

# OPAx391 Precision, Ultra-Low $I_Q$ , Low Offset Voltage, e-trim™ Operational Amplifiers

## 1 Features

- Low  $I_Q$ : 24  $\mu\text{A}$
- Gain bandwidth product: 1 MHz
- Low input bias current: 10 fA
- Low offset voltage:  $\pm 45 \mu\text{V}$  (maximum)
- Low drift:  $\pm 1.2 \mu\text{V}/^\circ\text{C}$
- Low supply voltage operation: 1.7 V to 5.5 V
- Input common mode range  $\pm 100 \text{ mV}$  beyond rail
- Fast slew rate: 1 V/ $\mu\text{s}$
- High load capacitance drive
- High output current drive: 60 mA
- Rail-to-rail output
- EMI/RFI filtered inputs
- Small package options: SC-70, DSBGA

## 2 Applications

- [Portable electronics](#)
- [Flow transmitter](#)
- [Blood glucose monitor](#)
- [Process analytics \(pH, gas, force, humidity\)](#)
- [Temperature transmitter](#)
- [Pressure transmitter](#)
- [Medical sensor patches](#)
- [Building automation](#)
- [Wearable fitness and activity monitor](#)
- [Gas detector](#)
- [Analog security camera](#)

## 3 Description

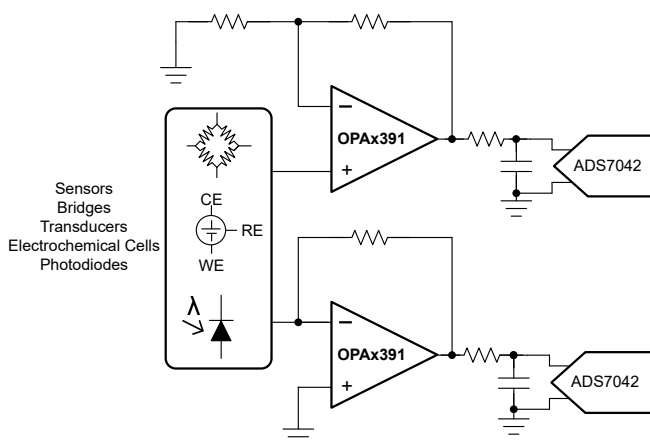
The OPA391 and OPA2391 (OPAx391) feature a unique combination of high bandwidth (1 MHz) along with very-low quiescent current (24  $\mu\text{A}$ ) in high-precision amplifiers. These features combined with rail-to-rail input and output make these devices an exceptional choice in high-gain, low-power applications. Ultra-low input bias current of 10 fA, only 45  $\mu\text{V}$  of offset (maximum), and 1.2  $\mu\text{V}/^\circ\text{C}$  of drift over temperature help maintain high precision in ratiometric and amperometric sensor front ends that have demanding low-power requirements.

The OPAx391 use Texas Instrument's proprietary e-trim™ operational amplifier technology, enabling a unique combination of ultra-low offset and low input offset drift without the need for any input switching or auto-zero techniques. The CMOS-based technology platform also features a modern, robust output stage design that is tolerant of high output capacitance, alleviating stability problems that are common in typical low-power amplifiers.

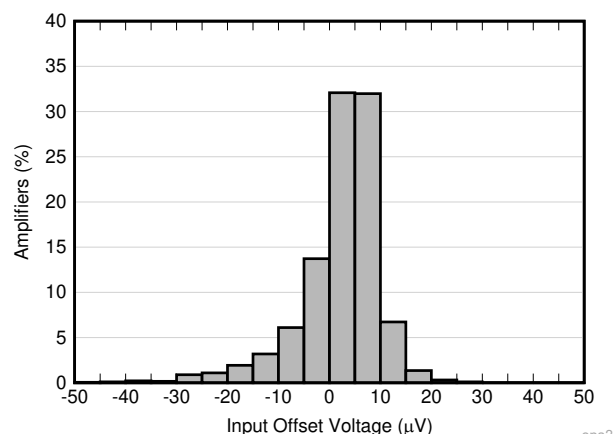
### Device Information

PART NUMBER	CHANNELS	PACKAGE <sup>(1)</sup>
OPA391	Single	DCK (SC70, 5)
	Single	DBV (SOT-23, 5) <sup>(2)</sup>
OPA2391	Dual	D (SOIC, 8) <sup>(2)</sup>
	Dual	DGK (VSSOP, 8) <sup>(2)</sup>
	Dual	YBJ (DSBGA, 9)
OPA4391 <sup>(2)</sup>	Quad	PW (TSSOP, 14) <sup>(2)</sup>

- (1) For all available packages, see the package option addendum at the end of the data sheet.
- (2) Preview information (not Production Data).



**High Input Impedance, Low Offset Buffer**



**OPA391 Offset Voltage**



## Table of Contents

<b>1 Features</b> .....	1	7.4 Device Functional Modes.....	19
<b>2 Applications</b> .....	1	<b>8 Application and Implementation</b> .....	20
<b>3 Description</b> .....	1	8.1 Application Information.....	20
<b>4 Revision History</b> .....	2	8.2 Typical Applications.....	20
<b>5 Pin Configuration and Functions</b> .....	3	8.3 Power Supply Recommendations.....	24
<b>6 Specifications</b> .....	6	8.4 Layout.....	24
6.1 Absolute Maximum Ratings.....	6	<b>9 Device and Documentation Support</b> .....	25
6.2 ESD Ratings.....	6	9.1 Device Support.....	25
6.3 Recommended Operating Conditions.....	6	9.2 Documentation Support.....	25
6.4 Thermal Information: OPA391.....	7	9.3 Receiving Notification of Documentation Updates.....	25
6.5 Thermal Information: OPA2391.....	7	9.4 Support Resources.....	25
6.6 Electrical Characteristics.....	8	9.5 Trademarks.....	25
6.7 Typical Characteristics.....	10	9.6 Electrostatic Discharge Caution.....	26
<b>7 Detailed Description</b> .....	17	9.7 Glossary.....	26
7.1 Overview.....	17	<b>10 Mechanical, Packaging, and Orderable Information</b> .....	26
7.2 Functional Block Diagram.....	17		
7.3 Feature Description.....	18		

## 4 Revision History

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

<b>Changes from Revision B (November 2022) to Revision C (December 2022)</b>	<b>Page</b>
• Changed OPA2391 in YBJ (DSBGA, 9) from advanced information (preview) to production data (active) and added associated content.....	1

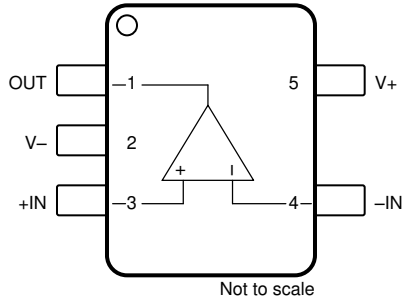
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<b>Changes from Revision A (January 2021) to Revision B (November 2022)</b>	<b>Page</b>
• Added OPA2391 advanced information (preview) device and associated content.....	1
• Added junction temperature to <i>Absolute Maximum Ratings</i> .....	6
• Changed JEDEC specification from JESD22-C101 to ANSI/ESDA/JEDEC JS-002.....	6
• Changed input common-mode voltage condition for input voltage noise in the <i>Electrical Characteristics</i> .....	8
• Changed Figure 6-7, <i>Open-Loop Gain and Phase vs Freq</i> , Y-axis scale for clarity; no change to data.....	10
• Changed Figure 8-7, <i>Layout Example</i> , to show correct pin configuration and names.....	24

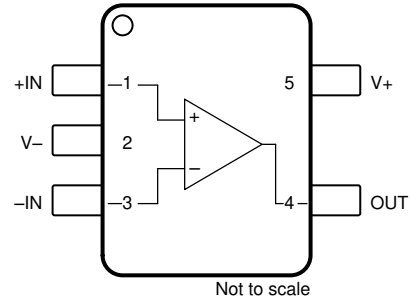
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<b>Changes from Revision * (December 2020) to Revision A (January 2021)</b>	<b>Page</b>
• Changed device from advanced information (preview) to production data (active).....	1

## 5 Pin Configuration and Functions



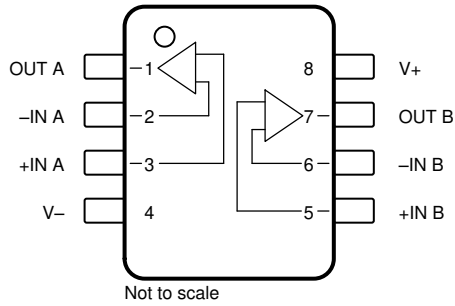
**Figure 5-1. OPA391: DBV Package (Preview), 5-Pin SOT-23 (Top View)**



**Figure 5-2. OPA391: DCK Package, 5-Pin SC-70 (Top View)**

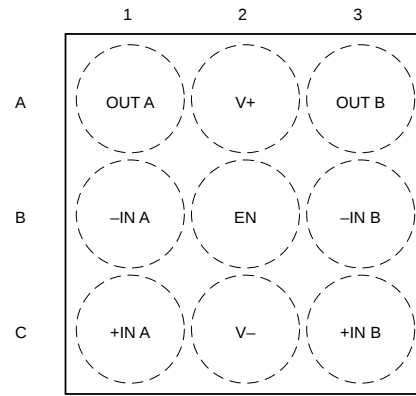
**Table 5-1. Pin Functions: OPA391**

NAME	PIN		TYPE	DESCRIPTION
	NO.			
	DBV (SOT-23)	DCK (SC70)		
-IN	4	3	Input	Inverting input
+IN	3	1	Input	Noninverting input
OUT	1	4	Output	Output
V-	2	2	Power	Negative (lowest) power supply
V+	5	5	Power	Positive (highest) power supply



Not to scale

Figure 5-3. OPA2391: D Package (Preview), 8-pin SOIC and DGK Package (Preview), 8-Pin VSSOP (Top View)

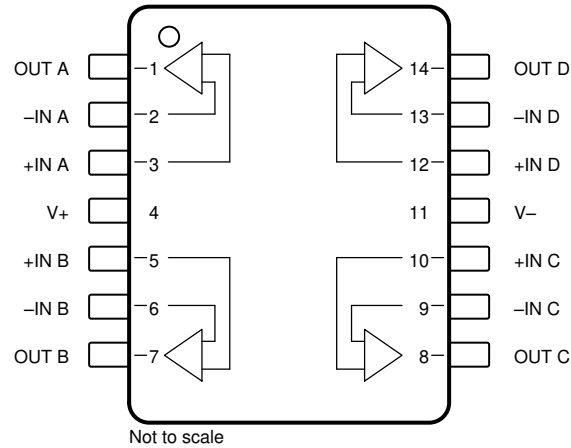


Not to scale

Figure 5-4. OPA2391: YBJ Package, 9-Pin DSBGA (Top View)

Table 5-2. Pin Functions: OPA2391

NAME	PIN		TYPE	DESCRIPTION
	NO.			
	D (SOIC), DGK (VSSOP)	YBJ (DSBGA)		
EN	—	B2	Input	Enable pin. High = both amplifiers enabled.
-IN A	2	B1	Input	Inverting input, channel A
+IN A	3	C1	Input	Noninverting input, channel A
-IN B	6	B3	Input	Inverting input, channel B
+IN B	5	C3	Input	Noninverting input, channel B
OUT A	1	A1	Output	Output, channel A
OUT B	7	A3	Output	Output, channel B
V-	4	C2	Power	Negative (lowest) power supply
V+	8	A2	Power	Positive (highest) power supply



**Figure 5-5. OPA4391: PW Package (Preview), 14-Pin TSSOP (Top View)**

**Table 5-3. Pin Functions: OPA4391**

PIN		TYPE	DESCRIPTION
NAME	NO.		
-IN A	2	Input	Inverting input, channel A
+IN A	3	Input	Noninverting input, channel A
-IN B	6	Input	Inverting input, channel B
+IN B	5	Input	Noninverting input, channel B
-IN C	9	Input	Inverting input, channel C
+IN C	10	Input	Noninverting input, channel C
-IN D	13	Input	Inverting input, channel D
+IN D	12	Input	Noninverting input, channel D
OUT A	1	Output	Output, channel A
OUT B	7	Output	Output, channel B
OUT C	8	Output	Output, channel C
OUT D	14	Output	Output, channel D
V-	11	Power	Negative (lowest) power supply
V+	4	Power	Positive (highest) power supply

## 6 Specifications

### 6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

			MIN	MAX	UNIT
V <sub>S</sub>	Supply voltage, V <sub>S</sub> = (V+) – (V–)	Single-supply		6	V
		Dual-supply		±3	
	Input voltage, all pins	Common-mode	(V–) – 0.5	(V+) + 0.5	V
		Differential		(V+) – (V–) + 0.5	
	Input current, all pins			±10	mA
	Output short circuit <sup>(2)</sup>		Continuous	Continuous	
T <sub>A</sub>	Operating temperature		–55	150	°C
T <sub>J</sub>	Junction temperature		–55	150	°C
T <sub>stg</sub>	Storage temperature		–65	150	°C

- (1) Operation outside the Absolute Maximum Ratings may cause permanent device damage. Absolute Maximum Ratings do not imply functional operation of the device at these or any other conditions beyond those listed under Recommended Operating Conditions. If used outside the Recommended Operating Conditions but within the Absolute Maximum Ratings, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.
- (2) Short-circuit to ground, one amplifier per package.

### 6.2 ESD Ratings

			VALUE	UNIT
V <sub>(ESD)</sub>	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>	±2000	V
		Charged-device model (CDM), per ANSI/ESDA/JEDEC JS-002 <sup>(2)</sup>	±500	

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

### 6.3 Recommended Operating Conditions

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

			MIN	NOM	MAX	UNIT
V <sub>S</sub>	Supply voltage, V <sub>S</sub> = (V+) – (V–)	Single-supply	1.7		5.5	V
		Dual-supply	±0.85		±2.75	
	Differential input voltage		–0.5		0.5	V
T <sub>A</sub>	Specified temperature		–40		125	°C

## 6.4 Thermal Information: OPA391

THERMAL METRIC <sup>(1)</sup>		OPA391	UNIT
		DCK (SC-70)	
		5 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	214	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	115	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	58	°C/W
$\Psi_{JT}$	Junction-to-top characterization parameter	29	°C/W
$\Psi_{JB}$	Junction-to-board characterization parameter	58	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	°C/W

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

## 6.5 Thermal Information: OPA2391

THERMAL METRIC <sup>(1)</sup>		OPA2391	UNIT
		YBJ (DSBGA)	
		9 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	110.7	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	0.7	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	32.1	°C/W
$\Psi_{JT}$	Junction-to-top characterization parameter	0.3	°C/W
$\Psi_{JB}$	Junction-to-board characterization parameter	32.1	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	°C/W

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

## 6.6 Electrical Characteristics

at  $V_S = 1.7\text{ V to }5.5\text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $R_L = 10\text{ k}\Omega$ , and  $V_{CM} = V_S / 2$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT	
<b>OFFSET VOLTAGE</b>								
$V_{OS}$	Input offset voltage	$V_S = 5.0\text{ V}$			$\pm 10$	$\pm 45$	$\mu\text{V}$	
		$V_{CM} = (V+) - 0.3\text{ V}$ , $V_S = 5.0\text{ V}$			$\pm 60$	$\pm 750$		
		$V_{CM} = (V-) - 0.1\text{ V}$		$\pm 15$	$\pm 80$			
		$T_A = -40^\circ\text{C to }+125^\circ\text{C}^{(1)}$				$\pm 600$		
$dV_{OS}/dT$	Input offset voltage drift	$T_A = 0^\circ\text{C to }85^\circ\text{C}^{(1)}$			$\pm 1$	$\pm 5$	$\mu\text{V}/^\circ\text{C}$	
		$T_A = -40^\circ\text{C to }+125^\circ\text{C}^{(1)}$			$\pm 1.2$	$\pm 6$		
PSRR	Power supply rejection ratio	$V_{CM} = (V-) - 0.1\text{ V}$				40	$\mu\text{V}/\text{V}$	
<b>INPUT BIAS CURRENT</b>								
$I_B$	Input bias current	$T_A = 25^\circ\text{C}^{(1)}$			$\pm 0.01$	0.8	$\text{pA}$	
		$T_A = 0^\circ\text{C to }85^\circ\text{C}^{(1)}$				5		
		$T_A = -40^\circ\text{C to }+125^\circ\text{C}^{(1)}$	OPA391DCK					30
			OPA2391YBJ					35
$I_{OS}$	Input offset current	$T_A = 25^\circ\text{C}^{(1)}$			$\pm 0.01$	0.8	$\text{pA}$	
		$T_A = 0^\circ\text{C to }85^\circ\text{C}^{(1)}$				5		
		$T_A = -40^\circ\text{C to }+125^\circ\text{C}^{(1)}$				30		
<b>NOISE</b>								
	Input voltage noise	$f = 0.1\text{ Hz to }10\text{ Hz}$ , $V_{CM} = (V-)$			0.91		$\mu\text{V}_{RMS}$	
					6.0		$\mu\text{V}_{PP}$	
$e_n$	Input voltage noise density	$f = 10\text{ Hz}$			130		$\text{nV}/\sqrt{\text{Hz}}$	
		$f = 1\text{ kHz}$			60			
		$f = 10\text{ kHz}$			55			
$i_n$	Input current noise density	$f = 1\text{ kHz}$			30		$\text{fA}/\sqrt{\text{Hz}}$	
<b>INPUT VOLTAGE</b>								
$V_{CM}$	Common-mode voltage	$T_A = -40^\circ\text{C to }+125^\circ\text{C}^{(1)}$		$(V-) - 0.1$		$(V+) + 0.1$	V	
CMRR	Common-mode rejection ratio	$(V-) - 0.1\text{ V} \leq V_{CM} \leq (V+) - 1.5\text{ V}$	OPA391DCK		89	100	dB	
			OPA2391YBJ			100		
		$(V-) - 0.1\text{ V} \leq V_{CM} \leq (V+) - 1.5\text{ V}$ , $V_S = 5.5\text{ V}$	$T_A = -40^\circ\text{C to }+125^\circ\text{C}^{(1)}$		100	121		
					90	100		
$(V+) - 0.6\text{ V} \leq V_{CM} \leq (V+) + 0.1\text{ V}$					69			
<b>INPUT IMPEDANCE</b>								
$Z_{id}$	Differential input impedance				$0.1 \parallel 1$		$\text{G}\Omega \parallel \text{pF}$	
$Z_{ic}$	Common-mode input impedance				$1 \parallel 1$		$\text{T}\Omega \parallel \text{pF}$	



## 6.6 Electrical Characteristics (continued)

 at  $V_S = 1.7\text{ V to }5.5\text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $R_L = 10\text{ k}\Omega$ , and  $V_{CM} = V_S / 2$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
<b>OPEN-LOOP GAIN</b>							
$A_{OL}$	Open-loop voltage gain	$V_S = 5.5\text{ V}$	$(V^-) + 0.1\text{ V} < V_O < (V^+) - 0.1\text{ V}$ , $V_{CM} = (V^-) - 100\text{ mV}$	100	121		dB
			$(V^-) + 0.45\text{ V} < V_O < (V^+) - 0.45\text{ V}$ , $V_{CM} = (V^-) - 100\text{ mV}$ , $R_L = 2\text{ k}\Omega$	100	121		
		$V_S = 1.7\text{ V}$	$(V^-) + 0.1\text{ V} < V_O < (V^+) - 0.1\text{ V}$ , $V_{CM} = (V^+) - 1.5\text{ V}$	90	113		
			$(V^-) + 0.45\text{ V} < V_O < (V^+) - 0.45\text{ V}$ , $V_{CM} = (V^+) - 1.5\text{ V}$ , $R_L = 2\text{ k}\Omega$	90	107		
<b>FREQUENCY RESPONSE</b>							
$UGB$	Unity-gain bandwidth	$G = 1$	$I_{OUT} = 0\text{ }\mu\text{A}$		450		kHz
			$I_{OUT} = 0\text{ }\mu\text{A}$ , $R_L = 50\text{ k}\Omega$		0.85		MHz
			$I_{OUT} = 100\text{ }\mu\text{A}$		0.75		MHz
$GBW$	Gain-bandwidth product				1		MHz
$SR$	Slew rate	$G = -1$ , 4-V step			1		V/ $\mu\text{s}$
$t_S$	Settling time	To 0.1%, $V_S = 5.5\text{ V}$ , $G = 1$ , 1-V step			8		$\mu\text{s}$
$t_{OR}$	Overload recovery time	$V_{IN} \times G = V_S$			15		$\mu\text{s}$
<b>OUTPUT</b>							
$V_O$	Voltage output swing from rail	No load				3	mV
						10	
			$R_L = 2\text{ k}\Omega$			40	
			$T_A = -40^\circ\text{C to }+125^\circ\text{C}^{(1)}$	OPA391DCK		10	
				OPA2391YBJ		12	
$I_{SC}$	Short-circuit current	$V_S = 5.5\text{ V}$			60		mA
$Z_O$	Open-loop output impedance	$f = 1\text{ MHz}$ , no load			500		$\Omega$
<b>POWER SUPPLY</b>							
$I_Q$	Quiescent current per amplifier	$V_{CM} = (V^+) - 1.5\text{ V}$			24	30	$\mu\text{A}$
			$T_A = -40^\circ\text{C to }+125^\circ\text{C}^{(1)}$				
<b>SHUTDOWN (OPA2391YBJ Only)</b>							
$I_{QSD}$	Quiescent current per amplifier <sup>(2)</sup>	All amplifiers disabled, $EN = (V^-)$			3.5		$\mu\text{A}$
$V_{IH}$	High-level input voltage <sup>(2)</sup>	Amplifier enabled			$(V^+) - 0.5$		V
$V_{IL}$	Low-level input voltage <sup>(2)</sup>	Amplifier disabled				$(V^-) + 0.5$	V
$t_{ON}$	Amplifier enable time <sup>(2)</sup>	$G = 1$ , $V_{OUT} = 0.9 \times V_S/2^{(3)}$			75		$\mu\text{s}$
$t_{OFF}$	Amplifier disable time <sup>(2)</sup>	$G = 1$ , $V_{OUT} = 0.1 \times V_S/2^{(3)}$			4		$\mu\text{s}$
	EN pin input leakage current <sup>(2)</sup>	$V_{IH} = (V^+)$			$\pm 0.01$		$\mu\text{A}$
		$V_{IL} = (V^-)$			-0.3		

(1) Specification established from device population bench system measurements across multiple lots.

(2) Specified by design and characterization; not production tested.

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

## 6.7 Typical Characteristics

at  $T_A = 25^\circ\text{C}$ ,  $V_S = 5.0\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)

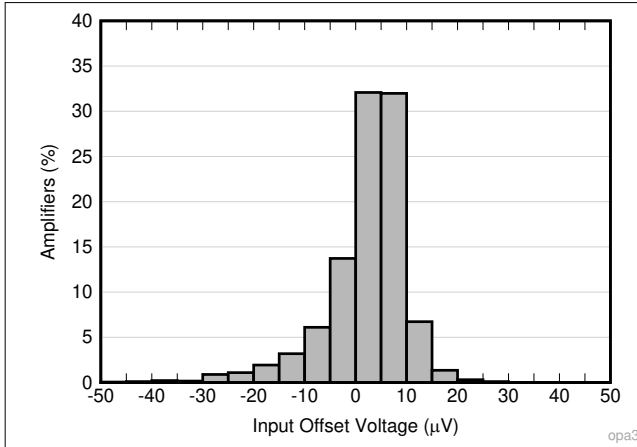


Figure 6-1. Offset Voltage Distribution

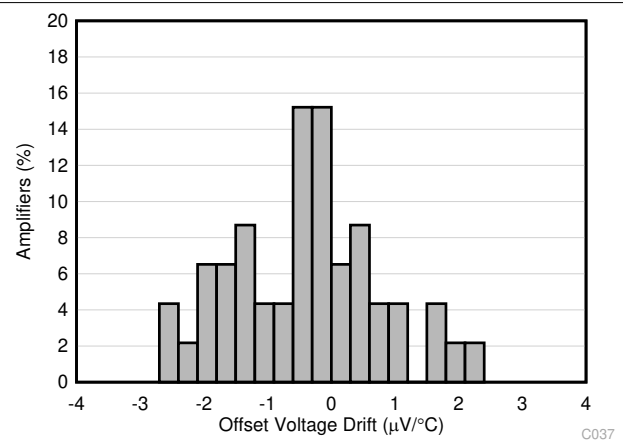


Figure 6-2. Offset Voltage Drift Distribution

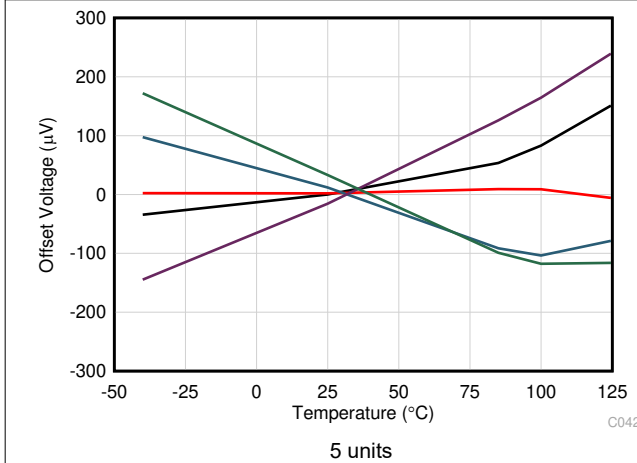


Figure 6-3. Offset Voltage vs Temperature

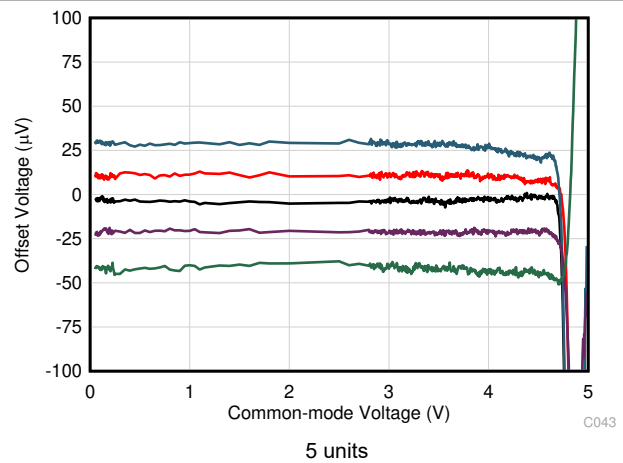


Figure 6-4. Offset Voltage vs Common-Mode Voltage

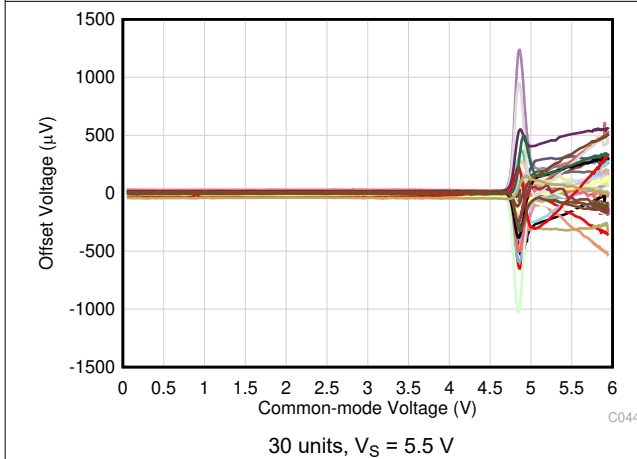


Figure 6-5. Offset Voltage vs Common-Mode Voltage

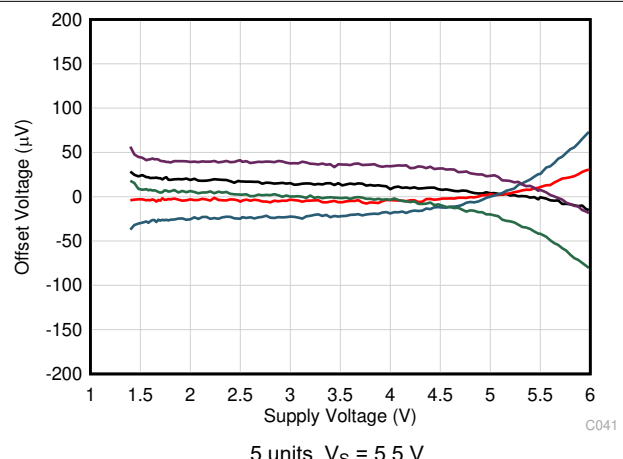
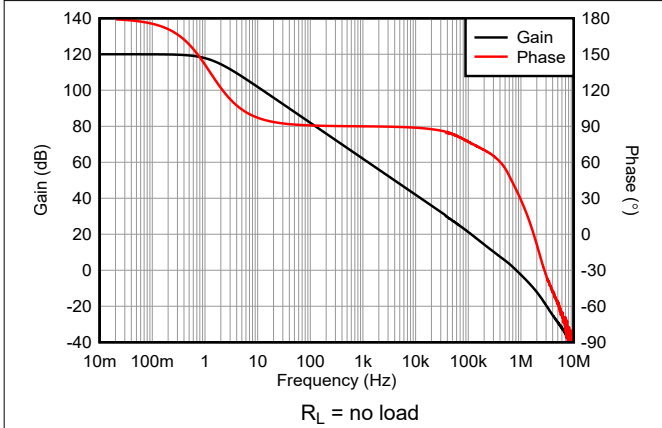


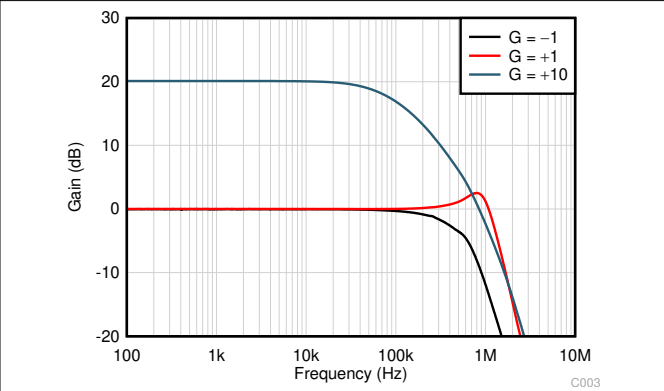
Figure 6-6. Offset Voltage vs Supply Voltage

### 6.7 Typical Characteristics (continued)

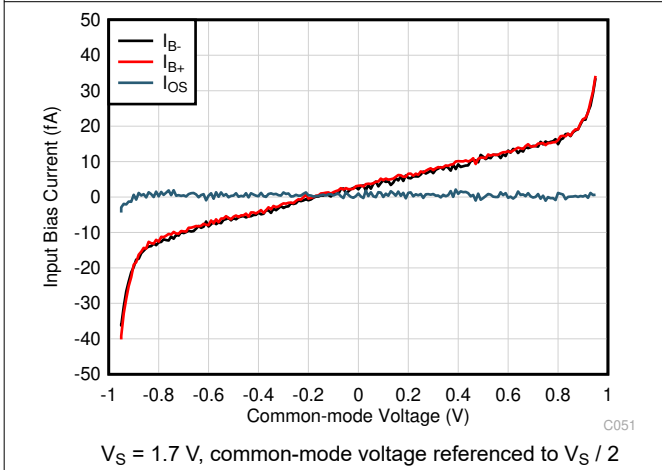
at  $T_A = 25^\circ\text{C}$ ,  $V_S = 5.0\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)



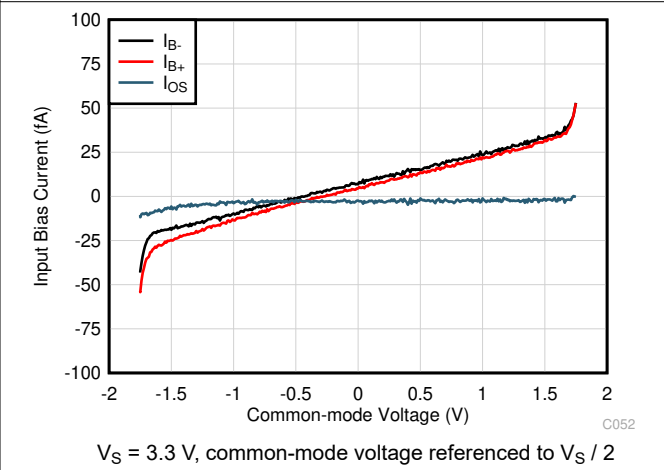
**Figure 6-7. Open-Loop Gain and Phase vs Frequency**



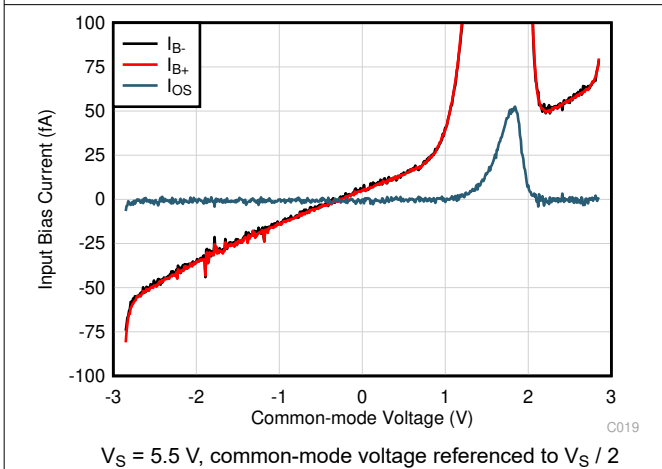
**Figure 6-8. Closed-Loop Gain and Phase vs Frequency**



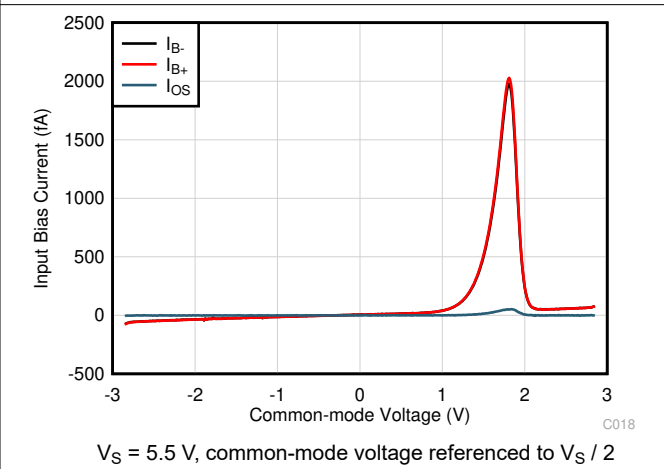
**Figure 6-9. Input Bias Current vs Common-Mode Voltage**



**Figure 6-10. Input Bias Current vs Common-Mode Voltage**



**Figure 6-11. Input Bias Current vs Common-Mode Voltage**



**Figure 6-12. Input Bias Current vs Common-Mode Voltage**

### 6.7 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = 5.0\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)

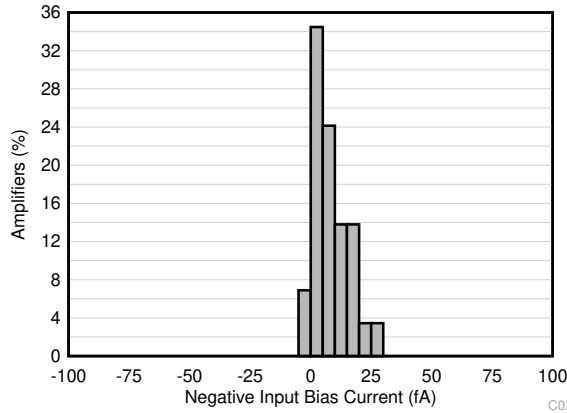


Figure 6-13. Negative Input Bias Current Distribution

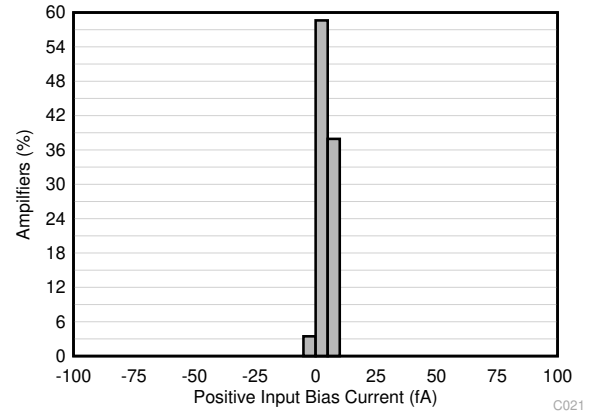


Figure 6-14. Positive Input Bias Current Distribution

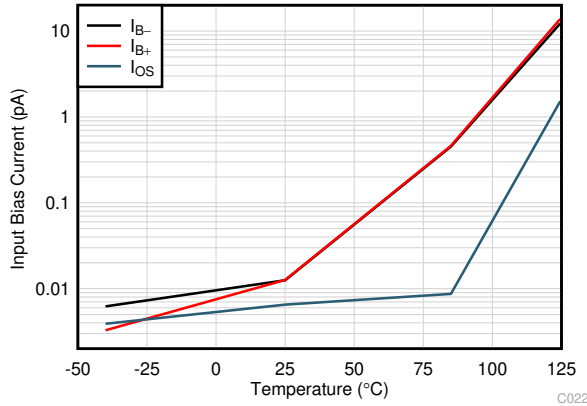


Figure 6-15. Input Bias Current vs Temperature

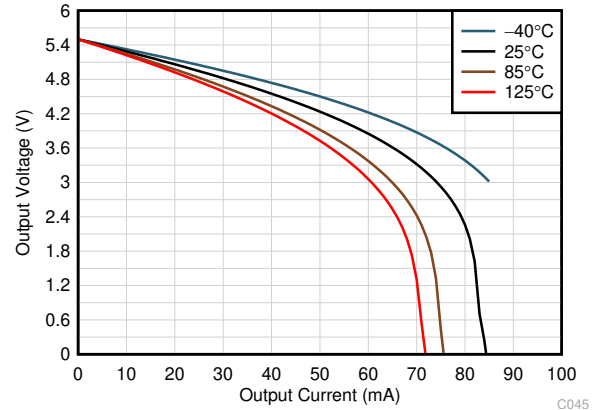


Figure 6-16. Output Voltage Swing vs Output Current (Maximum Supply)

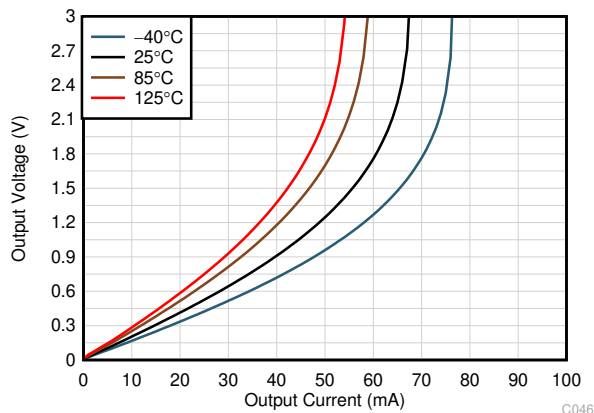


Figure 6-17. Output Voltage Swing vs Output Current (Maximum Supply)

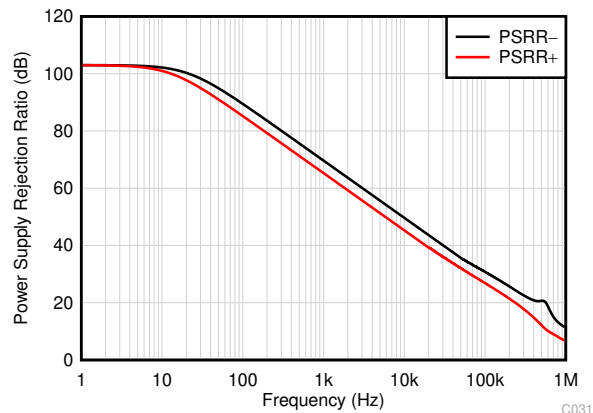
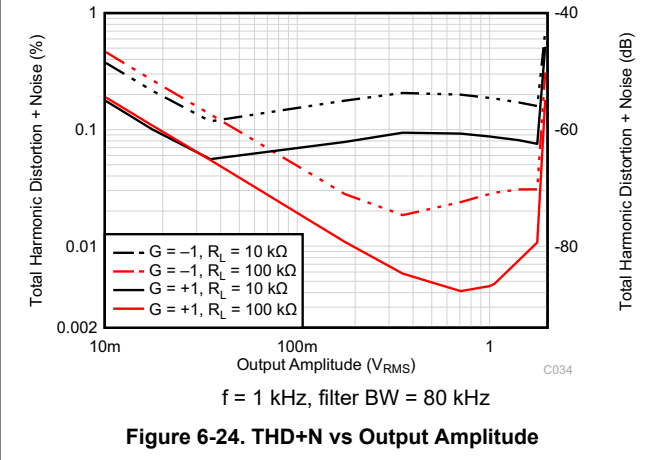
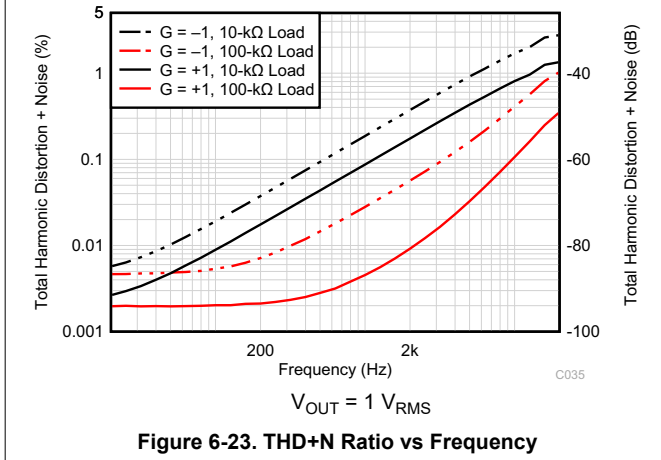
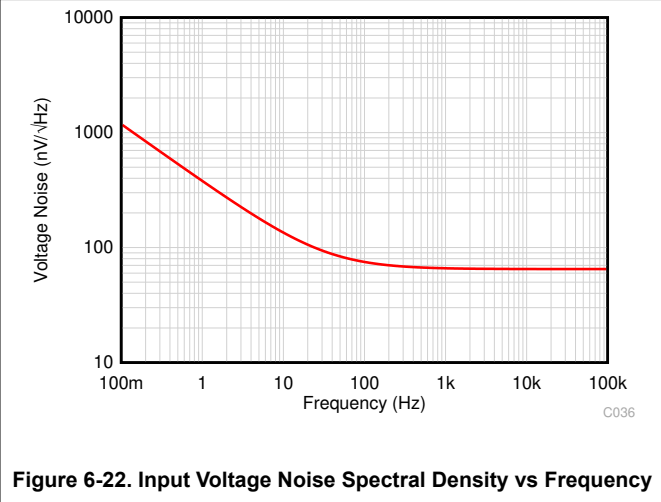
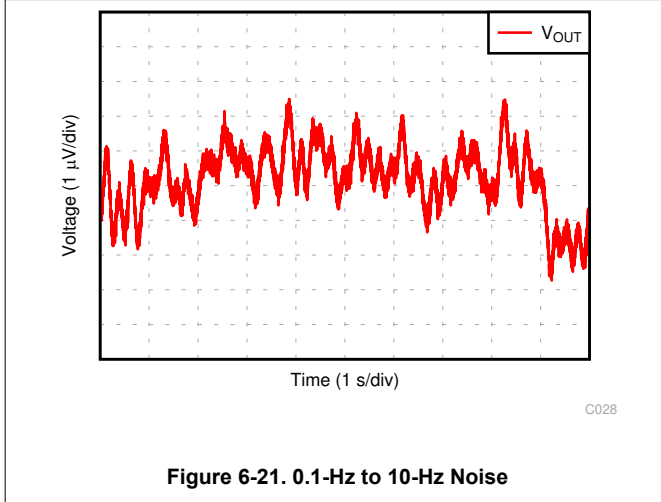
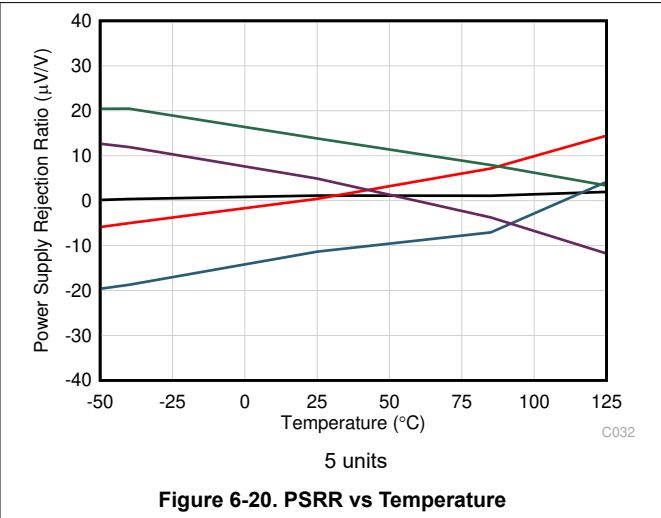
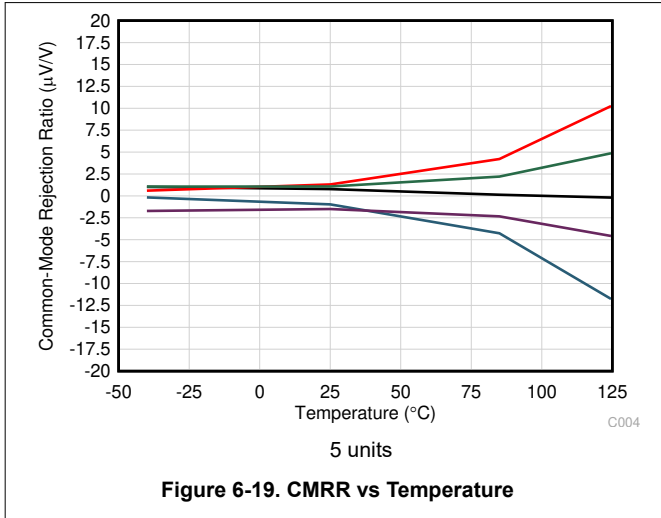


Figure 6-18. PSRR vs Frequency

### 6.7 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = 5.0\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)



### 6.7 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = 5.0\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)

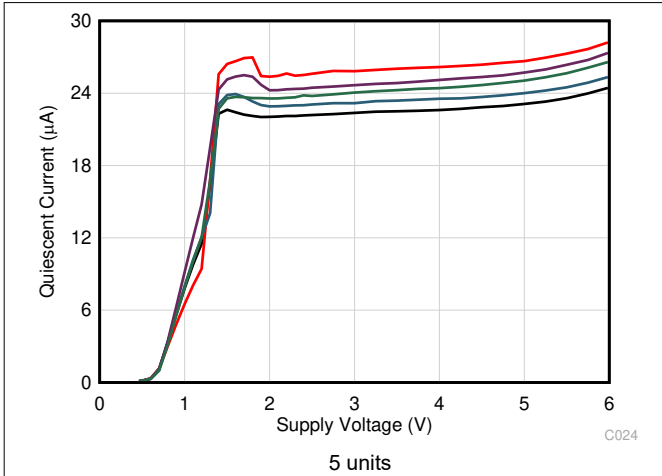


Figure 6-25. Quiescent Current vs Supply Voltage

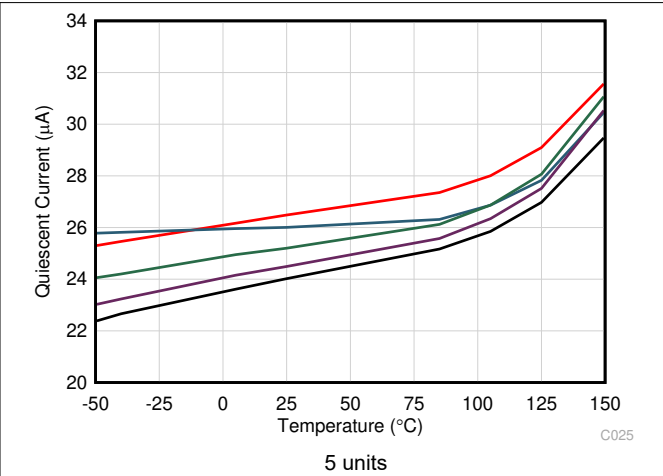


Figure 6-26. Quiescent Current vs Temperature

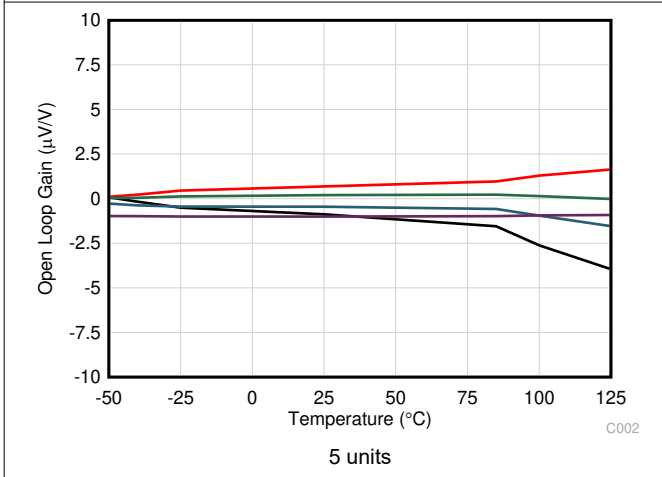


Figure 6-27. Open-Loop Gain vs Temperature

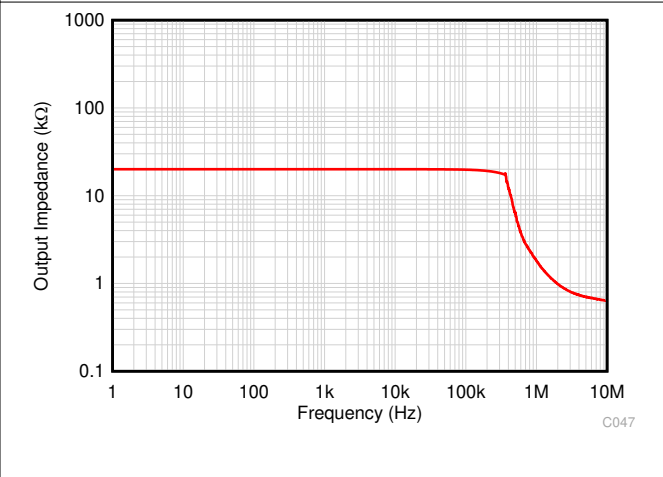


Figure 6-28. Open-Loop Output Impedance vs Frequency

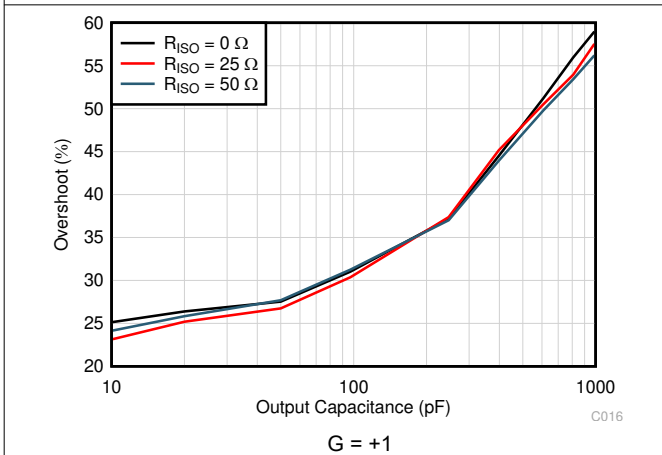


Figure 6-29. Small-Signal Overshoot vs Capacitive Load (10-mV Step)

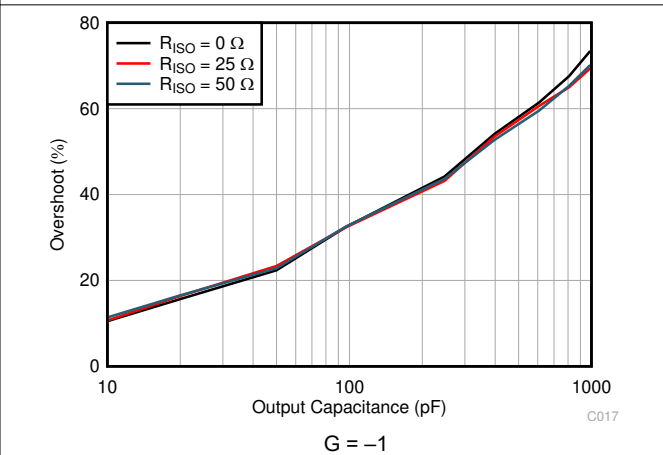
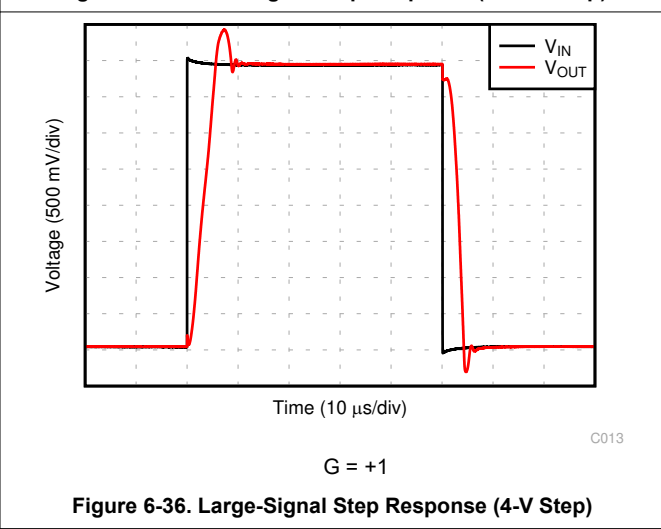
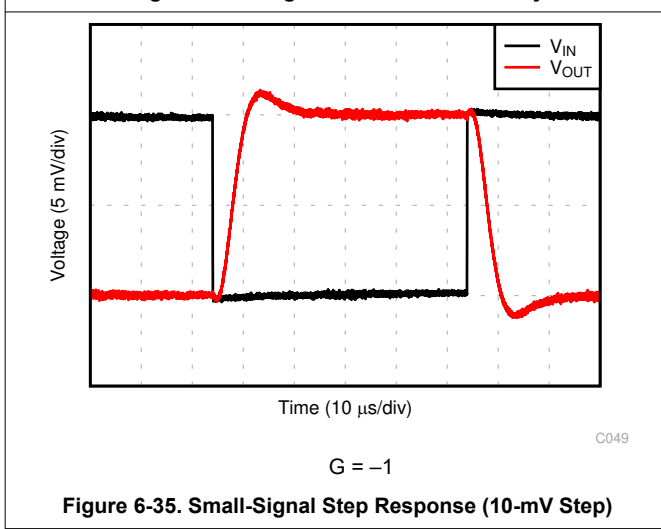
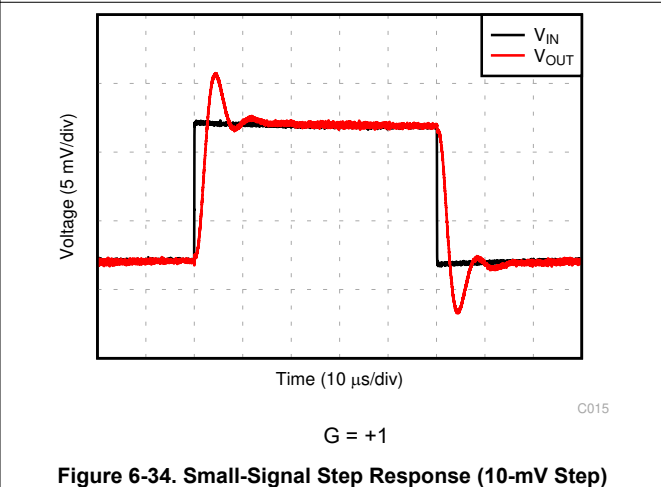
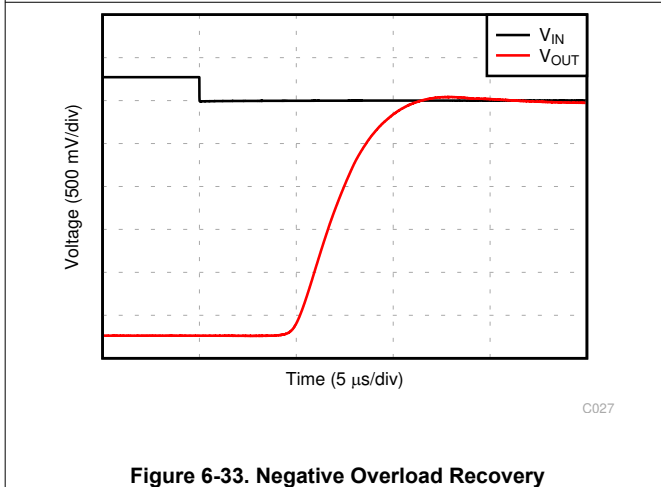
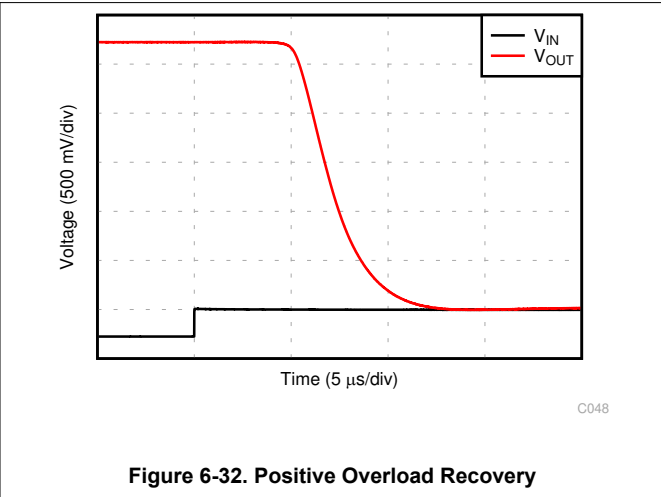
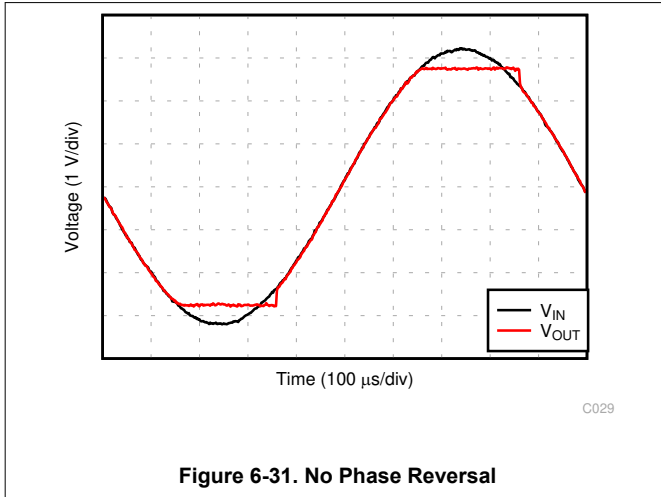


Figure 6-30. Small-Signal Overshoot vs Capacitive Load (10-mV Step)

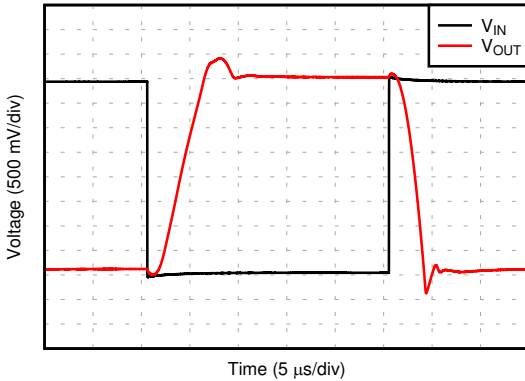
## 6.7 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = 5.0\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)



### 6.7 Typical Characteristics (continued)

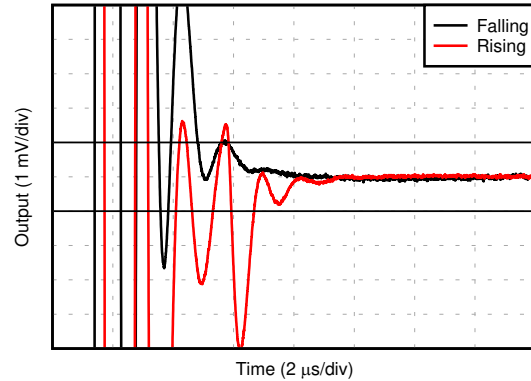
at  $T_A = 25^\circ\text{C}$ ,  $V_S = 5.0\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)



C014

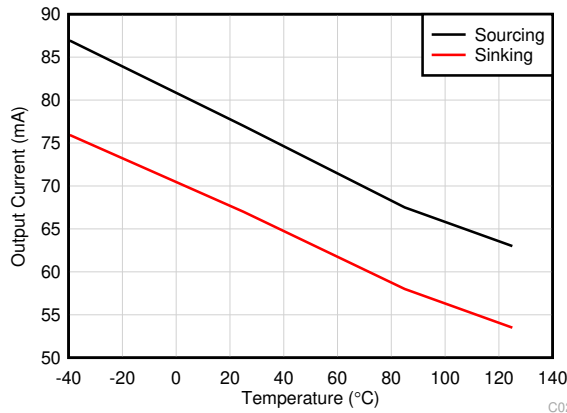
$G = -1$

Figure 6-37. Large-Signal Step Response (4-V Step)



C033

Figure 6-38. Settling Time (1-V Positive Step)



C026

Figure 6-39. Short-Circuit Current vs Temperature

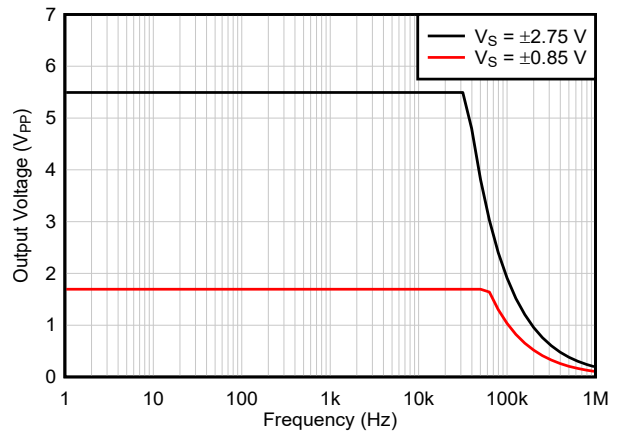
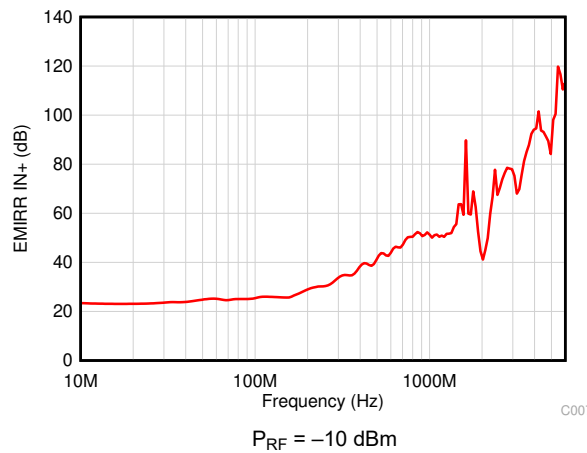


Figure 6-40. Maximum Output Voltage vs Frequency



C007

Figure 6-41. EMIRR vs Frequency



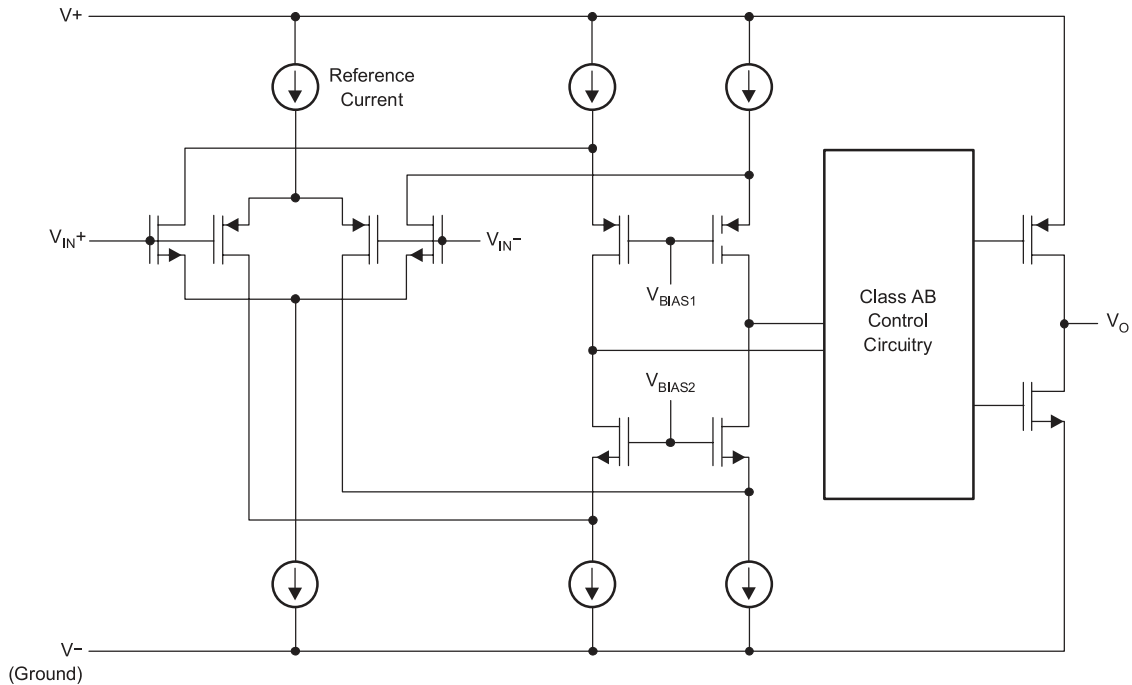
## 7 Detailed Description

### 7.1 Overview

The OPAX391 are low-offset, low-power, e-trim operational amplifiers (op amps) that uses a proprietary offset trim technique. These op amps offer ultra-low input offset voltage, drift, and input bias current, while achieving an excellent bandwidth-to-quiescent-current ratio. The OPAX391 operate from 1.7 V to 5.5 V, are unity-gain stable, and are designed for a wide range of general-purpose and precision applications.

The output features an advanced output stage that tolerates high capacitive loading for solid and stable performance. The OPAX391 strengths make these devices an excellent amplifier for high-impedance sensors, where input bias current, offset voltage, and power consumption are critical.

### 7.2 Functional Block Diagram



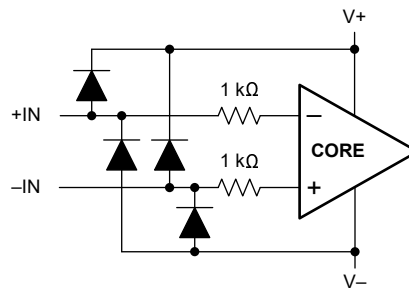
## 7.3 Feature Description

### 7.3.1 Low Input Bias Current

The OPAx391 achieve very low input bias current as a result of CMOS inputs and advanced electrostatic discharge (ESD) protection circuitry. Input bias current ( $I_B$ ) is primarily a function of the input protection scheme in CMOS input amplifiers. If careful consideration is not taken with the ESD cells, a CMOS input device can exhibit large input bias currents, especially over temperature. The OPAx391 achieve excellent input bias current ratings of  $\pm 30$  pA maximum at 125°C.

### 7.3.2 Input Differential Voltage

The OPAx391 do not have any diodes connected between the input nodes, allowing for input voltages anywhere between the supply voltage. The input structure can be seen in [Figure 7-1](#). Although these devices can tolerate any differential input voltage that does not exceed the supply voltage, do not operate continuously at differential input voltages greater than 0.5 V.



**Figure 7-1. Equivalent Input Circuit**

### 7.3.3 Capacitive Load Drive

The OPAx391 feature advanced output drive circuitry that maintain stability even with capacitive loads as high as 1 nF. Many low-quiescent-current amplifiers exhibit poor stability when connected to a capacitive load as a result of the low levels of current used to bias the output stage. The OPAx391 are designed with an output stage that adapts to high capacitive loads without sacrificing additional current consumption. This feature helps produce a highly stable device across all temperature and supply conditions, enabling robust system performance.

### 7.3.4 EMI Rejection

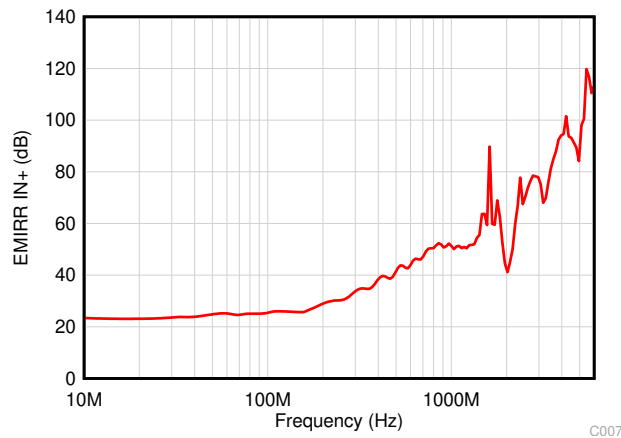
The OPAx391 use integrated electromagnetic interference (EMI) filtering to reduce the effects of EMI interference from sources such as wireless communications and densely-populated boards with a mix of analog signal chain and digital components. EMI immunity can be improved with circuit design techniques; the OPAx391 benefit 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 7-2](#) shows the results of this testing on the OPAx391. [Table 7-1](#) lists the EMIRR +IN values for the OPAx391 at particular frequencies commonly encountered in real-world applications. Applications listed in [Table 7-1](#) can be centered on or operated near the particular frequency shown. Detailed information can also be found in the [EMI Rejection Ratio of Operational Amplifiers application report](#), available for download from [www.ti.com](http://www.ti.com).

The electromagnetic interference (EMI) rejection ratio, or EMIRR, describes the EMI immunity of operational amplifiers. An adverse effect that is common to many op amps is a change in the offset voltage as a result of RF signal rectification. An op amp that is more efficient at rejecting this change in offset as a result of EMI has a higher EMIRR and is quantified by a decibel value. Measuring EMIRR can be performed in many ways, but this section provides the EMIRR +IN, which specifically describes the EMIRR performance when the RF signal is applied to the noninverting input pin of the op amp. In general, only the noninverting input is tested for EMIRR for the following three reasons:

1. Op amp input pins are known to be the most sensitive to EMI, and typically rectify RF signals better than the supply or output pins.
2. The noninverting and inverting op amp inputs have symmetrical physical layouts and exhibit nearly matching EMIRR performance.
3. EMIRR is more simple to measure on noninverting pins than on other pins because the noninverting input pin can be isolated on a PCB. This isolation allows the RF signal to be applied directly to the noninverting input pin with no complex interactions from other components or connecting PCB traces.

High-frequency signals conducted or radiated to any pin of the operational amplifier can result in adverse effects because the amplifier does not have sufficient loop gain to correct for signals with spectral content outside the bandwidth. Conducted or radiated EMI on inputs, power supply, or output can result in unexpected dc offsets, transient voltages, or other unknown behavior. Make sure to properly shield and isolate sensitive analog nodes from noisy radio signals, digital clocks, and interfaces.

The EMIRR +IN of the OPAX391 is plotted versus frequency as shown in Figure 7-2. The OPAX391 unity-gain bandwidth is 1 MHz. EMIRR performance less than this frequency denotes interfering signals that fall within the op amp bandwidth.



**Figure 7-2. EMIRR Testing**

**Table 7-1. OPAX391 EMIRR IN+ for Frequencies of Interest**

FREQUENCY	APPLICATION AND ALLOCATION	EMIRR IN+
400 MHz	Mobile radio, mobile satellite, space operation, weather, radar, ultra-high frequency (UHF) applications	39.1 dB
900 MHz	Global system for mobile communications (GSM) applications, radio communication, navigation, GPS (to 1.6 GHz), GSM, aeronautical mobile, UHF applications	46.5 dB
1.8 GHz	GSM applications, mobile personal communications, broadband, satellite, L-band (1 GHz to 2 GHz)	61.3 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)	69.8 dB
3.6 GHz	Radiolocation, aero communication and navigation, satellite, mobile, S-band	82.5 dB
5 GHz	802.11a, 802.11n, aero communication and navigation, mobile communication, space and satellite operation, C-band (4 GHz to 8 GHz)	83.6 dB

## 7.4 Device Functional Modes

The OPAX391 have a single functional mode and are operational when the power-supply voltage is greater than 1.7 V ( $\pm 0.85$  V). The maximum specified power-supply voltage for the OPAX391 is 5.5 V ( $\pm 2.75$  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, as well as validating and testing their design implementation to confirm system functionality.

### 8.1 Application Information

The OPAx391 are unity-gain stable, precision operational amplifier free from unexpected output and phase reversal. The OPAx391 are optimized for full rail-to-rail input, allowing for low-voltage, single-supply operation or split-supply use. These miniature, high-precision, low-noise amplifiers offer high-impedance inputs that have a common-mode range 100 mV beyond the supplies and can tolerate the full supply voltage across the input. The OPAx391 precision amplifier is designed for sensor amplification, low-power analog signal chain applications in low or high gains, as well as a low-power discrete MOSFET or bipolar driver.

### 8.2 Typical Applications

#### 8.2.1 Three-Terminal CO Gas Sensor

Figure 8-1 shows a simple micropower potentiostat circuit for use with three-terminal unbiased CO sensors. This same design is applicable to many other type of three-terminal gas sensors or electrochemical cells. The basic sensor has three electrodes: the sense or working electrode (WE), counter electrode (CE), and reference electrode (RE). A current flows between CE and WE proportional to the detected concentration. The RE monitors the potential of the internal reference point. For an unbiased sensor, the WE and RE must be maintained at the same potential by adjusting the bias on CE. Through the potentiostat circuit formed by U1, the servo feedback action maintains the RE pin at a potential set by  $V_{REF}$ . R1 maintains stability as a result of the large capacitance of the sensor. C1 and R2 form the potentiostat integrator and set the feedback time constant. U2 forms a transimpedance amplifier (TIA) to convert the resulting sensor current into a proportional voltage. Equation 1 calculates the transimpedance gain, and resulting sensitivity, using  $R_F$ :

$$V_{TIA} = (-I * R_F) + V_{REF} \quad (1)$$

$R_{Load}$  is a load resistor with a value that is normally specified by the sensor manufacturer (typically, 10  $\Omega$ ). The potential at WE is set by the applied  $V_{REF}$ .

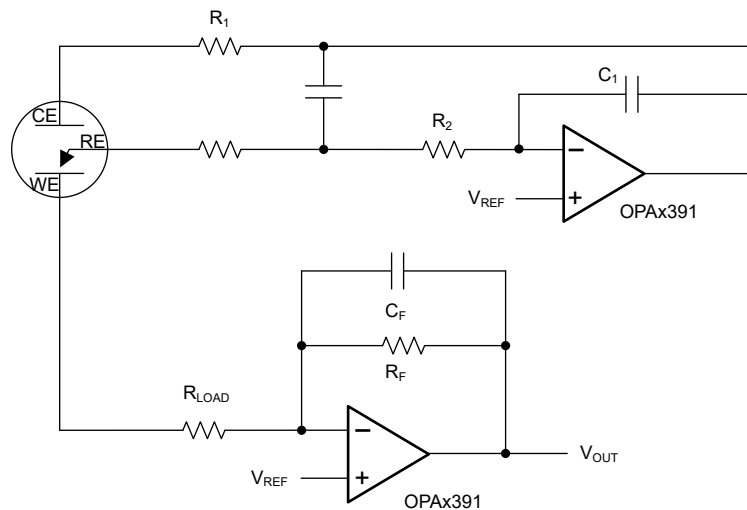
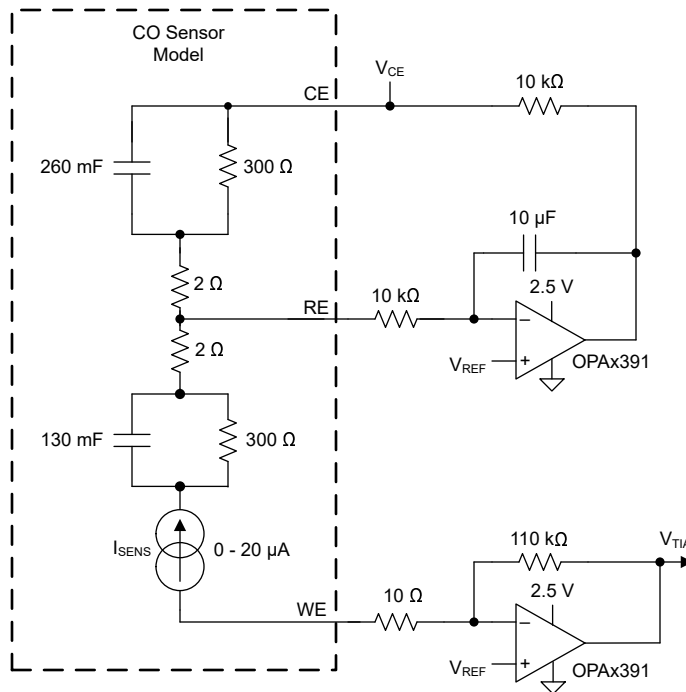


Figure 8-1. Three-Terminal CO Gas Sensor

### 8.2.1.1 Design Requirements

For this example, Figure 8-2 shows an electrical model of a CO sensor is used to simulate the sensor performance. The simulation is designed to model a CO sensor with a sensitivity of 69 nA/ppm. The supply voltage and maximum analog-to-digital converter (ADC) input voltage is 2.5 V, and the maximum concentration is 300 ppm.



**Figure 8-2. CO Sensor Simulation Schematic**

### 8.2.1.2 Detailed Design Procedure

First, determine the  $V_{REF}$  voltage. This voltage is a compromise between maximum headroom and resolution, as well as allowance for the minimum swing on the CE terminal because the CE terminal generally goes negative in relation to the RE potential as the concentration (sensor current) increases. Bench measurements found the difference between CE and RE to be 180 mV at 300 ppm for this particular sensor. To allow for negative CE swing, footroom, and voltage drop across the 10-kΩ resistor, 300 mV is chosen for  $V_{REF}$ .

$$V_{ZERO} = V_{REF} = 300 \text{ mV} \quad (2)$$

where

- $V_{REF}$  is the reference voltage (300 mV).
- $V_{ZERO}$  is the concentration voltage (300 mV).

Next, calculate the maximum sensor current at highest expected concentration:

$$I_{SENSMAX} = I_{PERPPM} * \text{ppmMAX} = 69 \text{ nA} * 300 \text{ ppm} = 20.7 \text{ } \mu\text{A} \quad (3)$$

where

- $I_{SENSMAX}$  is the maximum expected sensor current.
- $I_{PERPPM}$  is the manufacturer specified sensor current in amperes per ppm.
- ppmMAX is the maximum required ppm reading.

Then, find the available output swing range greater than the reference voltage available for the measurement:

$$V_{\text{SWING}} = V_{\text{OUTMAX}} - V_{\text{ZERO}} = 2.5 \text{ V} - 0.3 \text{ V} = 2.2 \text{ V} \tag{4}$$

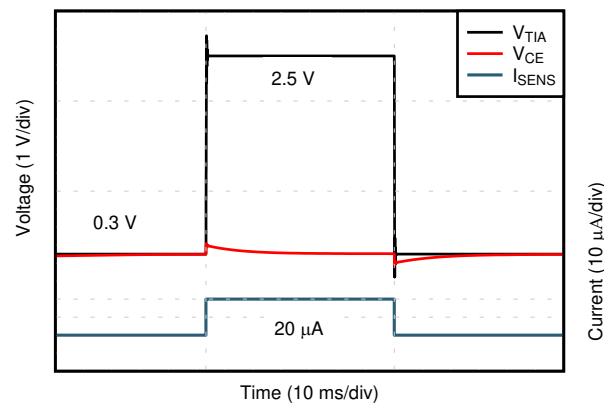
where

- $V_{\text{SWING}}$  is the expected change in output voltage.
- $V_{\text{OUTMAX}}$  is the maximum amplifier output swing.

Finally, calculate the transimpedance resistor ( $R_F$ ) value using the maximum swing and the maximum sensor current:

$$R_F = V_{\text{SWING}} / I_{\text{SENSMAX}} = 2.2 \text{ V} / 20.7 \text{ } \mu\text{A} = 106.28 \text{ k}\Omega \text{ (use } 110 \text{ k}\Omega \text{ for a common value)} \tag{5}$$

### 8.2.1.3 Application Curve



C012

**Figure 8-3. Sensor Transient Response to Simulated 300-ppm CO Exposure**

### 8.2.2 4-mA to 20-mA Loop Design

Factory automation systems commonly use the 4-mA to 20-mA (4-20 mA) communication protocol to enable process automation. In typical 2-wire, 4-mA to 20-mA loop applications, power to the remote transmitter is limited to less than 4 mA total consumption. As a result of the power limitations, low power consumption is essential. The OPAx391 solves many design challenges in 4-mA to 20-mA loop applications, where low power, high accuracy, and high bandwidth are required.

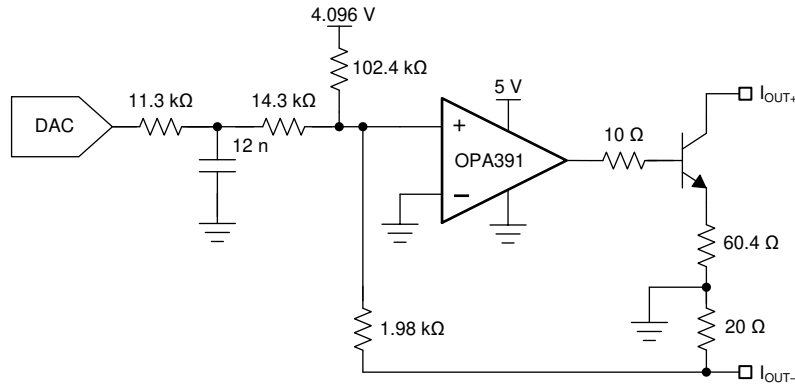


Figure 8-4. 4-20 mA Loop Interface Schematic

#### 8.2.2.1 Application Curve

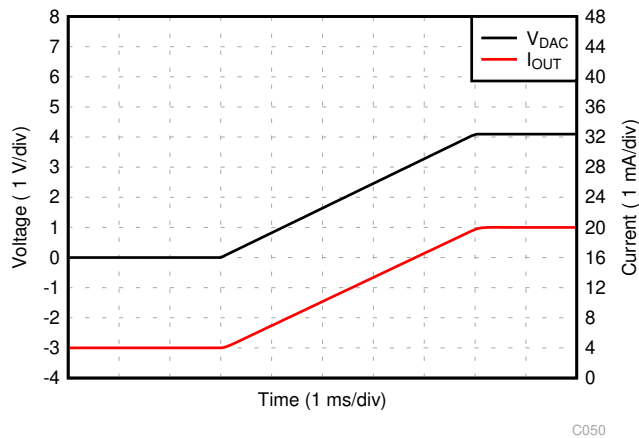


Figure 8-5. 4-mA to 20-mA Loop Response

## 8.3 Power Supply Recommendations

The OPAx391 devices are specified for operation from 1.7 V to 5.5 V ( $\pm 0.85$  V to  $\pm 2.75$  V).

## 8.4 Layout

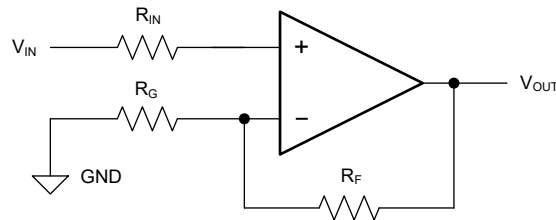
### 8.4.1 Layout Guidelines

Paying attention to good layout practice is always recommended:

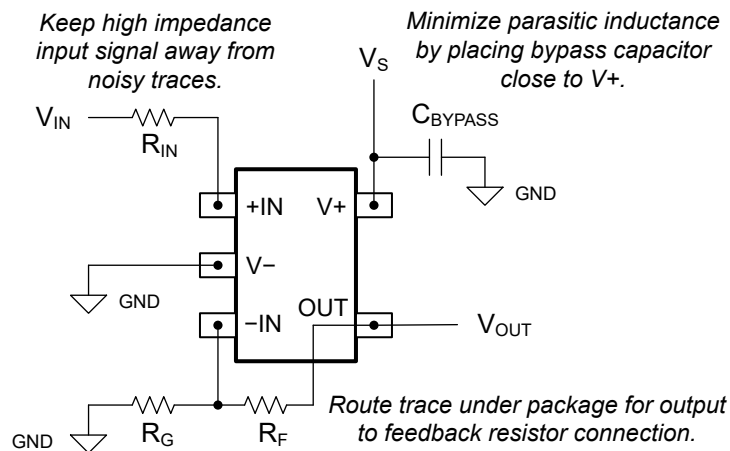
- Keep traces short.
- When possible, use a printed-circuit board (PCB) ground plane with surface-mount components placed as close as possible to the device pins.
- Place a 0.1- $\mu$ F capacitor closely across the supply pins.

These guidelines must be applied throughout the analog circuit to improve performance and provide benefits, such as reducing the electromagnetic interference (EMI) susceptibility.

### 8.4.2 Layout Example



**Figure 8-6. Schematic Representation**



**Figure 8-7. Layout Example**



## 9 Device and Documentation Support

### 9.1 Device Support

#### 9.1.1 Development Support

##### 9.1.1.1 PSpice® for TI

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

##### 9.1.1.2 TINA-TI™ Simulation Software (Free Download)

TINA-TI™ simulation software is a simple, powerful, and easy-to-use circuit simulation program based on a SPICE engine. TINA-TI simulation software is a free, fully-functional version of the TINA™ software, preloaded with a library of macromodels, in addition to a range of both passive and active models. TINA-TI simulation software 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 [Design tools and simulation](#) web page, TINA-TI simulation software 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.

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#### Note

These files require that either the TINA software or TINA-TI software be installed. Download the free TINA-TI simulation software from the [TINA-TI™ software folder](#).

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### 9.2 Documentation Support

#### 9.2.1 Related Documentation

For related documentation see the following:

- Texas Instruments, [Highly-Accurate, Loop-Powered, 4mA to 20mA Field Transmitter With HART Modem reference design](#)
- Texas Instruments, [Micropower Electrochemical Gas Sensor Amplifier reference design](#)
- Texas Instruments, [Compensate Transimpedance Amplifiers Intuitively application report](#)
- Texas Instruments, [Designing With pH Electrodes application report](#)

### 9.3 Receiving Notification of Documentation Updates

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

### 9.4 Support Resources

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

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PSpice® is a registered trademark of Cadence Design Systems, Inc.

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## 9.6 Electrostatic Discharge Caution



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

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

## 9.7 Glossary

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

## 10 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 finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
OPA2391YBJR	ACTIVE	DSBGA	YBJ	9	3000	RoHS & Green	SNAGCU	Level-1-260C-UNLIM	-40 to 125	O91	<a href="#">Samples</a>
OPA2391YBJT	ACTIVE	DSBGA	YBJ	9	250	RoHS & Green	SNAGCU	Level-1-260C-UNLIM	-40 to 125	O91	<a href="#">Samples</a>
OPA391DCKR	ACTIVE	SC70	DCK	5	3000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	1EJ	<a href="#">Samples</a>
OPA391DCKT	ACTIVE	SC70	DCK	5	250	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	1EJ	<a href="#">Samples</a>

(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.

**OBSELETE:** 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 <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm 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 finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

**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
OPA2391YBJR	DSBGA	YBJ	9	3000	180.0	8.4	1.26	1.26	0.43	4.0	8.0	Q1
OPA2391YBJT	DSBGA	YBJ	9	250	180.0	8.4	1.26	1.26	0.43	4.0	8.0	Q1
OPA391DCKR	SC70	DCK	5	3000	178.0	9.0	2.4	2.5	1.2	4.0	8.0	Q3
OPA391DCKT	SC70	DCK	5	250	178.0	9.0	2.4	2.5	1.2	4.0	8.0	Q3

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
OPA2391YBJR	DSBGA	YBJ	9	3000	182.0	182.0	20.0
OPA2391YBJT	DSBGA	YBJ	9	250	182.0	182.0	20.0
OPA391DCKR	SC70	DCK	5	3000	190.0	190.0	30.0
OPA391DCKT	SC70	DCK	5	250	190.0	190.0	30.0

DCK0005A



# PACKAGE OUTLINE

SOT - 1.1 max height

SMALL OUTLINE TRANSISTOR



4214834/C 03/2023

## NOTES:

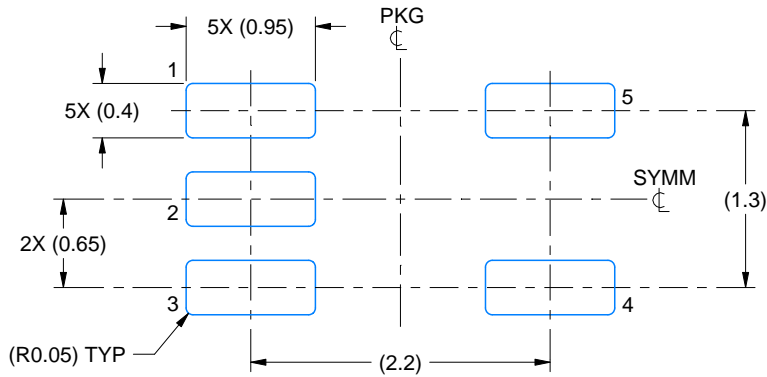
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC MO-203.
4. Support pin may differ or may not be present.

# EXAMPLE BOARD LAYOUT

DCK0005A

SOT - 1.1 max height

SMALL OUTLINE TRANSISTOR



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:18X



SOLDER MASK DETAILS

4214834/C 03/2023

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.

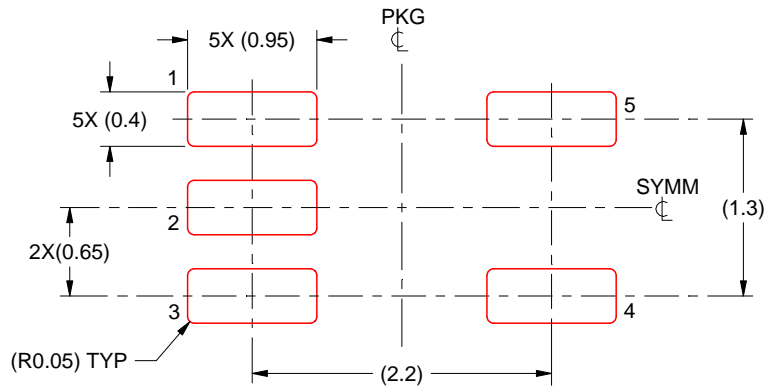


# EXAMPLE STENCIL DESIGN

DCK0005A

SOT - 1.1 max height

SMALL OUTLINE TRANSISTOR



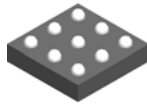
SOLDER PASTE EXAMPLE  
BASED ON 0.125 THICK STENCIL  
SCALE:18X

4214834/C 03/2023

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.

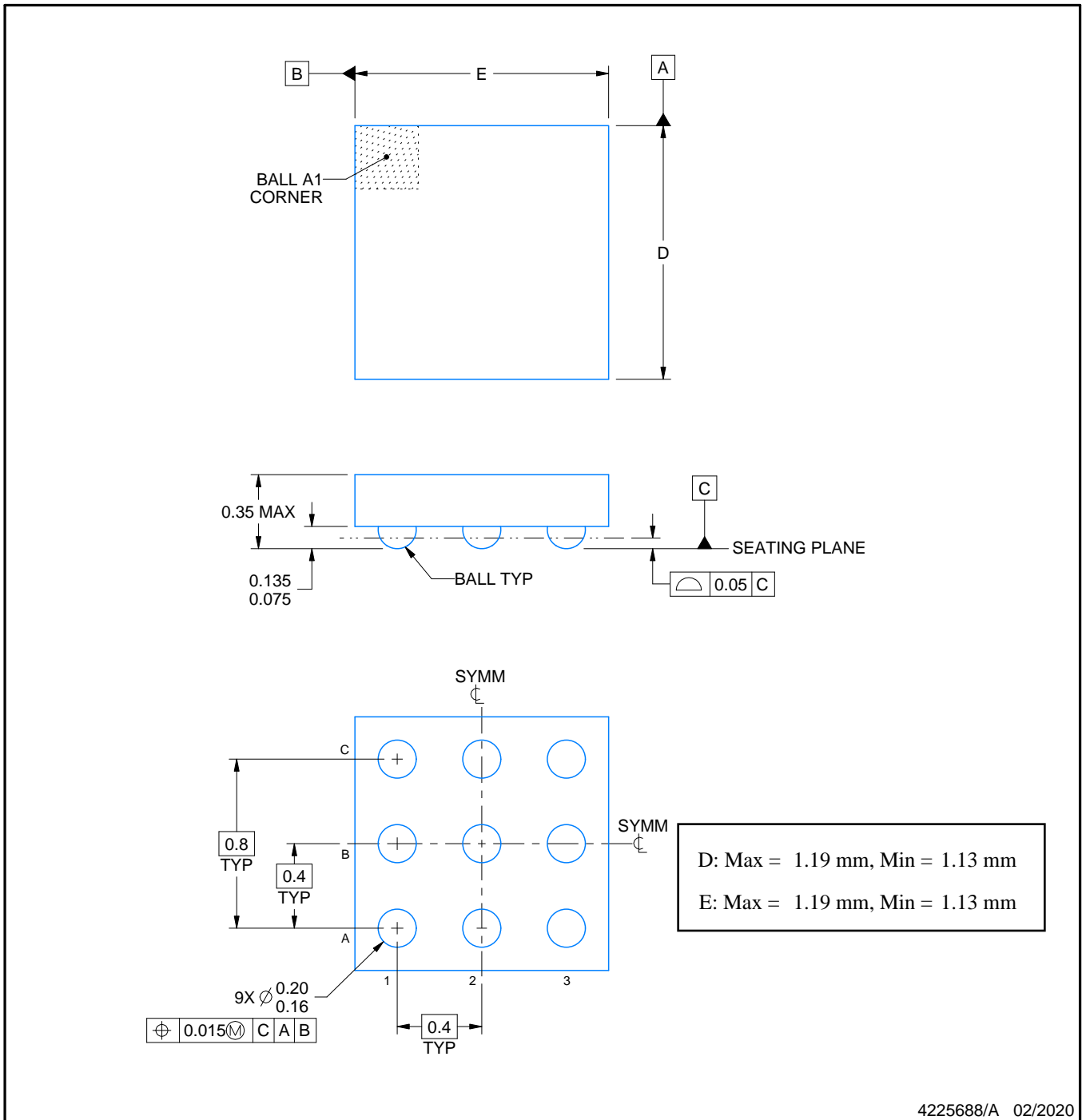
YBJ0009



# PACKAGE OUTLINE

DSBGA - 0.35 mm max height

DIE SIZE BALL GRID ARRAY



NOTES:

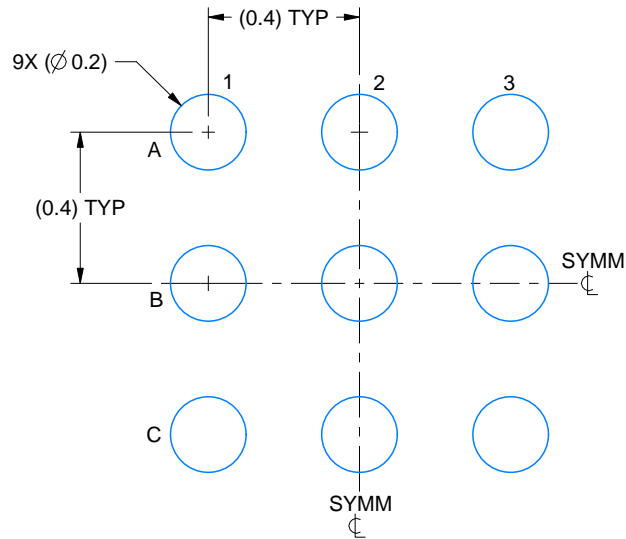
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.

# EXAMPLE BOARD LAYOUT

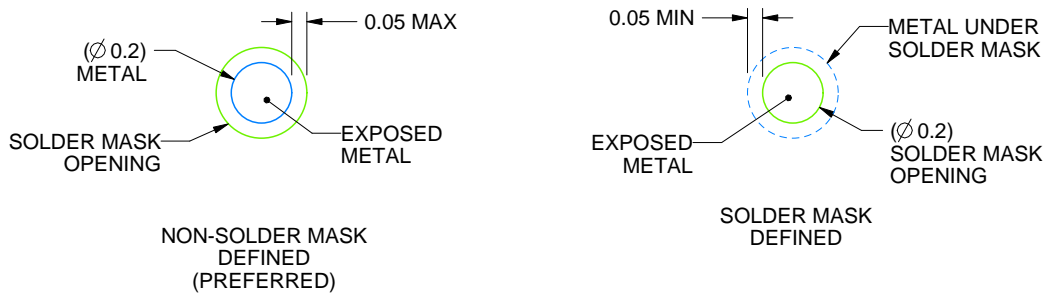
YBJ0009

DSBGA - 0.35 mm max height

DIE SIZE BALL GRID ARRAY



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE: 50X



SOLDER MASK DETAILS  
NOT TO SCALE

4225688/A 02/2020

NOTES: (continued)

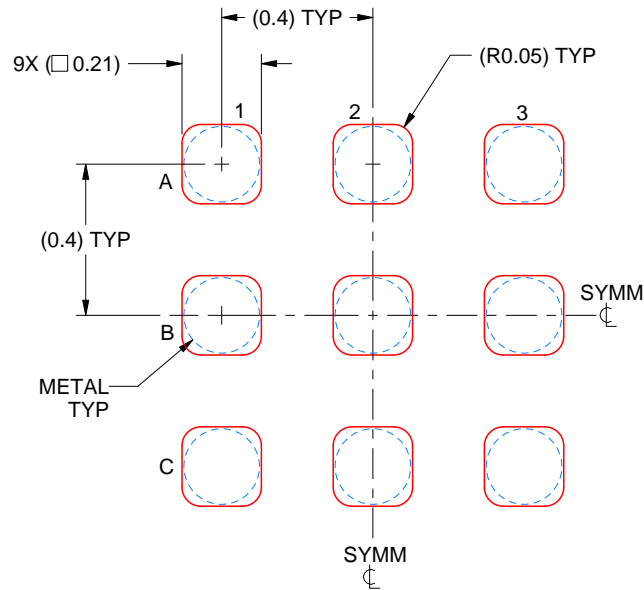
3. Final dimensions may vary due to manufacturing tolerance considerations and also routing constraints. See Texas Instruments Literature No. SNVA009 ([www.ti.com/lit/snva009](http://www.ti.com/lit/snva009)).

# EXAMPLE STENCIL DESIGN

YBJ0009

DSBGA - 0.35 mm max height

DIE SIZE BALL GRID ARRAY



SOLDER PASTE EXAMPLE  
BASED ON 0.1 mm THICK STENCIL  
SCALE: 50X

4225688/A 02/2020

NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release.

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