ADS1299-x Low-Noise, 4-, 6-, 8-Channel, 24-Bit, Analog-to-Digital Converter for EEG and Biopotential Measurements

1 Features

- Up to Eight Low-Noise PGAs and Eight High-Resolution Simultaneous-Sampling ADCs
- Input-Referred Noise: 1 μV_{PP} (70-Hz BW)
- Input Bias Current: 300 pA
- Data Rate: 250 SPS to 16 kSPS
- CMRR: –110 dB
- Programmable Gain: 1, 2, 4, 6, 8, 12, or 24
- Unipolar or Bipolar Supplies:
  - Analog: 4.75 V to 5.25 V
  - Digital: 1.8 V to 3.6 V
- Built-In Bias Drive Amplifier, Lead-Off Detection, Test Signals
- Built-In Oscillator
- Internal or External Reference
- Flexible Power-Down, Standby Mode
- Pin-Compatible with the ADS129x
- SPI-Compatible Serial Interface
- Operating Temperature Range: –40°C to +85°C

2 Applications

- Medical Instrumentation Including:
  - Electroencephalogram (EEG) Study
  - Fetal Electrocardiography (ECG)
  - Sleep Study Monitor
  - Bispectral Index (BIS)
  - Evoked Audio Potential (EAP)

3 Description

The ADS1299-4, ADS1299-6, and ADS1299 devices are a family of four-, six-, and eight-channel, low-noise, 24-bit, simultaneous-sampling delta-sigma ($\Delta\Sigma$) analog-to-digital converters (ADCs) with a built-in programmable gain amplifier (PGA), internal reference, and an onboard oscillator. The ADS1299-x incorporates all commonly-required features for extracranial electroencephalogram (EEG) and electrocardiography (ECG) applications. With its high levels of integration and exceptional performance, the ADS1299-x enables the creation of scalable medical instrumentation systems at significantly reduced size, power, and overall cost.

The ADS1299-x has a flexible input multiplexer per channel that can be independently connected to the internally-generated signals for test, temperature, and lead-off detection. Additionally, any configuration of input channels can be selected for derivation of the patient bias output signal. Optional SRB pins are available to route a common signal to multiple inputs for a referential montage configuration. The ADS1299-x operates at data rates from 250 SPS to 16 kSPS. Lead-off detection can be implemented internal to the device using an excitation current sink or source.

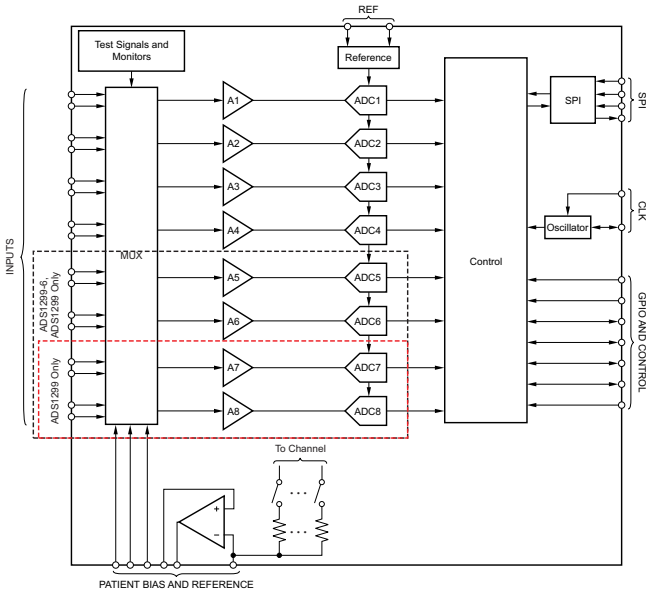
Multiple ADS1299-4, ADS1299-6, or ADS1299 devices can be cascaded in high channel count systems in a daisy-chain configuration. The ADS1299-x is offered in a TQFP-64 package specified from –40°C to +85°C.

Device Information[1]

PART NUMBER	PACKAGE	BODY SIZE (NOM)
ADS1299-x	TQFP (64)	10.00 mm × 10.00 mm

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

Block Diagram



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4 Revision History

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

Changes from Revision B (October 2016) to Revision C **Page**

- Changed *Maximum Junction* parameter name to *Junction* in *Absolute Maximum Ratings* table ... 7
- Changed *Recommended Operating Conditions* table: changed *free-air* to *ambient* in conditions statement, changed specifications of *Input voltage* parameter, and added V_{CM} and f_{CLK} symbols ... 8
- Changed conditions statement of *Electrical Characteristics* table: added T_A to temperature conditions, moved DVDD condition to after AVDD – AVSS condition ... 9
- Changed *Input bias current* parameter test conditions from *input* to *InxP and INxN* ... 9
- Changed *Drift* parameter unit from *ppm* to *ppm/°C* and changed *Internal clock accuracy* parameter test conditions from *–40°C ≤ T_A ≤ +85°C* to *T_A = –40°C to +85°C* in *Electrical Characteristics* table ... 10
- Changed I_{AVDD} and I_{DVDD} parameters [deleted *(normal mode)* from parameter names and added *Normal mode* to test conditions], and deleted *Quiescent* from *Power dissipation* parameter name in *Electrical Characteristics* table ... 11
- Changed *free-air* to *ambient* in conditions statement of *Timing Requirements: Serial Interface* table ... 12
- Changed *Analog Input* section ... 22
- Changed Table 9 cross-reference to Table 7 in *Settling Time* section ... 34
- Changed *Ideal Output Code versus Input Signal* table: changed all V_{REF} in first column to *FS* in and deleted footnote 1 ... 38
- Changed reset settings of bits 4 and 3 in bit register of CONFIG1 register ... 46
- Changed reset value settings of bits 7 to 5 in CONFIG2 register: split cells apart ... 47
- Changed reset value settings of bits 6 to 5 in CONFIG3 register: split cells apart ... 48
- Changed *AVDD – AVSS* to *AVDD + AVSS* in description of bit 3 in *Configuration Register 3 Field Descriptions* ... 48
- Changed *Lead-Off Control Register Field Descriptions* table: changed 01 bit setting of bits 3:2 to *24 nA* from *12 nA* changed description of bits 1:0 ... 49
- Changed *Unused Inputs and Outputs* section: added $\overline{\text{DRDY}}$ description, deleted statement of not floating unused

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Revision History (continued)

digital inputs 61
- Deleted second *Layout Guidelines* sub-section from *Layout* section 72

Changes from Revision A (August 2012) to Revision B **Page**

- Added *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section 1
- Added ADS1299-4 and ADS1299-6 to document 1
- Added 1
- Deleted Low Power *Features* bullet 1
- Changed extracranial electroencephalogram (EEG) in *Applications* and *Description* sections 1
- Deleted last *Applications* bullet 1
- Changed *Description* section: added sentence on SRB pins, changed last sentence of second paragraph 1
- Changed *ADS1299 family* to *ADS1299-x* throughout document 1
- Changed Block Diagram: added dotted boxes 1
- Changed specifications for Lead-Off Detect, *Frequency* parameter of *Electrical Characteristics* table 10
- Added specifications for ADS1299-4 and ADS1299-6 in *Supply Current (Bias Turned Off)* and *Power Dissipation (Analog Supply = 5 V, Bias Amplifiers Turned Off)* sections of *Electrical Characteristics* table 11
- Changed *Noise Measurements* section 16
- Changed *Functional Block Diagram* to show channels 5-8 not covered in ADS1299-4 and channels 7-8 not covered in ADS1299-6 19
- Changed INxP and INxN pins in Figure 18 20
- Changed Figure 23: changed PgaP, PgaN to PGAp, PGAn 23
- Changed *Input Common-Mode Range* section: changed input common-mode range description 23
- Changed differential input voltage range in the *Input Differential Dynamic Range* section 24
- Changed Figure 34: MUX8[2:0] = 010 on IN8N, and BIAS_MEAS = 1 on BIASIN 29
- Changed first sentence of second paragraph in *Lead-Off Detection* section 30
- Changed *AC Lead-Off (One Time or Periodic)* section 31
- Changed *Bias Lead-Off* section 32
- Changed title of Figure 38 and power-down description in *Bias Drive (DC Bias Circuit)* section 33
- Changed *START Opcode* to *START* in Figure 39 34
- Changed *Reset ($\overline{RESET}$)* section for clarity 35
- Changed title, first paragraph, *START Opcode* and *STOP Opcode* to *START* and *STOP* (Figure 42), and *STOP Opcode* to *STOP Command* (Figure 43) in *Continuous Conversion Mode* section 36
- Added last sentence to *Data Input (DIN)* section 39
- Added cross-reference to the *Sending Multi-Byte Commands* section in *RDATAC: Read Data Continuous* section 41
- Changed *RDATAC Opcode* to *RDATAC* in Figure 46 41
- Changed *RDATA Opcode* to *RDATA* in Figure 46 42
- Changed description of SCLK rate restrictions, *OPCODE 1* and *OPCODE 2* to *BYTE 1* and *BYTE 2* in Figure 48 of *RREG: Read From Register* section 43
- Changed footnotes 1 and 2 and added more cross-references to footnotes in rows 0Dh to 11h in Table 11 44
- Changed register description and description of bit 5 in *MISC1: Miscellaneous 1 Register* section 59
- Changed output names in Figure 68 from *RA*, *LA*, and *RL* to *Electrode 1*, *Electrode 2*, and *BIAS Electrode*, respectively 63
- Changed *Power-Up Sequencing* section 70

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Changes from Original (July 2012) to Revision A **Page**

- Changed product column of Family and Ordering Information table 1

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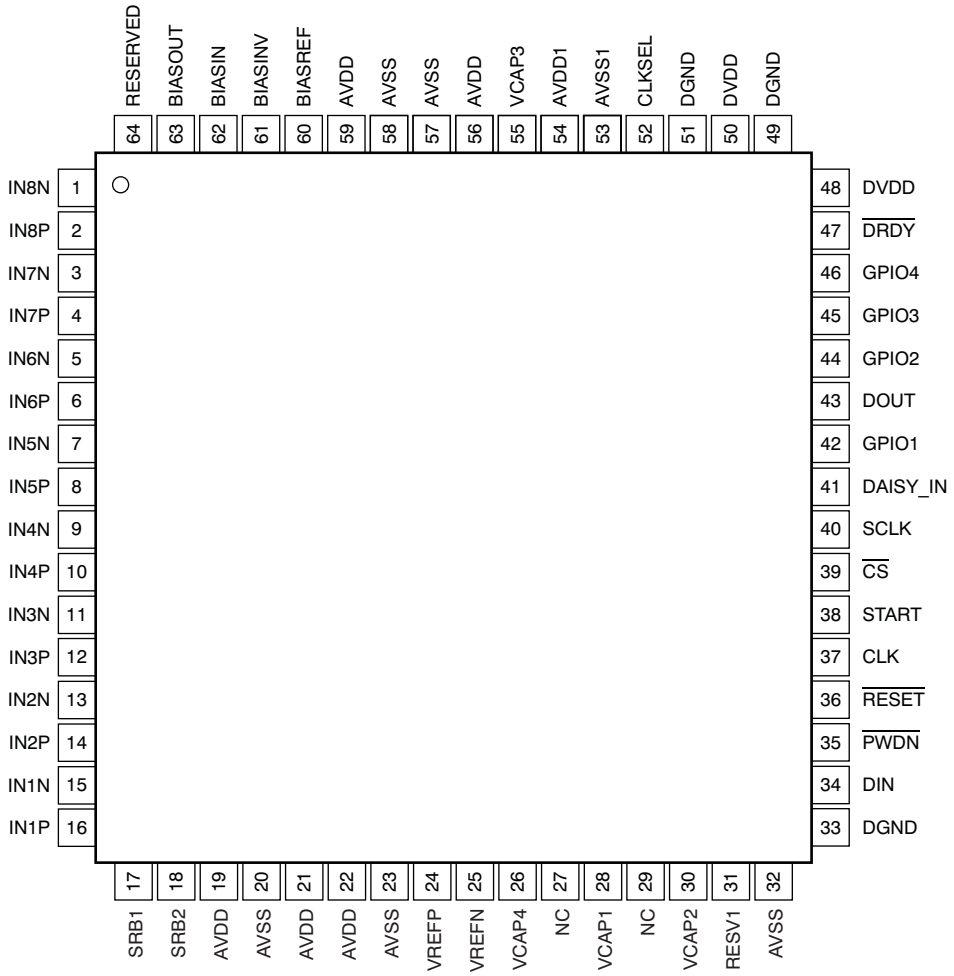
5 Device Comparison

PRODUCT	PACKAGE OPTIONS	OPERATING TEMPERATURE RANGE	CHANNELS	ADC RESOLUTION	MAXIMUM SAMPLING RATE
ADS1299-4	TQFP-64	–40°C to +85°C	4	24	16 kSPS
ADS1299-6	TQFP-64	–40°C to +85°C	6	24	16 kSPS
ADS1299	TQFP-64	–40°C to +85°C	8	24	16 kSPS

6 Pin Configuration and Functions

PAG Package
64-Pin TQFP
Top View



Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
AVDD	19, 21, 22, 56, 59	Supply	Analog supply. Connect a 1-µF capacitor to AVSS.
	59	Supply	Charge pump analog supply. Connect a 1-µF capacitor to AVSS, pin 58.
AVDD1	54	Supply	Analog supply. Connect a 1-µF capacitor to AVSS1.
AVSS	20, 23, 32, 57	Supply	Analog ground
	58	Supply	Analog ground for charge pump
AVSS1	53	Supply	Analog ground
BIASIN	62	Analog input	Bias drive input to MUX
BIASINV	61	Analog input/output	Bias drive inverting input
BIASOUT	63	Analog output	Bias drive output
BIASREF	60	Analog input	Bias drive noninverting input
$\overline{CS}$	39	Digital input	Chip select, active low
CLK	37	Digital input	Master clock input
CLKSEL	52	Digital input	Master clock select(1)
DAISY_IN	41	Digital input	Daisy-chain input
DGND	33, 49, 51	Supply	Digital ground
DIN	34	Digital input	Serial data input
DOUT	43	Digital output	Serial data output
$\overline{DRDY}$	47	Digital output	Data ready, active low
DVDD	48, 50	Supply	Digital power supply. Connect a 1-µF capacitor to DGND.
GPIO1	42	Digital input/output	General-purpose input/output pin 1. Connect to DGND with a ≥10-kΩ resistor if unused.
GPIO2	44	Digital input/output	General-purpose input/output pin 2. Connect to DGND with a ≥10-kΩ resistor if unused.
GPIO3	45	Digital input/output	General-purpose input/output pin 3. Connect to DGND with a ≥10-kΩ resistor if unused.
GPIO4	46	Digital input/output	General-purpose input/output pin 4. Connect to DGND with a ≥10-kΩ resistor if unused.
IN1N	15	Analog input	Differential analog negative input 1(2)
IN1P	16	Analog input	Differential analog positive input 1(2)
IN2N	13	Analog input	Differential analog negative input 2(2)
IN2P	14	Analog input	Differential analog positive input 2(2)
IN3N	11	Analog input	Differential analog negative input 3(2)
IN3P	12	Analog input	Differential analog positive input 3(2)
IN4N	9	Analog input	Differential analog negative input 4(2)
IN4P	10	Analog input	Differential analog positive input 4(2)
IN5N	7	Analog input	Differential analog negative input 5(2) (ADS1299-6 and ADS1299 only)
IN5P	8	Analog input	Differential analog positive input 5(2) (ADS1299-6 and ADS1299 only)
IN6N	5	Analog input	Differential analog negative input 6(2) (ADS1299-6 and ADS1299 only)
IN6P	6	Analog input	Differential analog positive input 6(2) (ADS1299-6 and ADS1299 only)
IN7N	3	Analog input	Differential analog negative input 7(2) (ADS1299 only)
IN7P	4	Analog input	Differential analog positive input 7(2) (ADS1299 only)
IN8N	1	Analog input	Differential analog negative input 8(2) (ADS1299 only)
IN8P	2	Analog input	Differential analog positive input 8(2) (ADS1299 only)
NC	27, 29	—	No connection, leave as open circuit
Reserved	64	Analog output	Reserved for future use, leave as open circuit
$\overline{RESET}$	36	Digital input	System reset, active low
RESV1	31	Digital input	Reserved for future use, connect directly to DGND
SCLK	40	Digital input	Serial clock input
SRB1	17	Analog input/output	Patient stimulus, reference, and bias signal 1
SRB2	18	Analog input/output	Patient stimulus, reference, and bias signal 2

(1) Set the two-state mode setting pins high to DVDD or low to DGND through ≥10-kΩ resistors.
(2) Connect unused analog inputs directly to AVDD.

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Pin Functions (continued)

PIN		TYPE	DESCRIPTION
NAME	NO.		
START	38	Digital input	Synchronization signal to start or restart a conversion
$\overline{\text{PWDN}}$	35	Digital input	Power-down, active low
VCAP1	28	Analog output	Analog bypass capacitor pin. Connect a 100-µF capacitor to AVSS.
VCAP2	30	Analog output	Analog bypass capacitor pin. Connect a 1-µF capacitor to AVSS.
VCAP3	55	Analog output	Analog bypass capacitor pin. Connect a parallel combination of 1-µF and 0.1-µF capacitors to AVSS.
VCAP4	26	Analog output	Analog bypass capacitor pin. Connect a 1-µF capacitor to AVSS.
VREFN	25	Analog input	Negative analog reference voltage.
VREFP	24	Analog input/output	Positive analog reference voltage. Connect a minimum 10-µF capacitor to VREFN.

7 Specifications

7.1 Absolute Maximum Ratings(1)

		MIN	MAX	UNIT
Voltage	AVDD to AVSS	–0.3	5.5	V
	DVDD to DGND	–0.3	3.9	
	AVSS to DGND	–3	0.2	
	VREFP to AVSS	–0.3	AVDD + 0.3	
	VREFN to AVSS	–0.3	AVDD + 0.3	
	Analog input	AVSS – 0.3	AVDD + 0.3	
	Digital input	DGND – 0.3	DVDD + 0.3	
Current	Input, continuous, any pin except power supply pins(2)	–10	10	mA
Temperature	Junction, T_J		150	°C
	Storage, T_{stg}	–60	150	

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) Input pins are diode-clamped to the power-supply rails. Limit the input current to 10 mA or less if the analog input voltage exceeds AVDD + 0.3 V or is less than AVSS – 0.3 V, or if the digital input voltage exceeds DVDD + 0.3 V or is less than DGND – 0.3 V.

7.2 ESD Ratings

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

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

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7.3 Recommended Operating Conditions

over operating ambient temperature range (unless otherwise noted)

			MIN	NOM	MAX	UNIT
POWER SUPPLY						
	Analog power supply	AVDD to AVSS	4.75	5	5.25	V
	Digital power supply	DVDD to DGND	1.8	1.8	3.6	V
	Analog to Digital supply	AVDD – DVDD	–2.1		3.6	V
ANALOG INPUTS						
	Full-scale differential input voltage	$V_{INxP} – V_{INxN}$		$\pm V_{REF}$ / gain		V
V_{CM}	Input common-mode range	$(V_{INxP} + V_{INxN}) / 2$		See the *Input Common-Mode Range* subsection of the *PGA Settings and Input Range* section		
VOLTAGE REFERENCE INPUTS						
V_{REF}	Reference input voltage	$V_{REF} = (V_{VREFP} – V_{VREFN})$		4.5		V
VREFN	Negative input			AVSS		V
VREFP	Positive input			AVSS + 4.5		V
CLOCK INPUT						
f_{CLK}	External clock input frequency	CLKSEL pin = 0	1.5	2.048	2.25	MHz
DIGITAL INPUTS						
	Input voltage		DGND – 0.1		DVDD + 0.1	V
TEMPERATURE RANGE						
T_A	Operating temperature range		–40		85	°C

7.4 Thermal Information

THERMAL METRIC(1)		ADS1299-4, ADS1299-6, ADS1299 PAG (TQFP) 64 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	46.2	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	5.8	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	19.6	°C/W
ψ_{JT}	Junction-to-top characterization parameter	0.2	°C/W
ψ_{JB}	Junction-to-board characterization parameter	19.2	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	n/a	°C/W

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

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7.5 Electrical Characteristics

Minimum and maximum specifications apply from T_A = –40°C to 85°C. Typical specifications are at T_A = +25°C. All specifications are at AVDD – AVSS = 5 V, DVDD = 3.3 V, V_{REF} = 4.5 V, external f_{CLK} = 2.048 MHz, data rate = 250 SPS, and gain = 12 (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
ANALOG INPUTS						
	Input capacitance			20		pF
	Input bias current	T_A = +25°C, InxP and INxN = 2.5 V			±300	pA
		T_A = –40°C to +85°C, InxP and INxN = 2.5 V		±300		
	DC input impedance	No lead-off	1000			MΩ
		Current source lead-off detection ($I_{LEADOFF}$ = 6 nA)		500		
PGA PERFORMANCE						
	Gain settings			1, 2, 4, 6, 8, 12, 24		
BW	Bandwidth			See Table 5		
ADC PERFORMANCE						
	Resolution		24			Bits
DR	Data rate	f_{CLK} = 2.048 MHz	250		16000	SPS
DC CHANNEL PERFORMANCE						
	Input-referred noise (0.01 Hz to 70 Hz)	10 seconds of data, gain = 24 (1)		1		μV_{PP}
		250 points, 1 second of data, gain = 24, T_A = +25°C		1	1.35	
		250 points, 1 second of data, gain = 24, T_A = –40°C to +85°C		1	1.6	
		All other sample rates and gain settings		See *Noise Measurements*		
INL	Integral nonlinearity	Full-scale with gain = 12, best fit		8		ppm
	Offset error			60		µV
	Offset error drift			80		nV/°C
	Gain error	Excluding voltage reference error		0.1	±0.5	% of FS
	Gain drift	Excluding voltage reference drift		3		ppm/°C
	Gain match between channels			0.2		% of FS
AC CHANNEL PERFORMANCE						
CMRR	Common-mode rejection ratio	f_{CM} = 50 Hz and 60 Hz (2)	–110	–120		dB
PSRR	Power-supply rejection ratio	f_{PS} = 50 Hz and 60 Hz		96		dB
	Crosstalk	f_{IN} = 50 Hz and 60 Hz		–110		dB
SNR	Signal-to-noise ratio	V_{IN} = –2 dBFs, f_{IN} = 10-Hz input, gain = 12		121		dB
THD	Total harmonic distortion	V_{IN} = –0.5 dBFs, f_{IN} = 10 Hz		–99		dB
PATIENT BIAS AMPLIFIER						
	Integrated noise	BW = 150 Hz		2		μV_{RMS}
	Gain bandwidth product	50-kΩ || 10-pF load, gain = 1		100		kHz
	Slew rate	50-kΩ || 10-pF load, gain = 1		0.07		V/µs
THD	Total harmonic distortion	f_{IN} = 10 Hz, gain = 1		–80		dB
	Common-mode input range		AVSS + 0.3		AVDD – 0.3	V
	Short-circuit current			1.1		mA
	Quiescent power consumption			20		µA

(1) Noise data measured in a 10-second interval. Test not performed in production. Input-referred noise is calculated with the input shorted (without electrode resistance) over a 10-second interval.
(2) CMRR is measured with a common-mode signal of AVSS + 0.3 V to AVDD – 0.3 V. The values indicated are the minimum of the eight channels.

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Electrical Characteristics (continued)

Minimum and maximum specifications apply from T_A = –40°C to 85°C. Typical specifications are at T_A = +25°C. All specifications are at AVDD – AVSS = 5 V, DVDD = 3.3 V, V_{REF} = 4.5 V, external f_{CLK} = 2.048 MHz, data rate = 250 SPS, and gain = 12 (unless otherwise noted)

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
LEAD-OFF DETECT							
	Frequency		Continuous		At dc, f_{DR} / 4, see *Register Maps* for settings		Hz
			One time or periodic		7.8, 31.2		
	Current		ILEAD_OFF[1:0] = 00		6		nA
			ILEAD_OFF[1:0] = 01		24		
			ILEAD_OFF[1:0] = 10		6		µA
			ILEAD_OFF[1:0] = 11		24		
	Current accuracy				±20%		
	Comparator threshold accuracy				±30		mV
EXTERNAL REFERENCE							
	Input impedance				5.6		kΩ
INTERNAL REFERENCE							
V_{REF}	Internal reference voltage				4.5		V
	V_{REF} accuracy				±0.2%		
	Drift		T_A = –40°C to +85°C		35		ppm/°C
	Start-up time				150		ms
SYSTEM MONITORS							
	Reading error	Analog supply			2%		
		Digital supply			2%		
	Device wake up		From power-up to $\overline{\text{DRDY}}$ low		150		ms
			STANDBY mode		31.25		µs
	Temperature sensor reading	Voltage	T_A = +25°C		145		mV
		Coefficient			490		µV/°C
	Test signal	Signal frequency	See *Register Maps* section for settings		f_{CLK} / 2^{21}, f_{CLK} / 2^{20}		Hz
		Signal voltage	See *Register Maps* section for settings		±1, ±2		mV
		Accuracy			±2%		
CLOCK							
	Internal oscillator clock frequency		Nominal frequency		2.048		MHz
	Internal clock accuracy		T_A = +25°C			±0.5%	
			T_A = –40°C to +85°C			±2.5%	
	Internal oscillator start-up time				20		µs
	Internal oscillator power consumption				120		µW
DIGITAL INPUT/OUTPUT (DVDD = 1.8 V to 3.6 V)							
V_{IH}	High-level input voltage			0.8 DVDD		DVDD + 0.1	V
V_{IL}	Low-level input voltage			–0.1		0.2 DVDD	V
V_{OH}	High-level output voltage		I_{OH} = –500 µA	0.9 DVDD			V
V_{OL}	Low-level output voltage		I_{OL} = +500 µA			0.1 DVDD	V
	Input current		0 V < $V_{DigitalInput}$ < DVDD	–10		10	µA

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Electrical Characteristics (continued)

Minimum and maximum specifications apply from T_A = –40°C to 85°C. Typical specifications are at T_A = +25°C. All specifications are at AVDD – AVSS = 5 V, DVDD = 3.3 V, V_{REF} = 4.5 V, external f_{CLK} = 2.048 MHz, data rate = 250 SPS, and gain = 12 (unless otherwise noted)

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY CURRENT (Bias Turned Off)							
I_{AVDD}	AVDD current	ADS1299-4	Normal mode, AVDD – AVSS = 5 V		4.06		mA
		ADS1299-6			5.57		
		ADS1299			7.14		
I_{DVDD}	DVDD current	ADS1299-4	Normal mode, DVDD = 3.3 V		0.54		mA
		ADS1299-6			0.66		
		ADS1299			1		
		ADS1299-4	Normal mode, DVDD = 1.8 V		0.27		
		ADS1299-6			0.34		
		ADS1299			0.5		
POWER DISSIPATION (Analog Supply = 5 V, Bias Amplifiers Turned Off)							
	Power dissipation	ADS1299-4	Normal mode		22	24	mW
			Power-down		10		µW
			Standby mode, internal reference		5.1		mW
		ADS1299-6	Normal mode		30	33	mW
			Power-down		10		µW
			Standby mode, internal reference		5.1		mW
		ADS1299	Normal mode		39	42	mW
			Power-down		10		µW
			Standby mode, internal reference		5.1		mW

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7.6 Timing Requirements: Serial Interface

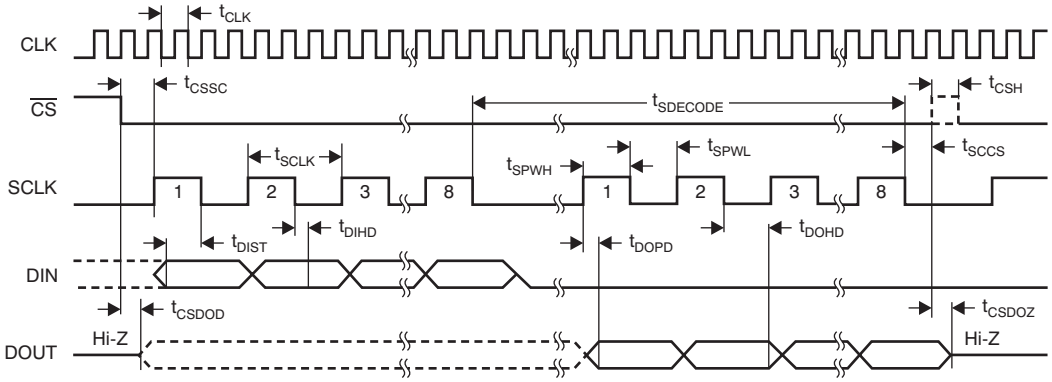
over operating ambient temperature range (unless otherwise noted)

		2.7 V ≤ DVDD ≤ 3.6 V		1.8 V ≤ DVDD ≤ 2.0 V		
		MIN	MAX	MIN	MAX	UNIT
t_{CLK}	Master clock period	414	666	414	666	ns
t_{CSSC}	Delay time, $\overline{CS}$ low to first SCLK	6		17		ns
t_{SCLK}	SCLK period	50		66.6		ns
$t_{SPWH, L}$	Pulse duration, SCLK pulse duration, high or low	15		25		ns
t_{DIST}	Setup time, DIN valid to SCLK falling edge	10		10		ns
t_{DIHD}	Hold time, valid DIN after SCLK falling edge	10		11		ns
t_{CSH}	Pulse duration, $\overline{CS}$ high	2		2		t_{CLK}
t_{SCCS}	Delay time, final SCLK falling edge to $\overline{CS}$ high	4		4		t_{CLK}
$t_{SDECODE}$	Command decode time	4		4		t_{CLK}
$t_{DISCK2ST}$	Setup time, DAISY_IN valid to SCLK rising edge	10		10		ns
$t_{DISCK2HT}$	Hold time, DAISY_IN valid after SCLK rising edge	10		10		ns

7.7 Switching Characteristics: Serial Interface

over operating ambient temperature range (unless otherwise noted)

PARAMETER		2.7 V ≤ DVDD ≤ 3.6 V		1.8 V ≤ DVDD ≤ 2.0 V		
		MIN	MAX	MIN	MAX	UNIT
t_{DOHD}	Hold time, SCLK falling edge to invalid DOUT	10		10		ns
t_{DOPD}	Propagation delay time, SCLK rising edge to DOUT valid		17		32	ns
t_{CSDOD}	Propagation delay time, $\overline{CS}$ low to DOUT driven	10		20		ns
t_{CSDOZ}	Propagation delay time, $\overline{CS}$ high to DOUT Hi-Z		10		20	ns



NOTE: SPI settings are CPOL = 0 and CPHA = 1.

Figure 1. Serial Interface Timing

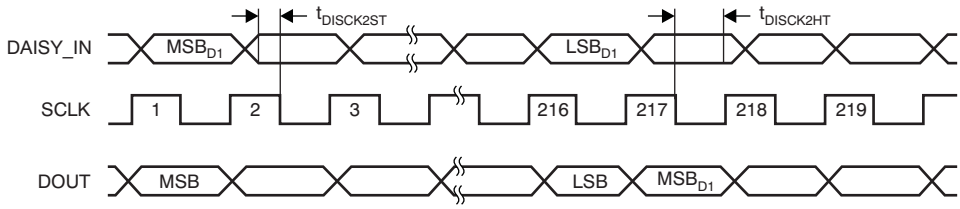


Figure 2. Daisy-Chain Interface Timing

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7.8 Typical Characteristics

At T_A = 25°C, AVDD = 5 V, AVSS = 0 V, DVDD = 3.3 V, internal VREFP = 4.5 V, VREFN = AVSS, external clock = 2.048 MHz, data rate = 250 SPS, and gain = 12 (unless otherwise noted)

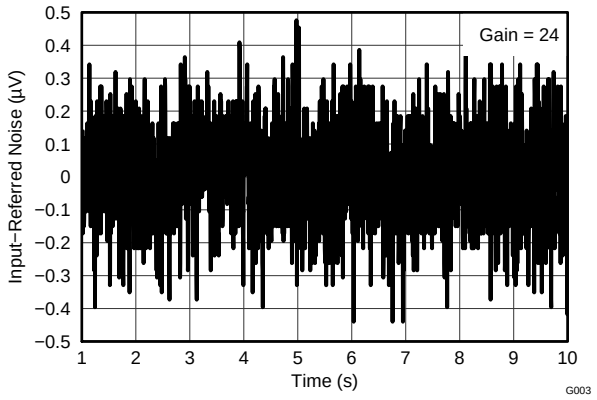

Figure 3. Input-Referred Noise

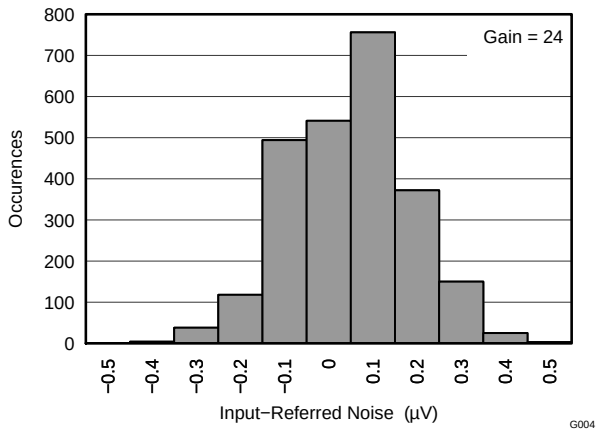

Figure 4. Noise Histogram

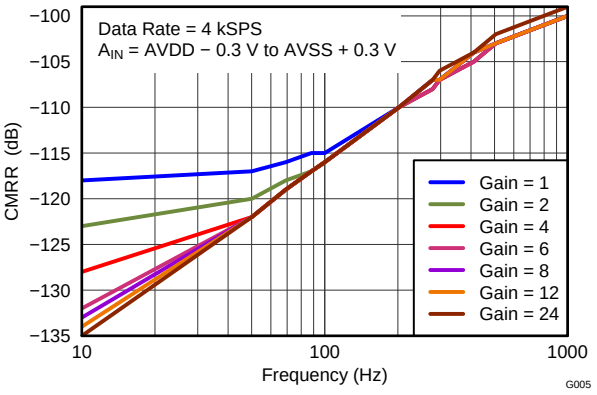

Figure 5. Common-Mode Rejection Ratio vs Frequency

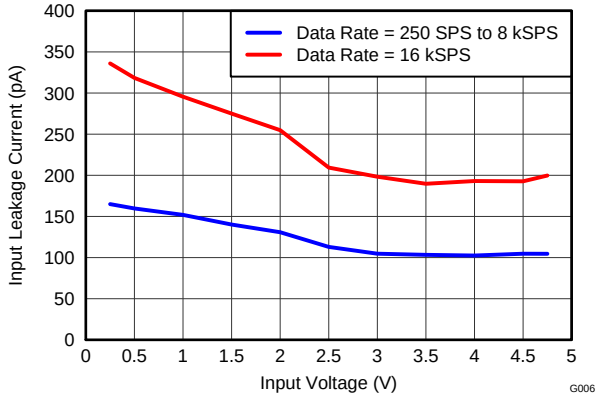

Figure 6. Leakage Current vs Input Voltage

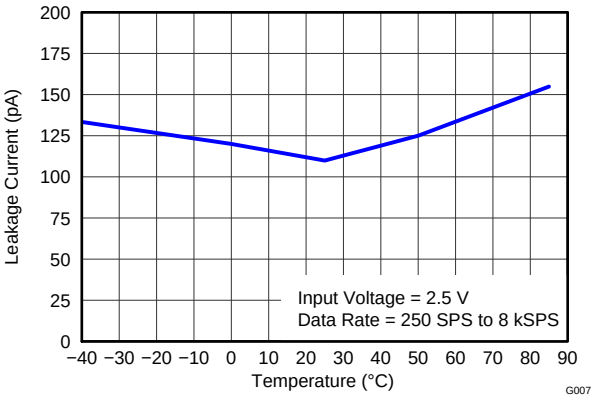

Figure 7. Leakage Current vs Temperature

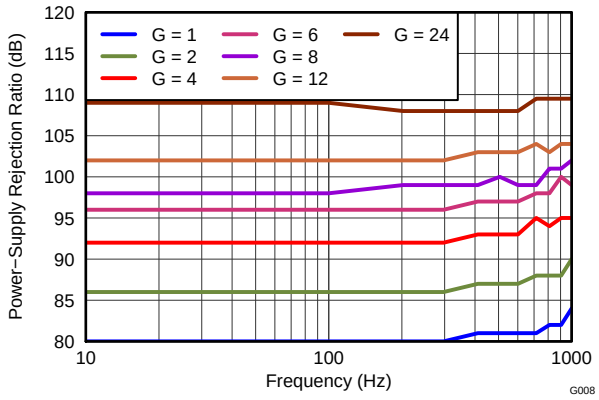

Figure 8. PSRR vs Frequency

Typical Characteristics (continued)

At T_A = 25°C, AVDD = 5 V, AVSS = 0 V, DVDD = 3.3 V, internal VREFP = 4.5 V, VREFN = AVSS, external clock = 2.048 MHz, data rate = 250 SPS, and gain = 12 (unless otherwise noted)

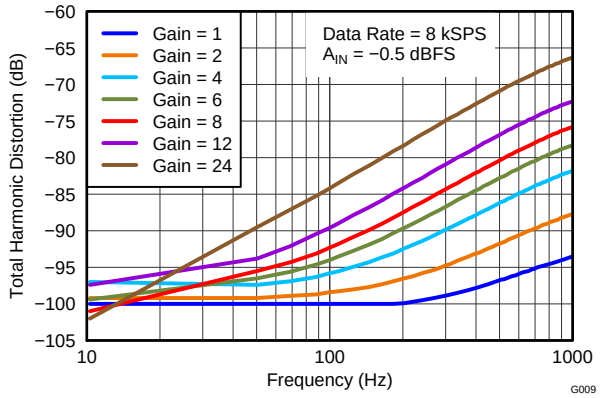

Figure 9. THD vs Frequency

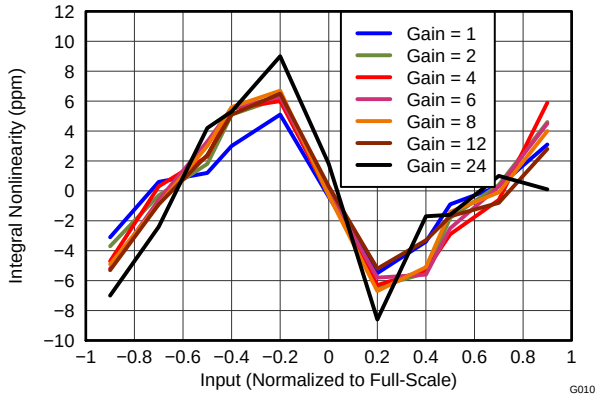

Figure 10. INL vs PGA Gain

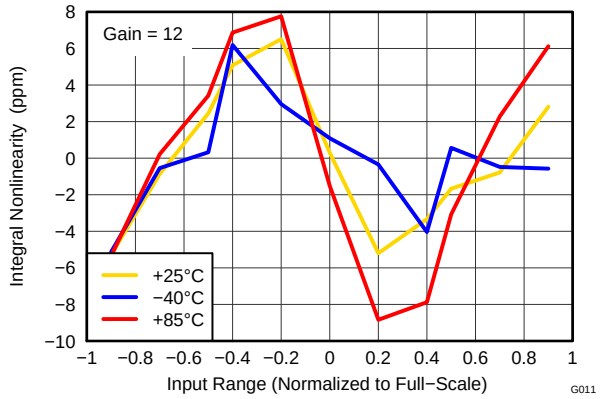

Figure 11. INL vs Temperature

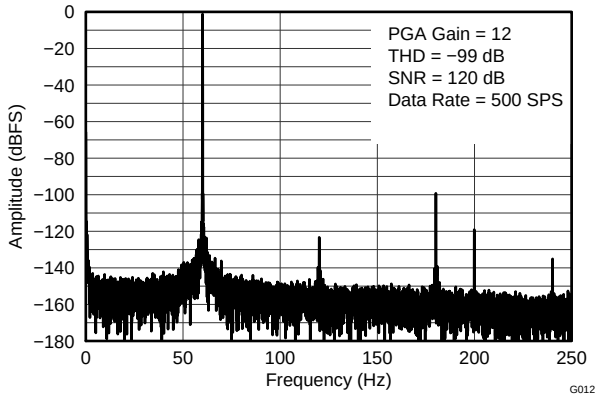

Figure 12. THD FFT Plot (60-Hz Signal)

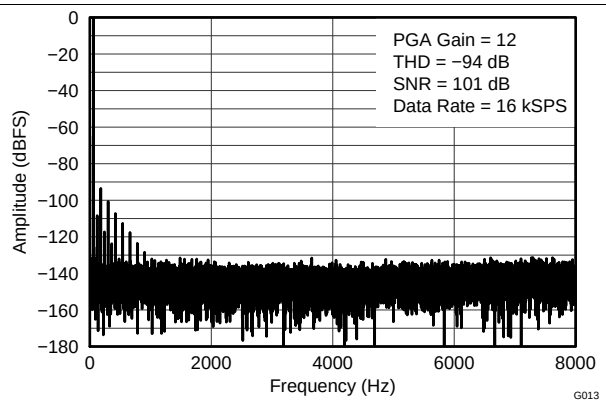

Figure 13. FFT Plot (60-Hz Signal)

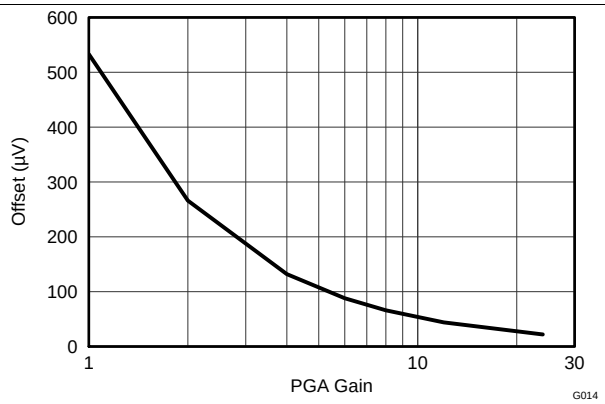

Figure 14. Offset vs PGA Gain (Absolute Value)

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Typical Characteristics (continued)

At T_A = 25°C, AVDD = 5 V, AVSS = 0 V, DVDD = 3.3 V, internal VREFP = 4.5 V, VREFN = AVSS, external clock = 2.048 MHz, data rate = 250 SPS, and gain = 12 (unless otherwise noted)

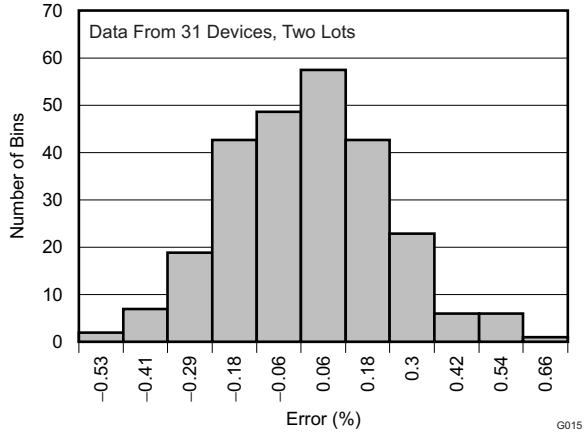

Figure 15. Test Signal Amplitude Accuracy

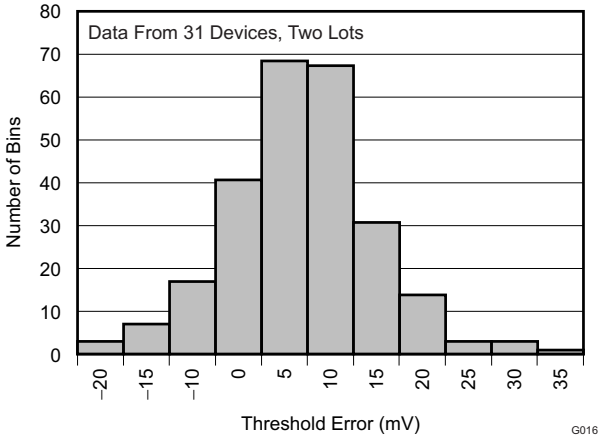

Figure 16. Lead-Off Comparator Threshold Accuracy

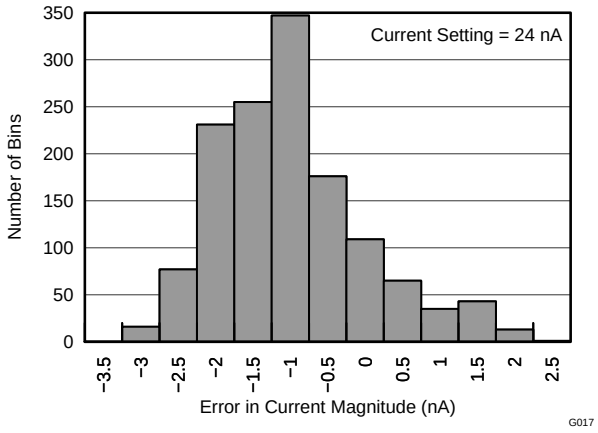

Figure 17. Lead-Off Current Source Accuracy Distribution

8 Parametric Measurement Information

8.1 Noise Measurements

NOTE

Unless otherwise noted, *ADS1299-x* refers to all specifications and functional descriptions of the ADS1299-4, ADS1299-6, and ADS1299.

Optimize the ADS1299-x noise performance by adjusting the data rate and PGA setting. Reduce the data rate to increase the averaging, and the noise drops correspondingly. Increase the PGA value to reduce the input-referred noise. This lowered noise level is particularly useful when measuring low-level biopotential signals. Table 1 to Table 4 summarize the ADS1299-x noise performance with a 5-V analog power supply. The data are representative of typical noise performance at T_A = +25°C. The data shown are the result of averaging the readings from multiple devices and are measured with the inputs shorted together. A minimum of 1000 consecutive readings are used to calculate the RMS and peak-to-peak noise for each reading. For the lower data rates, the ratio is approximately 6.6.

Table 1 shows measurements taken with an internal reference. The data are also representative of the ADS1299-x noise performance when using a low-noise external reference such as the REF5045.

Table 1, Table 2, Table 3, and Table 4 list the input-referred noise in units of μV_{RMS} and μV_{PP} for the conditions shown. The corresponding data in units of effective number of bits (ENOB) where ENOB for the RMS noise is defined as in Equation 1:

$$\text{ENOB} = \log_2\left(\frac{\text{VREF}}{\sqrt{2}\times\text{Gain}\times V_{RMS}}\right) \quad (1)$$

Noise-free bits for the peak-to-peak noise are calculated with the same method.

The dynamic range data in Table 1, Table 2, Table 3, and Table 4 are calculated using Equation 2:

$$\text{Dynamic Range} = 20\times\log\left(\frac{\text{VREF}}{\sqrt{2}\times\text{Gain}\times V_{RMS}}\right) \quad (2)$$

Table 1. Input-Referred Noise (μV_{RMS}, μV_{PP}) in Normal Mode 5-V Analog Supply and 4.5-V Reference(1)

DR BITS OF CONFIG1 REGISTER	OUTPUT DATA RATE (SPS)	–3-dB BANDWIDTH (Hz)	PGA GAIN = 1					PGA GAIN = 2				
			μV_{RMS}	μV_{PP}	DYNAMIC RANGE (dB)	NOISE-FREE BITS	ENOB	μV_{RMS}	μV_{PP}	DYNAMIC RANGE (dB)	NOISE-FREE BITS	ENOB
000	16000	4193	21.70	151.89	103.3	15.85	17.16	10.85	75.94	103.3	15.85	17.16
001	8000	2096	6.93	48.53	113.2	17.50	18.81	3.65	25.52	112.8	17.43	18.74
010	4000	1048	4.33	30.34	117.3	18.18	19.49	2.28	15.95	116.9	18.11	19.41
011	2000	524	3.06	21.45	120.3	18.68	19.99	1.61	11.29	119.9	18.60	19.91
100	1000	262	2.17	15.17	123.3	19.18	20.49	1.14	7.98	122.9	19.10	20.41
101	500	131	1.53	10.73	126.3	19.68	20.99	0.81	5.65	125.9	19.60	20.91
110	250	65	1.08	7.59	129.3	20.18	21.48	0.57	3.99	128.9	20.10	21.41
111	n/a	n/a	—	—	—	—	—	—	—	—	—	—

(1) At least 1000 consecutive readings were used to calculate the RMS and peak-to-peak noise values in this table.

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Table 2. Input-Referred Noise (μV_{RMS}, μV_{PP}) in Normal Mode 5-V Analog Supply and 4.5-V Reference(1)

DR BITS OF CONFIG1 REGISTER	OUTPUT DATA RATE (SPS)	–3-dB BANDWIDTH (Hz)	PGA GAIN = 4					PGA GAIN = 6				
			μV_{RMS}	μV_{PP}	DYNAMIC RANGE (dB)	NOISE-FREE BITS	ENOB	μV_{RMS}	μV_{PP}	DYNAMIC RANGE (dB)	NOISE-FREE BITS	ENOB
000	16000	4193	5.60	39.23	103.0	15.81	17.12	3.87	27.10	102.7	15.76	17.06
001	8000	2096	1.98	13.87	112.1	17.31	18.62	1.31	9.19	112.1	17.32	18.62
010	4000	1048	1.24	8.66	116.1	17.99	19.29	0.93	6.50	115.1	17.82	19.12
011	2000	524	0.88	6.13	119.2	18.49	19.79	0.66	4.60	118.1	18.32	19.62
100	1000	262	0.62	4.34	122.2	18.99	20.29	0.46	3.25	121.1	18.81	20.12
101	500	131	0.44	3.07	125.2	19.49	20.79	0.33	2.30	124.1	19.31	20.62
110	250	65	0.31	2.16	128.2	19.99	21.30	0.23	1.62	127.2	19.82	21.13
111	n/a	n/a	—	—	—	—	—	—	—	—	—	—

(1) At least 1000 consecutive readings were used to calculate the RMS and peak-to-peak noise values in this table.

Table 3. Input-Referred Noise (μV_{RMS}, μV_{PP}) in Normal Mode 5-V Analog Supply and 4.5-V Reference(1)

DR BITS OF CONFIG1 REGISTER	OUTPUT DATA RATE (SPS)	–3-dB BANDWIDTH (Hz)	PGA GAIN = 8					PGA GAIN = 12				
			μV_{RMS}	μV_{PP}	DYNAMIC RANGE (dB)	NOISE-FREE BITS	ENOB	μV_{RMS}	μV_{PP}	DYNAMIC RANGE (dB)	NOISE-FREE BITS	ENOB
000	16000	4193	3.05	21.32	102.3	15.69	16.99	2.27	15.89	101.3	15.53	16.83
001	8000	2096	1.11	7.80	111.0	17.14	18.45	0.92	6.41	109.2	16.84	18.14
010	4000	1048	0.79	5.52	114.0	17.64	18.95	0.65	4.53	112.2	17.34	18.64
011	2000	524	0.56	3.90	117.1	18.14	19.44	0.46	3.20	115.2	17.84	19.14
100	1000	262	0.39	2.76	120.1	18.64	19.94	0.32	2.26	118.3	18.34	19.65
101	500	131	0.28	1.95	123.1	19.14	20.44	0.23	1.61	121.2	18.83	20.14
110	250	65	0.20	1.38	126.1	19.64	20.95	0.16	1.13	124.3	19.34	20.65
111	n/a	n/a	—	—	—	—	—	—	—	—	—	—

(1) At least 1000 consecutive readings were used to calculate the RMS and peak-to-peak noise values in this table.

Table 4. Input-Referred Noise (μV_{RMS}, μV_{PP}) in Normal Mode 5-V Analog Supply and 4.5-V Reference(1)

DR BITS OF CONFIG1 REGISTER	OUTPUT DATA RATE (SPS)	–3-dB BANDWIDTH (Hz)	PGA GAIN = 24				
			μV_{RMS}	μV_{PP}	DYNAMIC RANGE (dB)	NOISE-FREE BITS	ENOB
000	16000	4193	1.66	11.64	98.0	14.98	16.28
001	8000	2096	0.80	5.57	104.4	16.04	17.35
010	4000	1048	0.56	3.94	107.4	16.54	17.84
011	2000	524	0.40	2.79	110.4	17.04	18.35
100	1000	262	0.28	1.97	113.5	17.54	18.85
101	500	131	0.20	1.39	116.5	18.04	19.35
110	250	65	0.14	0.98	119.5	18.54	19.85
111	n/a	n/a	—	—	—	—	—

(1) At least 1000 consecutive readings were used to calculate the RMS and peak-to-peak noise values in this table.

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9 Detailed Description

9.1 Overview

The ADS1299-x is a low-noise, low-power, multichannel, simultaneously-sampling, 24-bit, delta-sigma ($\Delta\Sigma$) analog-to-digital converter (ADC) with an integrated programmable gain amplifier (PGA). These devices integrate various EEG-specific functions that makes the family well-suited for scalable electrocardiogram (ECG), electroencephalography (EEG) applications. These devices can also be used in high-performance, multichannel, data acquisition systems by powering down the ECG or EEG-specific circuitry.

The devices have a highly-programmable multiplexer that allows for temperature, supply, input short, and bias measurements. Additionally, the multiplexer allows any input electrodes to be programmed as the patient reference drive. The PGA gain can be chosen from one of seven settings (1, 2, 4, 6, 8, 12, and 24). The ADCs in the device offer data rates from 250 SPS to 16 kSPS. Communication to the device is accomplished using an SPI-compatible interface. The device provides four general-purpose input/output (GPIO) pins for general use. Multiple devices can be synchronized using the START pin.

The internal reference generates a low noise 4.5 V internal voltage when enabled and the internal oscillator generates a 2.048-MHz clock when enabled. The versatile patient bias drive block allows the average of any electrode combination to be chosen in order to generate the patient drive signal. Lead-off detection can be accomplished by using a current source or sink. A one-time, in-band, lead-off option and a continuous, out-of-band, internal lead-off option are available.

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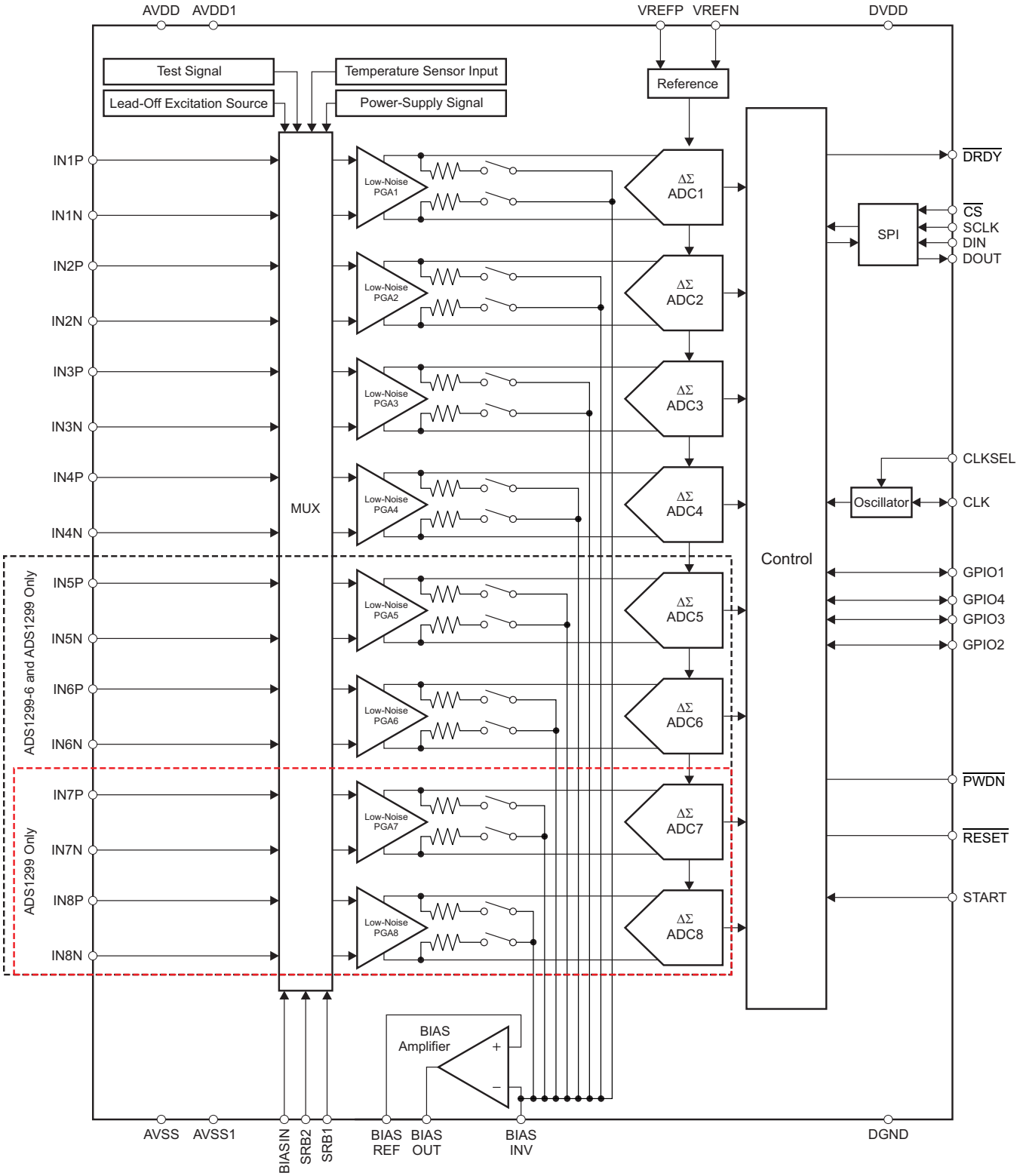
9.2 Functional Block Diagram



9.3 Feature Description

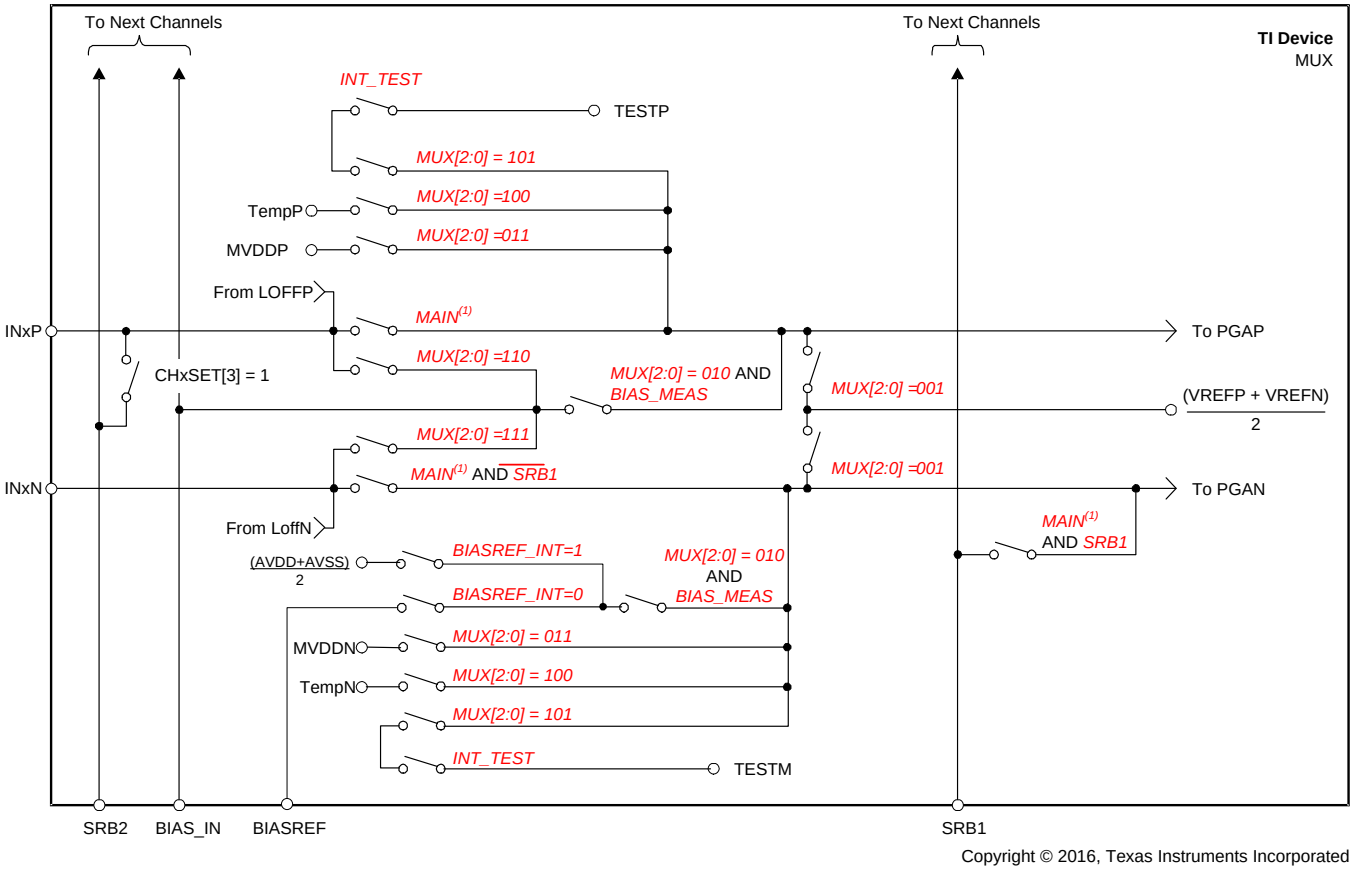
This section contains details of the ADS1299-x internal functional elements. The analog blocks are discussed first, followed by the digital interface. Blocks implementing EEG-specific functions are covered at the end of this section.

Throughout this document, f_{CLK} denotes the CLK pin signal frequency, t_{CLK} denotes the CLK pin signal period, f_{DR} denotes the output data rate, t_{DR} denotes the output data time period, and f_{MOD} denotes the frequency at which the modulator samples the input.

9.3.1 Analog Functionality

9.3.1.1 Input Multiplexer

The ADS1299-x input multiplexers are very flexible and provide many configurable signal-switching options. Figure 18 shows the multiplexer on a single channel of the device. Note that the device has either four (ADS1299-4), six (ADS1299-6) or eight (ADS1299) such blocks, one for each channel. SRB1, SRB2, and BIASIN are common to all blocks. INxP and INxN are separate for each of the four, six, or eight blocks. This flexibility allows for significant device and sub-system diagnostics, calibration, and configuration. Switch setting selections for each channel by writing the appropriate values to the CHnSET[3:0] register (see the *CHnSET: Individual Channel Settings* section for details) using the BIAS_MEAS bit in the CONFIG3 register and the SRB1 bit in the MISC1 register (see the *CONFIG3: Configuration Register 3* subsection of the *Register Maps* section for details). See the *Input Multiplexer* section for further information regarding the EEG-specific features of the multiplexer.



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(1) MAIN is equal to either MUX[2:0] = 000, MUX[2:0] = 110, or MUX[2:0] = 111.

Figure 18. Input Multiplexer Block for One Channel

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Feature Description (continued)

9.3.1.1.1 Device Noise Measurements

Setting CHnSET[2:0] = 001 sets the common-mode voltage of [(V_{VREFP} + V_{VREFN}) / 2] to both channel inputs. This setting can be used to test inherent device noise in the user system.

9.3.1.1.2 Test Signals (TestP and TestN)

Setting CHnSET[2:0] = 101 provides internally-generated test signals for use in sub-system verification at power-up. This functionality allows the device internal signal chain to be tested out.

Test signals are controlled through register settings (see the *CONFIG2: Configuration Register 2* subsection in the *Register Maps* section for details). TEST_AMP controls the signal amplitude and TEST_FREQ controls switching at the required frequency.

9.3.1.1.3 Temperature Sensor (TempP, TempN)

The ADS1299-x contains an on-chip temperature sensor. This sensor uses two internal diodes with one diode having a current density 16x that of the other, as shown in Figure 19. The difference in diode current densities yields a voltage difference proportional to absolute temperature.

As a result of the low thermal resistance of the package to the printed circuit board (PCB), the internal device temperature tracks PCB temperature closely. Note that self-heating of the ADS1299-x causes a higher reading than the temperature of the surrounding PCB.

The scale factor of Equation 3 converts the temperature reading to degrees Celsius. Before using this equation, the temperature reading code must first be scaled to microvolts.

$$\text{Temperature (°C)} = \left(\frac{\text{Temperature Reading (}\mu\text{V)} - 145{,}300\ \mu\text{V}}{490\ \mu\text{V/°C}} \right) + 25\text{°C} \tag{3}$$

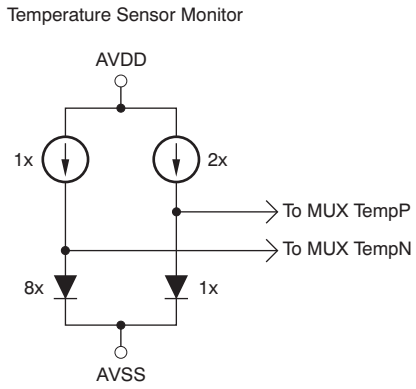

Figure 19. Temperature Sensor Measurement in the Input

9.3.1.1.4 Supply Measurements (MVDDP, MVDDN)

Setting CHnSET[2:0] = 011 sets the channel inputs to different supply voltages of the device. For channels 1, 2, 5, 6, 7, and 8, (MVDDP – MVDDN) is [0.5 × (AVDD + AVSS)].

For channels 3 and 4, (MVDDP – MVDDN) is DVDD / 4.

To avoid saturating the PGA when measuring power supplies, set the gain to 1.

9.3.1.1.5 Lead-Off Excitation Signals (LoffP, LoffN)

The lead-off excitation signals are fed into the multiplexer before the switches. The comparators that detect the lead-off condition are also connected to the multiplexer block before the switches. For a detailed description of the lead-off block, see the *Lead-Off Detection* section.

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Feature Description (continued)

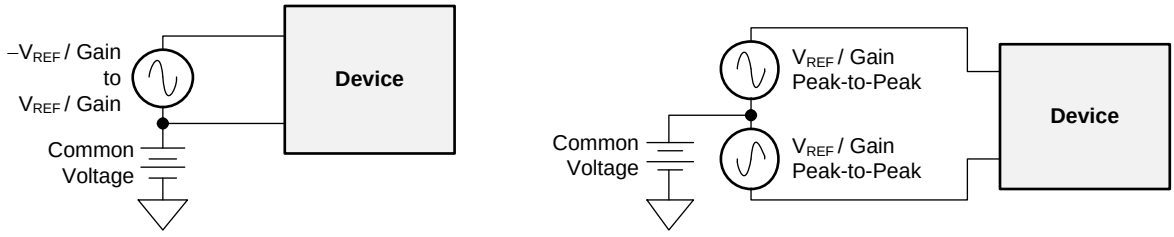
9.3.1.1.6 Auxiliary Single-Ended Input

The BIASIN pin is primarily used for routing the bias signal to any electrodes in case the bias electrode falls off. However, the BIASIN pin can be used as a multiple single-ended input channel. The signal at the BIASIN pin can be measured with respect to the voltage at the BIASREF pin using any of the eight channels. This measurement is done by setting the channel multiplexer setting to '010' and the BIAS_MEAS bit of the CONFIG3 register to '1'.

9.3.1.2 Analog Input

The analog inputs to the device connect directly to an integrated low-noise, low-drift, high input impedance, programmable gain amplifier. The amplifier is located following the individual channel multiplexer.

The ADS1299-x analog inputs are fully differential. The differential input voltage (V_{INxP} – V_{INxN}) can span from $–V_{REF}$ / gain to V_{REF} / gain. See the *Data Format* section for an explanation of the correlation between the analog input and digital codes. There are two general methods of driving the ADS1299-x analog inputs: pseudo-differential or fully-differential, as shown in Figure 20, Figure 21, and Figure 22.



a) Psuedo-Differential Input

b) Differential Input

Figure 20. Methods of Driving the ADS1299-x: Pseudo-Differential or Fully Differential

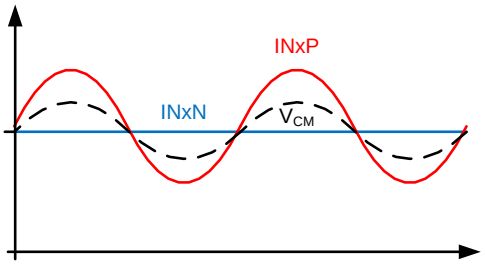


Figure 21. Pseudo-Differential Input Mode

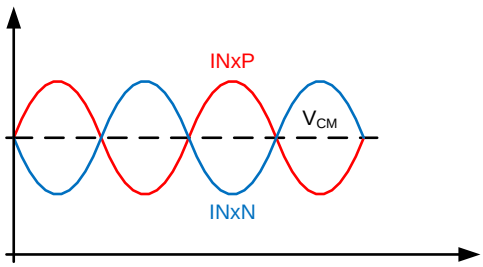


Figure 22. Fully-Differential Input Mode

Hold the INxN pin at a common voltage, preferably at mid supply, to configure the fully differential input for a pseudo-differential signal. Swing the INxP pin around the common voltage $–V_{REF}$ / gain to V_{REF} / gain and remain within the absolute maximum specifications. The common-mode voltage (V_{CM}) changes with varying signal level when the inputs are configured in pseudo-differential mode. Verify that the differential signal at the minimum and maximum points meets the common-mode input specification discussed in the *Input Common-Mode Range* section.

Configure the signals at INxP and INxN to be 180° out-of-phase centered around a common voltage to use a fully differential input method. Both the INxP and INxN inputs swing from the common voltage + ½ V_{REF} / gain to the common voltage – ½ V_{REF} / gain. The differential voltage at the maximum and minimum points is equal to $–V_{REF}$ / gain to V_{REF} / gain and centered around a fixed common-mode voltage (V_{CM}). Use the ADS1299-x in a differential configuration to maximize the dynamic range of the data converter. For optimal performance, the common voltage is recommended to be set at the midpoint of the analog supplies [(AVDD + AVSS) / 2].

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9.3.1.3 PGA Settings and Input Range

The low-noise PGA is a differential input and output amplifier, as shown in Figure 23. The PGA has seven gain settings (1, 2, 4, 6, 8, 12, and 24) that can be set by writing to the CHnSET register (see the *CHnSET: Individual Channel Settings* subsection of the *Register Maps* section for details). The ADS1299-x has CMOS inputs and therefore has negligible current noise. Table 5 shows the typical bandwidth values for various gain settings. Note that Table 5 shows small-signal bandwidth. For large signals, performance is limited by PGA slew rate.

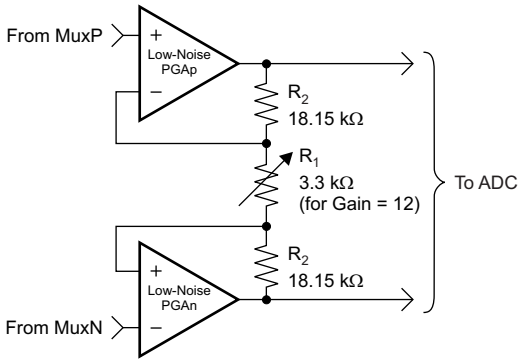


Figure 23. PGA Implementation

Table 5. PGA Gain versus Bandwidth

GAIN	NOMINAL BANDWIDTH AT ROOM TEMPERATURE (kHz)
1	662
2	332
4	165
6	110
8	83
12	55
24	27

The PGA resistor string that implements the gain has 39.6 kΩ of resistance for a gain of 12. This resistance provides a current path across the PGA outputs in the presence of a differential input signal. This current is in addition to the quiescent current specified for the device in the presence of a differential signal at the input.

9.3.1.3.1 Input Common-Mode Range

To stay within the linear operating range of the PGA, the input signals must meet certain requirements that are discussed in this section.

The outputs of the amplifiers in Figure 23 cannot swing closer to the supplies (AVSS and AVDD) than 200 mV. If the outputs of the amplifiers are driven to within 200 mV of the supply rails, then the amplifiers saturate and consequently become nonlinear. To prevent this nonlinear operating condition, the output voltages must not exceed the common-mode range of the front-end.

The usable input common-mode range of the front-end depends on various parameters, including the maximum differential input signal, supply voltage, PGA gain, and the 200 mV for the amplifier headroom. This range is described in Equation 4:

$$AVDD - 0.2\ V - \left(\frac{Gain \times V_{MAX_DIFF}}{2}\right) > CM > AVSS + 0.2\ V + \left(\frac{Gain \times V_{MAX_DIFF}}{2}\right) \quad (4)$$

where:

V_{MAX_DIFF} = maximum differential signal at the PGA input

CM = common-mode range

For example:

If AVDD = 5 V, gain = 12, and V_{MAX_DIFF} = 350 mV

Then 2.3 V < CM < 2.7 V

9.3.1.3.2 Input Differential Dynamic Range

The differential input voltage range (V_{INxP} – V_{INxN}) depends on the analog supply and reference used in the system. This range is shown in Equation 5.

$$\text{Full-Scale Range} = \frac{\pm V_{REF}}{\text{Gain}} = \frac{2V_{REF}}{\text{Gain}} \quad (5)$$

9.3.1.3.3 ADC ΔΣ Modulator

Each ADS1299-x channel has a 24-bit, ΔΣ ADC. This converter uses a second-order modulator optimized for low-noise applications. The modulator samples the input signal at the rate of (f_{MOD} = f_{CLK} / 2). As in the case of any ΔΣ modulator, the device noise is shaped until f_{MOD} / 2, as shown in Figure 24. The on-chip digital decimation filters explained in the next section can be used to filter out the noise at higher frequencies. These on-chip decimation filters also provide antialias filtering. This ΔΣ converter feature drastically reduces the complexity of the analog antialiasing filters typically required with nyquist ADCs.

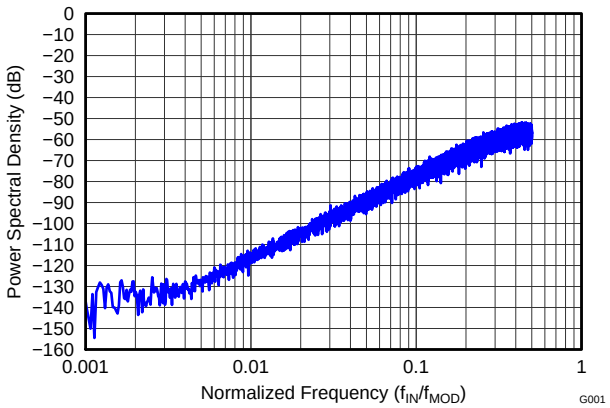
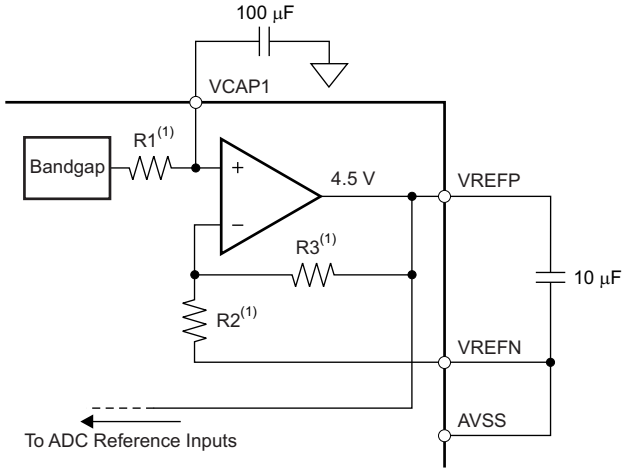


Figure 24. Modulator Noise Spectrum Up To 0.5 × f_{MOD}

9.3.1.3.4 Reference

Figure 25 shows a simplified block diagram of the ADS1299-x internal reference. The 4.5-V reference voltage is generated with respect to AVSS. When using the internal voltage reference, connect V_{REFN} to AVSS.



(1) For V_{REF} = 4.5 V: R1 = 9.8 kΩ, R2 = 13.4 kΩ, and R3 = 36.85 kΩ.

Figure 25. Internal Reference

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The external band-limiting capacitors determine the amount of reference noise contribution. For high-end EEG systems, the capacitor values should be chosen such that the bandwidth is limited to less than 10 Hz so that the reference noise does not dominate system noise.

Alternatively, the internal reference buffer can be powered down and an external reference can be applied to VREFP. Figure 26 shows a typical external reference drive circuitry. Power-down is controlled by the PD_REFBUF bit in the CONFIG3 register. This power-down is also used to share internal references when two devices are cascaded. By default, the device wakes up in external reference mode.

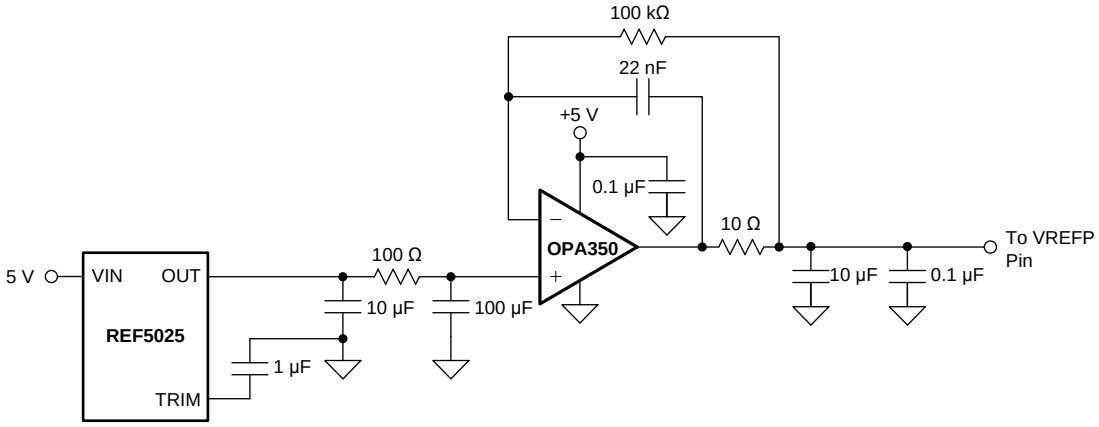

Figure 26. External Reference Driver

9.3.2 Digital Functionality

9.3.2.1 Digital Decimation Filter

The digital filter receives the modulator output and decimates the data stream. By adjusting the amount of filtering, tradeoffs can be made between resolution and data rate: filter more for higher resolution, filter less for higher data rates. Higher data rates are typically used in EEG applications for ac lead-off detection.

The digital filter on each channel consists of a third-order sinc filter. The sinc filter decimation ratio can be adjusted by the DR bits in the CONFIG1 register (see the *Register Maps* section for details). This setting is a global setting that affects all channels and, therefore, all channels operate at the same data rate in a device.

9.3.2.1.1 Sinc Filter Stage (sinx / x)

The sinc filter is a variable decimation rate, third-order, low-pass filter. Data are supplied to this section of the filter from the modulator at the rate of f_{MOD}. The sinc filter attenuates the modulator high-frequency noise, then decimates the data stream into parallel data. The decimation rate affects the overall converter data rate.

Equation 6 shows the scaled Z-domain transfer function of the sinc filter.

$$\left|H(z)\right| = \left|\frac{1 - Z^{-N}}{1 - Z^{-1}}\right|^{3} \tag{6}$$

The frequency domain transfer function of the sinc filter is shown in Equation 7.

$$\left|H(f)\right| = \left|\frac{\sin\left(\frac{N\pi f}{f_{MOD}}\right)}{N \times \sin\left(\frac{\pi f}{f_{MOD}}\right)}\right|^{3} \tag{7}$$

where:

N = decimation ratio

The sinc filter has notches (or zeroes) that occur at the output data rate and multiples thereof. At these frequencies, the filter has infinite attenuation. Figure 27 shows the sinc filter frequency response and Figure 28 shows the sinc filter roll-off. With a step change at input, the filter takes 3 × t_{DR} to settle. After a rising edge of the START signal, the filter takes t_{SETTLE} time to give the first data output. The settling time of the filters at various data rates are discussed in the *Start* subsection of the *SPI Interface* section. Figure 29 and Figure 30 show the filter transfer function until f_{MOD} / 2 and f_{MOD} / 16, respectively, at different data rates. Figure 31 shows the transfer function extended until 4 × f_{MOD}. The ADS1299-x pass band repeats itself at every f_{MOD}. The input R-C antialiasing filters in the system should be chosen such that any interference in frequencies around multiples of f_{MOD} are attenuated sufficiently.

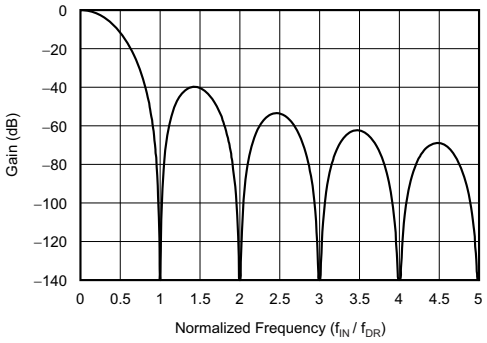

Figure 27. Sinc Filter Frequency Response

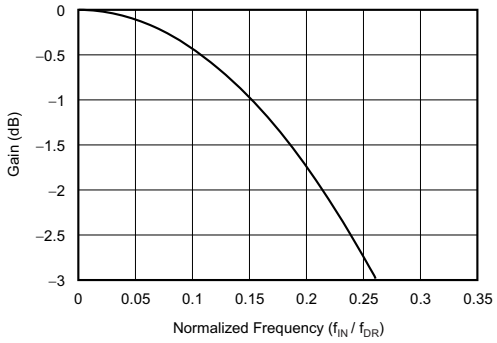

Figure 28. Sinc Filter Roll-Off

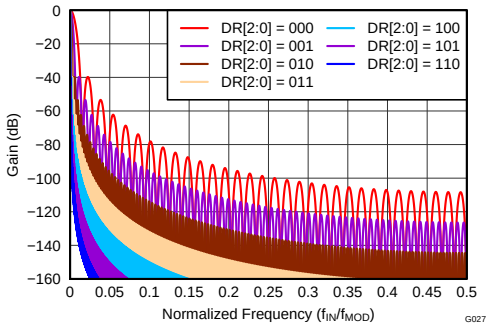

Figure 29. Transfer Function of On-Chip Decimation Filters Until f_{MOD} / 2

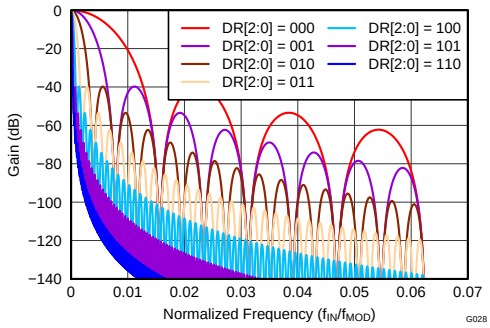

Figure 30. Transfer Function of On-Chip Decimation Filters Until f_{MOD} / 16

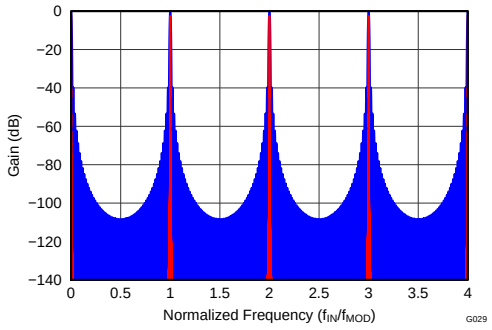

Figure 31. Transfer Function of On-Chip Decimation Filters Until 4 f_{MOD} for DR[2:0] = 000 and DR[2:0] = 110

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9.3.2.2 Clock

The ADS1299-x provides two methods for device clocking: internal and external. Internal clocking is ideally suited for low-power, battery-powered systems. The internal oscillator is trimmed for accuracy at room temperature. Accuracy varies over the specified temperature range; see the *Electrical Characteristics*. Clock selection is controlled by the CLKSEL pin and the CLK_EN register bit.

The CLKSEL pin selects either the internal or external clock. The CLK_EN bit in the CONFIG1 register enables and disables the oscillator clock to be output in the CLK pin. A truth table for these two pins is shown in Table 6. The CLK_EN bit is useful when multiple devices are used in a daisy-chain configuration. During power-down, the external clock is recommended be shut down to save power.

Table 6. CLKSEL Pin and CLK_EN Bit

CLKSEL PIN	CONFIG1.CLK_EN BIT	CLOCK SOURCE	CLK PIN STATUS
0	X	External clock	Input: external clock
1	0	Internal clock oscillator	3-state
1	1	Internal clock oscillator	Output: internal clock oscillator

9.3.2.3 GPIO

The ADS1299-x has a total of four general-purpose digital I/O (GPIO) pins available in normal mode of operation. The digital I/O pins are individually configurable as either inputs or outputs through the GPIOC bits register. The GPIOD bits in the GPIO register control the pin level. When reading the GPIOD bits, the data returned are the logic level of the pins, whether they are programmed as inputs or outputs. When the GPIO pin is configured as an input, a write to the corresponding GPIOD bit has no effect. When configured as an output, a write to the GPIOD bit sets the output value.

If configured as inputs, these pins must be driven (do not float). The GPIO pins are set as inputs after power-on or after a reset. Figure 32 shows the GPIO port structure. The pins should be shorted to DGND if not used.

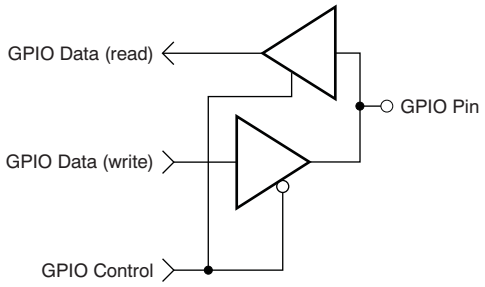
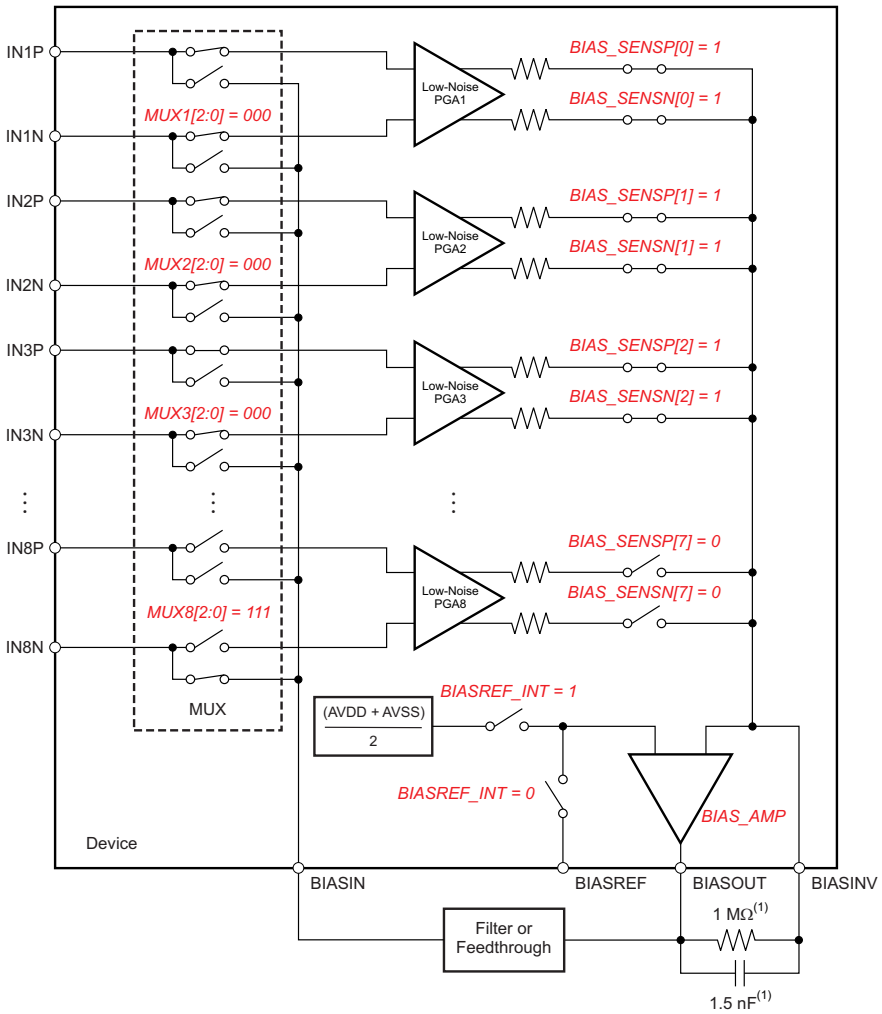


Figure 32. GPIO Port Pin

9.3.2.4 ECG and EEG Specific Features

9.3.2.4.1 Input Multiplexer (Rerouting the BIAS Drive Signal)

The input multiplexer has EEG-specific functions for the bias drive signal. The BIAS signal is available at the BIASOUT pin when the appropriate channels are selected for BIAS derivation, feedback elements are installed external to the chip, and the loop is closed. This signal can either be fed after filtering or fed directly into the BIASIN pin, as shown in Figure 33. This BIASIN signal can be multiplexed into any input electrode by setting the MUX bits of the appropriate channel set registers to '110' for P-side or '111' for N-side. Figure 33 shows the BIAS signal generated from channels 1, 2, and 3 and routed to the N-side of channel 8. This feature can be used to dynamically change the electrode that is used as the reference signal to drive the patient body.



(1) Typical values for example only.

Figure 33. Example of BIASOUT Signal Configured to be Routed to IN8N

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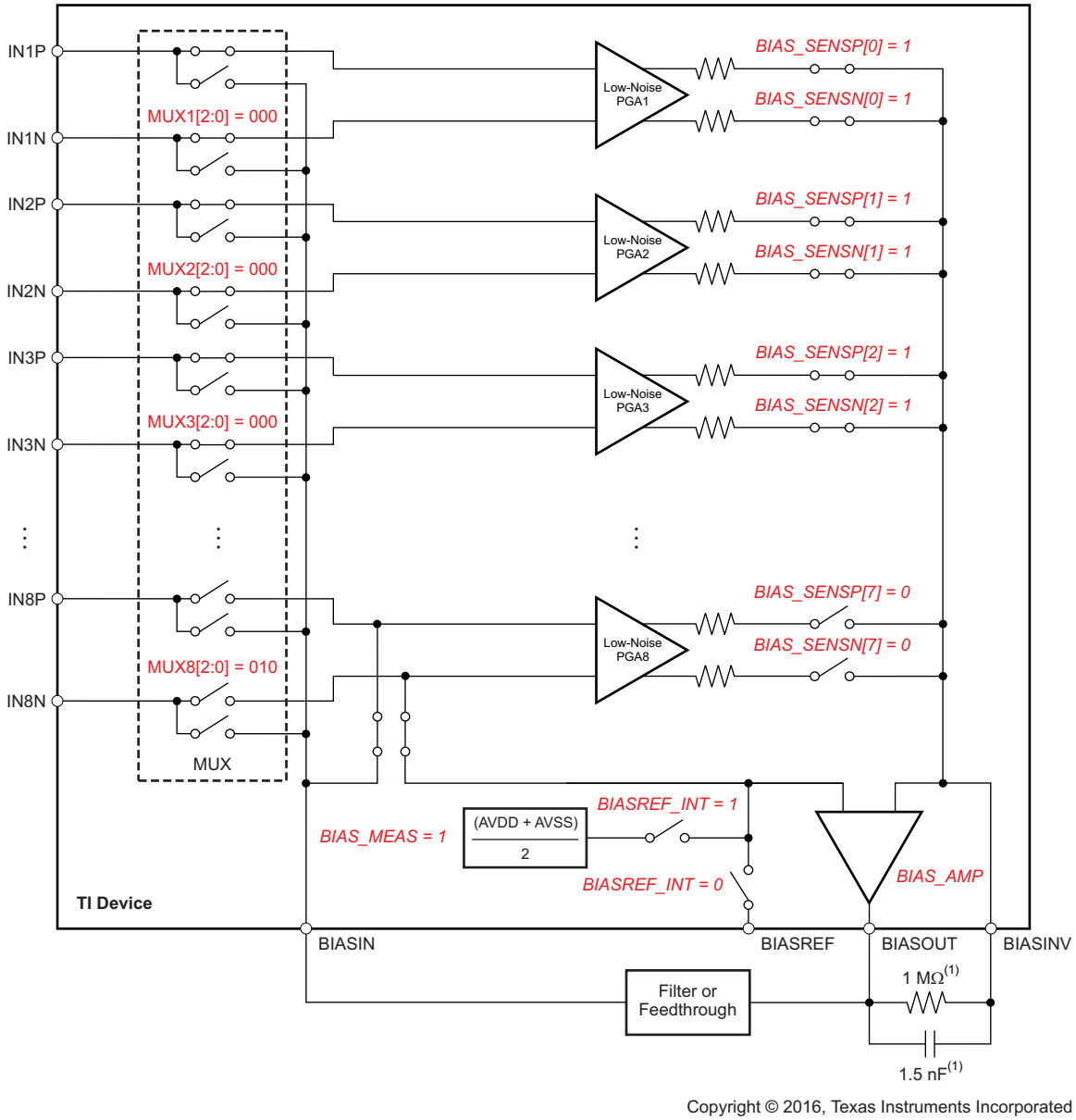
9.3.2.4.2 Input Multiplexer (Measuring the BIAS Drive Signal)

Also, the BIASOUT signal can be routed to a channel (that is not used for the calculation of BIAS) for measurement. Figure 34 shows the register settings to route the BIASIN signal to channel 8. The measurement is done with respect to the voltage on the BIASREF pin. If BIASREF is chosen to be internal, then BIASREF is at [(AVDD + AVSS) / 2]. This feature is useful for debugging purposes during product development.



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(1) Typical values for example only.

Figure 34. BIASOUT Signal Configured to be Read Back by Channel 8

9.3.2.4.3 Lead-Off Detection

Patient electrode impedances are known to decay over time. These electrode connections must be continuously monitored to verify that a suitable connection is present. The ADS1299-x lead-off detection functional block provides significant flexibility to the user to choose from various lead-off detection strategies. Though called lead-off detection, this is in fact an *electrode-off* detection.

The basic principle is to inject an excitation current and measure the voltage to determine if the electrode is off. As shown in the lead-off detection functional block diagram in Figure 35, this circuit provides two different methods of determining the state of the patient electrode. The methods differ in the frequency content of the excitation signal. Lead-off can be selectively done on a per channel basis using the LOFF_SENSP and LOFF_SENSN registers. Also, the internal excitation circuitry can be disabled and just the sensing circuitry can be enabled.

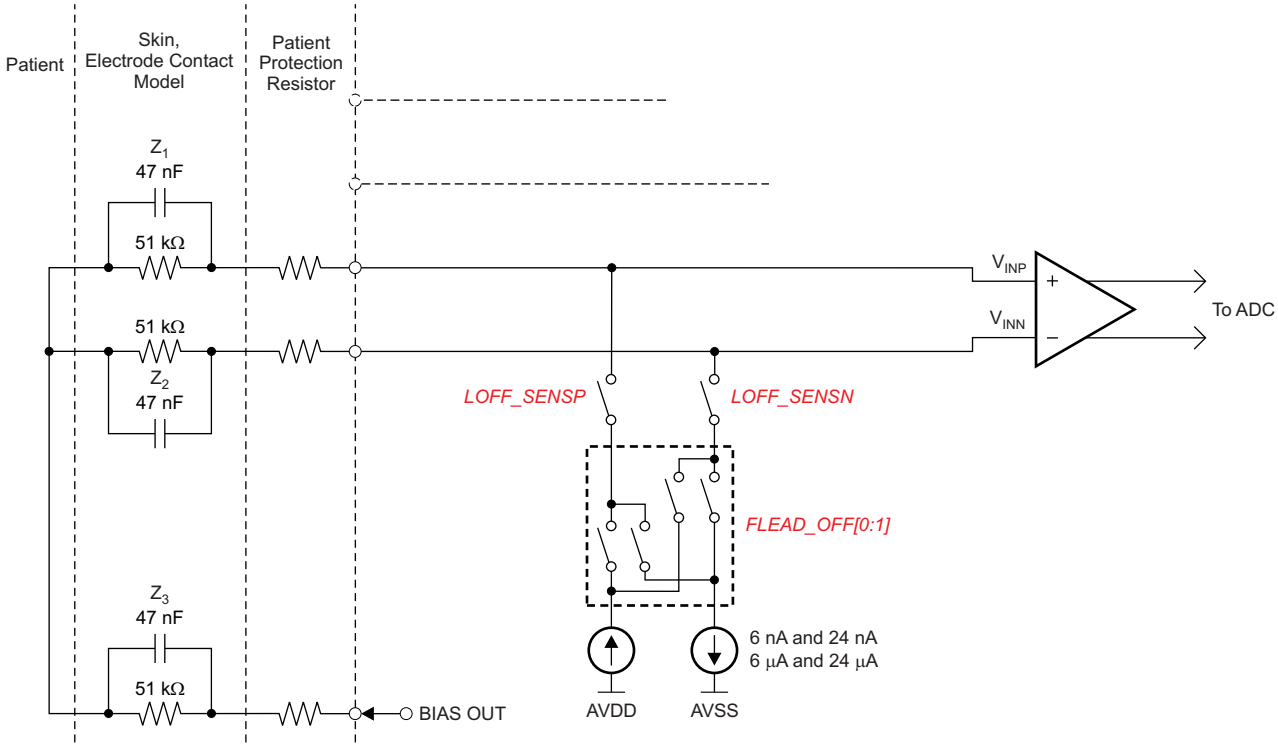

Figure 35. Lead-Off Detection

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9.3.2.4.3.1 DC Lead-Off

In this method, the lead-off excitation is with a dc signal. The dc excitation signal can be chosen from either an external pull-up or pull-down resistor or an internal current source or sink, as shown in Figure 36. One side of the channel is pulled to supply and the other side is pulled to ground. The pull-up and pull-down current can be swapped (as shown in Figure 36b and Figure 36c) by setting the bits in the LOFF_FLIP register. In case of a current source or sink, the magnitude of the current can be set by using the ILEAD_OFF[1:0] bits in the LOFF register. The current source or sink gives larger input impedance compared to the 10-MΩ pull-up or pull-down resistor.

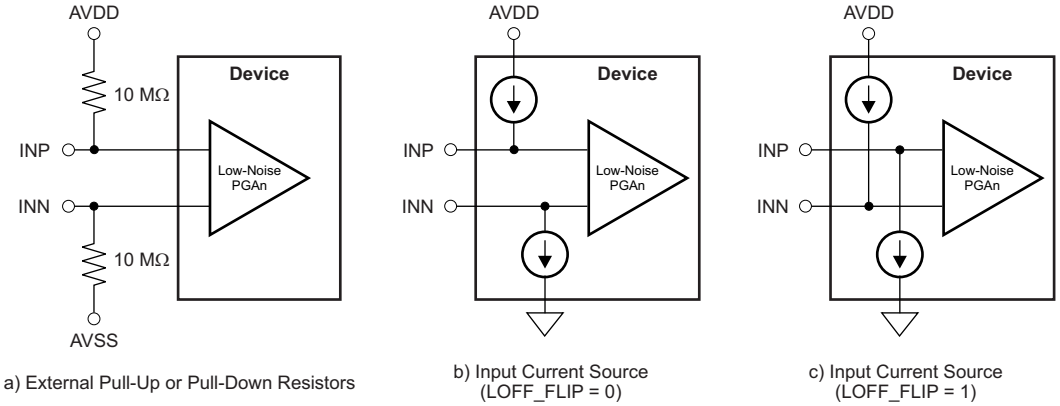

Figure 36. DC Lead-Off Excitation Options

Sensing of the response can be done either by searching the digital output code from the device or by monitoring the input voltages with an on-chip comparator. If either electrode is off, the pull-up and pull-down resistors saturate the channel. Searching the output code determines if either the P-side or the N-side is off. To pinpoint which one is off, the comparators must be used. The input voltage is also monitored using a comparator and a 3-bit DAC whose levels are set by the COMP_TH[2:0] bits in the LOFF register. The output of the comparators are stored in the LOFF_STATP and LOFF_STATN registers. These registers are available as a part of the output data stream. (See the *Data Output (DOUT)* subsection of the *SPI Interface* section.) If dc lead-off is not used, the lead-off comparators can be powered down by setting the PD_LOFF_COMP bit in the CONFIG4 register.

An example procedure to turn on dc lead-off is given in the *Lead-Off* section.

9.3.2.4.3.2 AC Lead-Off (One Time or Periodic)

In this method, an in-band ac signal is used for excitation. The ac signal is generated by alternatively providing a current source and sink at the input with a fixed frequency. The frequency can be chosen by the FLEAD_OFF[1:0] bits in the LOFF register. The excitation frequency is chosen to be one of the two in-band frequency selections (7.8 Hz or 31.2 Hz). This in-band excitation signal is passed through the channel and measured at the output.

Sensing of the ac signal is done by passing the signal through the channel to be digitized and then measured at the output. The ac excitation signals are introduced at a frequency that is in the band of interest. The signal can be filtered out separately and processed. By measuring the magnitude of the output at the excitation signal frequency, the electrode impedance can be calculated.

For continuous lead-off, an out-of-band ac current source or sink must be externally applied to the inputs. This signal can then be digitally processed to determine the electrode impedance.

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9.3.2.4.4 Bias Lead-Off

BIAS Lead-Off Detection During Normal Operation

During normal operation, the ADS1299-x BIAS lead-off at power-up function cannot be used because the BIAS amplifier must be powered off.

BIAS Lead Off Detection At Power-Up

This feature is included in the ADS1299-x for use in determining whether the bias electrode is suitably connected. At power-up, the ADS1299-x uses a current source and comparator to determine the BIAS electrode connection status, as shown in Figure 37. The reference level of the comparator is set to determine the acceptable BIAS impedance threshold.

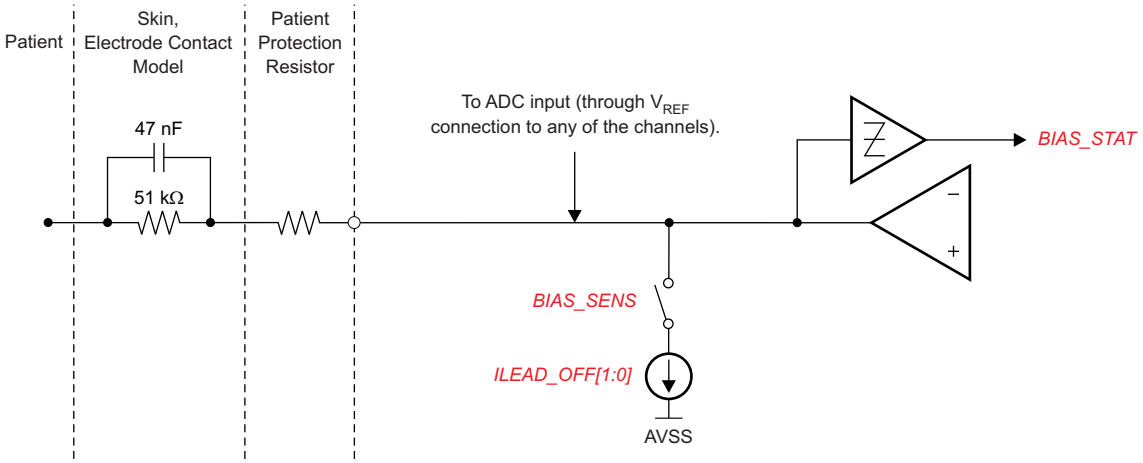

Figure 37. BIAS Lead-Off Detection at Power-Up

When the BIAS amplifier is powered on, the current source has no function. Only the comparator can be used to sense the voltage at the output of the BIAS amplifier. The comparator thresholds are set by the same LOFF[7:5] bits used to set the thresholds for other negative inputs.

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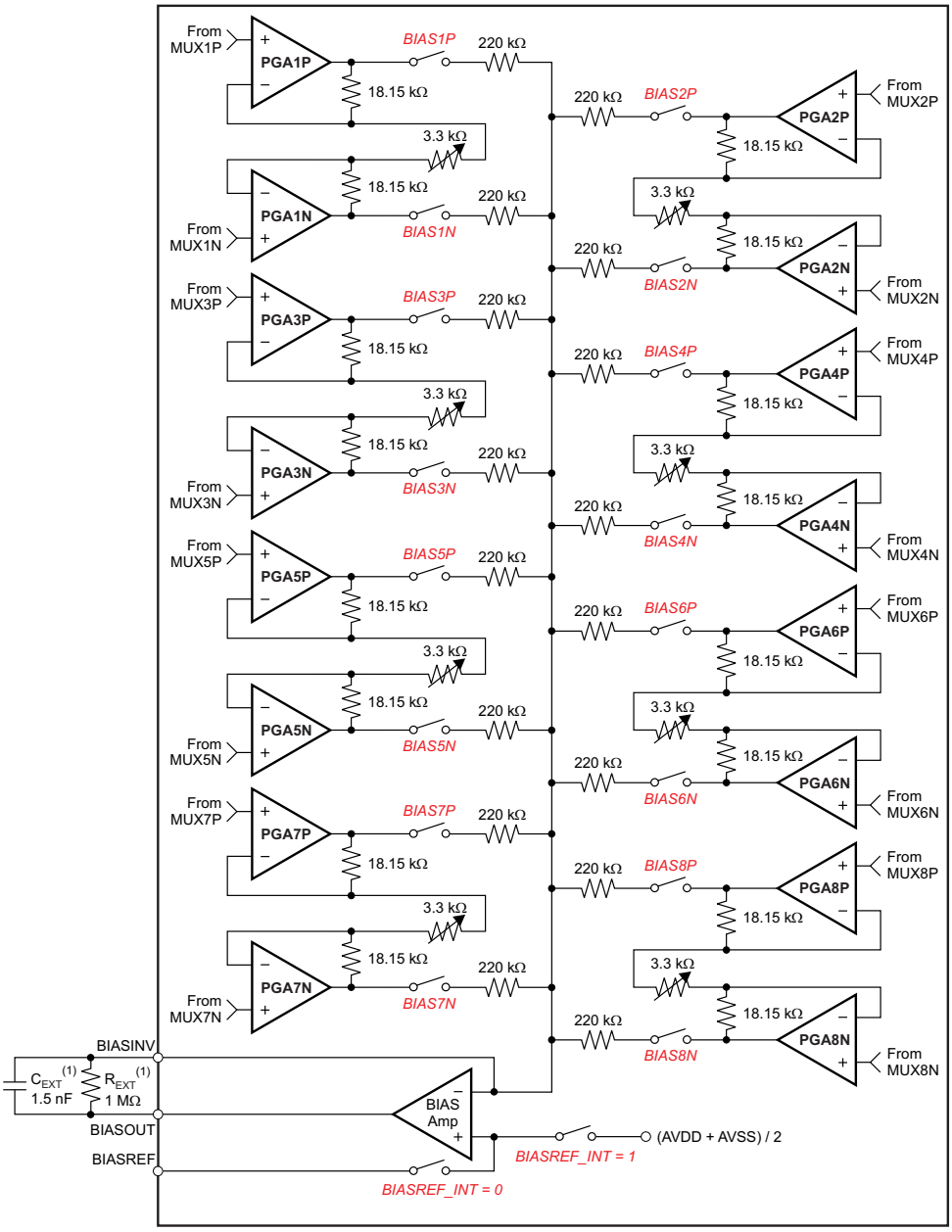
9.3.2.4.5 Bias Drive (DC Bias Circuit)

Use the bias circuitry to counter the common-mode interference in a EEG system as a result of power lines and other sources, including fluorescent lights. The bias circuit senses the common-mode voltage of a selected set of electrodes and creates a negative feedback loop by driving the body with an inverted common-mode signal. The negative feedback loop restricts the common-mode movement to a narrow range, depending on the loop gain. Stabilizing the entire loop is specific to the individual user system based on the various poles in the loop. The ADS1299-x integrates the muxes to select the channel and an operational amplifier. All the amplifier terminals are available at the pins, allowing the user to choose the components for the feedback loop. The circuit in Figure 38 shows the overall functional connectivity for the bias circuit.



(1) Typical values.

Figure 38. Bias Drive Amplifier Channel Selection

The reference voltage for the bias drive can be chosen to be internally generated [(AVDD + AVSS) / 2] or provided externally with a resistive divider. The selection of an internal versus external reference voltage for the bias loop is defined by writing the appropriate value to the BIASREF_INT bit in the CONFIG2 register.

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If the bias function is not used, the amplifier can be powered down using the PD_BIAS bit (see the *CONFIG3: Configuration Register 3* subsection of the *Register Maps* section for details). Use the PD_BIAS bit to power-down all but one of the bias amplifiers when daisy-chaining multiple ADS1299-x devices.

The BIASIN pin functionality is explained in the *Input Multiplexer* section. An example procedure to use the bias amplifier is shown in the *Bias Drive* section.

9.3.2.4.5.1 Bias Configuration with Multiple Devices

Figure 39 shows multiple devices connected to the bias drive.

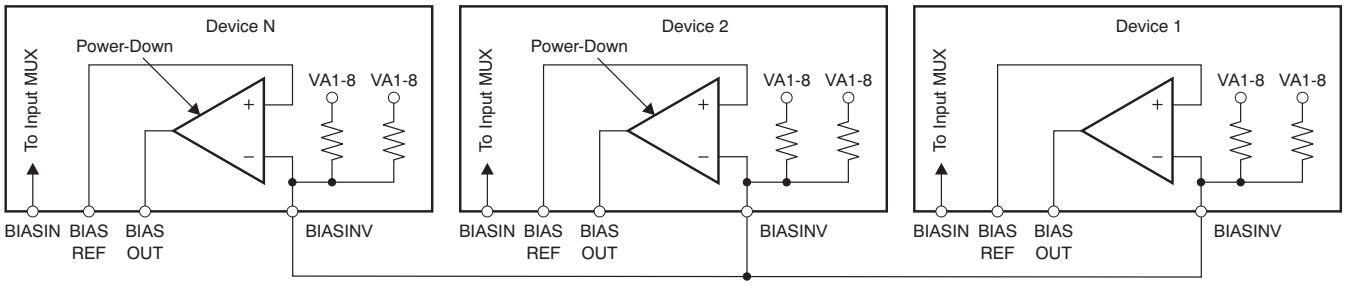

Figure 39. BIAS Drive Connection for Multiple Devices

9.4 Device Functional Modes

9.4.1 Start

Pull the START pin high for at least 2 t_{CLK} periods, or send the START command to begin conversions. When START is low and the START command has not been sent, the device does not issue a $\overline{DRDY}$ signal (conversions are halted).

When using the START command to control conversions, hold the START pin low. The ADS1299-x features two modes to control conversions: continuous mode and single-shot mode. The mode is selected by SINGLE_SHOT (bit 3 of the CONFIG4 register). In multiple device configurations, the START pin is used to synchronize devices (see the *Multiple Device Configuration* subsection of the *SPI Interface* section for more details).

9.4.1.1 Settling Time

The settling time (t_{SETTLE}) is the time required for the converter to output fully-settled data when the START signal is pulled high. When START is pulled high, $\overline{DRDY}$ is also pulled high. The next $\overline{DRDY}$ falling edge indicates that data are ready. Figure 40 shows the timing diagram and Table 7 lists the settling time for different data rates. The settling time depends on f_{CLK} and the decimation ratio (controlled by the DR[2:0] bits in the CONFIG1 register). When the initial settling time has passed, the $\overline{DRDY}$ falling edge occurs at the set data rate, t_{DR}. If data is not read back on DOUT and the output shift register needs to update, $\overline{DRDY}$ goes high for 4 t_{CLK} before returning back low indicating new data is ready. Table 7 lists the settling time as a function of t_{CLK}. Note that when START is held high and there is a step change in the input signal, 3 × t_{DR} is required for the filter to settle to the new value. Settled data are available on the fourth $\overline{DRDY}$ pulse.

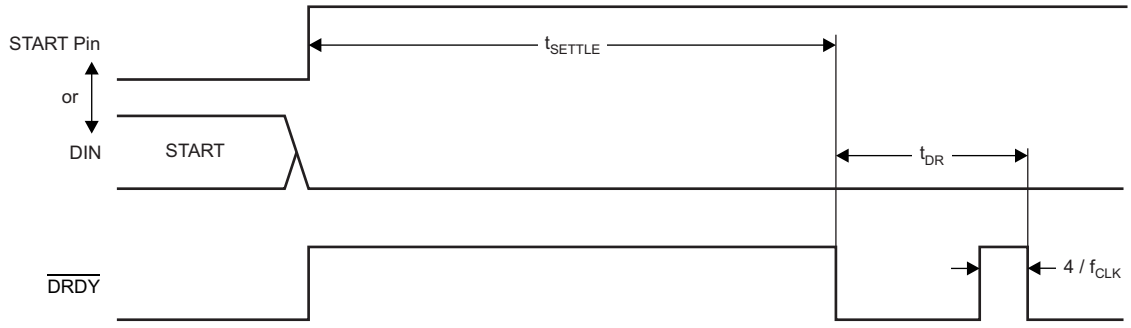

Figure 40. Settling Time

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Device Functional Modes (continued)

Table 7. Settling Time for Different Data Rates

DR[2:0]	NORMAL MODE	UNIT
000	521	t_{CLK}
001	1033	t_{CLK}
010	2057	t_{CLK}
011	4105	t_{CLK}
100	8201	t_{CLK}
101	16393	t_{CLK}
110	32777	t_{CLK}

9.4.2 Reset ($\overline{\text{RESET}}$)

There are two methods to reset the ADS1299-x: pull the $\overline{\text{RESET}}$ pin low, or send the RESET command. When using the $\overline{\text{RESET}}$ pin, make sure to follow the minimum pulse duration timing specifications before taking the pin back high. The RESET command takes effect on the eighth SCLK falling edge of the command. After a reset, 18 t_{CLK} cycles are required to complete initialization of the configuration registers to default states and start the conversion cycle. Note that an internal reset is automatically issued to the digital filter whenever the CONFIG1 register is set to a new value with a WREG command.

9.4.3 Power-Down ($\overline{\text{PWDN}}$)

When $\overline{\text{PWDN}}$ is pulled low, all on-chip circuitry is powered down. To exit power-down mode, take the $\overline{\text{PWDN}}$ pin high. Upon exiting from power-down mode, the internal oscillator and the reference require time to wake up. During power-down, the external clock is recommended to be shut down to save power.

9.4.4 Data Retrieval

9.4.4.1 Data Ready ($\overline{\text{DRDY}}$)

$\overline{\text{DRDY}}$ is an output signal which transitions from high to low indicating new conversion data are ready. The $\overline{\text{CS}}$ signal has no effect on the data ready signal. $\overline{\text{DRDY}}$ behavior is determined by whether the device is in RDATAC mode or the RDATA command is used to read data on demand. (See the *RDATAC: Read Data Continuous* and *RDATA: Read Data* subsections of the *SPI Command Definitions* section for further details).

When reading data with the RDATA command, the read operation can overlap the next $\overline{\text{DRDY}}$ occurrence without data corruption.

The START pin or the START command places the device either in normal data capture mode or pulse data capture mode.

Figure 41 shows the relationship between $\overline{\text{DRDY}}$, DOUT, and SCLK during data retrieval (in case of an ADS1299). DOUT is latched out at the SCLK rising edge. $\overline{\text{DRDY}}$ is pulled high at the SCLK falling edge. Note that $\overline{\text{DRDY}}$ goes high on the first SCLK falling edge, regardless of whether data are being retrieved from the device or a command is being sent through the DIN pin.

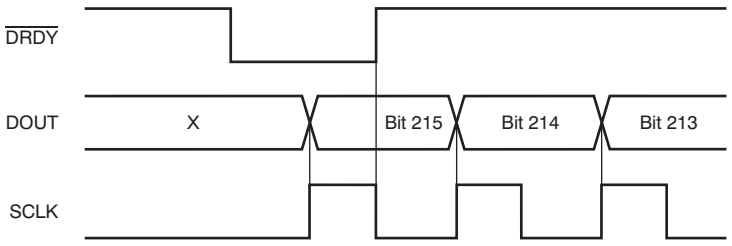


Figure 41. $\overline{\text{DRDY}}$ with Data Retrieval ($\overline{\text{CS}}$ = 0)

Device Functional Modes (continued)

9.4.4.2 Reading Back Data

Data retrieval can be accomplished in one of two methods:

1. RDATAC: the read data continuous command sets the device in a mode that reads data continuously without sending commands. See the *RDATAC: Read Data Continuous* section for more details.
2. RDATA: the read data command requires that a command is sent to the device to load the output shift register with the latest data. See the *RDATA: Read Data* section for more details.

Conversion data are read by shifting data out on DOUT. The MSB of the data on DOUT is clocked out on the first SCLK rising edge. DRDY returns high on the first SCLK falling edge. DIN should remain low for the entire read operation.

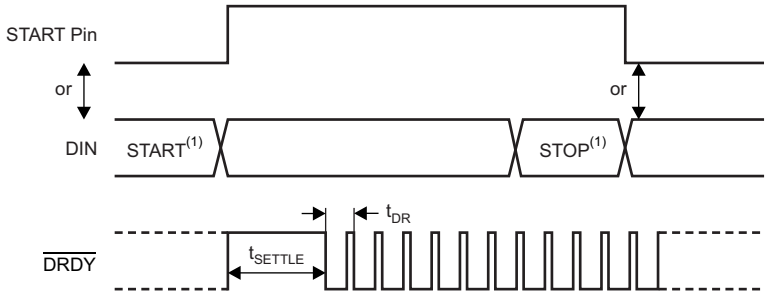
The number of bits in the data output depends on the number of channels and the number of bits per channel. For the 8-channel ADS1299, the number of data outputs is [(24 status bits + 24 bits × 8 channels) = 216 bits]. The format of the 24 status bits is: (1100 + LOFF_STATP + LOFF_STATN + bits[4:7] of the GPIO register). The data format for each channel data are twos complement and MSB first. When channels are powered down using the user register setting, the corresponding channel output is set to '0'. However, the channel output sequence remains the same.

The ADS1299-x also provides a multiple readback feature. Data can be read out multiple times by simply giving more SCLKs in RDATAC mode, in which case the MSB data byte repeats after reading the last byte. The DAISY_EN bit in the CONFIG1 register must be set to '1' for multiple readbacks.

9.4.5 Continuous Conversion Mode

Conversions begin when the START pin is taken high or when the START command is sent. As shown in Figure 42, the DRDY output goes high when conversions are started and goes low when data are ready. Conversions continue indefinitely until the START pin is taken low or the STOP command is transmitted. When the START pin is pulled low or the STOP command is issued, the conversion in progress is allowed to complete. Figure 43 and Table 8 illustrate the required DRDY timing to the START pin or the START and STOP commands when controlling conversions in this mode. The t_{SDSU} timing indicates when to take the START pin low or when to send the STOP command before the DRDY falling edge to halt further conversions. The t_{DSHD} timing indicates when to take the START pin low or send the STOP command after a DRDY falling edge to complete the current conversion and halt further conversions. To keep the converter running continuously, the START pin can be permanently tied high.

When switching from Single-Shot mode to Continuous Conversion mode, bring the START signal low and back high or send a STOP command followed by a START command. This conversion mode is ideal for applications that require a fixed continuous stream of conversions results.



(1) START and STOP commands take effect on the seventh SCLK falling edge.

Figure 42. Continuous Conversion Mode

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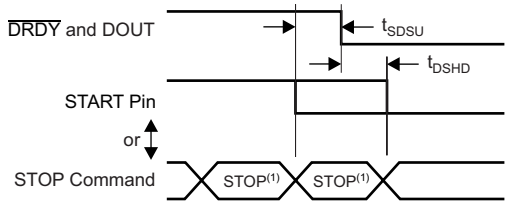
Device Functional Modes (continued)



(1) START and STOP commands take effect on the seventh SCLK falling edge at the end of the command.

Figure 43. START to DRDY Timing

Table 8. Timing Characteristics for Figure 43(1)

		MIN	UNIT
t_{SDSU}	START pin low or STOP command to DRDY setup time to halt further conversions	16	t_{CLK}
t_{DSHD}	START pin low or STOP command to complete current conversion	16	t_{CLK}

(1) START and STOP commands take effect on the seventh SCLK falling edge at the end of the command.

9.4.6 Single-Shot Mode

Single-shot mode is enabled by setting the SINGLE_SHOT bit in the CONFIG4 register to '1'. In single-shot mode, the ADS1299-x performs a single conversion when the START pin is taken high or when the START command is sent. As shown in Figure 44, when a conversion is complete, DRDY goes low and further conversions are stopped. Regardless of whether the conversion data are read or not, DRDY remains low. To begin a new conversion, take the START pin low and then back high, or send the START command again. When switching from Continuous Conversion mode to Single-Shot mode, bring the START signal low and back high or send a STOP command followed by a START command.

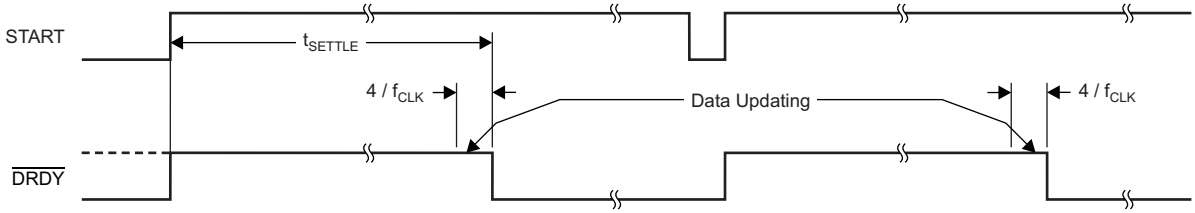


Figure 44. DRDY with No Data Retrieval in Single-Shot Mode

This conversion mode is ideal for applications that require non-standard or non-continuous data rates. Issuing a START command or toggling the START pin high resets the digital filter, effectively dropping the data rate by a factor of four. This mode leaves the system more susceptible to aliasing effects, requiring more complex analog or digital filtering. Loading on the host processor increases because the processor must toggle the START pin or send a START command to initiate a new conversion cycle.

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9.5 Programming

9.5.1 Data Format

The device provides 24 bits of data in binary twos complement format. The size of one code (LSB) is calculated using Equation 8.

$$1\ \text{LSB} = (2 \times V_{REF} / \text{Gain}) / 2^{24} = +\text{FS} / 2^{23} \quad (8)$$

A positive full-scale input produces an output code of 7FFFFFh and the negative full-scale input produces an output code of 800000h. The output clips at these codes for signals exceeding full-scale. Table 9 summarizes the ideal output codes for different input signals. All 24 bits toggle when the analog input is at positive or negative full-scale.

Table 9. Ideal Output Code versus Input Signal

INPUT SIGNAL, V_{IN} (INxP - INxN)	IDEAL OUTPUT CODE(1)
≥ FS	7FFFFFh
+FS / (2^{23} – 1)	000001h
0	000000h
–FS / (2^{23} – 1)	FFFFFFh
≤ –FS (2^{23} / 2^{23} – 1)	800000h

(1) Excludes effects of noise, linearity, offset, and gain error.

9.5.2 SPI Interface

The SPI-compatible serial interface consists of four signals: $\overline{CS}$, SCLK, DIN, and DOUT. The interface reads conversion data, reads and writes registers, and controls ADS1299-x operation. The data-ready output, $\overline{DRDY}$ (see the *Data Ready (DRDY)* section), is used as a status signal to indicate when data are ready. $\overline{DRDY}$ goes low when new data are available.

9.5.2.1 Chip Select ($\overline{CS}$)

The $\overline{CS}$ pin activates SPI communication. $\overline{CS}$ must be low before data transactions and must stay low for the entire SPI communication period. When $\overline{CS}$ is high, the DOUT pin enters a high-impedance state. Therefore, reading and writing to the serial interface are ignored and the serial interface is reset. $\overline{DRDY}$ pin operation is independent of $\overline{CS}$. $\overline{DRDY}$ still indicates that a new conversion has completed and is forced high as a response to SCLK, even if $\overline{CS}$ is high.

Taking $\overline{CS}$ high deactivates only the SPI communication with the device and the serial interface is reset. Data conversion continues and the $\overline{DRDY}$ signal can be monitored to check if a new conversion result is ready. A master device monitoring the $\overline{DRDY}$ signal can select the appropriate slave device by pulling the $\overline{CS}$ pin low. After the serial communication is finished, always wait four or more t_{CLK} cycles before taking $\overline{CS}$ high.

9.5.2.2 Serial Clock (SCLK)

SCLK provides the clock for serial communication. SCLK is a Schmitt-trigger input, but TI recommends keeping SCLK as free from noise as possible to prevent glitches from inadvertently shifting the data. Data are shifted into DIN on the falling edge of SCLK and shifted out of DOUT on the rising edge of SCLK.

The absolute maximum SCLK limit is specified in Figure 1. When shifting in commands with SCLK, make sure that the entire set of SCLKs is issued to the device. Failure to do so can result in the device serial interface being placed into an unknown state requiring $\overline{CS}$ to be taken high to recover.

For a single device, the minimum speed required for SCLK depends on the number of channels, number of bits of resolution, and output data rate. (For multiple cascaded devices, see the *Cascaded Mode* subsection of the *Multiple Device Configuration* section.)

For example, if the ADS1299 is used in a 500-SPS mode (8 channels, 24-bit resolution), the minimum SCLK speed is 110 kHz.

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Data retrieval can be accomplished either by placing the device in RDATAC mode or by issuing an RDATA command for data on demand. The SCLK rate limitation in Equation 9 applies to RDATAC. For the RDATA command, the limitation applies if data must be read in between two consecutive DRDY signals. Equation 9 assumes that there are no other commands issued in between data captures.

$$t_{SCLK} < \frac{t_{DR} - 4\,t_{CLK}}{N_{BITS} \times N_{CHANNELS} + 24} \quad (9)$$

9.5.2.3 Data Input (DIN)

DIN is used along with SCLK to send data to the device. Data on DIN are shifted into the device on the falling edge of SCLK.

The communication of this device is full-duplex in nature. The device monitors commands shifted in even when data are being shifted out. Data that are present in the output shift register are shifted out when sending in a command. Therefore, make sure that whatever is being sent on the DIN pin is valid when shifting out data. When no command is to be sent to the device when reading out data, send the NOP command on DIN. Make sure that the $t_{SDECODE}$ timing is met in the *Sending Multi-Byte Commands* section when sending multiple byte commands on DIN.

9.5.2.4 Data Output (DOUT)

DOUT is used with SCLK to read conversion and register data from the device. Data are clocked out on the rising edge of SCLK, MSB first. DOUT goes to a high-impedance state when $\overline{CS}$ is high. Figure 45 shows the ADS1299 data output protocol.

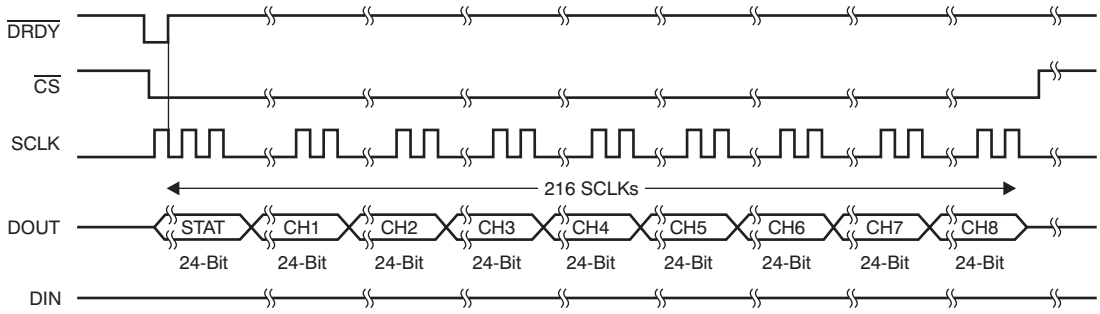

Figure 45. SPI Bus Data Output

9.5.3 SPI Command Definitions

The ADS1299-x provides flexible configuration control. The commands, summarized in Table 10, control and configure device operation. The commands are stand-alone, except for the register read and write operations that require a second command byte plus data. $\overline{CS}$ can be taken high or held low between commands but must stay low for the entire command operation (especially for multi-byte commands). System commands and the RDATA command are decoded by the device on the seventh SCLK falling edge. The register read and write commands are decoded on the eighth SCLK falling edge. Be sure to follow SPI timing requirements when pulling $\overline{CS}$ high after issuing a command.

Table 10. Command Definitions

COMMAND	DESCRIPTION	FIRST BYTE	SECOND BYTE
System Commands			
WAKEUP	Wake-up from standby mode	0000 0010 (02h)	
STANDBY	Enter standby mode	0000 0100 (04h)	
RESET	Reset the device	0000 0110 (06h)	
START	Start and restart (synchronize) conversions	0000 1000 (08h)	
STOP	Stop conversion	0000 1010 (0Ah)	
Data Read Commands			
RDATAC	Enable Read Data Continuous mode. This mode is the default mode at power-up.(1)	0001 0000 (10h)	
SDATAC	Stop Read Data Continuously mode	0001 0001 (11h)	
RDATA	Read data by command; supports multiple read back.	0001 0010 (12h)	
Register Read Commands			
RREG	Read *n nnnn* registers starting at address *r rrrr*	001*r rrrr* (2xh)(2)	000*n nnnn*(2)
WREG	Write *n nnnn* registers starting at address *r rrrr*	010*r rrrr* (4xh)(2)	000*n nnnn*(2)

(1) When in RDATAC mode, the RREG command is ignored.
(2) *n nnnn* = number of registers to be read or written – 1. For example, to read or write three registers, set *n nnnn* = 0 (0010). *r rrrr* = starting register address for read or write commands.

9.5.3.1 Sending Multi-Byte Commands

The ADS1299-x serial interface decodes commands in bytes and requires 4 t_{CLK} cycles to decode and execute. Therefore, when sending multi-byte commands (such as RREG or WREG), a 4 t_{CLK} period must separate the end of one byte (or command) and the next.

Assuming CLK is 2.048 MHz, then $t_{SDECODE}$ (4 t_{CLK}) is 1.96 µs. When SCLK is 16 MHz, one byte can be transferred in 500 ns. This byte transfer time does not meet the $t_{SDECODE}$ specification; therefore, a delay must be inserted so the end of the second byte arrives 1.46 µs later. If SCLK is 4 MHz, one byte is transferred in 2 µs. Because this transfer time exceeds the $t_{SDECODE}$ specification, the processor can send subsequent bytes without delay. In this later scenario, the serial port can be programmed to move from single-byte transfers per cycle to multiple bytes.

9.5.3.2 WAKEUP: Exit STANDBY Mode

The WAKEUP command exits low-power standby mode; see the *STANDBY: Enter STANDBY Mode* subsection of the *SPI Command Definitions* section. Time is required when exiting standby mode (see the *Electrical Characteristics* for details). **There are no SCLK rate restrictions for this command and can be issued at any time.** Any following commands must be sent after a delay of 4 t_{CLK} cycles.

9.5.3.3 STANDBY: Enter STANDBY Mode

The STANDBY command enters low-power standby mode. All parts of the circuit are shut down except for the reference section. The standby mode power consumption is specified in the *Electrical Characteristics*. **There are no SCLK rate restrictions for this command and can be issued at any time.** Do not send any other commands other than the wakeup command after the device enters standby mode.

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9.5.3.4 RESET: Reset Registers to Default Values

The RESET command resets the digital filter cycle and returns all register settings to default values. See the *Reset (RESET)* subsection of the *SPI Interface* section for more details. **There are no SCLK rate restrictions for this command and can be issued at any time.** 18 t_{CLK} cycles are required to execute the RESET command. Avoid sending any commands during this time.

9.5.3.5 START: Start Conversions

The START command starts data conversions. Tie the START pin low to control conversions by command. If conversions are in progress, this command has no effect. The STOP command stops conversions. If the START command is immediately followed by a STOP command, then there must be a 4-t_{CLK} cycle delay between them. When the START command is sent to the device, keep the START pin low until the STOP command is issued. (See the *Start* subsection of the *SPI Interface* section for more details.) **There are no SCLK rate restrictions for this command and can be issued at any time.**

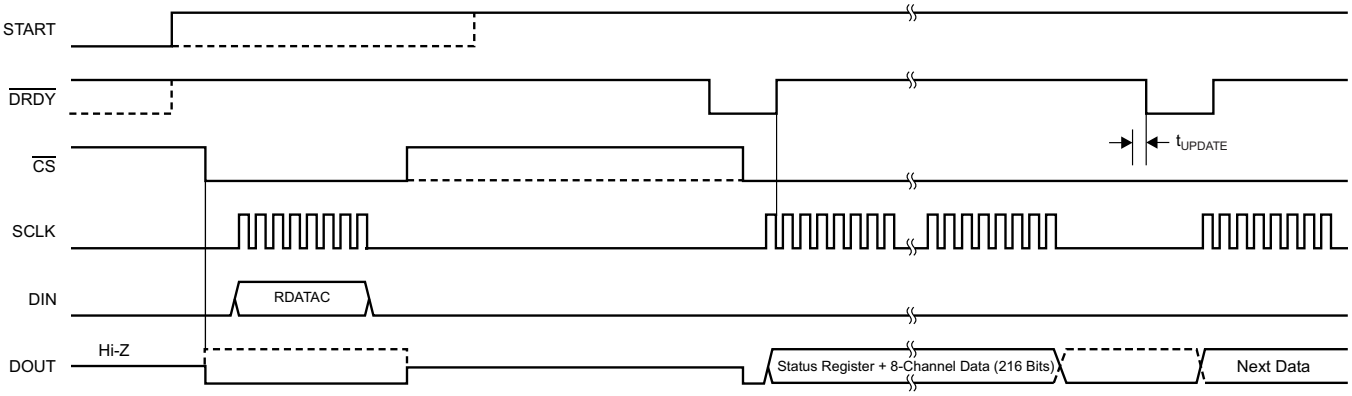
9.5.3.6 STOP: Stop Conversions

The STOP command stops conversions. Tie the START pin low to control conversions by command. When the STOP command is sent, the conversion in progress completes and further conversions are stopped. If conversions are already stopped, this command has no effect. **There are no SCLK rate restrictions for this command and can be issued at any time.**

9.5.3.7 RDATAC: Read Data Continuous

The RDATAC command enables conversion data output on each $\overline{\text{DRDY}}$ without the need to issue subsequent read data commands. This mode places the conversion data in the output register and may be shifted out directly. The read data continuous mode is the device default mode; the device defaults to this mode on power-up.

RDATAC mode is cancelled by the Stop Read Data Continuous command. If the device is in RDATAC mode, a SDATAC command must be issued before any other commands can be sent to the device. **There are no SCLK rate restrictions for this command.** However, subsequent data retrieval SCLKs or the SDATAC command should wait at least 4 t_{CLK} cycles before completion (see the *Sending Multi-Byte Commands* section). RDATAC timing is illustrated in Figure 46. As depicted in Figure 46, there is a *keep out* zone of 4 t_{CLK} cycles around the $\overline{\text{DRDY}}$ pulse where this command cannot be issued in. If no data are retrieved from the device, DOUT and $\overline{\text{DRDY}}$ behave similarly in this mode. To retrieve data from the device after the RDATAC command is issued, make sure either the START pin is high or the START command is issued. Figure 46 shows the recommended way to use the RDATAC command. RDATAC is ideally-suited for applications such as data loggers or recorders, where registers are set one time and do not need to be reconfigured.



(1) $t_{UPDATE} = 4 / f_{CLK}$. Do not read data during this time.

Figure 46. RDATAC Usage

9.5.3.8 SDATAC: Stop Read Data Continuous

The SDATAC command cancels the Read Data Continuous mode. **There are no SCLK rate restrictions for this command, but the next command must wait for 4 t_{CLK} cycles before completion.**

9.5.3.9 RDATA: Read Data

The RDATA command loads the output shift register with the latest data when not in Read Data Continuous mode. Issue this command after $\overline{\text{DRDY}}$ goes low to read the conversion result. There are no SCLK rate restrictions for this command, and there is no wait time needed for the subsequent commands or data retrieval SCLKs. To retrieve data from the device after the RDATA command is issued, make sure either the START pin is high or the START command is issued. When reading data with the RDATA command, the read operation can overlap the next $\overline{\text{DRDY}}$ occurrence without data corruption. Figure 47 shows the recommended way to use the RDATA command. RDATA is best suited for ECG- and EEG-type systems, where register settings must be read or changed often between conversion cycles.

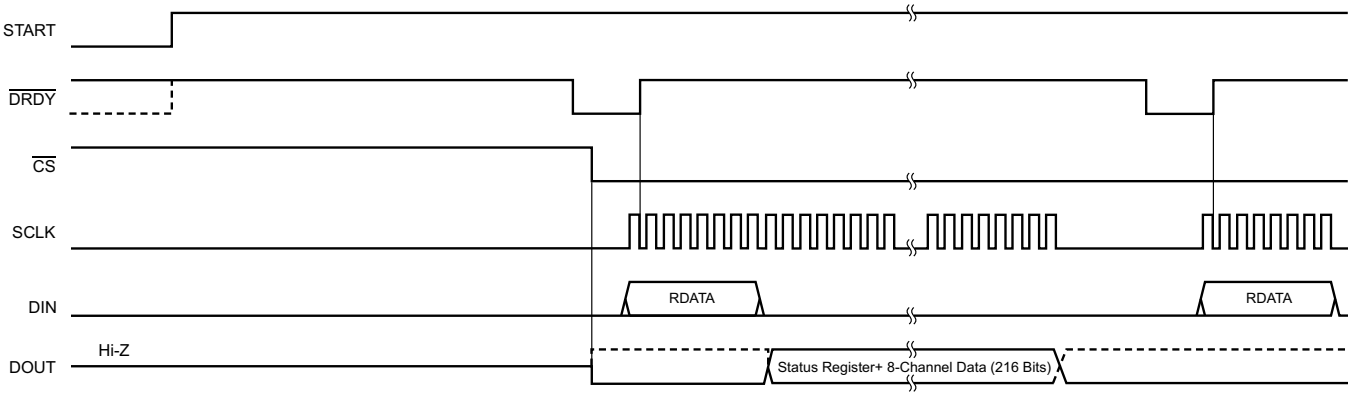


Figure 47. RDATA Usage

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9.5.3.10 RREG: Read From Register

This command reads register data. The Register Read command is a two-byte command followed by the register data output. The first byte contains the command and register address. The second command byte specifies the number of registers to read – 1.

First command byte: 001*r rrrr*, where *r rrrr* is the starting register address.

Second command byte: 000*n nnnn*, where *n nnnn* is the number of registers to read – 1.

The 17th SCLK rising edge of the operation clocks out the MSB of the first register, as shown in Figure 48. When the device is in read data continuous mode, an SDATAC command must be issued before the RREG command can be issued. The RREG command can be issued any time. However, because this command is a multi-byte command, there are SCLK rate restrictions depending on how the SCLKs are issued to meet the $t_{SDECODE}$ timing. See the *Serial Clock (SCLK)* subsection of the *SPI Interface* section for more details. Note that $\overline{CS}$ must be low for the entire command.

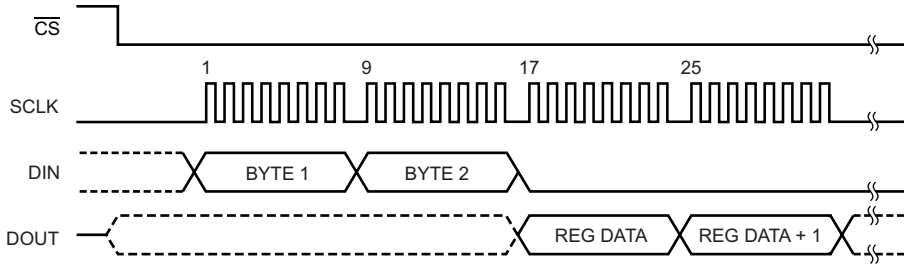

Figure 48. RREG Command Example: Read Two Registers Starting from Register 00h (ID Register) (BYTE 1 = 0010 0000, BYTE 2 = 0000 0001)

9.5.3.11 WREG: Write to Register

This command writes register data. The Register Write command is a two-byte command followed by the register data input. The first byte contains the command and register address. The second command byte specifies the number of registers to write – 1.

First command byte: 010*r rrrr*, where *r rrrr* is the starting register address.

Second command byte: 000*n nnnn*, where *n nnnn* is the number of registers to write – 1.

After the command bytes, the register data follows (in MSB-first format), as shown in Figure 49. The WREG command can be issued any time. However, because this command is a multi-byte command, there are SCLK rate restrictions depending on how the SCLKs are issued to meet the $t_{SDECODE}$ timing. See the *Serial Clock (SCLK)* subsection of the *SPI Interface* section for more details. Note that $\overline{CS}$ must be low for the entire command.

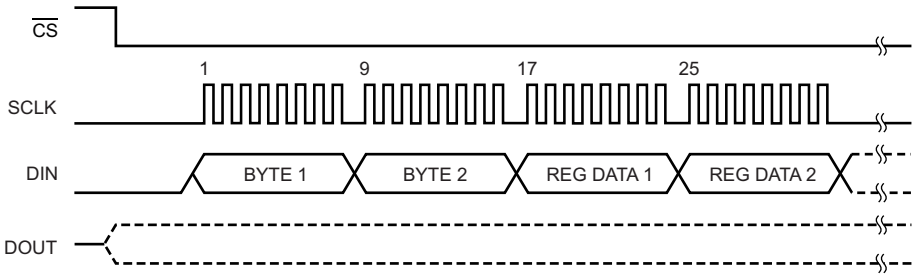

Figure 49. WREG Command Example: Write Two Registers Starting from 00h (ID Register) (BYTE 1 = 0100 0000, BYTE 2 = 0000 0001)

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9.6 Register Maps

Table 11 describes the various ADS1299-x registers.

Table 11. Register Assignments

ADDRESS	REGISTER	DEFAULT SETTING	REGISTER BITS							
			7	6	5	4	3	2	1	0
Read Only ID Registers										
00h	ID	xxh	REV_ID[2:0]			1	DEV_ID[1:0]		NU_CH[1:0]	
Global Settings Across Channels										
01h	CONFIG1	96h	1	$\overline{\text{DAISY_EN}}$	CLK_EN	1	0	DR[2:0]		
02h	CONFIG2	C0h	1	1	0	INT_CAL	0	CAL_AMP0	CAL_FREQ[1:0]	
03h	CONFIG3	60h	$\overline{\text{PD_REFBUF}}$	1	1	BIAS_MEAS	BIASREF_INT	$\overline{\text{PD_BIAS}}$	BIAS_LOFF_SENS	BIAS_STAT
04h	LOFF	00h	COMP_TH[2:0]			0	ILEAD_OFF[1:0]		FLEAD_OFF[1:0]	
Channel-Specific Settings										
05h	CH1SET	61h	PD1	GAIN1[2:0]			SRB2	MUX1[2:0]		
06h	CH2SET	61h	PD2	GAIN2[2:0]			SRB2	MUX2[2:0]		
07h	CH3SET	61h	PD3	GAIN3[2:0]			SRB2	MUX3[2:0]		
08h	CH4SET	61h	PD4	GAIN4[2:0]			SRB2	MUX4[2:0]		
09h	CH5SET (1)	61h	PD5	GAIN5[2:0]			SRB2	MUX5[2:0]		
0Ah	CH6SET (1)	61h	PD6	GAIN6[2:0]			SRB2	MUX6[2:0]		
0Bh	CH7SET (2)	61h	PD7	GAIN7[2:0]			SRB2	MUX7[2:0]		
0Ch	CH8SET (2)	61h	PD8	GAIN8[2:0]			SRB2	MUX8[2:0]		
0Dh	BIAS_SENSP	00h	BIASP8(2)	BIASP7(2)	BIASP6(1)	BIASP5(1)	BIASP4	BIASP3	BIASP2	BIASP1
0Eh	BIAS_SENSN	00h	BIASN8(2)	BIASN7(2)	BIASN6(1)	BIASN5(1)	BIASN4	BIASN3	BIASN2	BIASN1
0Fh	LOFF_SENSP	00h	LOFFP8(2)	LOFFP7(2)	LOFFP6(1)	LOFFP5(1)	LOFFP4	LOFFP3	LOFFP2	LOFFP1
10h	LOFF_SENSN	00h	LOFFM8(2)	LOFFM7(2)	LOFFM6(1)	LOFFM5(1)	LOFFM4	LOFFM3	LOFFM2	LOFFM1
11h	LOFF_FLIP	00h	LOFF_FLIP8(2)	LOFF_FLIP7(2)	LOFF_FLIP6(1)	LOFF_FLIP5(1)	LOFF_FLIP4	LOFF_FLIP3	LOFF_FLIP2	LOFF_FLIP1
Lead-Off Status Registers (Read-Only Registers)										
12h	LOFF_STATP	00h	IN8P_OFF	IN7P_OFF	IN6P_OFF	IN5P_OFF	IN4P_OFF	IN3P_OFF	IN2P_OFF	IN1P_OFF
13h	LOFF_STATN	00h	IN8M_OFF	IN7M_OFF	IN6M_OFF	IN5M_OFF	IN4M_OFF	IN3M_OFF	IN2M_OFF	IN1M_OFF
GPIO and OTHER Registers										
14h	GPIO	0Fh	GPIOD[4:1]				GPIOC[4:1]			
15h	MISC1	00h	0	0	SRB1	0	0	0	0	0
16h	MISC2	00h	0	0	0	0	0	0	0	0
17h	CONFIG4	00h	0	0	0	0	SINGLE_SHOT	0	$\overline{\text{PD_LOFF_COMP}}$	0

(1) Register or bit only available in the ADS1299-6 and ADS1299. Register bits set to 0h or 00h in the ADS1299-4.
(2) Register or bit only available in the ADS1299. Register bits set to 0h or 00h in the ADS1299-4 and ADS1299-6.

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9.6.1 User Register Description

The read-only ID control register is programmed during device manufacture to indicate device characteristics.

9.6.1.1 ID: ID Control Register (address = 00h) (reset = xxh)

Figure 50. ID Control Register

7	6	5	4	3	2	1	0
REV_ID[2:0]			1	DEV_ID[1:0]		NU_CH[1:0]	
R-xh			R-1h	R-3h		R-xh	

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 12. ID Control Register Field Descriptions

Bit	Field	Type	Reset	Description
7:5	REV_ID[2:0]	R	xh	**Reserved.** These bits indicate the revision of the device and are subject to change without notice.
4	Reserved	R	1h	**Reserved.** Always read 1.
3:2	DEV_ID[1:0]	R	3h	**Device Identification.** These bits indicates the device. 11 : ADS1299-x
1:0	NU_CH[1:0]	R	xh	**Number of Channels.** These bits indicates number of channels. 00 : 4-channel ADS1299-4 01 : 6-channel ADS1299-6 10 : 8-channel ADS1299

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9.6.1.2 CONFIG1: Configuration Register 1 (address = 01h) (reset = 96h)

This register configures the $\overline{\text{DAISY_EN}}$ bit, clock, and data rate.

Figure 51. CONFIG1: Configuration Register 1

7	6	5	4	3	2	1	0
1	$\overline{\text{DAISY_EN}}$	CLK_EN	1	0	DR[2:0]		
R/W-1h	R/W-0h	R/W-0h	R/W-1h	R/W-0h	R/W-6h		

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 13. Configuration Register 1 Field Descriptions

Bit	Field	Type	Reset	Description
7	Reserved	R/W	1h	**Reserved** Always write 1h
6	$\overline{\text{DAISY_EN}}$	R/W	0h	**Daisy-chain or multiple readback mode** This bit determines which mode is enabled. 0 : Daisy-chain mode 1 : Multiple readback mode
5	CLK_EN	R/W	0h	**CLK connection**(1) This bit determines if the internal oscillator signal is connected to the CLK pin when the CLKSEL pin = 1. 0 : Oscillator clock output disabled 1 : Oscillator clock output enabled
4:3	Reserved	R/W	2h	**Reserved** Always write 2h
2:0	DR[2:0]	R/W	6h	**Output data rate** These bits determine the output data rate of the device. $f_{MOD} = f_{CLK} / 2$. 000 : f_{MOD} / 64 (16 kSPS) 001 : f_{MOD} / 128 (8 kSPS) 010 : f_{MOD} / 256 (4 kSPS) 011 : f_{MOD} / 512 (2 kSPS) 100 : f_{MOD} / 1024 (1 kSPS) 101 : f_{MOD} / 2048 (500 SPS) 110 : f_{MOD} / 4096 (250 SPS) 111 : Reserved (do not use)

(1) Additional power is consumed when driving external devices.

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9.6.1.3 CONFIG2: Configuration Register 2 (address = 02h) (reset = C0h)

This register configures the test signal generation. See the *Input Multiplexer* section for more details.

Figure 52. CONFIG2: Configuration Register 2

7	6	5	4	3	2	1	0
1	1	0	INT_CAL	0	CAL_AMP	CAL_FREQ[1:0]	
R/W-1h	R/W-1h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 14. Configuration Register 2 Field Descriptions

Bit	Field	Type	Reset	Description
7:5	Reserved	R/W	6h	**Reserved** Always write 6h
4	INT_CAL	R/W	0h	**TEST source** This bit determines the source for the test signal. 0 : Test signals are driven externally 1 : Test signals are generated internally
3	Reserved	R/W	0h	**Reserved** Always write 0h
2	CAL_AMP	R/W	0h	**Test signal amplitude** These bits determine the calibration signal amplitude. 0 : 1 × –(VREFP – VREFN) / 2400 1 : 2 × –(VREFP – VREFN) / 2400
1:0	CAL_FREQ[1:0]	R/W	0h	**Test signal frequency** These bits determine the calibration signal frequency. 00 : Pulsed at f_{CLK} / 2^{21} 01 : Pulsed at f_{CLK} / 2^{20} 10 : Do not use 11 : At dc

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9.6.1.4 CONFIG3: Configuration Register 3 (address = 03h) (reset = 60h)

Configuration register 3 configures either an internal or exteral reference and BIAS operation.

Figure 53. CONFIG3: Configuration Register 3

7	6	5	4	3	2	1	0
$\overline{\text{PD_REFBUF}}$	1	1	BIAS_MEAS	BIASREF_INT	$\overline{\text{PD_BIAS}}$	BIAS_LOFF_SENS	BIAS_STAT
R/W-0h	R/W-1h	R/W-1h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 15. Configuration Register 3 Field Descriptions

Bit	Field	Type	Reset	Description
7	$\overline{\text{PD_REFBUF}}$	R/W	0h	**Power-down reference buffer** This bit determines the power-down reference buffer state. 0 : Power-down internal reference buffer 1 : Enable internal reference buffer
6:5	Reserved	R/W	3h	**Reserved** Always write 3h.
4	BIAS_MEAS	R/W	0h	**BIAS measurement** This bit enables BIAS measurement. The BIAS signal may be measured with any channel. 0 : Open 1 : BIAS_IN signal is routed to the channel that has the MUX_Setting *010* (V_{REF})
3	BIASREF_INT	R/W	0h	**BIASREF signal** This bit determines the BIASREF signal source. 0 : BIASREF signal fed externally 1 : BIASREF signal (AVDD + AVSS) / 2 generated internally
2	$\overline{\text{PD_BIAS}}$	R/W	0h	**BIAS buffer power** This bit determines the BIAS buffer power state. 0 : BIAS buffer is powered down 1 : BIAS buffer is enabled
1	BIAS_LOFF_SENS	R/W	0h	**BIAS sense function** This bit enables the BIAS sense function. 0 : BIAS sense is disabled 1 : BIAS sense is enabled
0	BIAS_STAT	R	0h	**BIAS lead-off status** This bit determines the BIAS status. 0 : BIAS is connected 1 : BIAS is not connected

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9.6.1.5 LOFF: Lead-Off Control Register (address = 04h) (reset = 00h)

The lead-off control register configures the lead-off detection operation.

Figure 54. LOFF: Lead-Off Control Register

7	6	5	4	3	2	1	0
COMP_TH2[2:0]			0	ILEAD_OFF[1:0]		FLEAD_OFF[1:0]	
R/W-0h			R/W-0h	R/W-0h		R/W-0h	

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 16. Lead-Off Control Register Field Descriptions

Bit	Field	Type	Reset	Description
7:5	COMP_TH[2:0]	R/W	0h	**Lead-off comparator threshold** Comparator positive side 000 : 95% 001 : 92.5% 010 : 90% 011 : 87.5% 100 : 85% 101 : 80% 110 : 75% 111 : 70% Comparator negative side 000 : 5% 001 : 7.5% 010 : 10% 011 : 12.5% 100 : 15% 101 : 20% 110 : 25% 111 : 30%
4	Reserved	R/W	0h	**Reserved** Always write 0h.
3:2	ILEAD_OFF[1:0]	R/W	0h	**Lead-off current magnitude** These bits determine the magnitude of current for the current lead-off mode. 00 : 6 nA 01 : 24 nA 10 : 6 µA 11 : 24 µA
1:0	FLEAD_OFF[1:0]	R/W	0h	**Lead-off frequency** These bits determine the frequency of lead-off detect for each channel. 00 : DC lead-off detection 01 : AC lead-off detection at 7.8 Hz (f_{CLK} / 2^{18}) 10 : AC lead-off detection at 31.2 Hz (f_{CLK} / 2^{16}) 11 : AC lead-off detection at f_{DR} / 4

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9.6.1.6 CHnSET: Individual Channel Settings (n = 1 to 8) (address = 05h to 0Ch) (reset = 61h)

The CH[1:8]SET control register configures the power mode, PGA gain, and multiplexer settings channels. See the *Input Multiplexer* section for details. CH[2:8]SET are similar to CH1SET, corresponding to the respective channels.

Figure 55. CHnSET: Individual Channel Settings Register

7	6	5	4	3	2	1	0
PD*n*	GAIN*n*[2:0]			SRB2	MUX*n*[2:0]		
R/W-0h	R/W-6h			R/W-0h	R/W-0h		

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 17. Individual Channel Settings (*n* = 1 to 8) Field Descriptions

Bit	Field	Type	Reset	Description
7	PD*n*	R/W	0h	**Power-down** This bit determines the channel power mode for the corresponding channel. 0 : Normal operation 1 : Channel power-down. When powering down a channel, TI recommends that the channel be set to input short by setting the appropriate MUXn[2:0] = 001 of the CHnSET register.
6:4	GAIN*n*[2:0]	R/W	6h	**PGA gain** These bits determine the PGA gain setting. 000 : 1 001 : 2 010 : 4 011 : 6 100 : 8 101 : 12 110 : 24 111 : Do not use
3	SRB2	R/W	0h	**SRB2 connection** This bit determines the SRB2 connection for the corresponding channel. 0 : Open 1 : Closed
2:0	MUX*n*[2:0]	R/W	1h	**Channel input** These bits determine the channel input selection. 000 : Normal electrode input 001 : Input shorted (for offset or noise measurements) 010 : Used in conjunction with BIAS_MEAS bit for BIAS measurements. 011 : MVDD for supply measurement 100 : Temperature sensor 101 : Test signal 110 : BIAS_DRP (positive electrode is the driver) 111 : BIAS_DRN (negative electrode is the driver)

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9.6.1.7 BIAS_SENSP: Bias Drive Positive Derivation Register (address = 0Dh) (reset = 00h)

This register controls the selection of the positive signals from each channel for bias voltage (BIAS) derivation. See the *Bias Drive (DC Bias Circuit)* section for details.

Registers bits[5:4] are not available for the ADS1299-4. Register bits[7:6] are not available for the ADS1299-4, or ADS1299-6. Set unavailable bits for the associated device to 0 when writing to the register.

Figure 56. BIAS_SENSP: BIAS Positive Signal Derivation Register

7	6	5	4	3	2	1	0
BIASP8	BIASP7	BIASP6	BIASP5	BIASP4	BIASP3	BIASP2	BIASP1
R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 18. BIAS Positive Signal Derivation Field Descriptions

Bit	Field	Type	Reset	Description
7	BIASP8	R/W	0h	**IN8P to BIAS** Route channel 8 positive signal into BIAS derivation 0 : Disabled 1 : Enabled
6	BIASP7	R/W	0h	**IN7P to BIAS** Route channel 7 positive signal into BIAS derivation 0 : Disabled 1 : Enabled
5	BIASP6	R/W	0h	**IN6P to BIAS** Route channel 6 positive signal into BIAS derivation 0 : Disabled 1 : Enabled
4	BIASP5	R/W	0h	**IN5P to BIAS** Route channel 5 positive signal into BIAS derivation 0 : Disabled 1 : Enabled
3	BIASP4	R/W	0h	**IN4P to BIAS** Route channel 4 positive signal into BIAS derivation 0 : Disabled 1 : Enabled
2	BIASP3	R/W	0h	**IN3P to BIAS** Route channel 3 positive signal into BIAS derivation 0 : Disabled 1 : Enabled
1	BIASP2	R/W	0h	**IN2P to BIAS** Route channel 2 positive signal into BIAS channel 0 : Disabled 1 : Enabled
0	BIASP1	R/W	0h	**IN1P to BIAS** Route channel 1 positive signal into BIAS channel 0 : Disabled 1 : Enabled

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9.6.1.8 BIAS_SENSN: Bias Drive Negative Derivation Register (address = 0Eh) (reset = 00h)

This register controls the selection of the negative signals from each channel for bias voltage (BIAS) derivation. See the *Bias Drive (DC Bias Circuit)* section for details.

Registers bits[5:4] are not available for the ADS1299-4. Register bits[7:6] are not available for the ADS1299-4, or ADS1299-6. Set unavailable bits for the associated device to 0 when writing to the register.

Figure 57. BIAS_SENSN: BIAS Negative Signal Derivation Register

7	6	5	4	3	2	1	0
BIASN8	BIASN7	BIASN6	BIASN5	BIASN4	BIASN3	BIASN2	BIASN1
R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 19. BIAS Negative Signal Derivation Field Descriptions

Bit	Field	Type	Reset	Description
7	BIASN8	R/W	0h	**IN8N to BIAS** Route channel 8 negative signal into BIAS derivation 0 : Disabled 1 : Enabled
6	BIASN7	R/W	0h	**IN7N to BIAS** Route channel 7 negative signal into BIAS derivation 0 : Disabled 1 : Enabled
5	BIASN6	R/W	0h	**IN6N to BIAS** Route channel 6 negative signal into BIAS derivation 0 : Disabled 1 : Enabled
4	BIASN5	R/W	0h	**IN5N to BIAS** Route channel 5 negative signal into BIAS derivation 0 : Disabled 1 : Enabled
3	BIASN4	R/W	0h	**IN4N to BIAS** Route channel 4 negative signal into BIAS derivation 0 : Disabled 1 : Enabled
2	BIASN3	R/W	0h	**IN3N to BIAS** Route channel 3 negative signal into BIAS derivation 0 : Disabled 1 : Enabled
1	BIASN2	R/W	0h	**IN2N to BIAS** Route channel 2 negative signal into BIAS derivation 0 : Disabled 1 : Enabled
0	BIASN1	R/W	0h	**IN1N to BIAS** Route channel 1 negative signal into BIAS derivation 0 : Disabled 1 : Enabled

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9.6.1.9 LOFF_SENSP: Positive Signal Lead-Off Detection Register (address = 0Fh) (reset = 00h)

This register selects the positive side from each channel for lead-off detection. See the *Lead-Off Detection* section for details. The LOFF_STATP register bits are only valid if the corresponding LOFF_SENSP bits are set to 1.

Registers bits[5:4] are not available for the ADS1299-4. Register bits[7:6] are not available for the ADS1299-4, or ADS1299-6. Set unavailable bits for the associated device to 0 when writing to the register.

Figure 58. LOFF_SENSP: Positive Signal Lead-Off Detection Register

7	6	5	4	3	2	1	0
LOFFP8	LOFFP7	LOFFP6	LOFFP5	LOFFP4	LOFFP3	LOFFP2	LOFFP1
R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 20. Positive Signal Lead-Off Detection Field Descriptions

Bit	Field	Type	Reset	Description
7	LOFFP8	R/W	0h	**IN8P lead off** Enable lead-off detection on IN8P 0 : Disabled 1 : Enabled
6	LOFFP7	R/W	0h	**IN7P lead off** Enable lead-off detection on IN7P 0 : Disabled 1 : Enabled
5	LOFFP6	R/W	0h	**IN6P lead off** Enable lead-off detection on IN6P 0 : Disabled 1 : Enabled
4	LOFFP5	R/W	0h	**IN5P lead off** Enable lead-off detection on IN5P 0 : Disabled 1 : Enabled
3	LOFFP4	R/W	0h	**IN4P lead off** Enable lead-off detection on IN4P 0 : Disabled 1 : Enabled
2	LOFFP3	R/W	0h	**IN3P lead off** Enable lead-off detection on IN3P 0 : Disabled 1 : Enabled
1	LOFFP2	R/W	0h	**IN2P lead off** Enable lead-off detection on IN2P 0 : Disabled 1 : Enabled
0	LOFFP1	R/W	0h	**IN1P lead off** Enable lead-off detection on IN1P 0 : Disabled 1 : Enabled

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9.6.1.10 LOFF_SENSN: Negative Signal Lead-Off Detection Register (address = 10h) (reset = 00h)

This register selects the negative side from each channel for lead-off detection. See the *Lead-Off Detection* section for details. The LOFF_STATN register bits are only valid if the corresponding LOFF_SENSN bits are set to 1.

Registers bits[5:4] are not available for the ADS1299-4. Register bits[7:6] are not available for the ADS1299-4, or ADS1299-6. Set unavailable bits for the associated device to 0 when writing to the register.

Figure 59. LOFF_SENSN: Negative Signal Lead-Off Detection Register

7	6	5	4	3	2	1	0
LOFFM8	LOFFM7	LOFFM6	LOFFM5	LOFFM4	LOFFM3	LOFFM2	LOFFM1
R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 21. Negative Signal Lead-Off Detection Field Descriptions

Bit	Field	Type	Reset	Description
7	LOFFM8	R/W	0h	**IN8N lead off** Enable lead-off detection on IN8N 0 : Disabled 1 : Enabled
6	LOFFM7	R/W	0h	**IN7N lead off** Enable lead-off detection on IN7N 0 : Disabled 1 : Enabled
5	LOFFM6	R/W	0h	**IN6N lead off** Enable lead-off detection on IN6N 0 : Disabled 1 : Enabled
4	LOFFM5	R/W	0h	**IN5N lead off** Enable lead-off detection on IN5N 0 : Disabled 1 : Enabled
3	LOFFM4	R/W	0h	**IN4N lead off** Enable lead-off detectionn on IN4N 0 : Disabled 1 : Enabled
2	LOFFM3	R/W	0h	**IN3N lead off** Enable lead-off detectionion on IN3N 0 : Disabled 1 : Enabled
1	LOFFM2	R/W	0h	**IN2N lead off** Enable lead-off detectionction on IN2N 0 : Disabled 1 : Enabled
0	LOFFM1	R/W	0h	**IN1N lead off** Enable lead-off detectionction on IN1N 0 : Disabled 1 : Enabled

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9.6.1.11 LOFF_FLIP: Lead-Off Flip Register (address = 11h) (reset = 00h)

This register controls the direction of the current used for lead-off derivation. See the *Lead-Off Detection* section for details.

Figure 60. LOFF_FLIP: Lead-Off Flip Register

7	6	5	4	3	2	1	0
LOFF_FLIP8	LOFF_FLIP7	LOFF_FLIP6	LOFF_FLIP5	LOFF_FLIP4	LOFF_FLIP3	LOFF_FLIP2	LOFF_FLIP1
R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 22. Lead-Off Flip Register Field Descriptions

Bit	Field	Type	Reset	Description
7	LOFF_FLIP8	R/W	0h	**Channel 8 LOFF polarity flip** Flip the pull-up or pull-down polarity of the current source on channel 8 for lead-off detection. 0 : No flip = IN8P is pulled to AVDD and IN8N pulled to AVSS 1 : Flipped = IN8P is pulled to AVSS and IN8N pulled to AVDD
6	LOFF_FLIP7	R/W	0h	**Channel 7 LOFF polarity flip** Flip the pull-up or pull-down polarity of the current source on channel 7 for lead-off detection. 0 : No flip = IN7P is pulled to AVDD and IN7N pulled to AVSS 1 : Flipped = IN7P is pulled to AVSS and IN7N pulled to AVDD
5	LOFF_FLIP6	R/W	0h	**Channel 6 LOFF polarity flip** Flip the pull-up or pull-down polarity of the current source on channel 6 for lead-off detection. 0 : No flip = IN6P is pulled to AVDD and IN6N pulled to AVSS 1 : Flipped = IN6P is pulled to AVSS and IN6N pulled to AVDD
4	LOFF_FLIP5	R/W	0h	**Channel 5 LOFF polarity flip** Flip the pull-up or pull-down polarity of the current source on channel 5 for lead-off detection. 0 : No flip = IN5P is pulled to AVDD and IN5N pulled to AVSS 1 : Flipped = IN5P is pulled to AVSS and IN5N pulled to AVDD
3	LOFF_FLIP4	R/W	0h	**Channel 4 LOFF polarity flip** Flip the pull-up or pull-down polarity of the current source on channel 4 for lead-off detection. 0 : No flip = IN4P is pulled to AVDD and IN4N pulled to AVSS 1 : Flipped = IN4P is pulled to AVSS and IN4N pulled to AVDD
2	LOFF_FLIP3	R/W	0h	**Channel 3 LOFF polarity flip** Flip the pull-up or pull-down polarity of the current source on channel 3 for lead-off detection. 0 : No flip = IN3P is pulled to AVDD and IN3N pulled to AVSS 1 : Flipped = IN3P is pulled to AVSS and IN3N pulled to AVDD
1	LOFF_FLIP2	R/W	0h	**Channel 2 LOFF Polarity Flip** Flip the pull-up or pull-down polarity of the current source on channel 2 for lead-off detection. 0 : No flip = IN2P is pulled to AVDD and IN2N pulled to AVSS 1 : Flipped = IN2P is pulled to AVSS and IN2N pulled to AVDD
0	LOFF_FLIP1	R/W	0h	**Channel 1 LOFF Polarity Flip** Flip the pull-up or pull-down polarity of the current source on channel 1 for lead-off detection. 0 : No flip = IN1P is pulled to AVDD and IN1N pulled to AVSS 1 : Flipped = IN1P is pulled to AVSS and IN1N pulled to AVDD

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9.6.1.12 LOFF_STATP: Lead-Off Positive Signal Status Register (address = 12h) (reset = 00h)

This register stores the status of whether the positive electrode on each channel is on or off. See the *Lead-Off Detection* section for details. Ignore the LOFF_STATP values if the corresponding LOFF_SENSP bits are not set to 1.

When the LOFF_SENSEP bits are 0, the LOFF_STATP bits should be ignored.

Figure 61. LOFF_STATP: Lead-Off Positive Signal Status Register (Read-Only)

7	6	5	4	3	2	1	0
IN8P_OFF	IN7P_OFF	IN6P_OFF	IN5P_OFF	IN4P_OFF	IN3P_OFF	IN2P_OFF	IN1P_OFF
R-0h	R-0h	R-0h	R-0h	R-0h	R-0h	R-0h	R-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 23. Lead-Off Positive Signal Status Field Descriptions

Bit	Field	Type	Reset	Description
7	IN8P_OFF	R	0h	**Channel 8 positive channel lead-off status** Status of whether IN8P electrode is on or off 0 : Electrode is on 1 : Electrode is off
6	IN7P_OFF	R	0h	**Channel 7 positive channel lead-off status** Status of whether IN7P electrode is on or off 0 : Electrode is on 1 : Electrode is off
5	IN6P_OFF	R	0h	**Channel 6 positive channel lead-off status** Status of whether IN6P electrode is on or off 0 : Electrode is on 1 : Electrode is off
4	IN5P_OFF	R	0h	**Channel 5 positive channel lead-off status** Status of whether IN5P electrode is on or off 0 : Electrode is on 1 : Electrode is off
3	IN4P_OFF	R	0h	**Channel 4 positive channel lead-off status** Status of whether IN4P electrode is on or off 0 : Electrode is on 1 : Electrode is off
2	IN3P_OFF	R	0h	**Channel 3 positive channel lead-off status** Status of whether IN3P electrode is on or off 0 : Electrode is on 1 : Electrode is off
1	IN2P_OFF	R	0h	**Channel 2 positive channel lead-off status** Status of whether IN2P electrode is on or off 0 : Electrode is on 1 : Electrode is off
0	IN1P_OFF	R	0h	**Channel 1 positive channel lead-off status** Status of whether IN1P electrode is on or off 0 : Electrode is on 1 : Electrode is off

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9.6.1.13 LOFF_STATN: Lead-Off Negative Signal Status Register (address = 13h) (reset = 00h)

This register stores the status of whether the negative electrode on each channel is on or off. See the *Lead-Off Detection* section for details. Ignore the LOFF_STATN values if the corresponding LOFF_SENSN bits are not set to 1.

When the LOFF_SENSEN bits are 0, the LOFF_STATP bits should be ignored.

Figure 62. LOFF_STATN: Lead-Off Negative Signal Status Register (Read-Only)

7	6	5	4	3	2	1	0
IN8N_OFF	IN7N_OFF	IN6N_OFF	IN5N_OFF	IN4N_OFF	IN3N_OFF	IN2N_OFF	IN1N_OFF
R-0h	R-0h	R-0h	R-0h	R-0h	R-0h	R-0h	R-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 24. Lead-Off Negative Signal Status Field Descriptions

Bit	Field	Type	Reset	Description
7	IN8N_OFF	R	0h	**Channel 8 negative channel lead-off status** Status of whether IN8N electrode is on or off 0 : Electrode is on 1 : Electrode is off
6	IN7N_OFF	R	0h	**Channel 7 negative channel lead-off status** Status of whether IN7N electrode is on or off 0 : Electrode is on 1 : Electrode is off
5	IN6N_OFF	R	0h	**Channel 6 negative channel lead-off status** Status of whether IN6N electrode is on or off 0 : Electrode is on 1 : Electrode is off
4	IN5N_OFF	R	0h	**Channel 5 negative channel lead-off status** Status of whether IN5N electrode is on or off 0 : Electrode is on 1 : Electrode is off
3	IN4N_OFF	R	0h	**Channel 4 negative channel lead-off status** Status of whether IN4N electrode is on or off 0 : Electrode is on 1 : Electrode is off
2	IN3N_OFF	R	0h	**Channel 3 negative channel lead-off status** Status of whether IN3N electrode is on or off 0 : Electrode is on 1 : Electrode is off
1	IN2N_OFF	R	0h	**Channel 2 negative channel lead-off status** Status of whether IN2N electrode is on or off 0 : Electrode is on 1 : Electrode is off
0	IN1N_OFF	R	0h	**Channel 1 negative channel lead-off status** Status of whether IN1N electrode is on or off 0 : Electrode is on 1 : Electrode is off

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9.6.1.14 GPIO: General-Purpose I/O Register (address = 14h) (reset = 0Fh)

The general-purpose I/O register controls the action of the three GPIO pins. When RESP_CTRL[1:0] is in mode 01 and 11, the GPIO2, GPIO3, and GPIO4 pins are not available for use.

Figure 63. GPIO: General-Purpose I/O Register

7	6	5	4	3	2	1	0
GPIOD[4:1]				GPIOC[4:1]			
R/W-0h				R/W-Fh			

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 25. General-Purpose I/O Field Descriptions

Bit	Field	Type	Reset	Description
7:4	GPIOD[4:1]	R/W	0h	**GPIO data** These bits are used to read and write data to the GPIO ports. When reading the register, the data returned correspond to the state of the GPIO external pins, whether they are programmed as inputs or as outputs. As outputs, a write to the GPIOD sets the output value. As inputs, a write to the GPIOD has no effect. GPIO is not available in certain respiration modes.
3:0	GPIOC[4:1]	R/W	Fh	**GPIO control (corresponding GPIOD)** These bits determine if the corresponding GPIOD pin is an input or output. 0 : Output 1 : Input

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9.6.1.15 MISC1: Miscellaneous 1 Register (address = 15h) (reset = 00h)

This register provides the control to route the SRB1 pin to all inverting inputs of the four, six, or eight channels (ADS1299-4, ADS1299-6, or ADS1299).

Figure 64. MISC1: Miscellaneous 1 Register

7	6	5	4	3	2	1	0
0	0	SRB1	0	0	0	0	0
R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 26. Miscellaneous 1 Register Field Descriptions

Bit	Field	Type	Reset	Description
7:6	Reserved	R/W	0h	**Reserved** Always write 0h
5	SRB1	R/W	0h	**Stimulus, reference, and bias 1** This bit connects the SRB1 to all 4, 6, or 8 channels inverting inputs 0 : Switches open 1 : Switches closed
4:0	Reserved	R/W	0h	**Reserved** Always write 0h

9.6.1.16 MISC2: Miscellaneous 2 (address = 16h) (reset = 00h)

This register is reserved for future use.

Figure 65. MISC1: Miscellaneous 1 Register

7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0
R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 27. Miscellaneous 1 Register Field Descriptions

Bit	Field	Type	Reset	Description
7:0	Reserved	R/W	0h	**Reserved** Always write 0h

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9.6.1.17 CONFIG4: Configuration Register 4 (address = 17h) (reset = 00h)

This register configures the conversion mode and enables the lead-off comparators.

Figure 66. CONFIG4: Configuration Register 4

7	6	5	4	3	2	1	0
0	0	0	0	SINGLE_SHOT	0	$\overline{\text{PD_LOFF_COMP}}$	0
R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-0h

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 28. Configuration Register 4 Field Descriptions

Bit	Field	Type	Reset	Description
7:4	Reserved	R/W	0h	**Reserved** Always write 0h
3	SINGLE_SHOT	R/W	0h	**Single-shot conversion** This bit sets the conversion mode. 0 : Continuous conversion mode 1 : Single-shot mode
2	Reserved	R/W	0h	**Reserved** Always write 0h
1	$\overline{\text{PD_LOFF_COMP}}$	R/W	0h	**Lead-off comparator power-down** This bit powers down the lead-off comparators. 0 : Lead-off comparators disabled 1 : Lead-off comparators enabled
0	Reserved	R/W	0h	**Reserved** Always write 0h

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10 Applications and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

10.1 Application Information

10.1.1 Unused Inputs and Outputs

Power down unused analog inputs and connect them directly to AVDD.

Power down the Bias amplifier if unused and float BIASOUT and BIASINV. BIASIN can also float or can be tied directly to AVSS if unused.

Tie BIASREF directly to AVSS or leave floating if unused.

Tie SRB1 and SRB2 directly to AVSS or leave them floating if unused.

Do not float unused digital inputs because excessive power-supply leakage current might result. Set the two-state mode setting pins high to DVDD or low to DGND through ≥10-kΩ resistors.

Pull $\overline{\text{DRDY}}$ to supply using weak pullup resistor if unused.

If not daisy-chaining devices, tie DAISYIN directly to DGND.

10.1.2 Setting the Device for Basic Data Capture

Figure 67 outlines the procedure to configure the device in a basic state and capture data. This procedure puts the device into a configuration that matches the parameters listed in the specifications section, in order to check if the device is working properly in the user system. Follow this procedure initially until familiar with the device settings. After this procedure has been verified, the device can be configured as needed. For details on the timings for commands, see the appropriate sections in the data sheet. Sample programming codes are added for the ECG and EEG-specific functions.

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Application Information (continued)

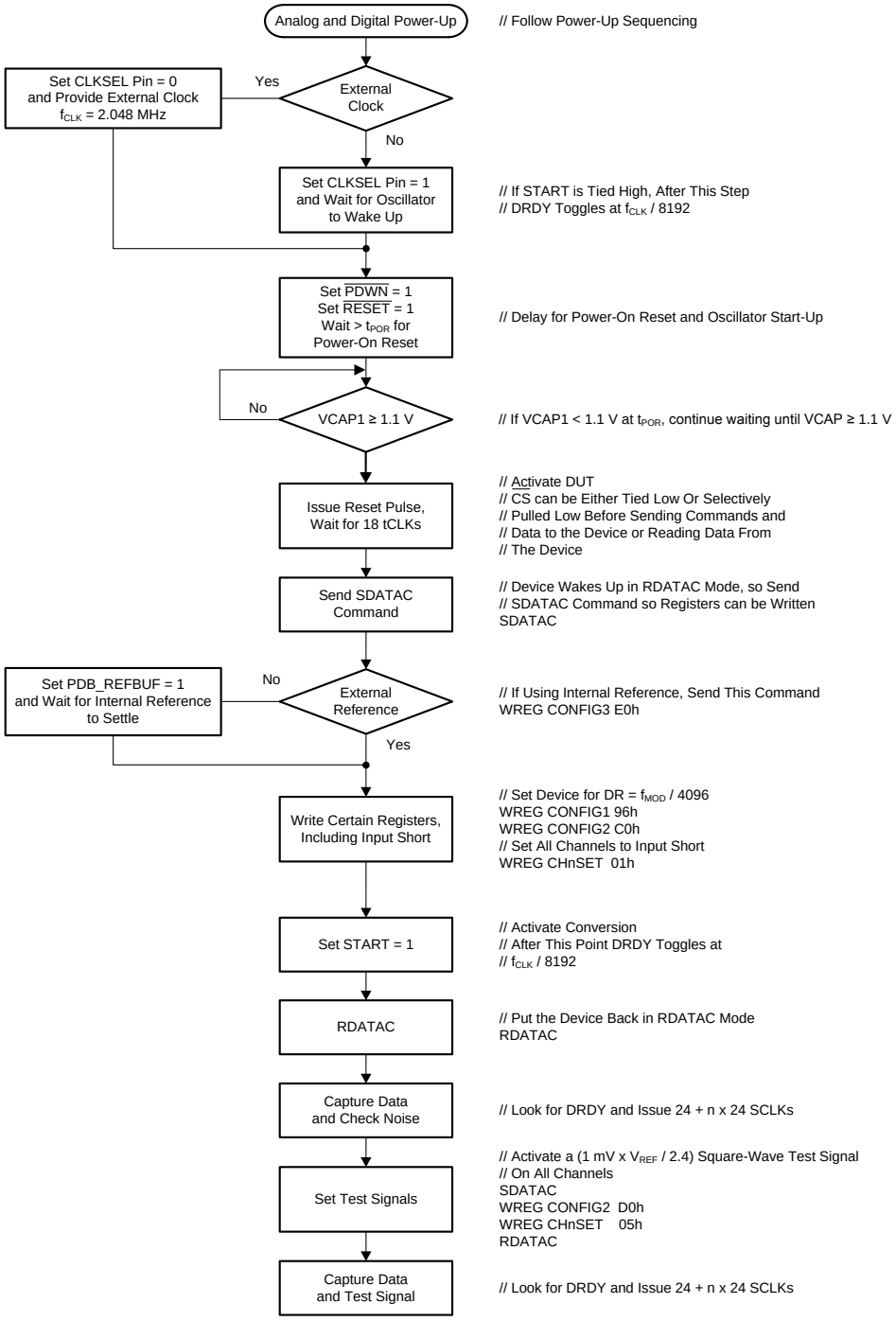

Figure 67. Initial Flow at Power-Up

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Application Information (continued)

10.1.2.1 Lead-Off

Sample code to set dc lead-off with pull-up and pull-down resistors on all channels.

```
WREG LOFF       0x13        // Comparator threshold at 95% and 5%, pullup or pulldown resistor
                            // dc lead-off
WREG CONFIG4    0x02        // Turn on dc lead-off comparators
WREG LOFF_SENSP 0xFF        // Turn on the P-side of all channels for lead-off sensing
WREG LOFF_SENSN 0xFF        // Turn on the N-side of all channels for lead-off sensing
```

Observe the status bits of the output data stream to monitor lead-off status.

10.1.2.2 Bias Drive

Sample code to choose bias as an average of the first three channels.

```
WREG RLD_SENSP 0x07        // Select channel 1-3 P-side for RLD sensing
WREG RLD_SENSN 0x07        // Select channel 1-3 N-side for RLD sensing
WREG CONFIG3   b'x1xx 1100 // Turn on BIAS amplifier, set internal BIASREF voltage
```

Sample code to route the BIASOUT signal through channel 4 N-side and measure bias with channel 5. Make sure the external side to the chip BIASOUT is connected to BIASIN.

```
WREG CONFIG3 b'xxx1 1100  // Turn on BIAS amp, set internal BIASREF voltage, set BIAS measurement bit
WREG CH4SET  b'xxxx 0111  // Route BIASIN to channel 4 N-side
WREG CH5SET  b'xxxx 0010  // Route BIASIN to be measured at channel 5 w.r.t BIASREF
```

10.1.3 Establishing the Input Common-Mode

The ADS1299-x measures fully-differential signals where the common-mode voltage point is the midpoint of the positive and negative analog input. The internal PGA restricts the common-mode input range because of the headroom required for operation. The human body is prone to common-mode drifts because noise easily couples onto the human body, similar to an antenna. These common-mode drifts may push the ADS1299-x input common-mode voltage out of the measurable range of the ADC.

If a patient-drive electrode is used by the system, the ADS1299-x includes an on-chip bias drive (BIAS) amplifier that connects to the patient drive electrode. The BIAS amplifier function is to bias the patient to maintain the other electrode common-mode voltages within the valid range. When powered on, the amplifier uses either the analog midsupply voltage, or the voltage present at the BIASREF pin, as a reference input to drive the patient to that voltage.

The ADS1299-x provides the option to use input electrode voltages as feedback to the amplifier to more effectively stabilize the output to the amplifier reference voltage by setting corresponding bits in the BIAS_SENSP and BIAS_SENSN registers. Figure 68 shows an example of a three-electrode system that leverages this technique.

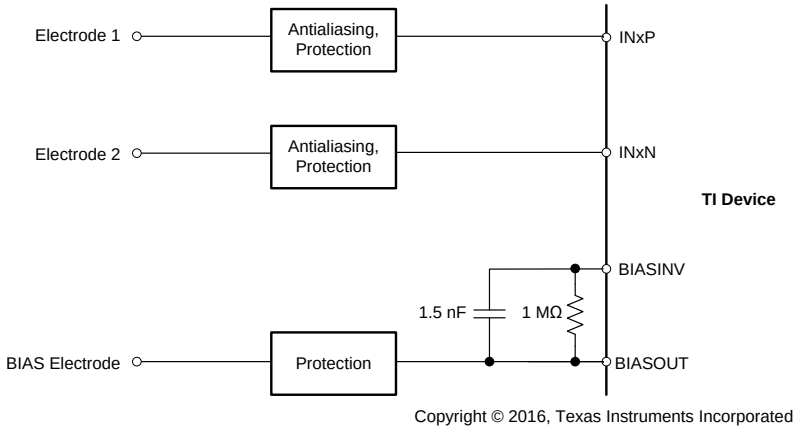

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Figure 68. Setting Common-Mode Using BIAS Electrode

Application Information (continued)

10.1.4 Multiple Device Configuration

The ADS1299-x is designed to provide configuration flexibility when multiple devices are used in a system. The serial interface typically needs four signals: DIN, DOUT, SCLK, and $\overline{CS}$. With one additional chip select signal per device, multiple devices can be connected together. The number of signals needed to interface *n* devices is 3 + *n*.

The BIAS drive amplifiers can be daisy-chained, as explained in the *Bias Configuration with Multiple Devices* section. To use the internal oscillator in a daisy-chain configuration, one device must be set as the master for the clock source with the internal oscillator enabled (CLKSEL pin = 1) and the internal oscillator clock brought out of the device by setting the $\overline{CLK}_EN$ register bit to '1'. This master device clock is used as the external clock source for other devices.

When using multiple devices, the devices can be synchronized with the START signal. The delay from START to the $\overline{DRDY}$ signal is fixed for a given data rate (see the *Start* subsection of the *SPI Interface* section for more details on the settling times). Figure 69 shows the behavior of two devices when synchronized with the START signal.

There are two ways to connect multiple devices with a optimal number of interface pins: cascade mode and daisy-chain mode.

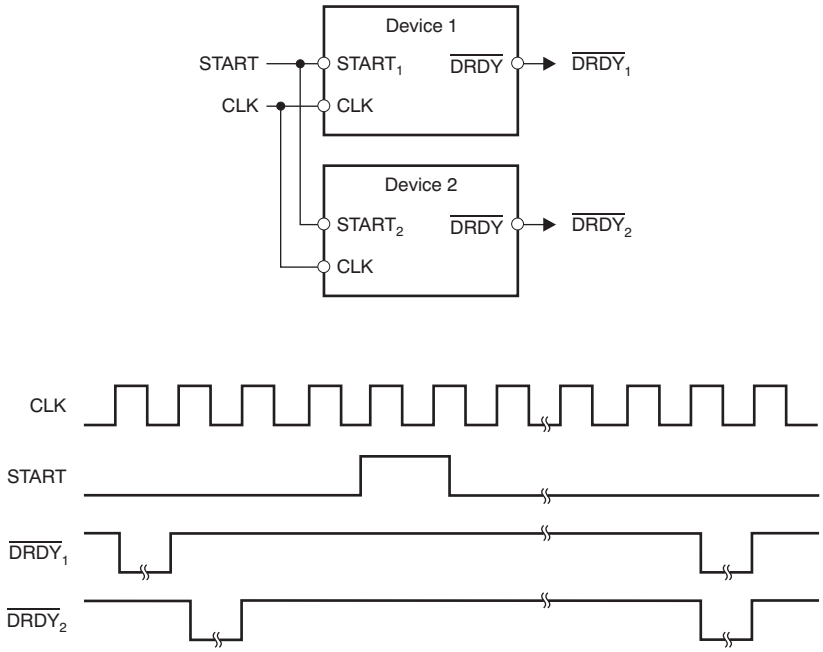

Figure 69. Synchronizing Multiple Converters

10.1.4.1 Cascaded Mode

Figure 70a illustrates a configuration with two devices cascaded together. Together, the devices create a system with 16 channels. DOUT, SCLK, and DIN are shared. Each device has its own chip select. When a device is not selected by the corresponding $\overline{CS}$ being driven to logic 1, the DOUT of this device is high-impedance. This structure allows the other device to take control of the DOUT bus. This configuration method is suitable for the majority of applications.

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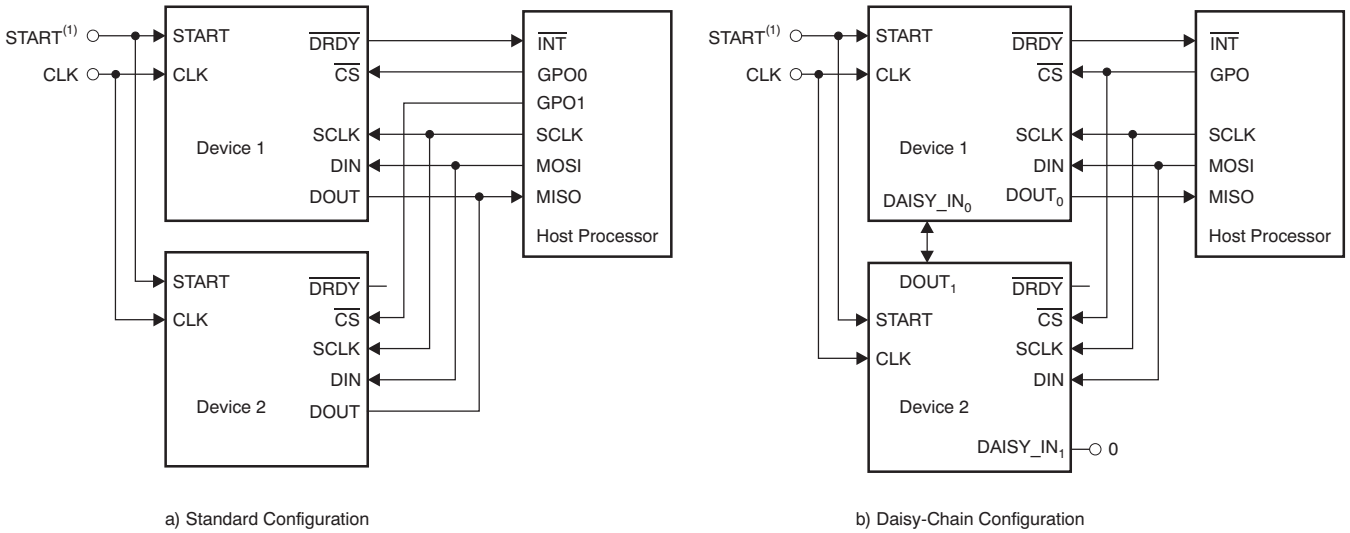
Application Information (continued)

10.1.4.2 Daisy-Chain Mode

Daisy-chain mode is enabled by setting the $\overline{\text{DAISY_EN}}$ bit in the CONFIG1 register. Figure 70b shows the daisy-chain configuration. In this mode SCLK, DIN, and $\overline{\text{CS}}$ are shared across multiple devices. The DOUT of the second device is connected to the DAISY_IN of the first device, thereby creating a chain. When using daisy-chain mode, the multiple readback feature is not available. Short the DAISY_IN pin to digital ground if not used. Figure 2 describes the required timing for the device shown in the configurations of Figure 70. Status and data from device 1 appear first on DOUT, followed by the status and data from device 2. The ADS1299 can be daisy chained with a second ADS1299, an ADS1299-6, or an ADS1299-4.



a) Standard Configuration b) Daisy-Chain Configuration

(1) To reduce pin count, set the START pin low and use the START serial command to synchronize and start conversions.

Figure 70. Multiple Device Configurations

When all devices in the chain operate in the same register setting, DIN can be shared as well. This configuration reduces the SPI communication signals to four, regardless of the number of devices. The BIAS driver cannot be shared among the multiple devices and an external clock must be used because the individual devices cannot be programmed when sharing a common DIN.

Note that from Figure 2, the SCLK rising edge shifts data out of the device on DOUT. The SCLK negative edge is used to latch data into the device DAISY_IN pin down the chain. This architecture allows for a faster SCLK rate speed, but also makes the interface sensitive to board-level signal delays. The more devices in the chain, the more challenging adhering to setup and hold times becomes. A star-pattern connection of SCLK to all devices, minimizing DOUT length, and other printed circuit board (PCB) layout techniques helps. Placing delay circuits (such as buffers) between DOUT and DAISY_IN are ways to mitigate this challenge. One other option is to insert a *D* flip-flop between DOUT and DAISY_IN clocked on an inverted SCLK. Note also that daisy-chain mode requires some software overhead to recombine data bits spread across byte boundaries. Figure 71 shows a timing diagram for this mode.

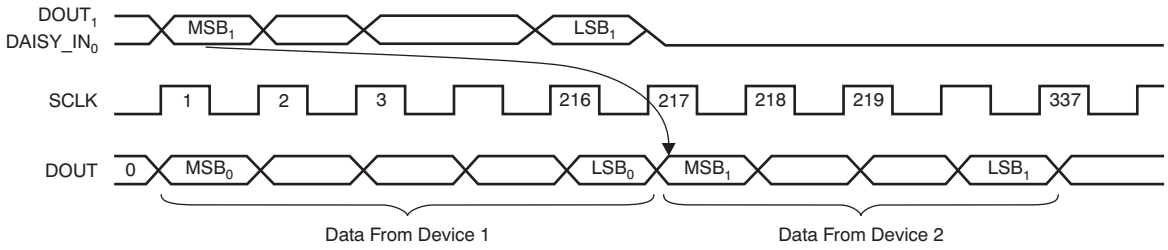


Figure 71. Daisy-Chain Timing

Application Information (continued)

The maximum number of devices that can be daisy-chained depends on the data rate at which the device is operated at. The maximum number of devices can be approximately calculated with Equation 10.

$$N_{DEVICES} = \frac{f_{SCLK}}{f_{DR}\,(N_{BITS})(N_{CHANNELS}) + 24} \quad (10)$$

where:

N_{BITS} = device resolution (depending on data rate), and

$N_{CHANNELS}$ = number of channels in the device.

For example, when the 8-channel ADS1299 is operated at a 2-kSPS data rate with a 4-MHz f_{SCLK}, 10 devices can be daisy-chained.

10.2 Typical Application

The biopotential signals that are measured in electroencephalography (EEG) are small when compared to other types of biopotential signals. The ADS1299 is equipped to measure such small signals due to its extremely low input-referred noise from its high performance internal PGA. Figure 72 and Figure 73 are examples of how the ADS1299 may be configured in typical EEG measurement setups. Figure 72 shows how to measure electrode potentials in a sequential montage, whereas Figure 73 illustrates referential montage measurement connections.

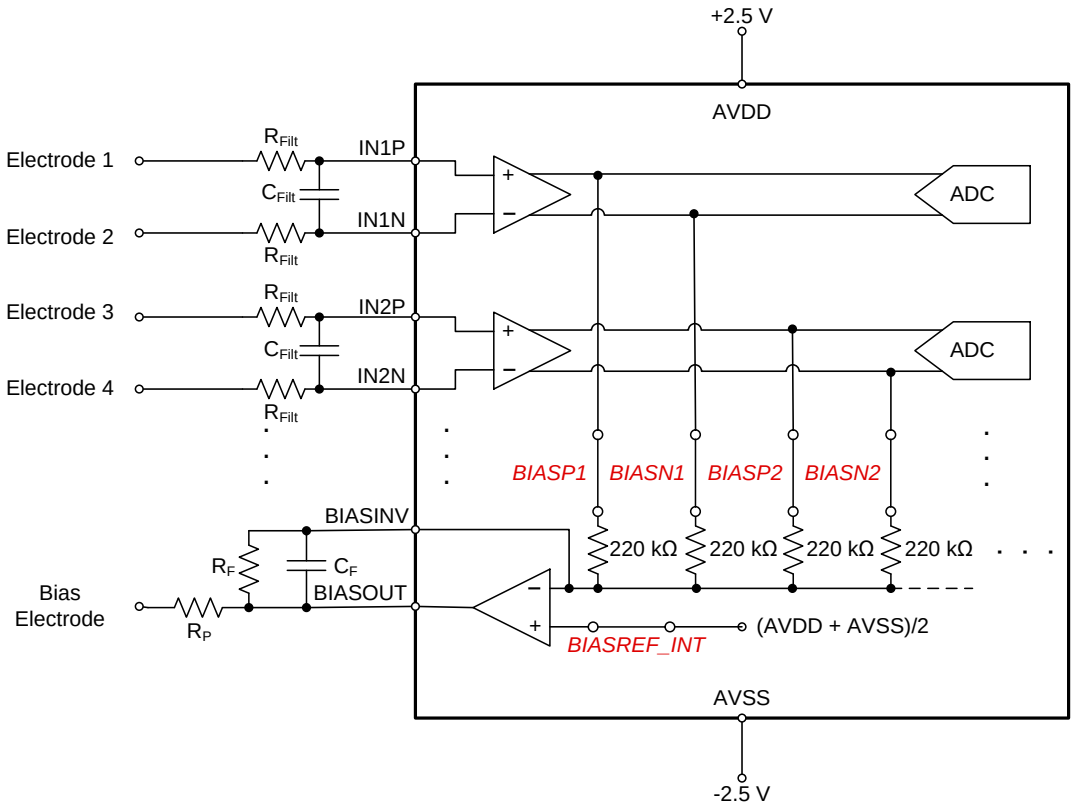


Figure 72. Example Schematic Using the ADS1299 in an EEG Data Acquisition Application, Sequential Montage

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Typical Application (continued)

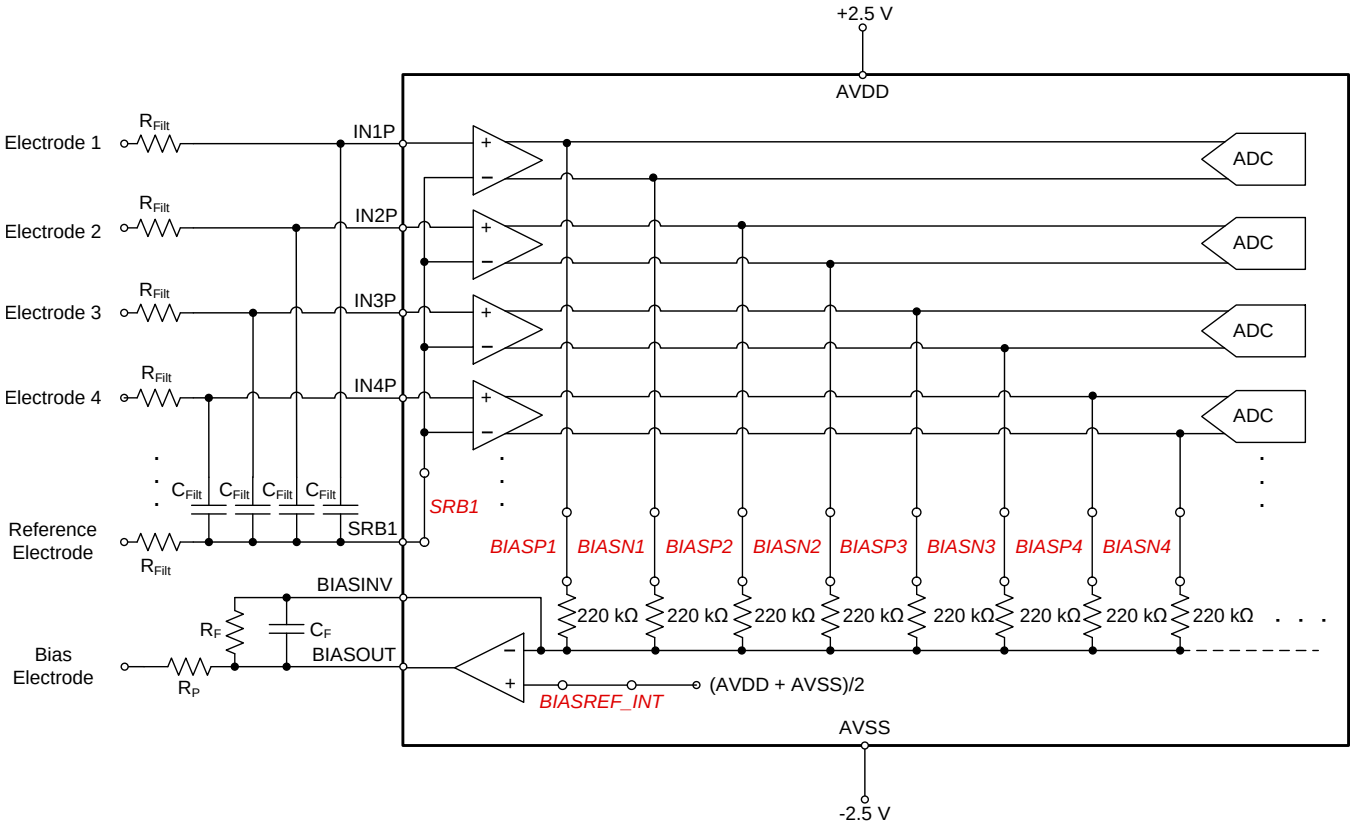

Figure 73. Example Schematic Using the ADS1299 in an EEG Data Acquisition Application, Referential Montage

10.2.1 Design Requirements

Table 29 shows the design requirements for a typical EEG measurement system.

Table 29. EEG Data Acquisition Design Requirements

DESIGN PARAMETER	VALUE
Bandwidth	1 Hz - 50 Hz
Minimum signal bandwidth	10 μV_{Pk}
Input Impedance	> 10 MΩ
Coupling	dc

10.2.2 Detailed Design Procedure

Each channel on the ADS1299 is optimized to measure a separate EEG waveform. The specific connections depend on the EEG montage. The sequential montage is a configuration where each channel represents the voltage between two adjacent electrodes. For example, to measure the potential between electrode Fp1 and F7 on channel 1 of the ADS1299, route the Fp1 electrode to IN1P and the F7 electrode to IN1N. The connections for a sequential montage are illustrated in Figure 72.

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Alternatively, EEG electrodes can be measured in a referential montage in which each of the electrodes is measured with respect to a single *reference electrode*. This montage also allows calculation of the waveforms that would have been measured in a sequential montage by finding the difference between two electrode waveforms which were measured with respect to the same electrode. The ADS1299 allows for such a configuration through the use of the SRB1 pin. The SRB1 pin on the ADS1299 may be internally routed to each channel negative input by setting the SRB1 bit in the MISC1 register. When the reference electrode is connected to the SRB1 pin and all other electrodes are connected to the respective positive channel inputs, the electrode voltages can be measured with a referential montage. The referential montage is illustrated in Figure 73. See Figure 18 for a diagram of the channel input multiplexer options.

The ADS1299 is designed to be an EEG front end such that no additional amplification or buffer stage is needed between the electrodes and ADS1299. The ADS1299 has a low-noise PGA with excellent input-referred noise performance. For certain data rate and gain settings, the ADS1299 introduces significantly less than 1 μV_{RMS} of input-referred noise to the signal chain making the device more than capable of handling the 10-μV_{Pk} minimum signal amplitude. ADS1299 noise performance for different PGA gains and data rate settings is listed in Table 1, Table 2, Table 3, and Table 4.

Traditional EEG data acquisition systems high-pass filter the signals in the front-end to remove dc signal content. This topology allows the signal to be amplified by a large gain so the signal can be digitized by a 12- to 16-bit ADC. The ADS1299 24-bit resolution allows the signal to be dc-coupled to the ADC because small EEG signal information can be measured in addition to a significant dc offset.

The ADS1299 channel inputs have very low input bias current allowing electrodes to be connected to the inputs of the ADS1299 with very little leakage current flowing on the patient cables. The ADS1299 has a minimum dc input impedance of 1 GΩ when the lead-off current sources are disabled and 500 MΩ typically when the lead-off current sources are enabled.

The passive components R_{Filt} and C_{Filt} form low-pass filters. In general, the filter is advised to be formed by using a differential capacitor C_{FIlt} that shunts the inputs rather than individual RC filters whose capacitors shunt to ground. The differential capacitor configuration significantly improves common-mode rejection because this approach removes dependence on component mismatch.

The cutoff frequency for the filter can be placed well past the data rate of the ADC because of the delta-sigma ADC filter-then-decimate topology. Take care to prevent aliasing around the first repetition of the digital decimation filter response at f_{MOD}. Assuming a 2.048-MHz f_{CLK}, f_{MOD} = 1.024 MHz. The value of R_{Filt} has a minimum set by technical standards for medical electronics. The capacitor value must be set to arrange the proper cutoff frequency.

If the system is likely to be exposed to high-frequency EMI, adding very small-value, common-mode capacitors to the inputs is advisable to filter high-frequency common-mode signals. If these capacitors are added, then the capacitors should be 10 or 20 times smaller than the differential capacitor to ensure their effect of CMRR is minimized.

The integrated bias amplifier serves two purposes in an EEG data acquisition system with the ADS1299. The bias amplifier provides a bias voltage that, when applied to the patient, keeps the measurement electrode common-mode voltage within the rails of the ADS1299. This scenario allows for dc coupling. In addition, the bias amplifier can be configured to provide negative common-mode feedback to the patient to cancel unwanted common-mode signals appearing on the electrodes. This feature is especially helpful because biopotential acquisition systems are notoriously prone to mains-frequency common-mode interference.

The bias amplifier is powered on by setting the $\overline{\text{PD_BIAS}}$ bit in the CONFIG3 register. Set the BIASREF_INT bit in the CONFIG3 register to input the internally generated analog mid-supply voltage the noninverting input of the bias amplifier. To enable an electrode as an input to the bias amplifier, set the corresponding bit in the BIAS_SENSP or BIAS_SENSN register.

The dc gain of the bias amplifier is determined by R_{Bias} and the number of channel inputs enabled as inputs to the bias amplifier. The bias amplifier circuit only passes common-mode signals. Therefore, the 330-kΩ resistors at each PGA output are *in parallel* for common-mode signals. The bias amplifier is configured in an inverting gain scheme. The formula for determining dc gain for common-mode signals input to the bias amplifier is shown in Equation 11. The capacitor C_f sets the bandwidth for the bias amplifier. Ensure that the amplifier has enough bandwidth to output all the intended common-mode signals.

$$\frac{V_{out}}{V_{in}} = -\frac{R_f \times N}{330k\Omega} \tag{11}$$

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Another advantage to a dc-coupled EEG data acquisition system is the ability to detect when an electrode no longer makes good contact with the patient. The ADS1299 features integrated lead-off detection electronics. The *Lead-Off Detection* section explains how to use the lead-off feature on the ADS1299. Note that when configured in a referential montage, only use one lead-off current source with the reference electrode.

10.2.3 Application Curves

Testing the capability of the ADS1299 to measure signals in the band and near the amplitude of typical EEG signals can be done with a precision signal generator. The ADS1299 was tested in a configuration like the one shown in Figure 74.

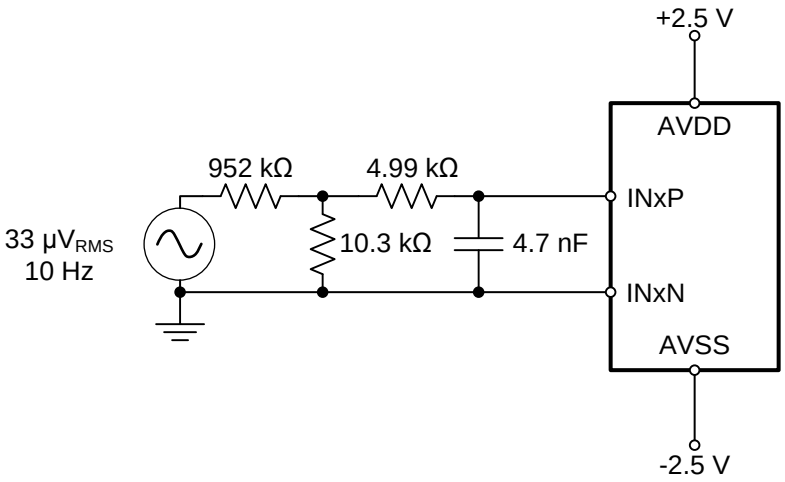

Figure 74. Example Schematic Using the ADS1299 in an EEG Data Acquisition Application, Referential Montage

The 952-kΩ and 10.3-kΩ resistors were used to attenuate the voltage from the signal source because the source could not reach the desired magnitude directly. With the voltage divider, the signal appearing at the inputs was a 3.5-μV_{RMS}, 10-Hz sine wave. Figure 75 shows the input-referred conversion results from the ADS1299 following calibration for offset. The signal that is measured is similar to some of the smallest extracranial EEG signals that can be measured with typical EEG acquisition systems. The signal can be clearly identified. Given this measurement setup was a single-ended configuration without shielding, the measurement setup was subject to significant mains interference. A digital low-pass filter was applied to remove the interference.

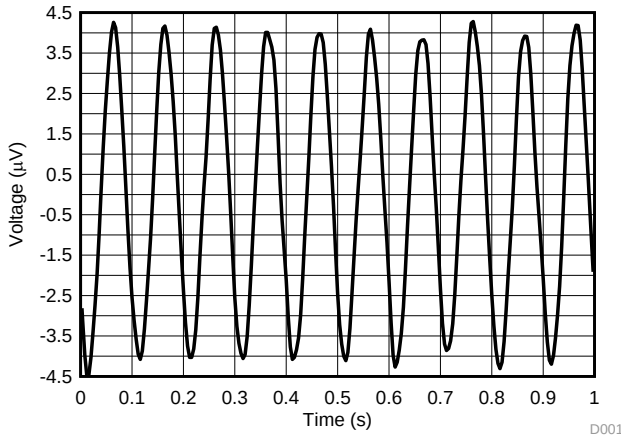

Figure 75. ADS1299 10-Hz Input Signal Results

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11 Power Supply Recommendations

The ADS1299-x has three power supplies: AVDD, AVDD1, and DVDD. For best performance, both AVDD and AVDD1 must be as quiet as possible. AVDD1 provides the supply to the charge pump block and has transients at f_{CLK}. Therefore, star connect AVDD1 to the AVDD pins and AVSS1 to the AVSS pins. AVDD and AVDD1 noise that is nonsynchronous with the ADS1299-x operation must be eliminated. Bypass each device supply with 10-µF and 0.1-µF solid ceramic capacitors. For best performance, place the digital circuits (DSP, microcontrollers, FPGAs, and so forth) in the system so that the return currents on those devices do not cross the analog return path of the device. Power the ADS1299-x from unipolar or bipolar supplies.

Use surface-mount, low-cost, low-profile, multilayer ceramic-type capacitors for decoupling. In most cases, the VCAP1 capacitor is also a multilayer ceramic; however, in systems where the board is subjected to high- or low-frequency vibration, install a nonferroelectric capacitor, such as a tantalum or class 1 capacitor (C0G or NPO). EIA class 2 and class 3 dielectrics such as (X7R, X5R, X8R, and so forth) are ferroelectric. The piezoelectric property of these capacitors can appear as electrical noise coming from the capacitor. When using internal reference, noise on the VCAP1 node results in performance degradation.

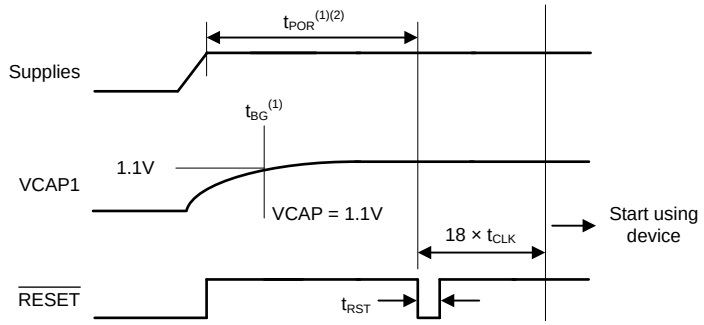
11.1 Power-Up Sequencing

Before device power up, all digital and analog inputs must be low. At the time of power up, keep all of these signals low until the power supplies have stabilized, as shown in Figure 76.

Allow time for the supply voltages to reach their final value, and then begin supplying the master clock signal to the CLK pin. Wait for time t_{POR}, then transmit a reset pulse using either the $\overline{\text{RESET}}$ pin or RESET command to initialize the digital portion of the chip. Issue the reset after t_{POR} or after the VCAP1 voltage is greater than 1.1 V, whichever time is longer. Note that:

- t_{POR} is described in Table 30.
- The VCAP1 pin charge time is set by the RC time constant set by the capacitor value on VCAP1; see Figure 25.

After releasing the $\overline{\text{RESET}}$ pin, program the configuration registers. The power-up sequence timing is shown in Table 30.



(1) Timing to reset pulse is t_{POR} or after t_{BG}, whichever is longer.

(2) When using an external clock, t_{POR} timing does not start until CLK is present and valid.

Figure 76. Power-Up Timing Diagram

Table 30. Timing Requirements for Figure 76

		MIN	MAX	UNIT
t_{POR}	Wait after power up until reset	2^{18}		t_{CLK}
t_{RST}	Reset low duration	2		t_{CLK}

11.2 Connecting the Device to Unipolar (5 V and 3.3 V) Supplies

Figure 77 illustrates the ADS1299-x connected to a unipolar supply. In this example, analog supply (AVDD) is referenced to analog ground (AVSS) and digital supply (DVDD) is referenced to digital ground (DGND).

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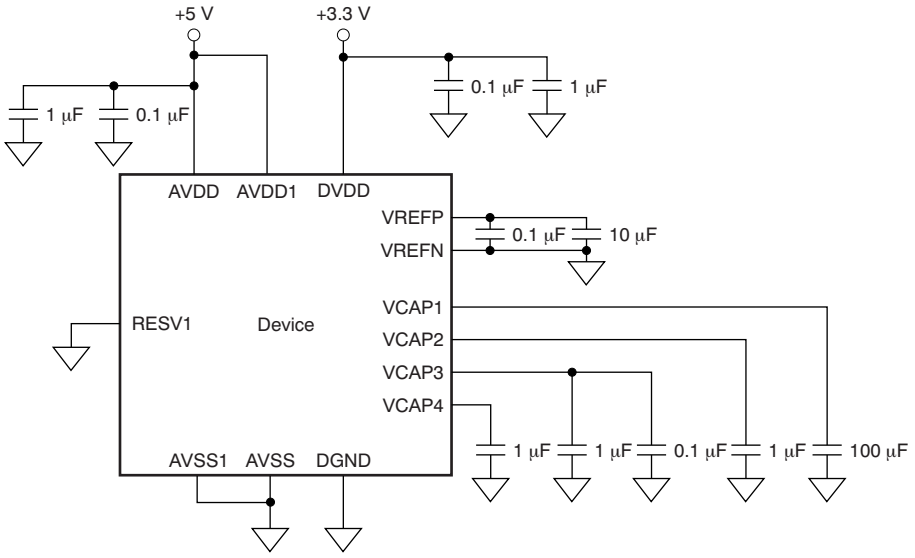
Connecting the Device to Unipolar (5 V and 3.3 V) Supplies (continued)

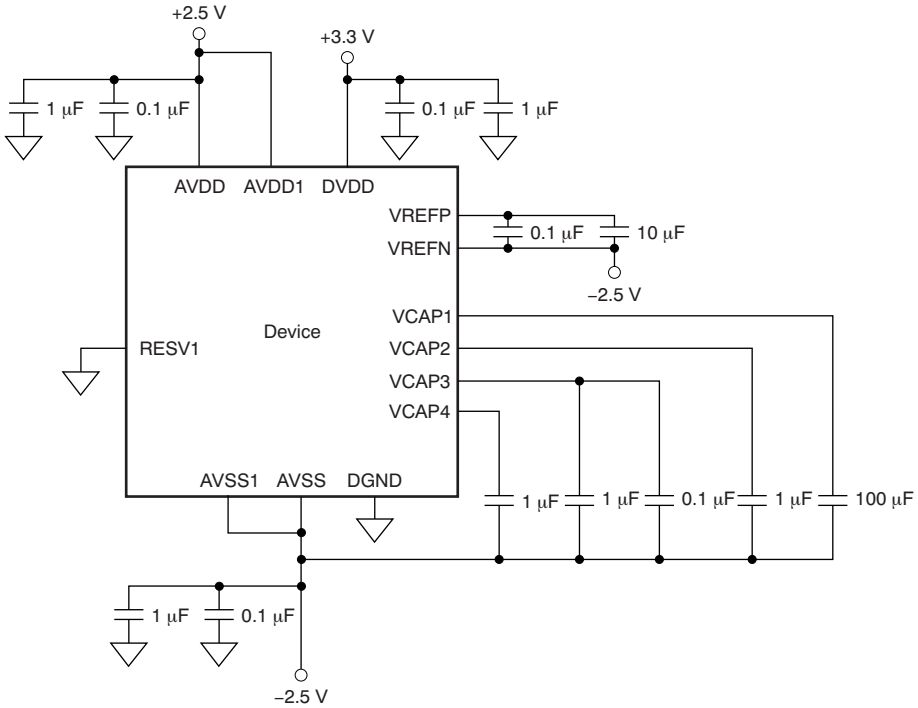


NOTE: Place the capacitors for supply, reference, and VCAP1 to VCAP4 as close to the package as possible.

Figure 77. Single-Supply Operation

11.3 Connecting the Device to Bipolar (±2.5 V and 3.3 V) Supplies

Figure 78 shows the ADS1299-x connected to a bipolar supply. In this example, the analog supplies connect to the device analog supply (AVDD). This supply is referenced to the device analog return (AVSS), and the digital supply (DVDD) is referenced to the device digital ground return (DGND).



NOTE: Place the capacitors for supply, reference, and VCAP1 to VCAP4 as close to the package as possible.

Figure 78. Bipolar Supply Operation

12 Layout

12.1 Layout Guidelines

TI recommends employing best design practices when laying out a printed-circuit board (PCB) for both analog and digital components. This recommendation generally means that the layout separates analog components [such as ADCs, amplifiers, references, digital-to-analog converters (DACs), and analog MUXs] from digital components [such as microcontrollers, complex programmable logic devices (CPLDs), field-programmable gate arrays (FPGAs), radio frequency (RF) transceivers, universal serial bus (USB) transceivers, and switching regulators]. An example of good component placement is shown in Figure 79. Although Figure 79 provides a good example of component placement, the best placement for each application is unique to the geometries, components, and PCB fabrication capabilities employed. That is, there is no single layout that is perfect for every design and careful consideration must always be used when designing with any analog component.

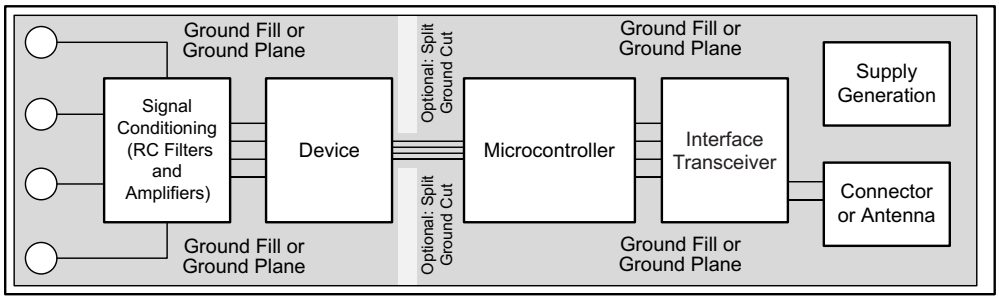


Figure 79. System Component Placement

The following outlines some basic recommendations for the layout of the ADS1299-x to get the best possible performance of the ADC. A good design can be ruined with a bad circuit layout.

- Separate analog and digital signals. To start, partition the board into analog and digital sections where the layout permits. Route digital lines away from analog lines. This configuration prevents digital noise from coupling back into analog signals.
- The ground plane can be split into an analog plane (AGND) and digital plane (DGND), but is not necessary. Place digital signals over the digital plane, and analog signals over the analog plane. As a final step in the layout, the split between the analog and digital grounds must be connected together at the ADC.
- Fill void areas on signal layers with ground fill.
- Provide good ground return paths. Signal return currents flow on the path of least impedance. If the ground plane is cut or has other traces that block the current from flowing right next to the signal trace, then the current must find another path to return to the source and complete the circuit. If current is forced into a longer path, the chances that the signal radiates increases. Sensitive signals are more susceptible to EMI interference.
- Use bypass capacitors on supplies to reduce high-frequency noise. Do not place vias between bypass capacitors and the active device. Placing the bypass capacitors on the same layer as close to the active device yields the best results.
- Analog inputs with differential connections must have a capacitor placed differentially across the inputs. The differential capacitors must be of high quality. The best ceramic chip capacitors are C0G (NPO), which have stable properties and low noise characteristics.

12.2 Layout Example

Figure 80 is an example layout of the ADS1299 requiring a minimum of two PCB layers. The example circuit is shown for either a single analog supply or a bipolar-supply connection. In this example, polygon pours are used as supply connections around the device. If a three- or four-layer PCB is used, the additional inner layers can be dedicated to route power traces. The PCB is partitioned with analog signals routed from the left, digital signals routed to the right, and power routed above and below the device.

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Layout Example (continued)

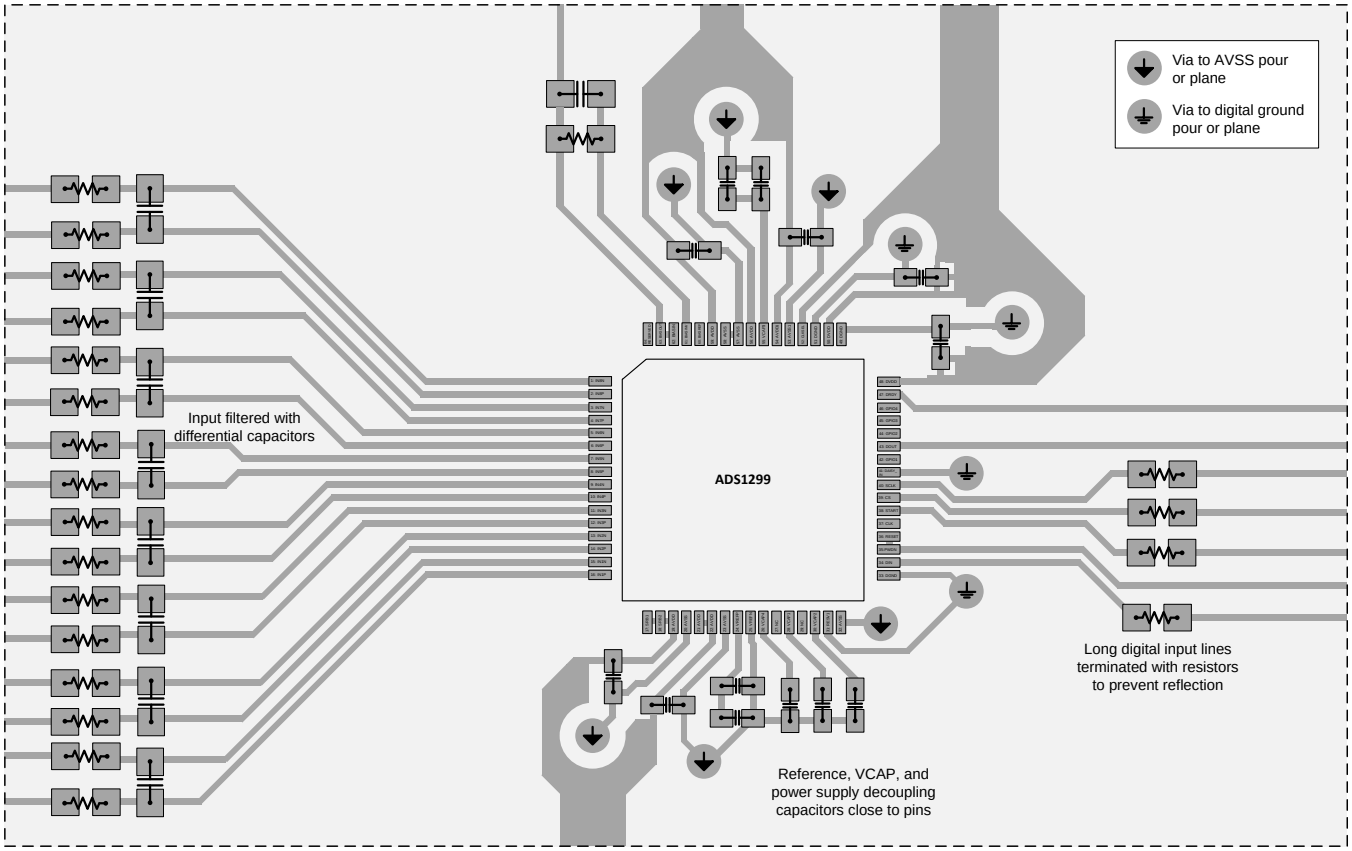

Figure 80. ADS1299 Example Layout

13 Device and Documentation Support

13.1 Documentation Support

13.1.1 Related Documentation

For related documentation see the following:

- *ADS129x Low-Power, 8-Channel, 24-Bit Analog Front-End for Biopotential Measurements*
- *REF50xx Low-Noise, Very Low Drift, Precision Voltage Reference*
- *Improving Common-Mode Rejection Using the Right-Leg Drive Amplifier*
- *ADS1299EEG-FE EEG Front-End Performance Demonstration Kit*

13.2 Related Links

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

Table 31. Related Links

PARTS	PRODUCT FOLDER	ORDER NOW	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
ADS1299	Click here	Click here	Click here	Click here	Click here
ADS1299-4	Click here	Click here	Click here	Click here	Click here
ADS1299-6	Click here	Click here	Click here	Click here	Click here

13.3 Receiving Notification of Documentation Updates

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

13.4 Community Resources

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

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

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

13.5 Trademarks

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All other trademarks are the property of their respective owners.

13.6 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.

13.7 Glossary

SLYZ022 — *TI Glossary*.

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

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14 Mechanical, Packaging, and Orderable Information

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

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
ADS1299-4PAG	ACTIVE	TQFP	PAG	64	160	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR	-40 to 85	ADS1299-4	Samples
ADS1299-4PAGR	ACTIVE	TQFP	PAG	64	1500	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR	-40 to 85	ADS1299-4	Samples
ADS1299-6PAG	ACTIVE	TQFP	PAG	64	160	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR	-40 to 85	ADS1299-6	Samples
ADS1299-6PAGR	ACTIVE	TQFP	PAG	64	1500	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR	-40 to 85	ADS1299-6	Samples
ADS1299IPAG	ACTIVE	TQFP	PAG	64	160	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR	-40 to 85	ADS1299	Samples
ADS1299IPAGR	ACTIVE	TQFP	PAG	64	1500	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR	-40 to 85	ADS1299	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

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

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

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

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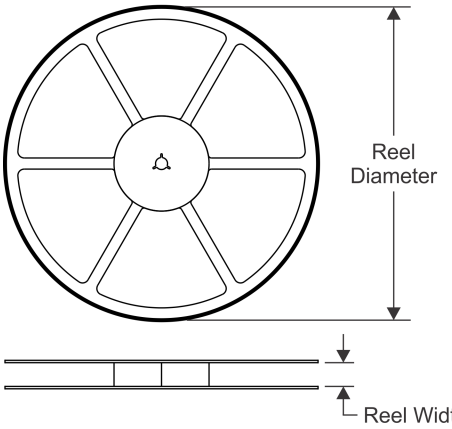
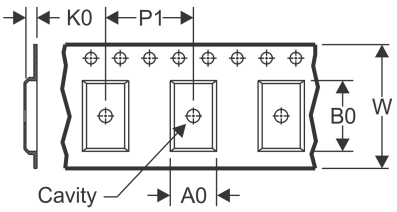
TAPE AND REEL INFORMATION

REEL DIMENSIONS

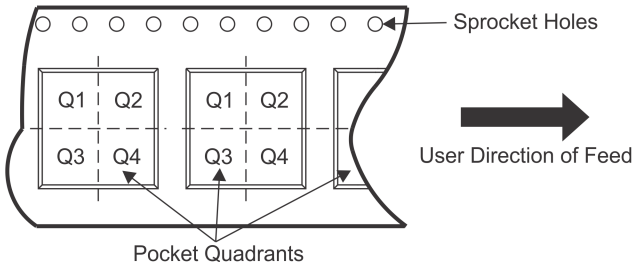


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

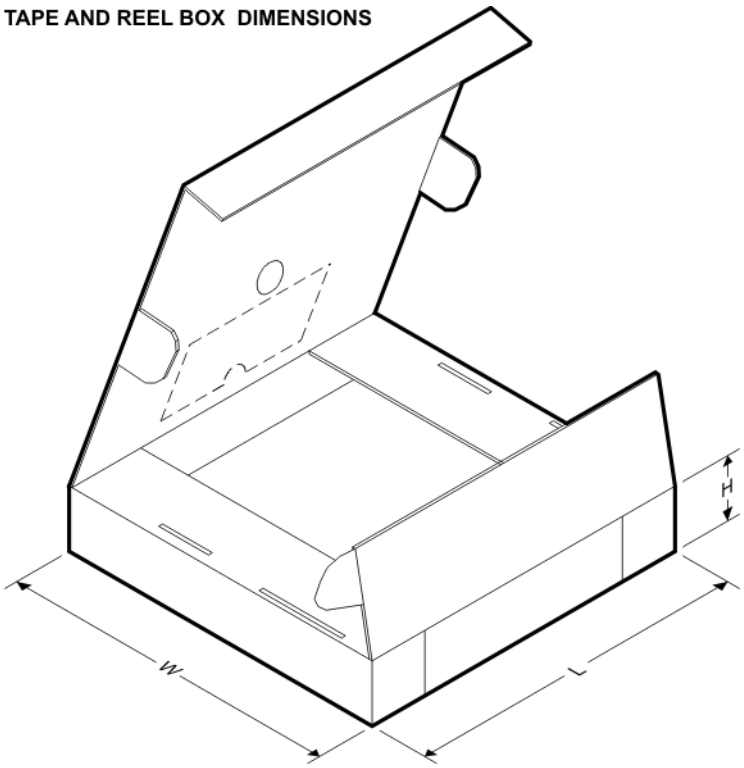
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
ADS1299-4PAGR	TQFP	PAG	64	1500	330.0	24.4	13.0	13.0	1.5	16.0	24.0	Q2
ADS1299-6PAGR	TQFP	PAG	64	1500	330.0	24.4	13.0	13.0	1.5	16.0	24.0	Q2
ADS1299IPAGR	TQFP	PAG	64	1500	330.0	24.4	13.0	13.0	1.5	16.0	24.0	Q2

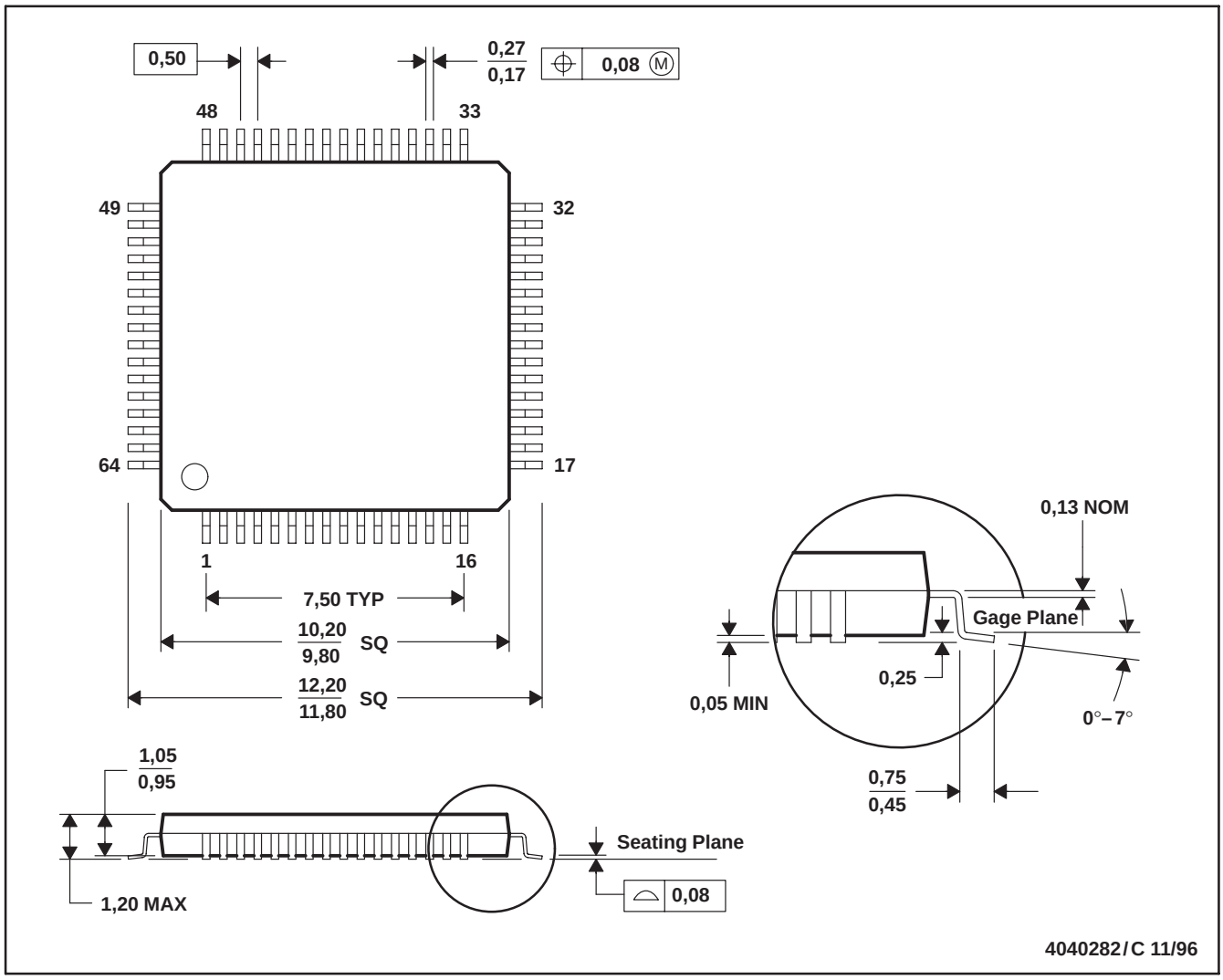
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

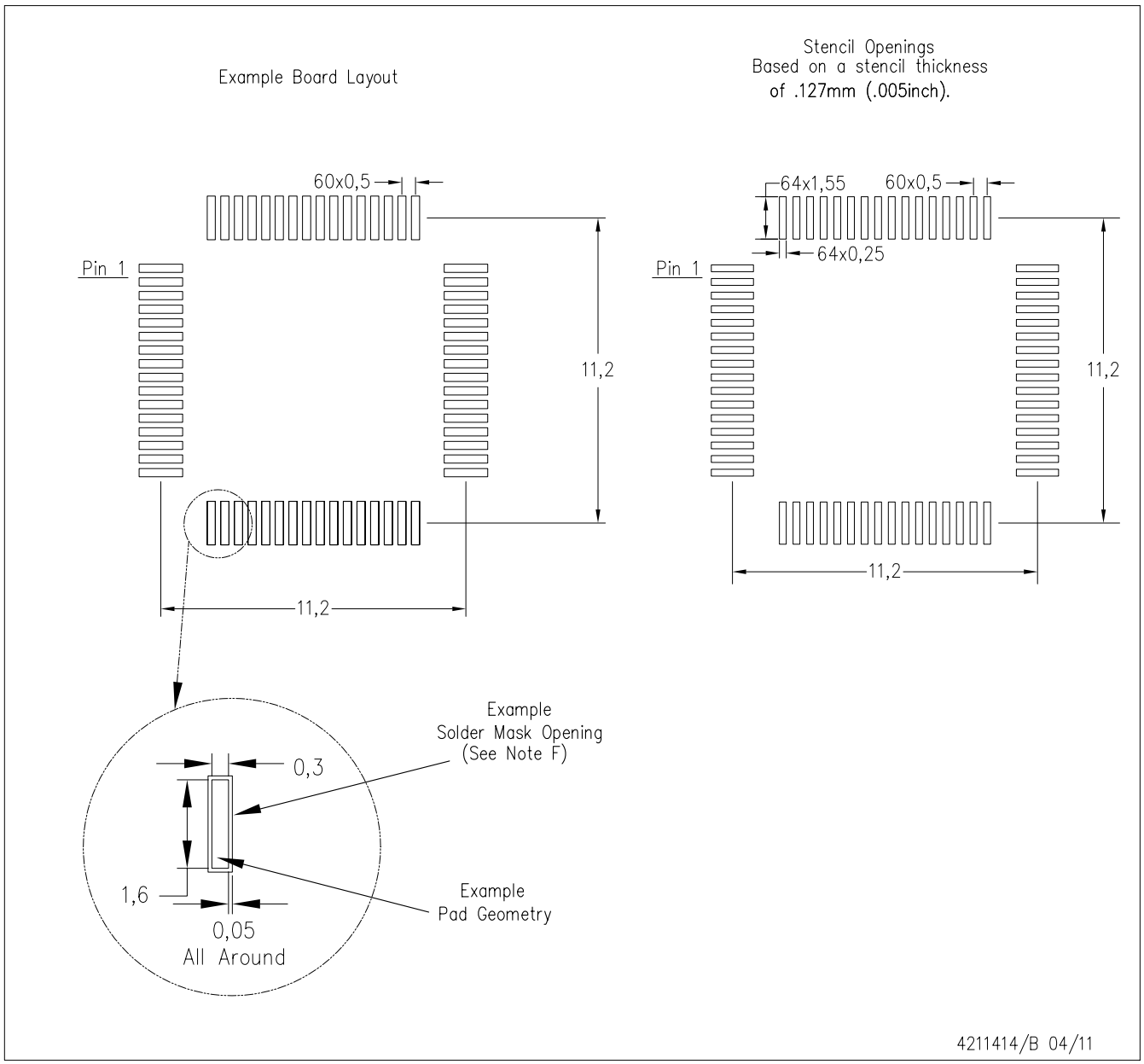
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
ADS1299-4PAGR	TQFP	PAG	64	1500	350.0	350.0	43.0
ADS1299-6PAGR	TQFP	PAG	64	1500	350.0	350.0	43.0
ADS1299IPAGR	TQFP	PAG	64	1500	350.0	350.0	43.0

PAG (S-PQFP-G64) **PLASTIC QUAD FLATPACK**



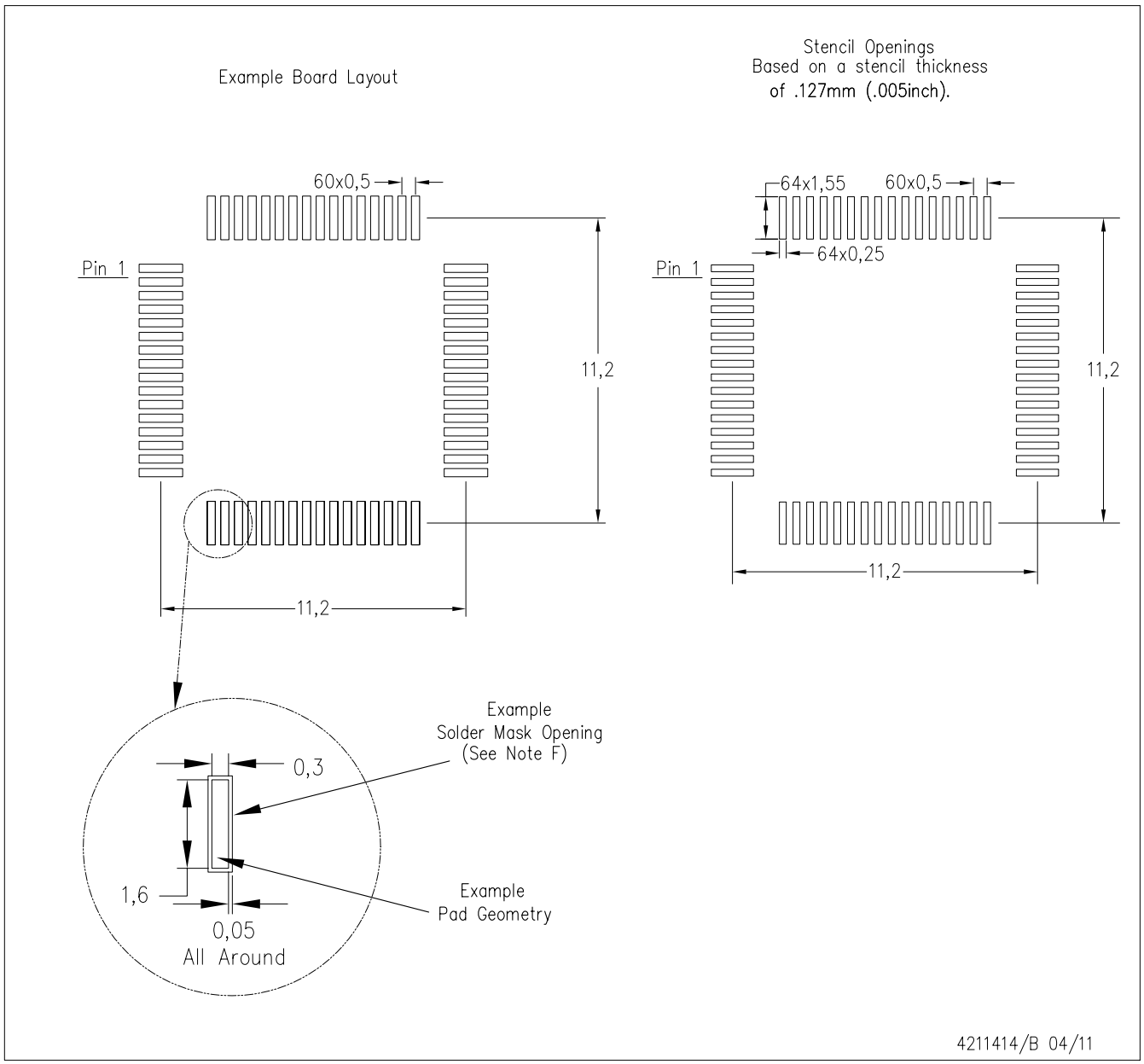
NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-026

PAG (S–PQFP–G64) PLASTIC QUAD FLATPACK



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC–7525 for other stencil recommendations.
D. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

PAG (S–PQFP–G64) PLASTIC QUAD FLATPACK



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A. All linear dimensions are in millimeters.
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