

# DAC11001B 20-Bit, Low-Noise, Ultra-Low Harmonic Distortion, Fast-Settling, High-Voltage-Output, Digital-to-Analog Converter (DAC)

## 1 Features

- 20-bit monotonic: 1-LSB DNL (max)
- Integral linearity: 1-LSB INL (max)
- Low noise: 7 nV/ $\sqrt{\text{Hz}}$
- Code independent low glitch: 1 nV-s
- Excellent THD:
  - 118 dB at 20-kHz  $f_{\text{OUT}}$ , 1-MHz  $f_{\text{DAC}}$
- Fast settling: 1  $\mu\text{s}$
- Flexible output ranges:  $V_{\text{REFPF}}$  to  $V_{\text{REFNF}}$
- Integrated, precision feedback resistors
- 50-MHz, 4-wire SPI-compatible interface
  - Readback
  - Daisy-chain
- Temperature range:  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$
- Package: 48-pin TQFP

## 2 Applications

- [Lab and field instrumentation](#)
- [Spectrometer](#)
- [Analog output module](#)
- [Battery Test](#)
- [Semiconductor test](#)
- [Arbitrary waveform generator \(AWG\)](#)
- [MRI](#)
- [X-ray systems](#)
- [Professional audio amplifier \(rack mount\)](#)

## 3 Description

The 20-bit DAC11001B is a highly accurate, low-noise, voltage-output, single-channel, digital-to-analog converter (DAC). The DAC11001B is specified monotonic by design, and offers excellent linearity across all output ranges.

The unbuffered voltage output offers low noise performance (7 nV/ $\sqrt{\text{Hz}}$ ) in combination with a fast settling time (1  $\mu\text{s}$ ), making this device an excellent choice for low-noise, fast control-loop, and waveform-generation applications. The DAC11001B integrates an enhanced deglitch circuit with code-independent ultra-low glitch (1 nV-s) to enable clean waveform ramps with ultra-low total harmonic distortion (THD).

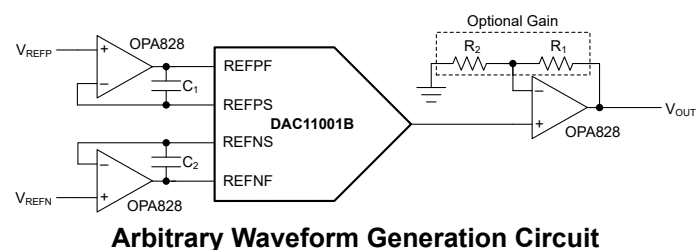
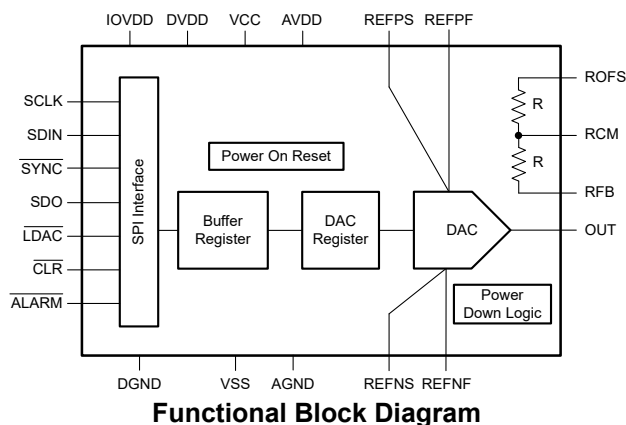
The DAC11001B device incorporates a power-on-reset (POR) circuit so that the DAC powers on with known values in the registers. With external references, DAC output ranges from  $V_{\text{REFPF}}$  to  $V_{\text{REFNF}}$  can be achieved, including asymmetric output ranges.

The DAC11001B uses a versatile 4-wire serial interface that operates at clock rates of up to 50 MHz.

### Device Information

PART NUMBER	PACKAGE <sup>(1)</sup>	BODY SIZE (NOM)
DAC11001B	TQFP (48)	7.00 mm × 7.00 mm

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



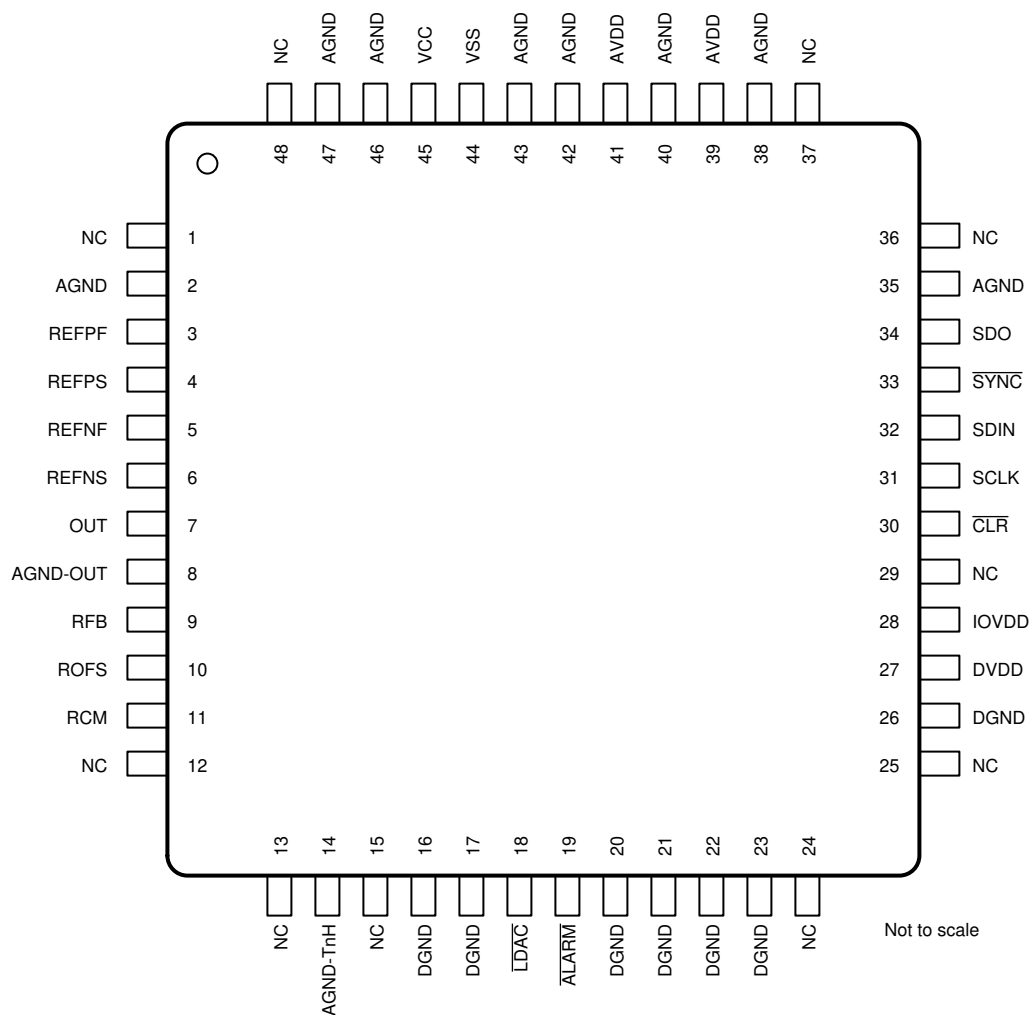
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## 4 Revision History

DATE	REVISION	NOTES
December 2021	*	Initial Release

## 5 Pin Configuration and Functions



**Figure 5-1. PFB Package, 48-Pin TQFP, Top View**

Table 5-1. Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
AGND	2, 35, 38, 40, 42, 43, 46, 47	Analog ground	Connect to 0 V.
AGND-OUT	8	Analog ground	Connect to 0 V. Measure DAC output voltage with respect to this node.
AGND-TnH	14	Analog ground	Connect to 0 V. Integrated deglitcher clock ground.
ALARM	19	Output	Alarm output
AVDD	39, 41	Power	Positive low voltage analog power supply
CLR	30	Input	DAC registers clear pin, active low
DGND	16, 17, 20, 21, 22, 23, 26	Digital ground	Connect to 0 V.
DVDD	27	Power	Digital power supply pin
RFB	9	Input	Integrated precision resistor feedback node
IOVDD	28	Power	Interface power supply pin
LDAC	18	Input	Load DAC pin, active low
NC	1, 12, 13, 15, 24, 25, 29, 36, 37, 48	—	No connection, leave floating
OUT	7	Output	Unbuffered voltage output
RCM	11	Input	Integrated precision resistor common-mode node
REFNF	5	Input	External negative reference input. Connect to 0 V for unipolar DAC output.
REFNS	6	Input	External negative reference sense node
REFPF	3	Input	External positive reference input
REFPS	4	Input	External positive reference sense node
ROFS	10	Input	Integrated precision resistor offset node
SCLK	31	Input	Serial clock input of serial peripheral interface (SPI). Schmitt-trigger logic input. Data are transferred at rates of up to 50 MHz.
SDIN	32	Input	Serial data input. Schmitt-trigger logic input. Data are clocked into the input shift register on the falling edge of the serial clock input.
SDO	34	Output	Serial data output. Data are valid on the falling edge of SCLK.
SYN $\bar{C}$	33	Input	SPI bus chip select input (active low). Data bits are not clocked into the serial shift register unless SYN $\bar{C}$ is low. When SYN $\bar{C}$ is high, the SDO pin is in high-impedance status.
VCC	45	Power	Analog positive power supply
VSS	44	Power	Analog negative power supply

## 6 Specifications

### 6.1 Absolute Maximum Ratings

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

			MIN	MAX	UNIT
	Positive supply voltage	AV <sub>DD</sub> to AGND	−0.3	7	V
		V <sub>CC</sub> to V <sub>SS</sub>	−0.3	40	
		V <sub>CC</sub> to AGND	−0.3	40	
	Negative supply voltage	V <sub>SS</sub> to AGND	−19	0.3	V
	Digital and IO supply voltage	DV <sub>DD</sub> , IOV <sub>DD</sub> to DGND	−0.3	7	V
	Positive reference voltage	V <sub>REFPF</sub> to V <sub>REFNF</sub>	−0.3	40	V
		V <sub>REFPF</sub> to V <sub>CC</sub>	−0.3	V <sub>CC</sub> + 0.3	
		V <sub>REFPF</sub> to AGND	−0.3	40	
	Negative reference voltage	V <sub>REFNF</sub> to AGND	−19	0.3	V
		V <sub>REFNF</sub> to V <sub>SS</sub>	V <sub>SS</sub> − 0.3	0.3	
	Digital input(s) to DGND		DGND − 0.3	IOV <sub>DD</sub> + 0.3	V
	OUT, RFB, RCM, ROFS pin voltage	to AGND (V <sub>SS</sub> = AGND)	V <sub>SS</sub>	V <sub>CC</sub>	V
		to V <sub>SS</sub>	0	V <sub>CC</sub>	
	Alarm pin voltage, $\overline{\text{ALARM}}$ to DGND		−0.3	DV <sub>DD</sub> + 0.3	V
	Digital output, SDO to DGND		−0.3	DV <sub>DD</sub> + 0.3	V
	Current into any pin		−10	10	mA
T <sub>J</sub>	Junction temperature			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.

### 6.2 ESD Ratings

			VALUE	UNIT
V <sub>(ESD)</sub>	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins <sup>(1)</sup>	±1000	V
		Charged device model (CDM), per ANSI/ESDA/JEDEC JS-002, all pins <sup>(2)</sup>	±250	

- (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
	AV <sub>DD</sub> to AGND	4.5		5.5	V
	V <sub>SS</sub> to AGND	−18		−3	V
	V <sub>CC</sub> to AGND	8		33	V
	V <sub>CC</sub> to V <sub>SS</sub>	11		36	V
	DV <sub>DD</sub> to DGND	2.7		5.5	V
	IOV <sub>DD</sub> to DGND	1.7		5.5	V
	AGND to DGND	−0.3		0.3	V
	V <sub>IH</sub> digital input high voltage	0.7 × IOV <sub>DD</sub>			V
	V <sub>IL</sub> digital input low voltage	0.3 × IOV <sub>DD</sub>			V
	V <sub>REFPF</sub> to AGND	3		15	V
	V <sub>REFNF</sub> to AGND	−15		0	V
	V <sub>REFPF</sub> to V <sub>REFNF</sub>	3		30	V
T <sub>A</sub>	Operating temperature	−40		125	°C

### 6.4 Thermal Information

THERMAL METRIC <sup>(1)</sup>		DAC11001B	UNIT
		PFB (TQFP)	
		48 PINS	
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	51.0	°C/W
R <sub>θJC(top)</sub>	Junction-to-case (top) thermal resistance	10.3	°C/W
R <sub>θJB</sub>	Junction-to-board thermal resistance	16.2	°C/W
Ψ <sub>JT</sub>	Junction-to-top characterization parameter	0.3	°C/W
Ψ <sub>JB</sub>	Junction-to-board characterization parameter	16.0	°C/W
R <sub>θJC(bot)</sub>	Junction-to-case (bottom) thermal resistance	N/A	°C/W

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

## 6.5 Electrical Characteristics

at  $T_A = -40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ ,  $V_{CC} = +15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5.5\text{ V}$ ,  $DV_{DD} = 3.3\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , see note<sup>(1)</sup> for  $V_{REFPF}$  and  $V_{REFNF}$ , OUT pin buffered with unity gain OPA827, ROFS, RCM, RFB unconnected, and all typical specifications at  $T_A = 25^{\circ}\text{C}$ , (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
STATIC PERFORMANCE						
	Resolution		20			Bits
INL	Relative accuracy <sup>(2) (3)</sup>	T <sub>A</sub> = 0°C to 70°C <sup>(4)</sup> V <sub>REFPF</sub> = 10 V and V <sub>REFNF</sub> = 0 V V <sub>REFPF</sub> = +5 V and V <sub>REFNF</sub> = −5 V	−1		1	LSB
		T <sub>A</sub> = 0°C to 70°C <sup>(4)</sup>	−1.25		1.25	
		T <sub>A</sub> = −40°C to +125°C	−2		2	
		Relative accuracy drift over time <sup>(2)</sup>		±0.1		
DNL	Differential nonlinearity <sup>(2) (3)</sup>	T <sub>A</sub> = −40°C to +125°C	−1		1	LSB
	Zero code error <sup>(4)</sup>	T <sub>A</sub> = 0°C to 70°C, code 0d into DAC, unipolar ranges only	−4		4	LSB
		T <sub>A</sub> = −40°C to +125°C, code 0d into DAC, unipolar ranges only	−4		4	
		T <sub>A</sub> = 25°C, unipolar ranges only	±2			
	Zero code error temperature coefficient	T <sub>A</sub> = 0°C to 70°C, code 0d into DAC, unipolar ranges only	±0.04		ppm FSR/°C	
		T <sub>A</sub> = −40°C to +125°C, code 0d into DAC, unipolar ranges only	±0.04			
	Gain error <sup>(2) (4)</sup>	T <sub>A</sub> = 0°C to 70°C	−8		8	ppm of FSR
		T <sub>A</sub> = −40°C to +125°C	−10		10	
		T <sub>A</sub> = 25°C	±2			
	Gain error temperature coefficient	T <sub>A</sub> = 0°C to 70°C	±0.04		ppm FSR/°C	
		T <sub>A</sub> = −40°C to +125°C	±0.04			
	Positive full-scale error <sup>(4)</sup>	T <sub>A</sub> = 0°C to 70°C, code 1048575d into DAC	−8		8	LSB
		T <sub>A</sub> = −40°C to +125°C, code 1048575d into DAC	−10		10	
		T <sub>A</sub> = 25°C, code 1048575d into DAC	±2			
	Full-scale error temperature coefficient	T <sub>A</sub> = 0°C to 70°C	±0.04		ppm FSR/°C	
		T <sub>A</sub> = −40°C to +125°C	±0.04			
OUTPUT CHARACTERISTICS						
	Headroom	From V <sub>REFPF</sub> to V <sub>CC</sub>	5			V
	Footroom	From V <sub>REFNF</sub> to V <sub>SS</sub>	5			V
	DC impedance	From ROFS to RCM	5			kΩ
		From RCM to RFB	5			
Z <sub>O</sub>	DC output impedance		2.5			kΩ
	Power supply rejection ratio (dc)	V <sub>CC</sub> = 15 V ±20%, V <sub>SS</sub> = −15 V	1.5			μV/V
		V <sub>CC</sub> = 15 V, V <sub>SS</sub> = −15 V ±20%	1			
	Output voltage drift over time	T <sub>A</sub> = 25°C, V <sub>OUT</sub> = midscale, 1000 hr	1			ppm of FSR
VOLTAGE REFERENCE INPUT						
	Reference input impedance (REFPF)	DAC at midscale, V <sub>REFPF</sub> = 10 V, V <sub>REFNF</sub> = 0 V	5.5			kΩ
	Reference input impedance (REFNF)	DAC at midscale, V <sub>REFPF</sub> = 10 V, V <sub>REFNF</sub> = 0 V	7			

## 6.5 Electrical Characteristics (continued)

at  $T_A = -40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ ,  $V_{CC} = +15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5.5\text{ V}$ ,  $DV_{DD} = 3.3\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , see note<sup>(1)</sup> for  $V_{REFPF}$  and  $V_{REFNF}$ , OUT pin buffered with unity gain OPA827, ROFS, RCM, RFB unconnected, and all typical specifications at  $T_A = 25^{\circ}\text{C}$ , (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>DYNAMIC PERFORMANCE</b>						
$t_s$	Output voltage settling time <sup>(5)</sup>	Full-scale settling to 0.1%FSR, $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$		1		$\mu\text{s}$
		Full-scale settling to $\pm 1\text{ LSB}$ , $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$		3		
		1-mV step settling to $\pm 1\text{ LSB}$ , $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$		2.5		
SR	Slew rate <sup>(6)</sup>	Full-scale step, measured at OUT pin, $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$		30		$\text{V}/\mu\text{s}$
	Power-on glitch magnitude	Measured at unbuffered DAC voltage output, $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$		-0.2		V
$V_n$	Output noise	0.1-Hz to 10-Hz, DAC at midscale, $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$		0.4		$\mu\text{V}_{pp}$
		100-kHz bandwidth, DAC at midscale, $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$		3		$\mu\text{V}_{rms}$
	Output noise density	Measured at 1 kHz, 10 kHz, 100 kHz, DAC at mid scale, $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$		7		$\text{nV}/\sqrt{\text{Hz}}$
SFDR	Spurious free dynamic range <sup>(6)</sup>	DAC update rate = 768 kHz, $f_{OUT} = 1\text{ kHz}$ , $V_{REFPF} = 4.5\text{ V}$ , $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter		-120		dB
		DAC update rate = 768 kHz, $f_{OUT} = 20\text{ kHz}$ , $V_{REFPF} = 4.5\text{ V}$ , $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter		-114		
		DAC update rate = 1 MHz, $f_{OUT} = 100\text{ kHz}$ , $V_{REFPF} = 4.5\text{ V}$ , $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 150-kHz output filter		-92		
THD	Total harmonic distortion <sup>(6)</sup>	DAC update rate = 768 kHz, $f_{OUT} = 1\text{ kHz}$ , $V_{REFPF} = 4.5\text{ V}$ , $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter		-118		dB
		DAC update rate = 768 kHz, $f_{OUT} = 20\text{ kHz}$ , $V_{REFPF} = 4.5\text{ V}$ , $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter		-118		
		DAC update rate = 1 MHz, $f_{OUT} = 100\text{ kHz}$ , $V_{REFPF} = 4.5\text{ V}$ , $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 150-kHz output filter		-96		
	Power supply rejection ratio (ac)	200-mV, 50-Hz or 60-Hz sine wave superimposed on $V_{SS}$ , $V_{CC} = 15\text{ V}$		95		dB
		200-mV, 50 Hz or 60 Hz sine wave superimposed on $V_{CC}$ , $V_{SS} = -15\text{ V}$		95		
	Code change glitch impulse	$\pm 1\text{ LSB}$ change around mid code (including feedthrough), $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$ , measured at output of buffer op amp		1		nV-s
	Code change glitch impulse magnitude	$\pm 1\text{ LSB}$ change around mid code (including feedthrough), $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$ , measured at output of buffer op amp		5		mV
	Reference feedthrough	$V_{REFPF} = 10\text{ V} \pm 10\%$ , $V_{REFNF} = 0\text{ V}$ , frequency = 100 Hz, DAC at zero scale		-90		dB
		$V_{REFNF} = -10\text{ V} \pm 10\%$ , $V_{REFPF} = 10\text{ V}$ , frequency = 100 Hz, DAC at full scale		-90		
	Digital feedthrough	SCLK = 1 MHz, DAC static at midscale, $V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$		1		nV-s



## 6.5 Electrical Characteristics (continued)

at  $T_A = -40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ ,  $V_{CC} = +15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5.5\text{ V}$ ,  $DV_{DD} = 3.3\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , see note<sup>(1)</sup> for  $V_{REFPF}$  and  $V_{REFNF}$ , OUT pin buffered with unity gain OPA827, ROFS, RCM, RFB unconnected, and all typical specifications at  $T_A = 25^{\circ}\text{C}$ , (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>DIGITAL INPUTS</b>						
	Hysteresis voltage			0.4		V
	Input current			$\pm 5$		$\mu\text{A}$
	Pin capacitance	Per pin		10		pF
<b>DIGITAL OUTPUTS</b>						
$V_{OL}$	Low-level output voltage	Sinking 200 $\mu\text{A}$			0.4	V
$V_{OH}$	High-level output voltage	Sourcing 200 $\mu\text{A}$	$IOV_{DD} - 0.5$			V
	High impedance leakage			$\pm 5$		$\mu\text{A}$
	High impedance output capacitance			10		pF
<b>POWER</b>						
$I_{AVDD}$	Current flowing into $AV_{DD}$	$V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$ , midscale code			2.5	mA
$I_{VCC}$	Current flowing into $V_{CC}$	$V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$ , midscale code			15	mA
$I_{VSS}$	Current flowing into $V_{SS}$	$V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$ , midscale code			15	mA
$I_{DVDD}$	Current flowing into $DV_{DD}$	$V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$ , midscale code		0.5		mA
$I_{IOVDD}$	Current flowing into $IOV_{DD}$	$V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$ , midscale code, all digital input pins static at $IOV_{DD}$		0.1		mA
$I_{REFPF}$	Reference input current ( $V_{REFPF}$ )	$V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$ , midscale code			7	mA
$I_{REFNF}$	Reference input current ( $V_{REFNF}$ )	$V_{REFPF} = 10\text{ V}$ , $V_{REFNF} = 0\text{ V}$ , midscale code			7	mA

- (1) Specified for the following pairs:  $V_{REFPF} = 5\text{ V}$  and  $V_{REFNF} = 0\text{ V}$ ;  $V_{REFPF} = 10\text{ V}$  and  $V_{REFNF} = 0\text{ V}$ ;  $V_{REFPF} = 5\text{ V}$  and  $V_{REFNF} = -5\text{ V}$ ;  $V_{REFPF} = 10\text{ V}$  and  $V_{REFNF} = -10\text{ V}$ .
- (2) Calculated between code 0d to 1048575d.
- (3) With device temperature calibration mode enabled and used.
- (4) Specified by design, not production tested.
- (5) Adaptive TnH mode. TnH action is disabled for large code steps. For small steps, TnH action happens with a hold time of 1.2  $\mu\text{s}$ .
- (6) OUT pin buffered with unity gain OPA828.

## 6.6 Timing Requirements: Write, $4.5\text{ V} \leq \text{DV}_{\text{DD}} \leq 5.5\text{ V}$

all input signals are specified with  $t_R = t_F = 1\text{ ns/V}$  (10% to 90% of  $\text{IOV}_{\text{DD}}$ ) and timed from a voltage level of  $(V_{\text{IL}} + V_{\text{IH}}) / 2$ , SDO loaded with 20 pF, and  $T_A = -40^\circ\text{C}$  to  $+125^\circ\text{C}$  (unless otherwise noted)

		MIN	NOM	MAX	UNIT
$f_{\text{SCLK}}$	SCLK frequency, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$			33	MHz
	SCLK frequency, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$			50	
$t_{\text{SCLKHIGH}}$	SCLK high time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	15			ns
	SCLK high time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	10			
$t_{\text{SCLKLOW}}$	SCLK low time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	15			ns
	SCLK low time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	10			
$t_{\text{SDIS}}$	SDI setup, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	13			ns
	SDI setup, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	8			
$t_{\text{SDIH}}$	SDI hold, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	13			ns
	SDI hold, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	8			
$t_{\text{CSS}}$	$\overline{\text{SYNC}}$ falling edge to SCLK falling edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	23			ns
	$\overline{\text{SYNC}}$ falling edge to SCLK falling edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	18			
$t_{\text{CSH}}$	SCLK falling edge to $\overline{\text{SYNC}}$ rising edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	15			ns
	SCLK falling edge to $\overline{\text{SYNC}}$ rising edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	10			
$t_{\text{CSHIGH}}$	$\overline{\text{SYNC}}$ high time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	55			ns
	$\overline{\text{SYNC}}$ high time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	50			
$t_{\text{CSIGNORE}}$	SCLK falling edge to $\overline{\text{SYNC}}$ ignore, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	10			ns
	SCLK falling edge to $\overline{\text{SYNC}}$ ignore, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	5			
$t_{\text{LDACSL}}$	Synchronous update: $\overline{\text{SYNC}}$ rising edge to $\overline{\text{LDAC}}$ falling edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	50			ns
	Synchronous update: $\overline{\text{SYNC}}$ rising edge to $\overline{\text{LDAC}}$ falling edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	50			
$t_{\text{LDACW}}$	$\overline{\text{LDAC}}$ low time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	20			ns
	$\overline{\text{LDAC}}$ low time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	20			
$t_{\text{CLR W}}$	$\overline{\text{CLR}}$ low time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	20			ns
	$\overline{\text{CLR}}$ low time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	20			

## 6.7 Timing Requirements: Write, $2.7\text{ V} \leq \text{DV}_{\text{DD}} < 4.5\text{ V}$

all input signals are specified with  $t_R = t_F = 1\text{ ns/V}$  (10% to 90% of  $\text{IOV}_{\text{DD}}$ ) and timed from a voltage level of  $(V_{\text{IL}} + V_{\text{IH}}) / 2$ , SDO loaded with 20 pF, and  $T_A = -40^\circ\text{C}$  to  $+125^\circ\text{C}$  (unless otherwise noted)

		MIN	NOM	MAX	UNIT
$f_{\text{SCLK}}$	SCLK frequency, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$			20	MHz
	SCLK frequency, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$			25	
$t_{\text{SCLKHIGH}}$	SCLK high time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	25			ns
	SCLK high time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	20			
$t_{\text{SCLKLOW}}$	SCLK low time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	25			ns
	SCLK low time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	20			
$t_{\text{SDIS}}$	SDI setup, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	21			ns
	SDI setup, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	16			
$t_{\text{SDIH}}$	SDI hold, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	21			ns
	SDI hold, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	16			
$t_{\text{CSS}}$	$\overline{\text{SYNC}}$ falling edge to SCLK falling edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	41			ns
	$\overline{\text{SYNC}}$ falling edge to SCLK falling edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	36			
$t_{\text{CSH}}$	SCLK falling edge to $\overline{\text{SYNC}}$ rising edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	25			ns
	SCLK falling edge to $\overline{\text{SYNC}}$ rising edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	20			
$t_{\text{CSHIGH}}$	$\overline{\text{SYNC}}$ high time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	100			ns
	$\overline{\text{SYNC}}$ high time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	100			
$t_{\text{CSIGNORE}}$	SCLK falling edge to $\overline{\text{SYNC}}$ ignore, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	10			ns
	SCLK falling edge to $\overline{\text{SYNC}}$ ignore, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	5			
$t_{\text{LDACSL}}$	Synchronous update: $\overline{\text{SYNC}}$ rising edge to $\overline{\text{LDAC}}$ falling edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	100			ns
	Synchronous update: $\overline{\text{SYNC}}$ rising edge to $\overline{\text{LDAC}}$ falling edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	100			
$t_{\text{LDACW}}$	$\overline{\text{LDAC}}$ low time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	40			ns
	$\overline{\text{LDAC}}$ low time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	40			
$t_{\text{CLR W}}$	$\overline{\text{CLR}}$ low time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$	40			ns
	$\overline{\text{CLR}}$ low time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$	40			

## 6.8 Timing Requirements: Read and Daisy-Chain Write, $4.5\text{ V} \leq \text{DV}_{\text{DD}} \leq 5.5\text{ V}$

all input signals are specified with  $t_R = t_F = 1\text{ ns/V}$  (10% to 90% of  $\text{IOV}_{\text{DD}}$ ) and timed from a voltage level of  $(V_{\text{IL}} + V_{\text{IH}}) / 2$ , SDO loaded with 20 pF, and  $T_A = -40^\circ\text{C}$  to  $+125^\circ\text{C}$  (unless otherwise noted)

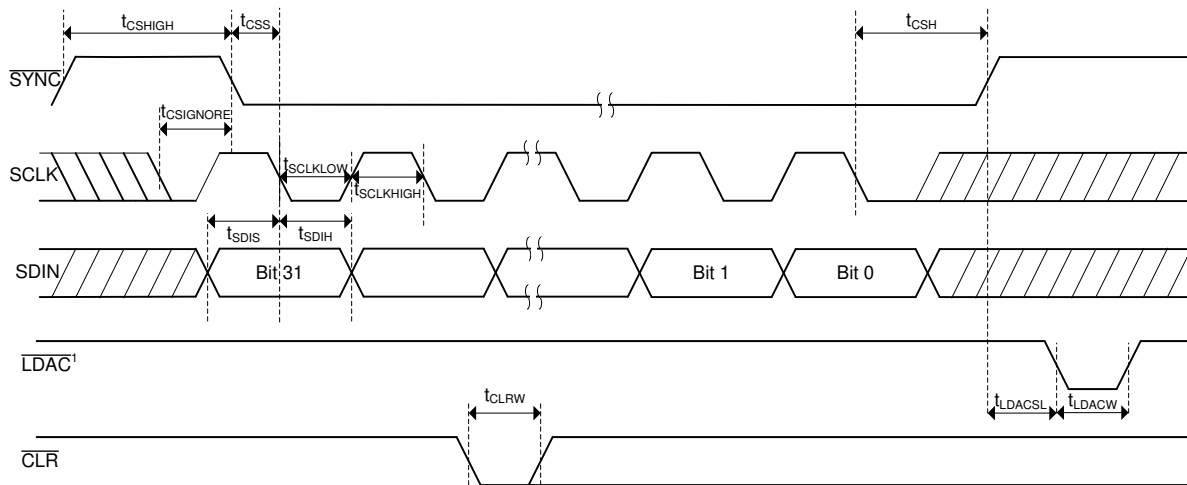
			MIN	NOM	MAX	UNIT
$f_{\text{SCLK}}$	SCLK frequency	$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , $\text{FSDO} = 0$			10	MHz
		$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , $\text{FSDO} = 1$			20	
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , $\text{FSDO} = 0$			15	
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , $\text{FSDO} = 1$			30	
$t_{\text{SCLKHIGH}}$	SCLK high time	$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , $\text{FSDO} = 0$	50			ns
		$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , $\text{FSDO} = 1$	25			
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , $\text{FSDO} = 0$	33			
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , $\text{FSDO} = 1$	16			
$t_{\text{SCLKLOW}}$	SCLK low time	$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , $\text{FSDO} = 0$	50			ns
		$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , $\text{FSDO} = 1$	25			
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , $\text{FSDO} = 0$	33			
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , $\text{FSDO} = 1$	16			
$t_{\text{SDIS}}$	SDI setup, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		13			ns
	SDI setup, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		8			
$t_{\text{SDIH}}$	SDI hold, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		13			ns
	SDI hold, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		8			
$t_{\text{CSS}}$	$\overline{\text{SYNC}}$ falling edge to SCLK falling edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		30			ns
	$\overline{\text{SYNC}}$ falling edge to SCLK falling edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		20			
$t_{\text{CSH}}$	SCLK falling edge to $\overline{\text{SYNC}}$ rising edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		15			ns
	SCLK falling edge to $\overline{\text{SYNC}}$ rising edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		10			
$t_{\text{CSHIGH}}$	$\overline{\text{SYNC}}$ high time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		55			ns
	$\overline{\text{SYNC}}$ high time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		50			
$t_{\text{CSIGNORE}}$	SCLK falling edge to $\overline{\text{SYNC}}$ ignore, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		10			ns
	SCLK falling edge to $\overline{\text{SYNC}}$ ignore, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		5			
$t_{\text{LDACSL}}$	Synchronous update: $\overline{\text{SYNC}}$ rising edge to $\overline{\text{LDAC}}$ falling edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		50			ns
	Synchronous update: $\overline{\text{SYNC}}$ rising edge to $\overline{\text{LDAC}}$ falling edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		50			
$t_{\text{LDACW}}$	$\overline{\text{LDAC}}$ low time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		20			ns
	$\overline{\text{LDAC}}$ low time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		20			
$t_{\text{CLR W}}$	$\overline{\text{CLR}}$ low time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		20			ns
	$\overline{\text{CLR}}$ low time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		20			
$t_{\text{SDODLY}}$	SCLK rising edge to SDO valid data, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , $\text{FSDO} = 0$		0		35	ns
	SCLK rising edge to SDO valid data, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , $\text{FSDO} = 0$		0		25	
	SCLK falling edge to SDO valid data, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , $\text{FSDO} = 1$		0		35	
	SCLK falling edge to SDO valid data, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , $\text{FSDO} = 1$		0		25	
$t_{\text{SDOZ}}$	$\overline{\text{SYNC}}$ rising edge to SDO HiZ, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		0		20	ns
	$\overline{\text{SYNC}}$ rising edge to SDO HiZ, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		0		20	

## 6.9 Timing Requirements: Read and Daisy-Chain Write, $2.7\text{ V} \leq \text{DV}_{\text{DD}} < 4.5\text{ V}$

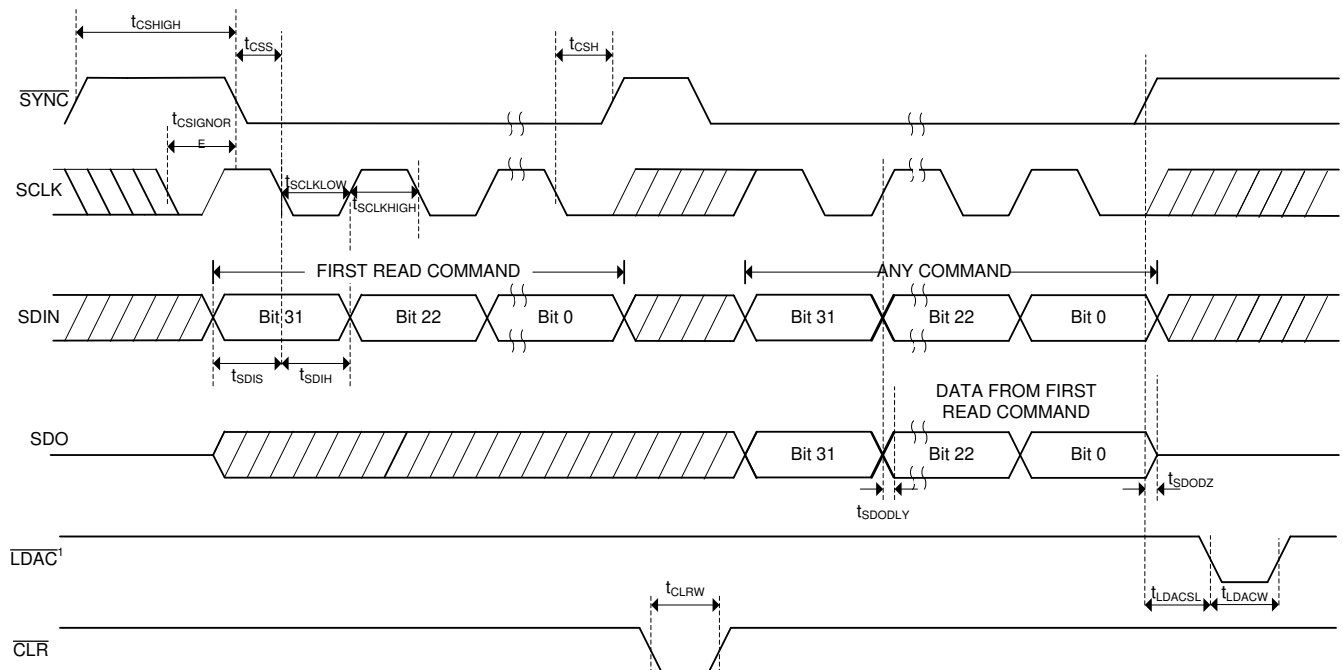
all input signals are specified with  $t_R = t_F = 1\text{ ns/V}$  (10% to 90% of  $\text{IOV}_{\text{DD}}$ ) and timed from a voltage level of  $(V_{\text{IL}} + V_{\text{IH}}) / 2$ , SDO loaded with 20 pF, and  $T_A = -40^\circ\text{C}$  to  $+125^\circ\text{C}$  (unless otherwise noted)

			MIN	NOM	MAX	UNIT
$f_{\text{SCLK}}$	SCLK frequency	$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , FSDO = 0			8	MHz
		$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , FSDO = 1			16	
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , FSDO = 0			10	
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , FSDO = 1			20	
$t_{\text{SCLKHIGH}}$	SCLK high time	$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , FSDO = 0	62			ns
		$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , FSDO = 1	31			
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , FSDO = 0	50			
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , FSDO = 1	25			
$t_{\text{SCLKLOW}}$	SCLK low time	$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , FSDO = 0	62			ns
		$1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , FSDO = 1	31			
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , FSDO = 0	50			
		$2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , FSDO = 1	25			
$t_{\text{SDIS}}$	SDI setup, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		21			ns
	SDI setup, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		16			
$t_{\text{SDIH}}$	SDI hold, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		21			ns
	SDI hold, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		16			
$t_{\text{CSS}}$	$\overline{\text{SYNC}}$ falling edge to SCLK falling edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		41			ns
	$\overline{\text{SYNC}}$ falling edge to SCLK falling edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		36			
$t_{\text{CSH}}$	SCLK falling edge to $\overline{\text{SYNC}}$ rising edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		25			ns
	SCLK falling edge to $\overline{\text{SYNC}}$ rising edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		20			
$t_{\text{CSHIGH}}$	$\overline{\text{SYNC}}$ high time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		100			ns
	$\overline{\text{SYNC}}$ high time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		100			
$t_{\text{CSIGNORE}}$	SCLK falling edge to $\overline{\text{SYNC}}$ ignore, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		10			ns
	SCLK falling edge to $\overline{\text{SYNC}}$ ignore, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		5			
$t_{\text{LDACSL}}$	Synchronous update: $\overline{\text{SYNC}}$ rising edge to $\overline{\text{LDAC}}$ falling edge, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		100			ns
	Synchronous update: $\overline{\text{SYNC}}$ rising edge to $\overline{\text{LDAC}}$ falling edge, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		100			
$t_{\text{LDACW}}$	$\overline{\text{LDAC}}$ low time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		40			ns
	$\overline{\text{LDAC}}$ low time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		40			
$t_{\text{CLR W}}$	$\overline{\text{CLR}}$ low time, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		40			ns
	$\overline{\text{CLR}}$ low time, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		40			
$t_{\text{SDODLY}}$	SCLK rising edge to SDO valid data, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , FSDO = 0		0		40	ns
	SCLK rising edge to SDO valid data, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , FSDO = 0		0		30	
	SCLK rising edge to SDO valid data, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$ , FSDO = 1		0		40	
	SCLK rising edge to SDO valid data, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$ , FSDO = 1		0		30	
$t_{\text{SDOZ}}$	$\overline{\text{SYNC}}$ rising edge to SDO HiZ, $1.7\text{ V} \leq \text{IOV}_{\text{DD}} < 2.7\text{ V}$		0		20	ns
	$\overline{\text{SYNC}}$ rising edge to SDO HiZ, $2.7\text{ V} \leq \text{IOV}_{\text{DD}} \leq 5.5\text{ V}$		0		20	

## 6.10 Timing Diagrams



**Figure 6-1. Serial Interface Write Timing: Standalone Mode**



**Figure 6-2. Serial Interface Read and Write Timing: Daisy-Chain Mode**

## 6.11 Typical Characteristics

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , gain resistors unconnected (gain = 1x), OPA827 used as reference amplifier, OPA828 used as output amplifier, UP = unipolar, BP = bipolar, and [temperature calibration](#) disabled (unless otherwise noted)

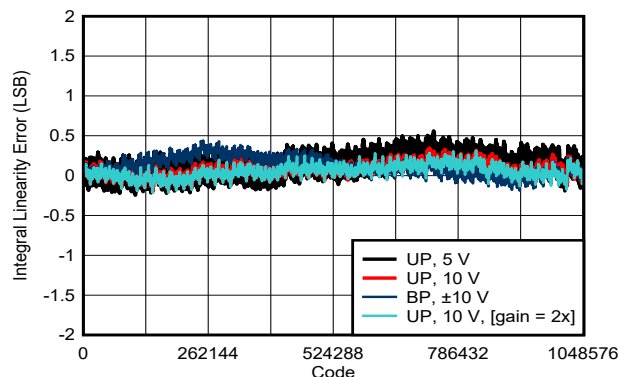


Figure 6-3. Integral Linearity Error vs Digital Input Code

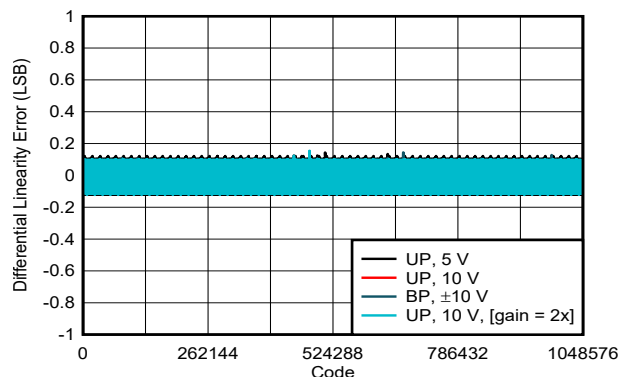
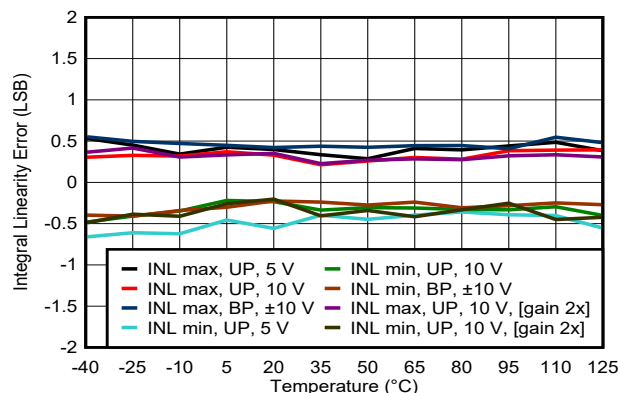
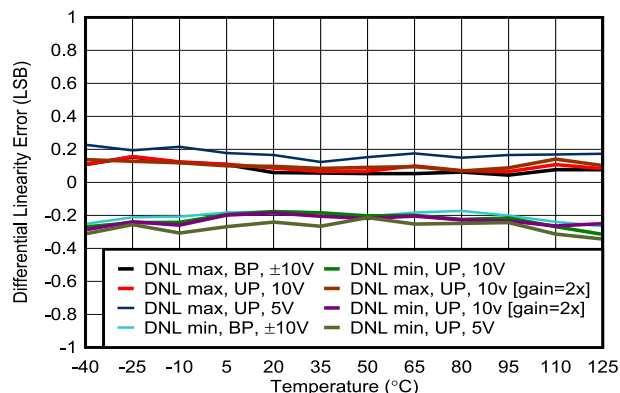


Figure 6-4. Differential Linearity Error vs Digital Input Code



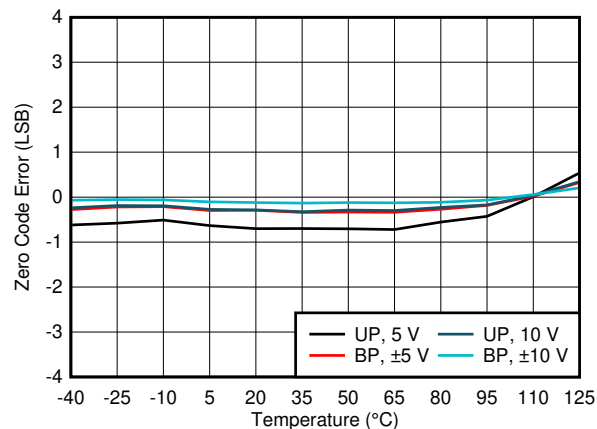
[Temperature calibration](#) enabled

Figure 6-5. Integral Linearity Error vs Temperature



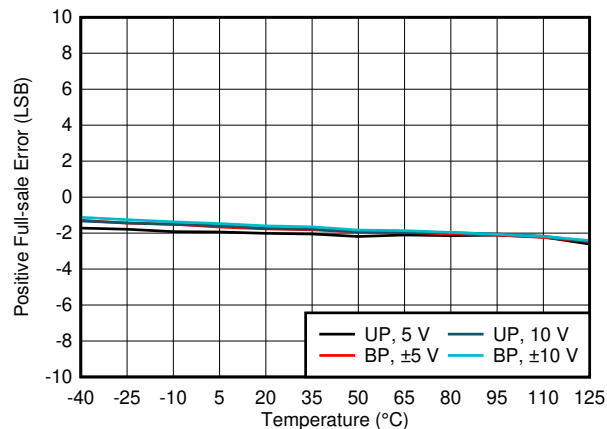
[Temperature calibration](#) enabled

Figure 6-6. Differential Linearity Error vs Temperature



[Temperature calibration](#) enabled

Figure 6-7. Zero Code Error vs Temperature

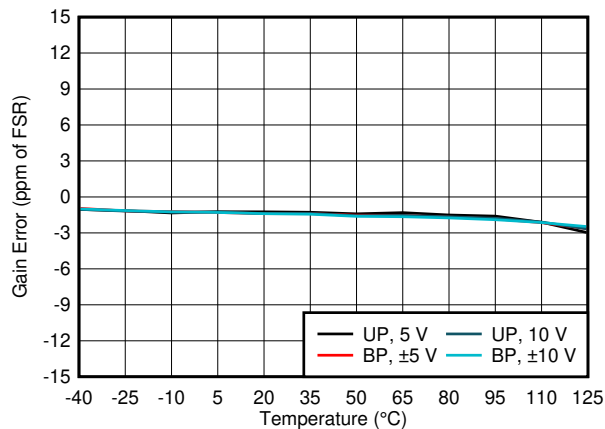


[Temperature calibration](#) enabled

Figure 6-8. Positive Full-Scale Error vs Temperature

## 6.11 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , gain resistors unconnected (gain = 1x), OPA827 used as reference amplifier, OPA828 used as output amplifier, UP = unipolar, BP = bipolar, and [temperature calibration](#) disabled (unless otherwise noted)



Temperature calibration enabled

Figure 6-9. Gain Error vs Temperature

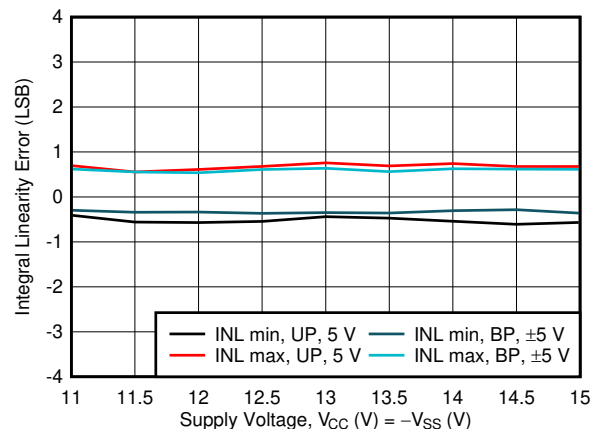


Figure 6-10. Integral Linearity Error vs Supply Voltage

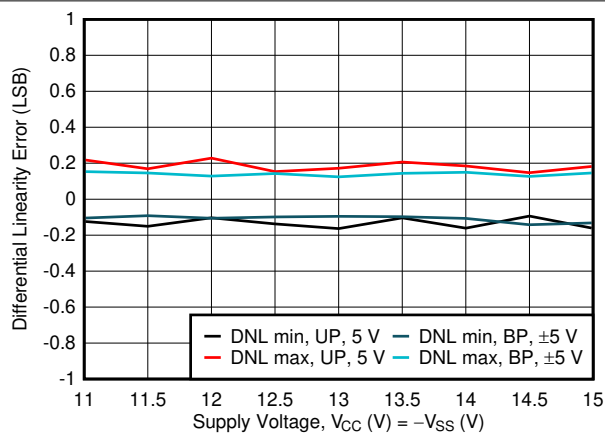


Figure 6-11. Differential Linearity Error vs Supply Voltage

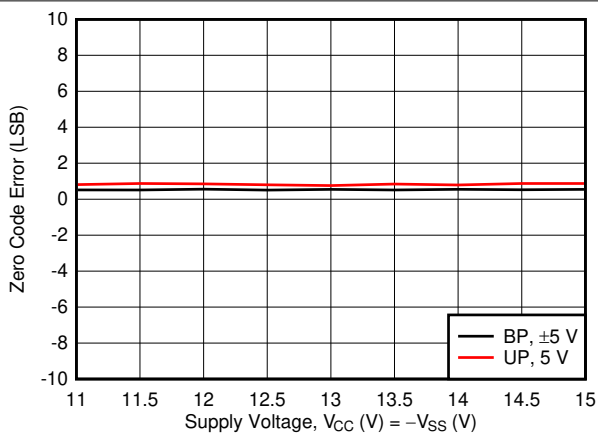


Figure 6-12. Zero Code Error vs Supply Voltage

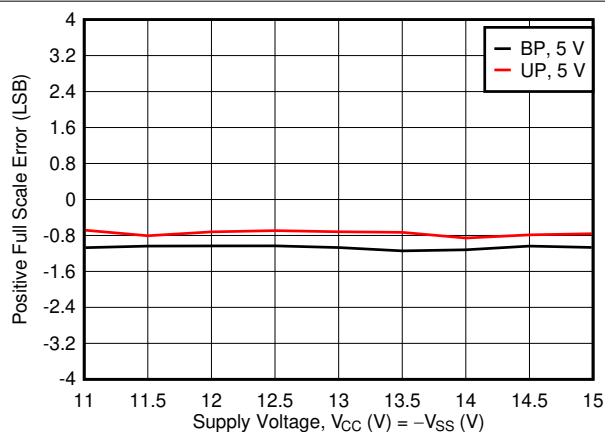


Figure 6-13. Positive Full-Scale Error vs Supply Voltage

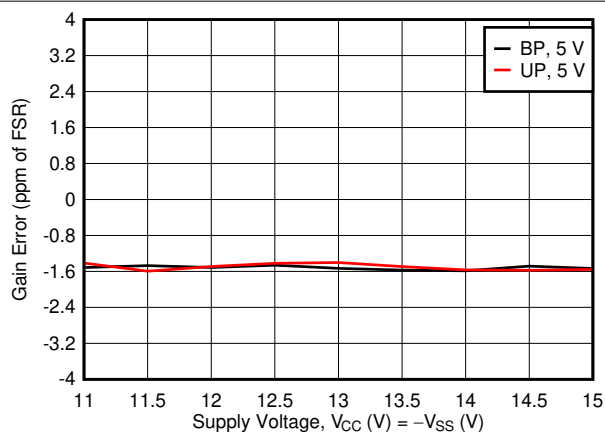


Figure 6-14. Gain Error vs Supply Voltage



## 6.11 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , gain resistors unconnected (gain = 1x), OPA827 used as reference amplifier, OPA828 used as output amplifier, UP = unipolar, BP = bipolar, and [temperature calibration](#) disabled (unless otherwise noted)

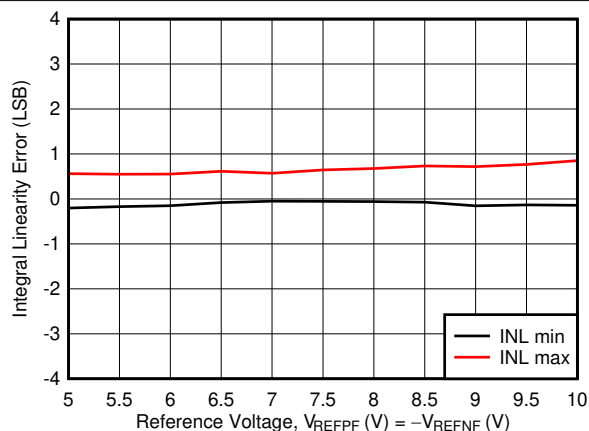


Figure 6-15. Integral Linearity Error vs Reference Voltage

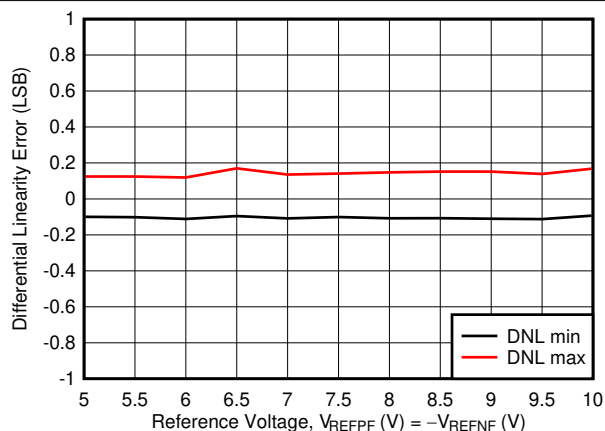


Figure 6-16. Differential Linearity Error vs Reference Voltage

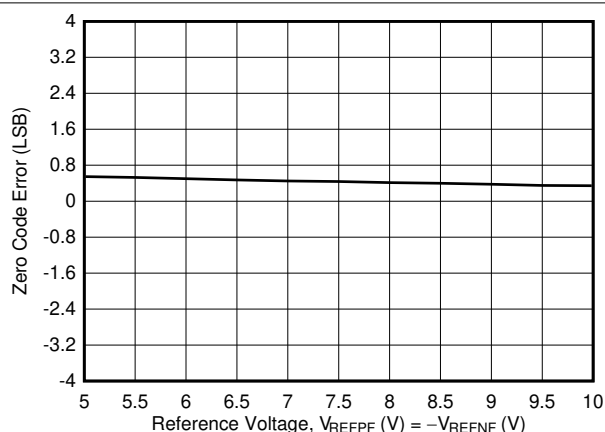


Figure 6-17. Zero Code Error vs Reference Voltage

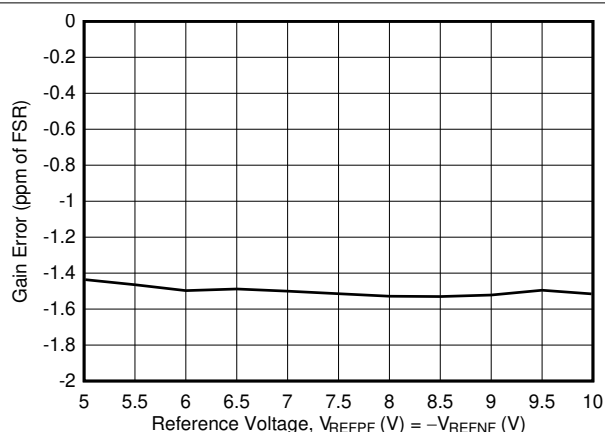


Figure 6-18. Gain Error vs Reference Voltage

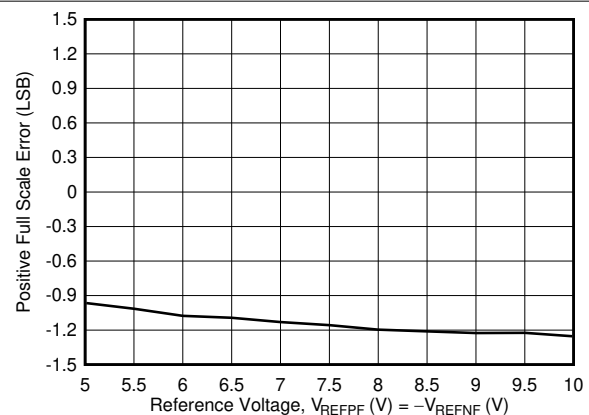


Figure 6-19. Positive Full-Scale Error vs Reference Voltage

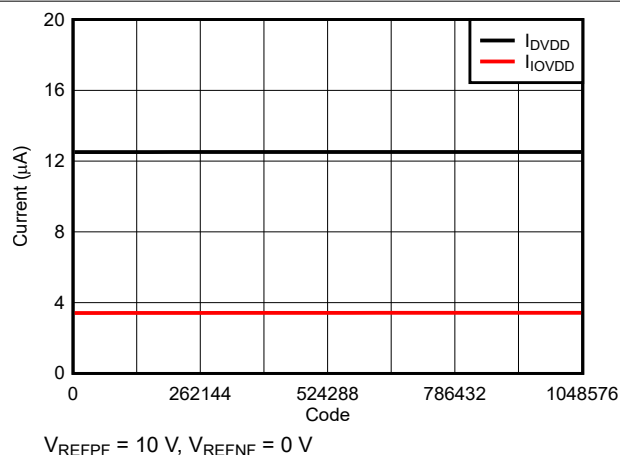
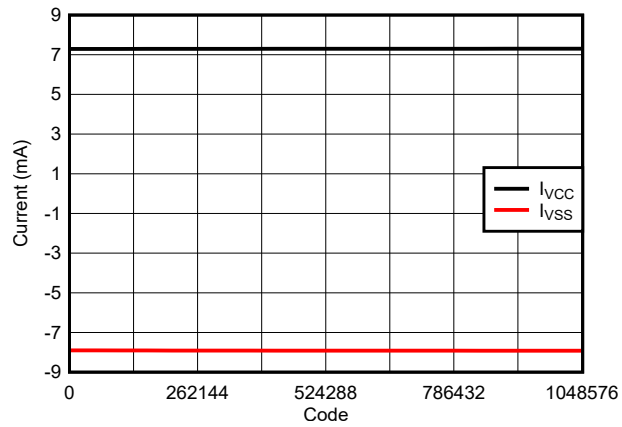


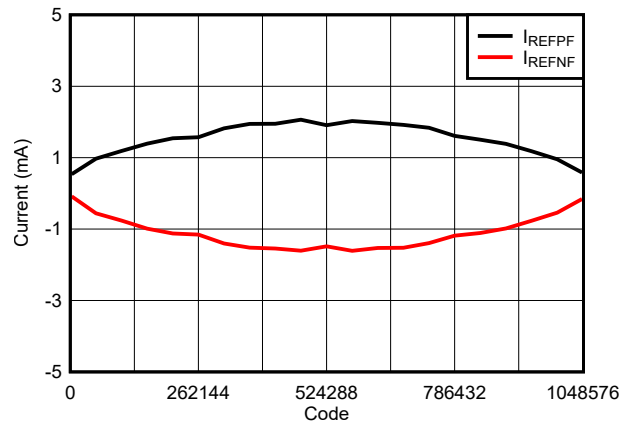
Figure 6-20. Supply Current ( $DV_{DD}$  and  $IOV_{DD}$ ) vs Digital Input Code

## 6.11 Typical Characteristics (continued)

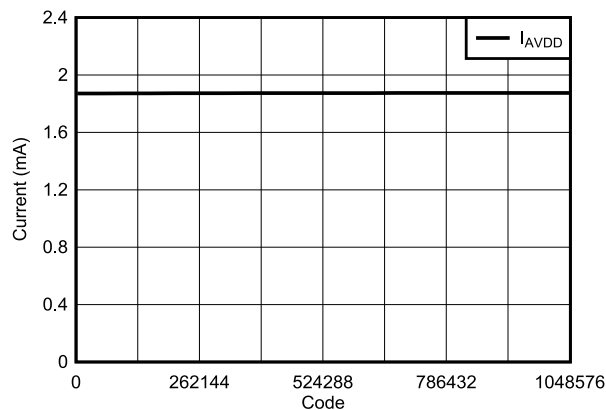
at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , gain resistors unconnected (gain = 1x), OPA827 used as reference amplifier, OPA828 used as output amplifier, UP = unipolar, BP = bipolar, and [temperature calibration](#) disabled (unless otherwise noted)



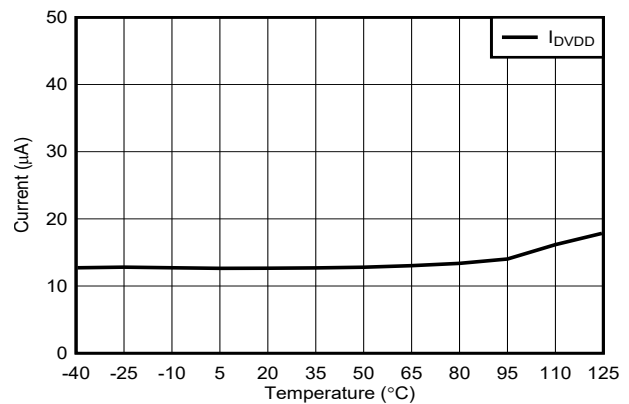
**Figure 6-21. Supply Current ( $V_{CC}$  and  $V_{SS}$ ) vs Digital Input Code**



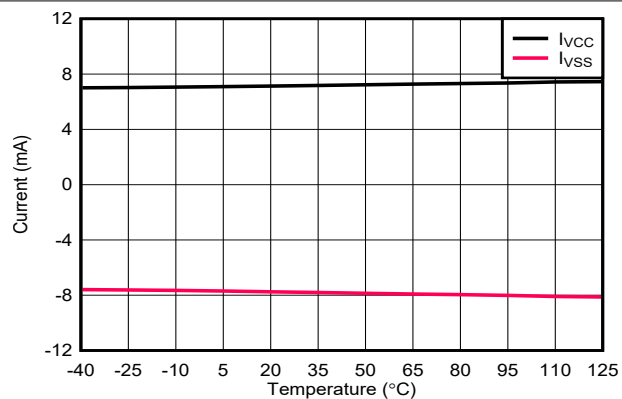
**Figure 6-22. Reference Current ( $V_{REFPF}$  and  $V_{REFNF}$ ) vs Digital Input Code**



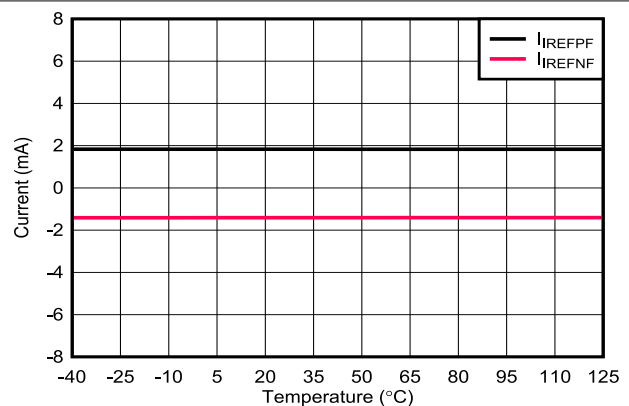
**Figure 6-23. Supply Current ( $AV_{DD}$ ) vs Digital Input Code**



**Figure 6-24. Supply Current ( $DV_{DD}$ ) vs Temperature**



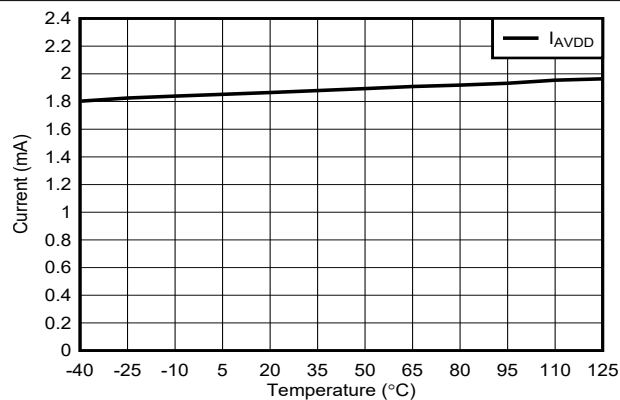
**Figure 6-25. Supply Current ( $V_{CC}$  and  $V_{SS}$ ) vs Temperature**



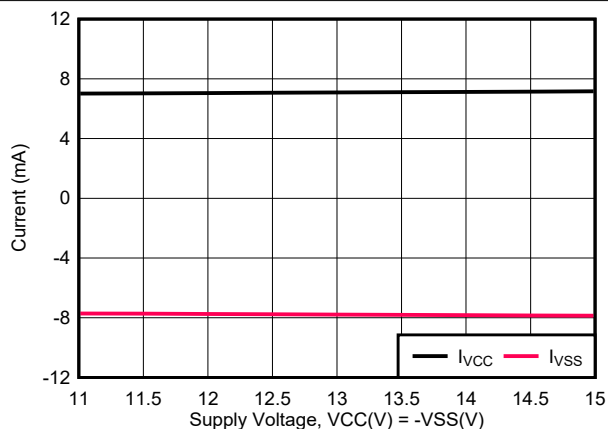
**Figure 6-26. Reference Current ( $V_{REFPF}$  and  $V_{REFNF}$ ) vs Temperature**

## 6.11 Typical Characteristics (continued)

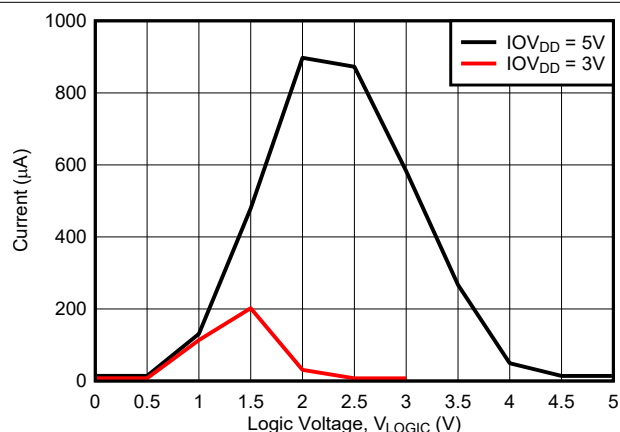
at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , gain resistors unconnected (gain = 1x), OPA827 used as reference amplifier, OPA828 used as output amplifier, UP = unipolar, BP = bipolar, and [temperature calibration](#) disabled (unless otherwise noted)



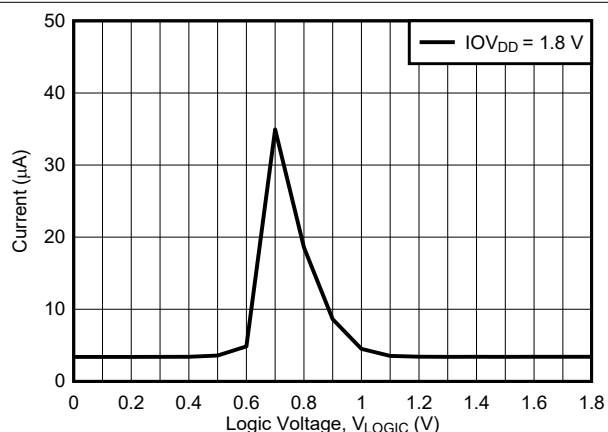
**Figure 6-27. Supply Current ( $AV_{DD}$ ) vs Temperature**



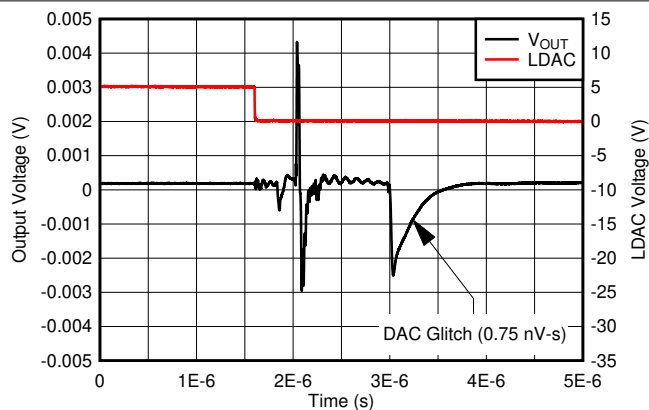
**Figure 6-28. Supply Current ( $V_{CC}$  and  $V_{SS}$ ) vs Supply Voltage**



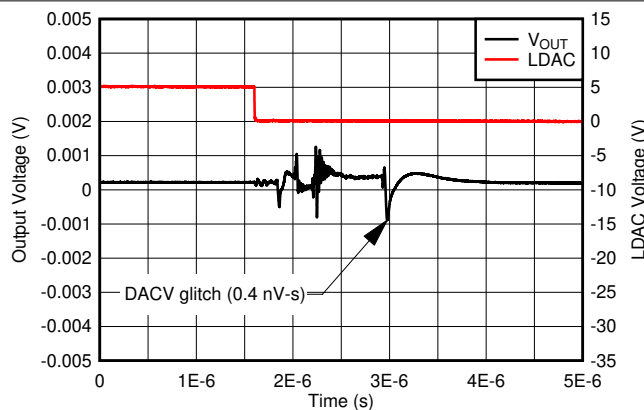
**Figure 6-29. Supply Current ( $IOV_{DD}$ ) vs Input Pin Logic Level**



**Figure 6-30. Supply Current ( $IOV_{DD}$ ) vs Input Pin Logic Level**



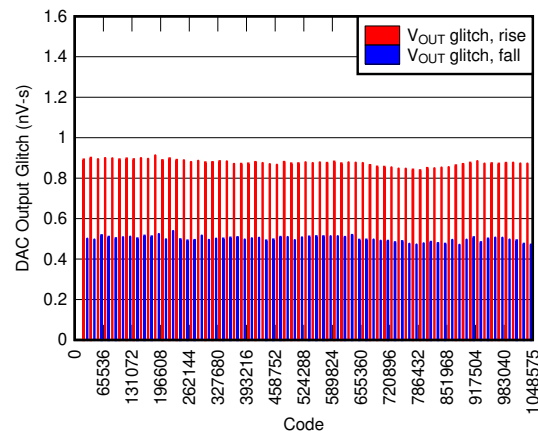
**Figure 6-31. Glitch Impulse, Rising Edge, 1-LSB Step**



**Figure 6-32. Glitch Impulse, Falling Edge, 1-LSB Step**

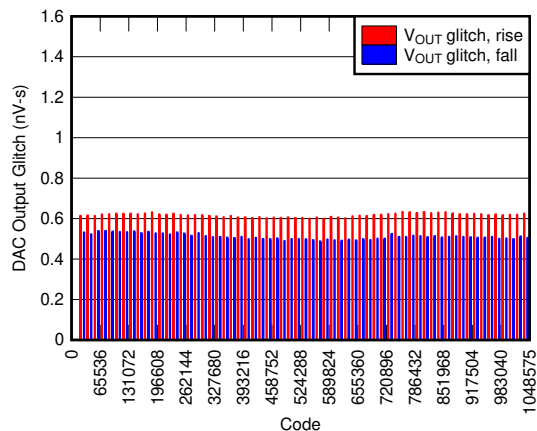
## 6.11 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , gain resistors unconnected (gain = 1x), OPA827 used as reference amplifier, OPA828 used as output amplifier, UP = unipolar, BP = bipolar, and [temperature calibration](#) disabled (unless otherwise noted)



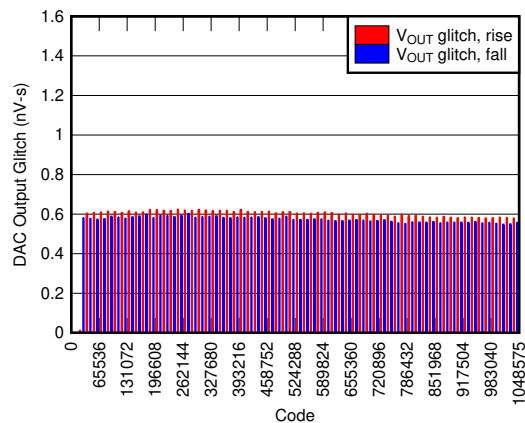
$V_{REFPF} = 10\text{ V}$ ,  $V_{REFNF} = -10\text{ V}$

**Figure 6-33. Segment Glitch Impulse, 1-LSB Step**



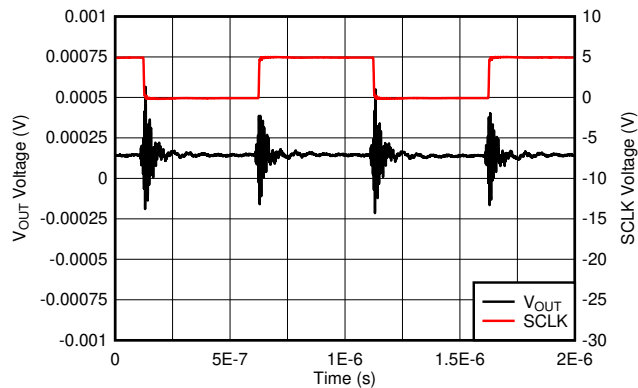
$V_{REFPF} = 10\text{ V}$ ,  $V_{REFNF} = 0\text{ V}$

**Figure 6-34. Segment Glitch Impulse, 1-LSB Step**



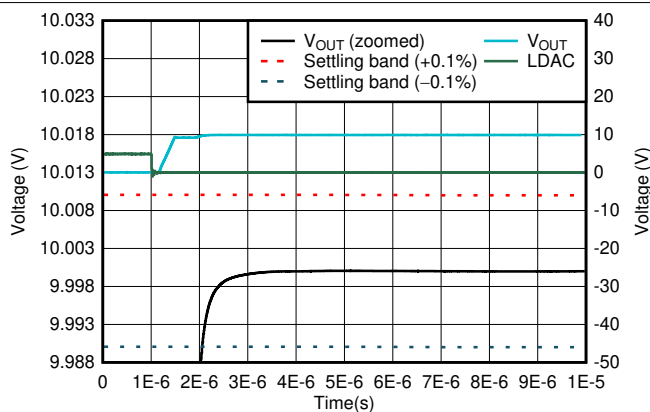
$V_{REFPF} = 5\text{ V}$ ,  $V_{REFNF} = 0\text{ V}$

**Figure 6-35. Segment Glitch Impulse, 1-LSB Step**



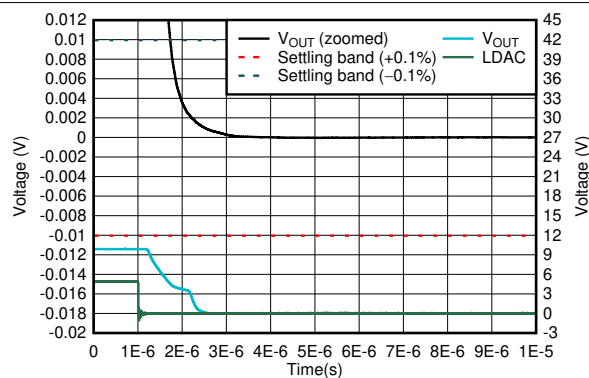
$V_{REFPF} = 10\text{ V}$ ,  $V_{REFNF} = 0\text{ V}$ ,  
DAC at midcode, measured at DAC output pin

**Figure 6-36. Clock Feedthrough**



$V_{REFPF} = 10\text{ V}$ ,  $V_{REFNF} = 0\text{ V}$

**Figure 6-37. Full-Scale Settling Time, Rising Edge**

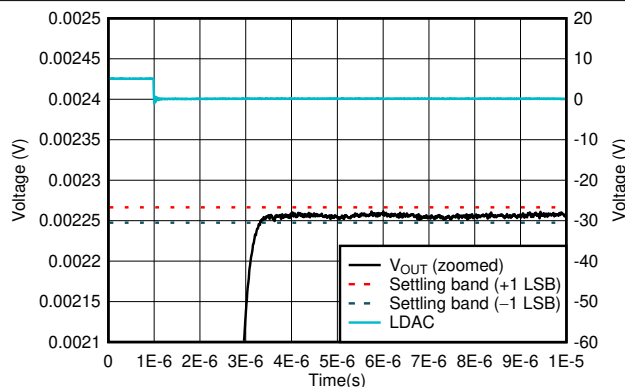


$V_{REFPF} = 10\text{ V}$ ,  $V_{REFNF} = 0\text{ V}$

**Figure 6-38. Full-Scale Settling Time, Falling Edge**

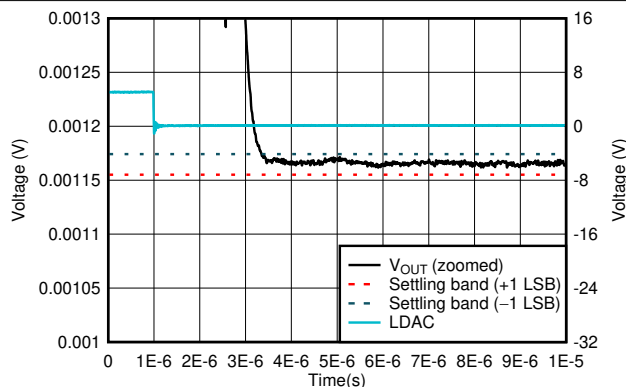
## 6.11 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , gain resistors unconnected (gain = 1x), OPA827 used as reference amplifier, OPA828 used as output amplifier, UP = unipolar, BP = bipolar, and **temperature calibration** disabled (unless otherwise noted)



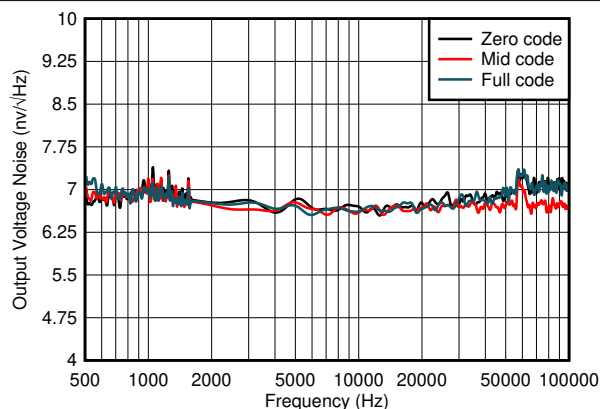
$V_{REFPF} = 10\text{ V}$ ,  $V_{REFNF} = 0\text{ V}$ ,  
DAC transitions 100 codes around midscale

**Figure 6-39. 100 Codes Settling Time, Rising Edge**



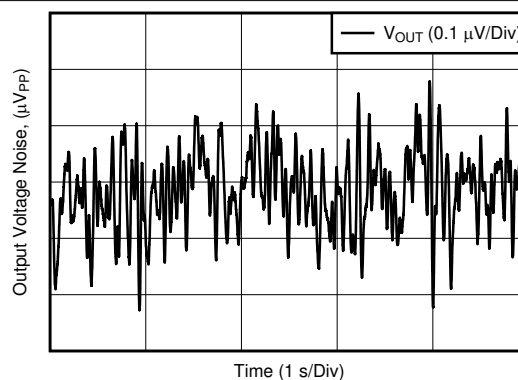
$V_{REFPF} = 10\text{ V}$ ,  $V_{REFNF} = 0\text{ V}$ ,  
DAC transitions 100 codes around midscale

**Figure 6-40. 100 Codes Settling Time, Falling Edge**



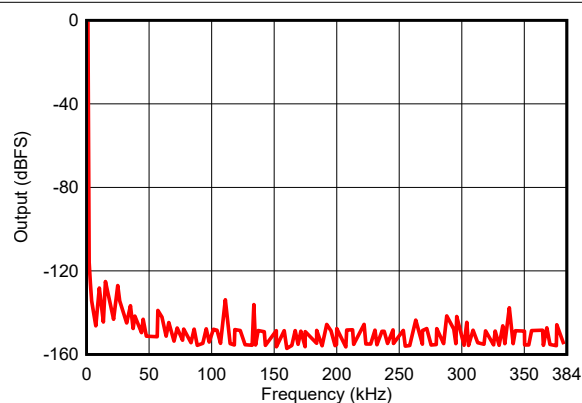
$V_{REFPF} = 10\text{ V}$ ,  $V_{REFNF} = 0\text{ V}$ , measured at DAC output

**Figure 6-41. DAC Output Noise Spectral Density**



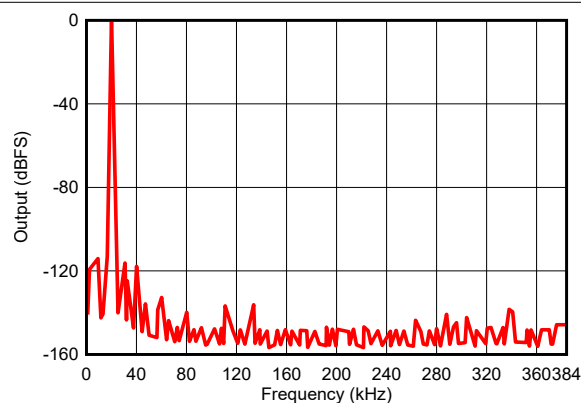
$V_{REFPF} = 10\text{ V}$ ,  $V_{REFNF} = 0\text{ V}$ ,  
DAC at midcode, measured at DAC output pin

**Figure 6-42. DAC Output Noise: 0.1 Hz to 10 Hz**



DAC update rate = 768 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ ,  
sixth-order, low-pass, 30-kHz output filter

**Figure 6-43. 1-kHz Spectrum vs Frequency**

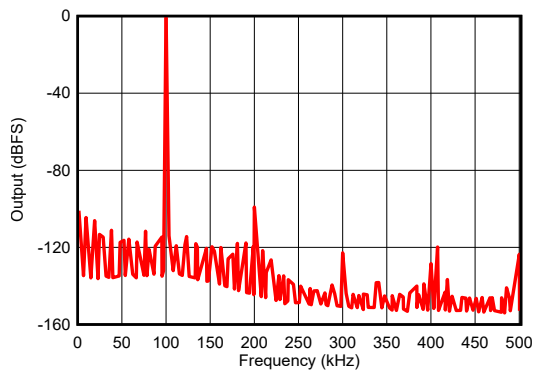


DAC update rate = 768 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ ,  
sixth-order, low-pass, 30-kHz output filter

**Figure 6-44. 20-kHz Spectrum vs Frequency**

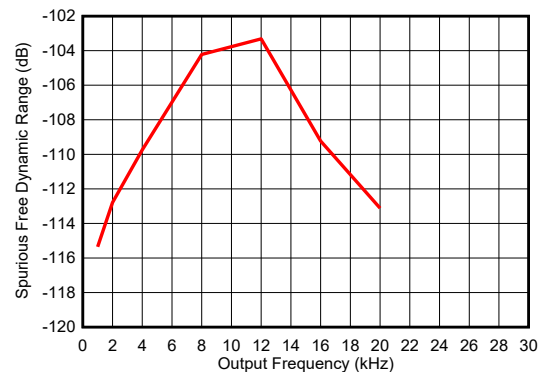
## 6.11 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , gain resistors unconnected (gain = 1x), OPA827 used as reference amplifier, OPA828 used as output amplifier, UP = unipolar, BP = bipolar, and [temperature calibration](#) disabled (unless otherwise noted)



DAC update rate = 1 MHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 150-kHz output filter

**Figure 6-45. 100-kHz Spectrum vs Frequency**



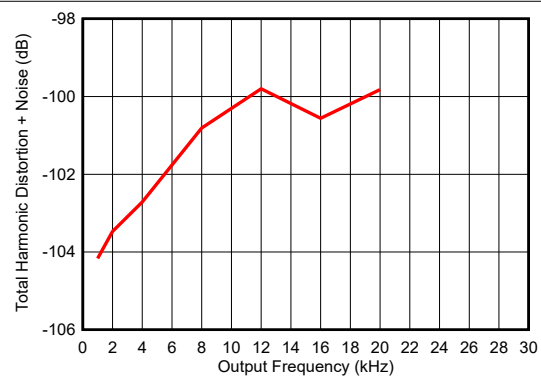
DAC update rate = 768 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter

**Figure 6-46. Spurious Free Dynamic Range vs Output Frequency,  $f_{DAC} = 768\text{ kHz}$**



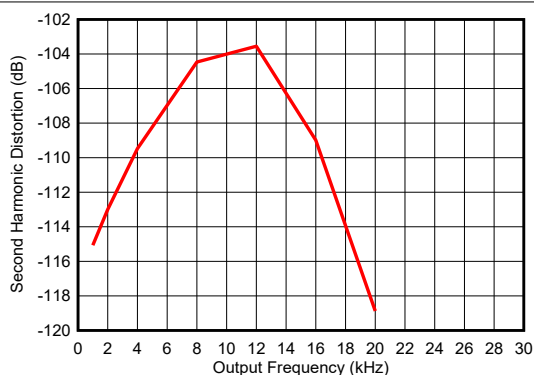
DAC update rate = 768 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter

**Figure 6-47. Total Harmonic Distortion vs Output Frequency,  $f_{DAC} = 768\text{ kHz}$**



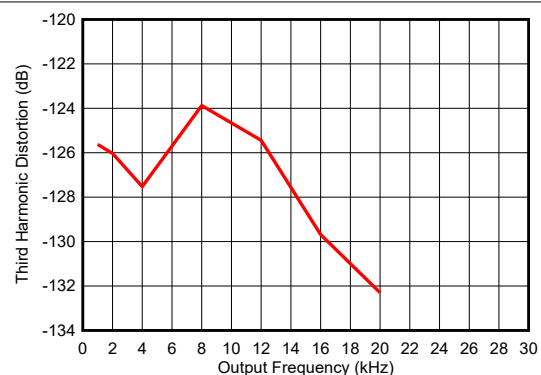
DAC update rate = 768 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter

**Figure 6-48. Total Harmonic Distortion + Noise vs Output Frequency,  $f_{DAC} = 768\text{ kHz}$**



DAC update rate = 768 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter

**Figure 6-49. Second Harmonic Distortion vs Output Frequency,  $f_{DAC} = 768\text{ kHz}$**

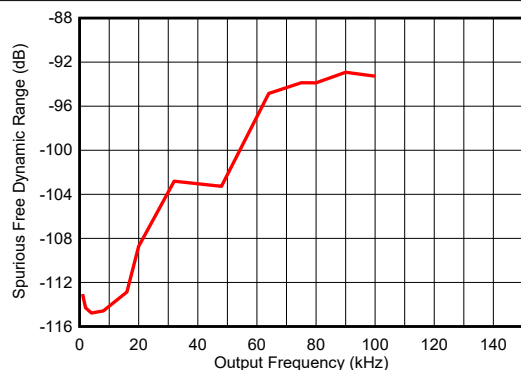


DAC update rate = 768 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter

**Figure 6-50. Third Harmonic Distortion vs Output Frequency,  $f_{DAC} = 768\text{ kHz}$**

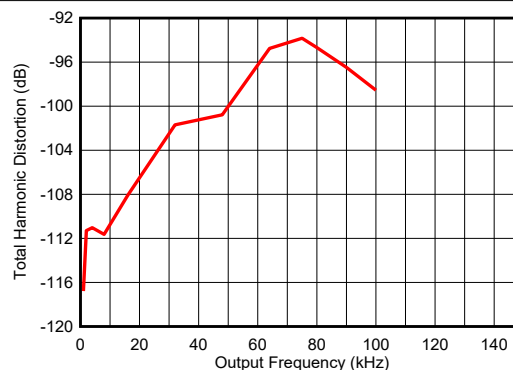
## 6.11 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , gain resistors unconnected (gain = 1x), OPA827 used as reference amplifier, OPA828 used as output amplifier, UP = unipolar, BP = bipolar, and [temperature calibration](#) disabled (unless otherwise noted)



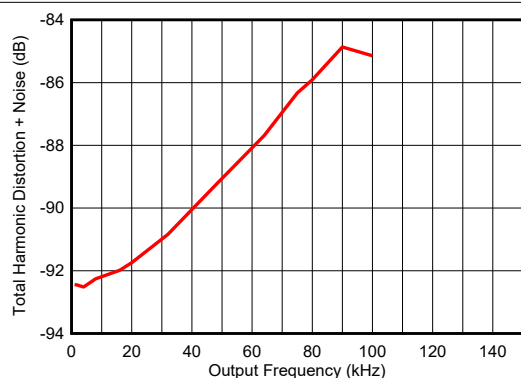
DAC update rate = 1 MHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 150-kHz output filter

**Figure 6-51. Spurious Free Dynamic Range vs Output Frequency,  $f_{DAC} = 1\text{ MHz}$**



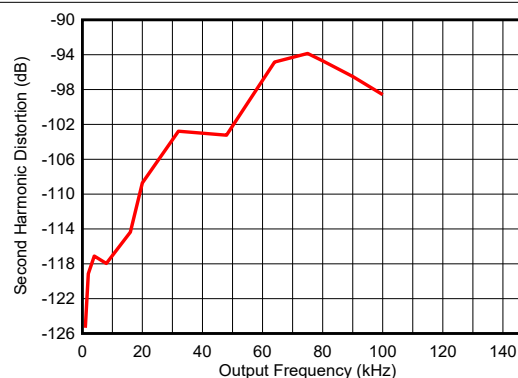
DAC update rate = 1 MHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 150-kHz output filter

**Figure 6-52. Total Harmonic Distortion vs Output Frequency,  $f_{DAC} = 1\text{ MHz}$**



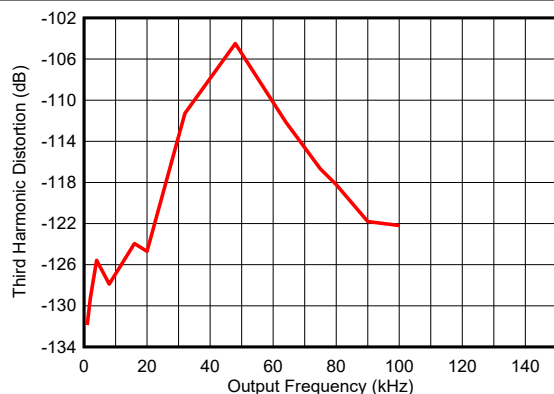
DAC update rate = 1 MHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 150-kHz output filter

**Figure 6-53. Total Harmonic Distortion + Noise vs Output Frequency,  $f_{DAC} = 1\text{ MHz}$**



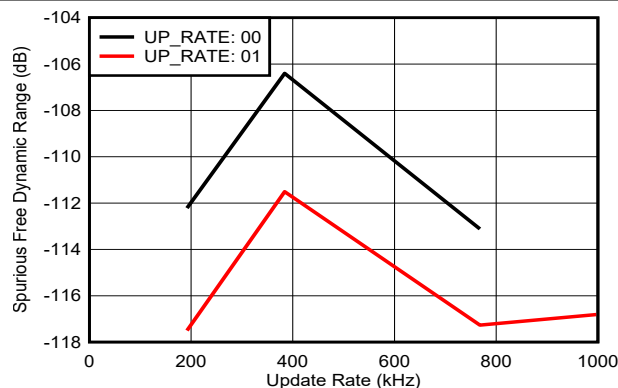
DAC update rate = 1 MHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 150-kHz output filter

**Figure 6-54. Second Harmonic Distortion vs Output Frequency,  $f_{DAC} = 1\text{ MHz}$**



DAC update rate = 1 MHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 150-kHz output filter

**Figure 6-55. Third Harmonic Distortion vs Output Frequency,  $f_{DAC} = 1\text{ MHz}$**

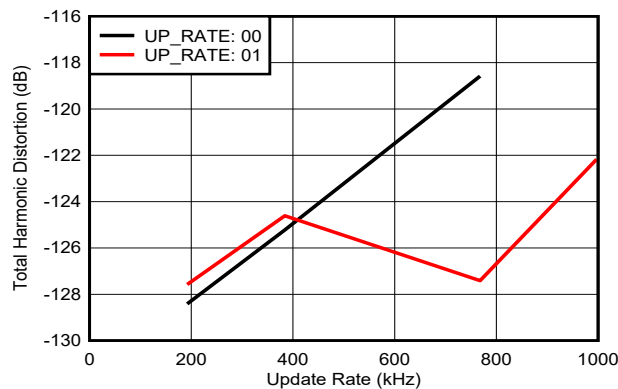


DAC output frequency = 20 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter

**Figure 6-56. Spurious Free Dynamic Range vs Update Rate**

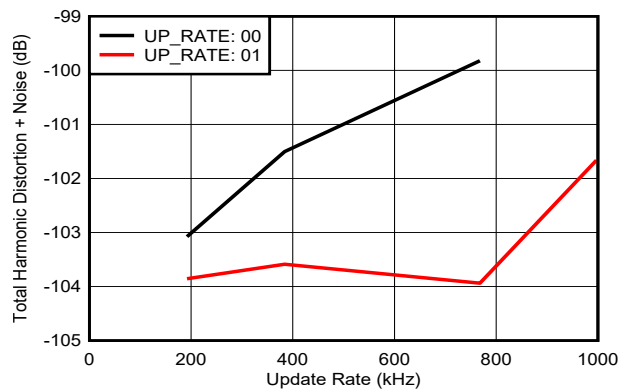
## 6.11 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{ V}$ ,  $V_{SS} = -15\text{ V}$ ,  $AV_{DD} = 5\text{ V}$ ,  $IOV_{DD} = 1.8\text{ V}$ , gain resistors unconnected (gain = 1x), OPA827 used as reference amplifier, OPA828 used as output amplifier, UP = unipolar, BP = bipolar, and [temperature calibration](#) disabled (unless otherwise noted)



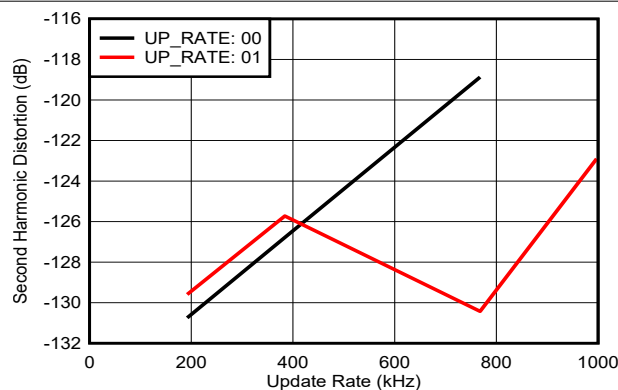
DAC output frequency = 20 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter

**Figure 6-57. Total Harmonic Distortion vs Update Rate**



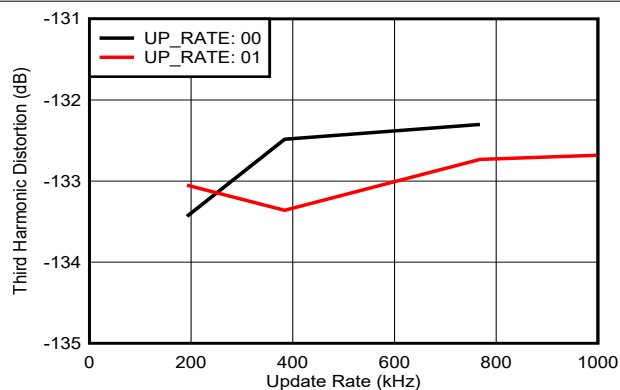
DAC output frequency = 20 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter

**Figure 6-58. Total Harmonic Distortion + Noise vs Update Rate**



DAC output frequency = 20 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter

**Figure 6-59. Second Harmonic Distortion vs Update Rate**



DAC output frequency = 20 kHz,  $V_{REFPF} = 4.5\text{ V}$ ,  $V_{REFNF} = -4.5\text{ V}$ , sixth-order, low-pass, 30-kHz output filter

**Figure 6-60. Third Harmonic Distortion vs Update Rate**



## 7 Detailed Description

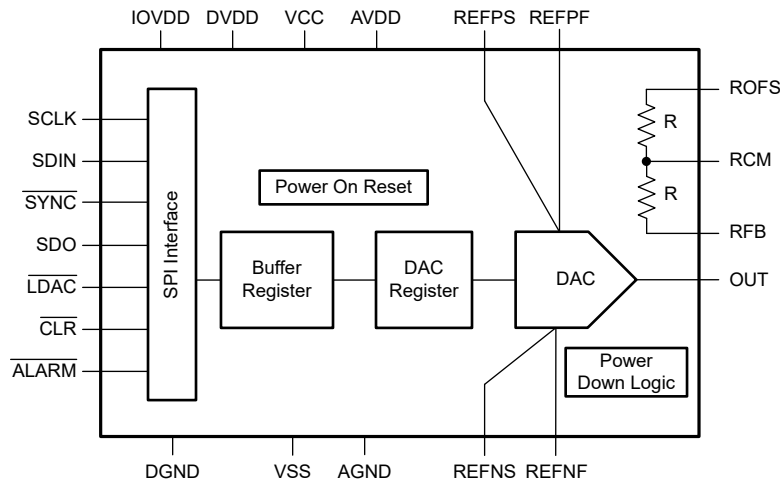
### 7.1 Overview

The 20-bit DAC11001B is a single-channel DAC. The unbuffered DAC output architecture is based on an R2R ladder that is designed to provide monotonicity and excellent linearity over wide reference and temperature ranges. This architecture provides a very low-noise ( $7 \text{ nV}/\sqrt{\text{Hz}}$ ) and fast-settling ( $1 \mu\text{s}$ ) output. The DAC11001B also implements a deglitch circuit that enables low, code-independent glitch at the DAC output. The deglitch circuit is extremely useful for creating ultra-low, harmonic-distortion waveform generation.

The DAC11001B requires external reference voltages on REFPPF and REFNF pins. The output of the DAC ranges from  $V_{\text{REFNF}}$  to  $V_{\text{REFPF}}$ . See [Section 6.3](#) for  $V_{\text{REFPF}}$  and  $V_{\text{REFNF}}$  voltage ranges.

The DAC11001B also includes precision matched gain setting pins (ROFS, RCM, and RFB). Use these pins and an external op amp to scale the DAC output. The DAC11001B incorporates a power-on reset (POR) circuit to make sure that the DAC output powers up at zero scale, and remains at zero scale until a valid DAC command is issued. The DAC11001B uses a 4-wire serial interface that operates at clock rates of up to 50 MHz.

### 7.2 Functional Block Diagram



### 7.3 Feature Description

#### 7.3.1 Digital-to-Analog Converter Architecture

The DAC11001B provides 20-bit monotonic outputs using an R2R ladder architecture. The DAC output ranges between  $V_{\text{REFNF}}$  and  $V_{\text{REFPF}}$  based on the 20-bit DAC data, as described in [Equation 1](#):

$$V_{\text{OUT}} = (V_{\text{REFPF}} - V_{\text{REFNF}}) \times \frac{\text{CODE}}{2^N} + V_{\text{REFNF}} \quad (1)$$

where

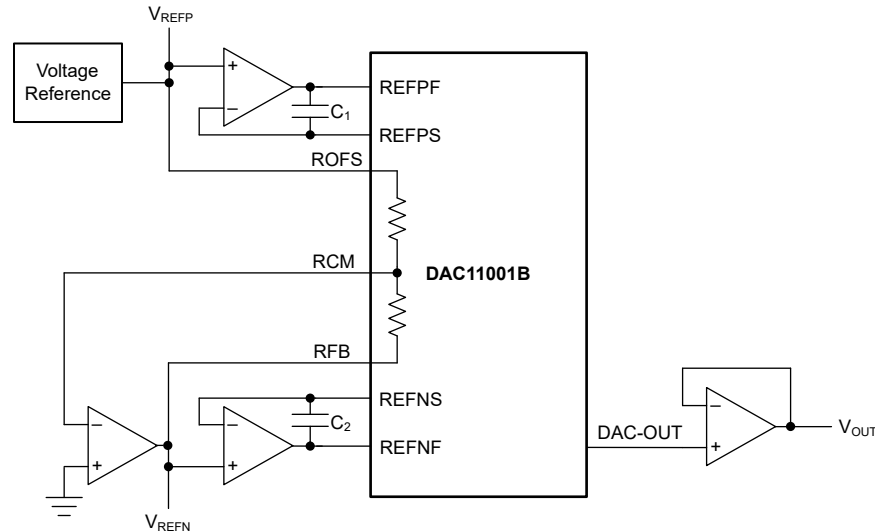
- CODE is the decimal equivalent of the DAC-DATA loaded to the DAC.
- N is the bits of resolution.
- $V_{\text{REFPF}}$ ,  $V_{\text{REFNF}}$  is the reference voltage (positive and negative).

### 7.3.2 External Reference

The DAC11001B requires external references (REFPF and REFNF) to operate. See [Section 6.3](#) for  $V_{REFPF}$  and  $V_{REFNF}$  voltage ranges.

The DAC11001B also contains dedicated sense pins, REFPS for REFPF and REFNS for REFNF. The reference pins are unbuffered; therefore, use a reference driver circuit for these pins. Set the VREFVAL bits (address 02h) as per a reference span equal to  $(V_{REFPF} - V_{REFNF})$ . For example, the VREFVAL bits must be set to 0100 for  $V_{REFPF} = 5\text{ V}$  and  $V_{REFNF} = -5\text{ V}$ .

[Figure 7-1](#) shows an example reference drive circuit for the DAC11001B. [Table 7-1](#) shows the op-amp options for the reference driver circuit.



**Figure 7-1. Reference Drive Circuit**

**Table 7-1. Reference Op Amp Options**

SELECTION PARAMETERS	OP AMPS
Low voltage and current noise	<a href="#">OPA211</a> , <a href="#">OPA827</a> , <a href="#">OPA828</a>
Low offset and drift	<a href="#">OPA189</a>

### 7.3.3 Output Buffers

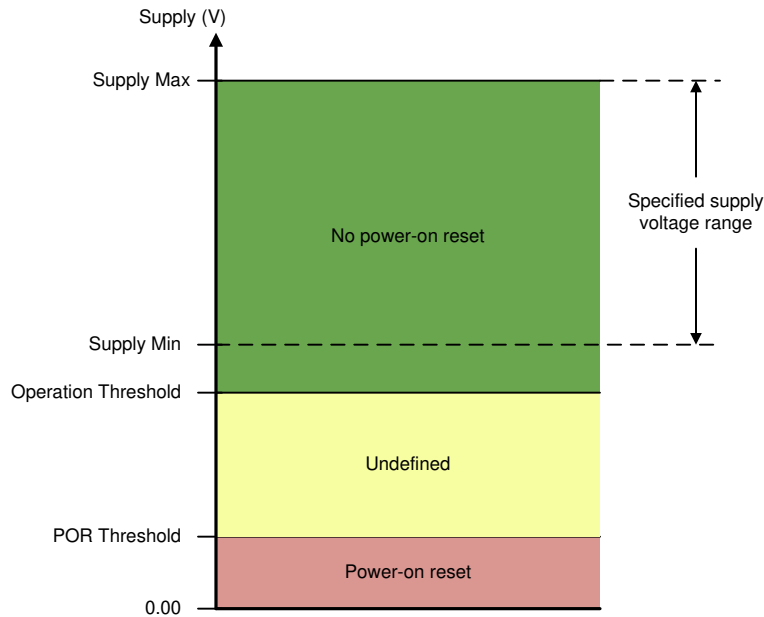
The DAC11001B outputs are unbuffered. Use an external op amp to buffer the DAC output. The DAC output voltage ranges from  $V_{REFPF}$  to  $V_{REFNF}$ . Two gain-setting resistors are integrated in the DAC11001B. These resistors are used to scale the DAC output, minimize the bias current mismatch of the external op amp, and generate a negative reference for the REFNF pin. See [Section 8.3.3](#) for more information. [Table 7-2](#) shows the op amp options for the output drive circuit.

**Table 7-2. Output Op Amp Options**

SELECTION PARAMETERS	OP AMPS
Low bias current	<a href="#">OPA827</a> , <a href="#">OPA828</a>
Low noise	<a href="#">OPA211</a> , <a href="#">OPA828</a>
Low offset and drift	<a href="#">OPA189</a>
Fast settling and low THD	<a href="#">OPA828</a>

### 7.3.4 Internal Power-On Reset (POR)

The DAC11001B incorporates two internal POR circuits for the  $DV_{DD}$ ,  $AV_{DD}$ ,  $IOV_{DD}$ ,  $V_{CC}$ , and  $V_{SS}$  supplies. The POR signals are ANDed together, so that all supplies must be at the minimum specified values for the device to *not* be in a reset condition. These POR circuits initialize internal registers, as well as set the analog outputs to a known state, all while the device supplies are ramping. All registers are reset to default values. The DAC11001B powers on with the DAC registers set to zero scale. The DAC output can be powered down by writing 1 to PDN (bit 4, address 02h). Typically, the POR function can be ignored as long as the device supplies power up and maintain the specified minimum voltage levels. However, a supply drop or brownout can trigger an internal POR reset event. Figure 7-2 represents the internal POR threshold levels for the  $DV_{DD}$ ,  $AV_{DD}$ ,  $IOV_{DD}$ ,  $V_{CC}$ , and  $V_{SS}$  supplies.



**Figure 7-2. Relevant Voltage Levels for the POR Circuit**

For the  $DV_{DD}$  supply, no internal POR occurs for nominal supply operation from 2.7 V (supply minimum) to 5.5 V (supply maximum). For a  $DV_{DD}$  supply region between 2.5 V (undefined operation threshold) and 1.6 V (POR threshold), the internal POR circuit may or may not provide a reset over all temperature conditions. For a  $DV_{DD}$  supply less than 1.6 V (POR threshold), the internal POR resets as long as the supply voltage is less than 1.6 V for approximately 1 ms.

For the  $AV_{DD}$  supply, no internal POR occurs for nominal supply operation from 4.5 V (supply minimum) to 5.5 V (supply maximum). For an  $AV_{DD}$  supply region between 4.1 V (undefined operation threshold) and 3.3 V (POR threshold), the internal POR circuit may or may not provide a reset over all temperature conditions. For an  $AV_{DD}$  supply less than 3.3 V (POR threshold), the internal POR resets as long as the supply voltage is less than 3.3 V for approximately 1 ms.

For the  $V_{CC}$  supply, no internal POR occurs for nominal supply operation from 8 V (supply minimum) to 36 V (supply maximum). For  $V_{CC}$  supply voltages between 7.5 V (undefined operation threshold) to 6 V (POR threshold), the internal POR circuit may or may not provide a reset over all temperature conditions. For a  $V_{CC}$  supply less than 6 V (POR threshold), the internal POR resets as long as the supply voltage is less than 6 V for approximately 1 ms.

For the  $V_{SS}$  supply, no internal POR occurs for nominal supply operation from -3 V (supply minimum) to -18 V (supply maximum). For  $V_{SS}$  supply voltages between -2.7 V (undefined operation threshold) to -1.8 V (POR threshold), the internal POR circuit may or may not provide a reset over all temperature conditions. For a  $V_{SS}$  supply greater than -1.8 V (POR threshold), the internal POR resets as long as the supply voltage is greater than -1.8 V for approximately 1 ms.

For the IOV<sub>DD</sub> supply, no internal POR occurs for nominal supply operation from 1.8 V (supply minimum) to 5.5 V (supply maximum). For IOV<sub>DD</sub> supply voltages between 1.5 V (undefined operation threshold) and 0.8 V (POR threshold), the internal POR circuit may or may not provide a reset over all temperature conditions. For an IOV<sub>DD</sub> supply less than 0.8 V (POR threshold), the internal POR resets as long as the supply voltage is less than 0.8 V for approximately 1 ms.

In case the DV<sub>DD</sub>, AV<sub>DD</sub>, IOV<sub>DD</sub>, V<sub>CC</sub>, or V<sub>SS</sub> supply drops to a level where the internal POR signal is indeterminate, power cycle the device followed by a software reset.

### 7.3.5 Temperature Drift and Calibration

The DAC11001B includes a calibration circuit that significantly reduces the temperature drift on integrated and differential nonlinearities. By default, this feature is disabled. Enable the temperature calibration feature by writing 1 to the EN\_TMP\_CAL bit (address 02h, B23). After the EN\_TMP\_CAL bit is set, issue a calibration cycle by writing 1 to RCLTMP (address 04h, B8). At this point, the device enters a calibration cycle. Do not issue any DAC update command during this period. The device has the capability to indicate the end of calibration using two methods:

1. Read the status bit ALM (address 05h, B12) using SPI.
2. Issue an alarm on the  $\overline{\text{ALARM}}$  pin by setting logic 0. To enable this feature, write 1 to ENALMP bit (address 02h, B12).

After the calibration cycle completes, update the DAC code to observe the impact at the DAC output. If the environmental temperature changes after calibration, then recalibrate the device.

### 7.3.6 DAC Output Deglitch Circuit

The DAC11001B includes a deglitch (track-and-hold) circuit at the output. This circuit is enabled by default. The deglitch circuit minimizes the code-to-code glitch at the DAC output at the expense of the DAC update rate. This circuit is disabled by writing 1 to DIS\_TNH (bit 7, address 06h). Disable this circuit to enable faster update of the DAC output, but with higher code-to-code glitches.

## 7.4 Device Functional Modes

### 7.4.1 Fast-Settling Mode and THD

The DAC11001B R2R ladder and deglitch circuit reduce the harmonic distortion for waveform generation applications. The fast settling bit (FSET, bit 10, address 02h) is set to 1 by default, so that the DAC is configured for enhanced THD performance. The FSET bit can be reset to 0 using an SPI write to enable fast-settling mode. In this mode, the DAC deglitcher circuit can be configured using TNH\_MASK (bits 19:18, address 02h). These bits disable the deglitch circuit for code changes specified in [Table 7-7](#). These bits are only writable when FSET = 0 (fast settling enabled) and DIS\_TNH = 0 (deglitch circuit enabled).

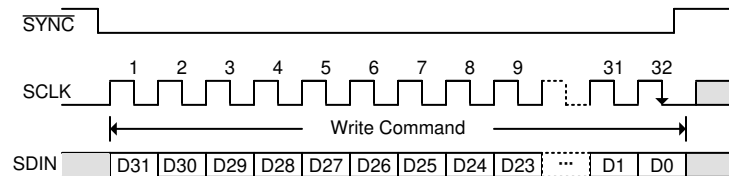
### 7.4.2 DAC Update Rate Mode

The DAC11001B maximum update rate can be configured up to 1 MHz by using UP\_RATE (bits 5:4, address 06h). These bits change the hold time of the deglitch circuit. The bits are set to a 0.8-MHz DAC update rate by default for enhanced THD performance. Changing the maximum update rate of the DAC impacts THD performance.

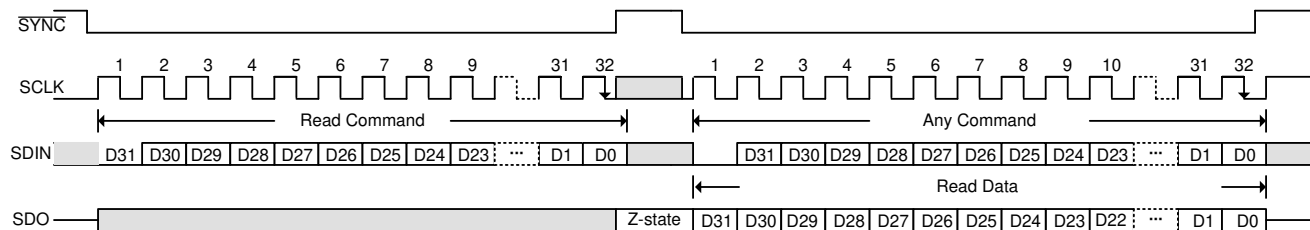
## 7.5 Programming

The DAC11001B is controlled through a flexible, four-wire serial interface that is compatible with serial interfaces used on many microcontrollers and DSP controllers. The interface provides read and write access to all registers of the DAC11001B. Additionally, the interface can be configured to daisy-chain multiple devices for write operations.

Each serial interface access cycle is exactly 32 bits long, as shown in [Figure 7-3](#). A frame is initiated by asserting the  $\overline{\text{SYNC}}$  pin low. The frame ends when the  $\overline{\text{SYNC}}$  pin is deasserted high. The first bit is read/write bit B31. A write is performed when this bit is set to 0, and a read is performed when this bit is set to 1. The next seven bits are address bits B30 to B24. The next 20 bits are data. For all writes, data are clocked on the falling edge of SCLK. As [Figure 7-4](#) shows, for read access and daisy-chain operation, the data are clocked out on the SDO terminal on the rising edge of SCLK.



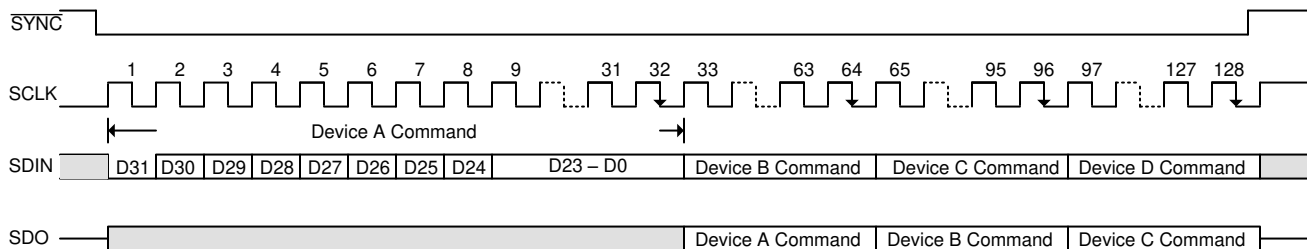
**Figure 7-3. Serial Interface Write Bus Cycle: Standalone Mode**



**Figure 7-4. Serial Interface Read Bus Cycle**

### 7.5.1 Daisy-Chain Operation

For systems that contain several DAC11001B devices, the SDO pin is used to daisy-chain the devices together. The daisy-chain feature is useful in reducing the number of serial interface lines. The first falling edge on the  $\overline{\text{SYNC}}$  pin starts the operation cycle, as shown in [Figure 7-5](#). SCLK is continuously applied to the input shift register while the  $\overline{\text{SYNC}}$  pin is kept low. The DAC is updated with the data on rising edge of  $\overline{\text{SYNC}}$  pin.



**Figure 7-5. Serial Interface Daisy-Chain Write Cycle**

If more than 32 clock pulses are applied, the data ripple out of the shift register and appear on the SDO line. These data are clocked out on the rising edge of SCLK and are valid on the falling edge. By connecting the SDO output of the first device to the SDI input of the next device in the chain, a multiple-device interface is constructed. Each device in the system requires 32 clock pulses.

As a result, the total number of clock cycles must be equal to  $32 \times N$ , where  $N$  is the total number of devices in the daisy-chain. When the serial transfer to all devices is complete the  $\overline{\text{SYNC}}$  signal is taken high. This action transfers the data from the SPI shift registers to the internal register of each device in the daisy-chain and prevents any further data from being clocked into the input shift register. The DAC11001B implements a bit that

enables higher speeds for clocking out data from the SDO pin. Enable this feature by setting FSDO (bit 13, address 02h) to 1.

### 7.5.2 $\overline{\text{CLR}}$ Pin Functionality and Software Clear

The  $\overline{\text{CLR}}$  pin is an asynchronous input pin to the DAC. When activated, this level-sensitive pin clears the DAC buffers and DAC latches to the DAC-CLEAR-DATA bits (address 03h). The device exits clear mode on the SYNC rising edge of the next valid write to the device. If the  $\overline{\text{CLR}}$  pin receives a logic 0 during a write sequence during normal operation, the clear mode is activated and the buffer and DAC registers are immediately cleared. The DAC registers can also be cleared using the SCLR bit (address 04h, B5); the contents are cleared at the rising edge of SYNC.

### 7.5.3 Output Update (Synchronous and Asynchronous)

The DAC11001B offers both a software and hardware simultaneous update and control function. The DAC double-buffered architecture has been designed so that new data can be entered for the DAC without disturbing the analog output. Data updates can be performed either in synchronous or in asynchronous mode, depending on the status of LDAC-MODE bit (address 02h, B14).

#### 7.5.3.1 Synchronous Update

In synchronous mode (LDACMODE = 1), the  $\overline{\text{LDAC}}$  pin is used as an active-low signal for simultaneous DAC updates. Data buffers must be loaded with the desired data before an  $\overline{\text{LDAC}}$  low pulse. After an  $\overline{\text{LDAC}}$  low pulse, the DAC is updated with the last contents of the corresponding data buffers. If the content of a data buffer is not changed, the DAC output remains unchanged after the  $\overline{\text{LDAC}}$  pin is pulsed low.

#### 7.5.3.2 Asynchronous Update

In asynchronous mode (LDACMODE = 0), data are updated with the rising edge of the SYNC (when daisy-chain mode is enabled, DSDO = 0), or at the 32nd falling edge of SCLK (When daisy-chain mode is disabled, DSDO = 1). For asynchronous updates, the  $\overline{\text{LDAC}}$  pin is not required, and must be connected to 0 V permanently.

### 7.5.4 Software Reset Mode

The DAC11001B implements a software reset feature. The software reset function uses the SRST bit (address 04h, B6). When this bit is set to 1, the device resets to the default state.

## 7.6 Register Map

**Table 7-3. Register Map**

REGISTER NAME	BIT																										
	31	30-24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3-0				
NOP	W	00h	NOP																					0h			
DAC-DATA	R/W	01h	DAC-DATA (20 bits, left-justified)																					0h			
CONFIG1	R/W	02h	EN_	000		TNH_MASK		000		LDAC	FSDO	ENALMP	DSDO	FSET	VREFVAL				0	PDN	0h						
			TMP_							MODE																	
			CAL																								
DAC-CLEAR-DATA	R/W	03h	DAC-CLEAR-DATA (8 bits left justified)								000h														0h		
TRIGGER	R/W	04h	0000h																RCLTMP	0	SRST	SCLR	0	0h			
STATUS	R	05h	000h										ALM		00h										0h		
CONFIG2	R/W	06h	0000h																				DIS_TNH	1	UP_RATE		0h

**Table 7-4. Access Type Codes**

Access Type	Code	Description
Read Type		
R	R	Read
Write Type		
W	W	Write
Reset or Default Value		
-n		Value after reset or the default value

### 7.6.1 NOP Register (address = 00h) [reset = 0x000000h for bits [23:0]]

**Figure 7-6. NOP Register Format**

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Read/ Write	Address							NOP							
W	W							W-00h							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NOP												RESERVED			
W-000h												W-0h			

**Table 7-5. NOP Register Field Descriptions**

Bit	Field	Type	Reset	Description
31	Read/Write	W	N/A	Write only register. Must be set to 0.
30-24	Address	W	N/A	00h
23-4	NOP	W	00000h	No operation; write 00000h
3-0	RESERVED	W	0h	These bits are reserved.

### 7.6.2 DAC-DATA Register (address = 01h) [reset = 0x000000h for bits [23:0]]

**Figure 7-7. DAC-DATA Register Format**

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Read/ Write	Address							DAC-DATA (20-bit, left justified)							
W	W							R/W-00h							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DAC-DATA (20-bit, left justified)												RESERVED			
R/W-000h												W-0h			

**Table 7-6. DAC-DATA Register Field Descriptions**

Bit	Field	Type	Reset	Description
31	Read/Write	W	N/A	Read when set to 1 or write when set to 0
30-24	Address	W	N/A	01h
23-4	DAC-DATA[19:0]	R/W	00000h	Stores the 20-bit data to be loaded to the DAC in MSB-aligned, straight-binary format.
3-0	RESERVED	W	0h	These bits are reserved.



### 7.6.3 CONFIG1 Register (address = 02h) [reset = 004C80h for bits [23:0]]

**Figure 7-8. CONFIG1 Register Format**

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Read/Write	Address							EN_TMP_CAL	RESERVED			TNH_MASK		RESERVED	
W	W							R/W-0h	W-0h			R/W-0h		W-0h	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RSVD	LDAC MODE	FSDO	ENALMP	DSDO	FSET	VREFVAL				RSVD	PDN	RESERVED			
W-0h	R/W-1h	R/W-0h	R/W-0h	R/W-1h	R/W-1h	R/W-2h				W-0h	R/W-0h	W-0h			

**Table 7-7. CONFIG1 Register Field Descriptions**

Bit	Field	Type	Reset	Description
31	Read/Write	W	N/A	Read when set to 1 or write when set to 0
30-24	Address	W	N/A	02h
23	EN_TMP_CAL	R/W	0h	Enables and disables the temperature calibration feature 0: Temperature calibration feature disabled (default) 1: Temperature calibration feature enabled
22-20	RESERVED	W	0h	These bits are reserved.
19-18	TNH_MASK	R/W	0h	Mask track and hold (TNH) circuit. This bit is writable only when FSET = 0 [fast-settling mode] and DIS_TNH = 0 [track-and-hold enabled] 00: TNH masked for code jump > 2 <sup>14</sup> (default) 01: TNH masked for code jump > 2 <sup>15</sup> 10: TNH masked for code jump > 2 <sup>13</sup> 11: TNH masked for code jump > 2 <sup>12</sup>
17-15	RESERVED	W	0h	These bits are reserved.
14	LDACMODE	R/W	1h	Synchronous or asynchronous mode select bit 0: DAC output updated on SYNC rising edge 1: DAC updated on LDAC falling edge (default)
13	FSDO	R/W	0h	Enable Fast SDO 0: Fast SDO disabled (Default) 1: Fast SDO enabled
12	ENALMP	R/W	0h	Enable ALARM pin to be pulled low, end of temperature calibration cycle 0: No alarm on the ALARM pin 1: Indicates end of temperature calibration cycle. ALARM pin pulled low.
11	DSDO	R/W	1h	Enable SDO (for readback and daisy-chain) 1: SDO enabled (default) 0: SDO disabled
10	FSET	R/W	1h	Fast-settling vs enhanced THD mode 0: Fast settling 1: Enhanced THD (default)
9-6	VREFVAL	R/W	2h	Reference span value bits 0000: Invalid 0001: Invalid 0010: Reference span = 5 V ± 1.25 V (default) 0011: Reference span = 7.5 V ± 1.25 V 0100: Reference span = 10 V ± 1.25 V 0101: Reference span = 12.5 V ± 1.25 V 0110: Reference span = 15 V ± 1.25 V 0111: Reference span = 17.5 V ± 1.25 V 1000: Reference span = 20 V ± 1.25 V 1001: Reference span = 22.5 V ± 1.25 V 1010: Reference span = 25 V ± 1.25 V 1011: Reference span = 27.5 V ± 1.25 V 1100: Reference span = 30 V ± 1.25 V
5	RESERVED	W	0h	This bit is reserved.
4	PDN	R/W	0h	Powers down and power up the DAC 0: DAC power up (default) 1: DAC power down
3-0	RESERVED	W	0h	These bits are reserved.

## 7.6.4 DAC-CLEAR-DATA Register (address = 03h) [reset = 000000h for bits [23:0]]

**Figure 7-9. DAC-CLEAR-DATA Register Format**

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Read/ Write	Address							DAC-CLEAR-DATA (8 bits, left justified)							
W	W							R/W-00h							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED												RESERVED			
W-000h												W-0h			

**Table 7-8. DAC-CLEAR-DATA Register Field Descriptions**

Bit	Field	Type	Reset	Description
31	Read/Write	W	N/A	Read when set to 1 or write when set to 0
30-24	Address	W	N/A	03h
23-16	DAC-CLEAR-DATA	R/W	00h	Stores the 8-bit data to be loaded to the DAC in left-justified, straight-binary format. DAC data registers are updated with this value when the CLR pin is asserted low
15-4	RESERVED	W	000h	These bits are reserved.
3-0	RESERVED	W	0h	These bits are reserved.

## 7.6.5 TRIGGER Register (address = 04h) [reset = 000000h for bits [23:0]]

**Figure 7-10. TRIGGER Register Format**

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Read/ Write	Address							RESERVED							
W	W							W-00h							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED							RCLTMP	RSVD	SRST	SCLR	RSVD	RESERVED			
W-00h							R/W-0h	W-0h	R/W-0h	R/W-0h	W-0h	W-0h			

**Table 7-9. TRIGGER Register Field Descriptions**

Bit	Field	Type	Reset	Description
31	Read/Write	W	N/A	Read when set to 1 or write when set to 0
30-24	Address	W	N/A	04h
23-9	RESERVED	W	0000h	These bits are reserved.
8	RCLTMP	R/W	0h	Trigger temperature recalibration DAC Codes 0: No temperature recalibration (default) 1: DAC codes recalibrated, ALARM pin pulled low (if ENALMP = 1) and ALM bit (address 05) set to 1 when calibration complete. Subsequent DAC codes use the latest calibrated coefficients.
7	RESERVED	W	0h	This bit is reserved.
6	SRST	R/W	0h	Software reset 0: No software reset (default) 1: Software reset initiated, device in default state
5	SCLR	R/W	0h	Software clear 0: No software clear (default) 1: Software clear initiated, DAC registers in clear mode, DAC code set by clear select register (address 03h). DAC output clears on 32nd SCLK falling (DSDO = 1) or SYNC rising edge (DSDO = 0)
4	RESERVED	W	0h	This bit is reserved.
3-0	RESERVED	W	0h	These bits are reserved.

## 7.6.6 STATUS Register (address = 05h) [reset = 000000h for bits [23:0]]

**Figure 7-11. STATUS Register Format**

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Read/Write	Address							RESERVED							
R	W							W-00h							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED			ALM	RESERVED								RESERVED			
W-0h			R-0h	W-00h								W-0h			

**Table 7-10. STATUS Register Field Descriptions**

Bit	Field	Type	Reset	Description
31	Read/Write	R	N/A	Read only register. Must be set to 1.
30-24	Address	W	N/A	05h
23-13	RESERVED	W	000h	These bits are reserved.
12	ALM	R	0	Alarm indicator bit, This bit is not masked by ENALMP bit 0: Temperature recalibration in progress 1: DAC codes recalibrated, ALARM pin is pulled low (if ENALMP = 1). Subsequent DAC codes will use latest calibrated coefficients. Reading back this register resets ALARM pin to 1 status.
11-4	RESERVED	W	00h	These bits are reserved.
3-0	RESERVED	W	0h	These bits are reserved.

## 7.6.7 CONFIG2 Register (address = 06h) [reset = 000040h for bits [23:0]]

**Figure 7-12. CONFIG2 Register Format**

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Read/Write	Address							RESERVED							
W	W							W-00h							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED								DIS_TNH	RSVD	UP_RATE	RESERVED				
W-00h								R/W-0h	W-1h	R/W-0h	W-0h				

**Table 7-11. CONFIG2 Register Field Descriptions**

Bit	Field	Type	Reset	Description
31	Read/Write	W	N/A	Read when set to 1 or write when set to 0
30-24	Address	W	N/A	06h
23-8	RESERVED	W	0000h	These bits are reserved.
7	DIS_TNH	R/W	0h	Disable track and hold: 0: Track and hold enabled (default) 1: Track and hold disabled
6	RESERVED	W	1h	This bit is reserved.
5-4	UP_RATE	R/W	0h	DAC output max update rate: 00: 0.8 MHz with 28-MHz SCLK, (default) 01: 1.05 MHz with 38.5-MHz SCLK 10: 0.7 MHz with 25.5-MHz SCLK 11: 0.95 MHz with 34.5-MHz SCLK
3-0	RESERVED	W	0h	These bits are reserved.

## 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 DAC11001B is targeted for high-precision applications where ultra-high dc accuracy, ultra-low noise, fast settling, or high total harmonic distortion (THD) are required. The DAC11001B provides 20-bit monotonic resolution and excellent linearity. The DAC11001B finds application in high-performance source measure unit (SMU), arbitrary waveform generation (AWG). The DAC11001B is an also excellent choice for closed-loop control applications such as microelectromechanical system (MEMS) actuators, linear actuators, precision motor control, lens autofocus control in precision microscopy, lens control in mass spectrometer, beam control in electron beam lithography, and so on.

### 8.2 Typical Application

#### 8.2.1 Source Measure Unit (SMU)

A source measure unit (SMU) is a common building block in memory and semiconductor test equipment and bench-top source measure units. A DAC is used in an SMU to force a desired voltage or a current to a device-under-test (DUT). [Figure 8-1](#) provides a simplified circuit diagram of the force-DAC in an SMU.

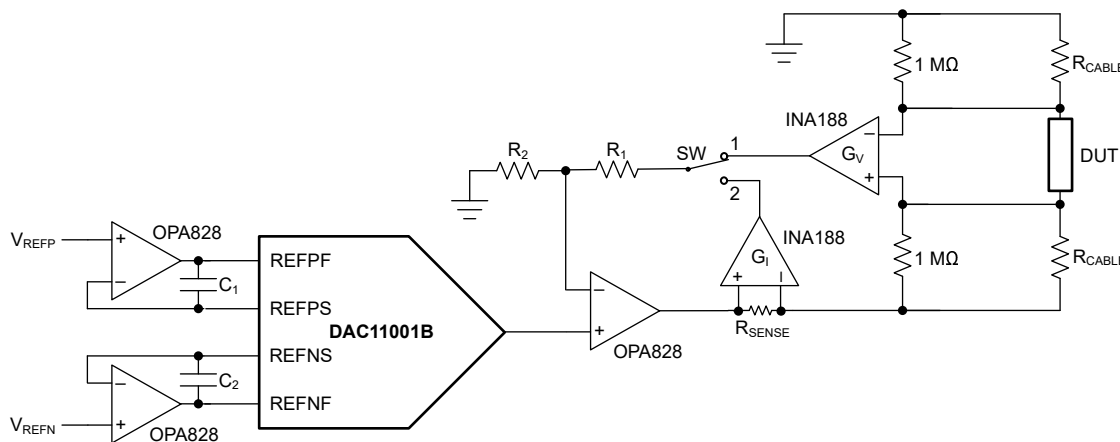


Figure 8-1. Source Measure Unit

#### 8.2.1.1 Design Requirements

- Force voltage range:  $\pm 10$  V
- Force current range:  $\pm 20$  mA

### 8.2.1.2 Detailed Design Procedure

The DAC11001B is an excellent choice for this application to meet the 20-bit resolution requirement. Switch SW is used to toggle between force-voltage and force-current modes, as shown in [Figure 8-1](#). The [OPA828](#) is a high-precision amplifier that provides a good balance between dc and ac performance, and can supply  $\pm 30$ -mA output current. The [INA188](#) is a zero-drift instrumentation amplifier with gain selected with an external resistor. The external resistor is not shown in the drawing for simplicity. The gain resistor is not required for a gain of 1. [Equation 2](#) shows the calculation of the voltage gain when switch SW is in position 1.

$$A_V = \frac{1}{G_V} \times \left( 1 + \frac{R_1}{R_2} \right) \quad (2)$$

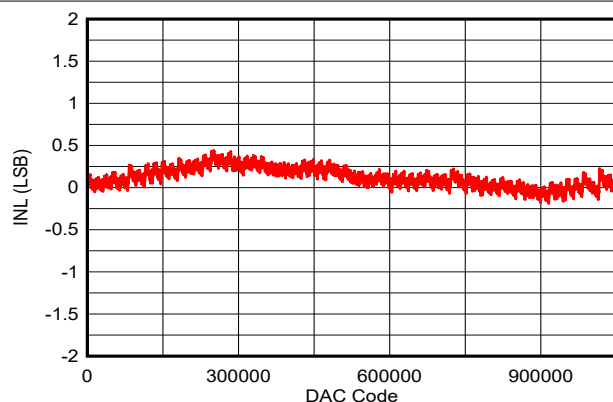
Precision reference sources are available at 5 V or less. Use a  $\pm 5$ -V reference with a 2x gain configuration to get an output of  $\pm 10$  V. The DAC output amplifier sets the gain at 2, assuming  $G_V = 1$ , as shown in [Equation 3](#).  $R_1$  and  $R_2$  are 1-k $\Omega$  each. [Equation 3](#) shows the calculation for the current gain when the switch is in the position 2.

$$A_V = \frac{1}{R_{SENSE} \times G_I} \times \left( 1 + \frac{R_1}{R_2} \right) \quad (3)$$

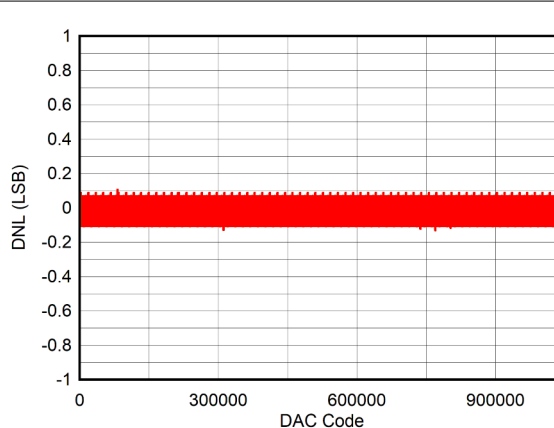
In order to get  $\pm 20$ -mA output current range with  $R_1 = R_2$ ,  $R_{SENSE} \times G_I$  must be 500. Set  $G_I$  to 50 so that  $R_{SENSE}$  is 10- $\Omega$ . For a  $\pm 20$ -mA output current, the voltage drop across  $R_{SENSE}$  is  $\pm 200$ -mV. In case the design requires a lower voltage headroom, choose a higher value for  $G_I$  and a smaller resistance value for  $R_{SENSE}$ .

There is no equation to select  $C_1$  and  $C_2$ . The values of  $C_1$  and  $C_2$  depend on the stability criteria of the reference buffers when driving the reference inputs of DAC11001B. The values are obtained through simulation. For the OPA828, use  $C_1 = C_2 = 100$  pF. The 1-M $\Omega$  resistors in the circuit are used for making sure the amplifiers are not left in an open-loop state.

### 8.2.1.3 Application Curves



**Figure 8-2. INL at  $\pm 10$ -V Output**



**Figure 8-3. DNL at  $\pm 10$ -V Output**

## 8.2.2 High-Precision Control Loop

High-precision control loops are used in precision motion-control applications, such as linear actuator control, servo motor control, galvanometer control, and more. The key requirements for such applications is resolution, monotonicity, settling time, and code-to-code glitch. Figure 8-4 provides a simplified circuit of a linear actuator control circuit, wherein the DAC11001B commands the set point and an analog loop controls the actuator.

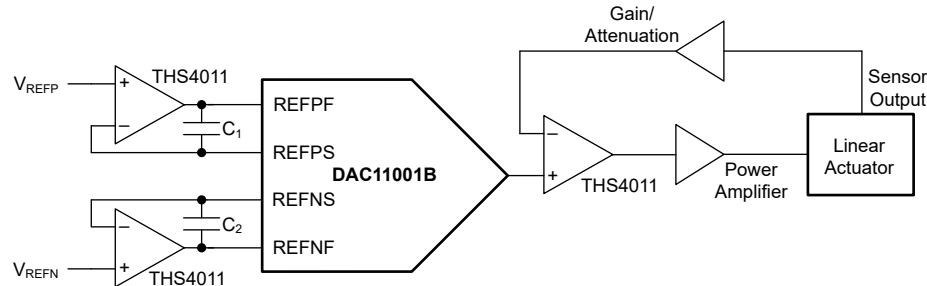


Figure 8-4. High-Precision Control Loop

### 8.2.2.1 Design Requirements

- DNL:  $\pm 1$  LSB max at 20-bits
- Settling time:  $< 2 \mu\text{s}$
- Code-to-code glitch:  $< 2 \text{ nV-s}$

### 8.2.2.2 Detailed Design Procedure

The DAC11001B provides 20-bit monotonic resolution at  $< \pm 1$  LSB DNL. The device provides  $< 2\text{-}\mu\text{s}$  settling time and  $< 2\text{-nV-s}$  code-to-code glitch for major carry transition. The reference and output buffer used for this design is the THS4011, a high-speed amplifier with a 90-ns settling time. For the best settling response, use  $C_1$  and  $C_2$  between 10 pF to 50 pF.

### 8.2.2.3 Application Curves

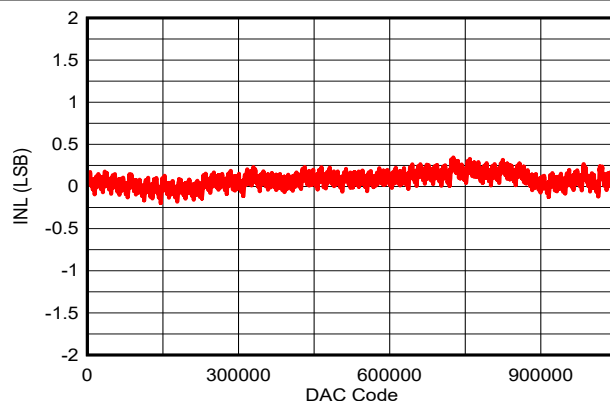


Figure 8-5. INL at  $\pm 5\text{-V}$  Output

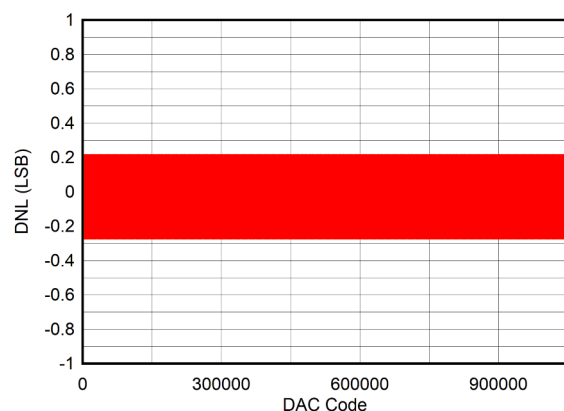
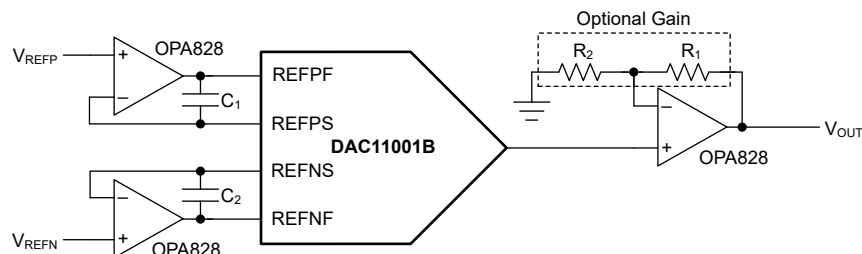


Figure 8-6. DNL at  $\pm 5\text{-V}$  Output

### 8.2.3 Arbitrary Waveform Generation (AWG)

Arbitrary waveform generation circuits are common in memory and semiconductor test equipment. These circuits are used to generate reference ac waveforms to test semiconductor devices. The key performance parameters of such circuits are THD, SNR, and the update rate. Figure 8-7 shows the basic building block example of an AWG circuit using the DAC11001B.



**Figure 8-7. Arbitrary Waveform Generation**

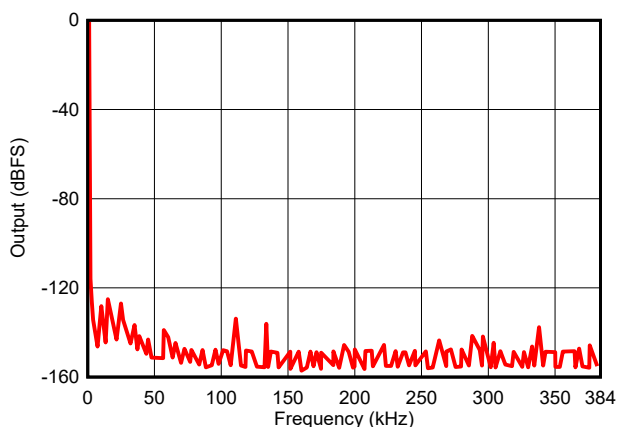
#### 8.2.3.1 Design Requirements

- THD at 1 kHz: > -105 dB
- Update rate: 768 kHz

#### 8.2.3.2 Detailed Design Procedure

The DAC11001B provides a THD of -115 dB at 1 kHz. The device provides update rates of up to 1 MHz, with marginal degradation in THD at higher frequencies. The OPA828 amplifier provides the best balance between the voltage and current noise densities, and is therefore an excellent choice to use as reference buffers. The OPA828 also offers low-distortion for high-THD applications.

#### 8.2.3.3 Application Curves



**Figure 8-8. 1-kHz Spectrum vs Frequency**

## 8.3 System Examples

This section provides details on the digital interface and the embedded resistor configurations.

### 8.3.1 Interfacing to a Processor

The DAC11001B works with a 4-wire SPI interface. The digital interface of the device to a processor is shown in Figure 8-9. The DAC11001B has an  $\overline{\text{LDAC}}$  input option for synchronous output update. In ac-signal-generation applications, the jitter in the  $\overline{\text{LDAC}}$  signal contributes to signal-to-noise ratio (SNR). Therefore, the  $\overline{\text{LDAC}}$  signal must be generated from a low-jitter timer in the processor. The  $\overline{\text{CLR}}$  and  $\overline{\text{ALARM}}$  pins are static signals, and therefore can be connected to general-purpose input-output (GPIO) pins on the processor. All active-low signals ( $\overline{\text{SYNC}}$ ,  $\overline{\text{LDAC}}$ ,  $\overline{\text{CLR}}$ , and  $\overline{\text{ALARM}}$ ) must be pulled up to IOVDD using 10-k $\Omega$  resistors.  $\overline{\text{ALARM}}$  is an output pin from the DAC; therefore, the corresponding GPIO on the processor must be configured as an input. Either poll the GPIO, or configure the GPIO as an interrupt to detect any failure alarm from the DAC. When using a high SCLK frequency, use source termination resistors, as shown in Section 8.3.1. Typically, 33- $\Omega$  resistors work on printed circuit boards (PCBs) with a 50- $\Omega$  trace impedance.

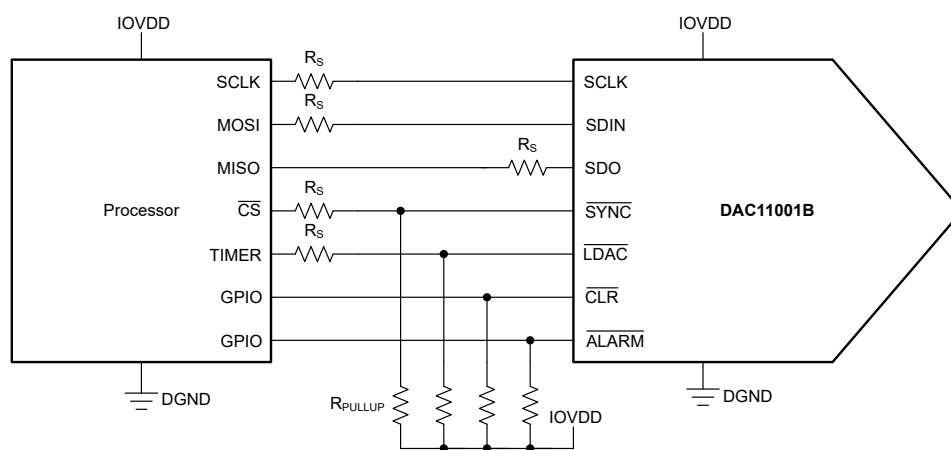


Figure 8-9. Interfacing to a Processor

### 8.3.2 Interfacing to a Low-Jitter $\overline{\text{LDAC}}$ Source

When the processor is not able to provide a low-jitter source for the  $\overline{\text{LDAC}}$  signal, an external low-jitter LDAC source can be used, as shown in Figure 8-10. The processor can take the  $\overline{\text{LDAC}}$  signal as an interrupt and trigger the SPI frame synchronously.

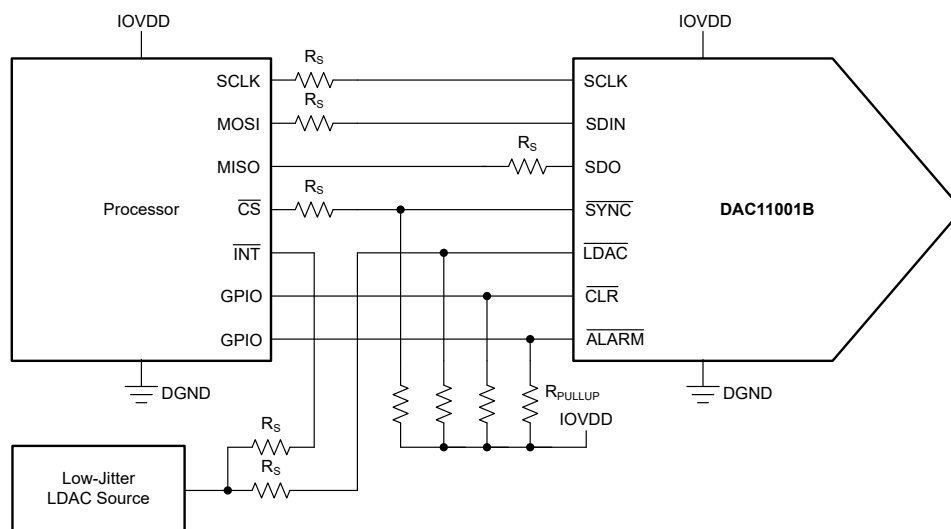


Figure 8-10. Interfacing to an External  $\overline{\text{LDAC}}$  Source



### 8.3.3 Embedded Resistor Configurations

The DAC11001B provides two embedded resistors with values that are double the value of the output impedance of the R2R ladder. These resistors can be used in various configurations, as shown in the following subsections.

#### 8.3.3.1 Minimizing Bias Current Mismatch

The bias current mismatch in the output amplifier can lead to offset error at the output. To minimize mismatch, the amplifier must have a matching resistor to that of the R2R output impedance on the feedback path. The feedback resistors are used in parallel for this purpose, as shown in Figure 8-11. Some amplifiers may become unstable with a feedback resistor in the buffer configuration; therefore, a compensation capacitor ( $C_{COMP}$ ) might be needed, as shown. The typical value of this capacitor is in the range of 22 pF to 100 pF, depending on the amplifier.

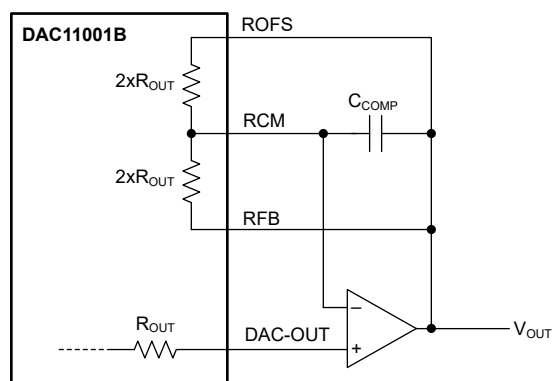


Figure 8-11. Minimizing Bias Current Mismatch

#### 8.3.3.2 2x Gain Configuration

The circuit of Figure 8-11 can be configured for 2x gain by connecting one of the resistor ends to ground, as shown in Figure 8-12.

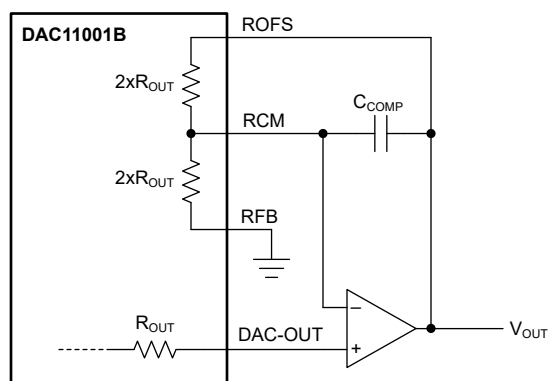
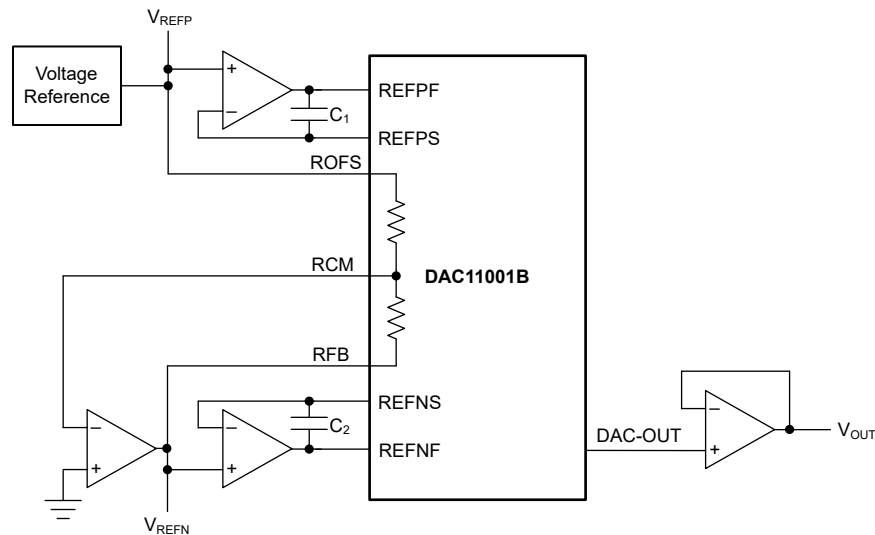


Figure 8-12. 2x Gain Configuration

### 8.3.3.3 Generating Negative Reference

Generating a negative reference is a challenge because of the fact that the circuit needs an inverting amplifier involving resistors. The resistor mismatch and temperature drift can lead to inaccuracy. The embedded, matched resistors in DAC11001B can be used as shown in [Figure 8-13](#), the inverting amplifier configuration, to generate an accurate negative reference voltage.



**Figure 8-13. Generating Negative Reference**

## 8.4 What to Do and What Not to Do

### 8.4.1 What to Do

- Follow recommended grounding, decoupling, and layout schemes for achieving best accuracy.
- Use a low-jitter  $\overline{\text{LDAC}}$  source for best ac performance.
- Choose the appropriate amplifiers depending on the application requirements as explained in above sections.

### 8.4.2 What Not to Do

- Do not apply the reference before the DAC power supplies are powered on.
- Do not use the reference source directly with the DAC reference inputs without using buffers. or else the accuracy drastically degrades.

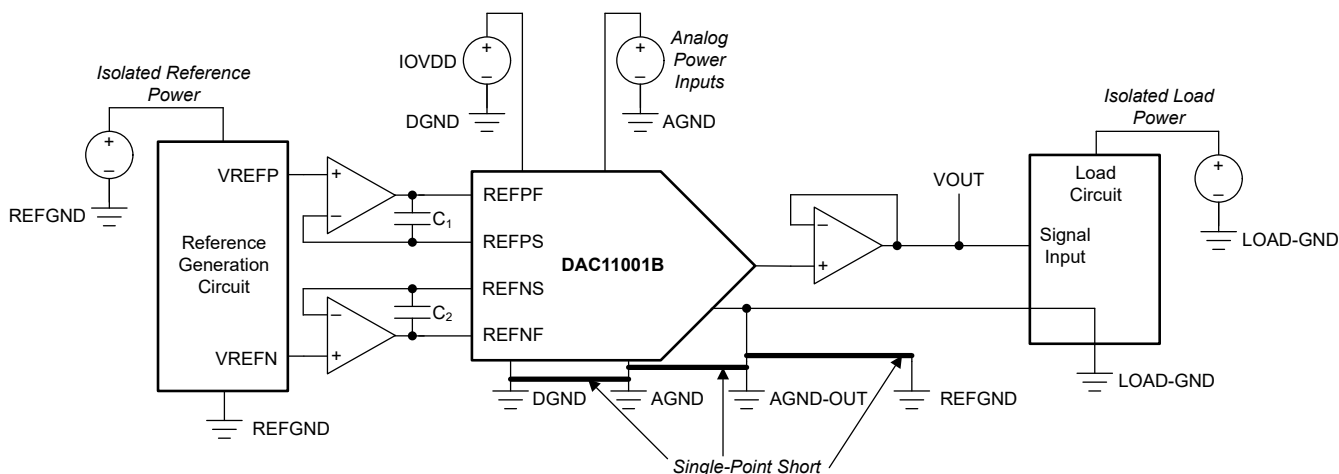
## 8.5 Initialization Set Up

The following text shows the pseudocode to get started with the DAC11001B:

```
//SPI Settings
//Mode: Mode-1 (CPOL: 0, CPHA: 1)
//CS Type: Active Low, Per Packet
//Frame length: 32
//SYNTAX: WRITE <REGISTER (HEX ADDRESS>, <HEX DATA>
//Select VREF, TnH mode (Good THD), LDAC mode and power-up the DAC
WRITE CONFIG (0x02), 0x004C80
//Write zero code to the DAC
WRITE DACDATA (0x01), 0x000000
//Write mid code to the DAC
WRITE DACDATA (0x01), 0x7FFFF0
//Write full code to the DAC
WRITE DACDATA (0x01), 0xFFFFF0
```

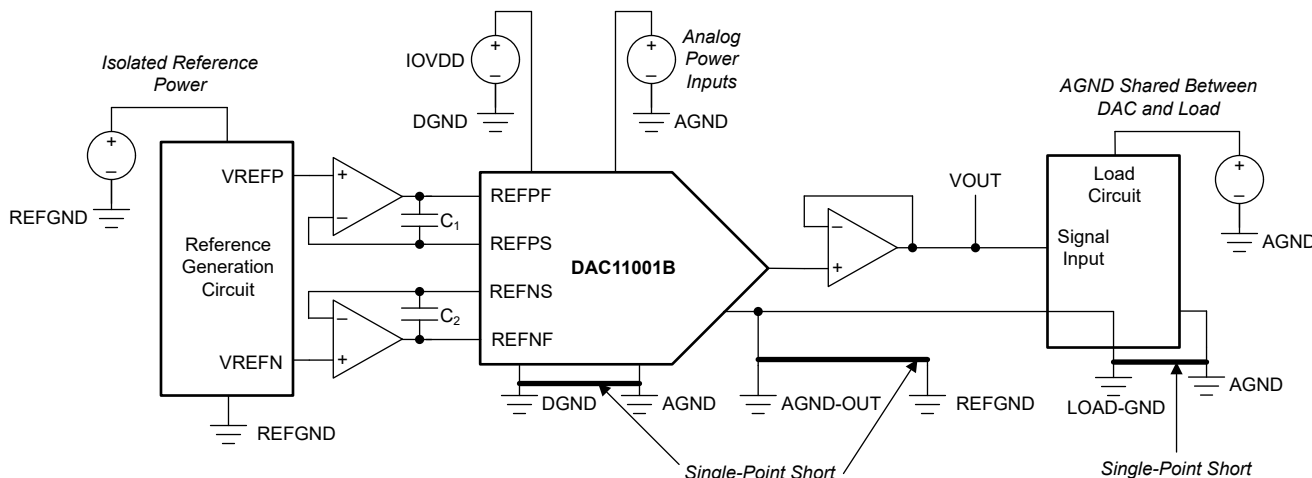
## 9 Power Supply Recommendations

To get the best performance out of the DAC11001B, the power supply, grounding, and decoupling are very important. Use a PCB with a ground-plane reference, which helps in confining the digital return currents. A low mutual inductance path is created just beneath the high-frequency digital traces causing the return currents to follow the respective signal traces, thus minimizing crosstalk. On the other hand, dc signals spread over the ground plane without being confined below the signal trace. Therefore, in precision dc applications, limiting the common-impedance coupling is very difficult unless the ground planes are physically separated. Figure 9-1 shows a method to divide the grounds so that there is no common-mode current flow between the grounds, while maintaining the same dc potential across all grounds. This circuit assumes that the REFNGND and LOAD-GND are provided from isolated power sources, therefore, there is no common-mode current flow through the reference or the load.



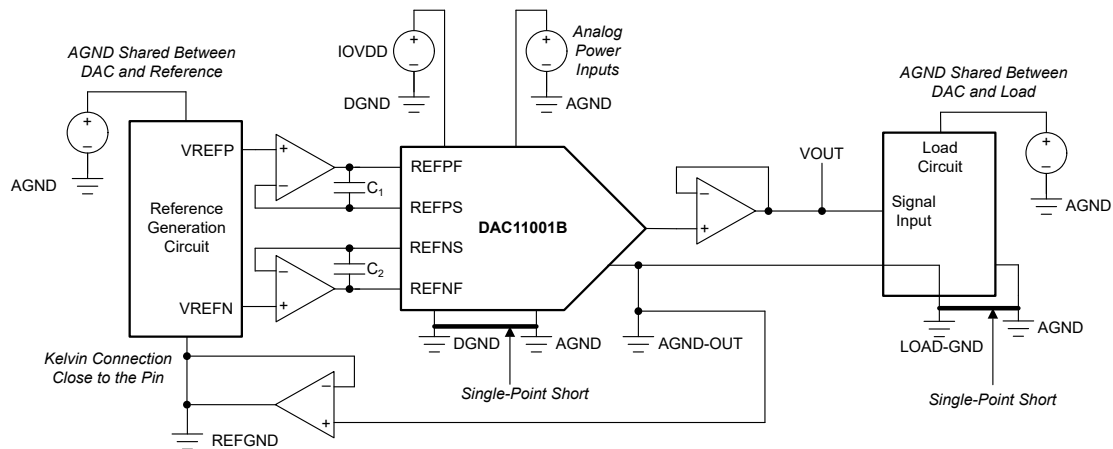
**Figure 9-1. Power and Signal Grounding**

When the load circuit is powered from a source referenced to AGND, and the LOAD-GND is shorted to AGND at the far end, the AGND-OUT must no longer be shorted to AGND locally near the DAC. The local shorting creates a ground loop, otherwise. The resulting connection that avoids the ground loop is shown in Figure 9-2.



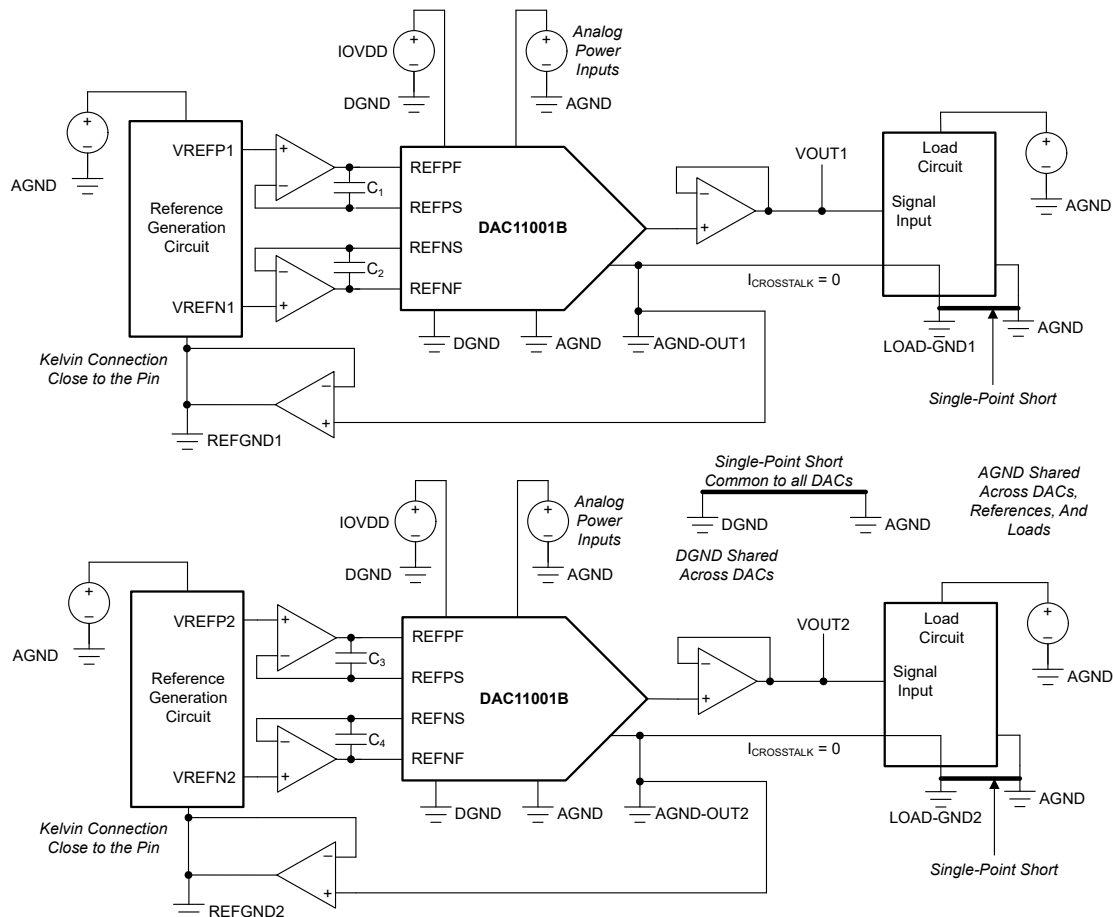
**Figure 9-2. Grounding Scheme When AGND is Load Ground**

When the reference source is powered from a power source with AGND as the ground, there is a possibility of common-impedance coupling causing a code-dependent shift in the reference voltage. To avoid undesired coupling, drive REFNGND using a buffer that maintains the reference ground potential equals to that of AGND-OUT, as shown in Figure 9-3.



**Figure 9-3. Connecting the Reference Ground**

Channel-to-channel dc crosstalk is a major concern in multichannel applications, such as battery test equipment. While the DAC11001B is single-channel, the crosstalk problem can appear at a system level when using multiple DAC11001B devices. The problem becomes severe when the grounds of the loads are shorted together creating a possible ground loop. In such cases, avoid the local short between AGND and AGND-OUT. Use a single short between AGND and DGND for all the DACs. If the PCB layout allows for the digital signal and analog power supplies to be kept separate, DGND and AGND can be combined to a single ground plane. Figure 9-4 shows an example circuit for minimizing dc crosstalk across DAC channels in a system.

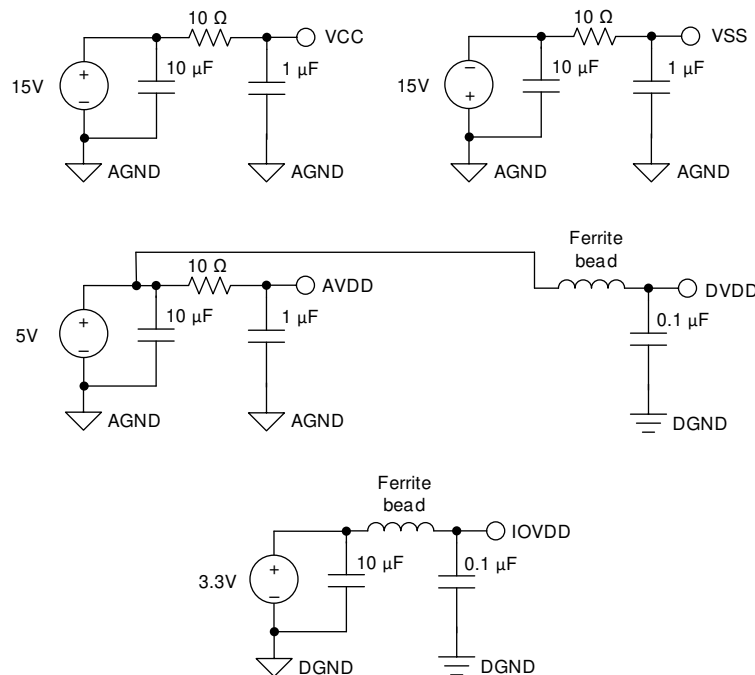


**Figure 9-4. Minimizing Multichannel DC Crosstalk**

Power-supply bypassing and decoupling is key to keeping power supply noise, switching transients, and common-mode currents away from the DAC output. There are three main objective of power-supply bypassing:

- **Filtering:** Filter out noise and ripple from power supplies
- **Bypassing:** Supply switching or load transient currents locally by avoiding trace inductances
- **Decoupling:** Stop local transient currents from impacting other circuits

To achieve these objectives, use the following 3-element scheme. Place a decoupling capacitor close to every power supply pin to provide the local current path for load and circuit switching transients. This capacitor must be referenced to the respective load ground for best load transient suppression. Use a 0.1- $\mu\text{F}$  to 1- $\mu\text{F}$ , X7R, multilayer ceramic capacitor (MLCC) for this purpose. For analog power supplies, a 10- $\Omega$  series resistor provides the best decoupling. For filtering the power-supply noise and ripple, 10- $\mu\text{F}$  capacitors work best when placed at the power entry point of the board. An example decoupling scheme is shown in [Figure 9-5](#).



**Figure 9-5. Power-Supply Decoupling**

## 9.1 Power-Supply Sequencing

The DAC11001B does not require any power-supply sequence. However, the power supplies to the AVDD pin must be capable of providing 30-mA of current if  $V_{SS}$  ramps before  $AV_{DD}$ . This current is derived from the AVDD pin, and flows out of the VSS pin. This condition is transient, and the device stops consuming this current when the power supplies are ramped up. To avoid this condition, make sure to ramp  $AV_{DD}$  before  $V_{SS}$ .

## 10 Layout

### 10.1 Layout Guidelines

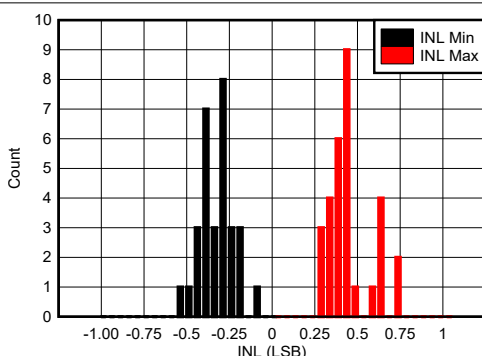
PCB layout plays a significant role for achieving desired ac and dc performance from the DAC11001B. The DAC11001B has a pinout that supports easy splitting of the noisy and quiet grounds. The digital signals are available on two adjacent sides of the device; whereas, the power and analog signals are available separate sides. Figure 10-4 shows an example layout, where the different ground planes have been clearly demarcated. The figure also shows the best positions for the single-point shorts between the ground planes. For best power-supply bypassing, place the bypass capacitors close to the respective power pins as shown. Provide unbroken ground reference planes for the digital signal traces, especially for the SPI and LDAC signals.

#### 10.1.1 PCB Assembly Effects on Precision

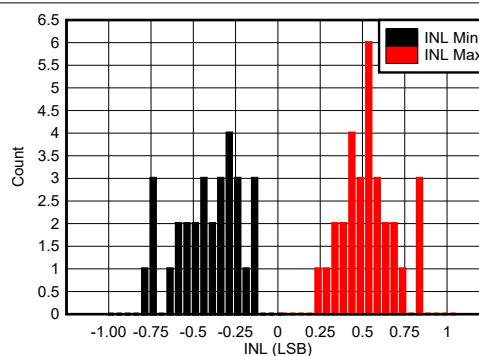
The printed-circuit board (PCB) assembly process, including reflow soldering, imparts thermal stresses on the device which can degrade the precision of the device and must be considered in the development of very-high-precision systems. Standard reflow guidelines must be followed to achieve the device specified performance. For more information please see Texas Instruments, [MSL Ratings and Reflow Profiles application report](#).

Baking the PCBs after the assembly process can restore the precision of the device to pre-assembly values. Figure 10-1 to Figure 10-3 show the effect of reflow soldering on the typical distribution of INL of the device.

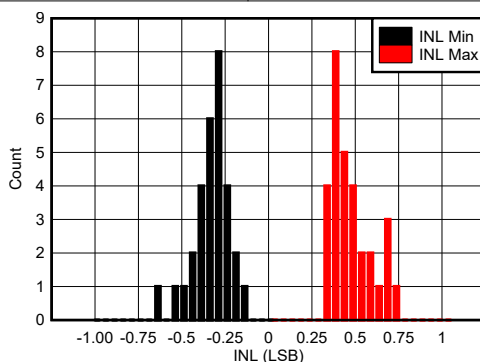
Figure 10-1 shows the INL distribution for a set of DAC11001B devices before the PCB assembly process. Exposing the devices to a JEDEC-standard thermal profile for reflow soldering produces the histogram shown in Figure 10-2 on another set of devices. The standard INL deviation increased due to the thermal stress imparted to the device from the reflow process. However, baking DAC11001B units for 60 minutes at 125°C after the reflow soldering process produced the distribution given in Figure 10-3. The post-reflow bake restored the INL standard deviation to pre-assembly levels.



**Figure 10-1. Typical INL Distribution Before Reflow Soldering**



**Figure 10-2. Typical INL Distribution After Reflow Soldering**



**Figure 10-3. Typical INL Distribution Post-Reflow Units Baked at 125°C for 60 Minutes**

## 10.2 Layout Example

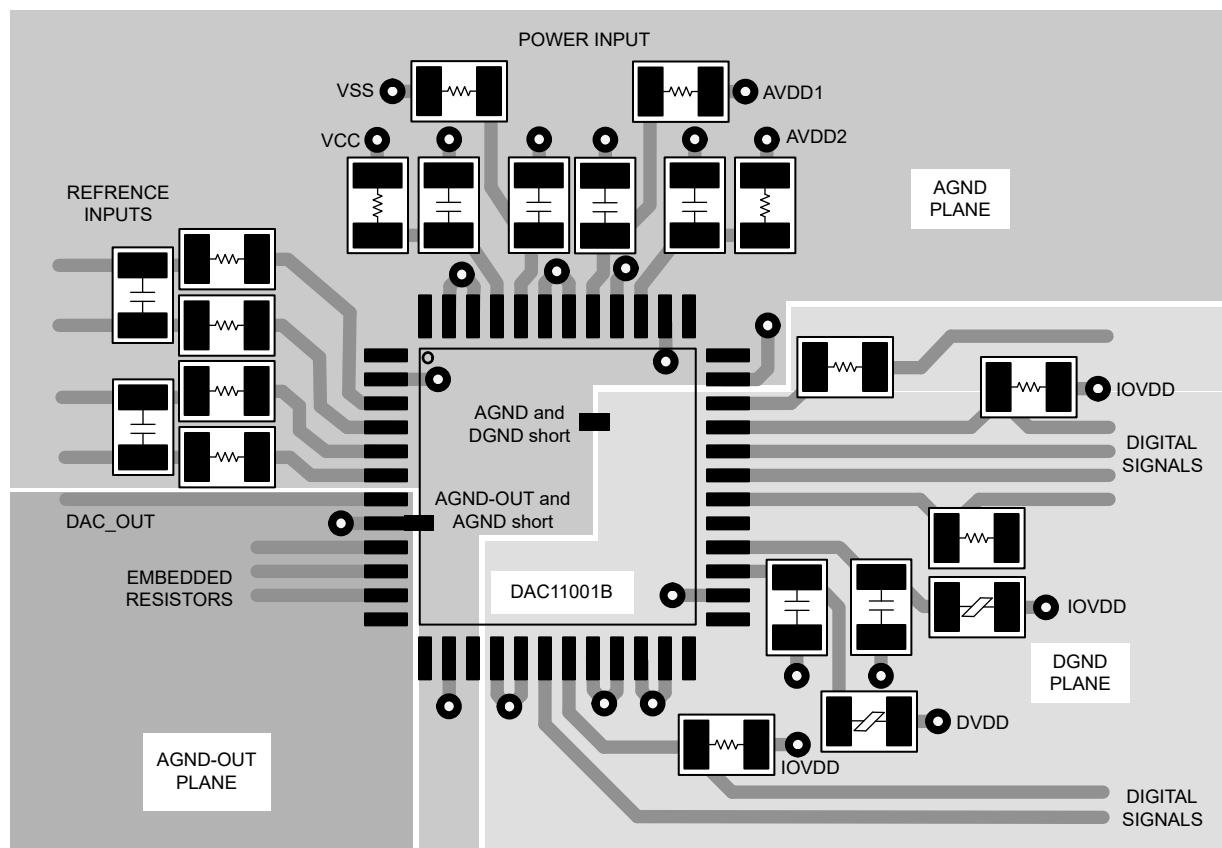


Figure 10-4. Layout Example



## 11 Device and Documentation Support

### 11.1 Device Support

#### 11.1.1 Development Support

[BP-DAC11001 Evaluation Module](#)

### 11.2 Documentation Support

#### 11.2.1 Related Documentation

For related documentation see the following:

- Texas Instruments, [BP-DAC11001EVM user's guide](#)
- Texas Instruments, [Impact of Code-to-Code Glitch in Precision Applications](#) application brief

### 11.3 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.

### 11.4 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.

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

### 11.5 Trademarks

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### 11.6 Electrostatic Discharge Caution



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

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

### 11.7 Glossary

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

## 12 Mechanical, Packaging, and Orderable Information

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

## PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package   Pins	Package qty   Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
<a href="#">DAC11001BPFBR</a>	Active	Production	TQFP (PFB)   48	1000   LARGE T&R	Yes	NIPDAU-DCC	Level-3-260C-168 HR	-40 to 125	DAC11001B
DAC11001BPFBR.B	Active	Production	TQFP (PFB)   48	1000   LARGE T&R	Yes	NIPDAU-DCC	Level-3-260C-168 HR	-40 to 125	DAC11001B
<a href="#">DAC11001BPFBT</a>	Active	Production	TQFP (PFB)   48	250   SMALL T&R	Yes	NIPDAU-DCC	Level-3-260C-168 HR	-40 to 125	DAC11001B
DAC11001BPFBT.B	Active	Production	TQFP (PFB)   48	250   SMALL T&R	Yes	NIPDAU-DCC	Level-3-260C-168 HR	-40 to 125	DAC11001B

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

<sup>(2)</sup> **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

<sup>(4)</sup> **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

<sup>(5)</sup> **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

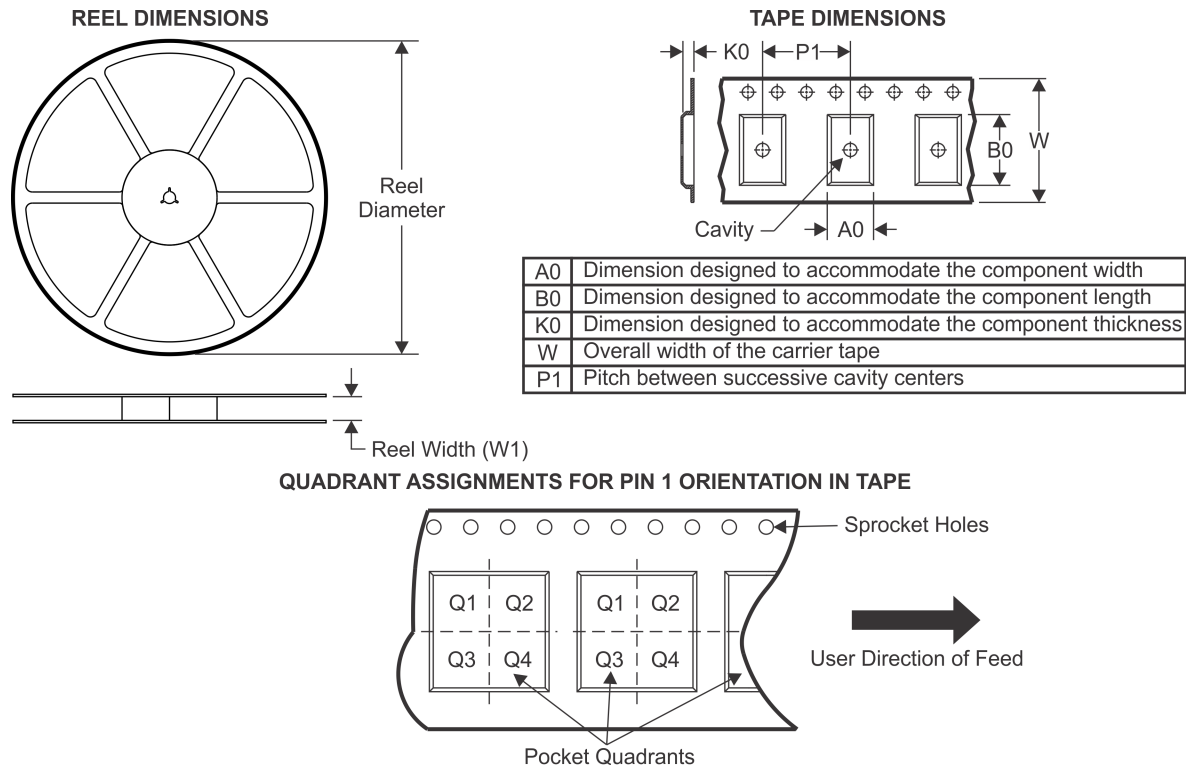
<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "-" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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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.

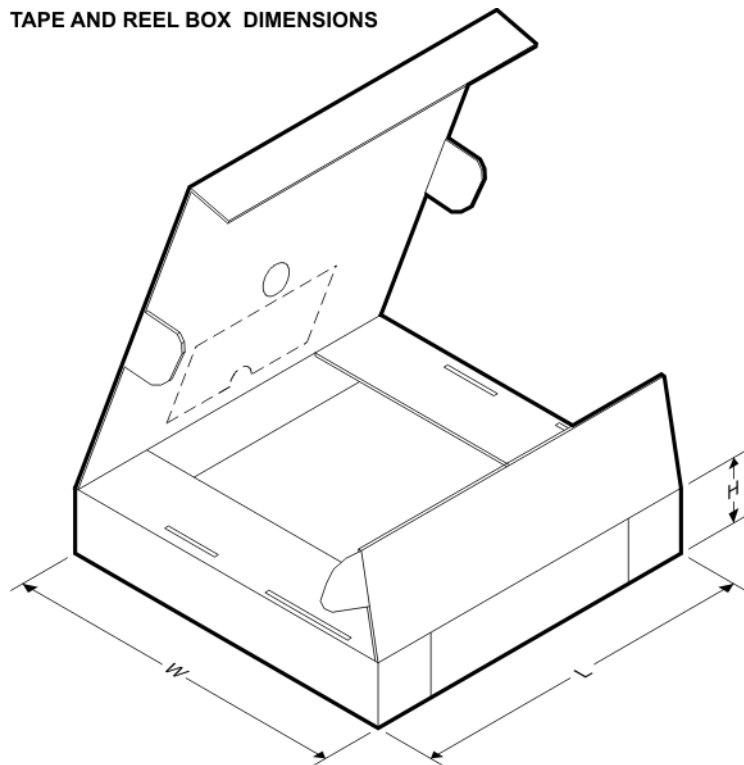
## TAPE AND REEL INFORMATION



\*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
DAC11001BPFBR	TQFP	PFB	48	1000	330.0	16.4	9.6	9.6	1.5	12.0	16.0	Q2
DAC11001BPFBT	TQFP	PFB	48	250	180.0	16.4	9.6	9.6	1.5	12.0	16.0	Q2

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

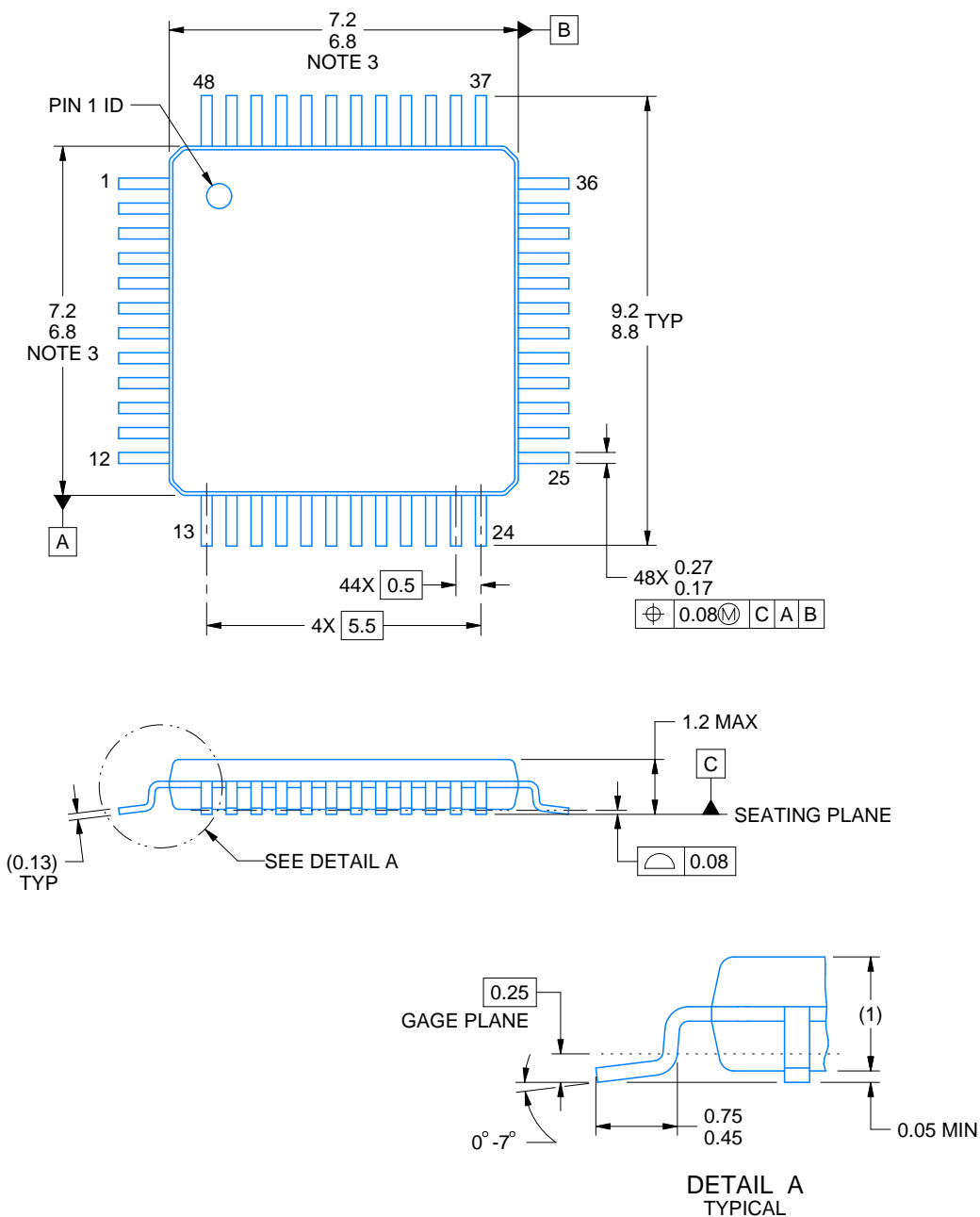
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
DAC11001BPFBR	TQFP	PFB	48	1000	350.0	350.0	43.0
DAC11001BPFBT	TQFP	PFB	48	250	213.0	191.0	55.0



## PACKAGE OUTLINE

**TQFP - 1.2 mm max height**

## PLASTIC QUAD FLATPACK



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NOTES:

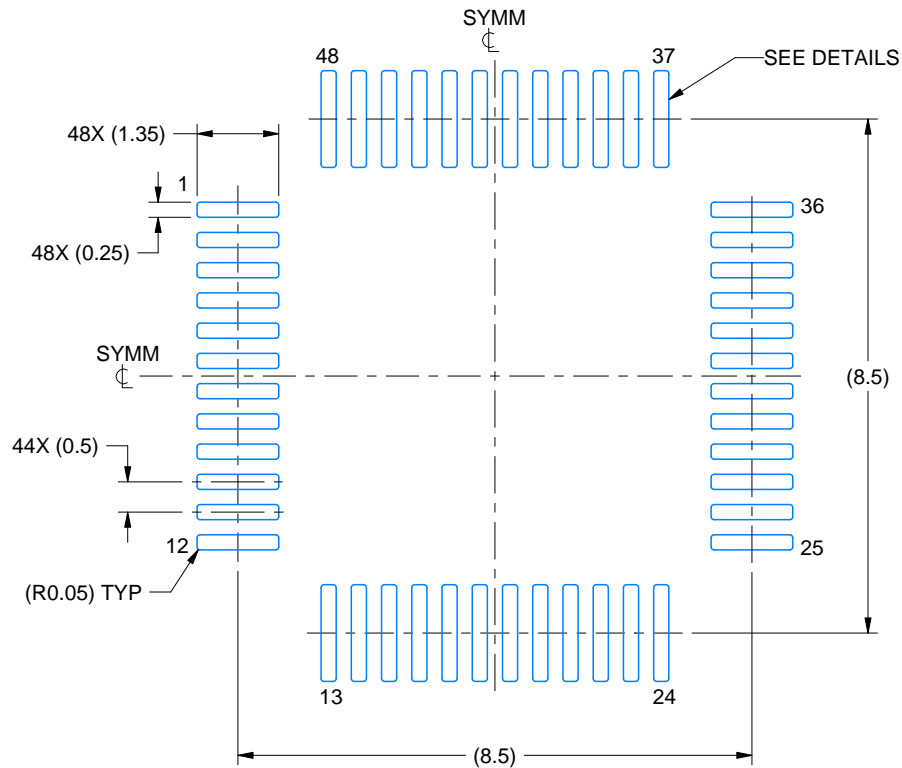
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC registration MS-026.

# EXAMPLE BOARD LAYOUT

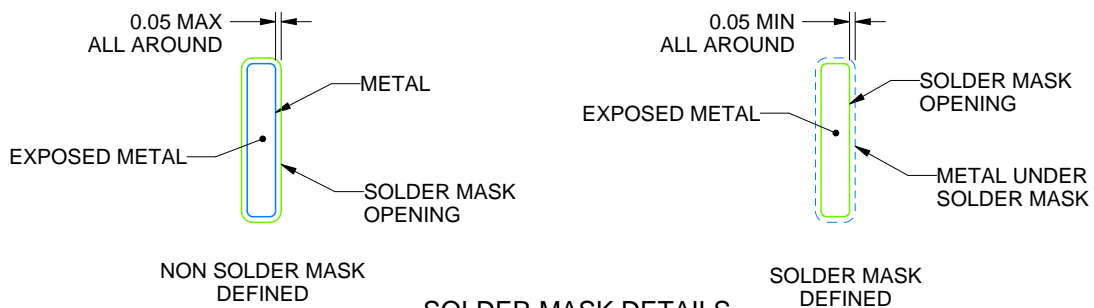
PFB0048A

TQFP - 1.2 mm max height

PLASTIC QUAD FLATPACK



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:8X



SOLDER MASK DETAILS

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NOTES: (continued)

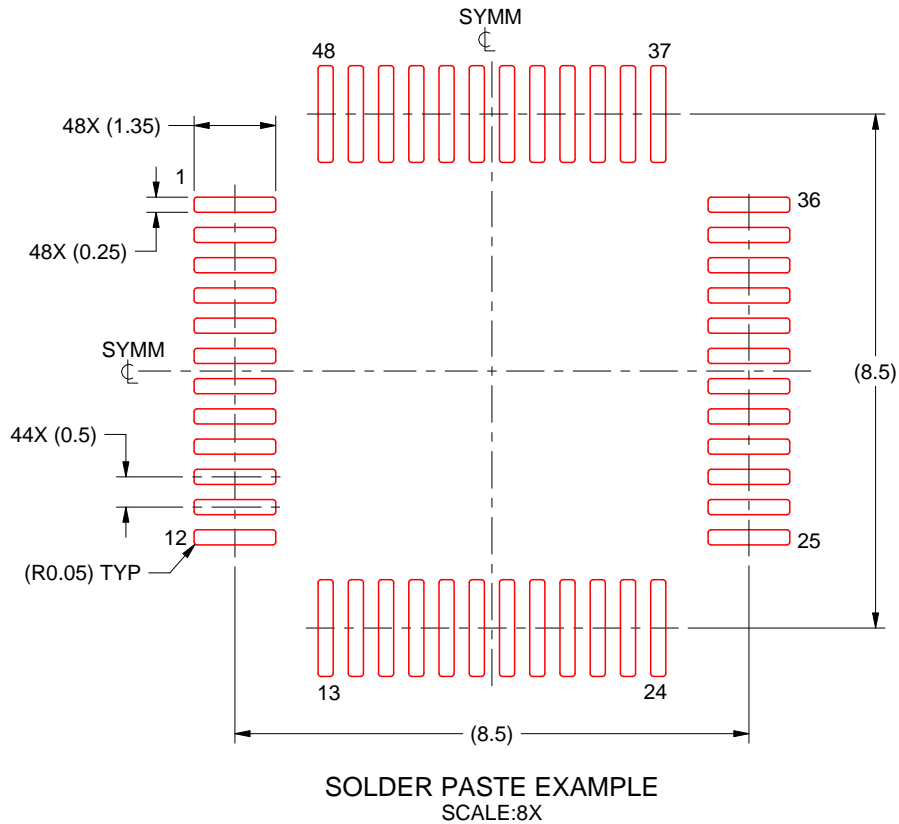
4. Publication IPC-7351 may have alternate designs.
5. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

# EXAMPLE STENCIL DESIGN

PFB0048A

TQFP - 1.2 mm max height

PLASTIC QUAD FLATPACK



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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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