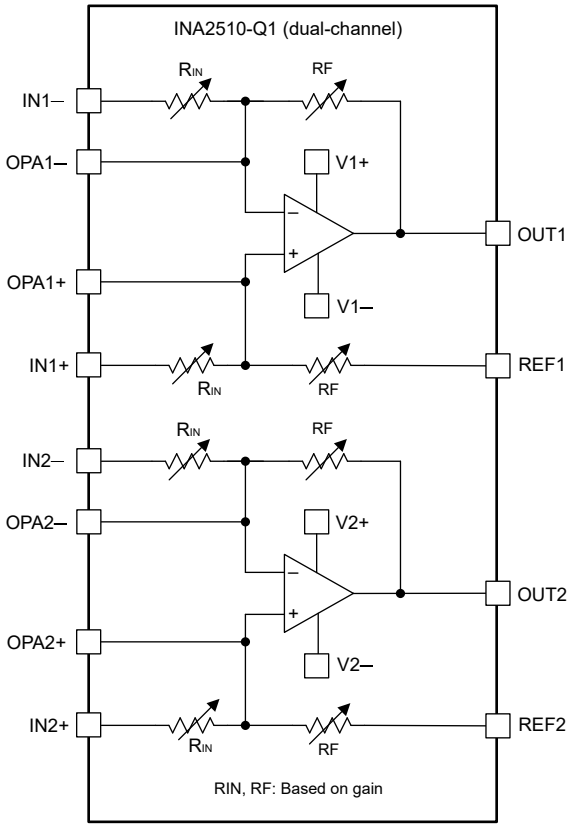
7.2 Functional Block Diagram



Note: Resistor values depend on the gain variant. See Table 7-1 for resistor values.

Figure 7-1. INA510Mxx-Q1 Simplified Internal Schematic



Note: Resistor values depend on the gain variant. See Table 7-1 for resistor values.

Figure 7-2. INA2510Exx-Q1 Simplified Internal Schematic

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7.3 Feature Description

7.3.1 Gain Options and Resistors

The gain value of the INA510-Q1 is given by the ratio of feedback resistor and input resistor. The gain options are offered across different device variants as provided in Table 7-1. While the typical values of the input and feedback resistors are shown in the following table and the resistors are ratiometrically matched, note that the absolute resistor value can vary by approximately ±15% while still maintaining the tighter gain error (tolerance) numbers specified in the *Electrical Characteristics* table.

Table 7-1. Gain Selection Table

DEVICE	INPUT RESISTOR	FEEDBACK RESISTOR	GAIN
INAx510x05	5kΩ	2.5kΩ	0.5
INAx510x07	3.333kΩ	2.5kΩ	0.75
INAx510x10	5kΩ	5kΩ	1.00
INAx510x15	3.333kΩ	5kΩ	1.5

7.3.1.1 Gain Error and Drift

Gain error in the INA510-Q1 is limited by the mismatch of the integrated precision resistors. A maximum gain error of ±0.05% can be expected for all gains of 0.50, 0.75, 1.00, and 1.5. Gain drift in the INA510-Q1 is limited by the slight mismatch of the temperature coefficient of the integrated resistors. Since these integrated resistors are precision matched with low temperature coefficient resistors to begin with, the overall gain drift is much better in comparison to discrete implementation of the difference amplifiers built using external resistors. Maximum gain error of ±0.1% can be expected for inputs from the reference pin that sets output common-mode voltage.

7.3.2 Input Common-Mode Voltage Range

The INA510-Q1 difference-amplifier rejects the input common mode. The rejection capability is based on the matching of the internal resistors. The input voltage range of the INA510-Q1 is primarily dictated by the signal swing at the op-amp inputs. The INA510-Q1 input common-mode voltage range can extend beyond the supply rails and is a major function of the gain configuration. To maximize performance, keeping the op-amp inside the INA510-Q1 within the linear range for a given combination of gain, reference voltage, and input common-mode voltage for a particular input differential voltage and output swing is critical. On the INA510M-Q1 variant, the difference amp reference is internally biased at mid-supply level using a precise internal resistor divider. The INA2510-Q1 dual channel variant provides external access to through the reference inputs. For more information on the reference pin configurations refer to the *Typical Characteristics* section.

The common-mode range for the INA510-Q1 in equation form is outlined in the *Electrical Characteristics* for each gain. The most common operating conditions are outlined graphically in the *Typical Characteristics* section.

7.3.2.1 Internal Rail-to-Rail Op Amp with Complementary CMOS Input Stage

The INA510-Q1 difference amplifier uses a complementary input operational amplifier architecture. This design employs parallel P-channel and N-channel differential pairs, allowing the internal op-amp common-mode input voltage ($V_{CM,OPA}$) to span the full supply range from from (V—) to (V+). The P-channel stage handles common-mode voltages from (V—) to approximately (V+) — 1V, while the N-channel stage handles (V+) — 1V to (V+). Because these transistor pairs are independent, they have uncorrelated input offset voltages. As the common-mode input voltage transitions through the region approximately 1V below the positive rail, the input offset voltage shifts, which may cause subtle crossover distortion and non-linearity. For high-precision applications requiring minimal distortion, designers should choose the INA510-Q1 gain variant and reference voltage to maintain operation within the PMOS region.

The circuit in Figure 7-3 shows a simplified schematic of the INA510-Q1 difference amplifier and its internal rail-to-rain input op-amp and defines the critical nodes where the input op-amp input common-mode ($V_{CM,OPA}$). The input common-mode of the op-amp is a function of the external differential and common-mode voltage at the difference amplifier inputs, the gain of the difference amplifier (0.50, 0.75, 1.00, and 1.5), the reference input voltages.

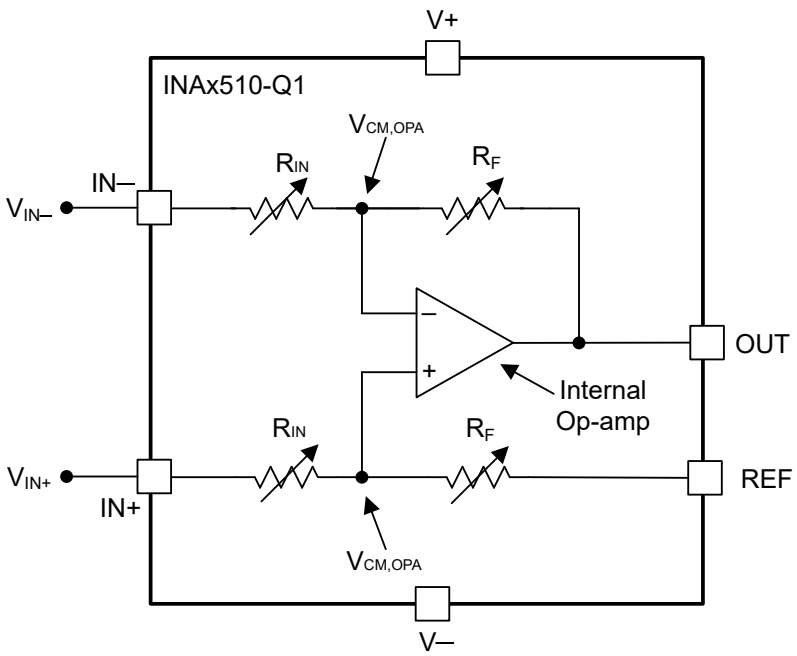

Figure 7-3. INA510-Q1 Simplified Schematic and Internal Op-Amp Common-Mode Voltage

Table 7-2 provides the necessary equations to derive the internal amplifier common-mode voltage ($V_{CM,OPA}$) , as a function of the difference amplifier input voltages, difference amplifier gain and reference voltage.

Table 7-2. Difference Amplifier Input Voltages, and Internal Op-Amp Common-Mode Voltage Calculations

PARAMETER	CALCULATION	COMMENT
Differential voltage V_{DIFF}	$V_{DIFF} = V_{IN+} - V_{IN-}$	Differential voltage at difference amplifier inputs
Common-mode voltage V_{CM}	$V_{CM} = \frac{V_{IN+} + V_{IN-}}{2}$	Common-mode voltage at difference amplifier inputs
Calculation for single-ended input $V_{IN,P}$	$V_{IN,P} = V_{CM} + V_{DIFF}$	For single-ended input configuration
Calculation for differential input $V_{IN,P}$	$V_{IN,P} = V_{CM} + \frac{V_{DIFF}}{2}$	For differential input configuration
Internal Op-amp common-mode $V_{CM,OPA}$	$V_{CM,OPA} = \frac{V_{REF}}{G+1} + \frac{V_{IN,P} \times G}{G+1}$	Internal Op-amp common-mode

Figure 7-4 and Figure 7-5 show the difference amplifier offset voltage change and variation as a function of the internal amplifier common-mode voltage ($V_{CM,OPA}$) for a number of devices, through the PMOS-to-NMOS transition region 1V below the positive supply.

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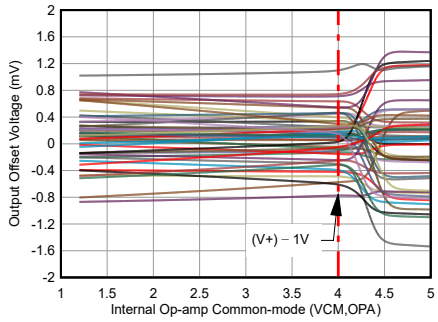

Figure 7-4. Output Offset Voltage vs Internal Op-Amp Common-Mode Voltage, Vs = 5V

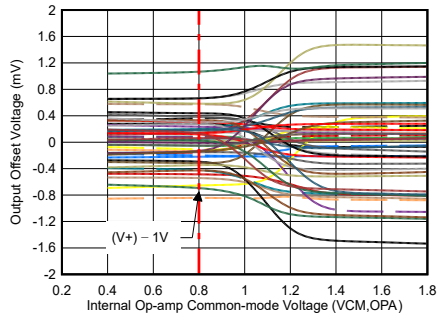

Figure 7-5. Output Offset Voltage vs Internal Op-Amp,Common-Mode Voltage, Vs = 1.8V

7.3.3 Typical Specifications and Distributions

Designers often have questions about a typical specification of an amplifier to design a more robust circuit. Due to natural variation in process technology and manufacturing procedures, every specification of an amplifier exhibits some amount of deviation from the desired value, like an amplifier's offset voltage. These deviations often follow *Gaussian* (*bell curve*), or *normal* distributions, and circuit designers can leverage this information to guard band the system, even when there is not a minimum or maximum specification in the *Electrical Characteristics* table.

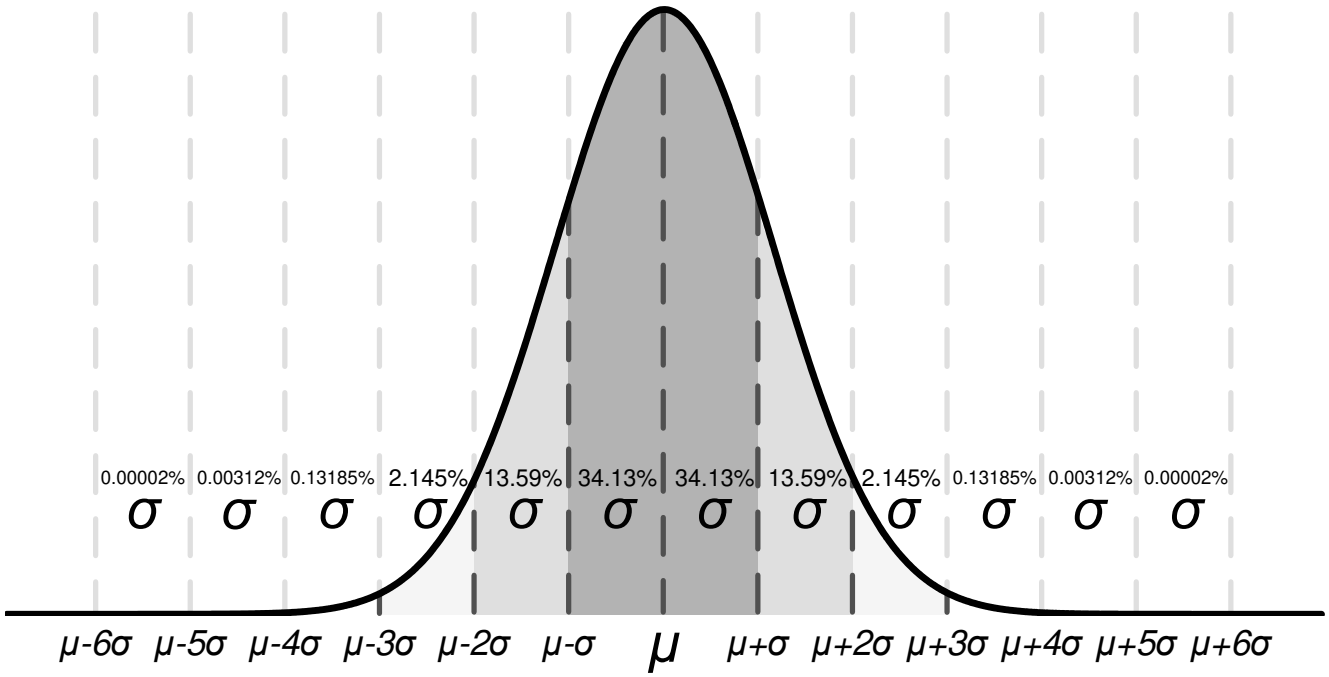

Figure 7-6. Desired Gaussian Distribution

Figure 7-6 shows an example distribution, where *μ*, or *mu*, is the mean of the distribution, and where *σ*, or *sigma*, is the standard deviation of a system. For a specification that exhibits this kind of distribution, approximately two-thirds (68.26%) of all units can be expected to have a value within one standard deviation, or one sigma, of the mean (from $\mu - \sigma$ to $\mu + \sigma$).

Depending on the specification, values listed in the *typical* column of the *Electrical Characteristics* table are represented in different ways. As a general rule, if a specification naturally has a nonzero mean (for example, like gain bandwidth), then the typical value is equal to the mean (μ). However, if a specification naturally has a

mean near zero (like offset voltage), then the typical value is equal to the mean plus one standard deviation (μ + σ) to most accurately represent the typical value.

This chart can be used to calculate approximate probability of a specification in a unit; for example, the INA510-Q1 typical offset voltage is 400μV, so 68.2% of all INA510-Q1 devices are expected to have an output referred offset from –400μV to +400μV. At 4 *σ* (±1600μV), 99.9937% of the distribution has an offset voltage less than ±1600μV, which means 0.0063% of the population is outside of these limits, which corresponds to about 1 in 15,873 units.

Specifications with a value in the minimum or maximum column are verified by TI, and units outside these limits are removed from production material. For example, the INA510M10-Q1 with G=1V/V has a maximum output referred offset voltage of ±2.6mV at 25°C, and even though this corresponds to >6σ event, which is extremely unlikely, TI verifies that any unit with larger offset than ±2.6mV are removed from production material.

For specifications with no value in the minimum or maximum column, consider selecting a sigma value of sufficient guard band for the application, and design worst-case conditions using this value. A 6σ value corresponds to about 1 in 500 million units, which is an extremely unlikely chance, and can be an option as a wide guard band to design a system around. Histograms for some of the important specifications like offset, offset drift, CMRR, gain error are shown in the *Typical Characteristics* section.

7.3.4 Electrical Overstress

Designers often ask questions about the capability of an operational amplifier to withstand electrical overstress. These questions tend to focus on the device inputs, but can involve the supply voltage pins or even the output pin. Each of these different pin functions have electrical stress limits determined by the voltage breakdown characteristics of the particular semiconductor fabrication process and specific circuits connected to the pin. Additionally, internal electrostatic discharge (ESD) protection is built into these circuits to protect them from accidental ESD events both before and during product assembly.

Having a good understanding of this basic ESD circuitry and the relevance to an electrical overstress event is helpful. Figure 7-7 shows the ESD circuits contained in the INA510-Q1 devices. On the input pins, the ESD protection circuitry involves local high impedance diode structures and do not route the ESD current to power supply ESD cell. On the output pin, there are reverse biased diodes to both the power supply rails. These diode structures route the ESD current back to the internal power supply lines, where there is an absorption power supply ESD cell internal to the difference amplifier. On the reference pin, the ESD protection is local and does not route current to the power supply ESD cell.

All of the ESD protection circuitry is intended to remain inactive during normal circuit operation.

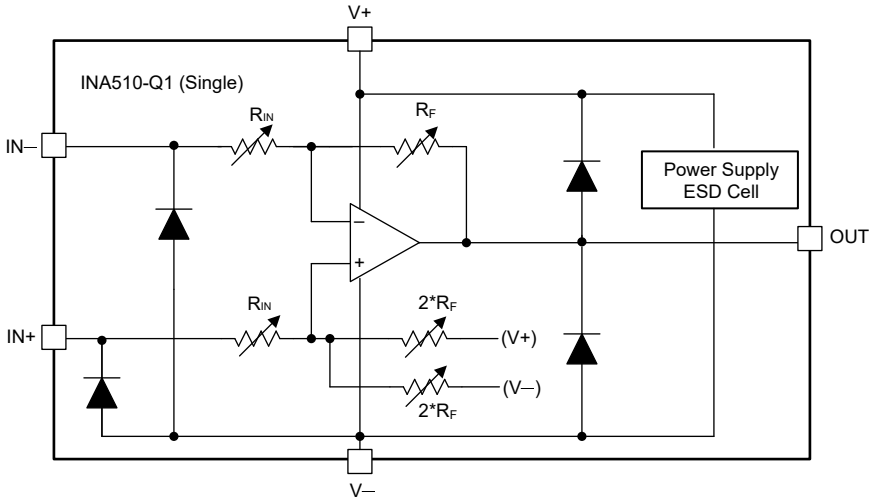

Figure 7-7. Equivalent Internal ESD Circuitry for INA510-Q1 (single-channel)

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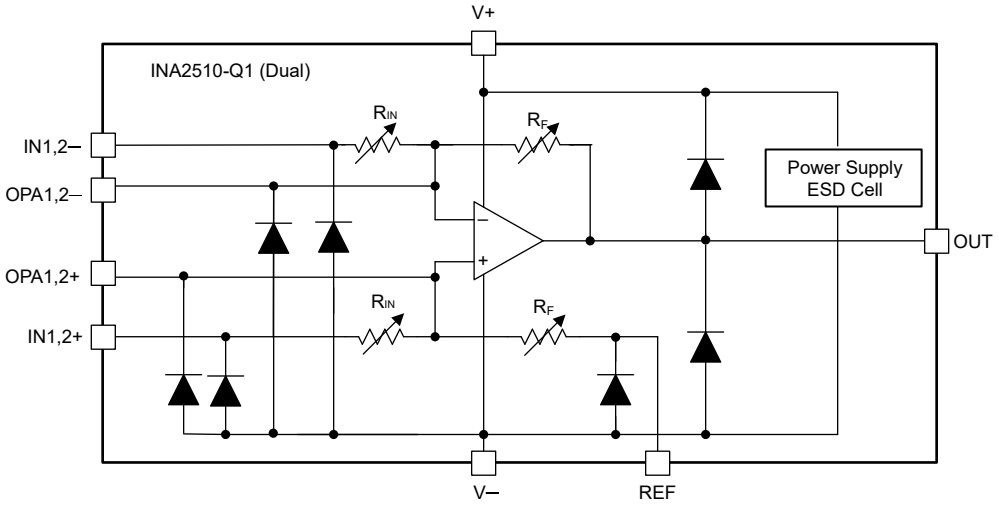

Figure 7-8. Equivalent Internal ESD Circuitry for INA2510-Q1 (dual-channel)

7.4 Device Functional Modes

The INA510-Q1 has only one functional mode. The device powers on, starts drawing quiescent current and is functional as long as the power supply voltages are in the recommended operating voltage range of 1.7V (±0.85V) to 5.5V (±2.75V). Operational temperature range of INA510-Q1 is from –40°C to 125°C.

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 Reference Pin

The INA510-Q1 is an integrated difference amplifier whose output voltage is developed with respect to the difference amplifier reference.

For the single-amplifier variant (INA510M-Q1), the difference amplifier reference is internally biased at mid-supply using a precision resistor divider. The INA510M-Q1 does not bond out the difference amplifier reference pin, which offers the most accurate and lowest-noise performance when interfaced with ADCs tha t share the same supply voltage as the ADC voltage reference.

The dual-channel variant (INA2510E-Q1) provides external access to the reference through the reference input pins REF_1 and REF_2. Figure 8-2 shows a simplified block diagram of the difference amplifier reference configurations for the INA510M-Q1 (single) and INA2510E-Q1 (dual).

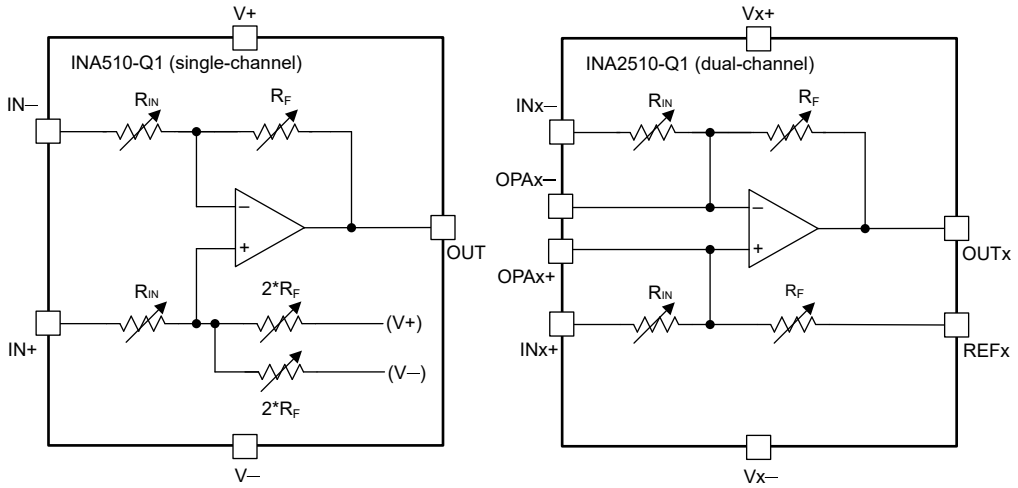

Figure 8-1. INA510M-Q1 and INA2510E-Q1 Reference Pin Configurations

The INA2510E-Q1 variants require REF_1 and REF_2 to be connected and biased to a stable, low-noise voltage source. Use the REF pins to offset the output signal to a precise mid-supply level, typically 2.5V in a 5V supply environment. To accomplish this level shift, a voltage source must be connected to the REF pins to shift the output level so that the INA2510E-Q1 can drive a single-supply analog-to-digital converter (ADC). Any resistance at the reference pins is in series with the internal RF resistor, creating an imbalance among the four resistors of the internal difference amplifier. Therefore, the reference pins must be driven with a low-impedance source, as any series resistance at the reference pins degrades common-mode rejection. This can be accomplished using an external reference buffer in a unity-gain, voltage-follower configuration, as shown in Figure 8-2. For dual-supply operation, the reference pin is typically connected to the low-impedance system ground.

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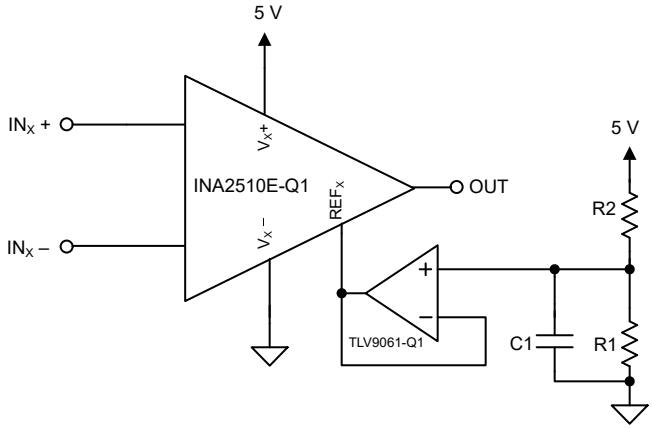

Figure 8-2. INA2510E-Q1 with External Reference Buffer

8.2 Typical Applications

8.2.1 Differential to Single Ended Conversion for Isolated Sensing Application

The INA510-Q1 is an integrated difference amplifier that can level-translate the differential output signal from a sensor or fully differential output circuit, and perform gain scaling, voltage level translation, and differential-to-single-ended conversion to condition the signal to the full scale of a single-ended ADC input, while satisfying the ADC's sample-and-hold settling time requirements.

Automotive power systems such as motor drives are in some cases divided into two or more voltage domains that are galvanically isolated from each other. For example, the high-voltage domain includes the AC grid, DC link, and power stage for driving the motor. The low-voltage domain can often incorporate the data acquisition system, that is, the ADC and/or microcontroller circuit and human interface. The ADC board measures the DC link voltage and shunt-based current sense values while remaining galvanically isolated from the high-voltage side for safety reasons.

Figure 8-3 shows an excerpt of a traction inverter application schematic with the AMC0302D-Q1 used for current shunt sensing. In this example, the ground reference point for the microcontroller is not connected by any means to the power stage. This configuration is typical in systems where the microcontroller is located on a dedicated control card or PCB. Current feedback is achieved using shunt resistors, R_SHUNT, and the AMC0302D-Q1 isolation amplifier. This isolated amplifier is primarily designed for shunt-based current-sensing applications where accurate current monitoring is required in the presence of high common-mode voltages.

In applications where the isolation barrier is not in close proximity to the ADC, a relatively long trace connection can be present between the isolation amplifier output and the ADC or MCU. These long traces can be susceptible to extraneous noise signals that can degrade signal accuracy or reliability and introduce error sources. In applications where the isolation amplifier and ADC are not located in close proximity, using a differential output signal provides an advantage by offering better noise immunity.

Figure 8-3 shows a circuit example using the INA510M07-Q1 to convert the differential output signal into a single-ended signal ahead of the single-ended input ADC. The ADS7138-Q1 is a compact, 8-channel, 12-bit Successive Approximation Register (SAR) ADC. The INA510M07-Q1 offers wide bandwidth, making the device capable of driving the ADC's sample-and-hold capacitor while settling to 12-bit resolution within the acquisition period.

Note that on the INA510M-Q1 single-device variant, where the difference amplifier reference pin is not bonded out, the reference is internally biased to mid-supply using an internal voltage divider. Therefore, this variant of the INA510-Q1, with the reference internally biased to mid-supply, offers the most accurate performance and best noise rejection when interfaced with ADCs that use the supply voltage as the voltage reference for conversion.

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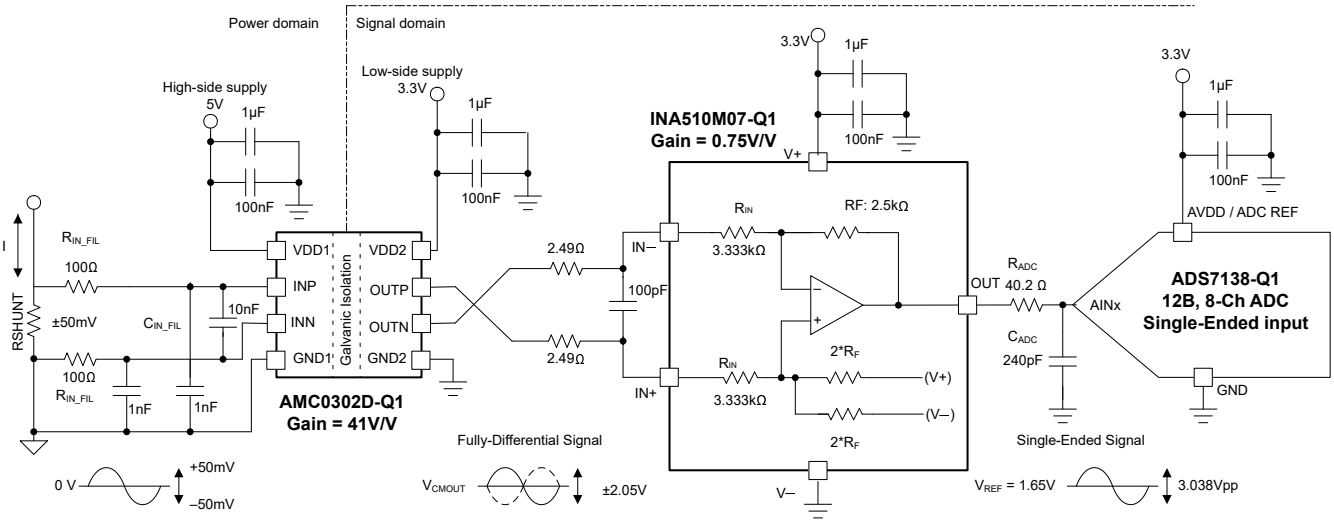

Figure 8-3. AMC0302D-Q1, INA510M07-Q1 and ADS7138-Q1 ADC Drive Single-Ended to Differential Conversion Circuit

8.2.1.1 Design Requirements

For this application, the design requirements are as provided in Table 8-1.

Table 8-1. Design Requirements

DESCRIPTION	VALUE
High-side supply voltage	3.3V or 5V
Low-side supply voltage	3.3V in this example (5V possible)
Voltage drop across RSHUNT for a linear response	±50mV(maximum)
Full-scale range of ADC	V_{ADC_REF} = Low-side supply Voltage = 3.3V
ADC Resolution	12-Bits

8.2.1.2 Detailed Design Procedure

- Use Ohm's Law to calculate the voltage drop across the shunt resistor (V_{SHUNT}) for the desired measured current: $V_{SHUNT} = I_{SHUNT} \times R_{SHUNT}$. Scale the R_{SHUNT} value so the voltage drop caused by the nominal current range does not exceed the recommended differential input voltage range of $V_{SHUNT} \leq \pm 50mV$, and the voltage drop caused by the maximum allowed overcurrent does not exceed the input voltage that causes output clipping.
- Place an input differential R-C-R filter (R_{IN_FIL}, C_{IN_FIL}) in front of the isolated amplifier to improve signal-to-noise performance of the signal path. Design the input filter such that the cutoff frequency of the filter is at least one order of magnitude lower than the sampling frequency (20MHz) of the ΔΣ modulator. The impedances on the positive path and negative path must be matched.
- The AMC0302D-Q1 provides a gain of 41V/V. Therefore, for a ±50mV input signal, the isolation amplifier produces a fully-differential output of ±2.05V centered at common-mode output of 1.44V. For more detailed information, please refer to the AMC0302D-Q1 data sheet.
- The ADS7138-Q1 requires a single-ended input signal with a maximum full-scale range of 3.3V. Figure 8-3 shows the ADC powered with a 3.3V supply, where the analog supply input is also used as the reference voltage to the ADC. Connect a 1-µF decoupling capacitor to GND on the ADC AVDD pin.
- The INA510M07-Q1 difference amplifier performs single-ended to differential conversion, offering a gain of 0.75V/V. The internal difference amplifier reference is biased at mid-supply of 1.65V. The fully-differential output of the AMC0302D-Q1 of ±2.05V (or 4.10Vpp) is scaled to a 3.075Vpp single-ended signal, centered at 1.65V.
- The RC filter at the ADS7138-Q1 inputs serves as a charge reservoir to filter the sampled input of the ADC. The charge reservoir reduces the instantaneous charge demand of the amplifier, maintaining low distortion that otherwise degrades due to incomplete amplifier settling. The RC filter combination (R_{ADC}, C_{ADC}) is optimized for the SAR ADC sample and hold settling.
- Use high-grade C0G (NP0) capacitors throughout the signal path for their low drift and low distortion properties. Among ceramic surface-mount capacitors, C0G (NP0) types provide the best capacitance accuracy. The dielectric used in C0G (NP0) ceramic capacitors offers the most stable electrical properties over variations in voltage, frequency, and temperature.

8.2.1.3 Application Curves

The following typical characteristic curve is for the circuit in Figure 8-3.

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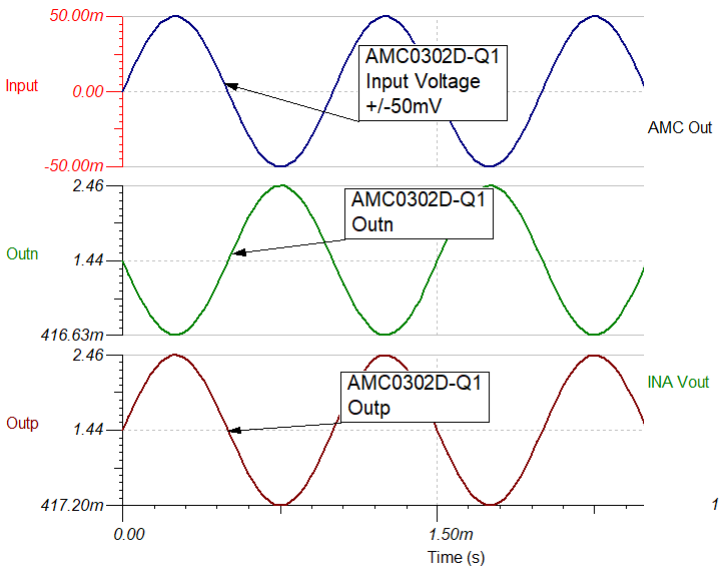

Figure 8-4. SPICE Simulated AMC0302D-Q1 Input and Output Voltage

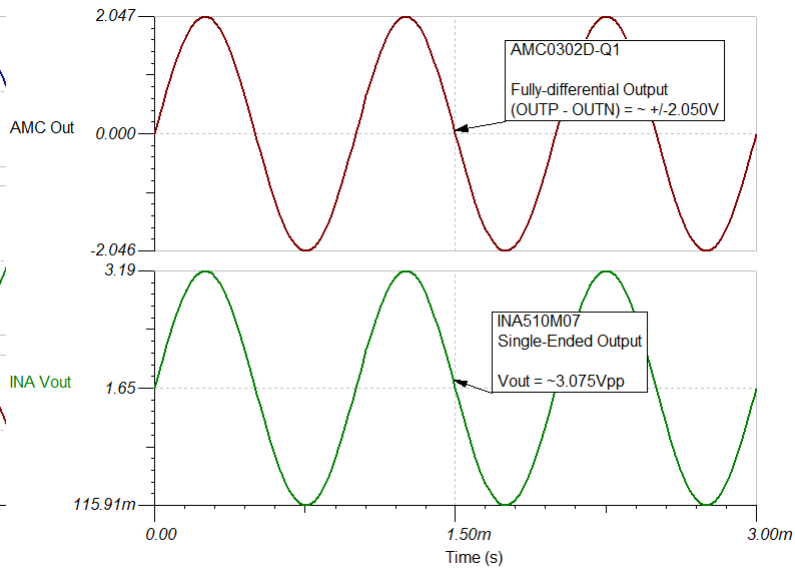

Figure 8-5. SPICE Simulated INA510M07-Q1 Input and Output Voltage

8.3 Power Supply Recommendations

The nominal performance of the INA510-Q1 is specified with a supply voltage of ±2.75V and midsupply reference voltage. The device also operates using power supplies from ±0.85V (1.7V) to ±2.75V (5.5V) and non-midsupply reference voltages with good performance. Many specifications apply from –40°C to 125°C. *Electrical Characteristics* presents parameters that can exhibit significant variance due to operating voltage or temperature.

TI highly recommends to add low-ESR ceramic bypass capacitors (C_{BYP}) between each supply pin and ground. Only one C_{BYP} is sufficient for single supply operation. Place the C_{BYP} as close to the device as possible to reduce coupling errors from noisy or high-impedance power supplies. Please maintain the power supply trace routes through C_{BYP} before reaching the amplifier power supply terminals. For more information, see *Layout Guidelines*.

Parameters can vary with operating voltage and reference voltage. *Typical Characteristics* section can be used to estimate the performance outside of the *Electrical Characteristics* section.

8.4 Layout

8.4.1 Layout Guidelines

Attention to good layout practices is always recommended. For best operational performance of the device, use the following PCB layout practices:

- Maintain that both input paths are well-matched for source impedance and capacitance to avoid converting common-mode signals into differential signals.
- Use bypass capacitors to reduce the coupled noise by providing low-impedance power sources local to the analog circuitry.
  - Connect low-ESR, 0.1µF ceramic bypass capacitors between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from V+ to ground is applicable for single-supply applications.
- Route the input traces as far away from the supply or output traces as possible to reduce parasitic coupling. If these traces cannot be kept separate, crossing the sensitive trace perpendicular is much better than crossing in parallel with the noisy trace.
- Place the external components as close to the device as possible.
- Keep the traces as short as possible.

8.4.2 Layout Example

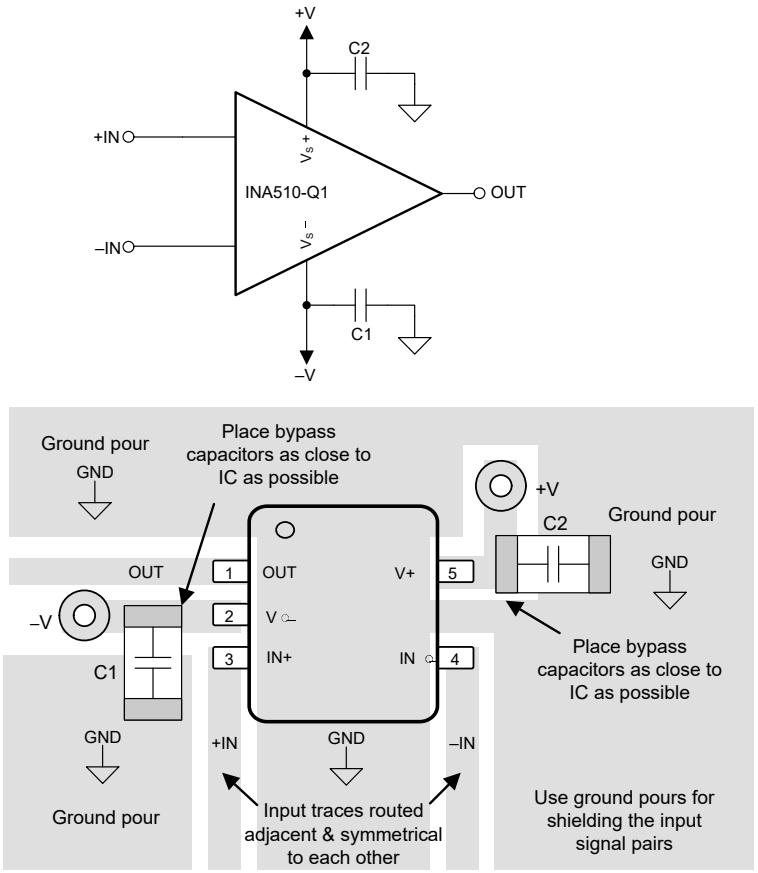

Figure 8-6. Example Schematic and Associated PCB Layout

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9 Device and Documentation Support

9.1 Device Support

9.1.1 Development Support

- *SPICE-based analog simulation program — TINA-TI software folder*
- *Analog Engineers Calculator*

9.1.1.1 PSpice® for TI

PSpice® for TI is a design and simulation environment that helps evaluate performance of analog circuits. Create subsystem designs and prototype designs before committing to layout and fabrication, reducing development cost and time to market.

9.2 Documentation Support

9.2.1 Related Documentation

For related documentation see the following:

- Texas Instruments, *EMI Rejection Ratio of Operational Amplifiers* application note

9.3 Receiving Notification of Documentation Updates

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

9.4 Support Resources

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

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9.5 Trademarks

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9.6 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.

9.7 Glossary

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

10 Revision History

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

Changes from Revision * (August 2026) to Revision A (September 2026)	Page
• Changed INA510-Q1 DBV (SOT-23,5) package status from *Advance Information* (preview) to *Production Data* (active)	1
• Updated device names from INAx510, INA510M and INA2510E to INAx510-Q1, INA510M-Q1 and INA2510E-Q1 throughout the document	1

- Added minimum (V–) – 0.3 for Signal input pins in *Absolute Maximum Ratings* 6
- Changed parameter description from Specified temperature to T_A Operating Temperature in *Recommended Operating Conditions* 6
- Updated thermal metric specifications for DBV (SOT-23) package in *Thermal Information* 7
- Changed I_{SC} from ±60mA typical to 50mA source and -40mA sink typical in *Electrical Characteristics* 8
- Changed THD + N, V_O = $4V_{PP}$ from 0.01% to 0.001% typical in *Electrical Characteristics* 8
- Changed EMIRR test condition: f = 400MHz, Common-Mode in *Electrical Characteristics*, and updated typical specifications.....8
- Changed V_{OSO} from ±2.8mV to ±3.2mV in *Electrical Characteristics - INA510, G = 1.5* 14
- Added Figures 6-67 to Figure 6-63 in *Typical Characteristics*.....16
- Added *Internal Rail-to-Rail Op Amp with Complementary CMOS Input Stage* section.....29
- Changed Figure 7-7 and added Figure 7-8 in *Electrical Overstress*..... 32

11 Mechanical, Packaging, and Orderable Information

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

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PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
INA510M05QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	46GF
INA510M07QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	46KF
INA510M10QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	46HF
INA510M15QDBVRQ1	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	46MF

(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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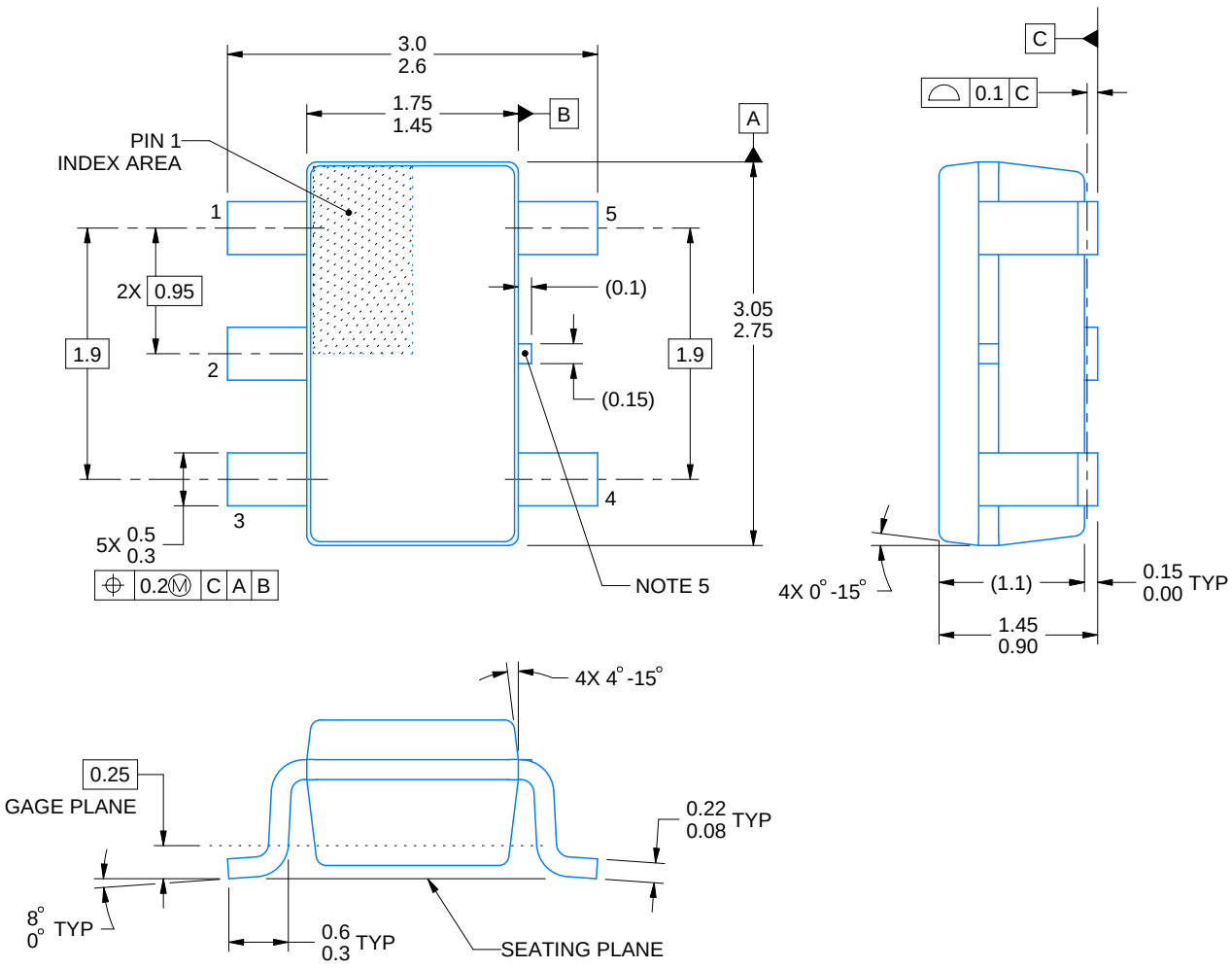

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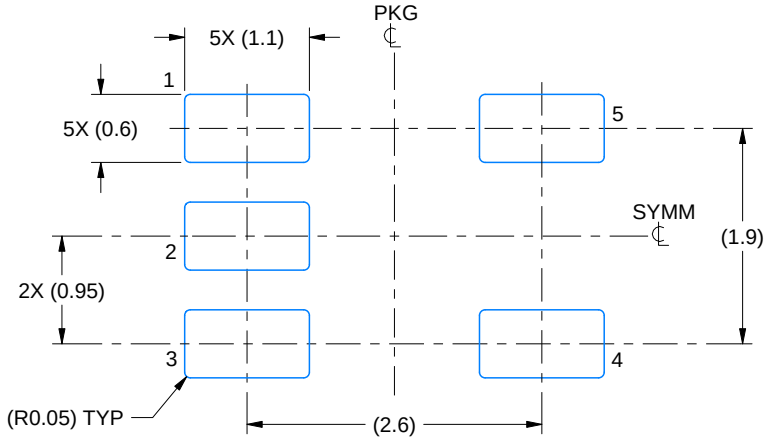
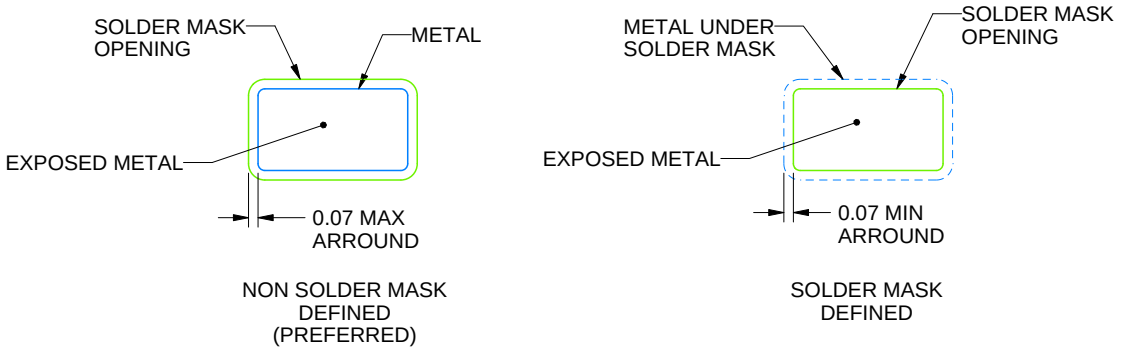
NOTES:

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



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:15X



SOLDER MASK DETAILS

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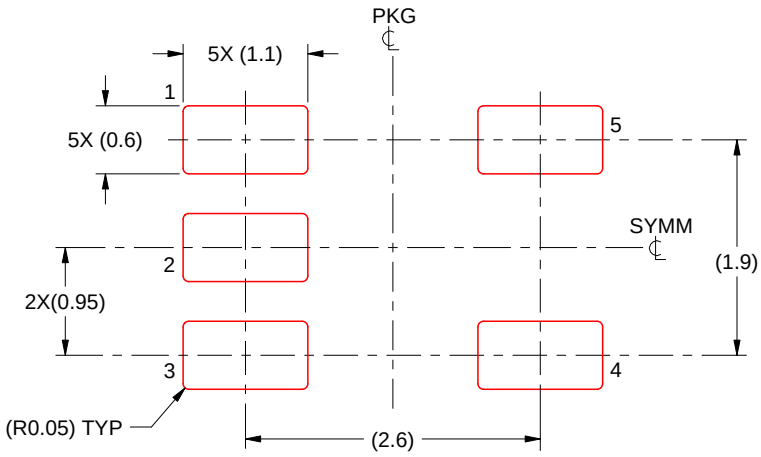
NOTES: (continued)

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



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

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NOTES: (continued)

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

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