

OPAx991 40-V Rail-to-Rail Input/Output, Low Offset Voltage, Low Noise Op Amp

1 Features

- Low offset voltage: $\pm 125 \mu\text{V}$
- Low offset voltage drift: $\pm 0.3 \mu\text{V}/^\circ\text{C}$
- Low noise: $10.8 \text{ nV}/\sqrt{\text{Hz}}$ at 1 kHz
- High common-mode rejection: 130 dB
- Low bias current: $\pm 10 \text{ pA}$
- Rail-to-rail input and output
- Wide bandwidth: 4.5 MHz GBW
- High slew rate: $21 \text{ V}/\mu\text{s}$
- High capacitive load drive: 1 nF
- MUX-friendly/comparator inputs
 - Amplifier operates with differential inputs up to supply rail
 - Amplifier can be used in open-loop or as comparator
- Low quiescent current: 560 μA per amplifier
- Wide supply: $\pm 1.35 \text{ V}$ to $\pm 20 \text{ V}$, 2.7 V to 40 V
- Robust EMIRR performance: EMI/RFI filters on input and supply pins
- Differential and common-mode input voltage range to supply rail

2 Applications

- Low-power audio preamplifier
- Multiplexed data-acquisition systems
- Test and measurement equipment
- ADC driver amplifiers
- SAR ADC reference buffers
- Programmable logic controllers
- High-side and low-side current sensing
- High precision comparator

3 Description

The OPAx991 family (OPA991, OPA2991, and OPA4991) is a family of high voltage (40-V) general purpose operational amplifiers. These devices offer exceptional DC precision and AC performance, including rail-to-rail input/output, low offset ($\pm 125 \mu\text{V}$, typ), low offset drift ($\pm 0.3 \mu\text{V}/^\circ\text{C}$, typ), low noise ($10.5 \text{ nV}/\sqrt{\text{Hz}}$ and $1.8 \mu\text{V}_{\text{PP}}$) and 4.5-MHz bandwidth.

Unique features such as differential and common-mode input-voltage range to the supply rail, high output current ($\pm 75 \text{ mA}$), high slew rate ($21 \text{ V}/\mu\text{s}$), high capacitive load drive (1 nF) and shutdown functionality make the OPAx991 a robust, high-performance operational amplifier for high-voltage industrial applications.

The OPAx991 family of op amps is available in *micro*-size packages (such as X2QFN, WSON, and SOT-553), as well as standard packages (such as SOT-23, SOIC, and TSSOP), and is specified from -40°C to 125°C .

Device Information⁽¹⁾

PART NUMBER	PACKAGE	BODY SIZE (NOM)
OPA991	SOT-23 (5) ⁽²⁾	2.90 mm x 1.60 mm
	SOT-23 (6) ⁽²⁾	2.90 mm x 1.60 mm
	SC70 (5) ⁽²⁾	2.00 mm x 1.25 mm
OPA2991	SOIC (8)	4.90 mm x 3.90 mm
	SOT-23-8 (8) ⁽²⁾	2.90 mm x 1.60 mm
	TSSOP (8)	3.00 mm x 4.40 mm
	VSSOP (8) ⁽²⁾	3.00 mm x 3.00 mm
	WSON (8)	2.00 mm x 2.00 mm
	X2QFN (10)	2.00 mm x 1.50 mm
OPA4991	SOIC (14) ⁽²⁾	8.65 mm x 3.90 mm
	TSSOP (14) ⁽²⁾	5.00 mm x 4.40 mm
	WQFN (16) ⁽²⁾	3.00 mm x 3.00 mm
	X2QFN (14) ⁽²⁾	2.00 mm x 2.00 mm

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

(2) Package is preview only.

OPAx991 in a High-Voltage, Multiplexed, Data-Acquisition System

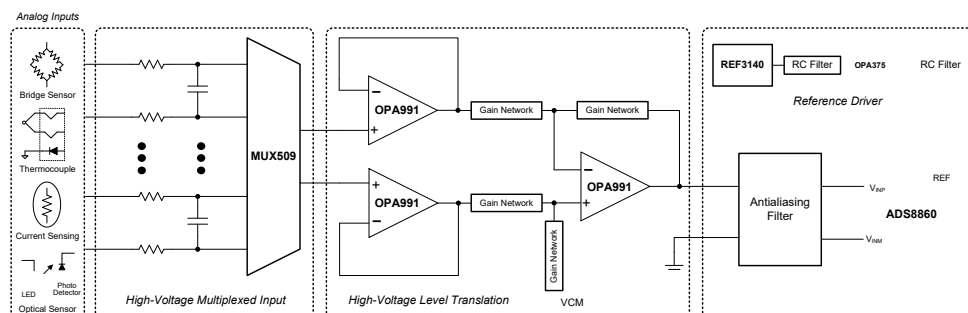


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4 Revision History

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

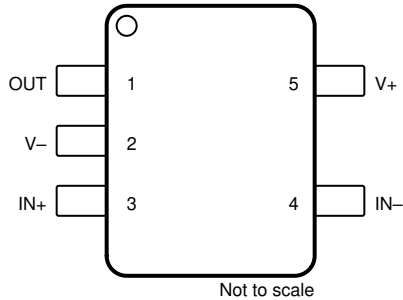
Changes from Revision B (May 2020) to Revision C	Page
Deleted preview notation from SOIC (D) package in <i>Device Information</i>	1
Removed preview notation from TSSOP (PW) package in <i>Pin Configuration and Functions</i> section	5
Removed preview notation from X2QFN (RUG) package in <i>Pin Configuration and Functions</i> section	6
Changed PW (TSSOP) and RUG (X2QFN) in <i>Thermal Information for Dual Channel</i> section	10
Added V_{IH} and V_{IL} in <i>Recommended Operating Conditions</i> Section	10
Added SHUTDOWN in <i>Electrical Characteristics</i> section	10

Changes from Revision A (December 2019) to Revision B	Page
Added OPA991 and OPA4991 devices to the data sheet.....	1
Deleted preview notation from WSON (DSG) package in <i>Device Information</i>	1
Changed X2QFN (10) dimension in <i>Device Information</i> section	1
Changed formatting of Pin Functions tables to align with data sheet standards	3
Deleted preview notation from WSON (DSG) package in <i>Pin Configuration and Functions</i> section	5
Changed DBV (SOT-23) 5 PINS, DBV (SOT-23) 6 PINS, and DCK (SC70) in <i>Thermal Information for Single Channel</i> section	10
Changed DSG (WSON) in <i>Thermal Information for Dual Channel</i> section.....	10

Changes from Original (October 2019) to Revision A	Page
Changed OPA2991 device status from <i>Advance Information</i> to <i>Production Data</i>	1
Removed preview notation from SOIC (D) package in <i>Device Information</i>	1
Removed preview notation from SOIC (D) package in <i>Pin Configuration and Functions</i> section	5
Added <i>Typical Characteristics</i> section in <i>Specifications</i> section	15
Added additional references in <i>Related Documentation</i> section.....	36

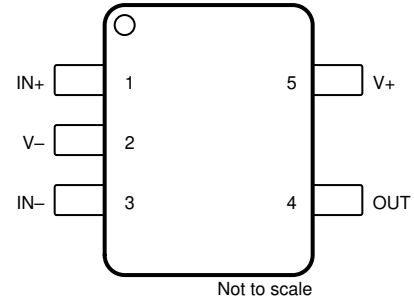
5 Pin Configuration and Functions

OPA991 DBV and DRL Package⁽¹⁾
5-Pin SOT-23 and SOT-553
Top View



(1) Package is preview only.

OPA991 DCK Package⁽¹⁾
5-Pin SC70
Top View

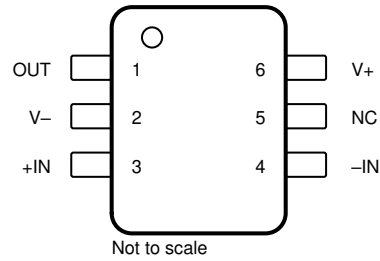


(1) Package is preview only.

Pin Functions: OPA991

PIN			I/O	DESCRIPTION
NAME	DBV, DRL	DCK		
IN+	3	1	I	Noninverting input
IN-	4	3	I	Inverting input
OUT	1	4	O	Output
V+	5	5	—	Positive (highest) power supply
V-	2	2	—	Negative (lowest) power supply

OPA991S DBV and DRL Package⁽¹⁾
6-Pin SOT-23 and SOT-563
Top View

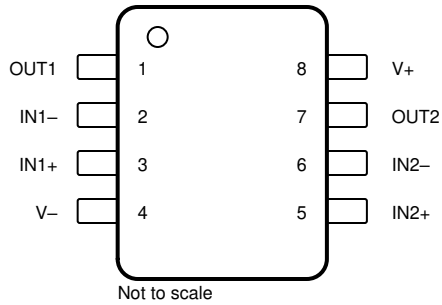


(1) Package is preview only.

Pin Functions: OPA991S

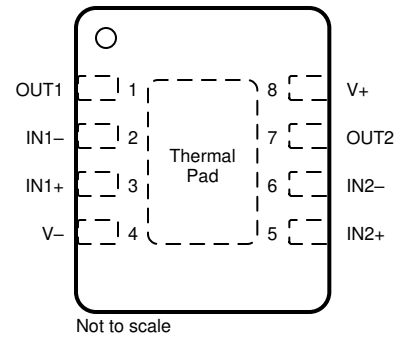
PIN		I/O	DESCRIPTION
NAME	NO.		
+IN	3	I	Noninverting input
-IN	4	I	Inverting input
OUT	1	O	Output
$\overline{\text{SHDN}}$	5	I	Shutdown (active low) logic input
V+	6	—	Positive (highest) power supply
V-	2	—	Negative (lowest) power supply

OPA2991 D, DDF, DGK, and PW Packages⁽¹⁾
8-Pin SOIC, SOT-23-8, TSSOP, and VSSOP
Top View



(1) DDF, and DGK packages are preview only.

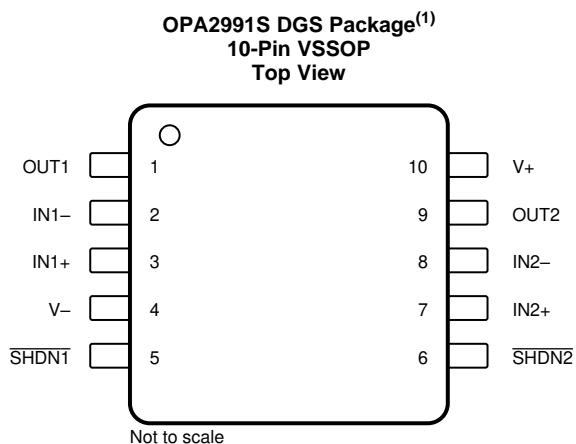
OPA2991 DSG Package⁽¹⁾
8-Pin WSON With Exposed Thermal Pad
Top View



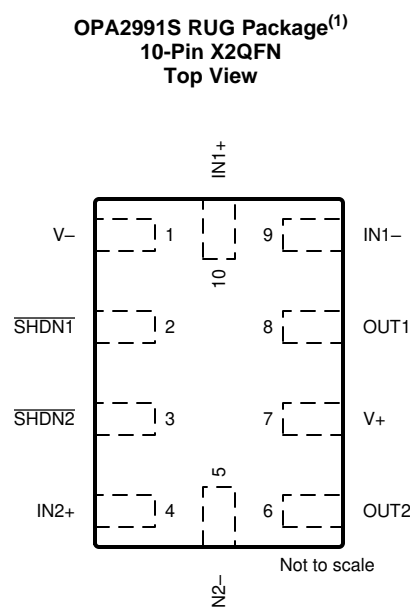
(1) Connect thermal pad to V-. See [Packages With an Exposed Thermal Pad](#) section for more information.

Pin Functions: OPA2991

PIN		I/O	DESCRIPTION
NAME	NO.		
+IN A	3	I	Noninverting input, channel A
+IN B	5	I	Noninverting input, channel B
–IN A	2	I	Inverting input, channel A
–IN B	6	I	Inverting input, channel B
OUT A	1	O	Output, channel A
OUT B	7	O	Output, channel B
V+	8	—	Positive (highest) power supply
V–	4	—	Negative (lowest) power supply



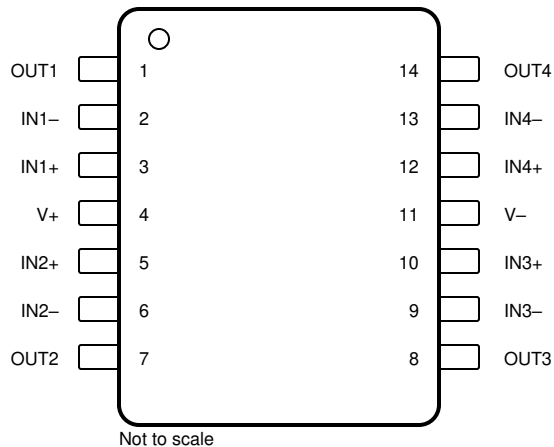
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Pin Functions: OPA2991S

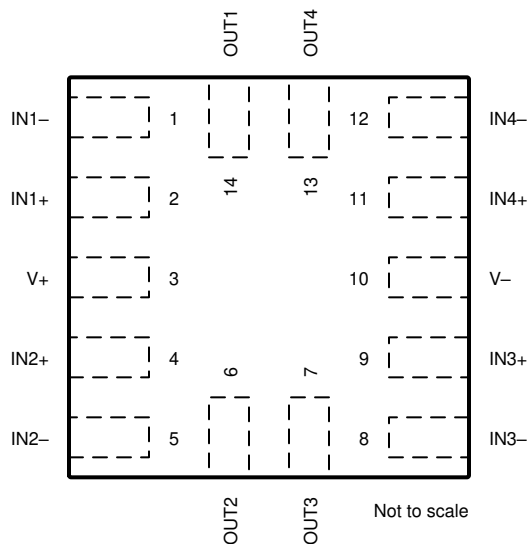
PIN			I/O	DESCRIPTION
NAME	VSSOP	X2QFN		
+IN A	3	10	I	Noninverting input, channel A
+IN B	7	4	I	Noninverting input, channel B
–IN A	2	9	I	Inverting input, channel A
–IN B	8	5	I	Inverting input, channel B
OUT A	1	8	O	Output, channel A
OUT B	9	6	O	Output, channel B
$\overline{\text{SHDN}}1$	5	2	I	Shutdown, channel 1: low = amplifier enabled, high = amplifier disabled. See Shutdown section for more information.
$\overline{\text{SHDN}}2$	6	3	I	Shutdown, channel 2: low = amplifier enabled, high = amplifier disabled. See Shutdown section for more information.
V+	10	7	—	Positive (highest) power supply
V–	4	1	—	Negative (lowest) power supply

OPA4991 D and PW Packages⁽¹⁾
14-Pin SOIC and TSSOP
Top View



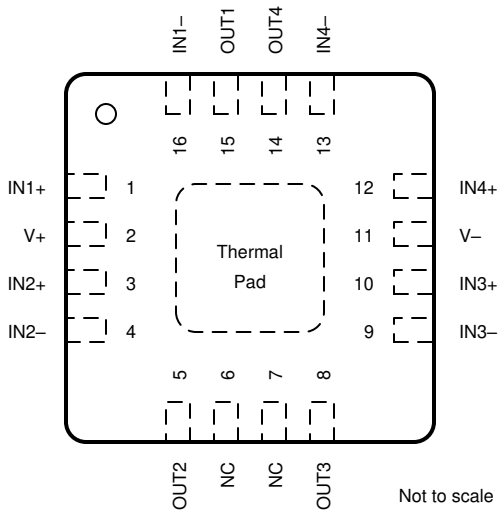
(1) Package is preview only.

OPA4991 RUC Packages⁽¹⁾
14-Pin WQFN With Exposed Thermal Pad
Top View



(1) Package is preview only.

OPA4991 RTE Package⁽¹⁾⁽²⁾
16-Pin WQFN With Exposed Thermal Pad
Top View



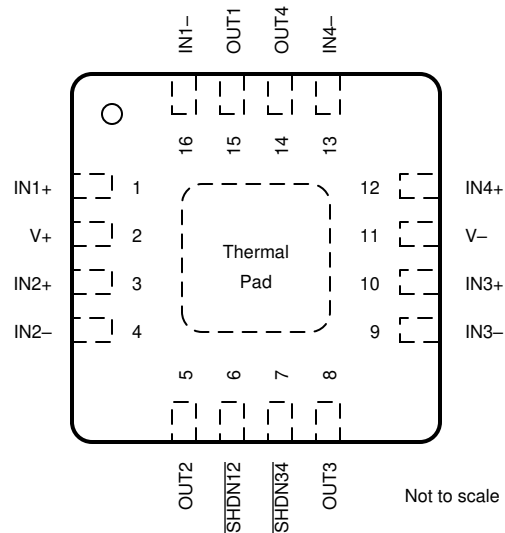
(1) Connect thermal pad to V-. See [Packages With an Exposed Thermal Pad](#) section for more information.

(2) Package is preview only.

Pin Functions: OPA4991

PIN			I/O	DESCRIPTION
NAME	SOIC, TSSOP	WQFN		
IN1+	3	1	I	Noninverting input, channel 1
IN1–	2	16	I	Inverting input, channel 1
IN2+	5	3	I	Noninverting input, channel 2
IN2–	6	4	I	Inverting input, channel 2
IN3+	10	10	I	Noninverting input, channel 3
IN3–	9	9	I	Inverting input, channel 3
IN4+	12	12	I	Noninverting input, channel 4
IN4–	13	13	I	Inverting input, channel 4
NC	—	6, 7	—	Do not connect
OUT1	1	15	O	Output, channel 1
OUT2	7	5	O	Output, channel 2
OUT3	8	8	O	Output, channel 3
OUT4	14	14	O	Output, channel 4
V+	4	2	—	Positive (highest) power supply
V–	11	11	—	Negative (lowest) power supply

**OPA4991S RTE Package⁽¹⁾
16-Pin WQFN With Exposed Thermal Pad
Top View**



(1) Package is preview only.

Pin Functions: OPA4991S

PIN		I/O	DESCRIPTION
NAME	NO.		
IN1+	1	I	Noninverting input, channel 1
IN1–	16	I	Inverting input, channel 1
IN2+	3	I	Noninverting input, channel 2
IN2–	4	I	Inverting input, channel 2
IN3+	10	I	Noninverting input, channel 3
IN3–	9	I	Inverting input, channel 3
IN4+	12	I	Noninverting input, channel 4
IN4–	13	I	Inverting input, channel 4
OUT1	15	O	Output, channel 1
OUT2	5	O	Output, channel 2
OUT3	8	O	Output, channel 3
OUT4	14	O	Output, channel 4
SHDN12	6	I	Shutdown (active low), channel 1 & 2, logic input
SHDN34	7	I	Shutdown (active low), channel 3 & 4, logic input
VCC+	2	—	Positive (highest) power supply
VCC–	11	—	Negative (lowest) power supply

6 Specifications

6.1 Absolute Maximum Ratings

over operating ambient temperature range (unless otherwise noted) ⁽¹⁾

		MIN	MAX	UNIT
Supply voltage, $V_S = (V+) - (V-)$		0	42	V
Signal input pins	Common-mode voltage ⁽²⁾	$(V-) - 0.5$	$(V+) + 0.5$	V
	Differential voltage ⁽²⁾		$V_S + 0.2$	V
	Current ⁽²⁾	-10	10	mA
Output short-circuit ⁽³⁾		Continuous		
Operating ambient temperature, T_A		-55	150	°C
Junction temperature, T_J			150	°C
Storage temperature, T_{stg}		-65	150	°C

- (1) Operating the device beyond the ratings listed under *Absolute Maximum Ratings* will cause permanent damage to the device. These are stress ratings only, based on process and design limitations, and this device has not been designed to function outside the conditions indicated under *Recommended Operating Conditions*. Exposure to any condition outside *Recommended Operating Conditions* for extended periods, including absolute-maximum-rated conditions, may affect device reliability and performance.
- (2) Input pins are diode-clamped to the power-supply rails. Input signals that may swing more than 0.5 V beyond the supply rails must be current limited to 10 mA or less.
- (3) Short-circuit to ground, one amplifier per package. This device has been designed to limit *electrical* damage due to excessive output current, but extended short-circuit current, especially with higher supply voltage, can cause excessive heating and eventual *thermal* destruction. See the [Thermal Protection](#) section for more information.

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 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 ambient temperature range (unless otherwise noted)

		MIN	MAX	UNIT
V_S	Supply voltage, $(V+) - (V-)$	2.7	40	V
V_I	Input voltage range	$(V-) - 0.1$	$(V+) + 0.1$	V
V_{IH}	High level input voltage at shutdown pin (amplifier enabled)	1.1	$(V+)$	V
V_{IL}	Low level input voltage at shutdown pin (amplifier disabled)	$(V-)$	0.2	V
T_A	Specified temperature	-40	125	°C

6.4 Thermal Information for Single Channel

THERMAL METRIC ⁽¹⁾		OPA991, OPA991S					UNIT
		DBV ⁽²⁾ (SOT-23)		DCK ⁽²⁾ (SC70)	DRL ⁽²⁾ (SOT-553)		
		5 PINS	6 PINS	5 PINS	5 PINS	6 PINS	
R _{θJA}	Junction-to-ambient thermal resistance	185.7	167.8	202.6	TBD	TBD	°C/W
R _{θJC(top)}	Junction-to-case (top) thermal resistance	108.2	107.9	101.5	TBD	TBD	°C/W
R _{θJB}	Junction-to-board thermal resistance	54.5	49.7	47.8	TBD	TBD	°C/W
Ψ _{JT}	Junction-to-top characterization parameter	31.2	33.9	18.8	TBD	TBD	°C/W
Ψ _{JB}	Junction-to-board characterization parameter	54.2	49.5	47.4	TBD	TBD	°C/W
R _{θJC(bot)}	Junction-to-case (bottom) thermal resistance	N/A	N/A	N/A	TBD	TBD	°C/W

- (1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, [SPRA953](#).
- (2) This package option is preview for OPA991.

6.5 Thermal Information for Dual Channel

THERMAL METRIC ⁽¹⁾		OPA2991, OPA2991S							UNIT
		D ⁽²⁾ (SOIC)	DDF ⁽²⁾ (SOT-23-8)	DGK ⁽²⁾ (VSSOP)	DGS ⁽²⁾ (VSSOP)	DSG (WSON)	PW (TSSOP)	RUG (X2QFN)	
		8 PINS	8 PINS	8 PINS	10 PINS	8 PINS	8 PINS	10 PINS	
R _{θJA}	Junction-to-ambient thermal resistance	130.7	TBD	TBD	TBD	77.6	185.1	142.3	°C/W
R _{θJC(top)}	Junction-to-case (top) thermal resistance	72.8	TBD	TBD	TBD	93.7	74.0	53.5	°C/W
R _{θJB}	Junction-to-board thermal resistance	74.0	TBD	TBD	TBD	43.9	115.7	68.5	°C/W
ψ _{JT}	Junction-to-top characterization parameter	24.0	TBD	TBD	TBD	4.4	12.3	1.0	°C/W
ψ _{JB}	Junction-to-board characterization parameter	73.3	TBD	TBD	TBD	43.9	114.0	68.4	°C/W
R _{θJC(bot)}	Junction-to-case (bottom) thermal resistance	N/A	TBD	TBD	TBD	19.0	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, [SPRA953](#).
- (2) This package option is preview for OPA2991.

6.6 Thermal Information for Quad Channel

THERMAL METRIC ⁽¹⁾		OPA4991, OPA4991S					UNIT
		D ⁽²⁾ (SOIC)	PW ⁽²⁾ (TSSOP)		RTE ⁽²⁾ (WQFN)	RUC ⁽²⁾ (WQFN)	
		14 PINS	14 PINS	16 PINS	16 PINS	14 PINS	
R _{θJA}	Junction-to-ambient thermal resistance	TBD	TBD	TBD	TBD	TBD	°C/W
R _{θJC(top)}	Junction-to-case (top) thermal resistance	TBD	TBD	TBD	TBD	TBD	°C/W
R _{θJB}	Junction-to-board thermal resistance	TBD	TBD	TBD	TBD	TBD	°C/W
ψ _{JT}	Junction-to-top characterization parameter	TBD	TBD	TBD	TBD	TBD	°C/W
ψ _{JB}	Junction-to-board characterization parameter	TBD	TBD	TBD	TBD	TBD	°C/W
R _{θJC(bot)}	Junction-to-case (bottom) thermal resistance	TBD	TBD	TBD	TBD	TBD	°C/W

- (1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, [SPRA953](#).
- (2) This package option is preview for OPA4991.

6.7 Electrical Characteristics

For $V_S = (V_+) - (V_-) = 2.7\text{ V to }40\text{ V}$ ($\pm 1.35\text{ V to } \pm 20\text{ V}$) at $T_A = 25^\circ\text{C}$, $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$, $V_{CM} = V_S / 2$, and $V_{OUT} = V_S / 2$, unless otherwise noted.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OFFSET VOLTAGE							
V _{OS}	Input offset voltage	V _{CM} = V−		±125	±750	μV	
			T _A = −40°C to 125°C		±780		
dV _{OS} /dT	Input offset voltage drift		T _A = −40°C to 125°C	±0.3		μV/°C	
PSRR	Input offset voltage versus power supply	V _{CM} = V−, V _S = 4 V to 40 V	T _A = −40°C to 125°C	±0.3	±1	μV/V	
		V _{CM} = V−, V _S = 2.7 V to 40 V ⁽¹⁾		±1	±5		
	Channel separation	f = 0 Hz		5		μV/V	
INPUT BIAS CURRENT							
I _B	Input bias current			±10		pA	
I _{OS}	Input offset current			±10		pA	
NOISE							
E _N	Input voltage noise	f = 0.1 Hz to 10 Hz		1.8		μV _{PP}	
				0.3		μV _{RMS}	
e _N	Input voltage noise density	f = 1 kHz		10.8		nV/√Hz	
		f = 10 kHz		9.4			
i _N	Input current noise	f = 1 kHz		2		fA/√Hz	
INPUT VOLTAGE RANGE							
V _{CM}	Common-mode voltage range			(V−) − 0.1	(V+) + 0.1	V	
CMRR	Common-mode rejection ratio	V _S = 40 V, (V−) − 0.1 V < V _{CM} < (V+) − 2 V (Main input pair)	T _A = −40°C to 125°C	109	130	dB	
		V _S = 4 V, (V−) − 0.1 V < V _{CM} < (V+) − 2 V (Main input pair)		84	100		
		V _S = 2.7 V, (V−) − 0.1 V < V _{CM} < (V+) − 2 V (Main input pair) ⁽¹⁾		75	95		
		V _S = 2.7 V to 40 V, (V+) − 1 V < V _{CM} < (V+) + 0.1 V (Aux input pair)			85		
INPUT CAPACITANCE							
Z _{ID}	Differential			100 9		MΩ pF	
Z _{ICM}	Common-mode			6 1		TΩ pF	
OPEN-LOOP GAIN							
A _{OL}	Open-loop voltage gain	V _S = 40 V, V _{CM} = V− (V−) + 0.1 V < V _O < (V+) − 0.1 V		120	145	dB	
			T _A = −40°C to 125°C		142		
		V _S = 4 V, V _{CM} = V− (V−) + 0.1 V < V _O < (V+) − 0.1 V		104	130		
			T _A = −40°C to 125°C		125		
		V _S = 2.7 V, V _{CM} = V− (V−) + 0.1 V < V _O < (V+) − 0.1 V ⁽¹⁾		101	120		
			T _A = −40°C to 125°C		118		

(1) Specified by characterization only.

Electrical Characteristics (continued)

For $V_S = (V_+ - V_-) = 2.7\text{ V to }40\text{ V}$ ($\pm 1.35\text{ V to } \pm 20\text{ V}$) at $T_A = 25^\circ\text{C}$, $R_L = 10\text{ k}\Omega$ connected to $V_S / 2$, $V_{CM} = V_S / 2$, and $V_{OUT} = V_S / 2$, unless otherwise noted.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
FREQUENCY RESPONSE							
GBW	Gain-bandwidth product			4.5			MHz
SR	Slew rate	$V_S = 40\text{ V}$, $G = +1$, $C_L = 20\text{ pF}$		21			V/ μs
t_S	Settling time	To 0.01%, $V_S = 40\text{ V}$, $V_{STEP} = 10\text{ V}$, $G = +1$, $CL = 20\text{ pF}$		2.5		μs	
		To 0.01%, $V_S = 40\text{ V}$, $V_{STEP} = 2\text{ V}$, $G = +1$, $CL = 20\text{ pF}$		1.5			
		To 0.1%, $V_S = 40\text{ V}$, $V_{STEP} = 10\text{ V}$, $G = +1$, $CL = 20\text{ pF}$		2			
		To 0.1%, $V_S = 40\text{ V}$, $V_{STEP} = 2\text{ V}$, $G = +1$, $CL = 20\text{ pF}$		1			
	Phase margin	$G = +1$, $R_L = 10\text{ k}\Omega$		60			°
	Overload recovery time	$V_{IN} \times \text{gain} > V_S$		400			ns
THD+N	Total harmonic distortion + noise	$V_S = 40\text{ V}$, $V_O = 3\text{ V}_{RMS}$, $G = 1$, $f = 1\text{ kHz}$		0.00021%			
OUTPUT							
	Voltage output swing from rail	Positive and negative rail headroom	$V_S = 40\text{ V}$, $R_L = \text{no load}^{(1)}$	5	10	mV	
			$V_S = 40\text{ V}$, $R_L = 10\text{ k}\Omega$	50	55		
			$V_S = 40\text{ V}$, $R_L = 2\text{ k}\Omega$	200	250		
			$V_S = 2.7\text{ V}$, $R_L = \text{no load}^{(1)}$	1	6		
			$V_S = 2.7\text{ V}$, $R_L = 10\text{ k}\Omega$	5	12		
			$V_S = 2.7\text{ V}$, $R_L = 2\text{ k}\Omega$	25	40		
I_{SC}	Short-circuit current			± 75			mA
C_{LOAD}	Capacitive load drive			1000			pF
Z_O	Open-loop output impedance	$f = 1\text{ MHz}$, $I_O = 0\text{ A}$		525			Ω
POWER SUPPLY							
I_Q	Quiescent current per amplifier	$V_{CM} = V_-$, $I_O = 0\text{ A}$		560	685	μA	
			$T_A = -40^\circ\text{C to }125^\circ\text{C}$		750		
SHUTDOWN							
I_{QSD}	Quiescent current per amplifier	$V_S = 2.7\text{ V to }40\text{ V}$, all amplifiers disabled, $\overline{\text{SHDN}} = V_-$		30	45	μA	
Z_{SHDN}	Output impedance during shutdown	$V_S = 2.7\text{ V to }40\text{ V}$, amplifier disabled		$10\parallel 2$		$\text{G}\Omega\parallel\text{pF}$	
V_{IH}	Logic high threshold voltage (amplifier enabled)			$(V_-) + 1.1$		V	
V_{IL}	Logic low threshold voltage (amplifier disabled)			$(V_-) + 0.2$		V	
t_{ON}	Amplifier enable time ⁽²⁾	$G = +1$, $V_{CM} = V_-$, $V_O = 0.1 \times V_S/2$		8		μs	
t_{OFF}	Amplifier disable time ⁽²⁾	$V_{CM} = V_-$, $V_O = V_S/2$		3		μs	
	$\overline{\text{SHDN}}$ pin input bias current (per pin)	$V_S = 2.7\text{ V to }40\text{ V}$, $(V_+) \geq \overline{\text{SHDN}} \geq (V_-) + 0.9\text{ V}$		500		nA	
		$V_S = 2.7\text{ V to }40\text{ V}$, $(V_-) \leq \overline{\text{SHDN}} \leq (V_-) + 0.7\text{ V}$		150			

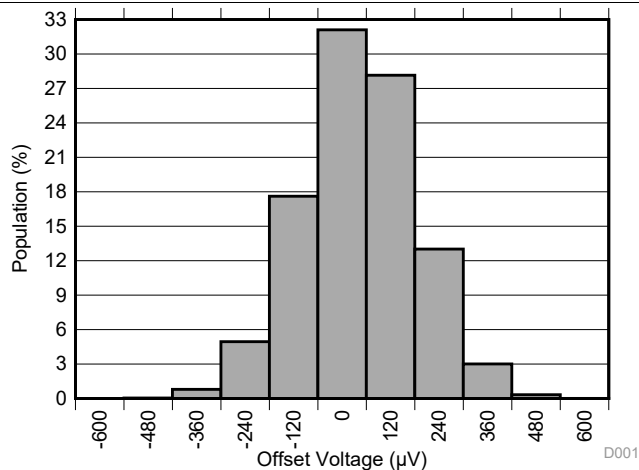
(2) Disable time (t_{OFF}) and enable time (t_{ON}) are defined as the time interval between the 50% point of the signal applied to the $\overline{\text{SHDN}}$ pin and the point at which the output voltage reaches the 10% (disable) or 90% (enable) level.

Table 1. Table of Graphs

DESCRIPTION	FIGURE
Offset Voltage Production Distribution	Figure 1
Offset Voltage Drift Distribution	Figure 2
Offset Voltage vs Temperature	Figure 3, Figure 4
Offset Voltage vs Common-Mode Voltage	Figure 5, Figure 6, Figure 7, Figure 8
Offset Voltage vs Power Supply	Figure 9
Open-Loop Gain and Phase vs Frequency	Figure 10
Closed-Loop Gain and Phase vs Frequency	Figure 11
Input Bias Current vs Common-Mode Voltage	Figure 12
Input Bias Current vs Temperature	Figure 13
Output Voltage Swing vs Output Current	Figure 14, Figure 15
CMRR and PSRR vs Frequency	Figure 16
CMRR vs Temperature	Figure 17
PSRR vs Temperature	Figure 18
0.1-Hz to 10-Hz Noise	Figure 19
Input Voltage Noise Spectral Density vs Frequency	Figure 20
THD+N Ratio vs Frequency	Figure 21
THD+N vs Output Amplitude	Figure 22
Quiescent Current vs Supply Voltage	Figure 23
Quiescent Current vs Temperature	Figure 24
Open Loop Voltage Gain vs Temperature	Figure 25
Open Loop Output Impedance vs Frequency	Figure 26
Small Signal Overshoot vs Capacitive Load (100-mV Output Step)	Figure 27, Figure 28
Phase Margin vs Capacitive Load	Figure 29
No Phase Reversal	Figure 30
Positive Overload Recovery	Figure 31
Negative Overload Recovery	Figure 32
Small-Signal Step Response (100 mV)	Figure 33, Figure 34
Large-Signal Step Response	Figure 35, Figure 36, Figure 37
Short-Circuit Current vs Temperature	Figure 38
Maximum Output Voltage vs Frequency	Figure 39
Channel Separation vs Frequency	Figure 40
EMIRR vs Frequency	Figure 41

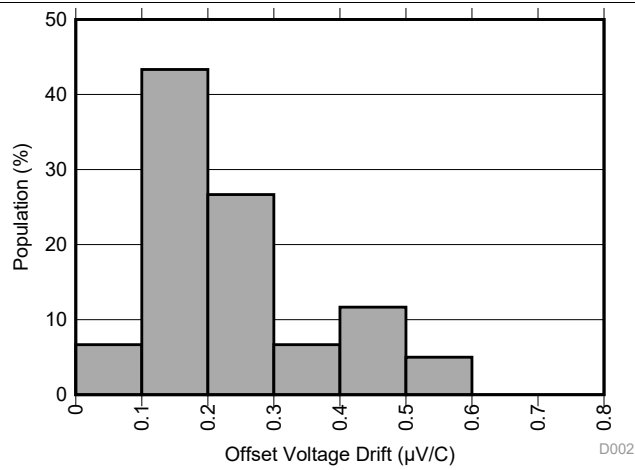
6.8 Typical Characteristics

at $T_A = 25^\circ\text{C}$, $V_S = \pm 20\text{ V}$, $V_{CM} = V_S / 2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 10\text{ pF}$ (unless otherwise noted)



Distribution from 15462 amplifiers, $T_A = 25^\circ\text{C}$

Figure 1. Offset Voltage Production Distribution



Distribution from 60 amplifiers

Figure 2. Offset Voltage Drift Distribution

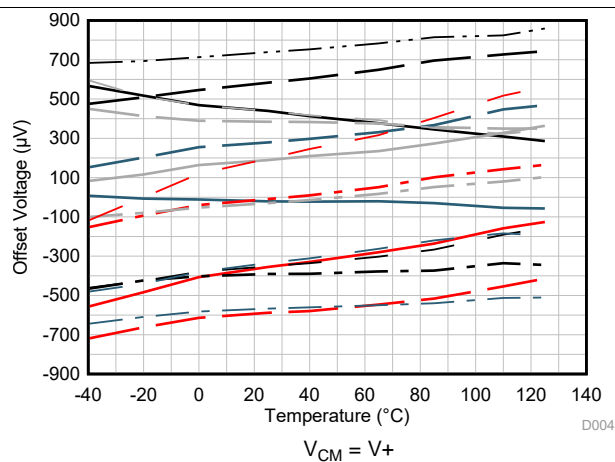


Figure 3. Offset Voltage vs Temperature

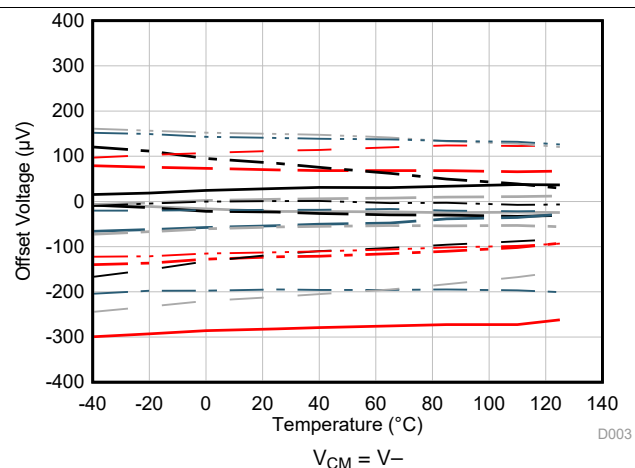


Figure 4. Offset Voltage vs Temperature

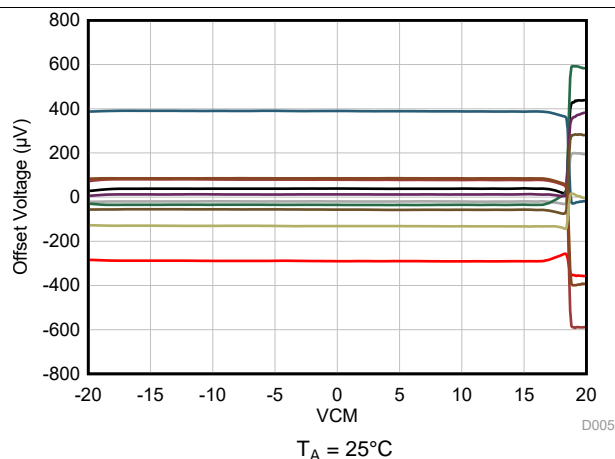


Figure 5. Offset Voltage vs Common-Mode Voltage

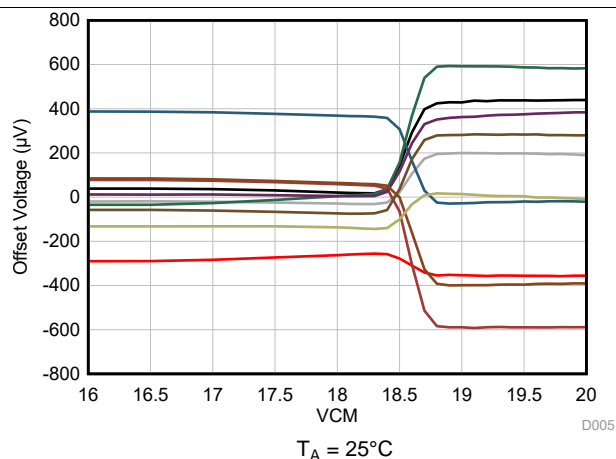


Figure 6. Offset Voltage vs Common-Mode Voltage (Transition Region)

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 20\text{ V}$, $V_{CM} = V_S / 2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 10\text{ pF}$ (unless otherwise noted)

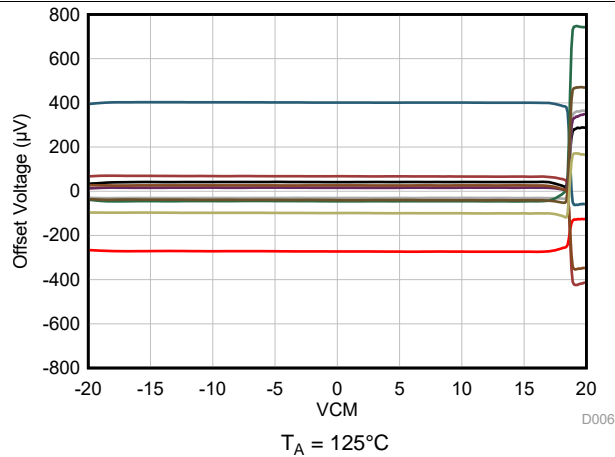


Figure 7. Offset Voltage vs Common-Mode Voltage

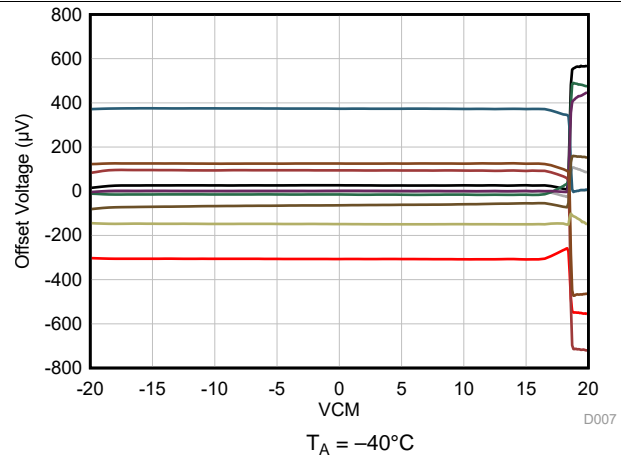


Figure 8. Offset Voltage vs Common-Mode Voltage

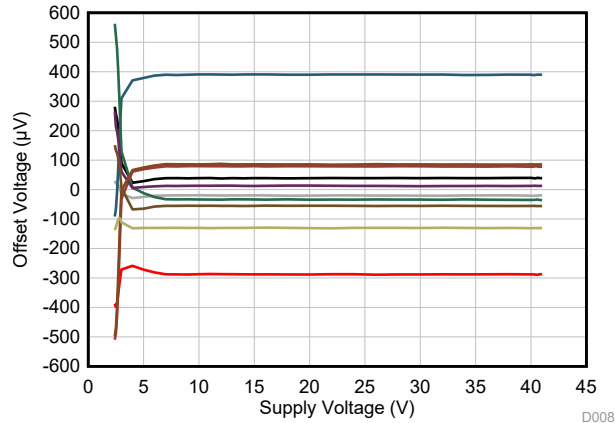


Figure 9. Offset Voltage vs Power Supply

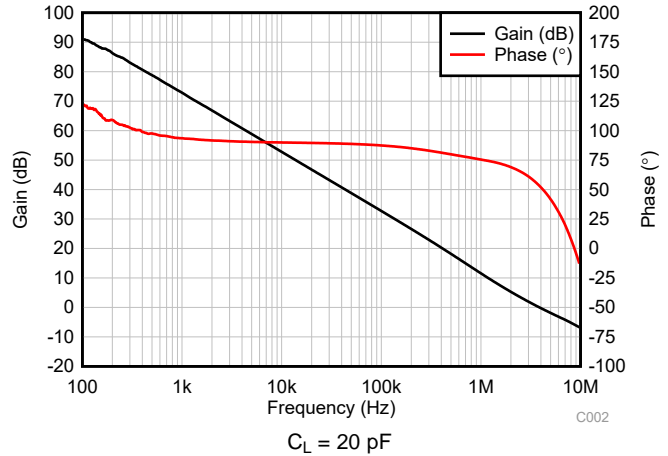


Figure 10. Open-Loop Gain and Phase vs Frequency

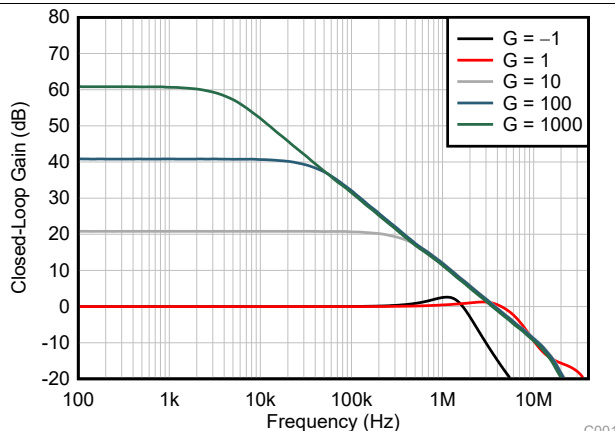


Figure 11. Closed-Loop Gain vs Frequency

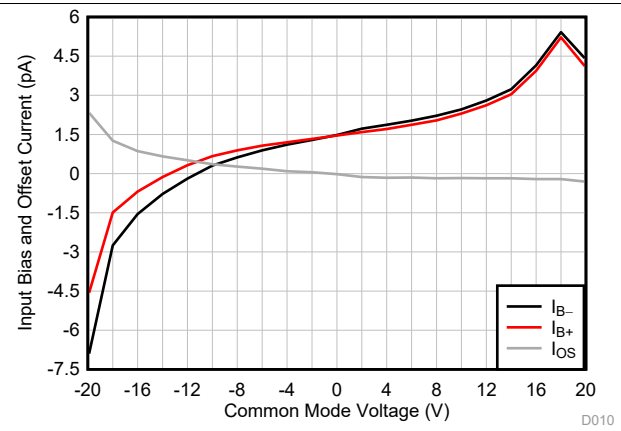


Figure 12. Input Bias Current vs Common-Mode Voltage

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 20\text{ V}$, $V_{CM} = V_S / 2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 10\text{ pF}$ (unless otherwise noted)

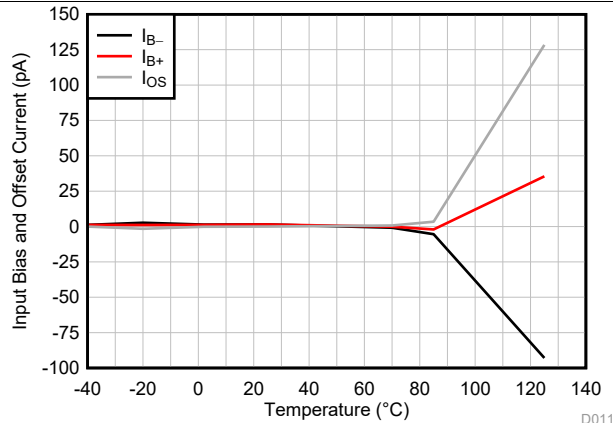


Figure 13. Input Bias Current vs Temperature

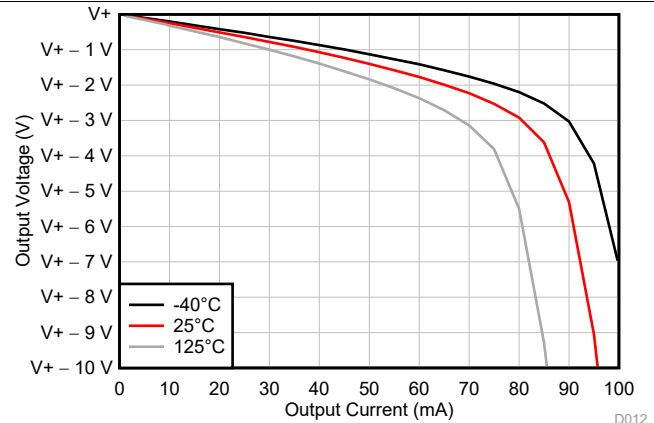


Figure 14. Output Voltage Swing vs Output Current (Sourcing)

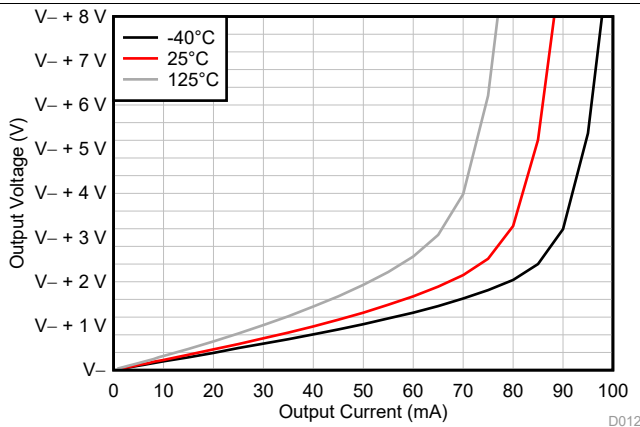


Figure 15. Output Voltage Swing vs Output Current (Sinking)

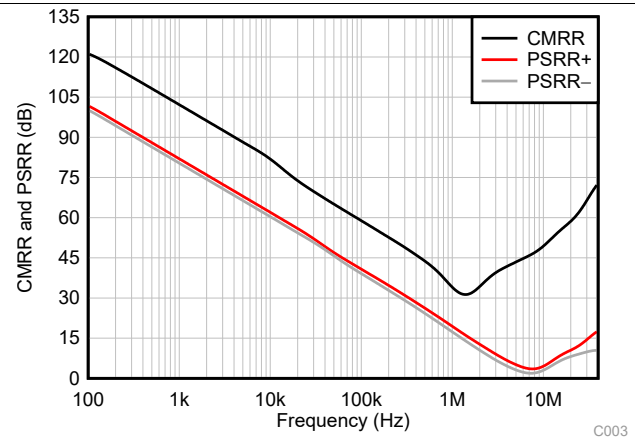


Figure 16. CMRR and PSRR vs Frequency

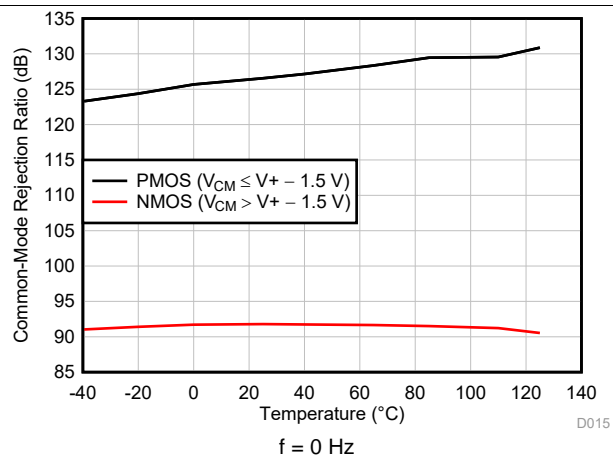


Figure 17. CMRR vs Temperature (dB)

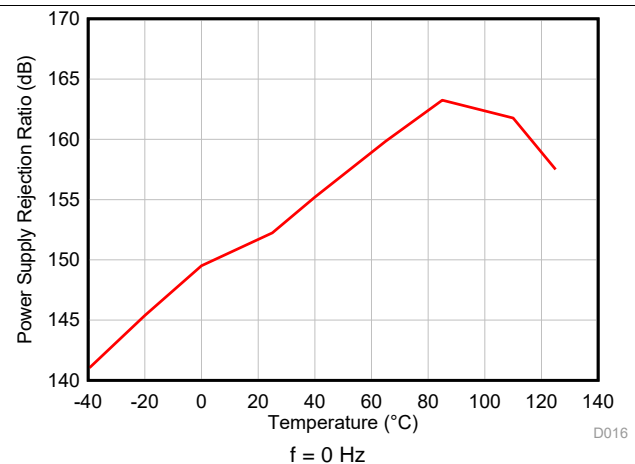


Figure 18. PSRR vs Temperature (dB)

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 20\text{ V}$, $V_{CM} = V_S / 2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 10\text{ pF}$ (unless otherwise noted)

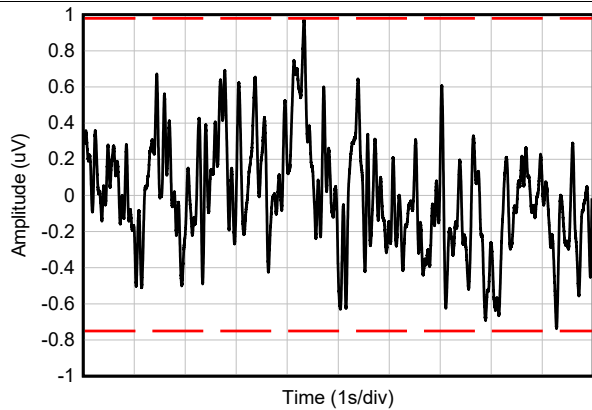


Figure 19. 0.1-Hz to 10-Hz Noise

C019

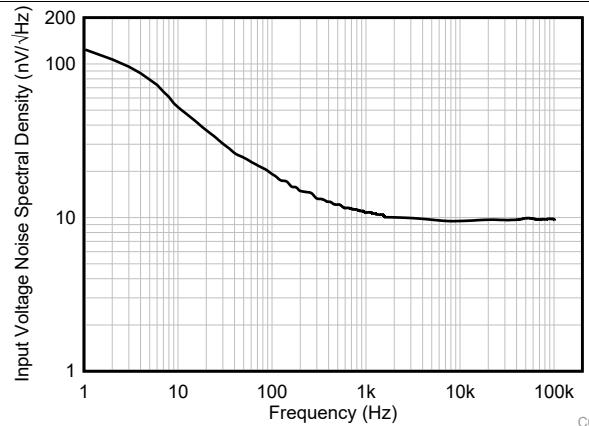


Figure 20. Input Voltage Noise Spectral Density vs Frequency

C017

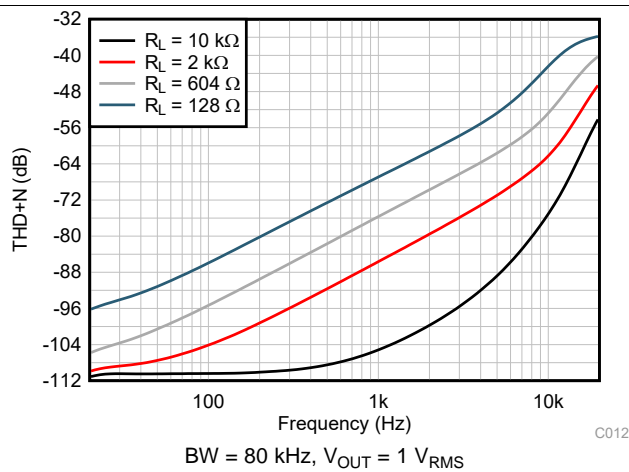


Figure 21. THD+N Ratio vs Frequency

C012

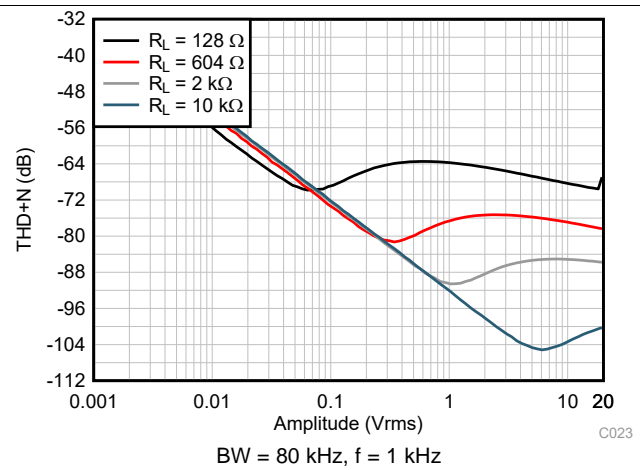


Figure 22. THD+N vs Output Amplitude

C023

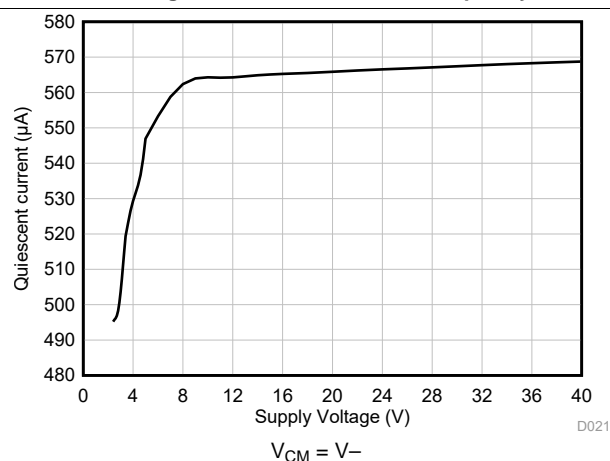


Figure 23. Quiescent Current vs Supply Voltage

D021

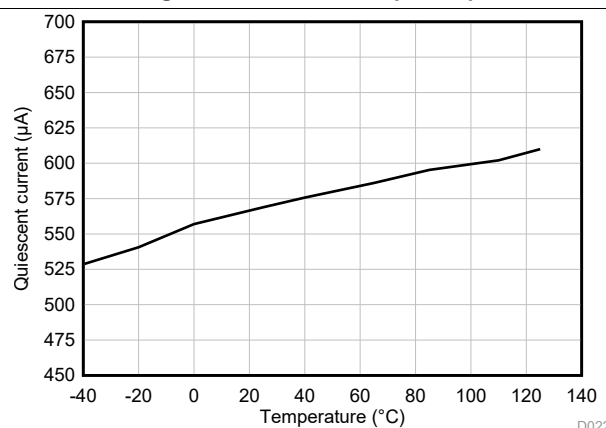


Figure 24. Quiescent Current vs Temperature

D022

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 20\text{ V}$, $V_{CM} = V_S / 2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 10\text{ pF}$ (unless otherwise noted)

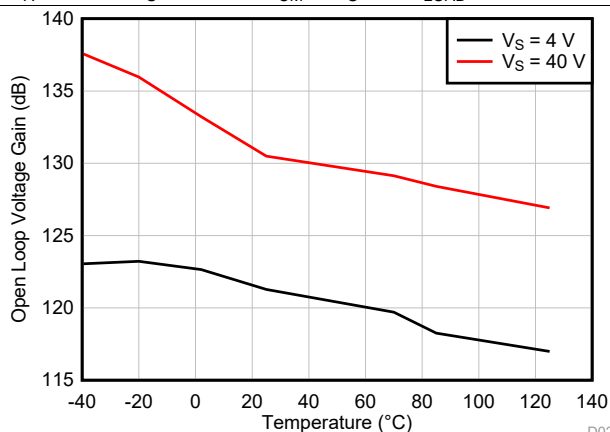


Figure 25. Open-Loop Voltage Gain vs Temperature (dB)

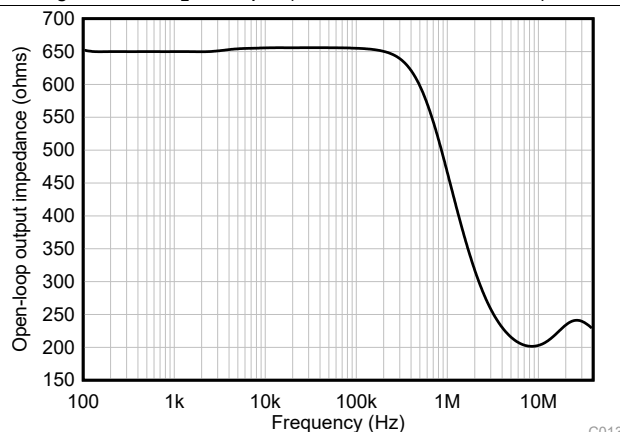


Figure 26. Open-Loop Output Impedance vs Frequency

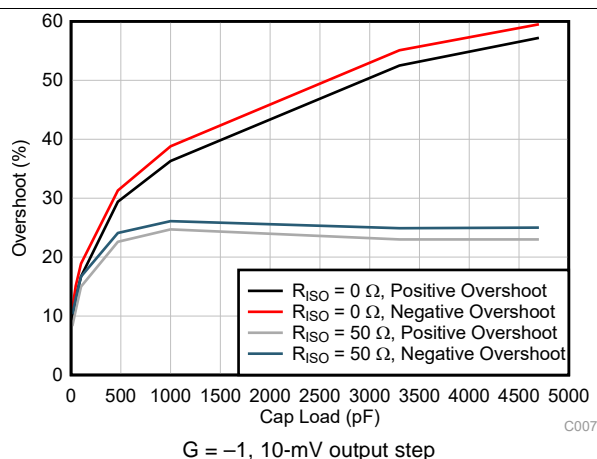


Figure 27. Small-Signal Overshoot vs Capacitive Load

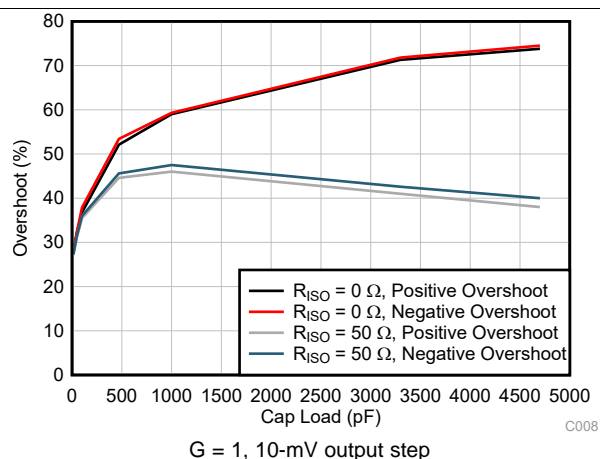


Figure 28. Small-Signal Overshoot vs Capacitive Load

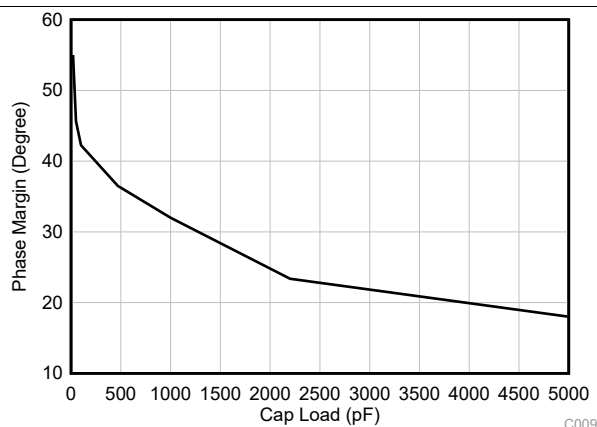
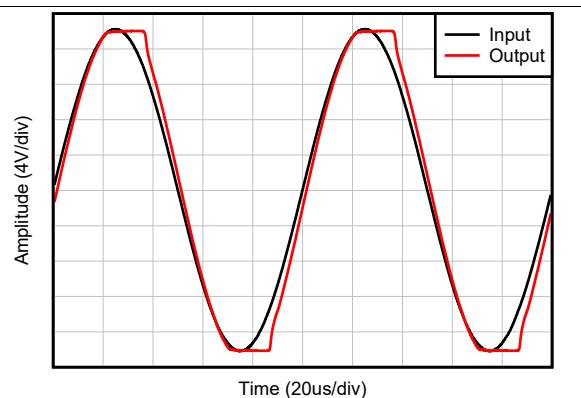


Figure 29. Phase Margin vs Capacitive Load



$V_{IN} = \pm 20\text{ V}$; $V_S = V_{OUT} = \pm 17\text{ V}$

Figure 30. No Phase Reversal

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 20\text{ V}$, $V_{CM} = V_S / 2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 10\text{ pF}$ (unless otherwise noted)

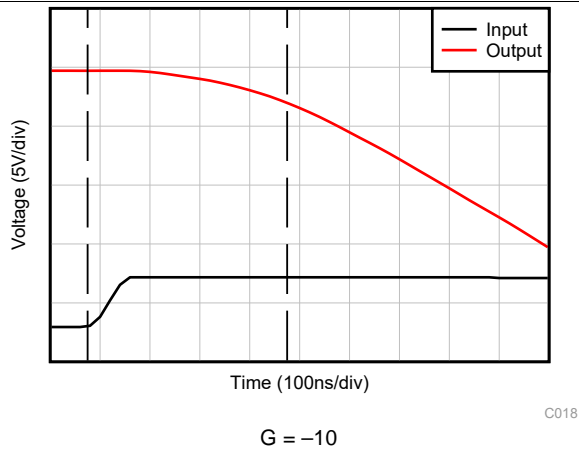


Figure 31. Positive Overload Recovery

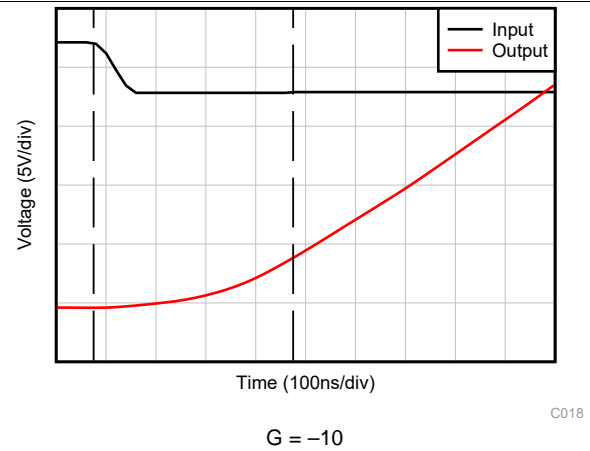


Figure 32. Negative Overload Recovery

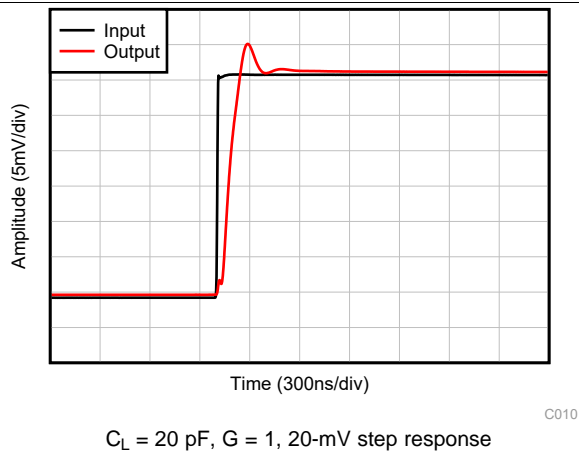


Figure 33. Small-Signal Step Response, Rising

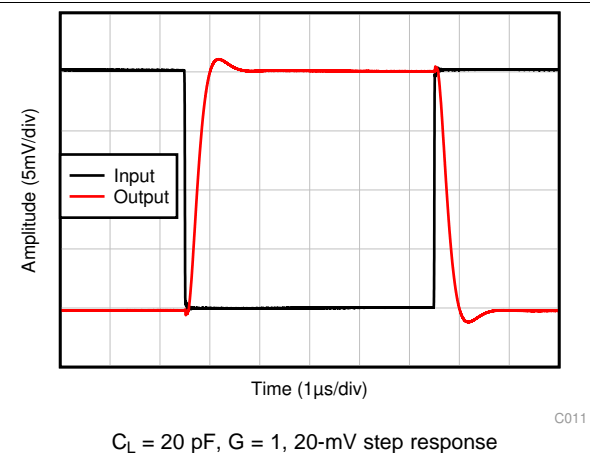


Figure 34. Small-Signal Step Response, Falling

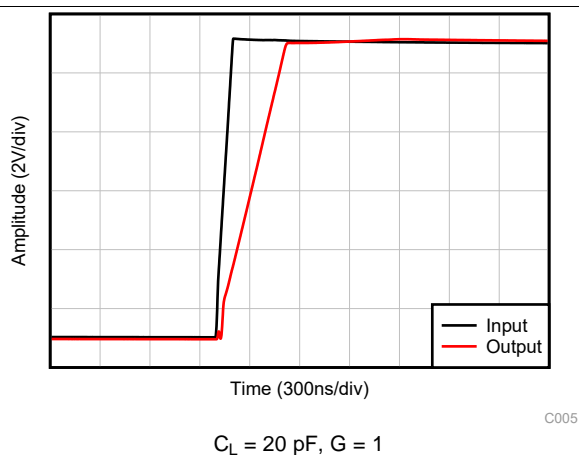


Figure 35. Large-Signal Step Response (Rising)

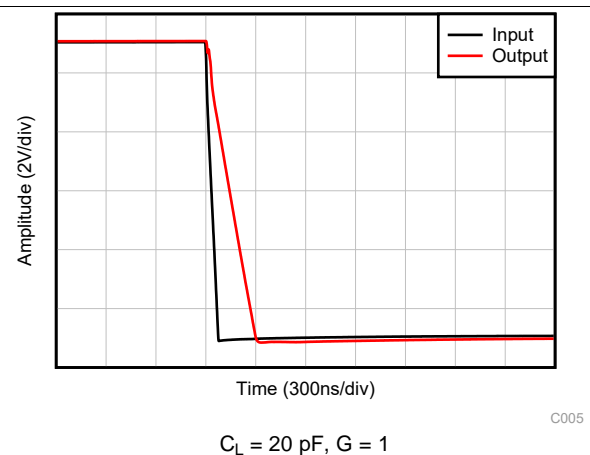
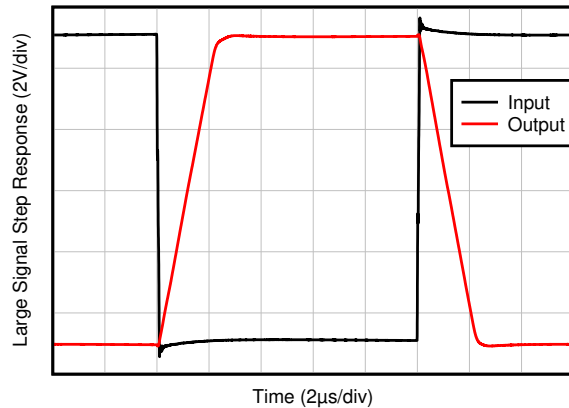


Figure 36. Large-Signal Step Response (Falling)

Typical Characteristics (continued)

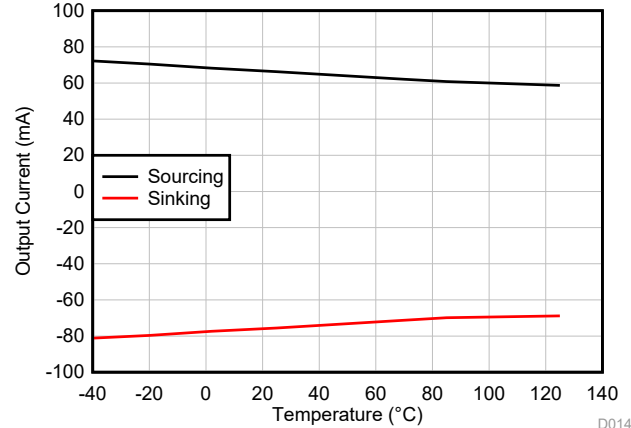
at $T_A = 25^\circ\text{C}$, $V_S = \pm 20\text{ V}$, $V_{CM} = V_S / 2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S / 2$, and $C_L = 10\text{ pF}$ (unless otherwise noted)



$C_L = 20\text{ pF}$, $G = -1$

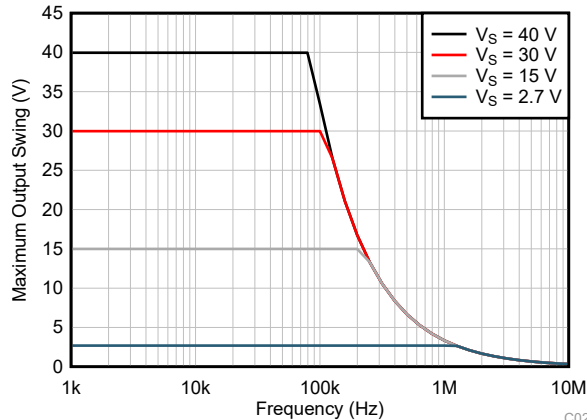
C021

Figure 37. Large-Signal Step Response



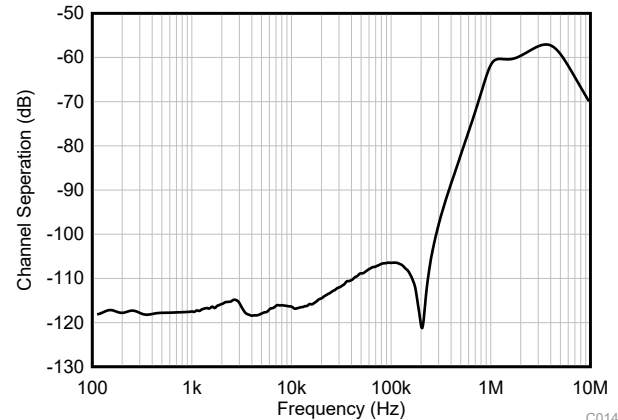
D014

Figure 38. Short-Circuit Current vs Temperature



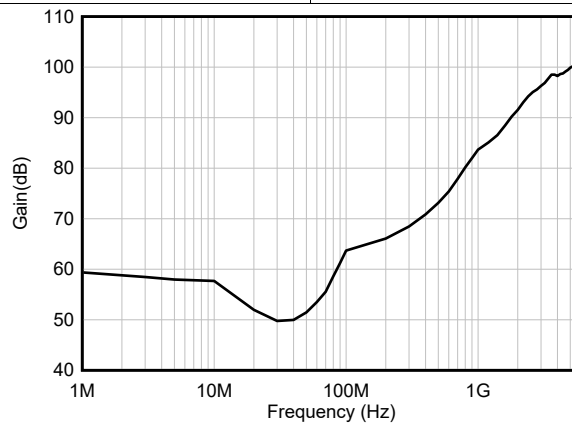
C020

Figure 39. Maximum Output Voltage vs Frequency



C014

Figure 40. Channel Separation vs Frequency



C004

Figure 41. EMIRR (Electromagnetic Interference Rejection Ratio) vs Frequency

7 Detailed Description

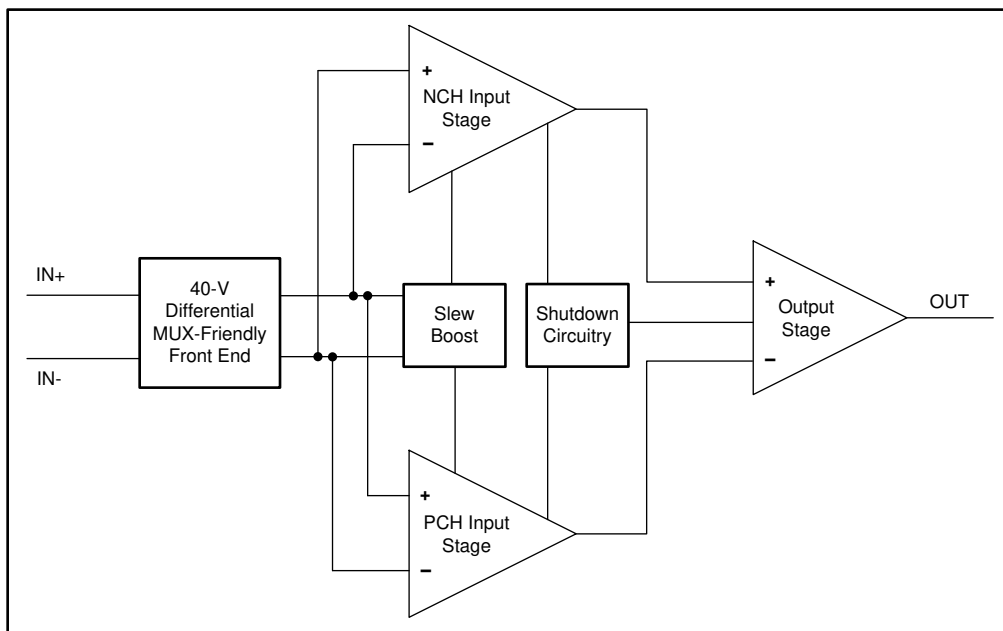
7.1 Overview

The OPAx991 family (OPA991, OPA2991, and OPA4991) is a new generation of 40-V general purpose operational amplifiers.

These devices offer excellent DC precision and AC performance, including rail-to-rail input/output, low offset ($\pm 125 \mu\text{V}$, typ), low offset drift ($\pm 0.3 \mu\text{V}/^\circ\text{C}$, typ), and 4.5-MHz bandwidth.

Unique features such as differential and common-mode input-voltage range to the supply rail, high output current ($\pm 75 \text{ mA}$), high slew rate ($21 \text{ V}/\mu\text{s}$), and shutdown functionality make the OPAx991 a robust, high-performance operational amplifier for high-voltage industrial applications.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Input Protection Circuitry

The OPAx991 uses a unique input architecture to eliminate the requirement for input protection diodes but still provides robust input protection under transient conditions. Figure 42 shows conventional input diode protection schemes that are activated by fast transient step responses and introduce signal distortion and settling time delays because of alternate current paths, as shown in Figure 43. For low-gain circuits, these fast-ramping input signals forward-bias back-to-back diodes, causing an increase in input current and resulting in extended settling time.

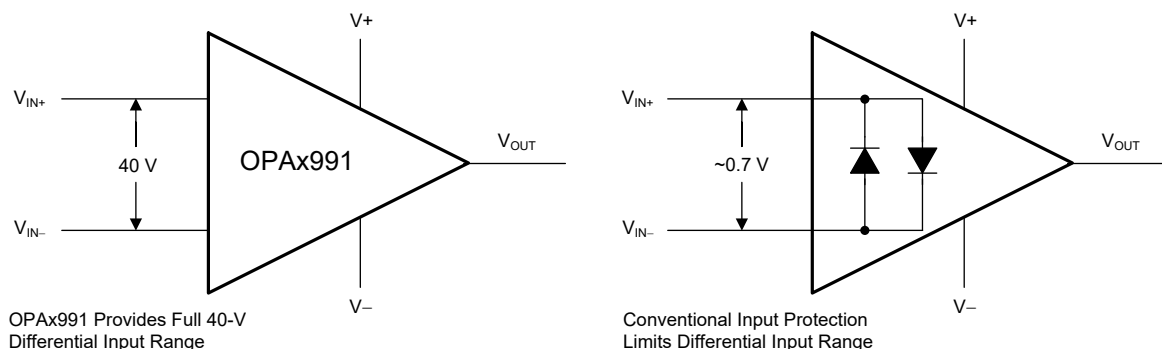


Figure 42. OPA_x991 Input Protection Does Not Limit Differential Input Capability

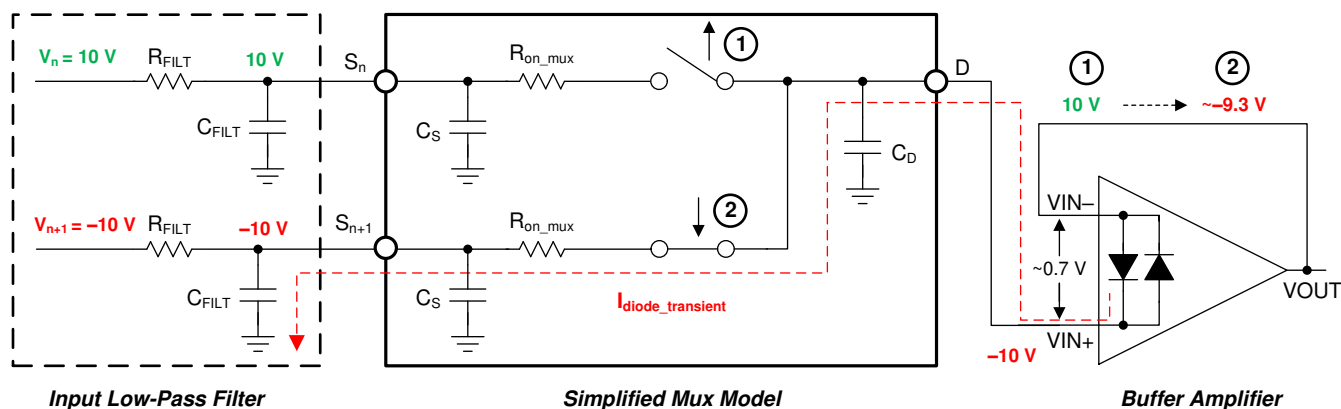


Figure 43. Back-to-Back Diodes Create Settling Issues

The OPA_x991 family of operational amplifiers provides a true high-impedance differential input capability for high-voltage applications using a patented input protection architecture that does not introduce additional signal distortion or delayed settling time, making the device an optimal op amp for multichannel, high-switched, input applications. The OPA991 tolerates a maximum differential swing (voltage between inverting and non-inverting pins of the op amp) of up to 40 V, making the device suitable for use as a comparator or in applications with fast-ramping input signals such as data-acquisition systems; see the TI TechNote [MUX-Friendly Precision Operational Amplifiers](#) for more information.

Feature Description (continued)

7.3.2 EMI Rejection

The OPAx991 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 OPAx991 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 44](#) shows the results of this testing on the OPAx991. [Table 2](#) shows the EMIRR IN+ values for the OPAx991 at particular frequencies commonly encountered in real-world applications. The [EMI Rejection Ratio of Operational Amplifiers](#) application report contains detailed information on the topic of EMIRR performance as it relates to op amps and is available for download from www.ti.com.

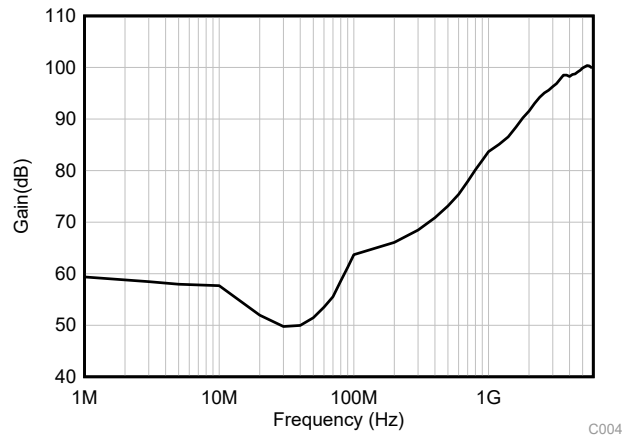


Figure 44. EMIRR Testing

Table 2. OPA991 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	73.2 dB
900 MHz	Global system for mobile communications (GSM) applications, radio communication, navigation, GPS (to 1.6 GHz), GSM, aeronautical mobile, UHF applications	82.5 dB
1.8 GHz	GSM applications, mobile personal communications, broadband, satellite, L-band (1 GHz to 2 GHz)	89.7 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)	93.9 dB
3.6 GHz	Radiolocation, aero communication and navigation, satellite, mobile, S-band	95.7 dB
5 GHz	802.11a, 802.11n, aero communication and navigation, mobile communication, space and satellite operation, C-band (4 GHz to 8 GHz)	98.0 dB

7.3.3 Thermal Protection

The internal power dissipation of any amplifier causes its internal (junction) temperature to rise. This phenomenon is called *self heating*. The absolute maximum junction temperature of the OPAx991 is 150°C. Exceeding this temperature causes damage to the device. The OPAx991 has a thermal protection feature that reduces damage from self heating. The protection works by monitoring the temperature of the device and turning off the op amp output drive for temperatures above 170°C. Figure 45 shows an application example for the OPA991 that has significant self heating because of its power dissipation (0.81 W). Thermal calculations indicate that for an ambient temperature of 65°C, the device junction temperature must reach 177°C. The actual device, however, turns off the output drive to recover towards a safe junction temperature. Figure 45 shows how the circuit behaves during thermal protection. During normal operation, the device acts as a buffer so the output is 3 V. When self heating causes the device junction temperature to increase above the internal limit, the thermal protection forces the output to a high-impedance state and the output is pulled to ground through resistor R_L . If the condition that caused excessive power dissipation is not removed, the amplifier will oscillate between a shutdown and enabled state until the output fault is corrected.

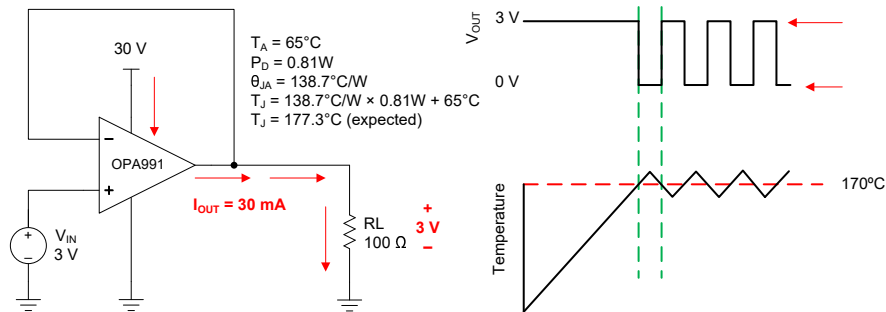


Figure 45. Thermal Protection

If the device continues to operate at high junction temperatures with high output power over a long period of time, regardless if the device is or is not entering thermal shutdown, the thermal dissipation of the device can slowly degrade performance of the device and eventually cause catastrophic destruction. Designers should be careful to limit output power of the device at high temperatures, or control ambient and junction temperatures under high output power conditions.

7.3.4 Capacitive Load and Stability

The OPAx991 features a resistive output stage capable of driving moderate capacitive loads, and by leveraging an isolation resistor, the device can easily be configured to drive large capacitive loads. Increasing the gain enhances the ability of the amplifier to drive greater capacitive loads; see Figure 46 and Figure 47. 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.

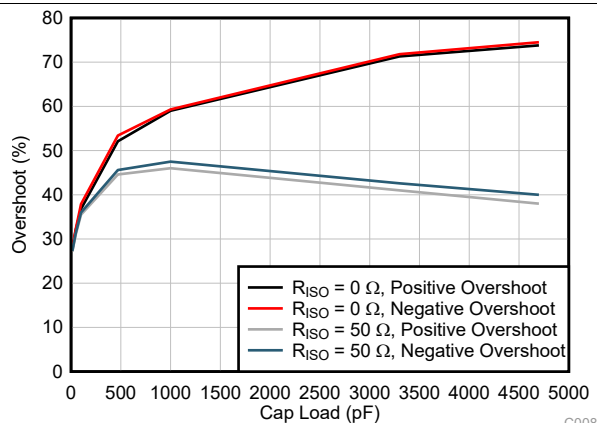


Figure 46. Small-Signal Overshoot vs Capacitive Load (10-mV Output Step, G = 1)

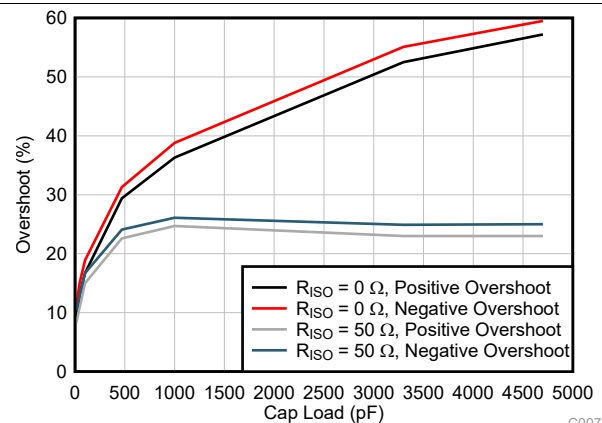


Figure 47. Small-Signal Overshoot vs Capacitive Load (10-mV Output Step, G = -1)

For additional drive capability in unity-gain configurations, improve capacitive load drive by inserting a small resistor, R_{ISO} , in series with the output, as shown in [Figure 48](#). This resistor significantly reduces ringing and maintains DC performance for purely capacitive loads. However, if a resistive load is in parallel with the capacitive load, then a voltage divider is created, thus 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 OPAx991 well suited for applications such as reference buffers, MOSFET gate drives, and cable-shield drives. The circuit shown in [Figure 48](#) uses an isolation resistor, R_{ISO} , to stabilize the output of an op amp. R_{ISO} modifies the open-loop gain of the system for increased phase margin.

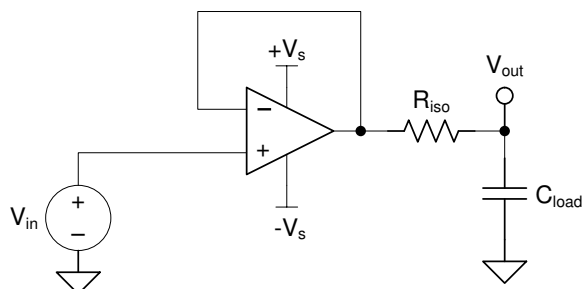


Figure 48. Extending Capacitive Load Drive With the OPA991

7.3.5 Common-Mode Voltage Range

The OPAx991 is a 40-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 49. The N-channel pair is active for input voltages close to the positive rail, typically $(V+) - 1\text{ V}$ to 100 mV above the positive supply. The P-channel pair is active for inputs from 100 mV below the negative supply to approximately $(V+) - 2\text{ V}$. There is a small transition region, typically $(V+) - 2\text{ V}$ to $(V+) - 1\text{ V}$ in which both input pairs are on. This transition region can vary modestly with process variation, and within this region PSRR, CMRR, offset voltage, offset drift, noise, and THD performance may be degraded compared to operation outside this region.

Figure 5 shows this transition region for a typical device in terms of input voltage offset in more detail.

For more information on common-mode voltage range and PMOS/NMOS pair interaction, see [Op Amps With Complementary-Pair Input Stages](#) application note.

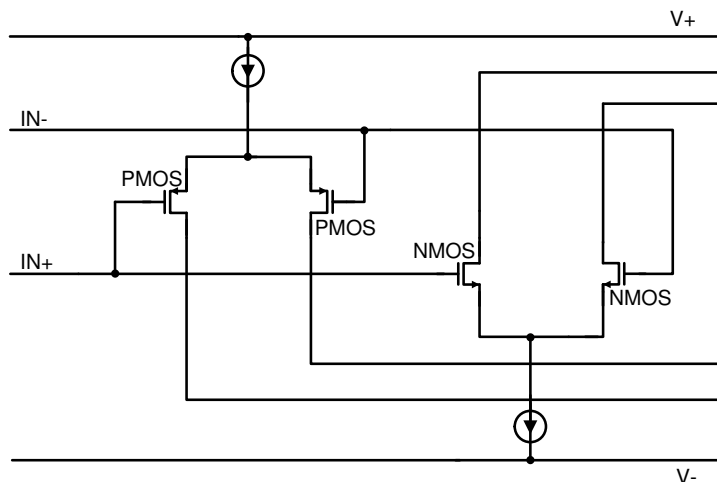


Figure 49. Rail-to-Rail Input Stage

7.3.6 Phase Reversal Protection

The OPAx991 family has internal phase-reversal protection. Many op amps exhibit a phase reversal when the input is driven beyond its linear common-mode range. This condition is most often encountered in non-inverting circuits when the input is driven beyond the specified common-mode voltage range, causing the output to reverse into the opposite rail. The OPAx991 is a rail-to-rail input op amp; 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 50. For more information on phase reversal, see [Op Amps With Complementary-Pair Input Stages](#) application note.

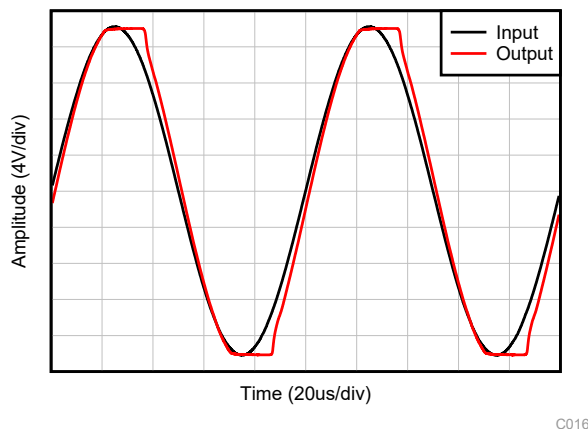


Figure 50. No Phase Reversal

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. Figure 51 shows an illustration of the ESD circuits contained in the OPAX991 (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.

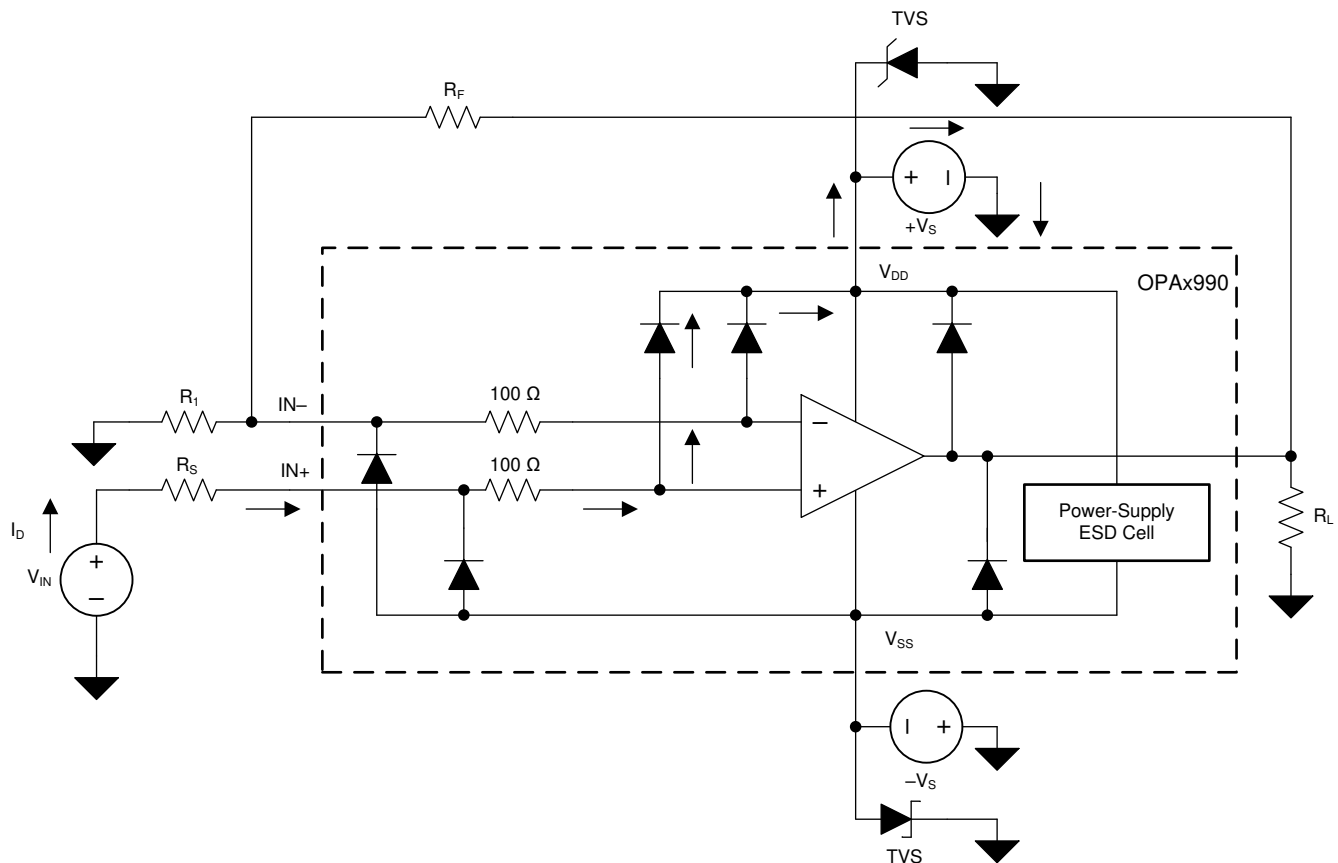


Figure 51. Equivalent Internal ESD Circuitry Relative to a Typical Circuit Application

An ESD event is very short in duration and very high voltage (for example; 1 kV, 100 ns), whereas an EOS event is long duration and lower voltage (for example; 50 V, 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 suppressors (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. The overload recovery time for the OPAx991 is approximately 500 ns.

7.3.9 Typical Specifications and Distributions

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

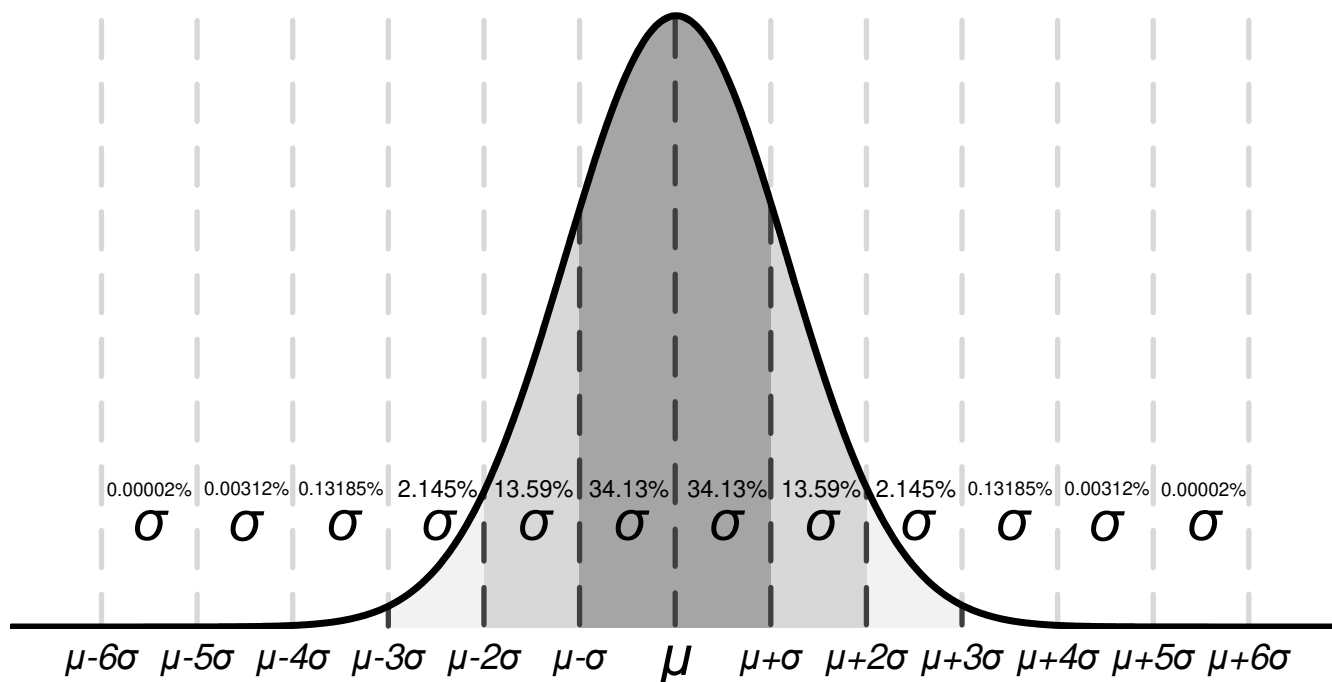


Figure 52. Ideal Gaussian Distribution

Figure 52 shows an example distribution, where μ , or μ , is the mean of the distribution, and where σ , or σ , 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 of thumb, 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 input offset voltage), then the typical value is equal to the mean plus one standard deviation ($\mu + \sigma$) in order to most accurately represent the typical value.

You can use this chart to calculate approximate probability of a specification in a unit; for example, for OPAx991, the typical input voltage offset is 125 μ V, so 68.2% of all OPAx991 devices are expected to have an offset from -125μ V to 125 μ V. At 4 σ ($\pm 500 \mu$ V), 99.9937% of the distribution has an offset voltage less than $\pm 500 \mu$ V, 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 assured by TI, and units outside these limits will be removed from production material. For example, the OPAX991 family has a maximum offset voltage of 675 μV at 25°C, and even though this corresponds to about 5 σ (≈ 1 in 1.7 million units), which is extremely unlikely, TI assures that any unit with larger offset than 675 μV will be removed from production material.

For specifications with no value in the minimum or maximum column, consider selecting a sigma value of sufficient guardband for your application, and design worst-case conditions using this value. For example, the 6 σ value corresponds to about 1 in 500 million units, which is an extremely unlikely chance, and could be an option as a wide guardband to design a system around. In this case, the OPAX991 family does not have a maximum or minimum for offset voltage drift, but based on [Figure 2](#) and the typical value of 0.3 $\mu\text{V}/^\circ\text{C}$ in the [Electrical Characteristics](#) table, it can be calculated that the 6- σ value for offset voltage drift is about 1.8 $\mu\text{V}/^\circ\text{C}$. When designing for worst-case system conditions, this value can be used to estimate the worst possible offset across temperature without having an actual minimum or maximum value.

However, process variation and adjustments over time can shift typical means and standard deviations, and unless there is a value in the minimum or maximum specification column, TI cannot assure the performance of a device. This information should be used only to estimate the performance of a device.

7.3.10 Packages With an Exposed Thermal Pad

The OPAX991 family is available in packages such as the WSON-8 (DSG) and WQFN-16 (RTE) which feature an exposed thermal pad. Inside the package, the die is attached to this thermal pad using an electrically conductive compound. For this reason, when using a package with an exposed thermal pad, the thermal pad must either be connected to V– or left floating. Attaching the thermal pad to a potential other than V– is not allowed, and performance of the device is not assured when doing so.

7.3.11 Shutdown

The OPAX991S devices feature one or more shutdown pins (SHDN) that disable the op amp, placing it into a low-power standby mode. In this mode, the op amp typically consumes about 20 μA . The SHDN pins are active high, meaning that shutdown mode is enabled when the input to the SHDN pin is a valid logic high.

The SHDN pins are referenced to the negative supply rail of the op amp. The threshold of the shutdown feature lies around 800 mV (typical) and does not change with respect to the supply voltage. Hysteresis has been included in the switching threshold to ensure smooth switching characteristics. To ensure optimal shutdown behavior, the SHDN pins should be driven with valid logic signals. A valid logic low is defined as a voltage between V– and V– + 0.4 V. A valid logic high is defined as a voltage between V– + 1.2 V and V– + 20 V. The shutdown pin circuitry includes a pull-down resistor, which will inherently pull the voltage of the pin to the negative supply rail if not driven. Thus, to enable the amplifier, the SHDN pins should either be left floating or driven to a valid logic low. To disable the amplifier, the SHDN pins must be driven to a valid logic high. The maximum voltage allowed at the SHDN pins is V– + 20 V. Exceeding this voltage level will damage the device.

The SHDN pins are high-impedance CMOS inputs. Channels of single and dual op amp packages are independently controlled, and channels of quad op amp packages are controlled in pairs. For battery-operated applications, this feature may be used to greatly reduce the average current and extend battery life. The typical enable time out of shutdown is 30 μs ; disable time is 3 μs . When disabled, the output assumes a high-impedance state. This architecture allows the OPAX991S family to operate as a gated amplifier, multiplexer, or programmable-gain amplifier. Shutdown time (t_{OFF}) depends on loading conditions and increases as load resistance increases. To ensure shutdown (disable) within a specific shutdown time, the specified 10-k Ω load to midsupply ($V_{\text{S}} / 2$) is required. If using the OPAX991S without a load, the resulting turnoff time significantly increases.

7.4 Device Functional Modes

The OPAx991 has a single functional mode and is operational when the power-supply voltage is greater than 2.7 V (± 1.35 V). The maximum power supply voltage for the OPAx991 is 40 V (± 20 V).

The OPAx991S devices feature a shutdown pin, which can be used to place the op amp into a low-power mode. See [Shutdown](#) section for more information.

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 OPAx991 family offers excellent DC precision and AC performance. These devices operate up to 40-V supply rails and offer true rail-to-rail input/output, low offset voltage and offset voltage drift, as well as 4.5-MHz bandwidth and high output drive. These features make the OPAx991 a robust, high-performance operational amplifier for high-voltage industrial applications.

8.2 Typical Applications

8.2.1 Low-Side Current Measurement

Figure 53 shows the OPA991 configured in a low-side current sensing application. For a full analysis of the circuit shown in Figure 53 including theory, calculations, simulations, and measured data, see TI Precision Design TIPD129, *0-A to 1-A Single-Supply Low-Side Current-Sensing Solution*.

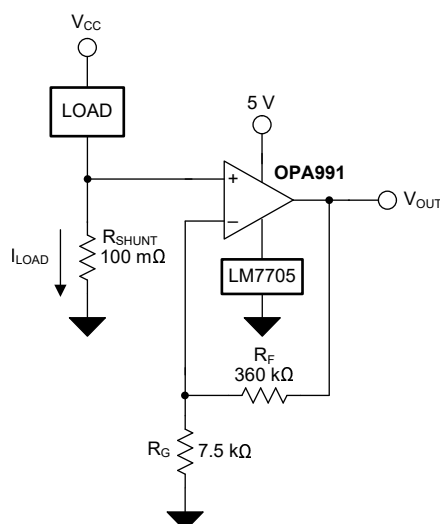


Figure 53. OPA991 in a Low-Side, Current-Sensing Application

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 53](#) 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 OPA991 to produce an output voltage of 0 V to 4.9 V. The gain needed by the OPA991 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 OPA991 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 54](#) shows the measured transfer function of the circuit shown in [Figure 53](#).

8.2.1.3 Application Curves

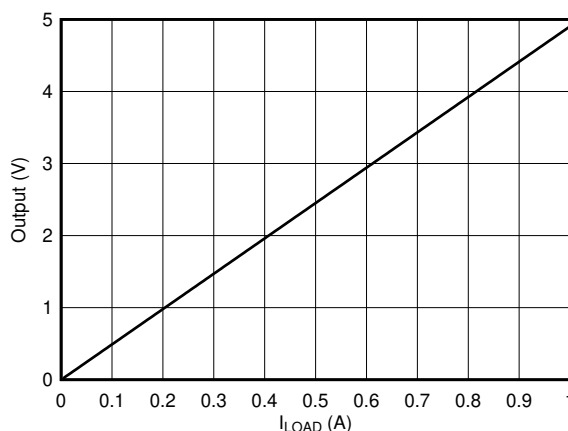


Figure 54. Low-Side, Current-Sense, Transfer Function

9 Power Supply Recommendations

The OPAx991 is specified for operation from 2.7 V to 40 V (± 1.35 V to ± 40 V); many specifications apply from -40°C to 125°C . Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in the [Typical Characteristics](#) section.

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:

- 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.
 - Connect low-ESR, 0.1- μF 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.
- 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. Make sure to physically separate digital and analog grounds paying attention to the flow of the ground current.
- In order to reduce parasitic coupling, run the input traces as far away from the supply or output traces as possible. 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 illustrated in [Figure 56](#), 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.
- Cleaning the PCB following board assembly is recommended for best performance.
- Any precision integrated circuit may experience performance shifts due to moisture ingress into the plastic package. Following any aqueous PCB cleaning process, baking the PCB assembly is recommended 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

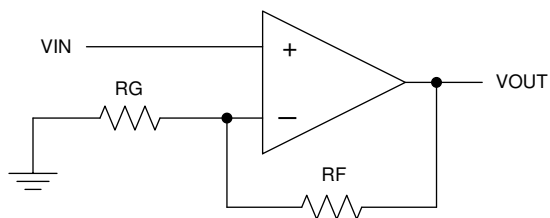


Figure 55. Schematic Representation

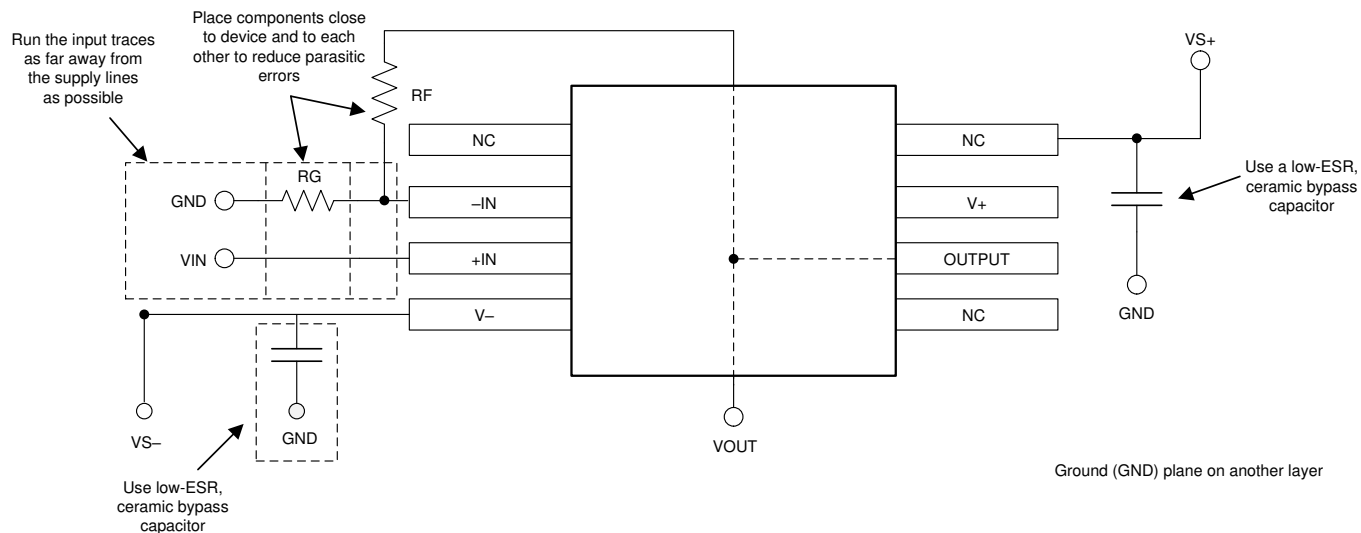


Figure 56. Operational Amplifier Board Layout for Noninverting Configuration

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](#).

11.1.1.2 TI Precision Designs

The OPAx991 is featured in several TI Precision Designs, available online at <http://www.ti.com/ww/en/analog/precision-designs/>. TI 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

For related documentation, see the following:

Texas Instruments, [Analog Engineer's Circuit Cookbook: Amplifiers](#) solution guide

Texas Instruments, [AN31 Amplifier Circuit Collection](#) application note

Texas Instruments, [MUX-Friendly Precision Operational Amplifiers](#) Tech Note

Texas Instruments, [EMI Rejection Ratio of Operational Amplifiers](#) application report

Texas Instruments, [Op Amps With Complementary-Pair Input Stages](#) application note

11.3 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to order now.

Table 3. Related Links

PARTS	PRODUCT FOLDER	ORDER NOW	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
OPA991	Click here	Click here	Click here	Click here	Click here
OPA2991	Click here	Click here	Click here	Click here	Click here
OPA4991	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 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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11.6 Trademarks

E2E is a trademark of Texas Instruments.

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Bluetooth is a registered trademark of Bluetooth SIG, Inc.

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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
OPA2991IDGKR	PREVIEW	VSSOP	DGK	8	2500	TBD	Call TI	Call TI	-40 to 125		
OPA2991IDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	OP2991	Samples
OPA2991IDSGR	ACTIVE	WSO	DSG	8	3000	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	O91G	Samples
OPA2991IPWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	O2991P	Samples
OPA4991IDR	PREVIEW	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	OPA4991D	
OPA4991IPWR	PREVIEW	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	SN	Level-2-260C-1 YEAR	-40 to 125	OP4991PW	
OPA991IDBVR	PREVIEW	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O91V	
OPA991SIDBVR	PREVIEW	SOT-23	DBV	6	3000	TBD	Call TI	Call TI	-40 to 125		
POPA2991IDDFR	ACTIVE	SOT-23-THIN	DDF	8	3000	TBD	Call TI	Call TI	-40 to 125		Samples
POPA2991IDGKR	ACTIVE	VSSOP	DGK	8	2500	TBD	Call TI	Call TI	-40 to 125		Samples
POPA2991IDSGR	ACTIVE	WSO	DSG	8	3000	TBD	Call TI	Call TI	-40 to 125		Samples
POPA2991IPWR	ACTIVE	TSSOP	PW	8	2000	TBD	Call TI	Call TI	-40 to 125		Samples
POPA4991IDR	ACTIVE	SOIC	D	14	2500	TBD	Call TI	Call TI	-40 to 125		Samples
POPA4991IPWR	ACTIVE	TSSOP	PW	14	2000	TBD	Call TI	Call TI	-40 to 125		Samples
POPA4991IRUCR	ACTIVE	QFN	RUC	14	3000	TBD	Call TI	Call TI	-40 to 125		Samples
POPA991IDBVR	ACTIVE	SOT-23	DBV	5	3000	TBD	Call TI	Call TI	-40 to 125		Samples
POPA991SIDBVR	ACTIVE	SOT-23	DBV	6	3000	TBD	Call TI	Call TI	-40 to 125		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.

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

OTHER QUALIFIED VERSIONS OF OPA2991 :

- Automotive: [OPA2991-Q1](#)

NOTE: Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

TAPE AND REEL INFORMATION


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
OPA2991IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
OPA2991IDSGR	WSOIC	DSG	8	3000	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2
OPA2991IPWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

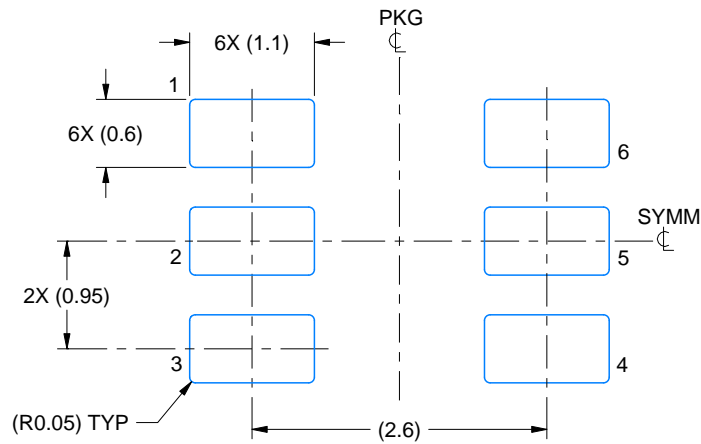
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
OPA2991IDR	SOIC	D	8	2500	367.0	367.0	35.0
OPA2991IDSGR	WSO	DSG	8	3000	210.0	185.0	35.0
OPA2991IPWR	TSSOP	PW	8	2000	367.0	367.0	35.0

EXAMPLE BOARD LAYOUT

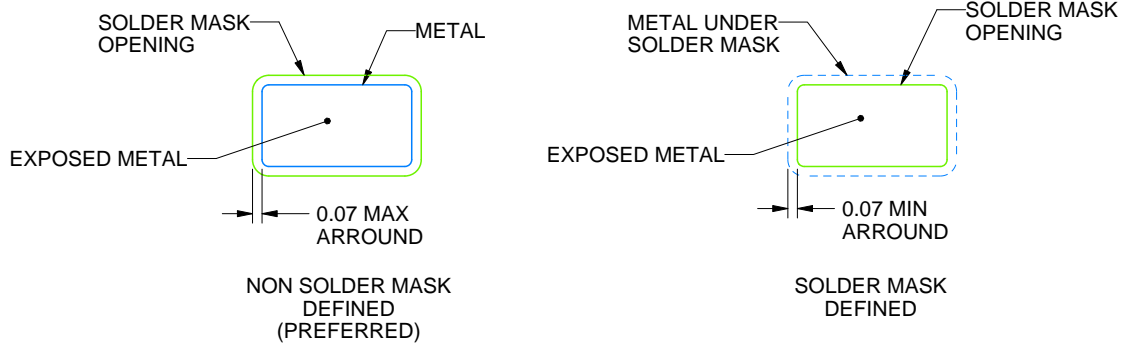
DBV0006A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:15X



SOLDER MASK DETAILS

4214840/B 03/2018

NOTES: (continued)

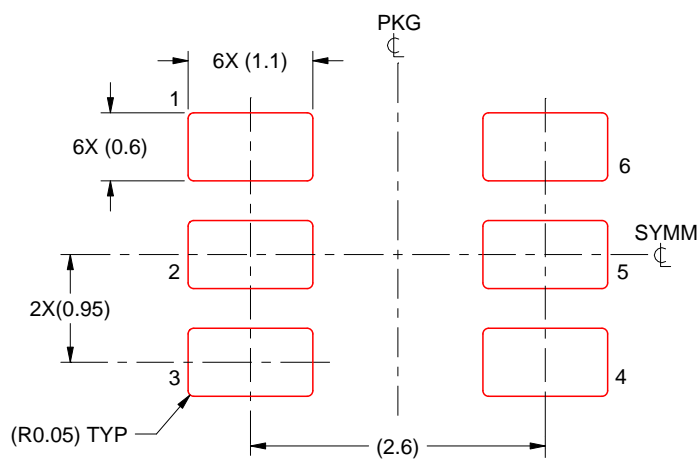
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

DBV0006A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



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

4214840/B 03/2018

NOTES: (continued)

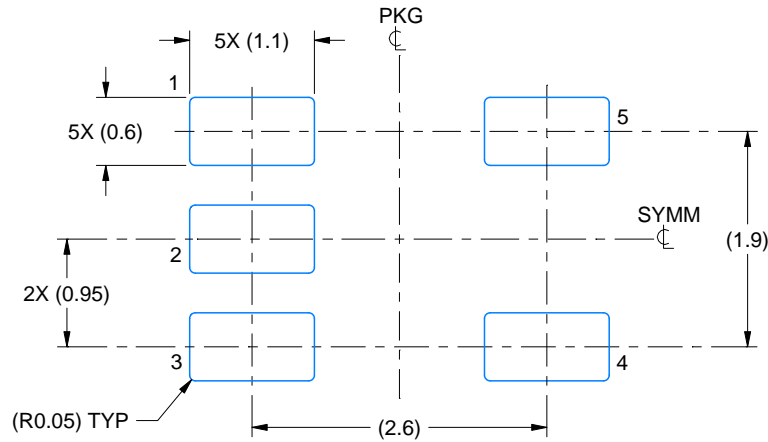
8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

EXAMPLE BOARD LAYOUT

DBV0005A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:15X



SOLDER MASK DETAILS

4214839/E 09/2019

NOTES: (continued)

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

EXAMPLE STENCIL DESIGN

DBV0005A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



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

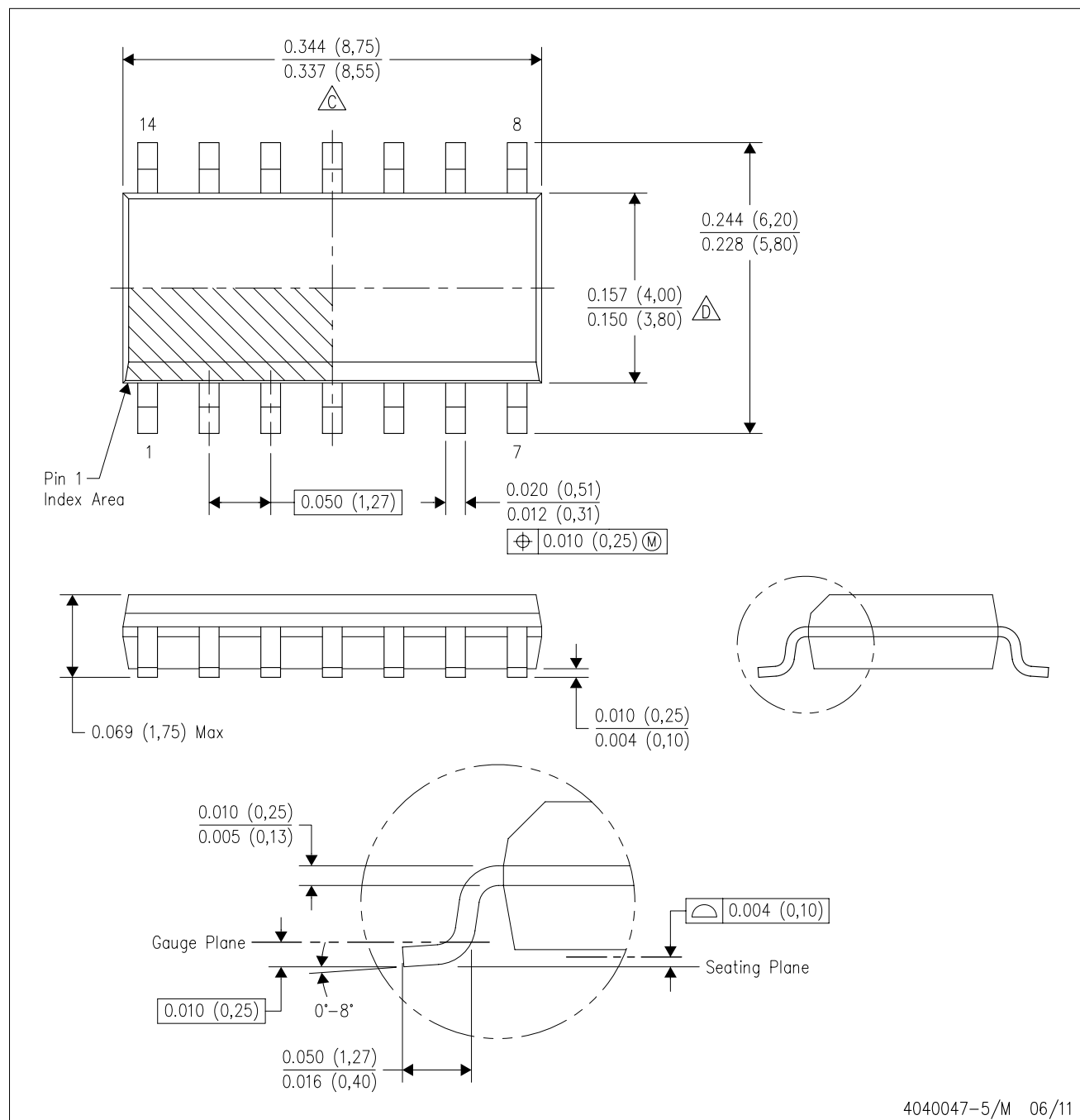
4214839/E 09/2019

NOTES: (continued)

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

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.
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 AB.

D (R-PDSO-G14)

PLASTIC SMALL OUTLINE



- 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.

PW (R-PDSO-G14)

PLASTIC SMALL OUTLINE



4040064-3/G 02/11

- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
 - 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 each side.
 - D. Body width does not include interlead flash. Interlead flash shall not exceed 0,25 each side.
 - E. Falls within JEDEC MO-153

PW (R-PDSO-G14)

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.

D0008A**PACKAGE OUTLINE****SOIC - 1.75 mm max height**

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X



SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

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

EXAMPLE STENCIL DESIGN

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

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.

DGK (S-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE



4073329/E 05/06

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.

GENERIC PACKAGE VIEW

DSG 8

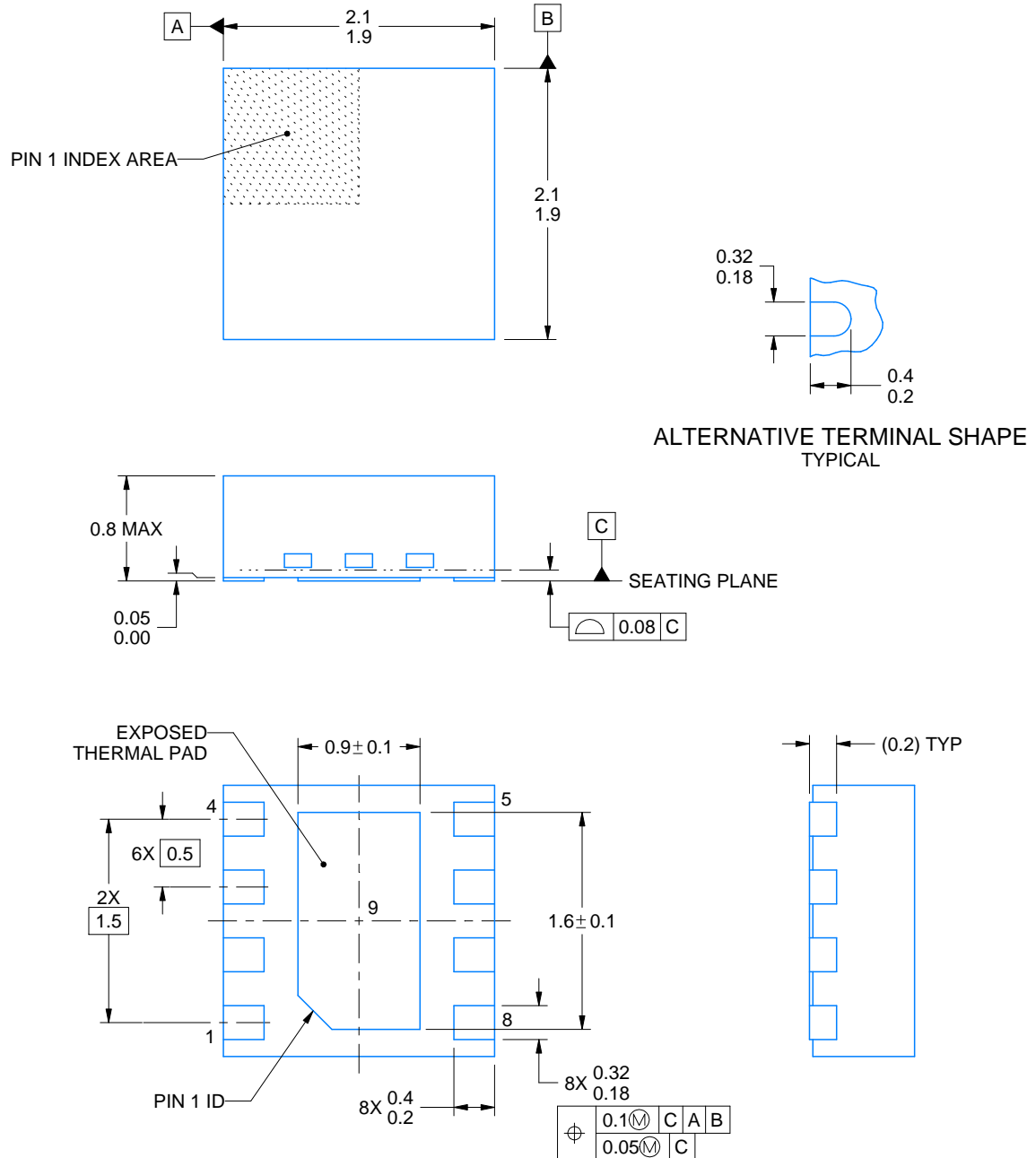
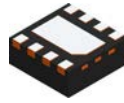
WSON - 0.8 mm max height

2 x 2, 0.5 mm pitch

PLASTIC SMALL OUTLINE - NO LEAD

This image is a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.





4218900/D 04/2020

NOTES:

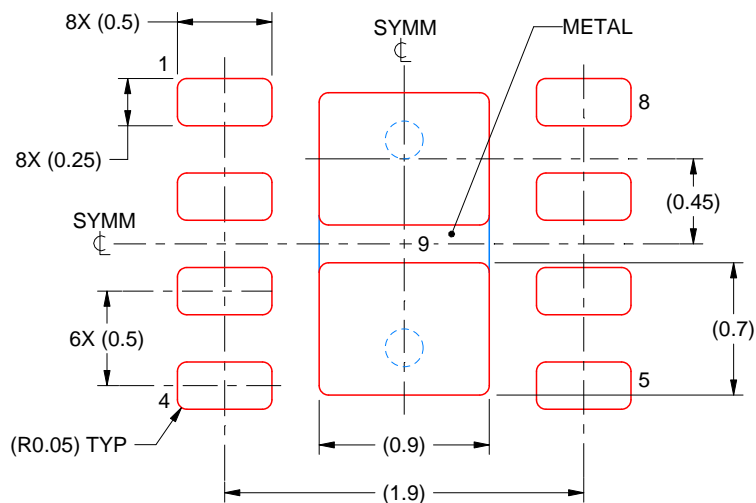
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

EXAMPLE STENCIL DESIGN

DSG0008A

WSN - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 9:
87% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
SCALE:25X

4218900/D 04/2020

NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

PW0008A



PACKAGE OUTLINE

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



4221848/A 02/2015

NOTES:

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

EXAMPLE BOARD LAYOUT

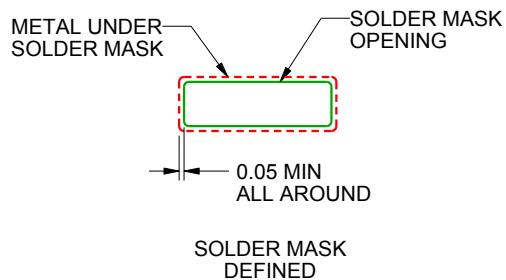
PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE
SCALE:10X



SOLDER MASK DETAILS
NOT TO SCALE

4221848/A 02/2015

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

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

EXAMPLE STENCIL DESIGN

PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE

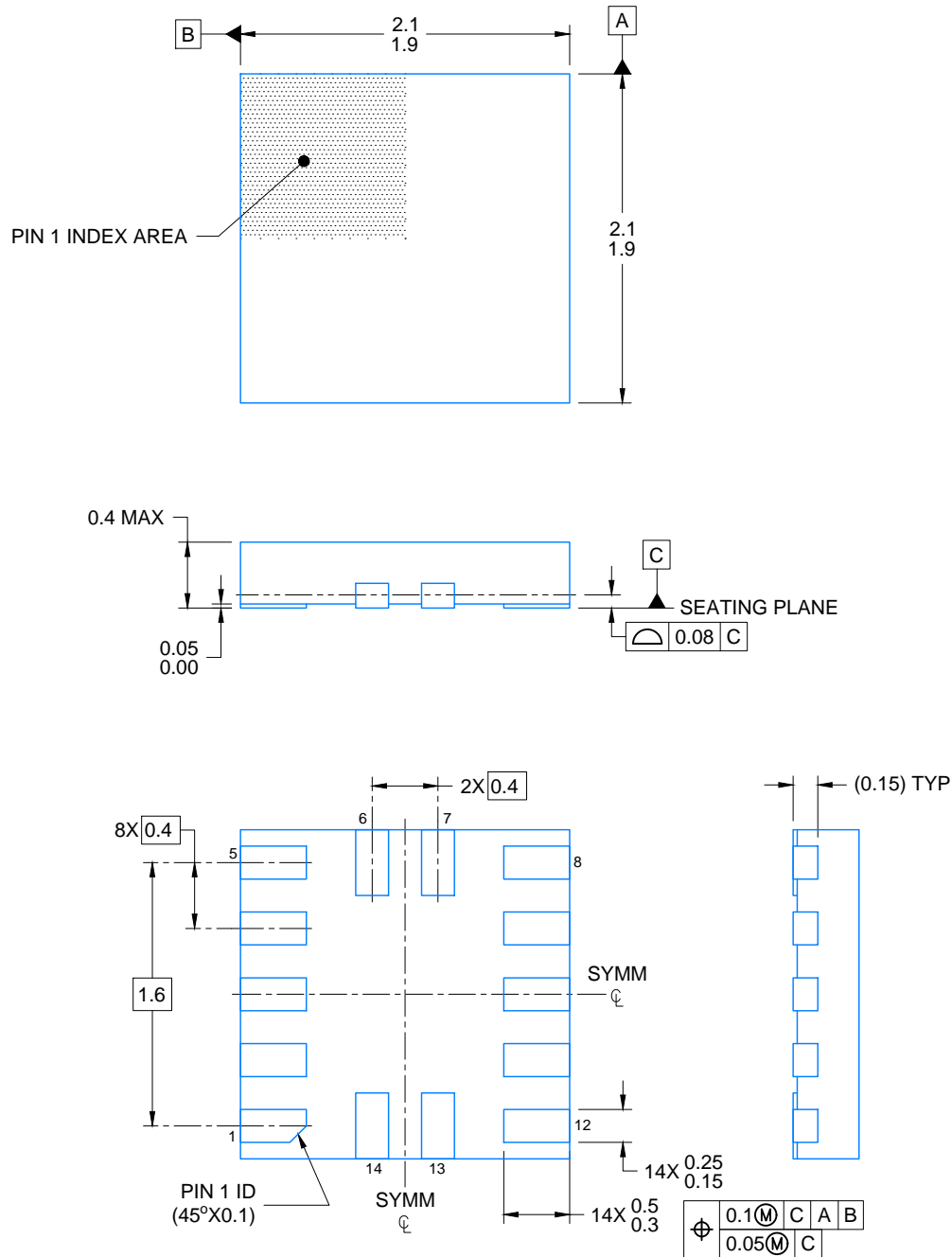


SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:10X

4221848/A 02/2015

NOTES: (continued)

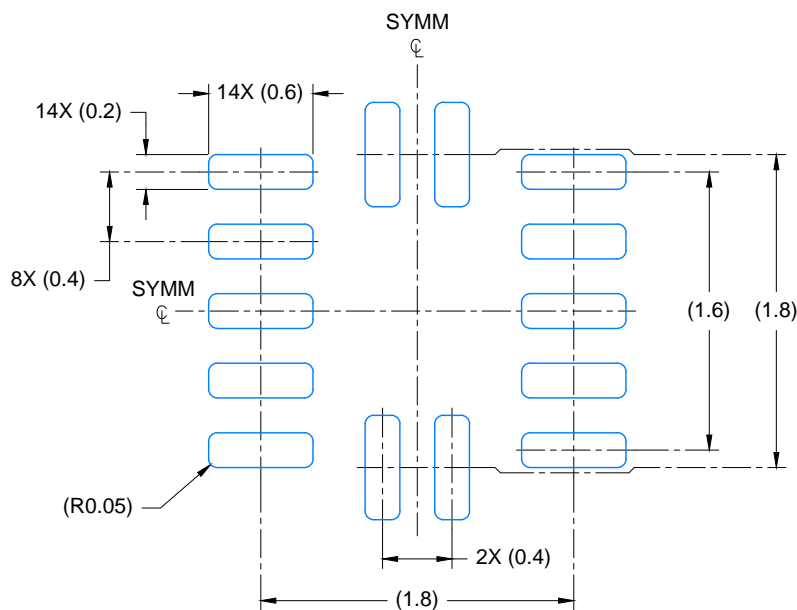
8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.



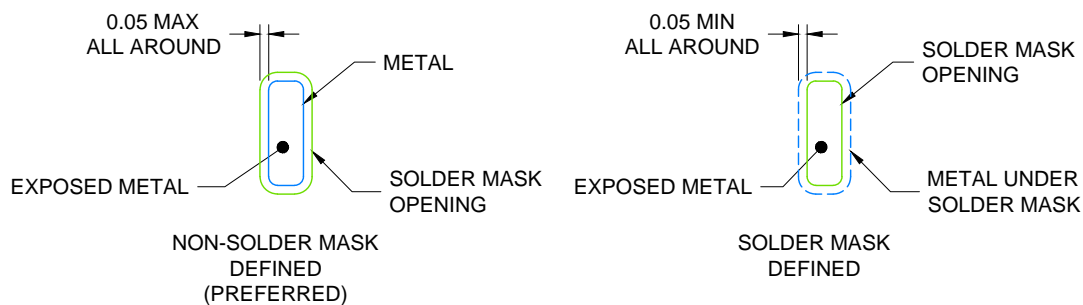
4220584/A 05/2019

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.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 23X



SOLDER MASK DETAILS

4220584/A 05/2019

NOTES: (continued)

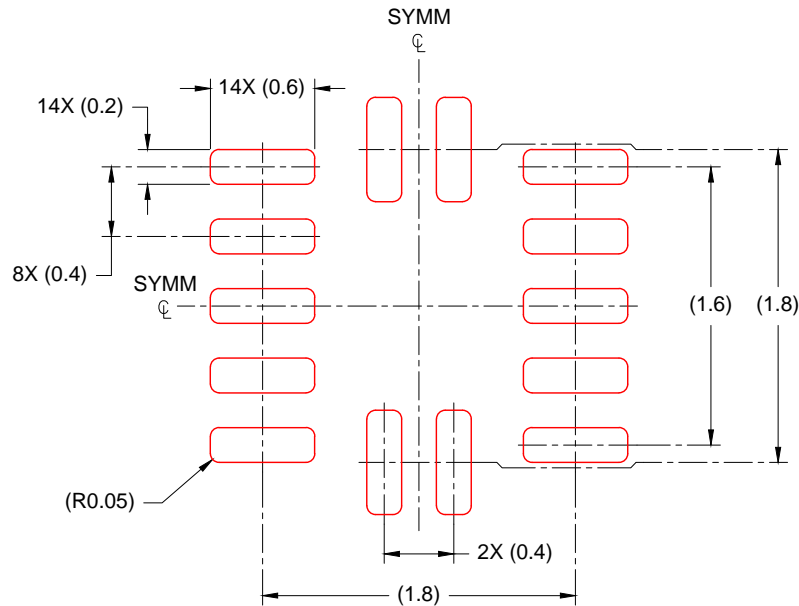
- For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/sluea271).

EXAMPLE STENCIL DESIGN

RUC0014A

X2QFN - 0.4 mm max height

PLASTIC QUAD FLAT PACK- NO LEAD



SOLDER PASTE EXAMPLE
BASED ON 0.100mm THICK STENCIL
SCALE: 23X

4220584/A 05/2019

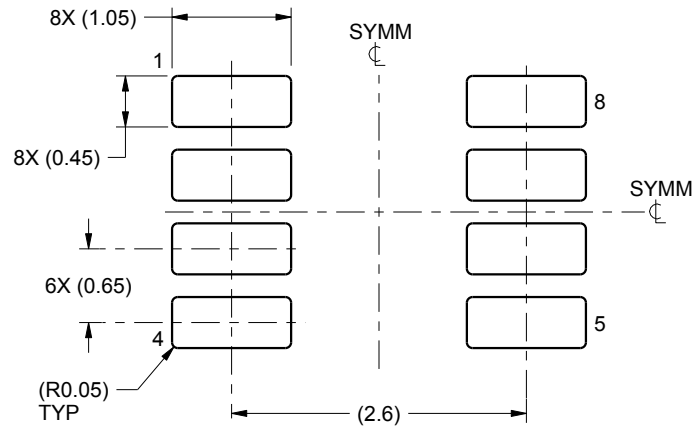
NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

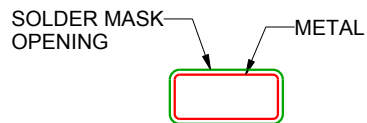
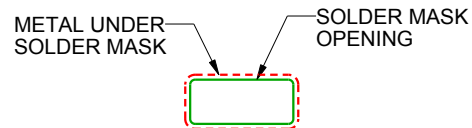
DDF0008A

SOT-23 - 1.1 mm max height

PLASTIC SMALL OUTLINE



LAND PATTERN EXAMPLE
SCALE:15X

NON SOLDER MASK
DEFINED

SOLDER MASK
DEFINED

SOLDER MASK DETAILS

4222047/B 11/2015

NOTES: (continued)

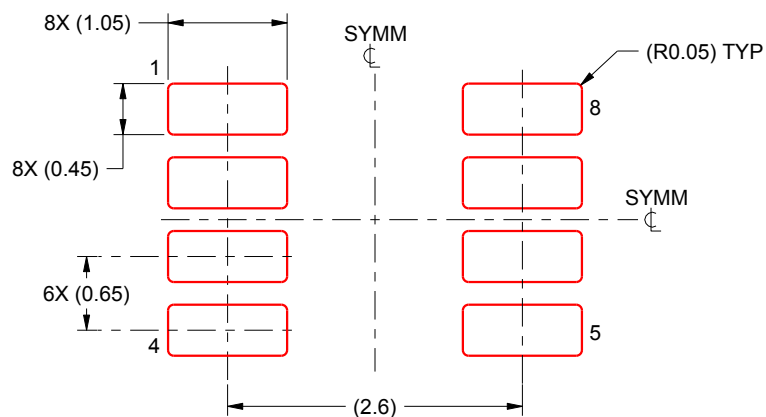
4. Publication IPC-7351 may have alternate designs.
5. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

DDF0008A

SOT-23 - 1.1 mm max height

PLASTIC SMALL OUTLINE



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

4222047/B 11/2015

NOTES: (continued)

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

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