

OPAx196 36-V, Low-Power, Low Offset Voltage, Rail-to-Rail Operational Amplifier

1 Features

- Low Offset Voltage: $\pm 100 \mu\text{V}$ (maximum)
- Low Offset Voltage Drift: $\pm 0.5 \mu\text{V}/^\circ\text{C}$ (typical)
- Low Bias Current: $\pm 5 \text{ pA}$ (typical)
- High Common-Mode Rejection: 140 dB
- Low Noise: $15 \text{ nV}/\sqrt{\text{Hz}}$ at 1 kHz
- Rail-to-Rail Input and Output
- Differential Input Voltage Range to Supply Rail
- Wide Bandwidth: 2.5-MHz GBW
- Low Quiescent Current: 140 μA per Amplifier (typical)
- Wide Supply: $\pm 2.25 \text{ V}$ to $\pm 18 \text{ V}$, 4.5 V to 36 V
- EMI/RFI Filtered Inputs
- High Capacitive Load Drive Capability: 1 nF
- Industry Standard Packages:
 - Single in SOIC-8, SOT-5, and VSSOP-8
 - Dual in SOIC-8 and VSSOP-8
 - Quad in SOIC-14, TSSOP-14, and QFN-16

2 Applications

- Multiplexed Data-Acquisition Systems
- Test and Measurement Equipment
- High-Resolution ADC Driver Amplifiers
- SAR ADC Reference Buffers
- Analog Input and Output Modules
- High-Side and Low-Side Current Sensing
- High-Precision Comparator
- Medical Instrumentation

3 Description

The OPAx196 family (OPA196, OPA2196, and OPA4196) is a new generation of 36-V, rail-to-rail e-trim™ operational amplifiers (op amps).

These devices offer very low offset voltage ($\pm 25 \mu\text{V}$, typical), drift ($\pm 0.5 \mu\text{V}/^\circ\text{C}$, typical), and low bias current ($\pm 5 \text{ pA}$, typical) combined with very low quiescent current (140 μA /channel, typical) across the entire output range.

Unique features, such as differential input-voltage range to the supply rail, high output current ($\pm 65 \text{ mA}$), and high capacitive load drive of up to 1 nF make the OPAx196 a robust, high-performance operational amplifier for high-voltage industrial applications.

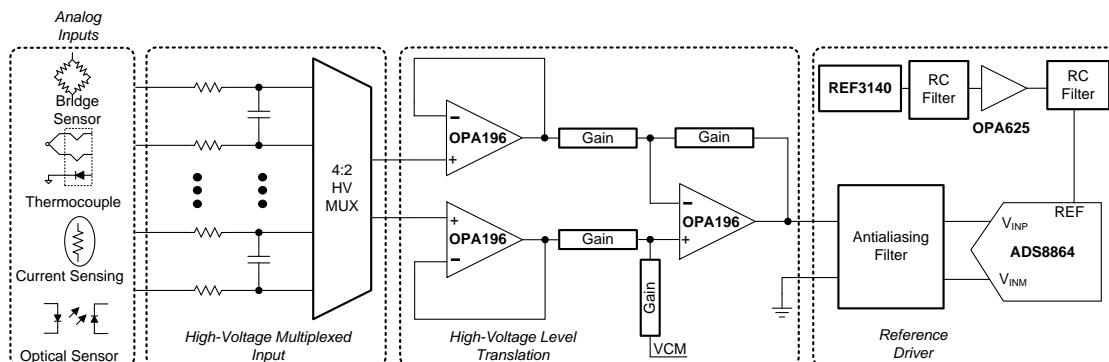
The OPAx196 family of op amps is available in standard packages and is specified from -40°C to $+125^\circ\text{C}$.

Device Information⁽¹⁾

PART NUMBER	PACKAGE	BODY SIZE (NOM)
OPA196	SOIC (8)	4.90 mm x 3.90 mm
	SOT (5)	2.90 mm x 1.60 mm
	VSSOP (8)	3.00 mm x 3.00 mm
OPA2196	SOIC (8)	4.90 mm x 3.90 mm
	VSSOP (8)	3.00 mm x 3.00 mm
OPA4196	SOIC (14)	8.65 mm x 3.90 mm
	TSSOP (14)	5.00 mm x 4.40 mm

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

OPA196 in a High-Voltage, Multiplexed, Data-Acquisition System



Copyright © 2017, Texas Instruments Incorporated



Table of Contents

1 Features	1	7.3 Feature Description	19
2 Applications	1	7.4 Device Functional Modes	26
3 Description	1	8 Application and Implementation	27
4 Revision History	2	8.1 Application Information	27
5 Pin Configuration and Functions	3	8.2 Typical Applications	27
6 Specifications	5	9 Power-Supply Recommendations	31
6.1 Absolute Maximum Ratings	5	10 Layout	31
6.2 ESD Ratings	5	10.1 Layout Guidelines	31
6.3 Recommended Operating Conditions	5	10.2 Layout Example	32
6.4 Thermal Information: OPA196	5	11 Device and Documentation Support	33
6.5 Thermal Information: OPA2196	6	11.1 Device Support	33
6.6 Thermal Information: OPA4196	6	11.2 Documentation Support	33
6.7 Electrical Characteristics: $V_S = \pm 4\text{ V}$ to $\pm 18\text{ V}$ ($V_S = 8\text{ V}$ to 36 V)	7	11.3 Related Links	33
6.8 Electrical Characteristics: $V_S = \pm 2.25\text{ V}$ to $\pm 4\text{ V}$ ($V_S = 4.5\text{ V}$ to 8 V)	9	11.4 Receiving Notification of Documentation Updates	33
6.9 Typical Characteristics	11	11.5 Community Resources	34
7 Detailed Description	18	11.6 Trademarks	34
7.1 Overview	18	11.7 Electrostatic Discharge Caution	34
7.2 Functional Block Diagram	18	11.8 Glossary	34
		12 Mechanical, Packaging, and Orderable Information	34

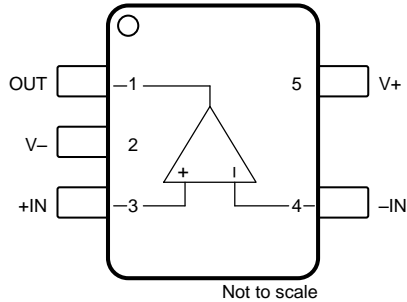
4 Revision History

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

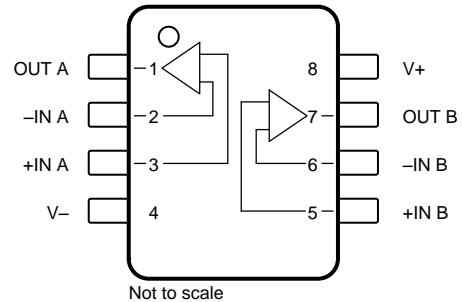
DATE	REVISION	NOTES
July 2017	*	Initial release

5 Pin Configuration and Functions

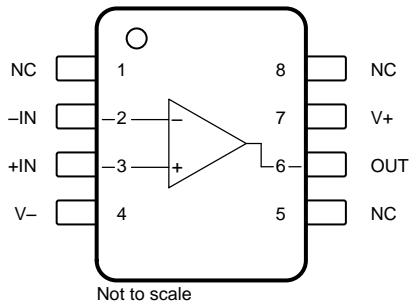
DBV Package: OPA196
5-Pin SOT
Top View



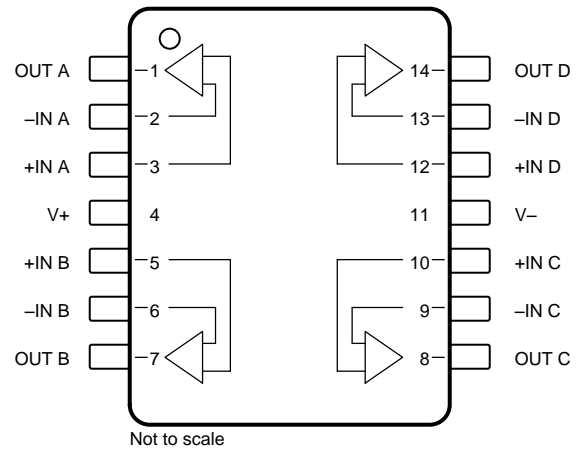
D and DGK Packages: OPA2196
8-Pin SOIC and VSSOP
Top View



D and DGK Packages: OPA196
8-Pin SOIC and VSSOP
Top View



D and PW Packages: OPA4196
14-Pin SOIC and TSSOP
Top View



(1) NC = No internal connection.

Pin Functions: OPA196

NAME	PIN		I/O	DESCRIPTION
	OPA196			
	D (SOIC), DGK (VSSOP)	DBV (SOT)		
+IN	3	3	I	Noninverting input
–IN	2	4	I	Inverting input
NC	1, 5, 8	—	—	No internal connection (can be left floating)
OUT	6	1	O	Output
V+	7	5	—	Positive (highest) power supply
V–	4	2	—	Negative (lowest) power supply

Pin Functions: OPA2196 and OPA4196

NAME	PIN		I/O	DESCRIPTION
	OPA2196	OPA4196		
	D (SOIC), DGK (VSSOP)	D (SOIC), PW (TSSOP)		
+IN A	3	3	I	Noninverting input, channel A
+IN B	5	5	I	Noninverting input, channel B
+IN C	—	10	I	Noninverting input, channel C
+IN D	—	12	I	Noninverting input, channel D
–IN A	2	2	I	Inverting input, channel A
–IN B	6	6	I	Inverting input, channel B
–IN C	—	9	I	Inverting input, channel C
–IN D	—	13	I	Inverting input, channel D
OUT A	1	1	O	Output, channel A
OUT B	7	7	O	Output, channel B
OUT C	—	8	O	Output, channel C
OUT D	—	14	O	Output, channel D
V+	8	4	—	Positive (highest) power supply
V–	4	11	—	Negative (lowest) power supply

6 Specifications

6.1 Absolute Maximum Ratings

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

			MIN	MAX	UNIT
Supply voltage, $V_S = (V+) - (V-)$				±20 (+40, single supply)	V
Signal input pins	Voltage	Common-mode	(V-) – 0.5	(V+) + 0.5	V
		Differential	(V+) – (V-) + 0.2		
Current			±10		mA
Output short circuit ⁽²⁾			Continuous	Continuous	Continuous
Temperature	Operating		–40	150	°C
	Junction		150		
	Storage, 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 ground, one amplifier per package.

6.2 ESD Ratings

				VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	OPAx196	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾	±3000	V
$V_{(ESD)}$	Electrostatic discharge	OPA196	Charged-device model (CDM), per JEDEC specification JESD22-C101 ⁽²⁾	±1000	V
		OPA2196		±500	V
		OPA4196		±500	V

- (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
Supply voltage, $V_S = (V+) - (V-)$	4.5 (±2.25)		36 (±18)	V
Specified temperature	–40		125	°C

6.4 Thermal Information: OPA196

THERMAL METRIC ⁽¹⁾		OPA196			UNIT
		8 PINS		5 PINS	
		D (SOIC)	DGK (VSSOP)	DBV (SOT)	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	115.8	180.4	158.8	°C/W
$R_{\theta JC(top)}$	Junction-to-case(top) thermal resistance	60.1	67.9	60.7	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	56.4	102.1	44.8	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	12.8	10.4	1.6	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	55.9	100.3	4.2	°C/W
$R_{\theta JC(bot)}$	Junction-to-case(bottom) thermal resistance	N/A	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 report.

6.5 Thermal Information: OPA2196

THERMAL METRIC ⁽¹⁾		OPA2196		UNIT
		8 PINS		
		D (SOIC)	DGK (VSSOP)	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	107.9	158	°C/W
$R_{\theta JC(top)}$	Junction-to-case(top) thermal resistance	53.9	48.6	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	48.9	78.7	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	6.6	3.9	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	48.3	77.3	°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 report.

6.6 Thermal Information: OPA4196

THERMAL METRIC ⁽¹⁾		OPA4196		UNIT
		14 PINS		
		D (SOIC)	PW (TSSOP)	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	86.4	92.6	°C/W
$R_{\theta JC(top)}$	Junction-to-case(top) thermal resistance	46.3	27.5	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	41.0	33.6	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	11.3	1.9	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	40.7	33.1	°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 report.

6.7 Electrical Characteristics: $V_S = \pm 4\text{ V to } \pm 18\text{ V}$ ($V_S = 8\text{ V to } 36\text{ V}$)

at $T_A = 25^\circ\text{C}$, $V_{CM} = V_{OUT} = V_S / 2$, and $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OFFSET VOLTAGE							
V_{OS}	Input offset voltage	$V_S = \pm 18\text{ V}$			± 25	± 100	μV
		$(V+) - 3.0\text{ V} < V_{CM} < (V+) - 1.5\text{ V}$		See Common-Mode Voltage Range			
		$V_S = \pm 18\text{ V}$, $V_{CM} = (V+) - 1.5\text{ V}$			± 25	± 100	
dV_{OS}/dT	Input offset voltage drift	$V_S = \pm 18\text{ V}$, $V_{CM} = (V+) - 3\text{ V}$	$T_A = -40^\circ\text{C to } +125^\circ\text{C}$		± 0.5		$\mu\text{V}/^\circ\text{C}$
		$V_S = \pm 18\text{ V}$, $V_{CM} = (V+) - 1.5\text{ V}$			± 0.8		
PSRR	Power-supply rejection ratio	$T_A = -40^\circ\text{C to } +125^\circ\text{C}$			± 0.3	± 1	$\mu\text{V/V}$
INPUT BIAS CURRENT							
I_B	Input bias current				± 5	± 20	pA
I_{OS}	Input offset current				± 2	± 20	pA
NOISE							
E_n	Input voltage noise	$(V-) - 0.1\text{ V} < V_{CM} < (V+) - 3\text{ V}$	$f = 0.1\text{ Hz to } 10\text{ Hz}$		1.4		μV_{PP}
		$(V+) - 1.5\text{ V} < V_{CM} < (V+) + 0.1\text{ V}$	$f = 0.1\text{ Hz to } 10\text{ Hz}$		7		
e_n	Input voltage noise density	$(V-) - 0.1\text{ V} < V_{CM} < (V+) - 3\text{ V}$	$f = 100\text{ Hz}$		18		$\text{nV}/\sqrt{\text{Hz}}$
			$f = 1\text{ kHz}$		15		
		$(V+) - 1.5\text{ V} < V_{CM} < (V+) + 0.1\text{ V}$	$f = 100\text{ Hz}$		53		
			$f = 1\text{ kHz}$		24		
i_n	Input current noise density	$f = 1\text{ kHz}$			1.5	$\text{fA}/\sqrt{\text{Hz}}$	
INPUT VOLTAGE							
V_{CM}	Common-mode voltage range			$(V-) - 0.1$		$(V+) + 0.1$	V
CMRR	Common-mode rejection ratio	$V_S = \pm 18\text{ V}$, $(V-) - 0.1\text{ V} < V_{CM} < (V+) - 3\text{ V}$		120	140		dB
		$V_S = \pm 18\text{ V}$, $(V-) < V_{CM} < (V+) - 3\text{ V}$	$T_A = -40^\circ\text{C to } +125^\circ\text{C}$	114	126		
		$V_S = \pm 18\text{ V}$, $(V+) - 1.5\text{ V} < V_{CM} < (V+)$		96	120		
		$(V+) - 3\text{ V} < V_{CM} < (V+) - 1.5\text{ V}$	$T_A = -40^\circ\text{C to } +125^\circ\text{C}$	86	100		
				See Typical Characteristics			
INPUT IMPEDANCE							
Z_{ID}	Differential				$100 \parallel 1.6$		$\text{M}\Omega \parallel \text{pF}$
Z_{IC}	Common-mode				$1 \parallel 6.4$		$10^{13}\Omega \parallel \text{pF}$
OPEN-LOOP GAIN							
A_{OL}	Open-loop voltage gain	$V_S = \pm 18\text{ V}$, $(V-) + 0.6\text{ V} < V_O < (V+) - 0.6\text{ V}$, $R_L = 2\text{ k}\Omega$		124	134		dB
			$T_A = -40^\circ\text{C to } +125^\circ\text{C}$	114	126		
		$V_S = \pm 18\text{ V}$, $(V-) + 0.3\text{ V} < V_O < (V+) - 0.3\text{ V}$, $R_L = 10\text{ k}\Omega$		126	140		
			$T_A = -40^\circ\text{C to } +125^\circ\text{C}$	120	134		

Electrical Characteristics: $V_S = \pm 4\text{ V}$ to $\pm 18\text{ V}$ ($V_S = 8\text{ V}$ to 36 V) (continued)

 at $T_A = 25^\circ\text{C}$, $V_{CM} = V_{OUT} = V_S / 2$, and $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
FREQUENCY RESPONSE							
GBW	Unity gain bandwidth				2.5		MHz
SR	Slew rate	$V_S = \pm 18\text{ V}$, $G = 1$, 10-V step	Rising		7.5		V/ μs
			Falling		5.5		
t_s	Settling time	To 0.01%, $C_L = 20\text{ pF}$	$V_S = \pm 18\text{ V}$, $G = 1$, 2-V step		0.7		μs
			$V_S = \pm 18\text{ V}$, $G = 1$, 5-V step		1		
		To 0.001%, $C_L = 20\text{ pF}$	$V_S = \pm 18\text{ V}$, $G = 1$, 2-V step		1.8		
			$V_S = \pm 18\text{ V}$, $G = 1$, 5-V step		3.7		
t_{OR}	Overload recovery time	$V_{IN} \times G = V_S$	From overload to negative rail		0.4		μs
			From overload to positive rail		1		
THD+N	Total harmonic distortion + noise	$G = 1$, $f = 1\text{ kHz}$, $V_O = 3.5\text{ V}_{RMS}$			0.0012%		
	Crosstalk	OPA2196 and OPA4196, at dc			150		dB
		OPA2196 and OPA4196, $f = 100\text{ kHz}$			130		dB
OUTPUT							
V_O	Voltage output swing from rail	Positive rail	No load		5	15	mV
			$R_L = 10\text{ k}\Omega$		50	110	
			$R_L = 2\text{ k}\Omega$		200	500	
		Negative rail	No load		5	15	
			$R_L = 10\text{ k}\Omega$		50	110	
			$R_L = 2\text{ k}\Omega$		200	500	
I_{SC}	Short-circuit current	$V_S = \pm 18\text{ V}$			± 65		mA
C_L	Capacitive load drive			See Typical Characteristics			
Z_O	Open-loop output impedance	$f = 1\text{ MHz}$, $I_O = 0\text{ A}$, See Figure 19			700		Ω
POWER SUPPLY							
I_Q	Quiescent current per amplifier	$I_O = 0\text{ A}$			140	200	μA
				$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		250	
TEMPERATURE							
	Thermal protection				180		$^\circ\text{C}$
	Thermal hysteresis				30		$^\circ\text{C}$

6.8 Electrical Characteristics: $V_S = \pm 2.25\text{ V}$ to $\pm 4\text{ V}$ ($V_S = 4.5\text{ V}$ to 8 V)

at $T_A = +25^\circ\text{C}$, $V_{CM} = V_{OUT} = V_S / 2$, and $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OFFSET VOLTAGE							
V_{OS}	Input offset voltage	$V_S = \pm 2.25\text{ V}$, $V_{CM} = (V+) - 3\text{ V}$			± 25	± 100	μV
		$(V+) - 3.0\text{ V} < V_{CM} < (V+) - 1.5\text{ V}$		See Common-Mode Voltage Range			
		$V_S = \pm 3\text{ V}$, $V_{CM} = (V+) - 1.5\text{ V}$			± 25	± 100	
dV_{OS}/dT	Input offset voltage drift	$V_S = \pm 2.25\text{ V}$, $V_{CM} = (V+) - 3\text{ V}$ $V_S = \pm 2.25\text{ V}$, $V_{CM} = (V+) - 1.5\text{ V}$	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		± 0.5 ± 0.5		$\mu\text{V}/^\circ\text{C}$
PSRR	Power-supply rejection ratio	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$, $V_{CM} = V_S / 2 - 0.75\text{ V}$			± 1		$\mu\text{V}/\text{V}$
INPUT BIAS CURRENT							
I_B	Input bias current				± 5	± 20	pA
I_{OS}	Input offset current				± 2	± 20	pA
NOISE							
E_n	Input voltage noise	$(V-) - 0.1\text{ V} < V_{CM} < (V+) - 3\text{ V}$ $(V+) - 1.5\text{ V} < V_{CM} < (V+) + 0.1\text{ V}$	$f = 0.1\text{ Hz}$ to 10 Hz $f = 0.1\text{ Hz}$ to 10 Hz		1.4 7		μV_{PP}
e_n	Input voltage noise density	$(V-) - 0.1\text{ V} < V_{CM} < (V+) - 3\text{ V}$ $(V+) - 1.5\text{ V} < V_{CM} < (V+) + 0.1\text{ V}$	$f = 100\text{ Hz}$ $f = 1\text{ kHz}$ $f = 100\text{ Hz}$ $f = 1\text{ kHz}$		18 15 53 24		$\text{nV}/\sqrt{\text{Hz}}$
i_n	Input current noise density	$f = 1\text{ kHz}$			1.5		$\text{fA}/\sqrt{\text{Hz}}$
INPUT VOLTAGE							
V_{CM}	Common-mode voltage range			$(V-) - 0.1$		$(V+) + 0.1$	V
CMRR	Common-mode rejection ratio	$V_S = \pm 2.25\text{ V}$, $(V-) - 0.1\text{ V} < V_{CM} < (V+) - 3\text{ V}$		96	110		dB
		$V_S = \pm 2.25\text{ V}$, $(V-) < V_{CM} < (V+) - 3\text{ V}$	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$	90	104		
		$V_S = \pm 2.25\text{ V}$, $(V+) - 1.5\text{ V} < V_{CM} < (V+)$		96	120		
		$(V+) - 3\text{ V} < V_{CM} < (V+) - 1.5\text{ V}$	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$	84	100		
				See Typical Characteristics			
INPUT IMPEDANCE							
Z_{ID}	Differential				$100 \parallel 1.6$		$\text{M}\Omega \parallel \text{pF}$
Z_{IC}	Common-mode				$1 \parallel 6.4$		$10^{13}\Omega \parallel \text{pF}$
OPEN-LOOP GAIN							
A_{OL}	Open-loop voltage gain	$V_S = \pm 2.25\text{ V}$, $(V-) + 0.6\text{ V} < V_O < (V+) - 0.6\text{ V}$, $R_L = 2\text{ k}\Omega$		110	120		dB
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$	100	114		
		$V_S = \pm 2.25\text{ V}$, $(V-) + 0.3\text{ V} < V_O < (V+) - 0.3\text{ V}$, $R_L = 10\text{ k}\Omega$		110	126		
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$	106	120		

Electrical Characteristics: $V_S = \pm 2.25\text{ V}$ to $\pm 4\text{ V}$ ($V_S = 4.5\text{ V}$ to 8 V) (continued)

 at $T_A = +25^\circ\text{C}$, $V_{CM} = V_{OUT} = V_S / 2$, and $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
FREQUENCY RESPONSE							
GBW	Unity gain bandwidth				2.2		MHz
SR	Slew rate	$V_S = \pm 2.25\text{V}$, $G = 1$, 1-V step	Rising		6.5		V/ μs
			Falling		5.5		
t_{OR}	Overload recovery time	$V_{IN} \times G = V_S$	From overload to negative rail		0.4		μs
			From overload to positive rail		1		
	Crosstalk	OPA2196 and OPA4196, at dc			150		dB
		OPA2196 and OPA4196, $f = 100\text{ kHz}$			130		dB
OUTPUT							
V_O	Voltage output swing from rail	Positive rail	No load		5	15	mV
			$R_L = 10\text{ k}\Omega$		15	110	
			$R_L = 2\text{ k}\Omega$		60	500	
		Negative rail	No load		5	15	
			$R_L = 10\text{ k}\Omega$		15	110	
			$R_L = 2\text{ k}\Omega$		60	500	
I_{SC}	Short-circuit current	$V_S = \pm 2.25\text{V}$			± 30		mA
C_L	Capacitive load drive			See Typical Characteristics			
Z_O	Open-loop output impedance	$f = 1\text{ MHz}$, $I_O = 0\text{ A}$, see Figure 19			700		Ω
POWER SUPPLY							
I_Q	Quiescent current per amplifier	$I_O = 0\text{ A}$			140	200	μA
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			250	
TEMPERATURE							
	Thermal protection				180		$^\circ\text{C}$
	Thermal hysteresis				30		$^\circ\text{C}$

6.9 Typical Characteristics

Table 1. Table of Graphs

DESCRIPTION	FIGURE
Offset Voltage vs Common-Mode Voltage	Figure 1
Open-Loop Gain and Phase vs Frequency	Figure 2
Closed-Loop Gain and Phase vs Frequency	Figure 3
Input Bias Current vs Common-Mode Voltage	Figure 4
Input Bias Current vs Temperature	Figure 5
Output Voltage Swing vs Output Current (maximum supply)	Figure 6, Figure 7
CMRR and PSRR vs Frequency	Figure 8
CMRR vs Temperature	Figure 9
PSRR vs Temperature	Figure 10
0.1-Hz to 10-Hz Noise	Figure 11
Input Voltage Noise Spectral Density vs Frequency	Figure 12
THD+N Ratio vs Frequency	Figure 13
THD+N vs Output Amplitude	Figure 14
Quiescent Current vs Supply Voltage	Figure 15
Quiescent Current vs Temperature	Figure 16
Open Loop Gain vs Temperature	Figure 17, Figure 18
Open Loop Output Impedance vs Frequency	Figure 19
Small Signal Overshoot vs Capacitive Load (100-mV output step)	Figure 20, Figure 21
No Phase Reversal	Figure 22
Overload Recovery	Figure 23
Small-Signal Step Response (100 mV)	Figure 24, Figure 25
Large-Signal Step Response	Figure 26, Figure 27
Settling Time	Figure 28, Figure 29, Figure 30, Figure 31
Short-Circuit Current vs Temperature	Figure 32
Maximum Output Voltage vs Frequency	Figure 33
Propagation Delay Rising Edge	Figure 34
Propagation Delay Falling Edge	Figure 35

At $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{ V}$, $V_{CM} = V_S / 2$, $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

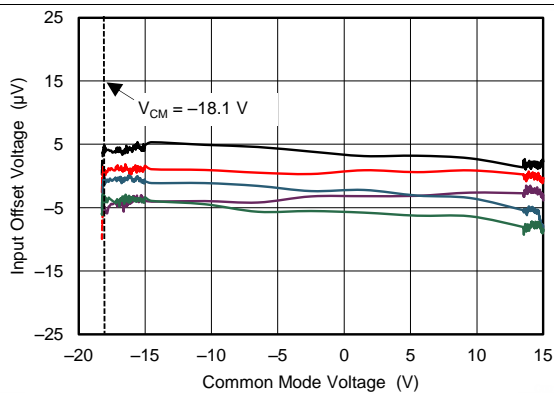


Figure 1. Offset Voltage vs Common-Mode Voltage

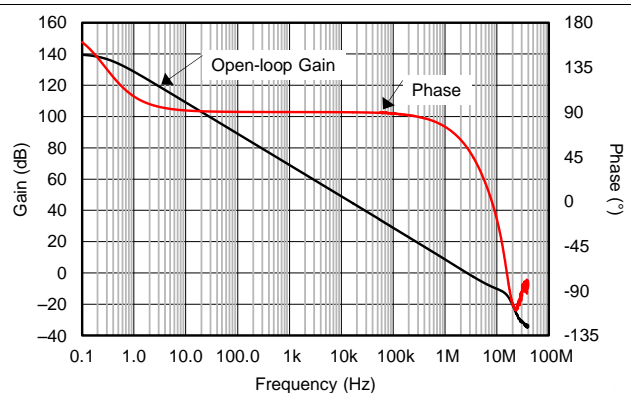


Figure 2. Open-Loop Gain and Phase vs Frequency

At $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{ V}$, $V_{CM} = V_S / 2$, $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

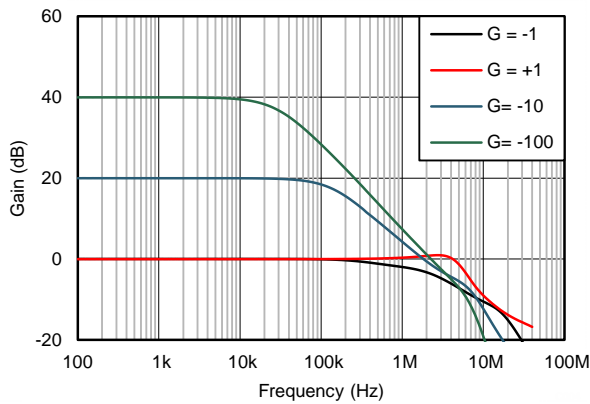


Figure 3. Closed-Loop Gain vs Frequency

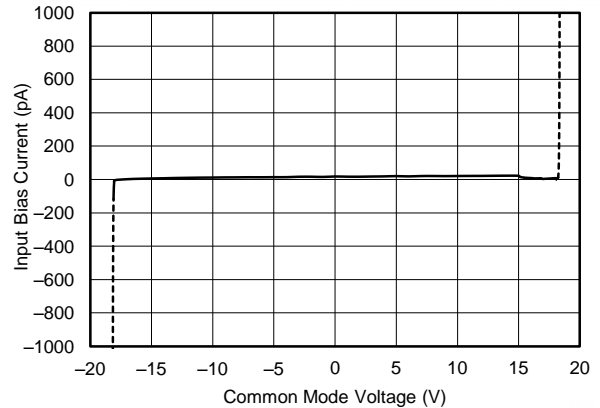


Figure 4. Input Bias Current vs Common-Mode Voltage

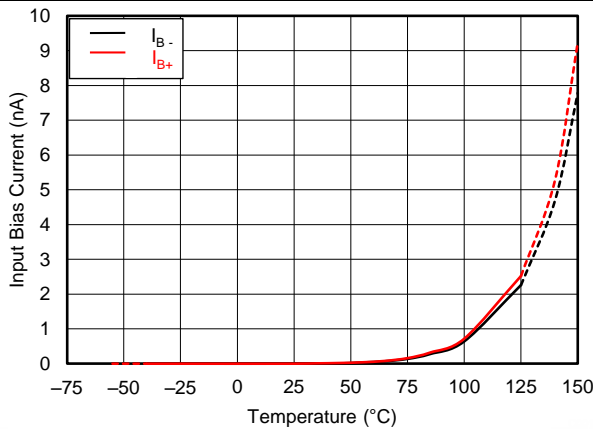


Figure 5. Input Bias Current vs Temperature

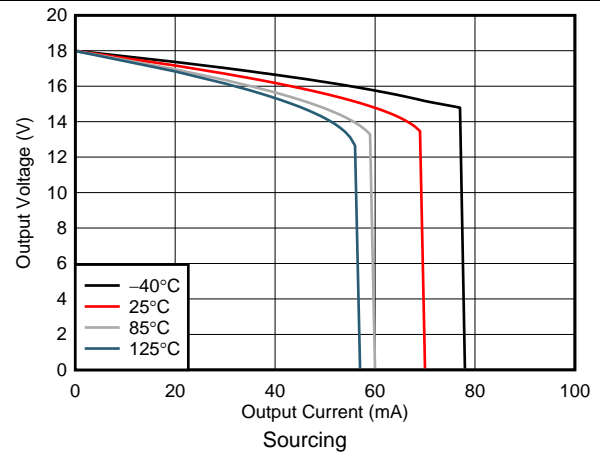


Figure 6. Output Voltage Swing vs Output Current

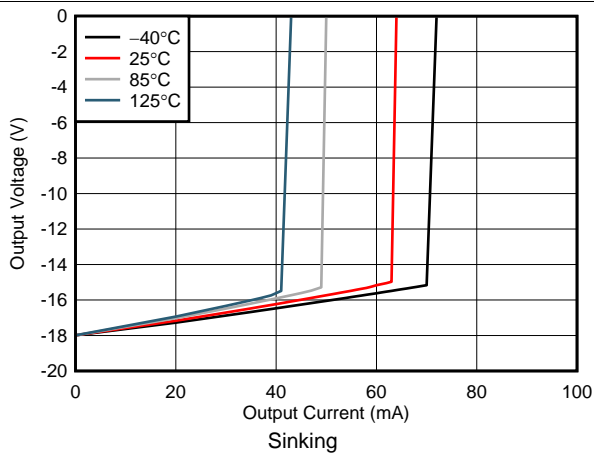


Figure 7. Output Voltage Swing vs Output Current

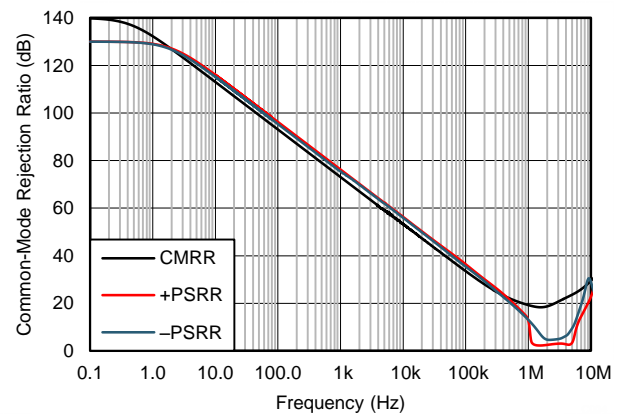


Figure 8. CMRR and PSRR vs Frequency

At $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{ V}$, $V_{CM} = V_S / 2$, $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

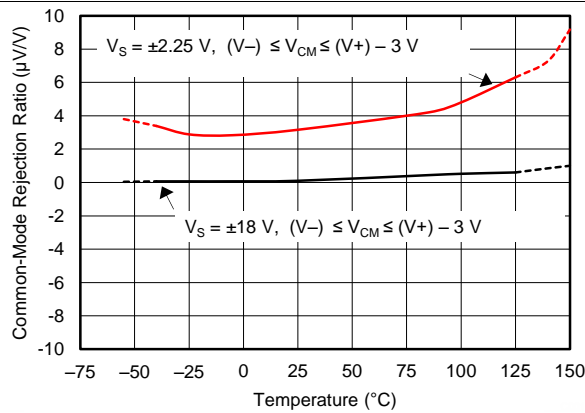


Figure 9. CMRR vs Temperature

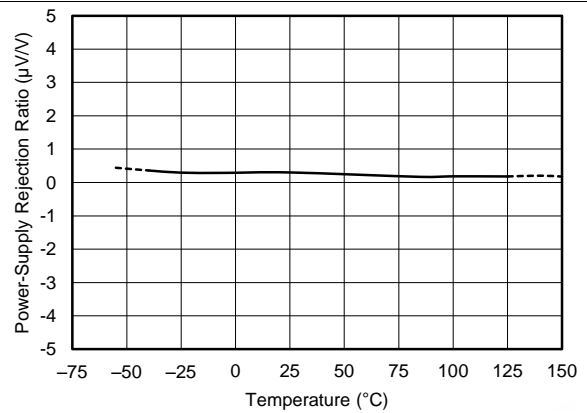


Figure 10. PSRR vs Temperature

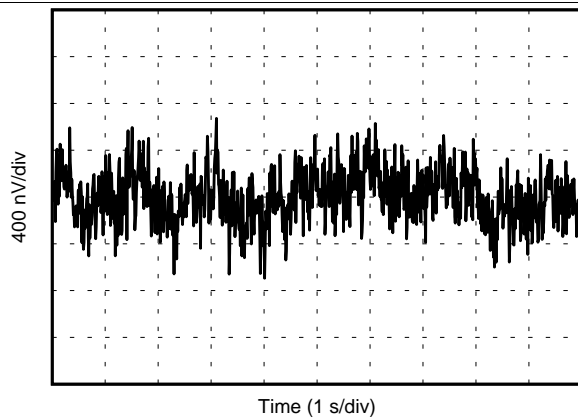


Figure 11. 0.1-Hz to 10-Hz Noise

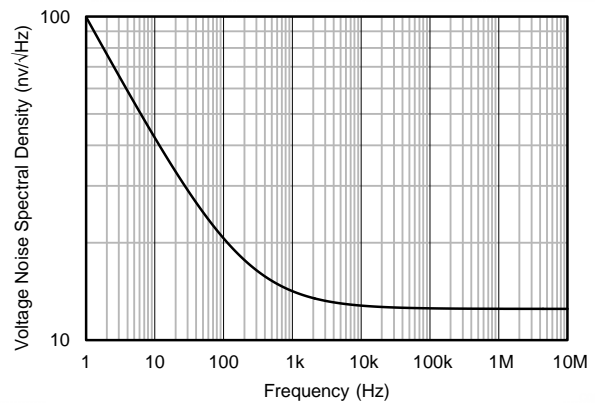


Figure 12. Input Voltage Noise Spectral Density vs Frequency

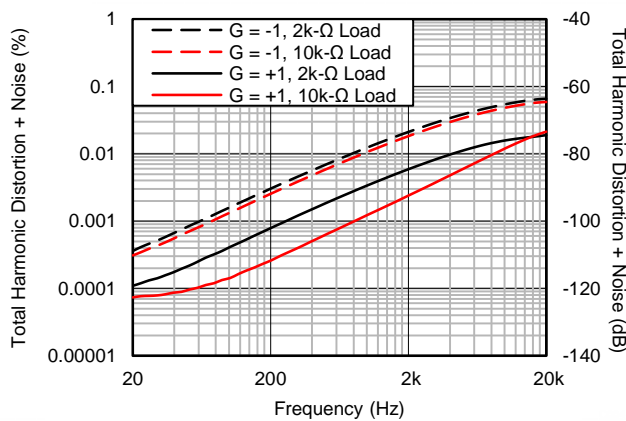


Figure 13. THD+N vs Frequency

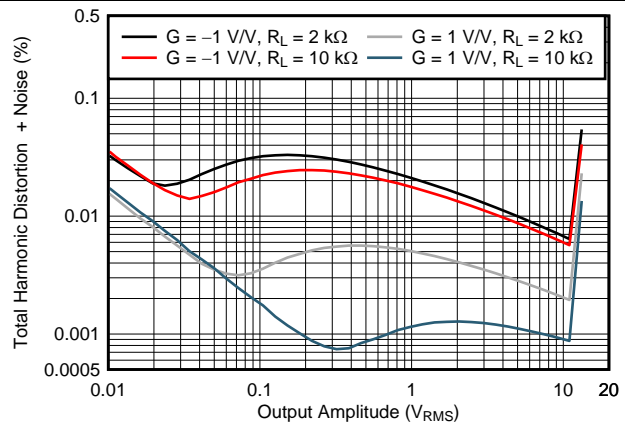


Figure 14. THD+N vs Output Amplitude

At $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{ V}$, $V_{CM} = V_S / 2$, $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

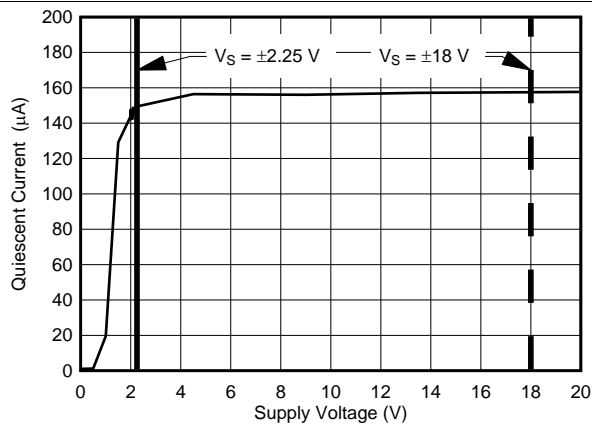


Figure 15. Quiescent Current vs Supply Voltage

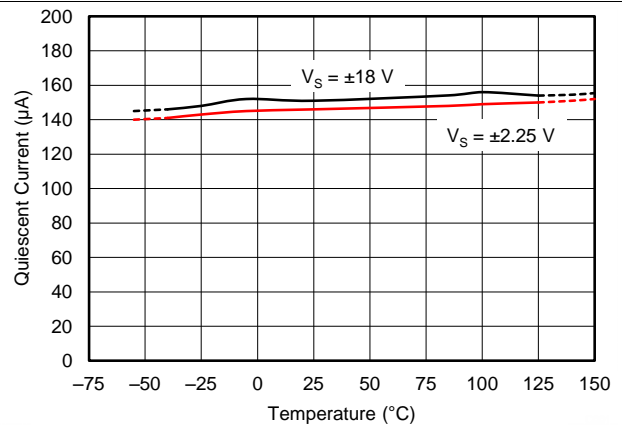


Figure 16. Quiescent Current vs Temperature

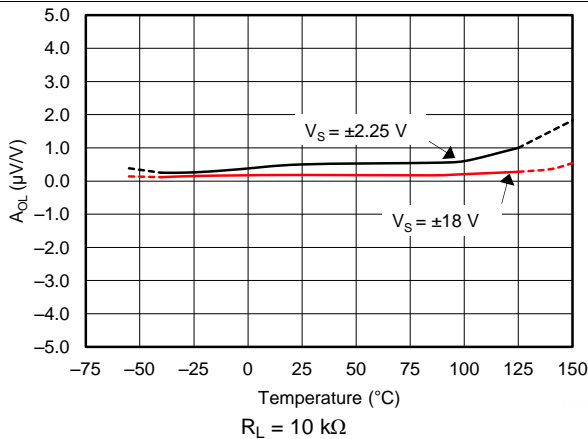


Figure 17. Open-Loop Gain vs Temperature

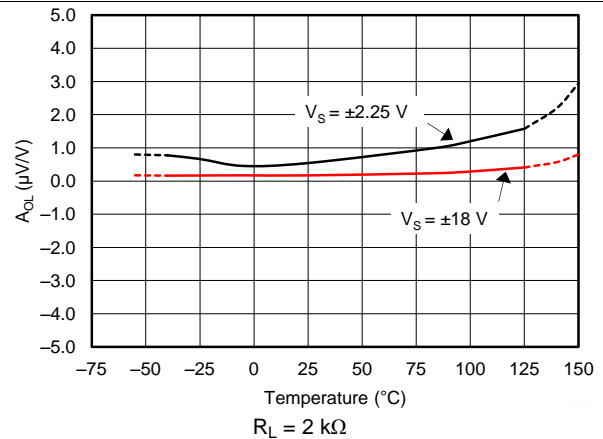


Figure 18. Open-Loop Gain vs Temperature

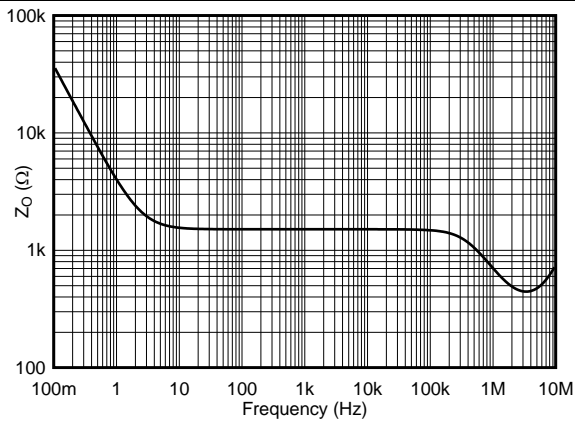


Figure 19. Open-Loop Output Impedance vs Frequency

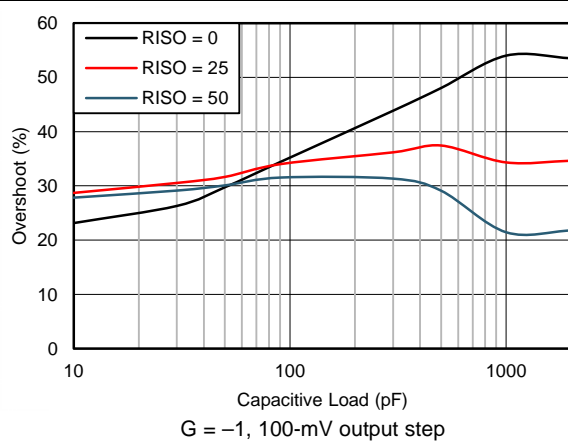


Figure 20. Small-Signal Overshoot vs Capacitive Load (100-mV Output Step)

At $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{ V}$, $V_{CM} = V_S / 2$, $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

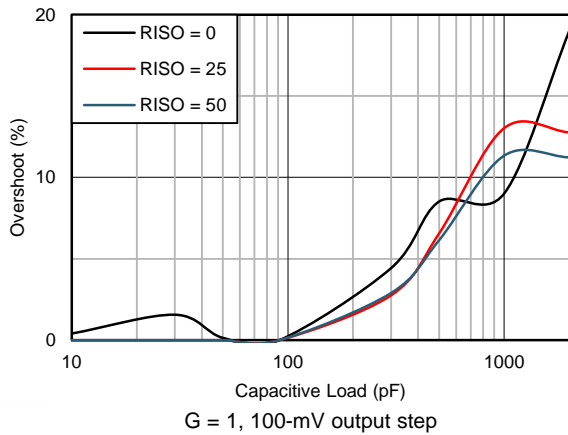


Figure 21. Small-Signal Overshoot vs Capacitive Load

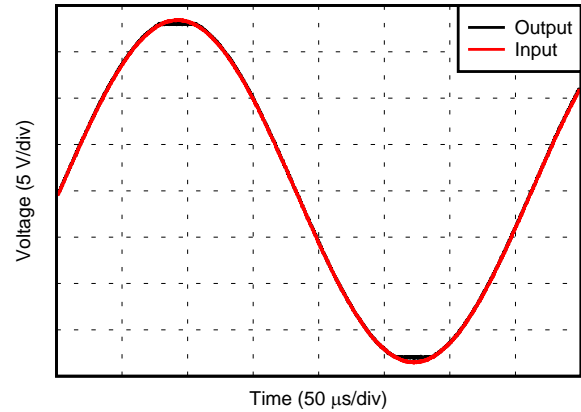


Figure 22. No Phase Reversal

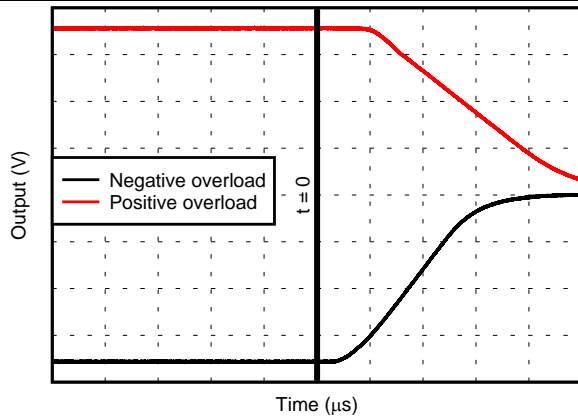


Figure 23. Overload Recovery

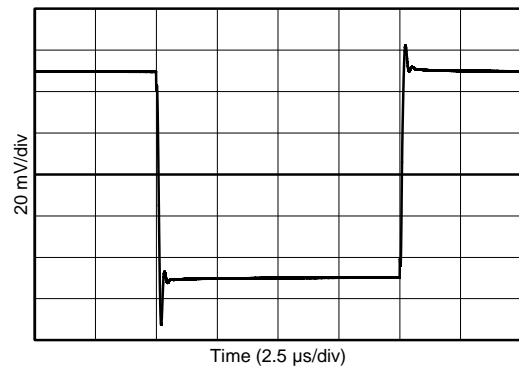


Figure 24. Small-Signal Step Response

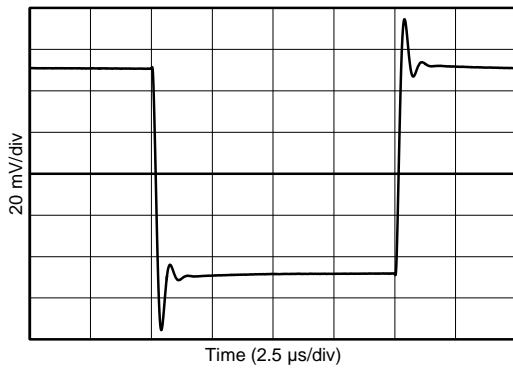


Figure 25. Small-Signal Step Response

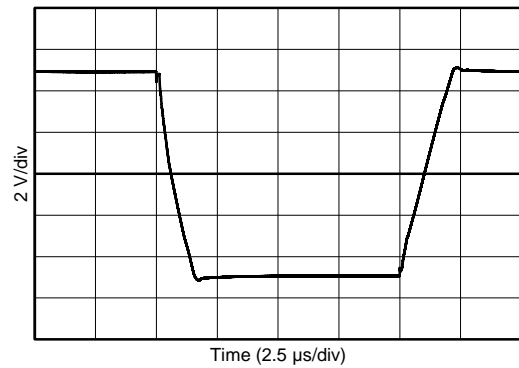
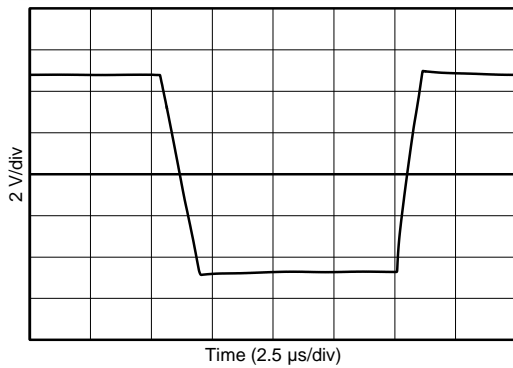


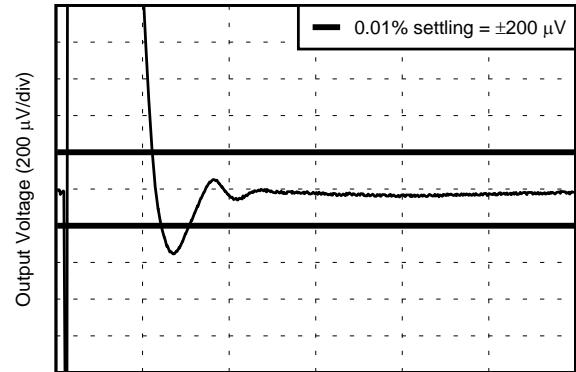
Figure 26. Large-Signal Step Response

At $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{ V}$, $V_{CM} = V_S / 2$, $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 100\text{ pF}$, unless otherwise noted.



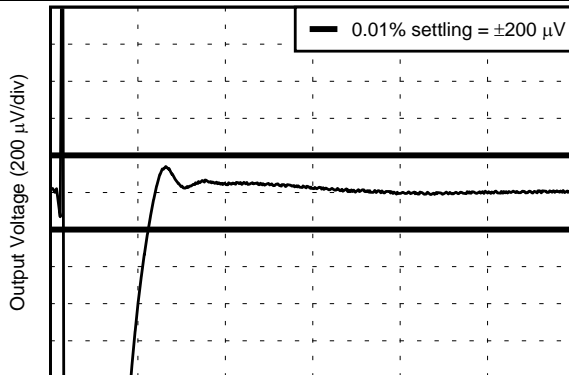
$G = -1$, $R_L = 1\text{ k}\Omega$, $C_L = 10\text{ pF}$

Figure 27. Large-Signal Step Response



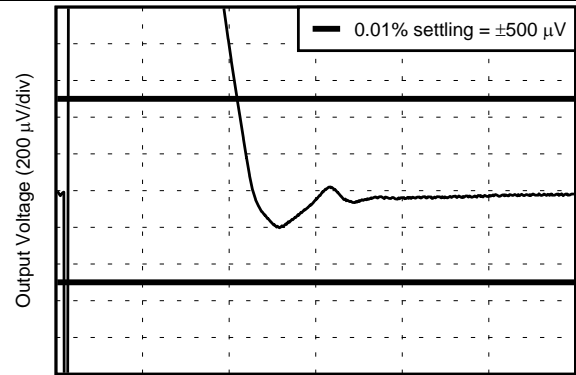
Gain = 1, 2-V step, rising, step applied at $t = 0\ \mu\text{s}$ on all four plots

Figure 28. 0.01% Settling Time



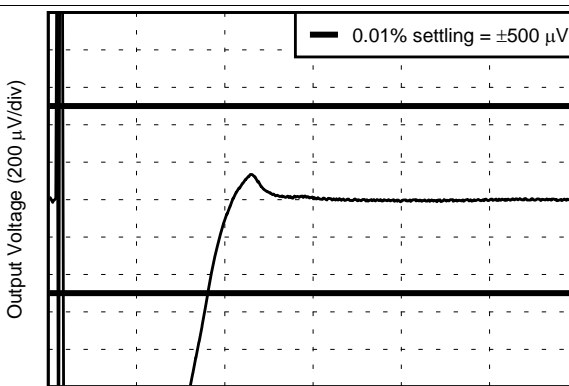
Gain = 1, 2-V step, falling, step applied at $t = 0\ \mu\text{s}$

Figure 29. 0.01% Settling Time



Gain = 1, 5-V step, rising, step applied at $t = 0\ \mu\text{s}$

Figure 30. 0.01% Settling Time



Gain = 1, 5-V step, falling, step applied at $t = 0\ \mu\text{s}$

Figure 31. 0.01% Settling Time

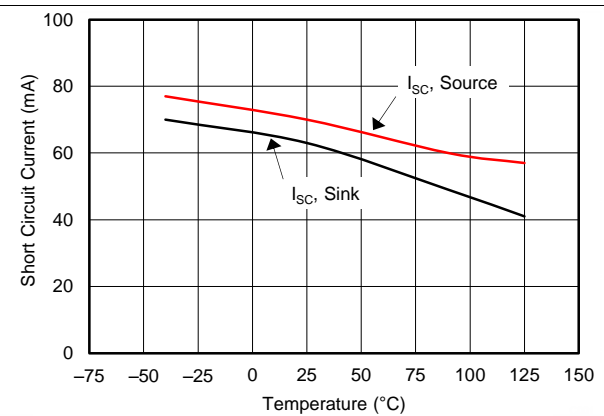


Figure 32. Short-Circuit Current vs Temperature

At $T_A = 25^\circ\text{C}$, $V_S = \pm 18\text{ V}$, $V_{CM} = V_S / 2$, $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

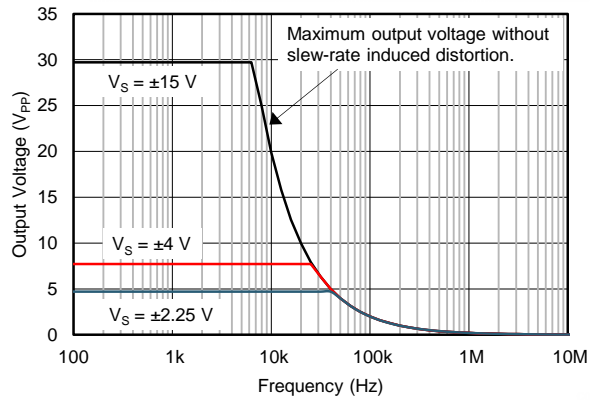


Figure 33. Maximum Output Voltage vs Frequency

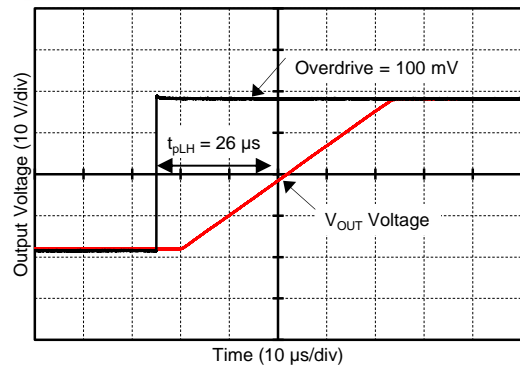


Figure 34. Propagation Delay Rising Edge

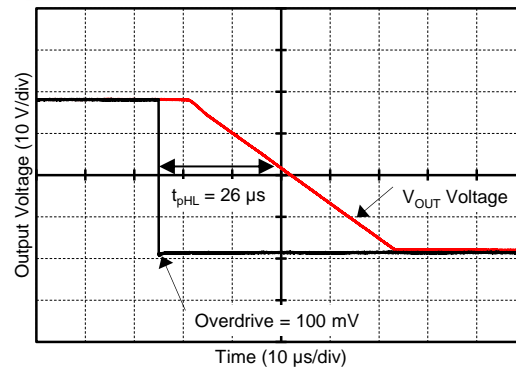


Figure 35. Propagation Delay Falling Edge

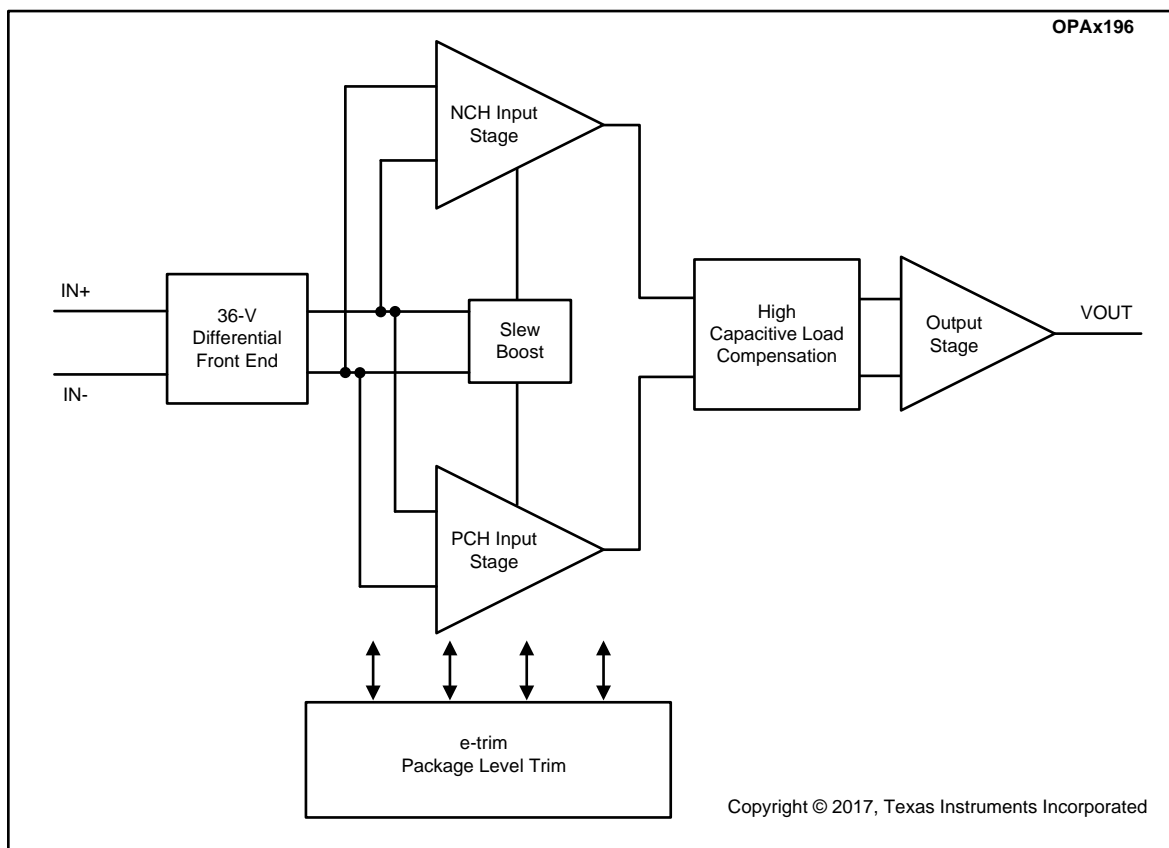
7 Detailed Description

7.1 Overview

The OPAx196 family of operational amplifiers use *e-trim*, a method of package-level trim for offset and offset temperature drift implemented during the final steps of manufacturing after the plastic molding process. This method minimizes the influence of inherent input transistor mismatch, as well as errors induced during package molding. The trim communication occurs on the output pin of the standard pinout, and after the trim points are set, further communication to the trim structure is permanently disabled. The [Functional Block Diagram](#) shows the simplified diagram of the OPA196 with e-trim.

Unlike previous e-trim op amps, the OPAx196 uses a patented two-temperature trim architecture to achieve a very low offset voltage and low voltage offset drift over the full specified temperature range. This level of precision performance at wide supply voltages makes these amplifiers useful for high-impedance industrial sensors, filters, and high-voltage data acquisition.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Input Protection Circuitry

The OPAX196 uses a unique input architecture to eliminate the need for input protection diodes but still provides robust input protection under transient conditions. Conventional input diode protection schemes shown in Figure 36 can be activated by fast transient step responses and can introduce signal distortion and settling time delays because of alternate current paths, as shown in Figure 37. For low-gain circuits, these fast-ramping input signals forward-bias back-to-back diodes that cause an increase in input current, resulting in extended settling time.

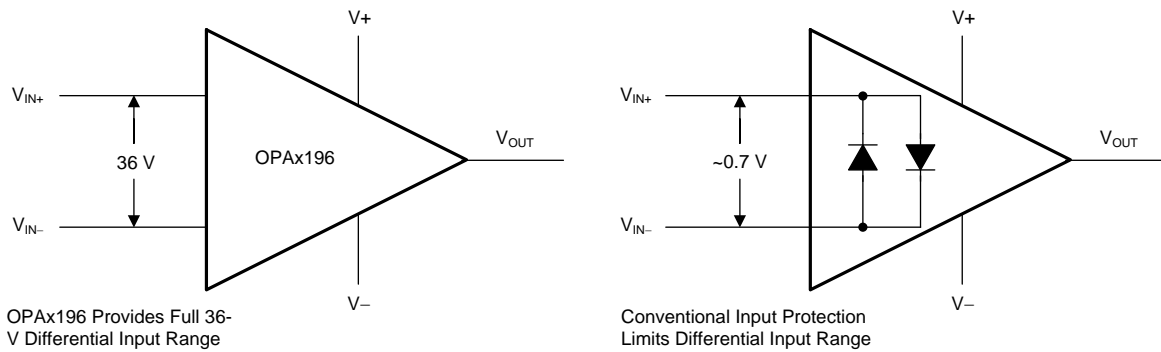


Figure 36. OPA196 Input Protection Does Not Limit Differential Input Capability

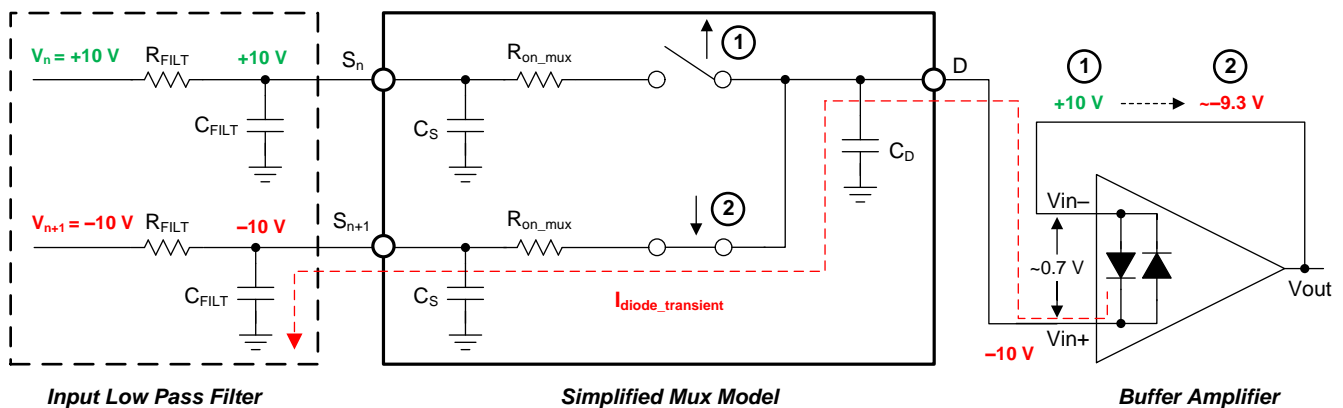


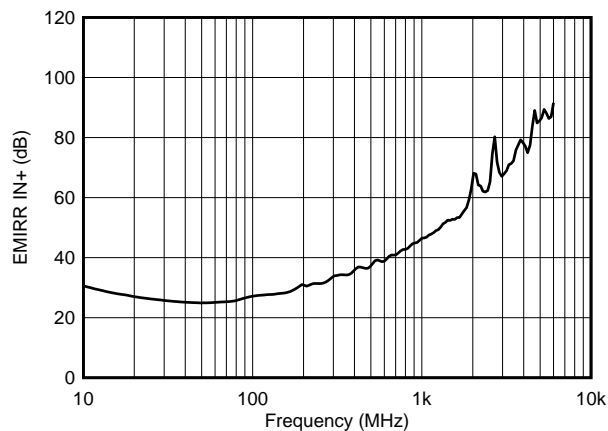
Figure 37. Back-to-Back Diodes Create Settling Issues

The OPAX196 family of operational amplifiers provides a true high-impedance differential input capability for high-voltage applications. This patented input protection architecture does not introduce additional signal distortion or delayed settling time, making the device an optimal op amp for multichannel, high-switched, input applications. The OPA196 can tolerate a maximum differential swing (voltage between inverting and noninverting pins of the op amp) of up to 36 V, making the device suitable for use as a comparator or in applications with fast-ramping input signals such as multiplexed data-acquisition systems (see Figure 49).

Feature Description (continued)

7.3.2 EMI Rejection

The OPAx196 uses integrated electromagnetic interference (EMI) filtering to reduce the effects of EMI from sources such as wireless communications and densely-populated boards with a mix of analog signal chain and digital components. EMI immunity can be improved with circuit design techniques; the OPAx196 benefits from these design improvements. Texas Instruments has developed the ability to accurately measure and quantify the immunity of an operational amplifier over a broad frequency spectrum extending from 10 MHz to 6 GHz. [Figure 38](#) shows the results of this testing on the OPAx196. [Table 2](#) shows the EMIRR IN+ values for the OPAx196 at particular frequencies commonly encountered in real-world applications. Applications listed in [Table 2](#) may be centered on or operated near the particular frequency shown. Detailed information can also be found in the application report [EMI Rejection Ratio of Operational Amplifiers](#), available for download from [www.ti.com](#).



$$P_{RF} = -10 \text{ dBm}, V_S = \pm 15 \text{ V}, V_{CM} = 0 \text{ V}$$

Figure 38. EMIRR Testing

Table 2. OPA196 EMIRR IN+ For Frequencies of Interest

FREQUENCY	APPLICATION OR ALLOCATION	EMIRR IN+
400 MHz	Mobile radio, mobile satellite, space operation, weather, radar, ultra-high frequency (UHF) applications	36 dB
900 MHz	Global system for mobile communications (GSM) applications, radio communication, navigation, GPS (to 1.6 GHz), GSM, aeronautical mobile, UHF applications	45 dB
1.8 GHz	GSM applications, mobile personal communications, broadband, satellite, L-band (1 GHz to 2 GHz)	57 dB
2.4 GHz	802.11b, 802.11g, 802.11n, Bluetooth®, mobile personal communications, industrial, scientific and medical (ISM) radio band, amateur radio and satellite, S-band (2 GHz to 4 GHz)	62 dB
3.6 GHz	Radiolocation, aero communication and navigation, satellite, mobile, S-band	76 dB
5.0 GHz	802.11a, 802.11n, aero communication and navigation, mobile communication, space and satellite operation, C-band (4 GHz to 8 GHz)	86 dB

7.3.3 Phase Reversal Protection

The OPAx196 family has internal phase-reversal protection. Many op amps exhibit phase reversal when the input is driven beyond the linear common-mode range. This condition is most often encountered in noninverting circuits when the input is driven beyond the specified common-mode voltage range, causing the output to reverse into the opposite rail. The OPAx196 is a rail-to-rail input op amp, and therefore the common-mode range can extend up to the rails. Input signals beyond the rails do not cause phase reversal; instead, the output limits into the appropriate rail. This performance is shown in [Figure 39](#).

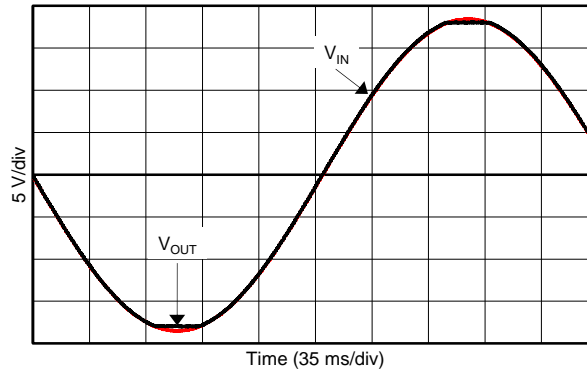


Figure 39. No Phase Reversal

7.3.4 Thermal Protection

The internal power dissipation of any amplifier causes the internal (junction) temperature to rise. This phenomenon is called *self heating*. The OPAx196 has a thermal protection feature that prevents damage from self heating.

This thermal protection works by monitoring the temperature of the output stage and turning off the op amp output drive for temperatures above approximately 180°C. Thermal protection forces the output to a high-impedance state. The OPAx196 is also designed with approximately 30°C of thermal hysteresis. Thermal hysteresis prevents the output stage from cycling in and out of the high-impedance state. The OPAx196 returns to normal operation when the output stage temperature falls below approximately 150°C.

The absolute maximum junction temperature of the OPAx196 is 150°C. Exceeding the limits shown in the [Absolute Maximum Ratings](#) table may cause damage to the device. Thermal protection triggers at 180°C because of unit-to-unit variance, but does not interfere with device operation up to the absolute maximum ratings. This thermal protection is not designed to prevent this device from exceeding absolute maximum ratings, but rather from excessive thermal overload.

7.3.5 Capacitive Load and Stability

The OPAx196 features a patented output stage capable of driving large capacitive loads, and in a unity-gain configuration, directly drives up to 1 nF of pure capacitive load. Increasing the gain enhances the ability of the amplifier to drive greater capacitive loads; see [Figure 40](#). The particular op amp circuit configuration, layout, gain, and output loading are some of the factors to consider when establishing whether an amplifier will be stable in operation.

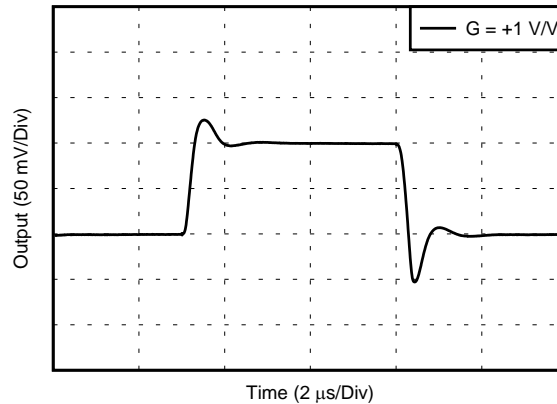


Figure 40. Transient Response with a Purely Capacitive Load of 1 nF

Like many low-power amplifiers, some ringing can occur even with capacitive loads less than 100 pF. In unity-gain configurations with no or very light dc loads, place an RC snubber circuit at the OPAx196 output to reduce any possibility of ringing in lightly-loaded applications. [Figure 41](#) illustrates the recommended RC snubber circuit.

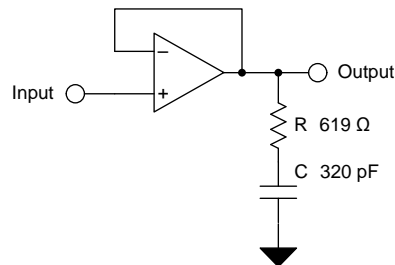


Figure 41. RC Snubber Circuit for Lightly-Loaded Applications in Unity Gain

For additional drive capability in unity-gain configurations, improve capacitive load drive by inserting a small, 10-Ω to 20-Ω resistor (R_{ISO}) in series with the output, as shown in Figure 42. This resistor significantly reduces ringing while maintaining dc performance for purely capacitive loads. However, if there is a resistive load in parallel with the capacitive load, a voltage divider is created, introducing a gain error at the output and slightly reducing the output swing. The error introduced is proportional to the ratio R_{ISO} / R_L and is generally negligible at low output levels. A high capacitive load drive makes the OPA196 well suited for applications such as reference buffers, MOSFET gate drives, and cable-shield drives. The circuit shown in Figure 42 uses R_{ISO} to stabilize the output of an op amp. R_{ISO} modifies the open-loop gain of the system for increased phase margin. Results using the OPA196 are summarized in Table 3. For additional information on techniques to optimize and design using this circuit, TI Precision Design TIDU032 details complete design goals, simulation, and test results.

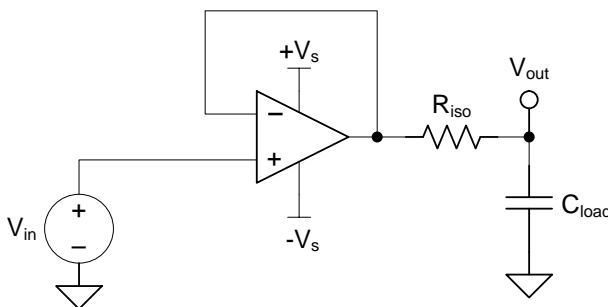


Figure 42. Extending Capacitive Load Drive With the OPA196

Table 3. OPA196 Capacitive Load Drive Solution Using Isolation Resistor Comparison of Calculated and Measured Results

PARAMETER	VALUE									
	100 pF	1000 pF		0.01 μF		0.1 μF		1 μF		
Phase Margin	45°	45°	60°	45°	60°	45°	60°	45°	60°	
R_{ISO} (Ω)	280	113	432	68	210	17.8	53.6	3.6	10	
Measured Overshoot (%)	23	23	8	23	8	23	8	23	8	



For step-by-step design procedure, circuit schematics, bill of materials, printed circuit board (PCB) files, simulation results, and test results, refer to [TI Precision Design TIDU032, Capacitive Load Drive Solution using an Isolation Resistor](#).

7.3.6 Common-Mode Voltage Range

The OPAx196 is a 36-V, true rail-to-rail input operational amplifier with an input common-mode range that extends 100 mV beyond either supply rail. This wide range is achieved with paralleled complementary N-channel and P-channel differential input pairs, as shown in Figure 43. The N-channel pair is active for input voltages close to the positive rail, typically $(V+) - 3\text{ V}$ to 100 mV above the positive supply. The P-channel pair is active for inputs from 100 mV below the negative supply to approximately $(V+) - 1.5\text{ V}$. There is a small transition region, typically $(V+) - 3\text{ V}$ to $(V+) - 1.5\text{ V}$ in which both input pairs are active. This transition region varies modestly with process variation. Within this region PSRR, CMRR, offset voltage, offset drift, noise, and THD performance are degraded compared to operation outside this region.

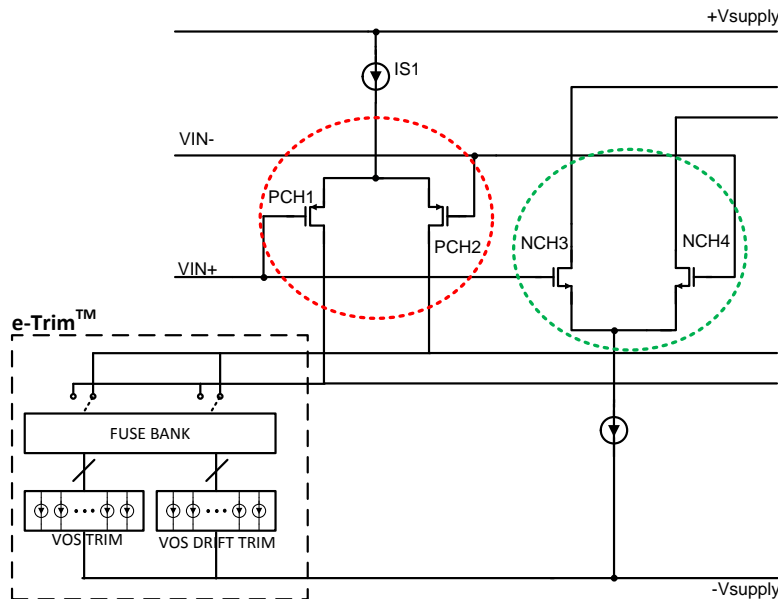


Figure 43. Rail-to-Rail Input Stage

To achieve the best performance for two-stage rail-to-rail input amplifiers, avoid the transition region when possible. The OPAx196 uses a precision trim for both the N-channel and P-channel regions. This technique enables significantly lower levels of offset than previous-generation devices, causing variance in the transition region of the input stages to appear exaggerated relative to offset over the full common-mode range, as shown in Figure 44.

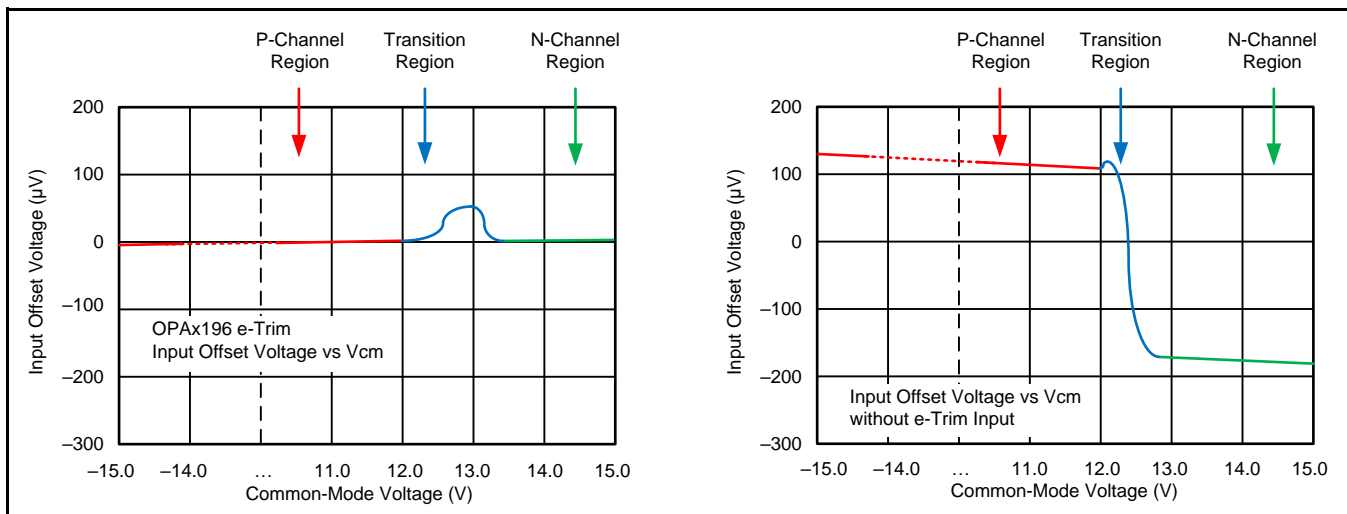


Figure 44. Common-Mode Transition vs Standard Rail-to-Rail Amplifiers

7.3.7 Electrical Overstress

Designers often ask questions about the capability of an operational amplifier to withstand electrical overstress (EOS). These questions tend to focus on the device inputs, but may 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 its relevance to an electrical overstress event is helpful. See [Figure 45](#) for an illustration of the ESD circuits contained in the OPAx196 (indicated by the dashed line area). The ESD protection circuitry involves several current-steering diodes connected from the input and output pins and routed back to the internal power-supply lines, where the diodes meet at an absorption device or the power-supply ESD cell, internal to the operational amplifier. This protection circuitry is intended to remain inactive during normal circuit operation.

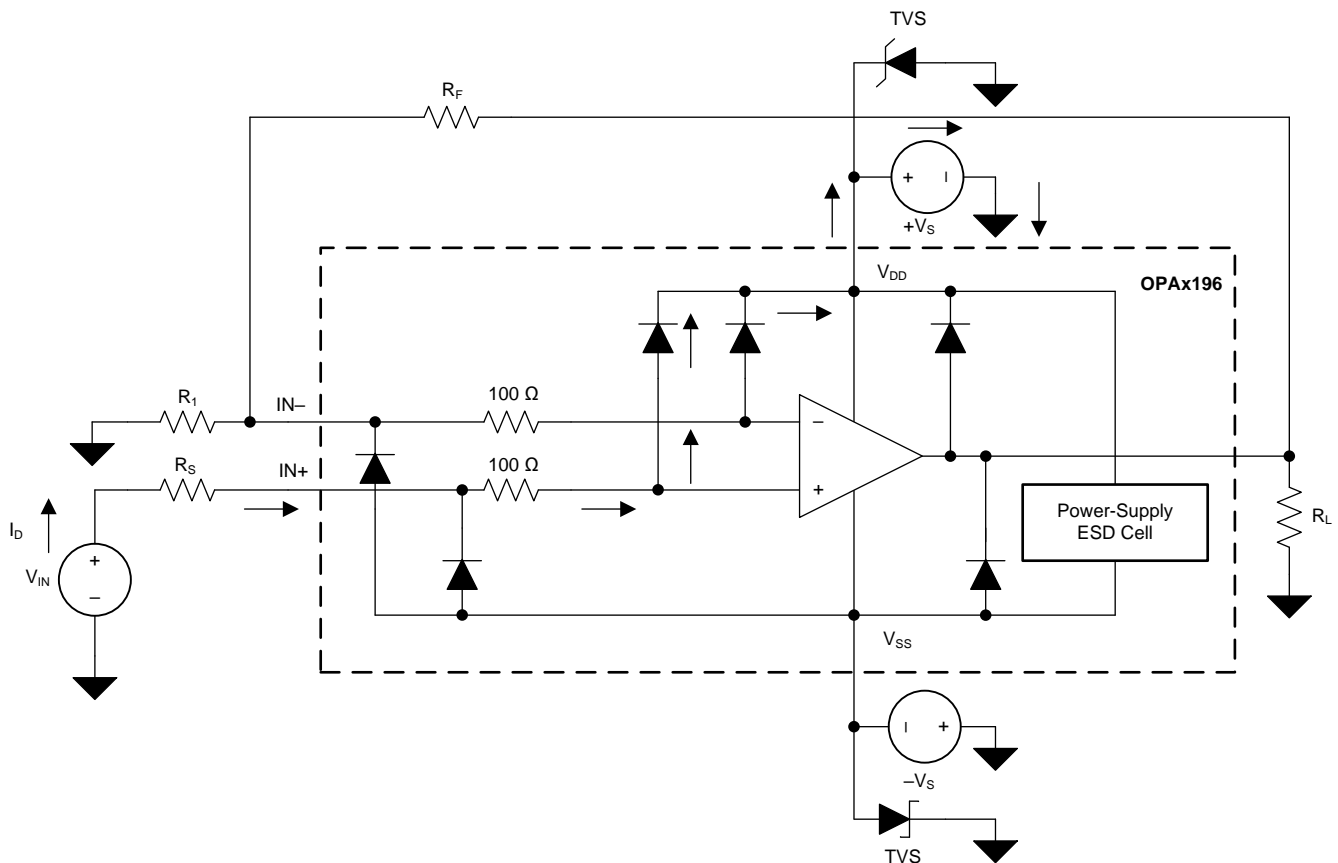


Figure 45. Equivalent Internal ESD Circuitry Relative to a Typical Circuit Application

An ESD event is very high voltage for a very short duration (for example, 1 kV for 100 ns); whereas, an EOS event is lower voltage for a longer duration (for example, 50 V for 100 ms). The ESD diodes are designed for out-of-circuit ESD protection (that is, during assembly, test, and storage of the device before being soldered to the PCB). During an ESD event, the ESD signal is passed through the ESD steering diodes to an absorption circuit labeled ESD power-supply circuit. The ESD absorption circuit clamps the supplies to a safe level.

Although this behavior is necessary for out-of-circuit protection, excessive current and damage is caused if activated in-circuit. A transient voltage suppressor (TVS) can be used to prevent against damage caused by turning on the ESD absorption circuit during an in-circuit ESD event. Using the appropriate current limiting resistors and TVS diodes allows for the use of device ESD diodes to protect against EOS events.

7.3.8 Overload Recovery

Overload recovery is defined as the time required for the op amp output to recover from a saturated state to a linear state. The output devices of the op amp enter a saturation region when the output voltage exceeds the rated operating voltage, either due to the high input voltage or the high gain. After the device enters the saturation region, the charge carriers in the output devices require time to return back to the linear state. After the charge carriers return back to the linear state, the device begins to slew at the specified slew rate. Thus, the propagation delay in case of an overload condition is the sum of the overload recovery time and the slew time.

7.4 Device Functional Modes

The OPAx196 has a single functional mode and is operational when the power-supply voltage is greater than 4.5 V (± 2.25 V). The maximum power supply voltage for the OPAx196 is 36 V (± 18 V).

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. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The OPAx196 family offers outstanding dc precision and ac performance. These devices operate up to 36-V supply rails and offer true rail-to-rail input/output, ultralow offset voltage and offset voltage drift, as well as 2-MHz bandwidth and high capacitive load drive. These features make the OPAx196 a robust, high-performance operational amplifier for high-voltage industrial applications.

8.2 Typical Applications

8.2.1 Low-side Current Measurement

Figure 46 shows the OPA196 configured in a low-side current sensing application. For a full analysis of the circuit shown in Figure 46 including theory, calculations, simulations, and measured data see the 0-1A, single-supply, low-side, current sensing solution, see TIPD129.

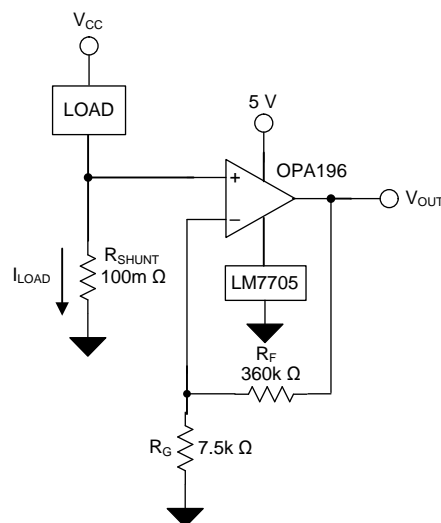


Figure 46. OPA196 in a Low-Side, Current-Sensing Application

8.2.1.1 Design Requirements

The design requirements for this design are:

- Load current: 0 A to 1 A
- Output voltage: 4.9 V
- Maximum shunt voltage: 100 mV

Typical Applications (continued)

8.2.1.2 Detailed Design Procedure

The transfer function of the circuit in [Figure 46](#) is given in [Equation 1](#):

$$V_{OUT} = I_{LOAD} \times R_{SHUNT} \times \text{Gain} \quad (1)$$

The load current (I_{LOAD}) produces a voltage drop across the shunt resistor (R_{SHUNT}). The load current is set from 0 A to 1 A. To keep the shunt voltage below 100 mV at maximum load current, the largest shunt resistor is defined using [Equation 2](#).

$$R_{SHUNT} = \frac{V_{SHUNT_MAX}}{I_{LOAD_MAX}} = \frac{100\text{mV}}{1\text{A}} = 100\text{m}\Omega \quad (2)$$

Using [Equation 2](#), R_{SHUNT} is calculated to be 100 mΩ. The voltage drop produced by I_{LOAD} and R_{SHUNT} is amplified by the OPA196 to produce an output voltage of 0 V to 4.9 V. The gain needed by the OPA196 to produce the necessary output voltage is calculated using [Equation 3](#):

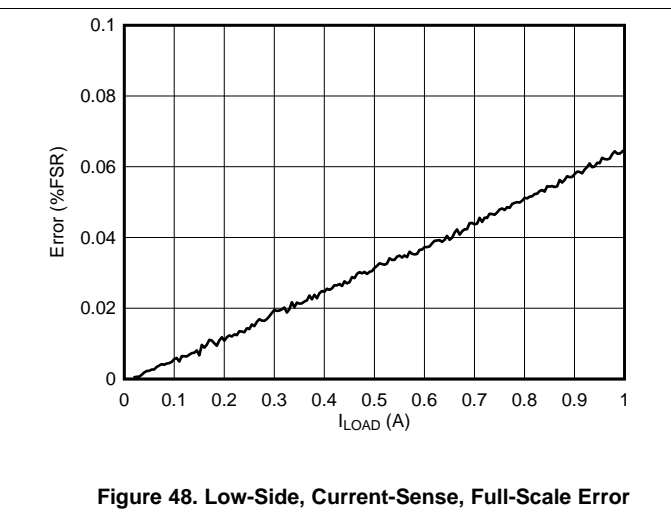
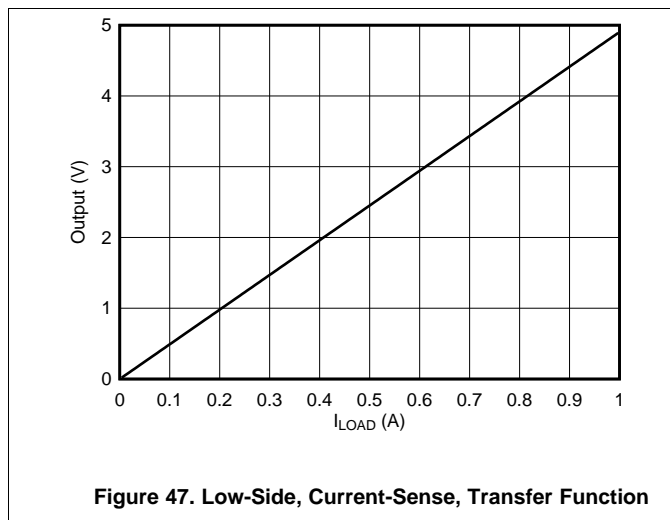
$$\text{Gain} = \frac{(V_{OUT_MAX} - V_{OUT_MIN})}{(V_{IN_MAX} - V_{IN_MIN})} \quad (3)$$

Using [Equation 3](#), the required gain is calculated to be 49 V/V, which is set with resistors R_F and R_G . [Equation 4](#) is used to size the resistors, R_F and R_G , to set the gain of the OPA196 to 49 V/V.

$$\text{Gain} = 1 + \frac{(R_F)}{(R_G)} \quad (4)$$

Choosing R_F as 360 kΩ, R_G is calculated to be 7.5 kΩ. R_F and R_G were chosen as 360 kΩ and 7.5 kΩ because they are standard value resistors that create a 49:1 ratio. Other resistors that create a 49:1 ratio can also be used. [Figure 2](#) shows the measured transfer function of the circuit shown in [Figure 46](#).

8.2.1.3 Application Curves



Typical Applications (continued)

8.2.2 16-Bit Precision Multiplexed Data-Acquisition System

Figure 49 shows a 16-bit, differential, 4-channel, multiplexed, data-acquisition system. This example is typical in industrial applications that require low distortion and a high-voltage differential input. The circuit uses the ADS8864, a 16-bit, 400-kSPS successive-approximation-resistor (SAR), analog-to-digital converter (ADC), along with a precision, high-voltage, signal-conditioning front-end, and a 4-channel differential multiplexer (mux). This application example shows the process for optimizing the precision, high-voltage, front-end drive circuit using the OPA196 and OPA140 to achieve excellent dynamic performance and linearity with the ADS8864. The full TI Precision Design can be found in TIDU181.

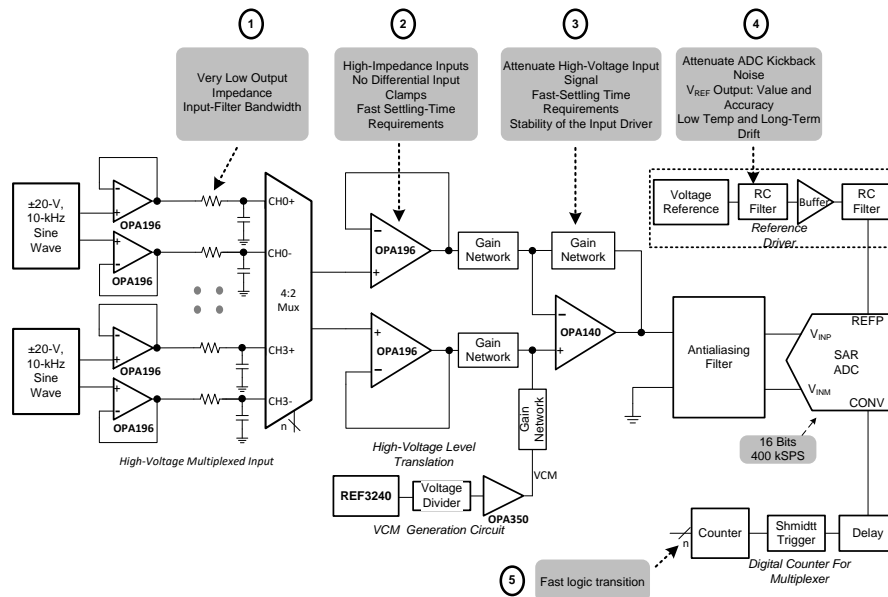


Figure 49. OPA196 in 16-Bit, 400-kSPS, 4-Channel, Multiplexed Data Acquisition System for High-Voltage Inputs With Lowest Distortion

8.2.2.1 Design Requirements

The primary objective is to design a $\pm 20\text{-V}$, differential, 4-channel, multiplexed, data acquisition system with lowest distortion using the 16-bit ADS8864 at a throughput of 400 kSPS for a 10-kHz, full-scale, pure sine-wave input. The design requirements for this block design are:

- System supply voltage: $\pm 15\text{ V}$
- ADC supply voltage: 3.3 V
- ADC sampling rate: 400 kSPS
- ADC reference voltage (REFP): 4.096 V
- System input signal: A high-voltage differential input signal with a peak amplitude of 10 V and frequency (f_{IN}) of 10 kHz are applied to each differential input of the mux.

8.2.2.2 Detailed Design Procedure

The purpose of this application example is to design an optimal, high-voltage, multiplexed, data-acquisition system for highest system linearity and fast settling. The overall system block diagram is shown in Figure 49. The circuit is a multichannel, data-acquisition, signal chain consisting of an input low-pass filter, multiplexer (mux), mux output buffer, attenuating SAR ADC driver, digital counter for the mux, and the reference driver. The architecture allows fast sampling of multiple channels using a single ADC, providing a low-cost solution. The two primary design considerations to maximize the performance of a precision, multiplexed, data-acquisition system are the mux input analog front-end and the high-voltage, level translation, SAR ADC driver design. However, carefully design each analog circuit block based on the ADC performance specifications in order to achieve the fastest settling at 16-bit resolution and lowest distortion system. Figure 49 includes the most important specifications for each individual analog block.

Typical Applications (continued)

This design systematically approaches each analog circuit block to achieve a 16-bit settling for a full-scale input stage voltage and linearity for a 10-kHz sinusoidal input signal at each input channel. The first step in the design is to understand the requirement for an extremely-low-impedance input-filter design for the mux. This understanding helps in the decision of an appropriate input filter and selection of a mux to meet the system settling requirements. The next important step is the design of the attenuating analog front-end (AFE) used to level translate the high-voltage input signal to a low-voltage ADC input while maintaining the amplifier stability. Then, the next step is to design a digital interface to switch the mux input channels with minimum delay. The final design challenge is to design a high-precision, reference-driver circuit that provides the required REFP reference voltage with low offset, drift, and noise contributions.



For step-by-step design procedure, circuit schematics, bill of materials, PCB files, simulation results, and test results, refer to [TI Precision Design TIDU181, 16-bit, 400-kSPS, 4-Channel, Multiplexed Data Acquisition System for High Voltage Inputs with Lowest Distortion.](#)

8.2.3 Slew Rate Limit for Input Protection

In control systems for valves or motors, abrupt changes in voltages or currents can cause mechanical damages. By controlling the slew rate of the command voltages into the drive circuits, the load voltages ramps up and down at a safe rate. For symmetrical slew-rate applications (positive slew rate equals negative slew rate), one additional op amp provides slew-rate control for a given analog gain stage. The unique input protection and high output current and slew rate of the OPAx196 make the device an optimal amplifier to achieve slew rate control for both dual- and single-supply systems. [Figure 50](#) shows the OPA196 in a slew-rate limit design.

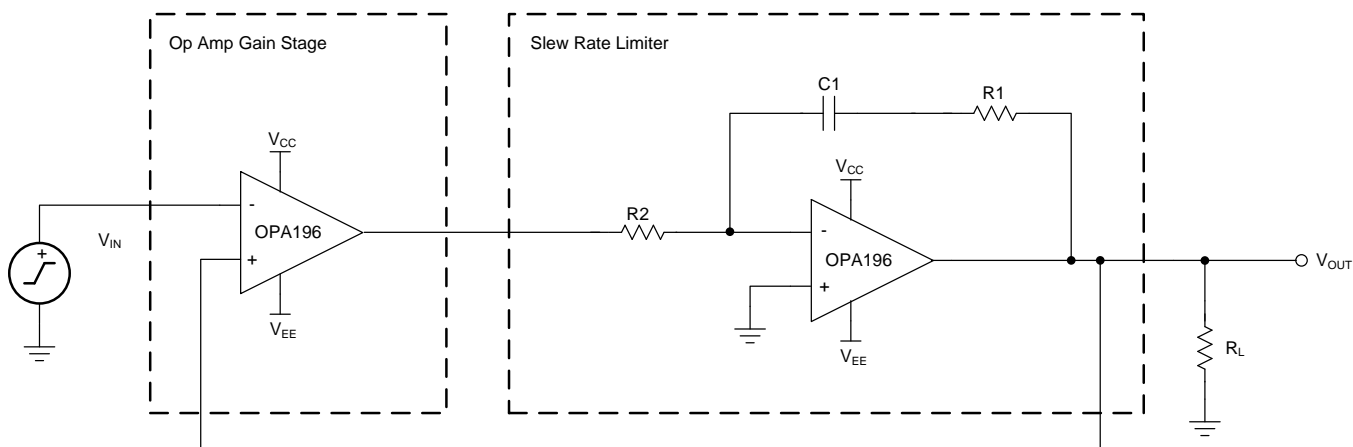


Figure 50. Slew Rate Limiter Uses One Op Amp



For step-by-step design procedure, circuit schematics, bill of materials, PCB files, simulation results, and test results, refer to [TI Precision Design TIDU026, Slew Rate Limiter Uses One Op Amp.](#)

9 Power-Supply Recommendations

The OPAx196 is specified for operation from 4.5 V to 36 V (± 2.25 V to ± 18 V); many specifications apply from -40°C to $+125^{\circ}\text{C}$. Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in the [Typical Characteristics](#).

CAUTION

Supply voltages larger than 40 V can permanently damage the device; see the [Absolute Maximum Ratings](#).

Place 0.1- μF bypass capacitors close to the power-supply pins to reduce errors coupling in from noisy or high-impedance power supplies. For more detailed information on bypass capacitor placement, refer to the [Layout](#) section.

10 Layout

10.1 Layout Guidelines

For best operational performance of the device, use good PCB layout practices, including:

- Connect low-ESR, 0.1- μF ceramic bypass capacitors between each supply pin and ground, placed as close as possible to the device. A single bypass capacitor from V+ to ground is applicable for single-supply applications.
 - Noise can propagate into analog circuitry through the power pins of the circuit as a whole and op amp itself. Bypass capacitors are used to reduce the coupled noise by providing low-impedance power sources local to the analog circuitry.
- Make sure to physically separate digital and analog grounds paying attention to the flow of the ground current. Separate grounding for analog and digital portions of circuitry is one of the simplest and most-effective methods of noise suppression. One or more layers on multilayer PCBs are usually devoted to ground planes. A ground plane helps distribute heat and reduces EMI noise pickup.
- In order to reduce parasitic coupling, run the input traces as far away as possible from the supply or output traces. If these traces cannot be kept separate, crossing the sensitive trace perpendicular is much better as opposed to in parallel with the noisy trace.
- Place the external components as close to the device as possible. As shown in [Figure 52](#), keeping RF and RG close to the inverting input minimizes parasitic capacitance.
- Keep the length of input traces as short as possible. Always remember that the input traces are the most sensitive part of the circuit.
- Consider a driven, low-impedance guard ring around the critical traces. A guard ring can significantly reduce leakage currents from nearby traces that are at different potentials.
- Clean the PCB following board assembly for best performance.
- Any precision integrated circuit may experience performance shifts due to moisture ingress into the plastic package. After any aqueous PCB cleaning process, bake the PCB assembly to remove moisture introduced into the device packaging during the cleaning process. A low-temperature, post-cleaning bake at 85°C for 30 minutes is sufficient for most circumstances.

10.2 Layout Example

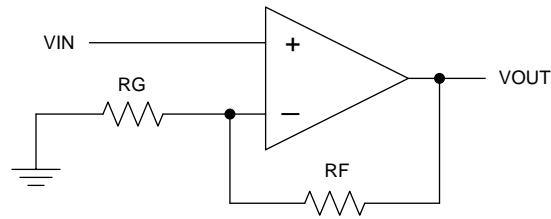
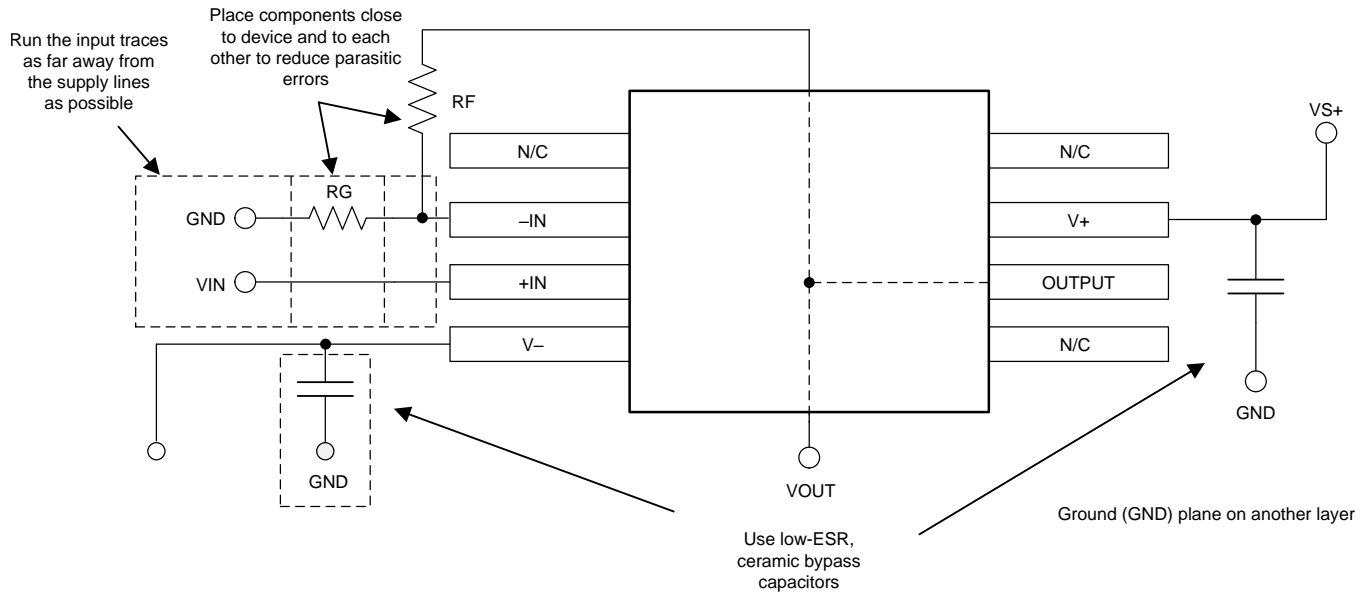


Figure 51. Schematic Representation



Copyright © 2017, Texas Instruments Incorporated

Figure 52. Operational Amplifier Board Layout for Non-inverting Configuration

11 Device and Documentation Support

11.1 Device Support

11.1.1 Development Support

11.1.1.1 TINA-TI™ (Free Software Download)

TINA™ is a simple, powerful, and easy-to-use circuit simulation program based on a SPICE engine. TINA-TI is a free, fully-functional version of the TINA software, preloaded with a library of macro models in addition to a range of both passive and active models. TINA-TI provides all the conventional dc, transient, and frequency domain analysis of SPICE, as well as additional design capabilities.

Available as a [free download](#) from the Analog eLab Design Center, TINA-TI offers extensive post-processing capability that allows users to format results in a variety of ways. Virtual instruments offer the ability to select input waveforms and probe circuit nodes, voltages, and waveforms, creating a dynamic quick-start tool.

NOTE

These files require that either the TINA software (from DesignSoft™) or TINA-TI software be installed. Download the free TINA-TI software from the [TINA-TI folder](#) at <http://www.ti.com/tool/tina-ti>.

11.1.1.2 TI Precision Designs

TI Precision Designs, available online at <http://www.ti.com/ww/en/analog/precision-designs/>, are analog solutions created by TI's precision analog applications experts and offer the theory of operation, component selection, simulation, complete PCB schematic and layout, bill of materials, and measured performance of many useful circuits.

11.2 Documentation Support

11.2.1 Related Documentation

- [EMI Rejection Ratio of Operational Amplifiers](#)
- [0-1A, Single-Supply, Low-Side, Current Sensing Solution](#)
- [Op Amps for Everyone](#)

11.3 Related Links

[Table 4](#) lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to order now.

Table 4. Related Links

PARTS	PRODUCT FOLDER	ORDER NOW	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
OPA196	Click here	Click here	Click here	Click here	Click here
OPA2196	Click here	Click here	Click here	Click here	Click here
OPA4196	Click here	Click here	Click here	Click here	Click here

11.4 Receiving Notification of Documentation Updates

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

11.5 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

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

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

11.6 Trademarks

e-trim, E2E are trademarks of Texas Instruments.

TINA-TI is a trademark of Texas Instruments, Inc and DesignSoft, Inc.

Bluetooth is a registered trademark of Bluetooth SIG, Inc.

TINA, DesignSoft are trademarks of DesignSoft, Inc.

11.7 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.

11.8 Glossary

[SLYZ022](#) — *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 Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
OPA196ID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	OPA196	Samples
OPA196IDBVR	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	O196	Samples
OPA196IDBVT	ACTIVE	SOT-23	DBV	5	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	O196	Samples
OPA196IDGKR	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	O196	Samples
OPA196IDGKT	ACTIVE	VSSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	O196	Samples
OPA196IDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	OPA196	Samples
OPA2196ID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	OP2196	Samples
OPA2196IDGKR	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	2196	Samples
OPA2196IDGKT	ACTIVE	VSSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	2196	Samples
OPA2196IDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	OP2196	Samples
OPA4196ID	ACTIVE	SOIC	D	14	50	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 125	OPA4196	Samples
OPA4196IDR	ACTIVE	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 125	OPA4196	Samples

(1) The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of ≤ 1000 ppm threshold. Antimony trioxide based flame retardants must also meet the ≤ 1000 ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

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
OPA196IDBVR	SOT-23	DBV	5	3000	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
OPA196IDBVT	SOT-23	DBV	5	250	180.0	8.4	3.23	3.17	1.37	4.0	8.0	Q3
OPA196IDGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
OPA196IDGKT	VSSOP	DGK	8	250	177.8	12.4	5.3	3.4	1.4	8.0	12.0	Q1
OPA196IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
OPA2196IDGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
OPA2196IDGKT	VSSOP	DGK	8	250	180.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
OPA4196IDR	SOIC	D	14	2500	330.0	16.4	6.5	9.0	2.1	8.0	16.0	Q1

TAPE AND REEL BOX DIMENSIONS




*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
OPA196IDBVR	SOT-23	DBV	5	3000	213.0	191.0	35.0
OPA196IDBVT	SOT-23	DBV	5	250	213.0	191.0	35.0
OPA196IDGKR	VSSOP	DGK	8	2500	346.0	346.0	29.0
OPA196IDGKT	VSSOP	DGK	8	250	213.0	191.0	35.0
OPA196IDR	SOIC	D	8	2500	367.0	367.0	35.0
OPA2196IDGKR	VSSOP	DGK	8	2500	367.0	367.0	35.0
OPA2196IDGKT	VSSOP	DGK	8	250	210.0	185.0	35.0
OPA4196IDR	SOIC	D	14	2500	367.0	367.0	38.0

D (R-PDSO-G14)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 -  Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
 -  Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
 - E. Reference JEDEC MS-012 variation AB.

D (R-PDSO-G14)

PLASTIC SMALL OUTLINE

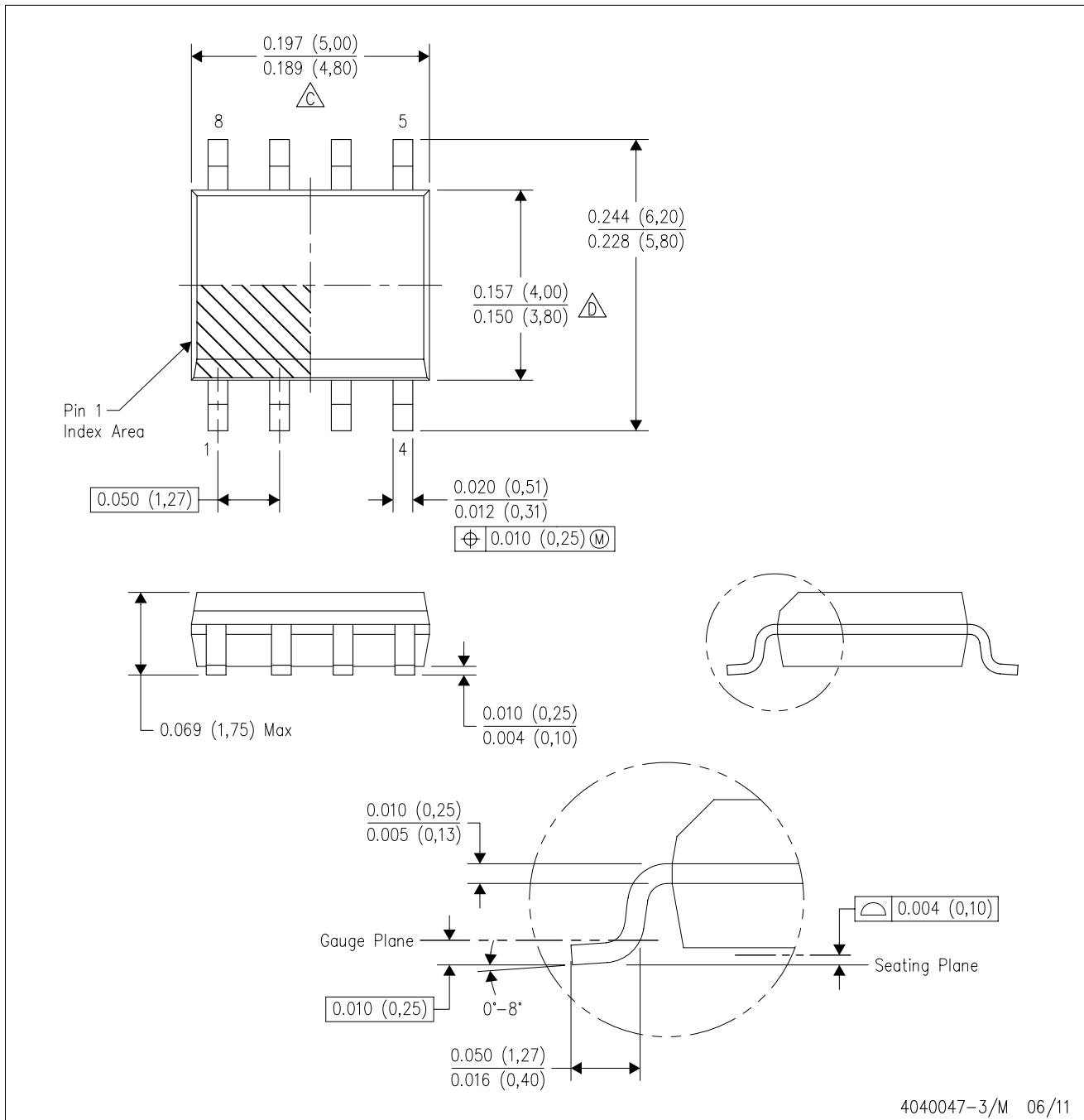


4211283-3/E 08/12

- NOTES:
- All linear dimensions are in millimeters.
 - This drawing is subject to change without notice.
 - Publication IPC-7351 is recommended for alternate designs.
 - Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
 - Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

D (R-PDSO-G8)

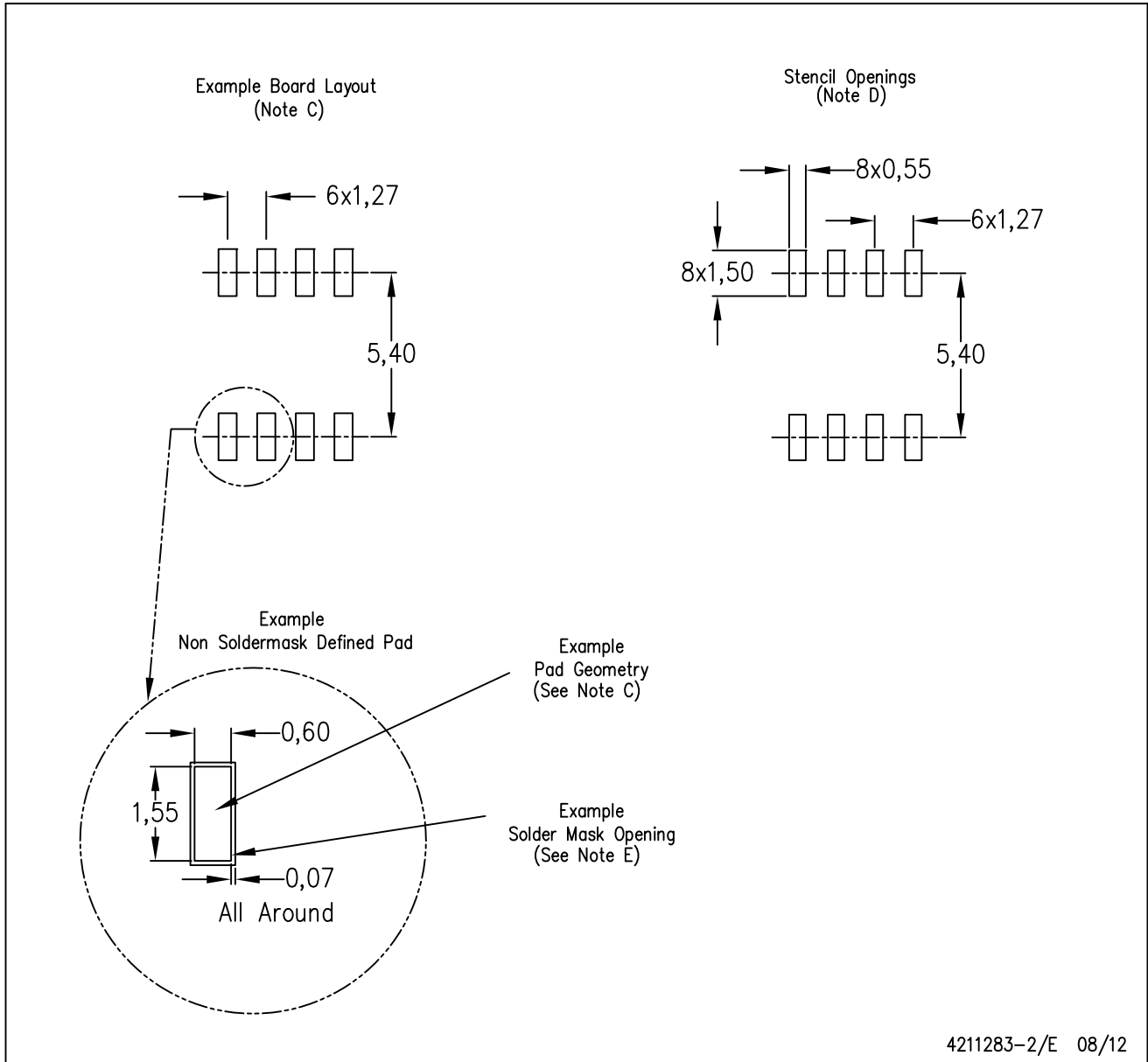
PLASTIC SMALL OUTLINE



NOTES: A. All linear dimensions are in inches (millimeters).
 B. This drawing is subject to change without notice.
 C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
 D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
 E. Reference JEDEC MS-012 variation AA.

D (R-PDSO-G8)

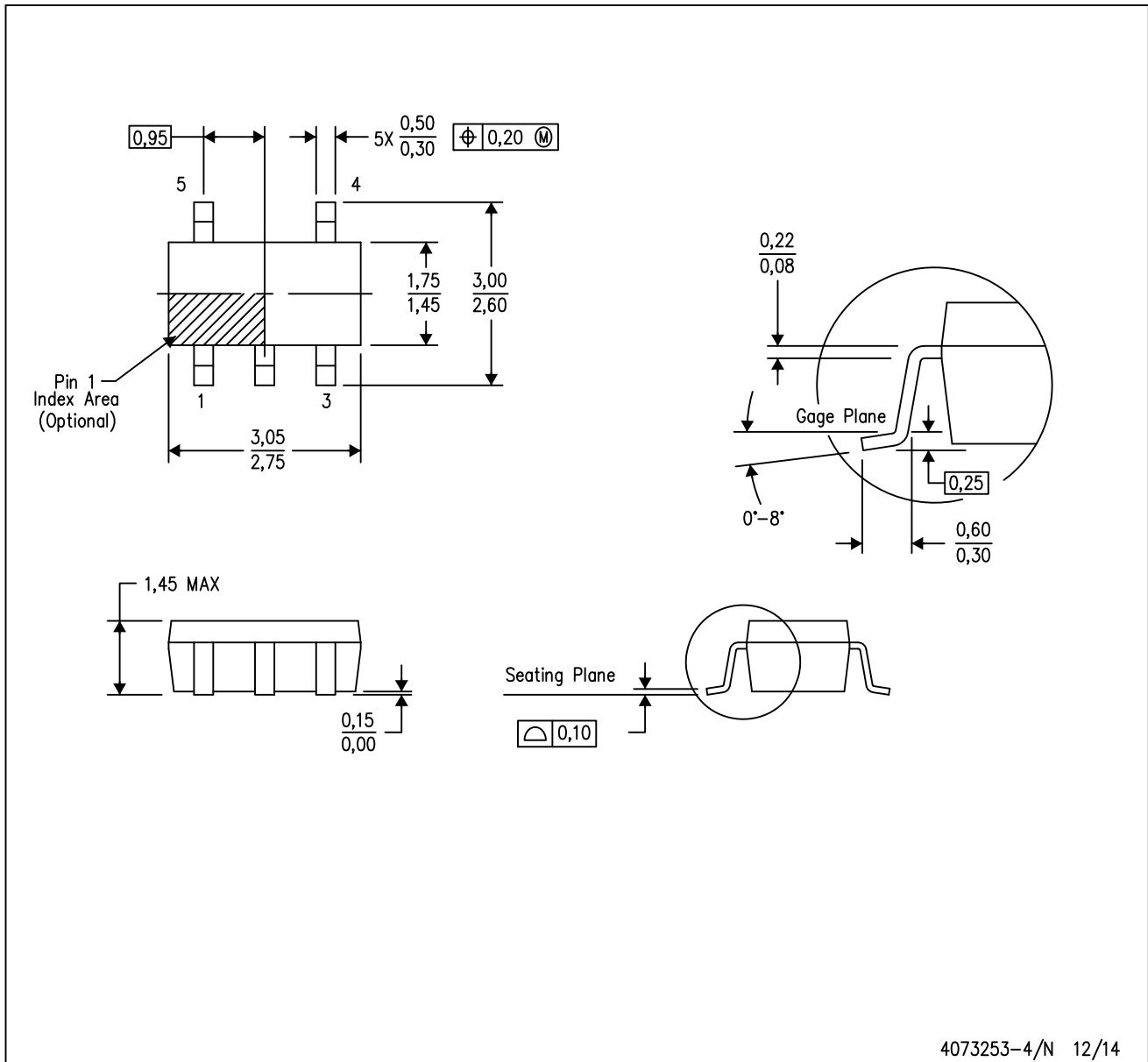
PLASTIC SMALL OUTLINE



- NOTES:
- All linear dimensions are in millimeters.
 - This drawing is subject to change without notice.
 - Publication IPC-7351 is recommended for alternate designs.
 - Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
 - Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

DBV (R-PDSO-G5)

PLASTIC SMALL-OUTLINE PACKAGE

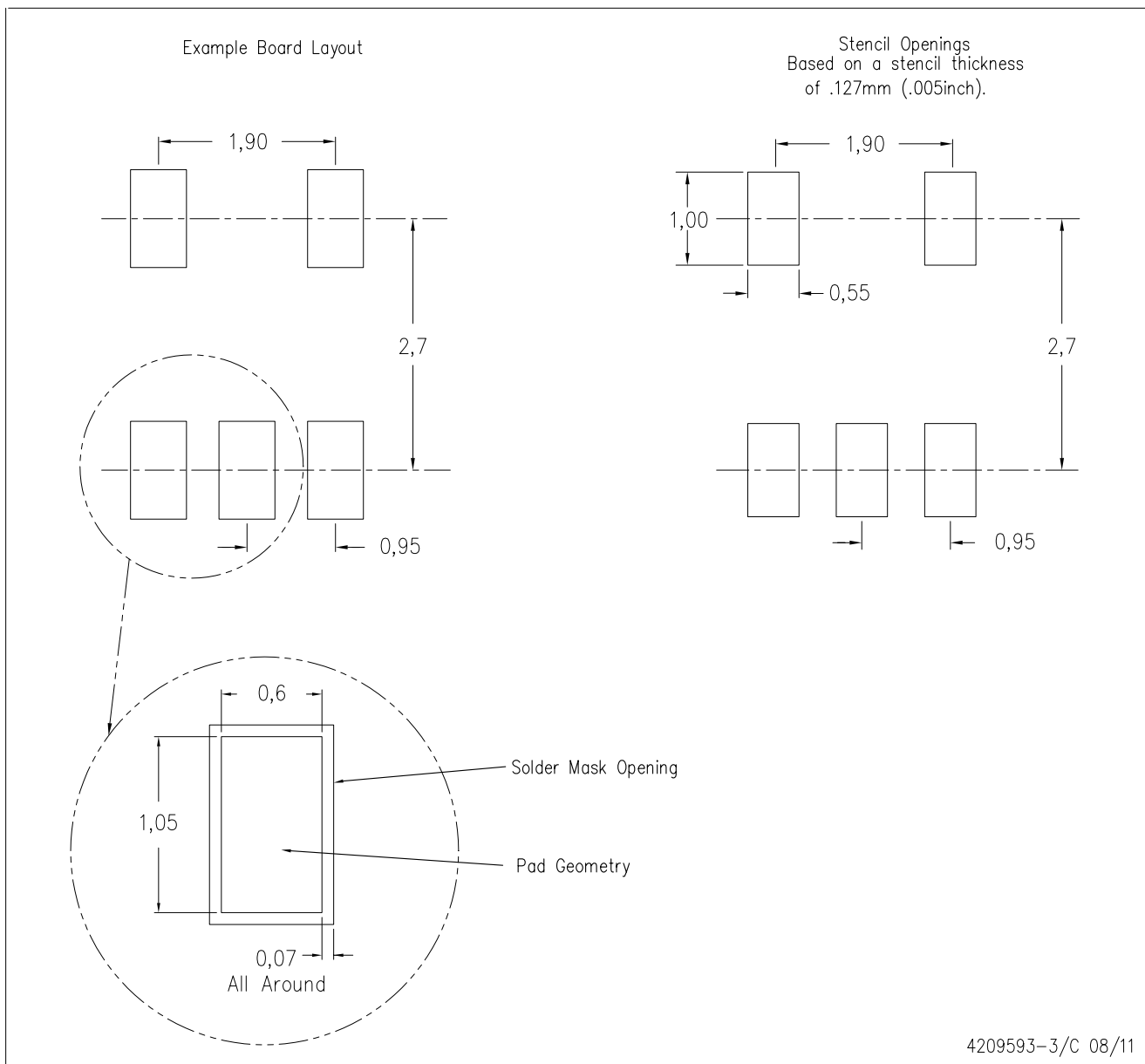


4073253-4/N 12/14

- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
 - D. Falls within JEDEC MO-178 Variation AA.

DBV (R-PDSO-G5)

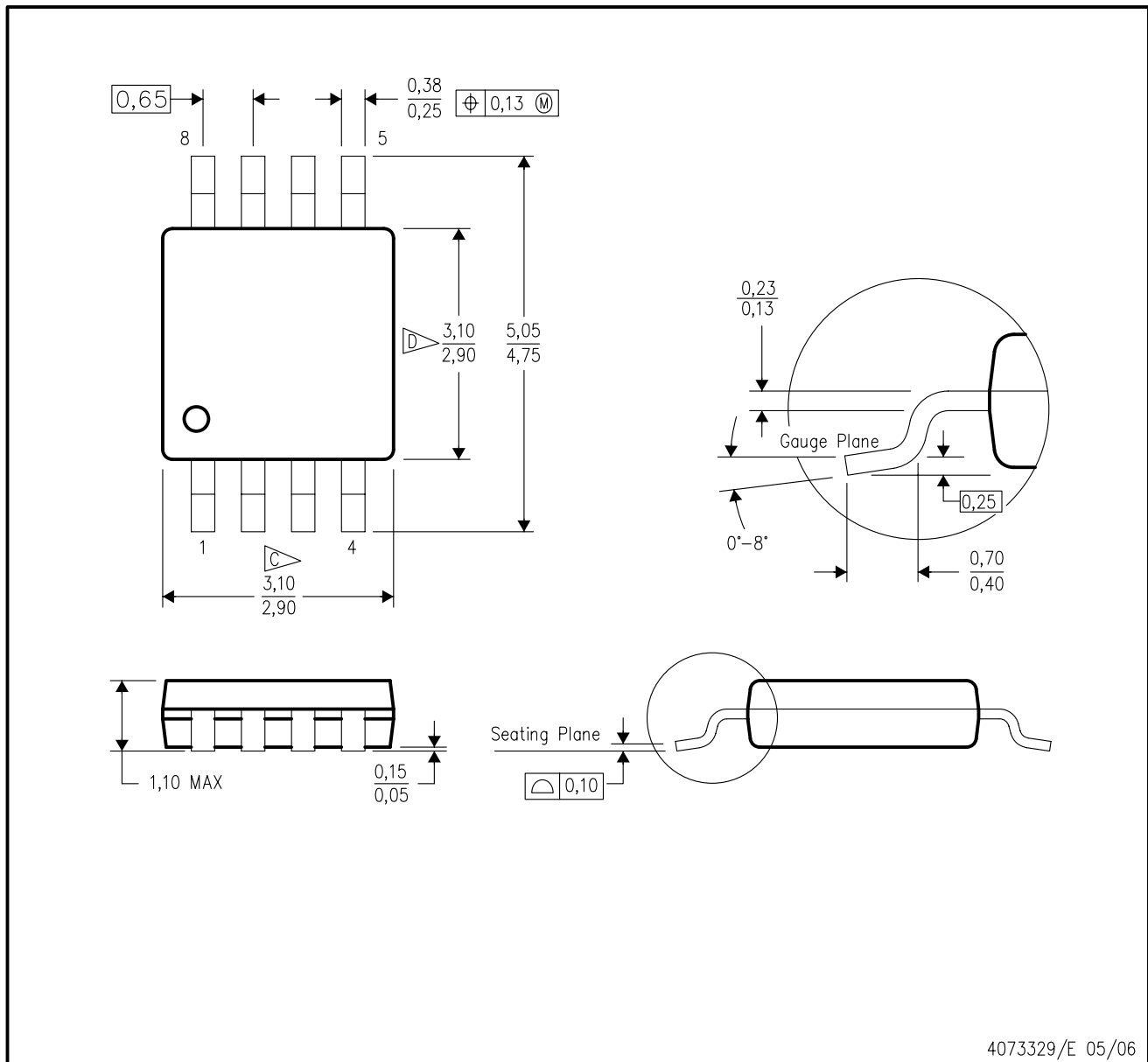
PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
 - D. Publication IPC-7351 is recommended for alternate designs.
 - E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC-7525 for other stencil recommendations.

DGK (S-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
 - D. Body width does not include interlead flash. Interlead flash shall not exceed 0.50 per side.
 - E. Falls within JEDEC MO-187 variation AA, except interlead flash.



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Publication IPC-7351 is recommended for alternate designs.
 - D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
 - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

IMPORTANT NOTICE

Texas Instruments Incorporated (TI) reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete.

TI's published terms of sale for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>) apply to the sale of packaged integrated circuit products that TI has qualified and released to market. Additional terms may apply to the use or sale of other types of TI products and services.

Reproduction of significant portions of TI information in TI data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such reproduced documentation. Information of third parties may be subject to additional restrictions. Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyers and others who are developing systems that incorporate TI products (collectively, "Designers") understand and agree that Designers remain responsible for using their independent analysis, evaluation and judgment in designing their applications and that Designers have full and exclusive responsibility to assure the safety of Designers' applications and compliance of their applications (and of all TI products used in or for Designers' applications) with all applicable regulations, laws and other applicable requirements. Designer represents that, with respect to their applications, Designer has all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. Designer agrees that prior to using or distributing any applications that include TI products, Designer will thoroughly test such applications and the functionality of such TI products as used in such applications.

TI's provision of technical, application or other design advice, quality characterization, reliability data or other services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using TI Resources in any way, Designer (individually or, if Designer is acting on behalf of a company, Designer's company) agrees to use any particular TI Resource solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

Designer is authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY DESIGNER AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

Unless TI has explicitly designated an individual product as meeting the requirements of a particular industry standard (e.g., ISO/TS 16949 and ISO 26262), TI is not responsible for any failure to meet such industry standard requirements.

Where TI specifically promotes products as facilitating functional safety or as compliant with industry functional safety standards, such products are intended to help enable customers to design and create their own applications that meet applicable functional safety standards and requirements. Using products in an application does not by itself establish any safety features in the application. Designers must ensure compliance with safety-related requirements and standards applicable to their applications. Designer may not use any TI products in life-critical medical equipment unless authorized officers of the parties have executed a special contract specifically governing such use. Life-critical medical equipment is medical equipment where failure of such equipment would cause serious bodily injury or death (e.g., life support, pacemakers, defibrillators, heart pumps, neurostimulators, and implantables). Such equipment includes, without limitation, all medical devices identified by the U.S. Food and Drug Administration as Class III devices and equivalent classifications outside the U.S.

TI may expressly designate certain products as completing a particular qualification (e.g., Q100, Military Grade, or Enhanced Product). Designers agree that it has the necessary expertise to select the product with the appropriate qualification designation for their applications and that proper product selection is at Designers' own risk. Designers are solely responsible for compliance with all legal and regulatory requirements in connection with such selection.

Designer will fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of Designer's non-compliance with the terms and provisions of this Notice.