ADS111x 具有内部基准、振荡器和可编程比较器且兼容 I²C 的超小型、低功耗 860SPS、16 位 ADC

1 特性

- 超小型封装：
  - X2QFN：2mm × 1.5mm × 0.4mm
  - SOT：2.9mm × 2.8mm × 0.6mm
- 宽电源电压范围：2.0V 至 5.5V
- 低电流消耗：150 μA（连续转换模式）
- 可编程数据速率：8SPS 至 860SPS
- 单周期稳定
- 内部低漂移电压基准
- 内部振荡器
- I²C 接口：四个引脚可选地址
- 工作温度范围：-40°C 至 +125°C
- 器件系列：
  - ADS1113：1 个单端 (SE) 或差分 (DE) 输入
  - ADS1114：1 个单端或差分输入，具有比较器和 PGA
  - ADS1115：4 个单端输入或 2 个差分输入，具有比较器和 PGA

2 应用

- 便携式仪表
- 电池电压和电流监测
- 温度测量系统
- 消费类电子产品
- 工厂自动化和过程控制

3 说明

ADS1113、ADS1114 和 ADS1115 (ADS111x) 是采用无引线 X2QFN-10 封装、SOT-10 封装和 VSSOP-10 封装、兼容 I²C 的 16 位低功耗精密模数转换器 (ADC)。ADS111x 器件采用了低漂移电压基准和振荡器。ADS1114 和 ADS1115 还包含一个可编程增益放大器 (PGA) 和一个数字比较器。除了这些特性，这些器件还具有宽工作电源电压范围，因而非常适用于功率受限型和空间受限型传感器测量应用。

ADS111x 器件的数据转换速率最高可达每秒 860 次采样 (SPS)。PGA 可提供从 ±256mV 到 ±6.144V 的输入范围，从而实现精准的大小信号测量。ADS1115 具有一个输入多路复用器 (MUX)，可实现双路差分输入或四路单端输入测量。在 ADS1114 和 ADS1115 中使用数字比较器可进行欠压和过压检测。

封装信息

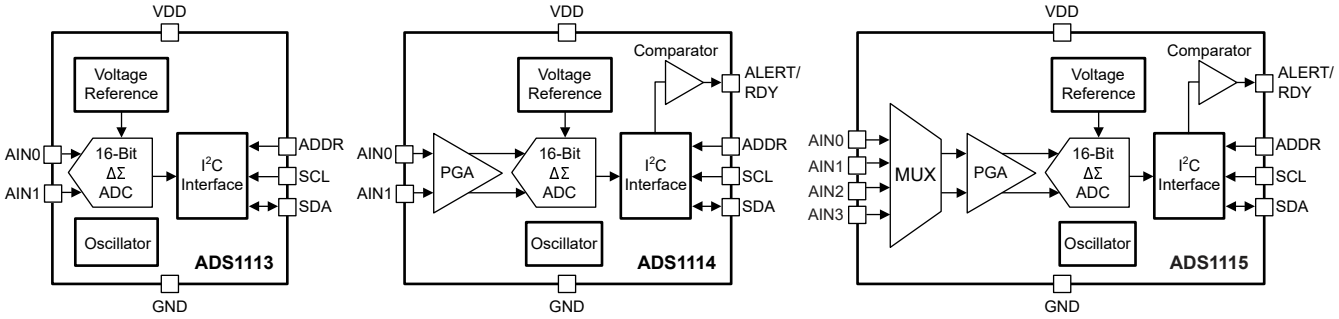
器件型号	封装(1)	封装尺寸(2)
ADS111x	RUG（X2QFN，10）	1.50mm × 2.00mm
	DYN（SOT，10）	2.90mm × 2.80mm
	DGS（VSSOP，10）	3.00mm × 4.90mm

(1) 有关更多信息，请参阅节 14。
(2) 封装尺寸（长 × 宽）为标称值，并包括引脚（如适用）。

器件信息

器件型号	输入通道	特性(1)
ADS1113	1 个差分（1 个单端）	—
ADS1114	1 个差分（1 个单端）	PGA、比较器
ADS1115	2 个差分（4 个单端）	PGA、比较器

(1) 有关详细信息，请参阅 *Device Comparison Table*。



简化的方框图

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Device Comparison Table

DEVICE	RESOLUTION (Bits)	MAXIMUM SAMPLE RATE (SPS)	INPUT CHANNELS Differential (Single-Ended)	PGA	INTERFACE	SPECIAL FEATURES
ADS1115	16	860	2 (4)	Yes	I²C	Comparator
ADS1114	16	860	1 (1)	Yes	I²C	Comparator
ADS1113	16	860	1(1)	No	I²C	None
ADS1015	12	3300	2 (4)	Yes	I²C	Comparator
ADS1014	12	3300	1 (1)	Yes	I²C	Comparator
ADS1013	12	3300	1 (1)	No	I²C	None
ADS1118	16	860	2 (4)	Yes	SPI	Temperature sensor
ADS1018	12	3300	2 (4)	Yes	SPI	Temperature sensor

4 Pin Configuration and Functions

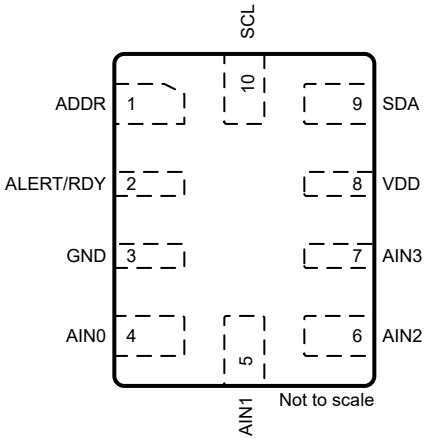


图 4-1. RUG Package, 10-Pin (Top View)

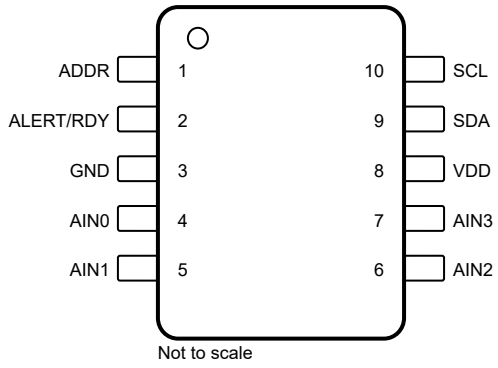


图 4-2. DYN and DGS Packages, 10-Pin (Top View)

表 4-1. Pin Functions: RUG, DYN, and DGS Packages

PIN				TYPE	DESCRIPTION(1)
NAME	ADS1113	ADS1114	ADS1115		
ADDR	1	1	1	Digital input	I²C target address select
AIN0	4	4	4	Analog input	Analog input 0
AIN1	5	5	5	Analog input	Analog input 1
AIN2	—	—	6	Analog input	Analog input 2 (ADS1115 only)
AIN3	—	—	7	Analog input	Analog input 3 (ADS1115 only)
ALERT/RDY	—	2	2	Digital output	Comparator output or conversion ready (ADS1114 and ADS1115 only). Open-drain output. Connect to VDD using a pullup resistor.
GND	3	3	3	Analog	Ground
NC	2, 6, 7	6, 7	—	—	No connect. Leave the pin floating or connect to GND.
SCL	10	10	10	Digital input	Serial clock input. Connect to VDD using a pullup resistor.
SDA	9	9	9	Digital I/O	Serial data input and output. Connect to VDD using a pullup resistor.
VDD	8	8	8	Analog	Power supply. Connect a 0.1 μF, power-supply decoupling capacitor to GND.

(1) See the *Unused Inputs and Outputs* section for unused pin connections.

5 Specifications

5.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Power-supply voltage	VDD to GND	–0.3	7	V
Analog input voltage	AIN0, AIN1, AIN2, AIN3	GND – 0.3	VDD + 0.3	V
Digital input voltage	SDA, SCL, ADDR, ALERT/RDY	GND – 0.3	5.5	V
Input current, continuous	Any pin except power supply pins	–10	10	mA
Temperature	Operating ambient, T_A	–40	125	°C
	Junction, T_J	–40	150	
	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.

5.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)	±2000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101(2)	±500	

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

5.3 Recommended Operating Conditions

		MIN	NOM	MAX	UNIT
POWER SUPPLY					
	Power supply (VDD to GND)	2		5.5	V
ANALOG INPUTS(1)					
FSR	Full-scale input voltage range(2) ($V_{IN} = V_{(AINP)} - V_{(AINN)}$)	±0.256		±6.144	V
$V_{(AINx)}$	Absolute input voltage	GND		VDD	V
DIGITAL INPUTS					
V_{DIG}	Digital input voltage	GND		5.5	V
TEMPERATURE					
T_A	Operating ambient temperature	–40		125	°C

(1) AINP and AINN denote the selected positive and negative inputs. AINx denotes one of the four available analog inputs.
(2) This parameter expresses the full-scale range of the ADC scaling. No more than VDD + 0.3V must be applied to the analog inputs of the device. See 表 7-1 for more information.

5.4 Thermal Information

THERMAL METRIC(1)		RUG (X2QFN)	DYN (SOT)	DGS (VSSOP)	UNIT
		10 PINS	10 PINS	10 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	245.2	147.1	182.7	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	69.3	59.3	67.2	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	172.0	71.3	103.8	°C/W
ψ_{JT}	Junction-to-top characterization parameter	8.2	2.8	10.2	°C/W
ψ_{JB}	Junction-to-board characterization parameter	170.8	70.4	102.1	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	N/A	N/A	°C/W

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

5.5 Electrical Characteristics

at VDD = 3.3V, data rate = 8SPS, and full-scale input voltage range (FSR) = ±2.048V (unless otherwise noted); maximum and minimum specifications apply from T_A = –40°C to +125°C; typical specifications are at T_A = 25°C

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
ANALOG INPUT						
	Common-mode input impedance	FSR = ±6.144V(1)		10		MΩ
		FSR = ±4.096V(1), FSR = ±2.048V		6		
		FSR = ±1.024V		3		
		FSR = ±0.512V, FSR = ±0.256V		100		
	Differential input impedance	FSR = ±6.144V(1)		22		MΩ
		FSR = ±4.096V(1)		15		
		FSR = ±2.048V		4.9		
		FSR = ±1.024V		2.4		
		FSR = ±0.512V, ±0.256V		710		kΩ
SYSTEM PERFORMANCE						
	Resolution (no missing codes)		16			Bits
DR	Data rate		8, 16, 32, 64, 128, 250, 475, 860			SPS
	Data rate variation	All data rates	–10%		10%	
	Output noise		See *Noise Performance* section			
INL	Integral nonlinearity	DR = 8SPS, FSR = ±2.048V(2)			1	LSB
	Offset error	FSR = ±2.048V, differential inputs	–3	±1	3	LSB
		FSR = ±2.048V, single-ended inputs		±3		
	Offset drift over temperature	FSR = ±2.048V		0.005		LSB/°C
	Long-term Offset drift	FSR = ±2.048V, T_A = 125°C, 1000 hours		±1		LSB
	Offset power-supply rejection	FSR = ±2.048V, DC supply variation		1		LSB/V
	Offset channel match	Match between any two inputs		3		LSB
	Gain error(3)	FSR = ±2.048V, T_A = 25°C		0.01%	0.15%	
	Gain drift over temperature(3)	FSR = ±0.256V		7		ppm/°C
		FSR = ±2.048V		5	40	
		FSR = ±6.144V(1)		5		
	Long-term gain drift(3)	FSR = ±2.048V, T_A = 125°C, 1000 hours		±0.05%		
	Gain power-supply rejection			80		ppm/V
	Gain match(3)	Match between any two gains		0.02%	0.1%	
	Gain channel match	Match between any two inputs		0.05%	0.1%	
CMRR	Common-mode rejection ratio	At DC, FSR = ±0.256V		105		dB
		At DC, FSR = ±2.048V		100		
		At DC, FSR = ±6.144V(1)		90		
		f_{CM} = 60Hz, DR = 8SPS		105		
		f_{CM} = 50Hz, DR = 8SPS		105		
DIGITAL INPUT/OUTPUT						
V_{IH}	High-level input voltage		0.7 VDD		5.5	V
V_{IL}	Low-level input voltage		GND		0.3 VDD	V
V_{OL}	Low-level output voltage	I_{OL} = 3mA	GND	0.15	0.4	V
	Input leakage current	GND < V_{DIG} < VDD	–10		10	µA

5.5 Electrical Characteristics（续）

at VDD = 3.3V, data rate = 8SPS, and full-scale input voltage range (FSR) = ±2.048V (unless otherwise noted); maximum and minimum specifications apply from T_A = –40°C to +125°C; typical specifications are at T_A = 25°C

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
POWER-SUPPLY							
I_{VDD}	Supply current	Power-down	T_A = 25°C		0.5	2	μA
						5	
		Operating	T_A = 25°C		150	200	
						300	
P_D	Power dissipation	VDD = 5.0V			0.9		mW
		VDD = 3.3 V			0.5		
		VDD = 2.0V			0.3		

(1) This parameter expresses the full-scale range of the ADC scaling. No more than VDD + 0.3V must be applied to the analog inputs of the device. See 表 7-1 for more information.
(2) Best-fit INL; covers 99% of full-scale
(3) Includes all errors from onboard PGA and voltage reference

5.6 Timing Requirements: I²C

over operating ambient temperature range and VDD = 2.0V to 5.5V (unless otherwise noted)

		FAST MODE		HIGH-SPEED MODE		UNIT
		MIN	MAX	MIN	MAX	
f_{SCL}	SCL clock frequency	0.01	0.4	0.01	3.4	MHz
t_{BUF}	Bus free time between START and STOP condition	600		160		ns
t_{HDSTA}	Hold time after repeated START condition. After this period, the first clock is generated.	600		160		ns
t_{SUSTA}	Setup time for a repeated START condition	600		160		ns
t_{SUSTO}	Setup time for STOP condition	600		160		ns
t_{HDDAT}	Data hold time	0		0		ns
t_{SUDAT}	Data setup time	100		10		ns
t_{LOW}	Low period of the SCL clock pin	1300		160		ns
t_{HIGH}	High period for the SCL clock pin	600		60		ns
t_F	Fall time for both SDA and SCL signals(1)		300		160	ns
t_R	Rise time for both SDA and SCL signals(1)		300		160	ns

(1) For high-speed mode maximum values, the capacitive load on the bus line must not exceed 400pF.

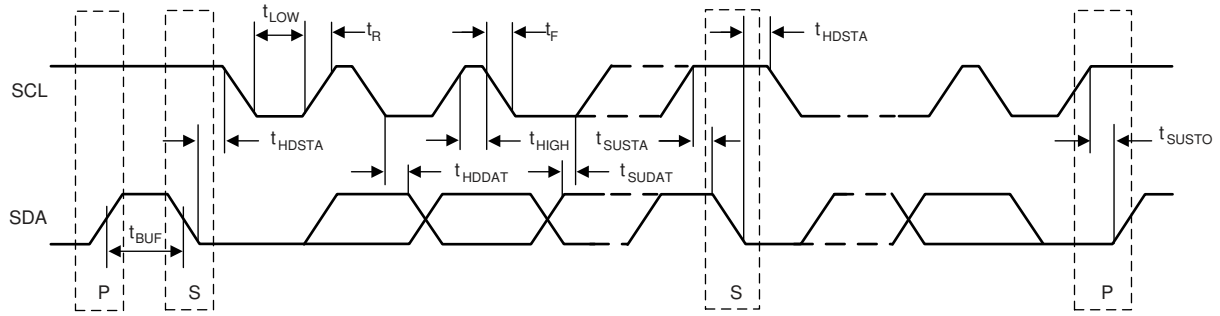


图 5-1. I²C Interface Timing

5.7 Typical Characteristics

at T_A = 25°C, VDD = 3.3V, FSR = ±2.048V, DR = 8SPS (unless otherwise noted)

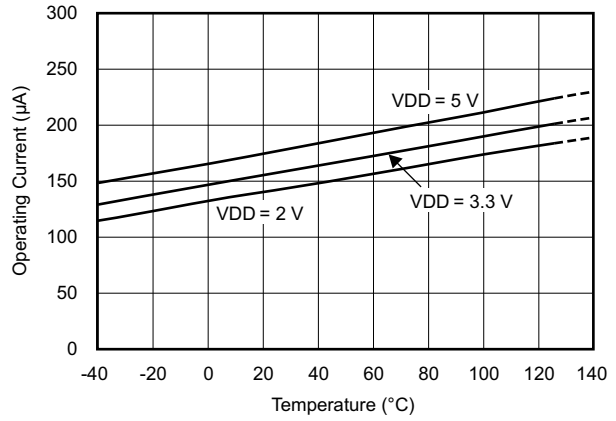


图 5-2. Operating Current vs Temperature

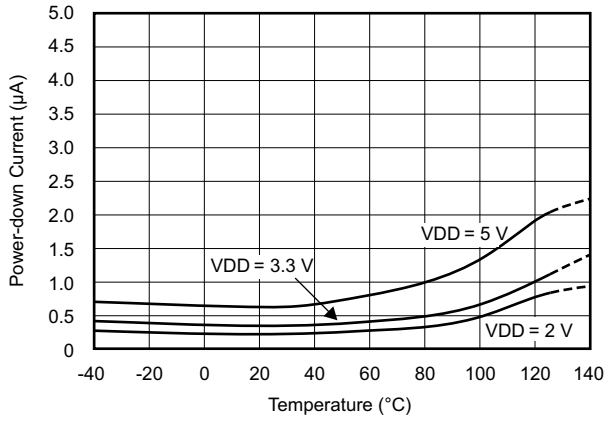


图 5-3. Power-Down Current vs Temperature

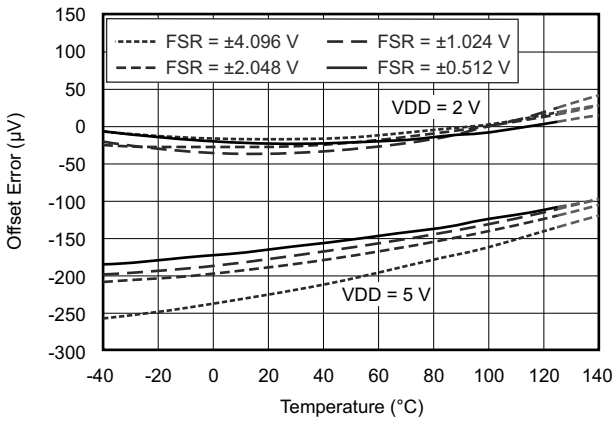


图 5-4. Single-Ended Offset Error vs Temperature

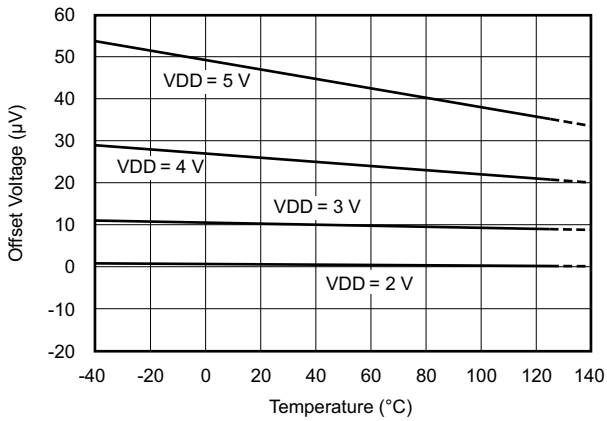


图 5-5. Differential Offset Error vs Temperature

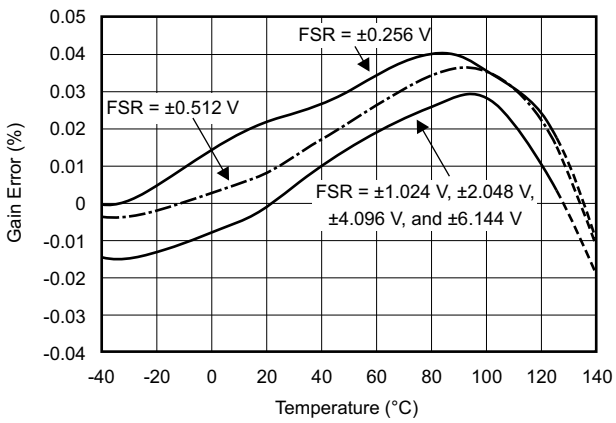


图 5-6. Gain Error vs Temperature

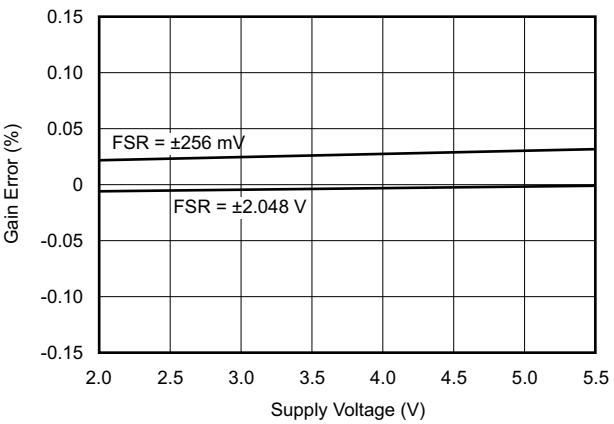


图 5-7. Gain Error vs Supply Voltage

5.7 Typical Characteristics (continued)

at T_A = 25°C, VDD = 3.3V, FSR = ±2.048V, DR = 8SPS (unless otherwise noted)

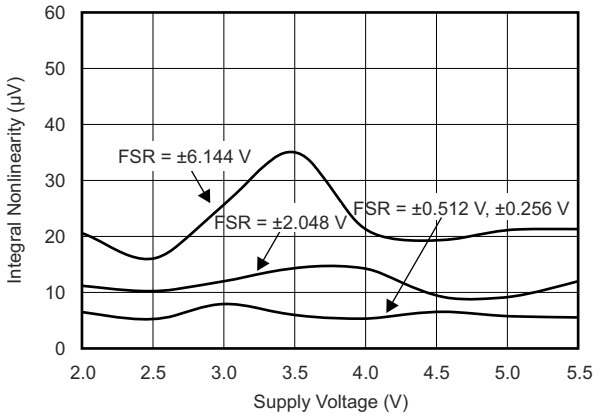
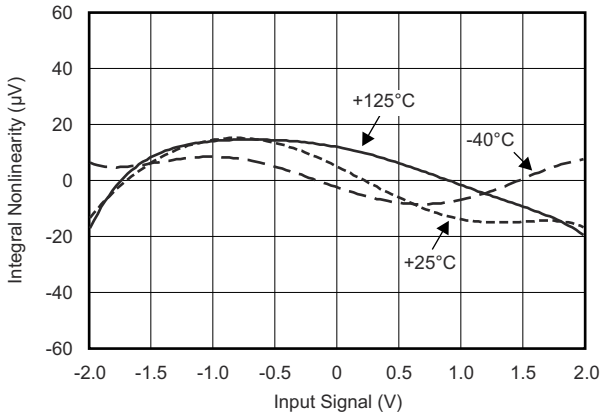
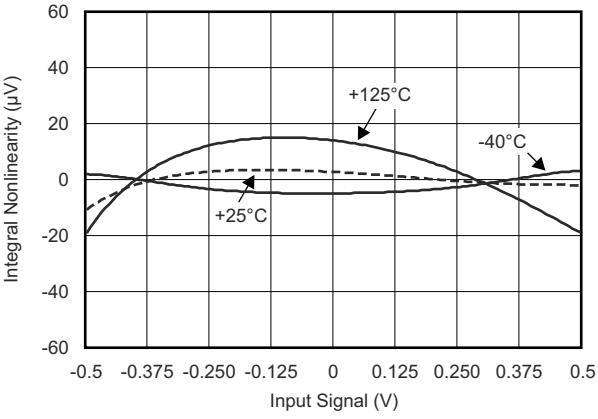


图 5-8. INL vs Supply Voltage



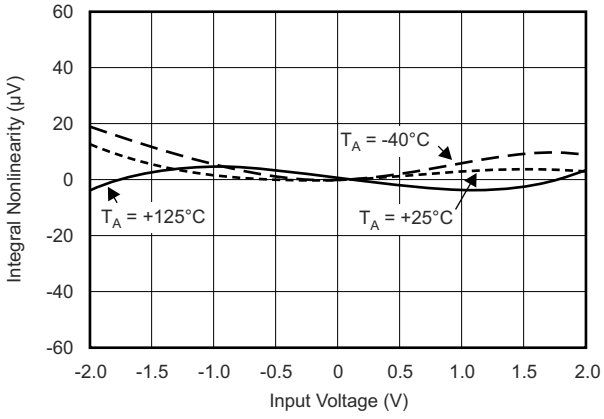
VDD = 3.3V, FSR = ±2.048V, DR = 8SPS, best fit

图 5-9. INL vs Input Signal



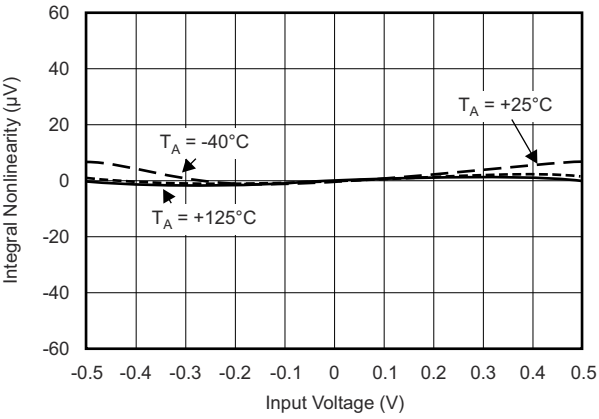
VDD = 3.3V, FSR = ±0.512V, DR = 8SPS, best fit

图 5-10. INL vs Input Signal



VDD = 5V, FSR = ±2.048V, DR = 8SPS, best fit

图 5-11. INL vs Input Signal



VDD = 5V, FSR = ±0.512V, DR = 8SPS, best fit

图 5-12. INL vs Input Signal

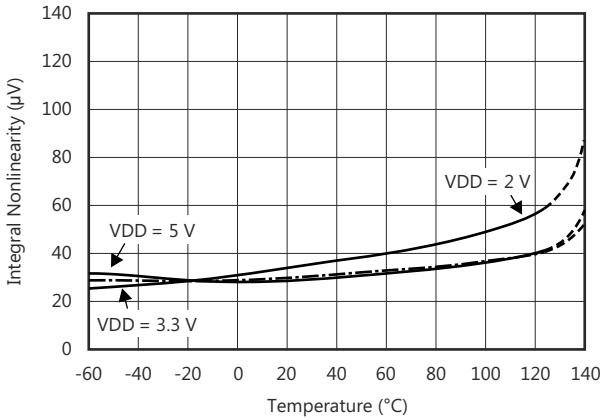
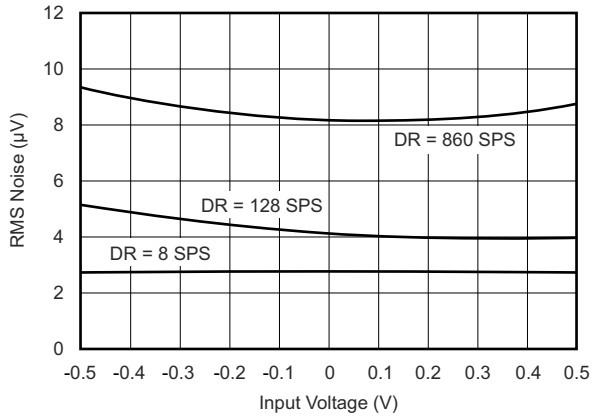


图 5-13. INL vs Temperature

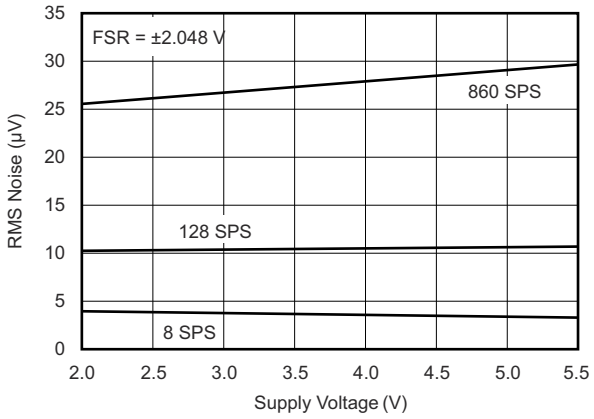
5.7 Typical Characteristics (continued)

at T_A = 25°C, VDD = 3.3V, FSR = ±2.048V, DR = 8SPS (unless otherwise noted)



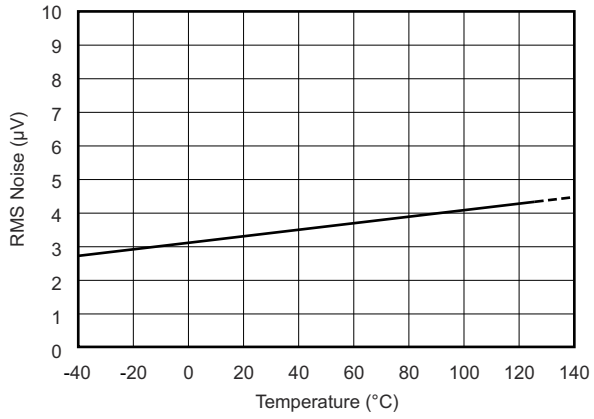
FSR = ±0.512V

图 5-14. Noise vs Input Signal



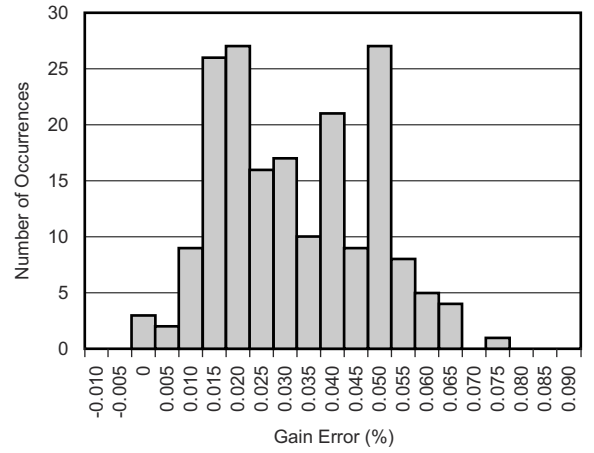
FSR = ±2.048V

图 5-15. Noise vs Supply Voltage



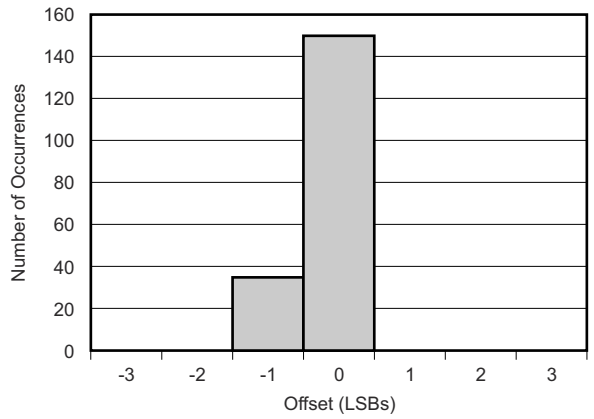
FSR = ±2.048V, DR = 8SPS

图 5-16. Noise vs Temperature



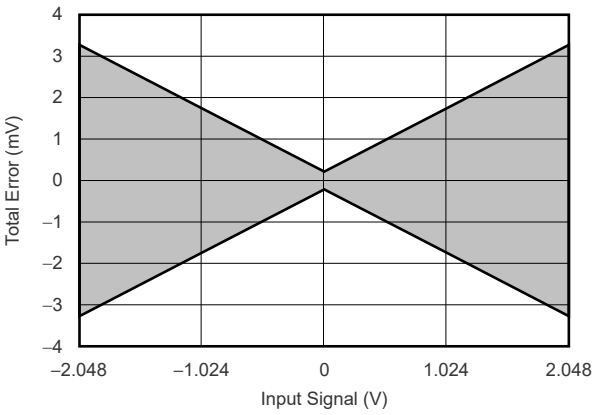
FSR = ±2.048V, 185 units

图 5-17. Gain Error Histogram



FSR = ±2.048V, 185 units

图 5-18. Offset Histogram



Differential inputs; includes noise, offset and gain error

图 5-19. Total Error vs Input Signal

5.7 Typical Characteristics (continued)

at T_A = 25°C, VDD = 3.3V, FSR = ±2.048V, DR = 8SPS (unless otherwise noted)

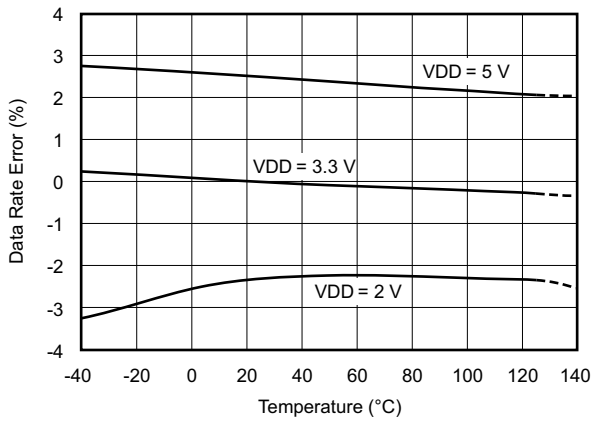


图 5-20. Data Rate vs Temperature

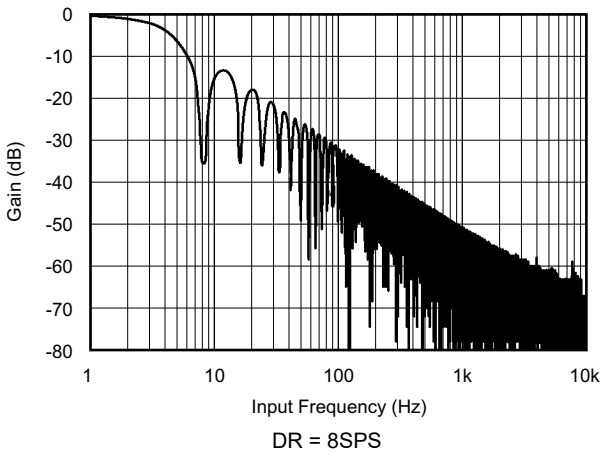


图 5-21. Digital Filter Frequency Response

6 Parameter Measurement Information

6.1 Noise Performance

Delta-sigma ($\Delta\Sigma$) analog-to-digital converters (ADCs) are based on the principle of oversampling. The input signal of a $\Delta\Sigma$ ADC is sampled at a high frequency (modulator frequency) and subsequently filtered and decimated in the digital domain to yield a conversion result at the respective output data rate. The ratio between modulator frequency and output data rate is called *oversampling ratio* (OSR). By increasing the OSR, and thus reducing the output data rate, the noise performance of the ADC can be optimized. In other words, the input-referred noise drops when reducing the output data rate because more samples of the internal modulator are averaged to yield one conversion result. Increasing the gain also reduces the input-referred noise, which is particularly useful when measuring low-level signals.

表 6-1 and 表 6-2 summarize the ADS111x noise performance. Data are representative of typical noise performance at T_A = 25°C with the inputs shorted together externally. 表 6-1 shows the input-referred noise in units of μV_{RMS} for the conditions shown. The μV_{PP} values are shown in parentheses. 表 6-2 shows the effective resolution calculated from μV_{RMS} values using 方程式 1. The noise-free resolution calculated from peak-to-peak noise values using 方程式 2 are shown in parentheses.

$$\text{Effective Resolution} = \ln(\text{FSR} / V_{\text{RMS-Noise}}) / \ln(2) \quad (1)$$

$$\text{Noise-Free Resolution} = \ln(\text{FSR} / V_{\text{PP-Noise}}) / \ln(2) \quad (2)$$

表 6-1. Noise in μV_{RMS} (μV_{PP}) at VDD = 3.3V

DATA RATE (SPS)	FSR (Full-Scale Range)					
	±6.144V	±4.096V	±2.048V	±1.024V	±0.512 V	±0.256 V
8	187.5 (187.5)	125 (125)	62.5 (62.5)	31.25 (31.25)	15.62 (15.62)	7.81 (7.81)
16	187.5 (187.5)	125 (125)	62.5 (62.5)	31.25 (31.25)	15.62 (15.62)	7.81 (7.81)
32	187.5 (187.5)	125 (125)	62.5 (62.5)	31.25 (31.25)	15.62 (15.62)	7.81 (7.81)
64	187.5 (187.5)	125 (125)	62.5 (62.5)	31.25 (31.25)	15.62 (15.62)	7.81 (7.81)
128	187.5 (187.5)	125 (125)	62.5 (62.5)	31.25 (31.25)	15.62 (15.62)	7.81 (12.35)
250	187.5 (252.09)	125 (148.28)	62.5 (84.03)	31.25 (39.54)	15.62 (16.06)	7.81 (18.53)
475	187.5 (266.92)	125 (227.38)	62.5 (79.08)	31.25 (56.84)	15.62 (32.13)	7.81 (25.95)
860	187.5 (430.06)	125 (266.93)	62.5 (118.63)	31.25 (64.26)	15.62 (40.78)	7.81 (35.83)

表 6-2. Effective Resolution from RMS Noise (Noise-Free Resolution from Peak-to-Peak Noise) at VDD = 3.3V

DATA RATE (SPS)	FSR (Full-Scale Range)					
	±6.144V	±4.096V	±2.048V	±1.024V	±0.512 V	±0.256 V
8	16 (16)	16 (16)	16 (16)	16 (16)	16 (16)	16 (16)
16	16 (16)	16 (16)	16 (16)	16 (16)	16 (16)	16 (16)
32	16 (16)	16 (16)	16 (16)	16 (16)	16 (16)	16 (16)
64	16 (16)	16 (16)	16 (16)	16 (16)	16 (16)	16 (16)
128	16 (16)	16 (16)	16 (16)	16 (16)	16 (16)	16 (15.33)
250	16 (15.57)	16 (15.75)	16 (15.57)	16 (15.66)	16 (15.96)	16 (14.75)
475	16 (15.49)	16 (15.13)	16 (15.66)	16 (15.13)	16 (14.95)	16 (14.26)
860	16 (14.8)	16 (14.9)	16 (15.07)	16 (14.95)	16 (14.61)	16 (13.8)

7 Detailed Description

7.1 Overview

The ADS111x devices are very small, low-power, 16-bit, delta-sigma ($\Delta\Sigma$) analog-to-digital converters (ADCs). The ADS111x consist of a $\Delta\Sigma$ ADC core with an internal voltage reference, a clock oscillator, and an I^2C interface. The ADS1114 and ADS1115 also integrate a programmable gain amplifier (PGA) and a programmable digital comparator. 图 7-1, 图 7-2, and 图 7-3 show the functional block diagrams of the ADS1115, ADS1114, and ADS1113, respectively.

The ADS111x ADC core measures a differential signal, V_{IN}, that is the difference of $V_{(AINP)}$ and $V_{(AINN)}$. The converter core consists of a differential, switched-capacitor $\Delta\Sigma$ modulator followed by a digital filter. This architecture results in a very strong attenuation of any common-mode signals. Input signals are compared to the internal voltage reference. The digital filter receives a high-speed bitstream from the modulator and outputs a code proportional to the input voltage.

The ADS111x have two available conversion modes: single-shot and continuous-conversion. In single-shot mode, the ADC performs one conversion of the input signal upon request, stores the conversion value to an internal conversion register, and then enters a power-down state. This mode is intended to provide significant power savings in systems that only require periodic conversions or when there are long idle periods between conversions. In continuous-conversion mode, the ADC automatically begins a conversion of the input signal as soon as the previous conversion is completed. The rate of continuous conversion is equal to the programmed data rate. Data can be read at any time and always reflect the most recent completed conversion.

7.2 Functional Block Diagrams

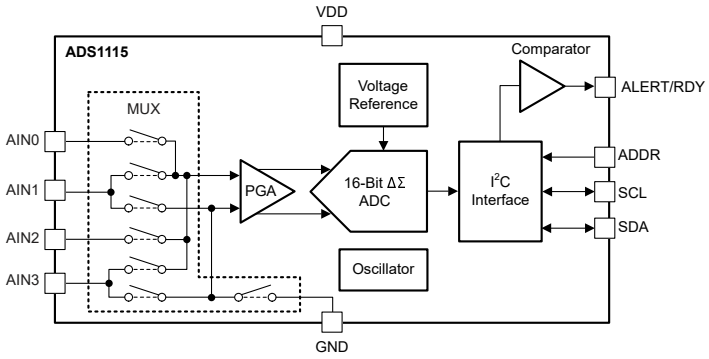


图 7-1. ADS1115 Block Diagram

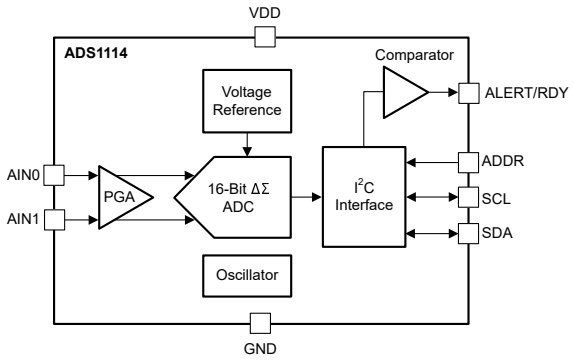


图 7-2. ADS1114 Block Diagram

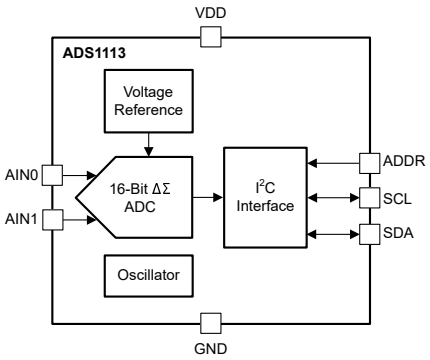


图 7-3. ADS1113 Block Diagram

7.3 Feature Description

7.3.1 Multiplexer

The ADS1115 contains an input multiplexer (MUX), as shown in 图 7-4. Either four single-ended or two differential signals can be measured. Additionally, AIN0 and AIN1 can be measured differentially to AIN3. The multiplexer is configured by bits MUX[2:0] in the Config register. When single-ended signals are measured, the negative input of the ADC is internally connected to GND by a switch within the multiplexer.

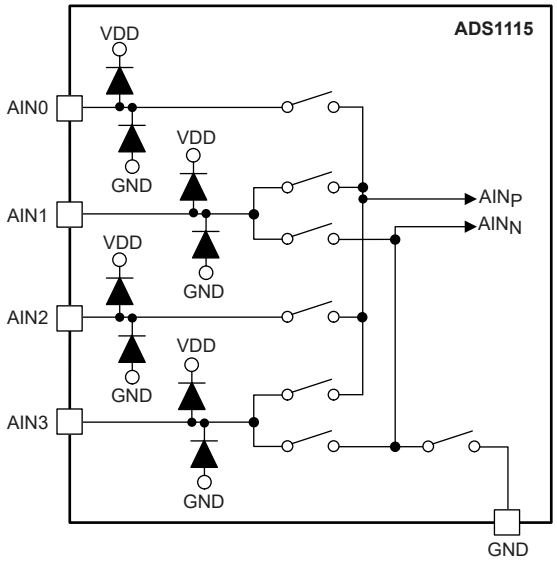


图 7-4. Input Multiplexer

The ADS1113 and ADS1114 do not have an input multiplexer and can measure either one differential signal or one single-ended signal. For single-ended measurements, connect the AIN1 pin to GND externally. In subsequent sections of this data sheet, AIN_P refers to AIN0 and AIN_N refers to AIN1 for the ADS1113 and ADS1114.

Electrostatic discharge (ESD) diodes connected to VDD and GND protect the ADS111x analog inputs. Keep the absolute voltage of any input within the range shown in 方程式 3 to prevent the ESD diodes from turning on.

$$GND - 0.3V < V_{(AINX)} < VDD + 0.3V \quad (3)$$

If the voltages on the input pins can potentially violate these conditions, use external Schottky diodes and series resistors to limit the input current to safe values (see the *Absolute Maximum Ratings* table). Overdriving an input on the ADS1115 can affect conversions taking place on other inputs. If overdriving an input is possible, clamp the signal with external Schottky diodes.

7.3.2 Analog Inputs

The ADS111x use a switched-capacitor input stage where capacitors are continuously charged and then discharged to measure the voltage between AIN_P and AIN_N. The frequency at which the input signal is sampled is called the sampling frequency or the modulator frequency (f_{MOD}). The ADS111x has a 1MHz internal oscillator that is further divided by a factor of 4 to generate f_{MOD} at 250kHz. The capacitors used in this input stage are small, and to external circuitry, the average loading appears resistive. 图 7-5 shows this structure. The capacitor values set the resistance and switching rate. 图 7-6 shows the timing for the switches in 图 7-5. During the sampling phase, switches S_1 are closed. This event charges C_{A1} to $V_{(AINP)}$, C_{A2} to $V_{(AINN)}$, and C_B to ($V_{(AINP)}$ – $V_{(AINN)}$). During the discharge phase, S_1 is first opened and then S_2 is closed. Both C_{A1} and C_{A2} then discharge to approximately 0.7V and C_B discharges to 0V. This charging draws a very small transient current from the source driving the ADS111x analog inputs. The average value of this current can be used to calculate the effective impedance (Z_{eff}), where $Z_{eff} = V_{IN} / I_{AVERAGE}$.

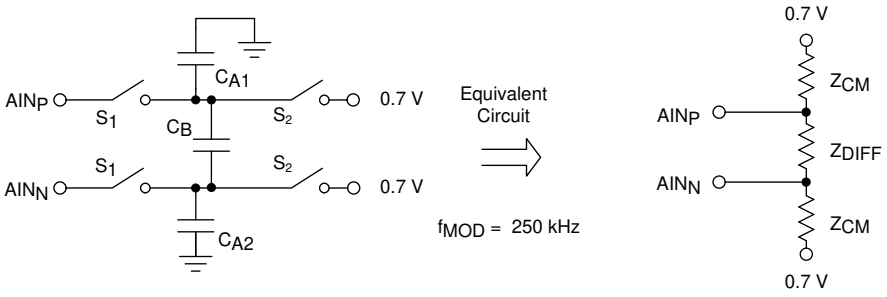


图 7-5. Simplified Analog Input Circuit

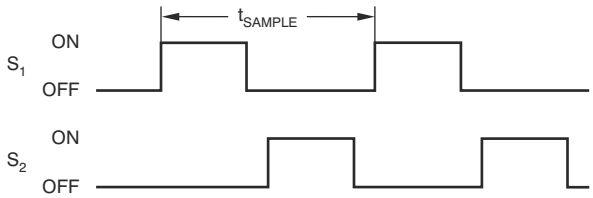


图 7-6. S_1 and S_2 Switch Timing

The common-mode input impedance is measured by applying a common-mode signal to the shorted AIN_P and AIN_N inputs and measuring the average current consumed by each pin. The common-mode input impedance changes depending on the full-scale range, but is approximately 6MΩ for the default full-scale range. In 图 7-5, the common-mode input impedance is Z_{CM}.

The differential input impedance is measured by applying a differential signal to AIN_P and AIN_N inputs where one input is held at 0.7V. The current that flows through the pin connected to 0.7 V is the differential current and scales with the full-scale range. In 图 7-5, the differential input impedance is Z_{DIFF}.

Make sure to consider the typical value of the input impedance. Unless the input source has a low impedance, the ADS111x input impedance can affect the measurement accuracy. For sources with high-output impedance, buffering can be necessary. Active buffers introduce noise, and also introduce offset and gain errors. Consider all of these factors in high-accuracy applications.

The clock oscillator frequency drifts slightly with temperature; therefore, the input impedances also drift. For most applications, this input impedance drift is negligible, and can be ignored.

7.3.3 Full-Scale Range (FSR) and LSB Size

A programmable gain amplifier (PGA) is implemented before the ΔΣ ADC of the ADS1114 and ADS1115. The full-scale range is configured by bits PGA[2:0] in the Config register and can be set to ±6.144V, ±4.096V, ±2.048V, ±1.024V, ±0.512V, and ±0.256V. 表 7-1 shows the FSR together with the corresponding LSB size. 方程式 4 shows how to calculate the LSB size from the selected full-scale range.

$$LSB = FSR / 2^{16} \quad (4)$$

表 7-1. Full-Scale Range and Corresponding LSB Size

FSR	LSB SIZE
±6.144V(1)	187.5 μV
±4.096V(1)	125 μV
±2.048V	62.5 μV
±1.024V	31.25 μV
±0.512V	15.625 μV
±0.256V	7.8125 μV

(1) This parameter expresses the full-scale range of the ADC scaling. Do not apply more than VDD + 0.3V to the analog inputs of the device.

The FSR of the ADS1113 is fixed at ±2.048V.

Analog input voltages must never exceed the analog input voltage limits given in the *Absolute Maximum Ratings*. If a VDD supply voltage greater than 4V is used, the ±6.144V full-scale range allows input voltages to extend up to the supply. Although in this case (or whenever the supply voltage is less than the full-scale range; for example, VDD = 3.3V and full-scale range = ±4.096V), a full-scale ADC output code cannot be obtained. For example, with VDD = 3.3V and FSR = ±4.096V, only differential signals up to V_{IN} = ±3.3V can be measured. The code range that represents voltages $|V_{IN}| > 3.3V$ is not used in this case.

7.3.4 Voltage Reference

The ADS111x have an integrated voltage reference. An external reference cannot be used with these devices.

The ADS111x does not use a traditional band-gap reference to generate the internal voltage reference. For that reason, the reference does not have an actual specified voltage value. Instead of using the reference voltage value and the gain setting to derive the full-scale range of the ADC, use the FSR values provided in 表 7-1 directly.

Errors associated with the initial voltage reference accuracy and the reference drift with temperature are included in the gain error and gain drift specifications in the *Electrical Characteristics* table.

7.3.5 Oscillator

The ADS111x have an integrated oscillator running at 1MHz. No external clock can be applied to operate these devices. The internal oscillator drifts over temperature and time. The output data rate scales proportionally with the oscillator frequency.

7.3.6 Output Data Rate and Conversion Time

The ADS111x offer programmable output data rates. Use the DR[2:0] bits in the Config register to select output data rates of 8SPS, 16SPS, 32SPS, 64SPS, 128SPS, 250SPS, 475SPS, or 860SPS.

Conversions in the ADS111x settle within a single cycle; thus, the conversion time is equal to 1 / DR.

7.3.7 Digital Comparator (ADS1114 and ADS1115 Only)

The ADS1115 and ADS1114 feature a programmable digital comparator that can issue an alert on the ALERT/RDY pin. The COMP_MODE bit in the Config register configures the comparator as either a traditional comparator or a window comparator. In traditional comparator mode, the ALERT/RDY pin asserts (active low by default) when conversion data exceeds the limit set in the high-threshold register (Hi_thresh). The comparator then deasserts only when the conversion data falls below the limit set in the low-threshold register (Lo_thresh). In window comparator mode, the ALERT/RDY pin asserts when the conversion data exceeds the Hi_thresh register or falls below the Lo_thresh register value.

In either window or traditional comparator mode, the comparator can be configured to latch after being asserted by the COMP_LAT bit in the Config register. This setting causes the assertion to remain even if the input signal is not beyond the bounds of the threshold registers. This latched assertion can only be cleared by issuing an SMBus alert response or by reading the Conversion register. The ALERT/RDY pin can be configured as active high or active low by the COMP_POL bit in the Config register. Operational diagrams for both the comparator modes are shown in ALERT Pin Timing Diagram.

The comparator can also be configured to activate the ALERT/RDY pin only after a set number of successive readings exceed the threshold values set in the threshold registers (Hi_thresh and Lo_thresh). The COMP_QUE[1:0] bits in the Config register configure the comparator to wait for one, two, or four readings beyond the threshold before activating the ALERT/RDY pin. The COMP_QUE[1:0] bits can also disable the comparator function and put the ALERT/RDY pin into a high state.

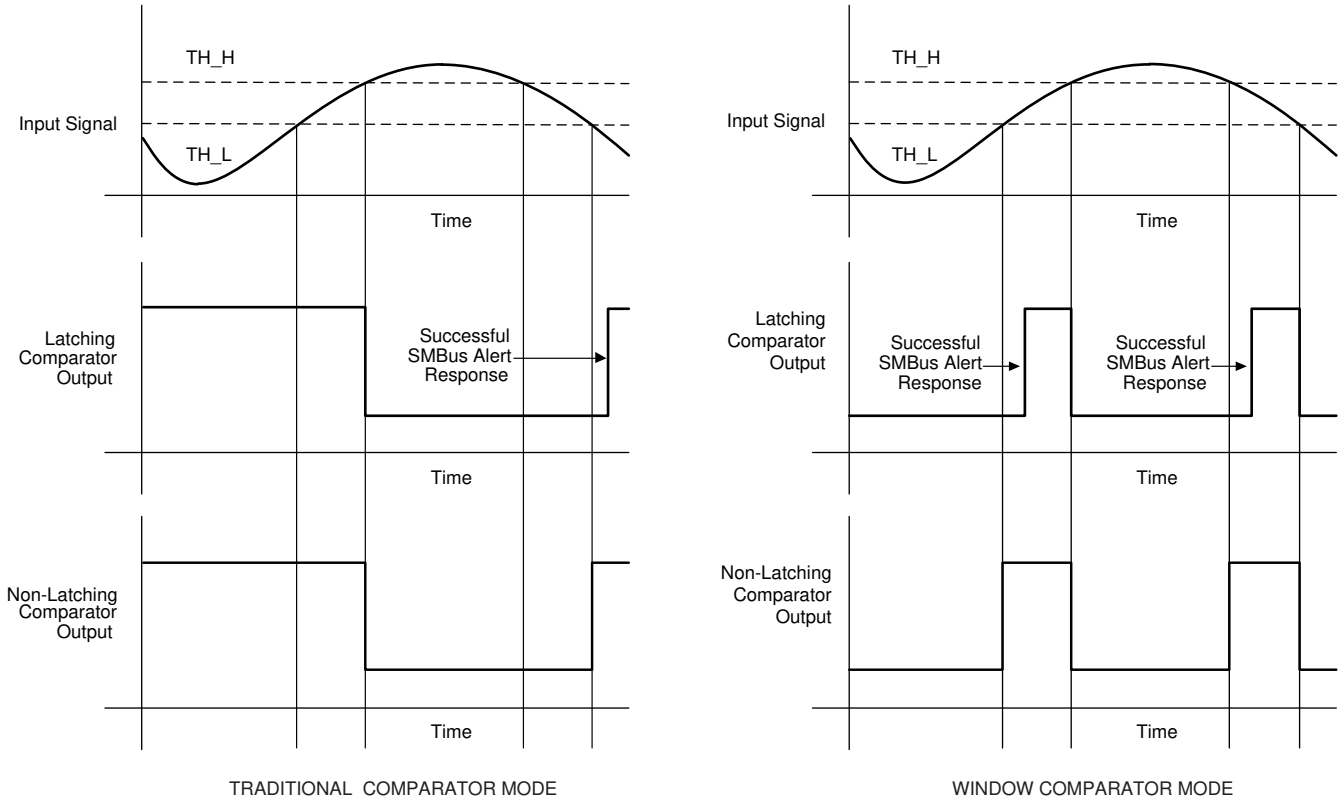


图 7-7. ALERT Pin Timing Diagram

7.3.8 Conversion Ready Pin (ADS1114 and ADS1115 Only)

The ALERT/RDY pin can also be configured as a conversion-ready pin. Set the most-significant bit of the Hi_thresh register to 1b and the most-significant bit of Lo_thresh register to 0b to enable the pin as a conversion-ready pin. The COMP_POL bit continues to function as expected. Set the COMP_QUE[1:0] bits to any 2-bit value other than 11b to keep the ALERT/RDY pin enabled, and allow the conversion-ready signal to appear at the ALERT/RDY pin output. The COMP_MODE and COMP_LAT bits no longer control any function. When configured as a conversion-ready pin, ALERT/RDY continues to require a pullup resistor. The ADS111x provide an approximately 8μs conversion-ready pulse on the ALERT/RDY pin at the end of each conversion in continuous-conversion mode, as shown in 图 7-8. In single-shot mode, the ALERT/RDY pin asserts low at the end of a conversion if the COMP_POL bit is set to 0b.

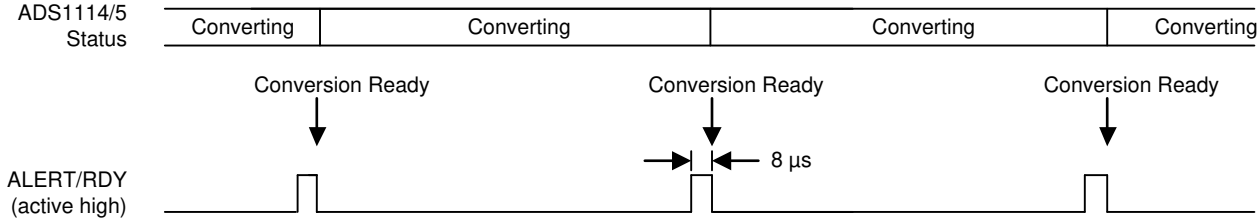


图 7-8. Conversion Ready Pulse in Continuous-Conversion Mode

7.3.9 SMbus Alert Response

In latching comparator mode (COMP_LAT = 1b), the ALERT/RDY pin asserts when the comparator detects a conversion that exceeds the upper or lower threshold value. This assertion is latched and can be cleared only by reading conversion data, or by issuing a successful SMBus alert response and reading the asserting device I^2C address. If conversion data exceed the upper or lower threshold values after being cleared, the pin reasserts. This assertion does not affect conversions that are already in progress. The ALERT/RDY pin is an open-drain output. This architecture allows several devices to share the same interface bus. When disabled, the pin holds a high state so that the pin does not interfere with other devices on the same bus line.

When the controller senses that the ALERT/RDY pin has latched, the controller issues an SMBus alert command (00011001b) to the I^2C bus. Any ADS1114 and ADS1115 data converters on the I^2C bus with the ALERT/RDY pins asserted respond to the command with the target address. If more than one ADS111x on the I^2C bus assert the latched ALERT/RDY pin, arbitration during the address response portion of the SMBus alert determines which device clears assertion. The device with the lowest I^2C address always wins arbitration. If a device loses arbitration, the device does not clear the comparator output pin assertion. The controller then repeats the SMBus alert response until all devices have the respective assertions cleared. In window comparator mode, the SMBus alert status bit indicates a 1b if signals exceed the high threshold, and a 0b if signals exceed the low threshold.

7.4 Device Functional Modes

7.4.1 Reset and Power-Up

The ADS111x reset on power-up and set all the bits in the Config register to the respective default settings. The ADS111x enter a power-down state after completion of the reset process. The device interface and digital blocks are active, but no data conversions are performed. The initial power-down state of the ADS111x relieves systems with tight power-supply requirements from encountering a surge during power-up.

The ADS111x respond to the I^2C general-call reset commands. When the ADS111x receive a general call reset command (06h), an internal reset is performed as if the device is powered up.

7.4.2 Operating Modes

The ADS111x operate in one of two modes: continuous-conversion or single-shot. The MODE bit in the Config register selects the respective operating mode.

7.4.2.1 Single-Shot Mode

When the MODE bit in the Config register is set to 1b, the ADS111x enter a power-down state, and operate in single-shot mode. This power-down state is the default state for the ADS111x when power is first applied. Although powered down, the devices still respond to commands. The ADS111x remain in this power-down state until a 1b is written to the operational status (OS) bit in the Config register. When the OS bit is asserted, the device powers up in approximately 25 μs, resets the OS bit to 0b, and starts a single conversion. When conversion data are ready for retrieval, the device powers down again. Writing a 1b to the OS bit while a conversion is ongoing has no effect. To switch to continuous-conversion mode, write a 0b to the MODE bit in the Config register.

7.4.2.2 Continuous-Conversion Mode

In continuous-conversion mode (MODE bit set to 0b), the ADS111x perform conversions continuously. When a conversion is complete, the ADS111x place the result in the Conversion register and immediately begin another conversion. When writing new configuration settings, the currently ongoing conversion completes with the previous configuration settings. Thereafter, continuous conversions with the new configuration settings start. To switch to single-shot conversion mode, write a 1b to the MODE bit in the configuration register or reset the device.

7.4.3 Duty Cycling For Low Power

The noise performance of a $\Delta\Sigma$ ADC generally improves when lowering the output data rate because more samples of the internal modulator are averaged to yield one conversion result. In applications where power consumption is critical, improved noise performance at low data rates is not always required. For these applications, the ADS111x support duty cycling that yields significant power savings by periodically requesting high data rate readings at an effectively lower data rate. For example, an ADS111x in the power-down state with a data rate set to 860SPS can be operated by a microcontroller that instructs a single-shot conversion every 125ms (8SPS). A conversion at 860SPS only requires approximately 1.2ms, so the ADS111x enter power-down state for the remaining 123.8ms. In this configuration, the ADS111x consume approximately 1/100th the power that is otherwise consumed in continuous-conversion mode. The duty cycling rate is completely arbitrary and is defined by the controller. The ADS111x offer lower data rates that do not implement duty cycling and also offer improved noise performance if required.

7.5 Programming

7.5.1 I²C Interface

The ADS111x communicate through an I²C interface. I²C is a two-wire open-drain interface that supports multiple devices and controllers on a single bus. Devices on the I²C bus only drive the bus lines low by connecting them to ground; the devices never drive the bus lines high. Instead, the bus wires are pulled high by pullup resistors, so the bus wires are always high when no device is driving them low. As a result of this configuration, two devices cannot conflict. If two devices drive the bus simultaneously, there is no driver contention.

Communication on the I²C bus always takes place between two devices, one acting as the controller and the other as the target. Both the controller and target can read and write, but the target can only do so under the direction of the controller. Some I²C devices can act as a controller or target, but the ADS111x can only act as a target device.

An I²C bus consists of two lines: SDA and SCL. SDA carries data; SCL provides the clock. All data are transmitted across the I²C bus in groups of eight bits. To send a bit on the I²C bus, drive the SDA line to the appropriate level while SCL is low (a low on SDA indicates the bit is zero; a high indicates the bit is one). After the SDA line settles, the SCL line is brought high, then low. This pulse on SCL clocks the SDA bit into the receiver shift register. If the I²C bus is held idle for more than 25 ms, the bus times out.

The I²C bus is bidirectional; that is, the SDA line is used for both transmitting and receiving data. When the controller reads from a target, the target drives the data line; when the controller writes to a target, the controller drives the data line. The controller always drives the clock line. The ADS111x cannot act as a controller, and therefore can never drive SCL.

Most of the time the bus is idle; no communication occurs, and both lines are high. When communication takes place, the bus is active. Only a controller device can start a communication and initiate a START condition on the bus. Normally, the data line is only allowed to change state when the clock line is low. If the data line changes state when the clock line is high, this change is either a START condition or a STOP condition. A START condition occurs when the clock line is high, and the data line goes from high to low. A STOP condition occurs when the clock line is high, and the data line goes from low to high.

After the controller issues a START condition, the controller sends a byte that indicates which target device to communicate with. This byte is called the *address byte*. Each device on an I²C bus has a unique 7-bit address that the device responds to. The controller sends an address in the address byte, together with a bit that indicates whether the controller wishes to read from or write to the target device.

Every byte (address and data) transmitted on the I²C bus is acknowledged with an *acknowledge* bit. When the controller finishes sending a byte (eight data bits) to a target, the controller stops driving SDA and waits for the target to acknowledge the byte. The target acknowledges the byte by pulling SDA low. The controller then sends a clock pulse to clock the acknowledge bit. Similarly, when the controller completes reading a byte, the controller pulls SDA low to acknowledge this completion to the target. The controller then sends a clock pulse to clock the bit. The controller always drives the clock line.

If a device is not present on the bus, and the controller attempts to address the device, the controller receives a *not-acknowledge* because no device is present at that address to pull the line low. A not-acknowledge is performed by simply leaving SDA high during an acknowledge cycle.

When the controller has finished communicating with a target, the controller can issue a STOP condition. When a STOP condition is issued, the bus becomes idle again. The controller can also issue another START condition. When a START condition is issued while the bus is active, this condition is called a repeated start condition.

The *Timing Requirements* section shows a timing diagram for the ADS111x I²C communication.

7.5.1.1 I²C Address Selection

The ADS111x have one address pin, ADDR, that configures the I²C address of the device. This pin can be connected to GND, VDD, SDA, or SCL, allowing for four different addresses to be selected with one pin, as shown in 表 7-2. The state of address pin ADDR is sampled continuously. Use the GND, VDD and SCL addresses first. If SDA is used as the device address, hold the SDA line low for at least 100 ns after the SCL line goes low to make sure the device decodes the address correctly during I²C communication.

表 7-2. ADDR Pin Connection and Corresponding Target Address

ADDR PIN CONNECTION	TARGET ADDRESS
GND	1001000b
VDD	1001001b
SDA	1001010b
SCL	1001011b

7.5.1.2 I²C General Call

The ADS111x respond to the I²C general call address (0000000b) if the eighth bit is 0b. The devices acknowledge the general call address and respond to commands in the second byte. If the second byte is 00000110b (06h), the ADS111x reset the internal registers and enter a power-down state.

7.5.1.3 I²C Speed Modes

The I²C bus operates at one of three speeds. Standard mode allows a clock frequency of up to 100kHz; fast mode permits a clock frequency of up to 400kHz; and high-speed mode (also called Hs mode) allows a clock frequency of up to 3.4MHz. The ADS111x are fully compatible with all three modes.

No special action is required to use the ADS111x in standard or fast mode, but high-speed mode must be activated. To activate high-speed mode, send a special address byte of *00001xxxb* following the START condition, where *xxx* are bits unique to the Hs-capable controller. This byte is called the Hs controller code, and is different from normal address bytes; the eighth bit does not indicate read/write status. The ADS111x do not acknowledge this byte; the I²C specification prohibits acknowledgment of the Hs controller code. Upon receiving a controller code, the ADS111x switch on Hs mode filters, and communicate at up to 3.4MHz. The ADS111x switch out of Hs mode with the next STOP condition.

For more information on high-speed mode, consult the I²C specification.

7.5.2 Target Mode Operations

The ADS111x act as target receivers or target transmitters. The ADS111x cannot drive the SCL line as target devices.

7.5.2.1 Receive Mode

In target receive mode, the first byte transmitted from the controller to the target consists of the 7-bit device address followed by a low R/$\overline{W}$ bit. The next byte transmitted by the controller is the Address Pointer register. The ADS111x then acknowledge receipt of the Address Pointer register byte. The next two bytes are written to the address given by the register address pointer bits, P[1:0]. The ADS111x acknowledge each byte sent. Register bytes are sent with the most significant byte first, followed by the least significant byte.

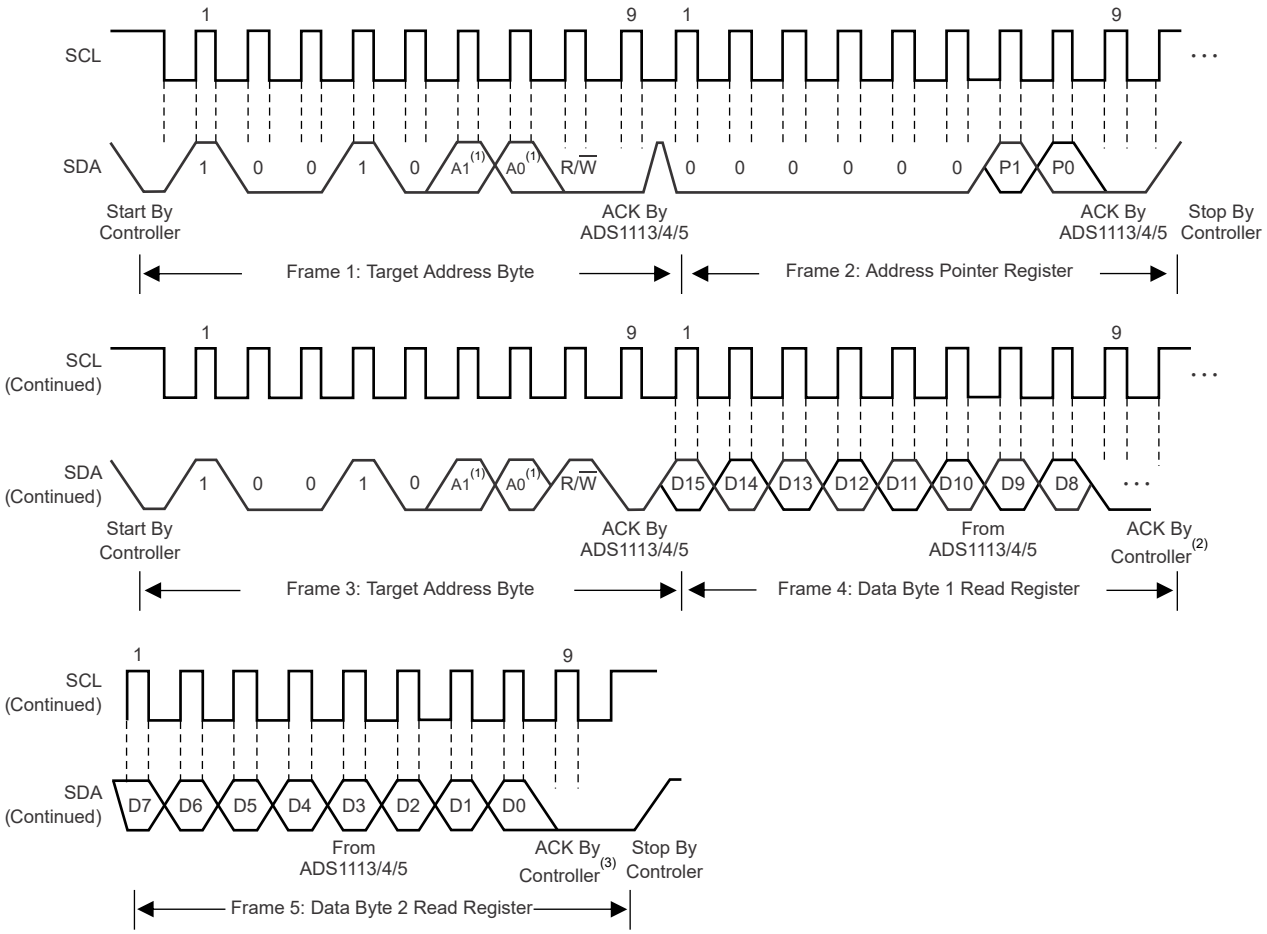
7.5.2.2 Transmit Mode

In target transmit mode, the first byte transmitted by the controller is the 7-bit target address followed by the high R/$\overline{W}$ bit. This byte places the target into transmit mode and indicates that the ADS111x are being read from. The next byte transmitted by the target is the most significant byte of the register that is indicated by the register address pointer bits, P[1:0]. This byte is followed by an acknowledgment from the controller. The remaining least significant byte is then sent by the target and is followed by an acknowledgment from the controller. The controller can terminate transmission after any byte by not acknowledging or issuing a START or STOP condition.

7.5.3 Writing To and Reading From the Registers

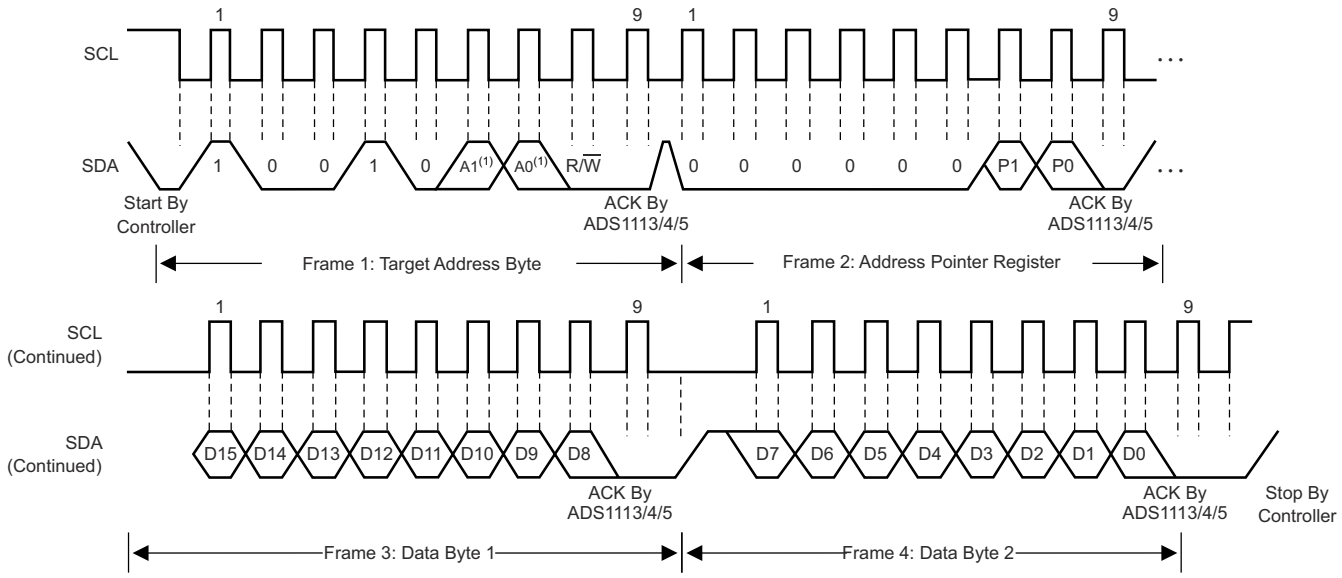
To access a specific register from the ADS111x, the controller must first write an appropriate value to register address pointer bits P[1:0] in the Address Pointer register. The Address Pointer register is written to directly after the target address byte, low R/$\overline{W}$ bit, and a successful target acknowledgment. After the Address Pointer register is written, the target acknowledges, and the controller issues a STOP or a repeated START condition.

When reading from the ADS111x, the previous value written to bits P[1:0] determines the register that is read. To change which register is read, a new value must be written to P[1:0]. To write a new value to P[1:0], the controller issues a target address byte with the R/$\overline{W}$ bit low, followed by the Address Pointer register byte. No additional data has to be transmitted, and a STOP condition can be issued by the controller. The controller can now issue a START condition and send the target address byte with the R/$\overline{W}$ bit high to begin the read. 图 7-9 details this sequence. If repeated reads from the same register are desired, there is no need to continually send the Address Pointer register, because the ADS111x store the value of P[1:0] until modified by a write operation. However, for every write operation, the Address Pointer register must be written with the appropriate values.



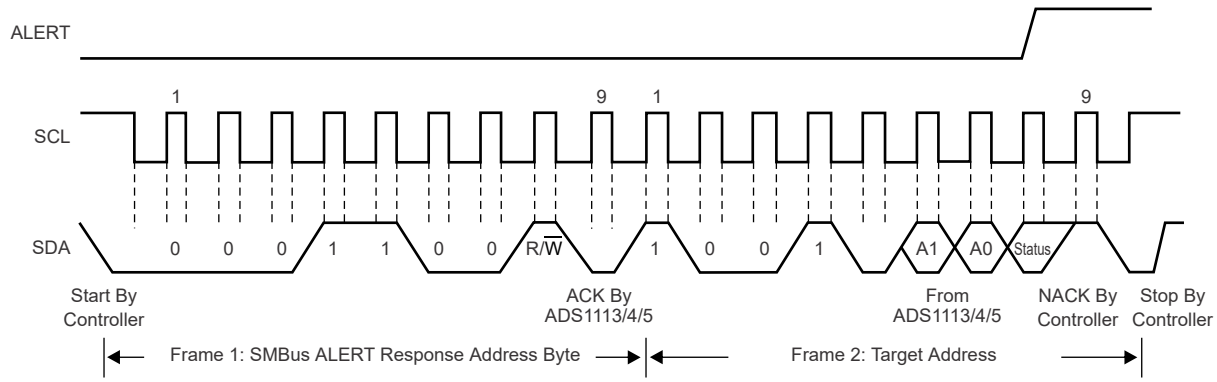
A. The values of A0 and A1 are determined by the ADDR pin.
B. The controller can leave SDA high to terminate a single-byte read operation.
C. The controller can leave SDA high to terminate a two-byte read operation.

图 7-9. Timing Diagram for Reading From the ADS111x



A. The values of A0 and A1 are determined by the ADDR pin.

图 7-10. Timing Diagram for Writing to the ADS111x



A. The values of A0 and A1 are determined by the ADDR pin.

图 7-11. Timing Diagram for SMBus Alert Response

7.5.4 Data Format

The ADS111x provide 16 bits of data in binary 2's-complement format. A positive full-scale (+FS) input produces an output code of 7FFFh and a negative full-scale (–FS) input produces an output code of 8000h. The output clips at these codes for signals that exceed full-scale. 表 7-3 summarizes the ideal output codes for different input signals. 图 7-12 shows code transitions versus input voltage.

表 7-3. Input Signal Versus Ideal Output Code

INPUT SIGNAL $V_{IN} = (V_{AINP} - V_{AINN})$	IDEAL OUTPUT CODE(1) (1)
≥ +FS $(2^{15} - 1)/2^{15}$	7FFFh
$+FS/2^{15}$	0001h
0	0000h
$-FS/2^{15}$	FFFFh
≤ –FS	8000h

(1) Excludes the effects of noise, INL, offset, and gain errors.

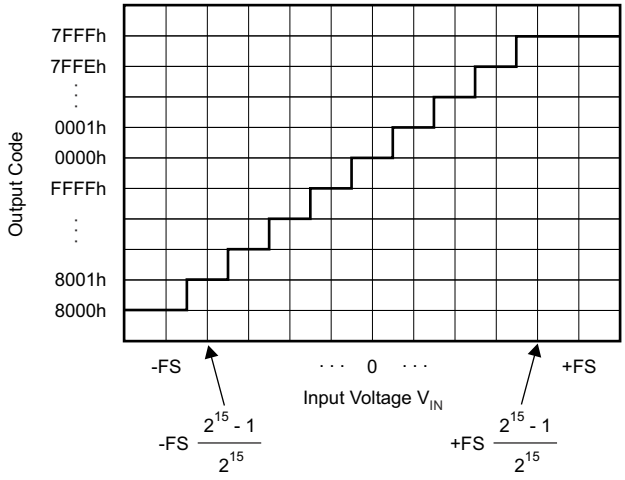


图 7-12. Code Transition Diagram

备注

Single-ended signal measurements, where V_{AINN} = 0V and V_{AINP} = 0V to +FS, only use the positive code range from 0000h to 7FFFh. However, because of device offset, the ADS111x can still output negative codes in case V_{AINP} is close to 0V.

8 Registers

8.1 Register Map

The ADS111x have four registers that are accessible through the I^2C interface using the Address Pointer register. The Conversion register contains the result of the last conversion. The Config register is used to change the ADS111x operating modes and query the status of the device. The other two registers, Lo_thresh and Hi_thresh, set the threshold values used for the comparator function, and are not available in the ADS1113.

8.1.1 Address Pointer Register (address = N/A) [reset = N/A]

All four registers are accessed by writing to the Address Pointer register; see 图 7-9.

图 8-1. Address Pointer Register

7	6	5	4	3	2	1	0
RESERVED						P[1:0]	
W-000000b						W-00b	

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

表 8-1. Address Pointer Register Field Descriptions

Bit	Field	Type	Reset	Description
7:2	RESERVED	W	000000b	Always write 000000b
1:0	P[1:0]	W	00b	**Register address pointer** 00b : Conversion register 01b : Config register 10b : Lo_thresh register 11b : Hi_thresh register

8.1.2 Conversion Register (P[1:0] = 00b) [reset = 0000h]

The 16-bit Conversion register contains the result of the last conversion in binary two's-complement format. Following power-up, the Conversion register is cleared to 0000h, and remains 0000h until the first conversion completes.

图 8-2. Conversion Register

15	14	13	12	11	10	9	8
D[15:8]							
R-00h							
7	6	5	4	3	2	1	0
D[7:0]							
R-00h							

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

表 8-2. Conversion Register Field Descriptions

Bit	Field	Type	Reset	Description
15:0	D[15:0]	R	0000h	16-bit conversion result

8.1.3 Config Register (P[1:0] = 01b) [reset = 8583h]

The 16-bit Config register controls the operating mode, input selection, data rate, full-scale range, and comparator modes.

图 8-3. Config Register — ADS1113

15	14	13	12	11	10	9	8
OS	RESERVED						MODE
R/W-1b	R/W-000010b						R/W-1b
7	6	5	4	3	2	1	0
DR[2:0]			RESERVED				
R/W-100b			R/W-00011b				

图 8-4. Config Register — ADS1114

15	14	13	12	11	10	9	8
OS	RESERVED			PGA[2:0]			MODE
R/W-1b	R/W-000b			R/W-010b			R/W-1b
7	6	5	4	3	2	1	0
DR[2:0]			COMP_MODE	COMP_POL	COMP_LAT	COMP_QUE[1:0]	
R/W-100b			R/W-0b	R/W-0b	R/W-0b	R/W-11b	

图 8-5. Config Register — ADS1115

15	14	13	12	11	10	9	8
OS	MUX[2:0]			PGA[2:0]			MODE
R/W-1b	R/W-000b			R/W-010b			R/W-1b
7	6	5	4	3	2	1	0
DR[2:0]			COMP_MODE	COMP_POL	COMP_LAT	COMP_QUE[1:0]	
R/W-100b			R/W-0b	R/W-0b	R/W-0b	R/W-11b	

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

表 8-3. Config Register Field Descriptions

Bit	Field	Type	Reset	Description
15	OS	R/W	1b	**Operational status or single-shot conversion start** This bit determines the operational status of the device. OS can only be written when in power-down state and has no effect when a conversion is ongoing. When writing: 0b : No effect 1b : Start a single conversion (when in power-down state) When reading: 0b : Device is currently performing a conversion. 1b : Device is not currently performing a conversion.
14:12	MUX[2:0]	R/W	000b	**Input multiplexer configuration (ADS1115 only)** These bits configure the input multiplexer. *These bits serve no function on the ADS1113 and ADS1114. ADS1113 and ADS1114 always use inputs AIN_P = AIN0 and AIN_N = AIN1.* 000b : AIN_P = AIN0 and AIN_N = AIN1 (default) 001b : AIN_P = AIN0 and AIN_N = AIN3 010b : AIN_P = AIN1 and AIN_N = AIN3 011b : AIN_P = AIN2 and AIN_N = AIN3 100b : AIN_P = AIN0 and AIN_N = GND 101b : AIN_P = AIN1 and AIN_N = GND 110b : AIN_P = AIN2 and AIN_N = GND 111b : AIN_P = AIN3 and AIN_N = GND

表 8-3. Config Register Field Descriptions（续）

Bit	Field	Type	Reset	Description
11:9	PGA[2:0]	R/W	010b	**Programmable gain amplifier configuration** These bits set the FSR of the programmable gain amplifier. *These bits serve no function on the ADS1113. ADS1113 always uses FSR = ±2.048V.* 000b : FSR = ±6.144V(1) 001b : FSR = ±4.096V(1) 010b : FSR = ±2.048V (default) 011b : FSR = ±1.024V 100b : FSR = ±0.512V 101b : FSR = ±0.256V 110b : FSR = ±0.256V 111b : FSR = ±0.256V
8	MODE	R/W	1b	**Device operating mode** This bit controls the operating mode. 0b : Continuous-conversion mode 1b : Single-shot mode or power-down state (default)
7:5	DR[2:0]	R/W	100b	**Data rate** These bits control the data rate setting. 000b : 8SPS 001b : 16SPS 010b : 32SPS 011b : 64SPS 100b : 128SPS (default) 101b : 250SPS 110b : 475SPS 111b : 860SPS
4	COMP_MODE	R/W	0b	**Comparator mode (ADS1114 and ADS1115 only)** This bit configures the comparator operating mode. *This bit serves no function on the ADS1113.* 0b : Traditional comparator (default) 1b : Window comparator
3	COMP_POL	R/W	0b	**Comparator polarity (ADS1114 and ADS1115 only)** This bit controls the polarity of the ALERT/RDY pin. *This bit serves no function on the ADS1113.* 0b : Active low (default) 1b : Active high
2	COMP_LAT	R/W	0b	**Latching comparator (ADS1114 and ADS1115 only)** This bit controls whether the ALERT/RDY pin latches after being asserted or clears after conversions are within the margin of the upper and lower threshold values. *This bit serves no function on the ADS1113.* 0b : Nonlatching comparator. The ALERT/RDY pin does not latch when asserted (default). 1b : Latching comparator. The asserted ALERT/RDY pin remains latched until conversion data are read by the controller or an appropriate SMBus alert response is sent by the controller. The device responds with an address, and is the lowest address currently asserting the ALERT/RDY bus line.
1:0	COMP_QUE[1:0]	R/W	11b	**Comparator queue and disable (ADS1114 and ADS1115 only)** These bits perform two functions. When set to 11, the comparator is disabled and the ALERT/RDY pin is set to a high-impedance state. When set to any other value, the ALERT/RDY pin and the comparator function are enabled, and the set value determines the number of successive conversions exceeding the upper or lower threshold required before asserting the ALERT/RDY pin. *These bits serve no function on the ADS1113.* 00b : Assert after one conversion 01b : Assert after two conversions 10b : Assert after four conversions 11b : Disable comparator and set ALERT/RDY pin to high-impedance (default)

(1) This parameter expresses the full-scale range of the ADC scaling. Do not apply more than VDD + 0.3V to the analog inputs of the device.

8.1.4 Lo_thresh (P[1:0] = 10b) [reset = 8000h] and Hi_thresh (P[1:0] = 11b) [reset = 7FFFh] Registers

These two registers are applicable to the ADS1115 and ADS1114. These registers serve no purpose in the ADS1113. The upper and lower threshold values used by the comparator are stored in two 16-bit registers in 2's complement format. The comparator is implemented as a digital comparator; therefore, the values in these registers must be updated whenever the PGA settings are changed.

The conversion-ready function of the ALERT/RDY pin is enabled by setting the Hi_thresh register MSB to 1b and the Lo_thresh register MSB to 0b. To use the comparator function of the ALERT/RDY pin, the Hi_thresh register value must always be greater than the Lo_thresh register value. The threshold register formats are shown in 图 8-6. When set to RDY mode, the ALERT/RDY pin outputs the OS bit when in single-shot mode, and provides a continuous-conversion ready pulse when in continuous-conversion mode.

图 8-6. Lo_thresh Register

15	14	13	12	11	10	9	8
Lo_thresh[15:8]							
R/W-80h							
7	6	5	4	3	2	1	0
Lo_thresh[7:0]							
R/W-00h							

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

表 8-4. Hi_thresh Register

15	14	13	12	11	10	9	8
Hi_thresh[15:8]							
R/W-7Fh							
7	6	5	4	3	2	1	0
Hi_thresh[7:0]							
R/W-FFh							

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

表 8-5. Lo_thresh and Hi_thresh Register Field Descriptions

Bit	Field	Type	Reset	Description
15:0	Lo_thresh[15:0]	R/W	8000h	Low threshold value
15:0	Hi_thresh[15:0]	R/W	7FFFh	High threshold value

9 Application and Implementation

备注

以下应用部分中的信息不属于 TI 器件规格的范围，TI 不担保其准确性和完整性。TI 的客 户应负责确定器件是否适用于其应用。客户应验证并测试其设计，以确保系统功能。

9.1 Application Information

The following sections give example circuits and suggestions for using the ADS111x in various situations.

9.1.1 Basic Connections

The principle I²C connections for the ADS1115 are shown in 图 9-1.

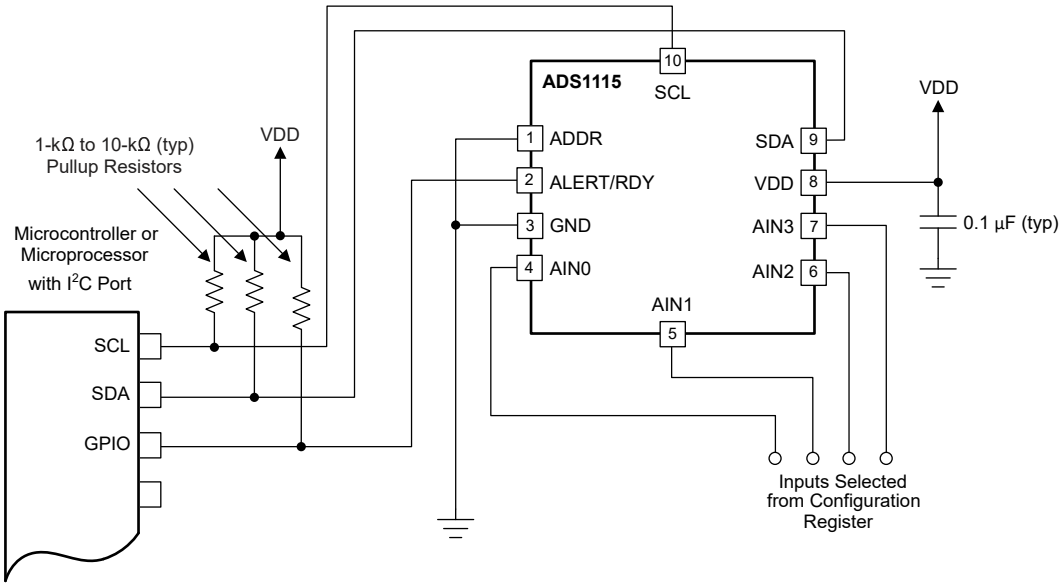


图 9-1. Typical Connections of the ADS1115

The fully-differential voltage input of the ADS111x is ideal for connection to differential sources with moderately low source impedance, such as thermocouples and thermistors. Although the ADS111x can read bipolar differential signals, these devices cannot accept negative voltages on either input.

The ADS111x draw transient currents during conversion. A 0.1 µF power-supply bypass capacitor supplies the momentary bursts of extra current required from the supply.

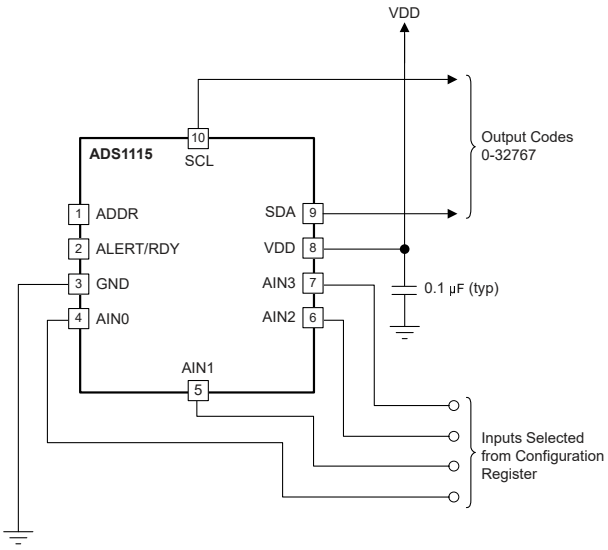
The ADS111x interface directly to standard mode, fast mode, and high-speed mode I²C controllers. Any microcontroller I²C peripheral, including controller-only and single-controller I²C peripherals, operates with the ADS111x. The ADS111x does not perform clock-stretching (that is, the device never pulls the clock line low), so this function does not need to be provided for unless other clock-stretching devices are on the same I²C bus.

Pullup resistors are required on both the SDA and SCL lines because I²C bus drivers are open drain. The size of these resistors depends on the bus operating speed and capacitance of the bus lines. Higher-value resistors consume less power, but increase the transition times on the bus, thus limiting the bus speed. Lower-value resistors allow higher speed, but at the expense of higher power consumption. Long bus lines have higher capacitance and require smaller pullup resistors to compensate. Do not use resistors that are too small to avoid bus drivers being unable to pull the bus lines low.

9.1.2 Single-Ended Inputs

The ADS1113 and ADS1114 can measure one, and the ADS1115 up to four, single-ended signals. The ADS1113 and ADS1114 can measure single-ended signals by connecting AIN1 to GND externally. The ADS1115 measures single-ended signals by appropriate configuration of the MUX[2:0] bits in the Config register. 图 9-2 shows a single-ended connection scheme for ADS1115. The single-ended signal ranges from 0 V up to positive supply or +FS, whichever is lower. Negative voltages cannot be applied to these devices because the ADS111x can only accept positive voltages with respect to ground. The ADS111x do not lose linearity within the input range.

The ADS111x offer a differential input voltage range of ±FSR. Single-ended configurations use only one-half of the full-scale input voltage range. Differential configurations maximize the dynamic range of the ADC and provide better common-mode noise rejection than single-ended configurations.



NOTE: Digital pin connections are omitted for clarity.

图 9-2. Measuring Single-Ended Inputs

The ADS1115 also allows AIN3 to serve as a common point for measurements by the appropriate setting of the MUX[2:0] bits. AIN0, AIN1, and AIN2 can all be measured with respect to AIN3. In this configuration, the ADS1115 operates with inputs, where AIN3 serves as the common point. This ability improves the usable range over the single-ended configuration because negative differential voltages are allowed when
GND < $V_{(AIN3)}$ < VDD; however, common-mode noise attenuation is not offered.

9.1.3 Input Protection

The ADS111x are fabricated in a small-geometry, low-voltage process. The analog inputs feature protection diodes to the supply rails. However, the current-handling ability of these diodes is limited, and the ADS111x can be permanently damaged by analog input voltages that exceed approximately 300mV beyond the rails for extended periods. One way to protect against overvoltage is to place current-limiting resistors on the input lines. The ADS111x analog inputs can withstand continuous currents as large as 10mA.

9.1.4 Unused Inputs and Outputs

Follow the guidelines below for the connection of unused device pins:

- Either float unused analog inputs, or tie unused analog inputs to GND.
- Either float NC (not connected) pins, or tie the NC pins to GND.
- If the ALERT/RDY output pin is not used, leave the pin unconnected or tie the pin to VDD using a weak pullup resistor.

9.1.5 Analog Input Filtering

Analog input filtering serves two purposes:

1. Limits the effect of aliasing during the sampling process
2. Reduces external noise from being a part of the measurement

Aliasing occurs when frequency components are present in the input signal that are higher than half the sampling frequency of the ADC (also known as the *Nyquist frequency*). These frequency components fold back and show up in the actual frequency band of interest below half the sampling frequency. The filter response of the digital filter repeats at multiples of the sampling frequency, also known as the modulator frequency (f_{MOD}), as shown in 图 9-3. Signals or noise up to a frequency where the filter response repeats are attenuated to a certain amount by the digital filter depending on the filter architecture. Any frequency components present in the input signal around the modulator frequency, or multiples thereof, are not attenuated and alias back into the band of interest, unless attenuated by an external analog filter.

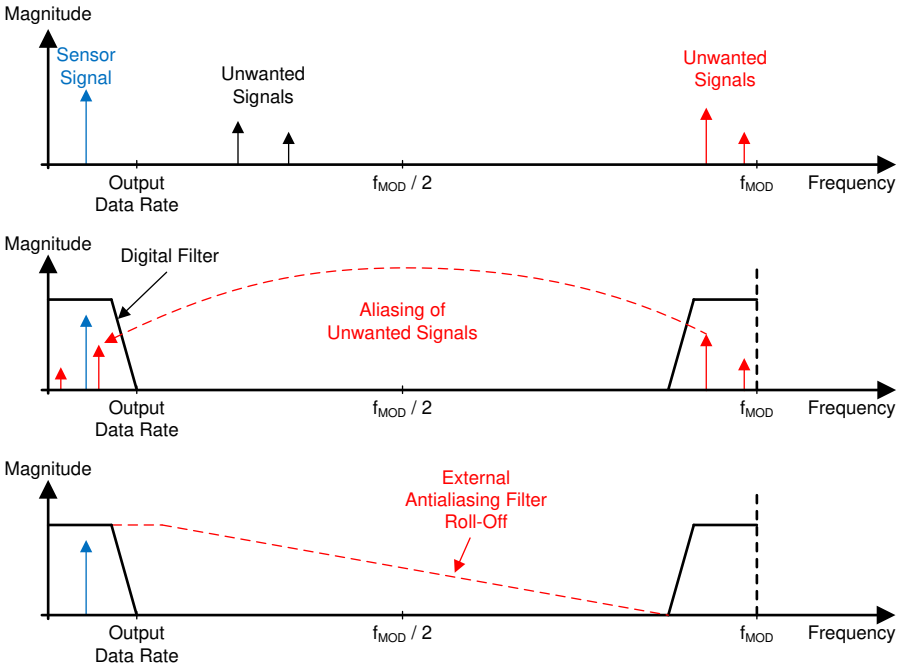


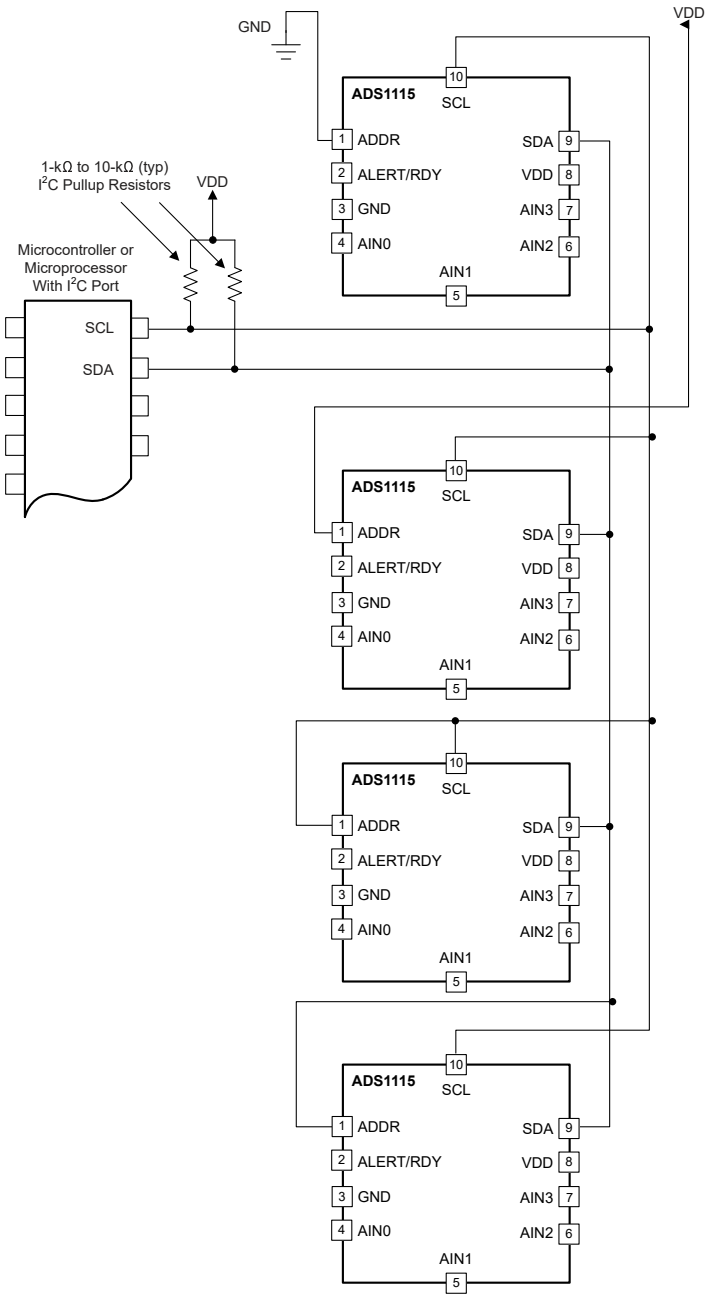
图 9-3. Effect of Aliasing

Many sensor signals are inherently band-limited; for example, the output of a thermocouple has a limited rate of change. In this case, the sensor signal does not alias back into the pass-band when using a ΔΣ ADC. However, any noise pick-up along the sensor wiring or the application circuitry can potentially alias into the pass-band. Power line-cycle frequency and harmonics are one common noise source. External noise can also be generated from electromagnetic interference (EMI) or radio frequency interference (RFI) sources, such as nearby motors and cellular phones. Another noise source typically exists on the printed-circuit-board (PCB) in the form of clocks and other digital signals. Analog input filtering helps remove unwanted signals from affecting the measurement result.

A first-order resistor-capacitor (RC) filter is (in most cases) sufficient to either totally eliminate aliasing, or to reduce the effect of aliasing to a level within the noise floor of the sensor. Ideally, any signal beyond f_{MOD} / 2 is attenuated to a level below the noise floor of the ADC. The digital filter of the ADS111x attenuate signals to a certain degree, as shown in 图 5-21. In addition, noise components are usually smaller in magnitude than the actual sensor signal. Therefore, use a first-order RC filter with a cutoff frequency set at the output data rate or 10x higher as a generally good starting point for a system design.

9.1.6 Connecting Multiple Devices

Up to four ADS111x devices can be connected to a single I²C bus using different address pin configurations for each device. Use the address pin to set the ADS111x to one of four different I²C addresses. Use the GND, VDD, and SCL addresses first. If SDA is used as the device address, hold the SDA line low for at least 100 ns after the SCL line goes low to make sure the device decodes the address correctly during I²C communication. An example showing four ADS111x devices on the same I²C bus is shown in 图 9-4. One set of pullup resistors is required per bus. If needed, lower the pullup resistor values to compensate for the additional bus capacitance presented by multiple devices and increased line length.



NOTE: The ADS111x power and input connections are omitted for clarity. The ADDR pin selects the I²C address.

图 9-4. Connecting Multiple ADS111x Devices

9.1.7 Quick-Start Guide

This section provides a brief example of ADS111x communications. Hardware for this design includes: one ADS111x configured with an I²C address of 1001000b; a microcontroller with an I²C interface; discrete components such as resistors, capacitors, and serial connectors; and a 2-V to 5V power supply. 图 9-5 shows the basic hardware configuration.

The ADS111x communicate with the controller (microcontroller) through an I²C interface. The controller provides a clock signal on the SCL pin and data are transferred using the SDA pin. The ADS111x never drive the SCL pin. For information on programming and debugging the microcontroller being used, see the device-specific product data sheet.

The first byte sent by the controller is the ADS111x address, followed by the R/$\overline{W}$ bit that instructs the ADS111x to listen for a subsequent byte. The second byte is the Address Pointer register byte. The third and fourth bytes sent from the controller are written to the register indicated in register address pointer bits P[1:0]. See 图 7-9 and 图 7-10 for read and write operation timing diagrams, respectively. All read and write transactions with the ADS111x must be preceded by a START condition, and followed by a STOP condition.

For example, to write to the configuration register to set the ADS111x to continuous-conversion mode and then read the conversion result, send the following bytes in this order:

1. **Write to Config register:**
   - First byte: 10010000b (first 7-bit I²C address followed by a low R/$\overline{W}$ bit)
   - Second byte: 00000001b (points to Config register)
   - Third byte: 10000100b (MSB of the Config register to be written)
   - Fourth byte: 10000011b (LSB of the Config register to be written)
2. **Write to Address Pointer register:**
   - First byte: 10010000b (first 7-bit I²C address followed by a low R/$\overline{W}$ bit)
   - Second byte: 00000000b (points to Conversion register)
3. **Read Conversion register:**
   - First byte: 10010001b (first 7-bit I²C address followed by a high R/$\overline{W}$ bit)
   - Second byte: the ADS111x responds with the MSB of the Conversion register.
   - Third byte: the ADS111x responds with the LSB of the Conversion register.

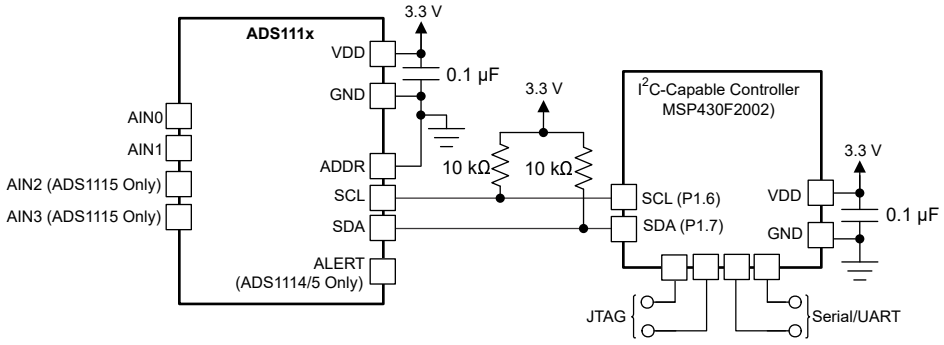


图 9-5. Basic Hardware Configuration

9.2 Typical Application

Shunt-based, current-measurement solutions are widely used to monitor load currents. Low-side, current-shunt measurements are independent of the bus voltage because the shunt common-mode voltage is near ground. 图 9-6 shows an example circuit for a bidirectional, low-side, current-shunt measurement system. The load current is determined by measuring the voltage across the shunt resistor that is amplified and level-shifted by a low-drift operational amplifier, OPA333 . The OPA333 output voltage is digitized with ADS1115 and sent to the microcontroller using the I^2C interface. This circuit is capable of measuring bidirectional currents flowing through the shunt resistor with great accuracy and precision.

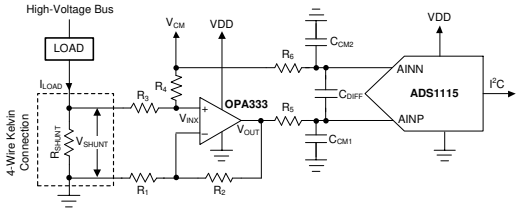


图 9-6. Low-Side Current Shunt Monitoring

9.2.1 Design Requirements

表 9-1 shows the design parameters for this application.

表 9-1. Design Parameters

DESIGN PARAMETER	VALUE
Supply voltage (VDD)	5V
Voltage across shunt resistor (V_{SHUNT})	±50mV
Output data rate (DR)	⩾200 readings per second
Typical measurement accuracy at T_A = 25°C(1)	±0.2%

(1) Does not account for inaccuracy of shunt resistor and the precision resistors used in the application.

9.2.2 Detailed Design Procedure

The first stage of the application circuit consists of an OPA333 in a noninverting summing amplifier configuration and serves two purposes:

1. To level-shift the ground-referenced signal to allow bidirectional current measurements while running off a unipolar supply. The voltage across the shunt resistor, V_{SHUNT}, is level-shifted by a common-mode voltage, V_{CM}, as shown in 图 9-6. The level-shifted voltage, V_{INX}, at the noninverting input, is given by 方程式 5.

$$V_{INX} = (V_{CM} \cdot R_3 + V_{SHUNT} \cdot R_4) / (R_3 + R_4) \quad (5)$$

2. To amplify the level-shifted voltage (V_{INX}). The OPA333 is configured in a noninverting gain configuration with the output voltage, V_{OUT}, given by 方程式 6.

$$V_{OUT} = V_{INX} \cdot (1 + R_2 / R_1) \quad (6)$$

Using 方程式 5 and 方程式 6, V_{OUT} is given as a function of V_{SHUNT} and V_{CM} by 方程式 7.

$$V_{OUT} = (V_{CM} \cdot R_3 + V_{SHUNT} \cdot R_4) / (R_3 + R_4) \cdot (1 + R_2 / R_1) \quad (7)$$

Using 方程式 7 the ADC differential input voltage, before the first-order RC filter, is given by 方程式 8.

$$V_{OUT} - V_{CM} = V_{SHUNT} \cdot (1 + R_2 / R_1) / (1 + R_4 / R_3) + V_{CM} \cdot (R_2 / R_1 - R_3 / R_4) / (1 + R_3 / R_4) \quad (8)$$

If $R_1 = R_4$ and $R_2 = R_3$, 方程式 8 is simplified to 方程式 9.

$$V_{OUT} - V_{CM} = V_{SHUNT} \cdot (1 + R_2 / R_1) / (1 + R_4 / R_3) \quad (9)$$

9.2.2.1 Shunt Resistor Considerations

A shunt resistor (R_{SHUNT}) is an accurate resistance inserted in series with the load as shown in 图 9-6. If the absolute voltage drop across the shunt, $|V_{SHUNT}|$, is a larger percentage of the bus voltage, the voltage drop can reduce the overall efficiency and system performance. If $|V_{SHUNT}|$ is too low, measuring the small voltage drop requires careful design attention and proper selection of the ADC, operation amplifier, and precision resistors. Make sure that the absolute voltage at the shunt terminals does not result in violation of the input common-mode voltage range requirements of the operational amplifier. The power dissipation on the shunt resistor increases the temperature because of the current flowing through the resistor. To minimize the measurement errors resulting from variation in temperature, select a low-drift shunt resistor. To minimize the measurement gain error, select a shunt resistor with low tolerance value. To remove the errors caused by stray ground resistance, use a four-wire Kelvin-connected shunt resistor, as shown in 图 9-6.

9.2.2.2 Operational Amplifier Considerations

The operational amplifier used for this design example requires the following features:

- Unipolar supply operation (5V)
- Low input offset voltage (< 10µV) and input offset voltage drift (< 0.5µV/°C)
- Rail-to-rail input and output capability
- Low thermal and flicker noise
- High common-mode rejection (> 100dB)

The OPA333 offers all these benefits and is selected for this application.

9.2.2.3 ADC Input Common-Mode Considerations

V_{CM} sets the V_{OUT} common-mode voltage by appropriate selection of precision resistors R_1, R_2, R_3, and R_4.

If $R_1 = R_3$, $R_2 = R_4$, and $V_{SHUNT} = 0V$, V_{OUT} is given by 方程式 10.

$$V_{OUT} = V_{CM} \tag{10}$$

If V_{OUT} is connected to the ADC positive input (AINP) and V_{CM} is connected to the ADC negative input (AINN), V_{CM} appears as a common-mode voltage to the ADC. This configuration allows pseudo-differential measurements and uses the maximum dynamic range of the ADC if V_{CM} is set at mid-supply (VDD / 2). A resistor divider from VDD to GND followed by a buffer amplifier can be used to generate V_{CM}.

9.2.2.4 Resistor (R_1, R_2, R_3, R_4) Considerations

Proper selection of resistors R_1, R_2, R_3, and R_4 is critical for meeting the overall accuracy requirements.

Using 方程式 8, the offset term, V_{OUT-OS}, and the gain term, A_{OUT}, of the differential ADC input are represented by 方程式 11 and 方程式 12, respectively. The error contributions from the first-order RC filters are ignored.

$$V_{OUT-OS} = V_{CM} \cdot (R_2 / R_1 - R_3 / R_4) / (1 + R_3 / R_4) \tag{11}$$

$$A_{OUT} = (1 + R_2 / R_1) / (1 + R_4 / R_3) \tag{12}$$

The tolerance, drift, and linearity performance of these resistors is critical to meeting the overall accuracy requirements. In 方程式 11, if $R_1 = R_3$ and $R_2 = R_4$, $V_{OUT-OS} = 0V$ and therefore, the common-mode voltage, V_{CM}, only contributes to level-shift V_{SHUNT} and does not introduce any error at the differential ADC inputs. High-precision resistors provide better common-mode rejection from V_{CM}.

9.2.2.5 Noise and Input Impedance Considerations

If v_{n_res} represents the input-referred rms noise from all the resistors, v_{n_op} represents the input-referred rms noise of OPA333, and v_{n_ADC} represents the input-referred rms noise of ADS1115, the total input-referred noise of the entire system, v_N, can be approximated by 方程式 13.

$$v_N^2 = v_{n\_res}^2 + v_{n\_op}^2 + v_{n\_ADC}/ (1 + R_2 / R_1)^2 \quad (13)$$

The ADC noise contribution, v_{n_ADC}, is attenuated by the noninverting gain stage.

If the gain of the noninverting gain stage is high (≥ 5), a good approximation for $v_{n\_res}^2$ is given by 方程式 14. The noise contribution from resistors R_2, R_4, R_5, and R_6 when referred to the input is smaller in comparison to R_1 and R_3 and can be neglected for approximation purposes.

$$v_{n\_res}^2 = 4 \cdot k \cdot T \cdot (R_1 + R_3) \cdot \Delta f \quad (14)$$

where:

- where k = Boltzmann constant
- T = temperature (in kelvins)
- Δf = noise bandwidth

An approximation for the input impedance, R_{IN}, of the application circuit is given by 方程式 15. R_{IN} can be modeled as a resistor in parallel with the shunt resistor, and can contribute to additional gain error.

$$R_{IN} = R_3 + R_4 \quad (15)$$

From 方程式 14 and 方程式 15, a trade-off exists between v_N and R_{IN}. If R_3 increases, v_{n_res} increases, and therefore, the total input-referred rms system noise, v_N, increases. If R_3 decreases, the input impedance, R_{IN}, drops, and causes additional gain error.

9.2.2.6 First-Order RC Filter Considerations

Although the device's digital filter attenuates high-frequency noise, use a first-order, low-pass RC filter at the ADC inputs to further reject out-of-bandwidth noise and avoid aliasing. A differential low-pass RC filter formed by R5, R6, and the differential capacitor C_{DIFF} sets the –3dB cutoff frequency, f_C, given by 方程式 16. These filter resistors produce a voltage drop because of the input currents flowing into and out of the ADC. This voltage drop can contribute to an additional gain error. Limit the filter resistor values to below 1kΩ.

$$f_C = 1 / [2\pi \cdot (R_5 + R_6) \cdot C_{DIFF}] \quad (16)$$

Two common-mode filter capacitors (C_{CM1} and C_{CM2}) are also added to offer attenuation of high-frequency, common-mode noise components. Select a differential capacitor, C_{DIFF}, that is at least an order of magnitude (10x) larger than these common-mode capacitors because mismatches in these common-mode capacitors can convert common-mode noise into differential noise.

9.2.2.7 Circuit Implementation

表 9-2 shows the chosen values for this design.

表 9-2. Parameters

PARAMETER	VALUE
V_{CM}	2.5V
FSR of ADC	±0.256V
Output data rate	250SPS
R_1, R_3	1kΩ (1)
R_2, R_4	5kΩ (1)
R_5, R_6	100Ω (1)
C_{DIFF}	0.22µF
C_{CM1}, C_{CM2}	0.022µF

(1) 1% precision resistors used.

Using 方程式 7, if V_{SHUNT} ranges from –50mV to +50mV, the application circuit produces a differential voltage ranging from –0.250V to +0.250V across the ADC inputs. The ADC is therefore configured at an FSR of ±0.256V to maximize the dynamic range of the ADC.

The –3dB cutoff frequencies of the differential low-pass filter and the common-mode low-pass filters are set at 3.6kHz and 0.36kHz, respectively.

R_{SHUNT} typically ranges from 0.01mΩ to 100mΩ. Therefore, if $R_1 = R_3 = 1k\Omega$, a good trade-off exists between the circuit input impedance and input referred resistor noise as explained in the *Noise and Input Impedance Considerations* section.

A simple resistor divider followed by a buffer amplifier is used to generate V_{CM} of 2.5V from a 5V supply.

9.2.2.8 Results Summary

A precision voltage source is used to sweep V_{SHUNT} from –50mV to +50mV. The application circuit produces a differential voltage of –250mV to +250mV across the ADC inputs. 图 9-7 and 图 9-8 show the measurement results. The measurements are taken at $T_A = 25°C$. Although 1% tolerance resistors are used, the exact value of these resistors are measured with a Fluke 4.5 digit multimeter to exclude the errors resulting from inaccuracy of these resistors. In 图 9-7, the x-axis represents V_{SHUNT} and the black line represents the measured digital output voltage in mV. In 图 9-8, the x-axis represents V_{SHUNT}, the black line represents the total measurement error in %, the blue line represents the total measurement error in % after excluding the errors from precision resistors, and the green line represents the total measurement error in % after excluding the errors from precision resistors and performing a system offset calibration with $V_{SHUNT} = 0V$. 表 9-3 shows a results summary.

表 9-3. Results Summary

PARAMETER(1)	VALUE
Total error, including errors from 1% precision resistors	1.89%
Total error, excluding errors from 1% precision resistors	0.17%
Total error, after offset calibration, excluding errors from 1% precision resistors	0.11%

(1) $T_A = 25°C$, not accounting for inaccuracy of shunt resistor.

9.2.3 Application Curves

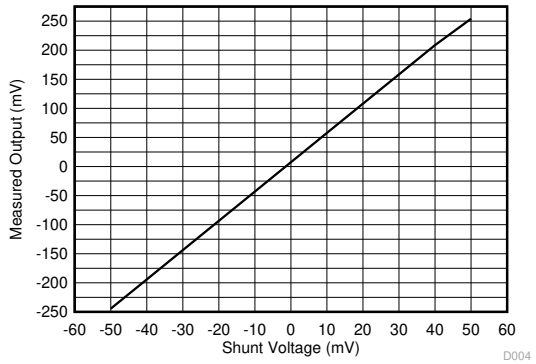


图 9-7. Measured Output vs Shunt Voltage (V_{SHUNT})

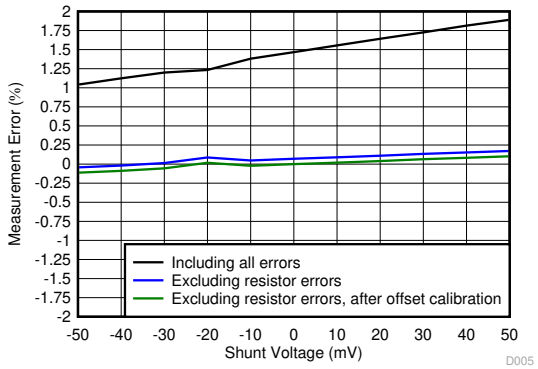


图 9-8. Measurement Error vs Shunt Voltage (V_{SHUNT})

10 Power Supply Recommendations

The device requires a single unipolar supply, VDD, to power both the analog and digital circuitry of the device.

10.1 Power-Supply Sequencing

Wait approximately 50μs after VDD is stabilized before communicating with the device to allow the power-up reset process to complete.

10.2 Power-Supply Decoupling

Good power-supply decoupling is important to achieve optimum performance. VDD must be decoupled with at least a 0.1μF capacitor, as shown in 图 10-1. The 0.1 μ F bypass capacitor supplies the momentary bursts of extra current required from the supply when the device is converting. Place the bypass capacitor as close to the power-supply pin of the device as possible using low-impedance connections. Use multilayer ceramic chip capacitors (MLCCs) that offer low equivalent series resistance (ESR) and inductance (ESL) characteristics for power-supply decoupling purposes. For very sensitive systems, or for systems in harsh noise environments, avoid using vias for connecting the capacitors to the device pins for better noise immunity. Using multiple vias in parallel lowers the overall inductance, and is beneficial for connections to ground planes.

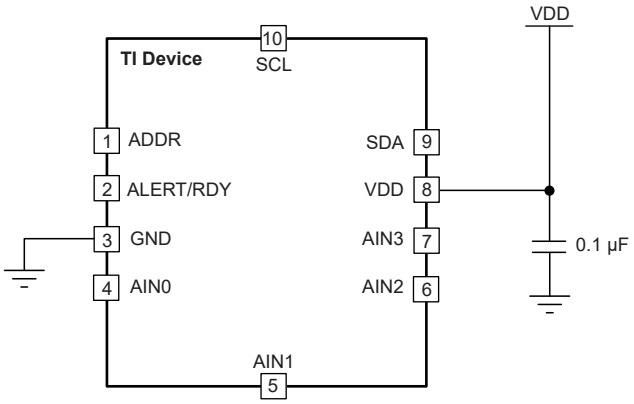


图 10-1. ADS1115 Power-Supply Decoupling

11 Layout

11.1 Layout Guidelines

Employ best design practices when laying out a printed-circuit board (PCB) for both analog and digital components. For optimal performance, separate the 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 图 11-1. Although 图 11-1 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.

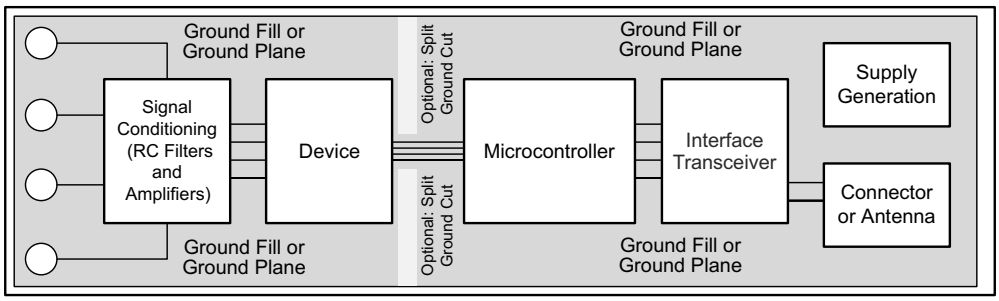


图 11-1. System Component Placement

The following outlines some basic recommendations for the layout of the ADS111x 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 placement prevents digital noise from coupling back into analog signals.
- 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, the current must find another path to return to the source and complete the circuit. A longer return current path increases the chance that the signal radiates. 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.
- Consider the resistance and inductance of the routing. Often, traces for the inputs have resistances that react with the input bias current and cause an added error voltage. Reduce the loop area enclosed by the source signal and the return current in order to reduce the inductance in the path. Reduce the inductance to reduce the EMI pickup, and reduce the high frequency impedance observed by the device.
- Differential inputs must be matched for both the inputs going to the measurement source.
- Analog inputs with differential connections must have a capacitor placed differentially across the inputs. Best input combinations for differential measurements use adjacent analog input lines such as AIN0, AIN1 and AIN2, AIN3. The differential capacitors must be of high quality. The best ceramic chip capacitors are C0G (NPO), which have stable properties and low-noise characteristics.

11.2 Layout Example

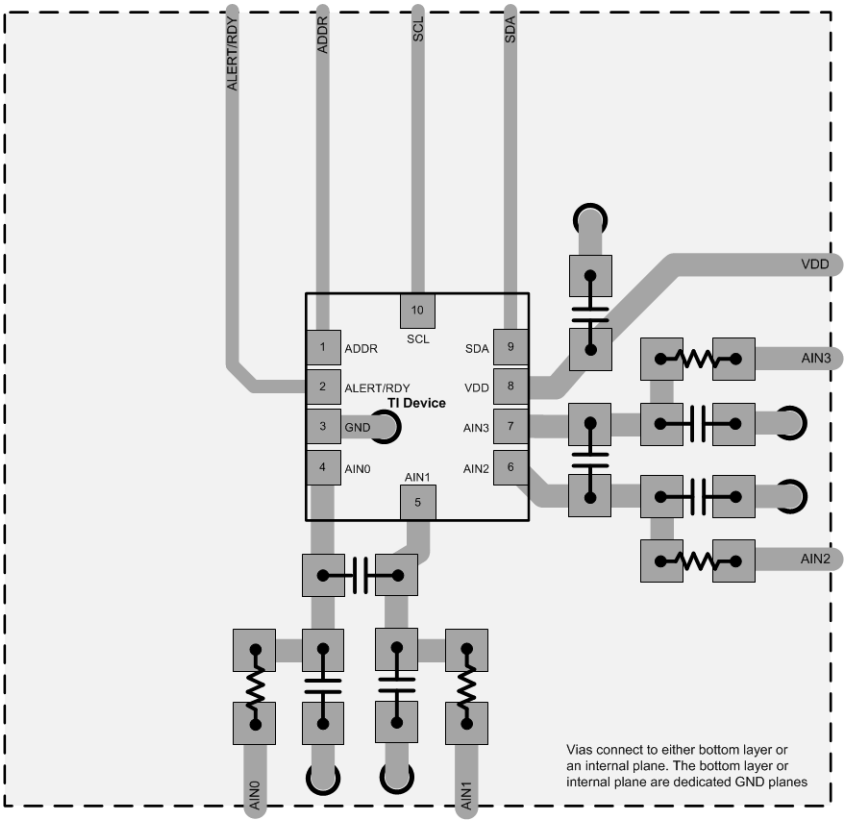


图 11-2. ADS1115 X2QFN Package

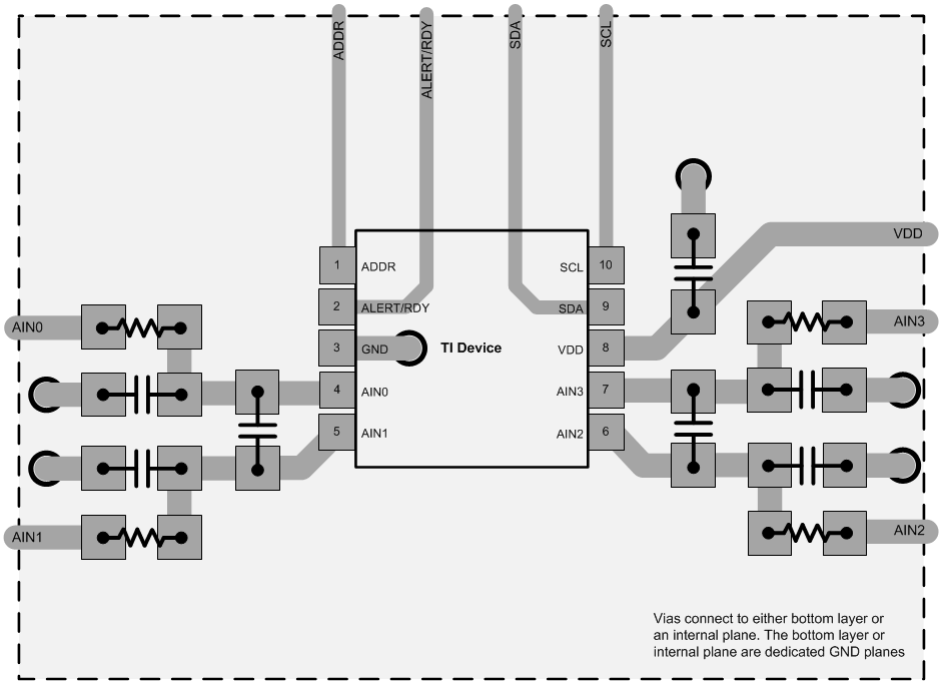


图 11-3. ADS1115 VSSOP Package

12 Device and Documentation Support

12.1 Documentation Support

12.1.1 Related Documentation

For related documentation see the following:

- *OPAx333 1.8-V, microPower, CMOS Operational Amplifiers, Zero-Drift Series* (SBOS351)
- *MSP430F20x3, MSP430F20x2, MSP430F20x1 Mixed-Signal Microcontrollers* (SLAS491)
- *TIDA-00824 Human Skin Temperature Sensing for Wearable Applications Reference Design* (TIDUAY7)

12.2 接收文档更新通知

要接收文档更新通知，请导航至 ti.com 上的器件产品文件夹。点击*通知* 进行注册，即可每周接收产品信息更改摘要。有关更改的详细信息，请查看任何已修订文档中包含的修订历史记录。

12.3 支持资源

TI E2E™ 中文支持论坛是工程师的重要参考资料，可直接从专家处获得快速、经过验证的解答和设计帮助。搜索现有解答或提出自己的问题，获得所需的快速设计帮助。

链接的内容由各个贡献者“按原样”提供。这些内容并不构成 TI 技术规范，并且不一定反映 TI 的观点；请参阅 TI 的使用条款。

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12.5 静电放电警告

静电放电 (ESD) 会损坏这个集成电路。德州仪器 (TI) 建议通过适当的预防措施处理所有集成电路。如果不遵守正确的处理和安装程序，可能会损坏集成电路。

ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

12.6 术语表

TI 术语表　　本术语表列出并解释了术语、首字母缩略词和定义。

13 Revision History

注：以前版本的页码可能与当前版本的页码不同

Changes from January 1, 2018 to December 5, 2024 (from Revision D (January 2018) to Revision E (December 2024)) **Page**

- 将提到 I²C 的旧术语实例通篇更改为*控制器* 和*目标* 1
- 更新了整个文档中的表格、图和交叉参考的编号格式..... 1
- 向*特性* 部分添加了 DYN 封装和器件系列信息..... 1
- 添加了*器件信息* 表，向*封装信息* 表中添加了 DYN 封装并删除了*说明* 部分的最后一段..... 1
- Added DYN package to *Pin Configuration and Functions* section and changed *Pin Functions* table..... 3
- Added DYN package to *Thermal Information* table..... 4
- Changed Y-axis unit of *Total Error vs Input Signal* figure from µV to mV in *Typical Characteristics* section..... 7
- Added additional information to last paragraph in *Multiplexer* section..... 13
- Added additional information to the *Voltage Reference* section..... 15
- Moved the ALERT Pin Timing Diagram from the *Conversion Ready Pin* section to the *Digital Comparator* section..... 16
- Corrected cross reference to *Timing Diagram for Reading From the ADS111x* figure in *Writing to and Reading From the Registers* section..... 21
- Changed bit setting notation from hexadecimal to binary where beneficial for clarity throughout *Register Map* section..... 24
- Added dedicated *Config Register* tables for ADS1113, ADS1114, and ADS1115 and changed bit descriptions in *Config Register Field Descriptions* table in *Config Register* section..... 25
- Changed first paragraph in *Lo_threh and Hi_thresh Registers* section..... 27
- Changed *Unused Inputs and Outputs* section..... 29
- Changed *ADS1115 Power-Supply Decoupling* figure..... 37

Changes from Revision C (May 2009) to Revision D (January 2018) **Page**

- Changed *Digital input voltage* max value from VDD + 0.3 V to 5.5 V in *Absolute Maximum Ratings* table..... 4
- Added "over temperature" to Offset drift parameter for clarity..... 5
- Added Long-term Offset drift parameter in *Electrical Characteristics* table..... 5
- Added "over temperature" to Gain drift parameter for clarity..... 5
- Added Long-term gain drift parameter in *Electrical Characteristics* table..... 5
- Changed V_{IH} parameter max value from VDD to 5.5V in *Electrical Characteristics* table..... 5
- Added *Output Data Rate and Conversion Time* section for clarity..... 15
- Changed Figure 28, *ALERT Pin Timing Diagram* for clarity..... 17
- Changed Figure 39, *Typical Connections of the ADS1115*, for clarity..... 28
- Changed the resistor values in Figure 43, *Basic Hardware Configuration*, from 10 Ω to 10k Ω..... 32

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.

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
ADS1113IDGSR	Active	Production	VSSOP (DGS) | 10	2500 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BROI
ADS1113IDGSR.A	Active	Production	VSSOP (DGS) | 10	2500 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BROI
ADS1113IDGSR.B	Active	Production	VSSOP (DGS) | 10	2500 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BROI
ADS1113IDGST	Active	Production	VSSOP (DGS) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BROI
ADS1113IDGST.A	Active	Production	VSSOP (DGS) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BROI
ADS1113IDGST.B	Active	Production	VSSOP (DGS) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BROI
ADS1113IRUGR	Active	Production	X2QFN (RUG) | 10	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N6J
ADS1113IRUGR.A	Active	Production	X2QFN (RUG) | 10	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N6J
ADS1113IRUGR.B	Active	Production	X2QFN (RUG) | 10	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N6J
ADS1113IRUGT	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N6J
ADS1113IRUGT.A	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N6J
ADS1113IRUGT.B	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N6J
ADS1114IDGSR	Active	Production	VSSOP (DGS) | 10	2500 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BRNI
ADS1114IDGSR.A	Active	Production	VSSOP (DGS) | 10	2500 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BRNI
ADS1114IDGSR.B	Active	Production	VSSOP (DGS) | 10	2500 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BRNI
ADS1114IDGST	Active	Production	VSSOP (DGS) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BRNI
ADS1114IDGST.A	Active	Production	VSSOP (DGS) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BRNI
ADS1114IDGST.B	Active	Production	VSSOP (DGS) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BRNI
ADS1114IRUGR	Active	Production	X2QFN (RUG) | 10	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N5J
ADS1114IRUGR.A	Active	Production	X2QFN (RUG) | 10	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N5J
ADS1114IRUGR.B	Active	Production	X2QFN (RUG) | 10	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N5J
ADS1114IRUGT	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N5J
ADS1114IRUGT.A	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N5J
ADS1114IRUGT.B	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N5J
ADS1114IRUGTG4	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N5J
ADS1114IRUGTG4.A	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N5J
ADS1114IRUGTG4.B	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N5J
ADS1115IDGSR	Active	Production	VSSOP (DGS) | 10	2500 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BOGI
ADS1115IDGSR.A	Active	Production	VSSOP (DGS) | 10	2500 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BOGI

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
ADS1115IDGSR.B	Active	Production	VSSOP (DGS) | 10	2500 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BOGI
ADS1115IDGST	Active	Production	VSSOP (DGS) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BOGI
ADS1115IDGST.A	Active	Production	VSSOP (DGS) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BOGI
ADS1115IDGST.B	Active	Production	VSSOP (DGS) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BOGI
ADS1115IRUGR	Active	Production	X2QFN (RUG) | 10	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N4J
ADS1115IRUGR.A	Active	Production	X2QFN (RUG) | 10	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N4J
ADS1115IRUGR.B	Active	Production	X2QFN (RUG) | 10	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N4J
ADS1115IRUGT	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N4J
ADS1115IRUGT.A	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N4J
ADS1115IRUGT.B	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N4J
ADS1115IRUGTG4	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N4J
ADS1115IRUGTG4.A	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N4J
ADS1115IRUGTG4.B	Active	Production	X2QFN (RUG) | 10	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	N4J

(1) **Status:** For more details on status, see our product life cycle.

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

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

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

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

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

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

OTHER QUALIFIED VERSIONS OF ADS1113, ADS1114, ADS1115 :

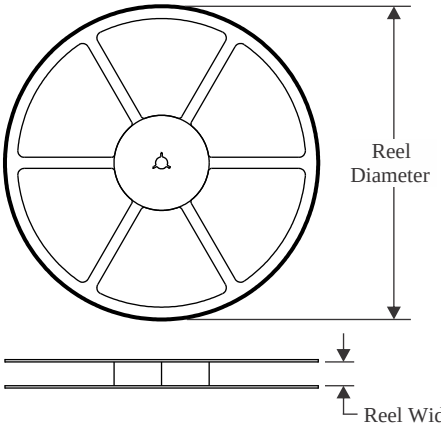
- Automotive : ADS1113-Q1, ADS1114-Q1, ADS1115-Q1

NOTE: Qualified Version Definitions:

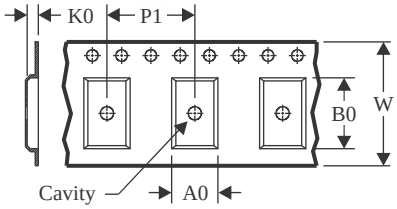
- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

TAPE AND REEL INFORMATION

REEL DIMENSIONS

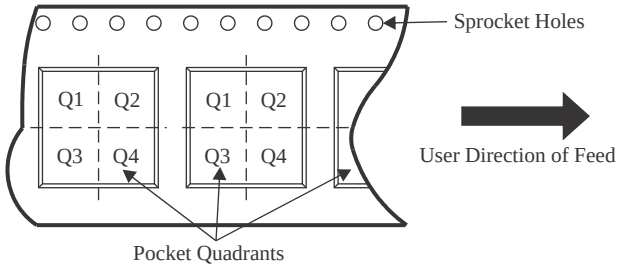


TAPE DIMENSIONS



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

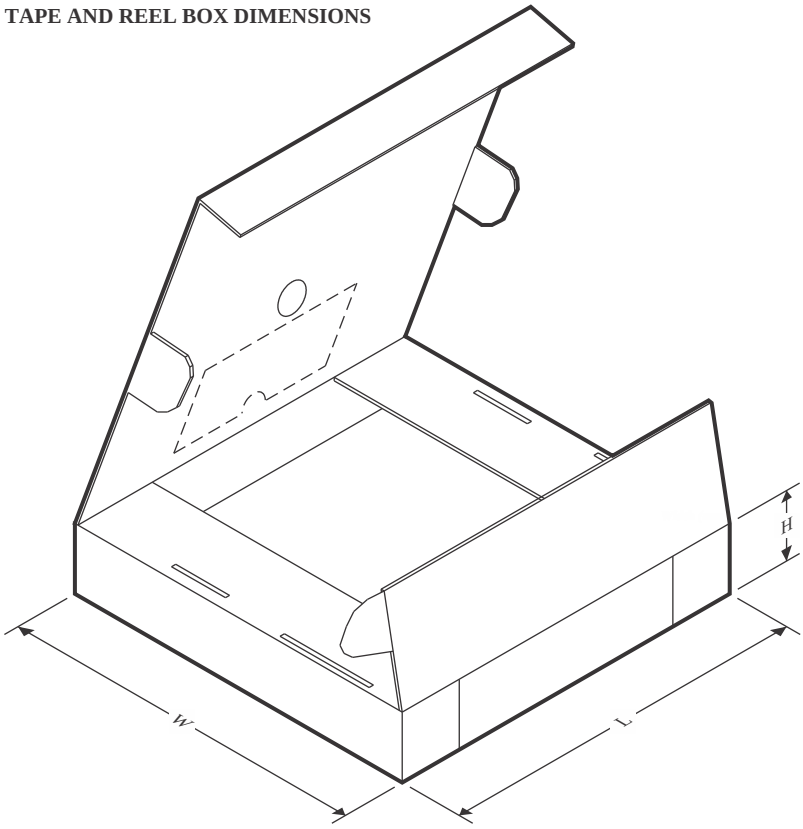
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
ADS1113IDGSR	VSSOP	DGS	10	2500	330.0	12.4	5.3	3.3	1.3	8.0	12.0	Q1
ADS1113IDGST	VSSOP	DGS	10	250	180.0	12.4	5.3	3.3	1.3	8.0	12.0	Q1
ADS1113IRUGR	X2QFN	RUG	10	3000	180.0	8.4	1.75	2.25	0.55	4.0	8.0	Q1
ADS1113IRUGT	X2QFN	RUG	10	250	180.0	8.4	1.75	2.25	0.55	4.0	8.0	Q1
ADS1114IDGSR	VSSOP	DGS	10	2500	330.0	12.4	5.3	3.3	1.3	8.0	12.0	Q1
ADS1114IDGST	VSSOP	DGS	10	250	180.0	12.4	5.3	3.3	1.3	8.0	12.0	Q1
ADS1114IRUGR	X2QFN	RUG	10	3000	180.0	8.4	1.75	2.25	0.55	4.0	8.0	Q1
ADS1114IRUGT	X2QFN	RUG	10	250	180.0	8.4	1.75	2.25	0.55	4.0	8.0	Q1
ADS1114IRUGTG4	X2QFN	RUG	10	250	180.0	8.4	1.75	2.25	0.55	4.0	8.0	Q1
ADS1115IDGSR	VSSOP	DGS	10	2500	330.0	12.4	5.3	3.3	1.3	8.0	12.0	Q1
ADS1115IDGST	VSSOP	DGS	10	250	180.0	12.4	5.3	3.3	1.3	8.0	12.0	Q1
ADS1115IRUGR	X2QFN	RUG	10	3000	180.0	8.4	1.75	2.25	0.55	4.0	8.0	Q1
ADS1115IRUGT	X2QFN	RUG	10	250	180.0	8.4	1.75	2.25	0.55	4.0	8.0	Q1
ADS1115IRUGTG4	X2QFN	RUG	10	250	180.0	8.4	1.75	2.25	0.55	4.0	8.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

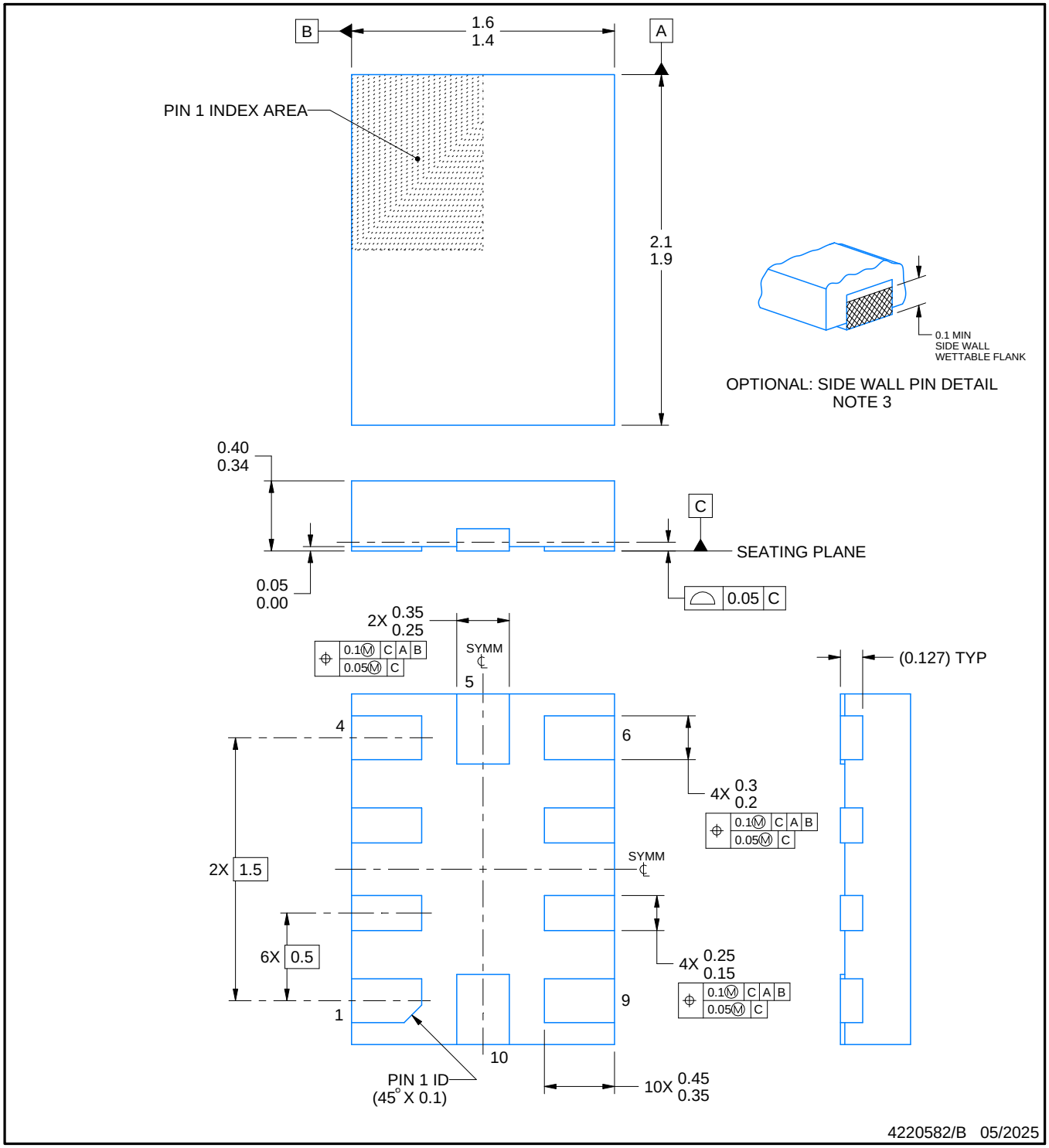
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
ADS1113IDGSR	VSSOP	DGS	10	2500	367.0	367.0	38.0
ADS1113IDGST	VSSOP	DGS	10	250	213.0	191.0	35.0
ADS1113IRUGR	X2QFN	RUG	10	3000	210.0	185.0	35.0
ADS1113IRUGT	X2QFN	RUG	10	250	210.0	185.0	35.0
ADS1114IDGSR	VSSOP	DGS	10	2500	367.0	367.0	38.0
ADS1114IDGST	VSSOP	DGS	10	250	213.0	191.0	35.0
ADS1114IRUGR	X2QFN	RUG	10	3000	210.0	185.0	35.0
ADS1114IRUGT	X2QFN	RUG	10	250	210.0	185.0	35.0
ADS1114IRUGTG4	X2QFN	RUG	10	250	210.0	185.0	35.0
ADS1115IDGSR	VSSOP	DGS	10	2500	367.0	367.0	38.0
ADS1115IDGST	VSSOP	DGS	10	250	213.0	191.0	35.0
ADS1115IRUGR	X2QFN	RUG	10	3000	210.0	185.0	35.0
ADS1115IRUGT	X2QFN	RUG	10	250	210.0	185.0	35.0
ADS1115IRUGTG4	X2QFN	RUG	10	250	210.0	185.0	35.0

RUG0010B

PACKAGE OUTLINE

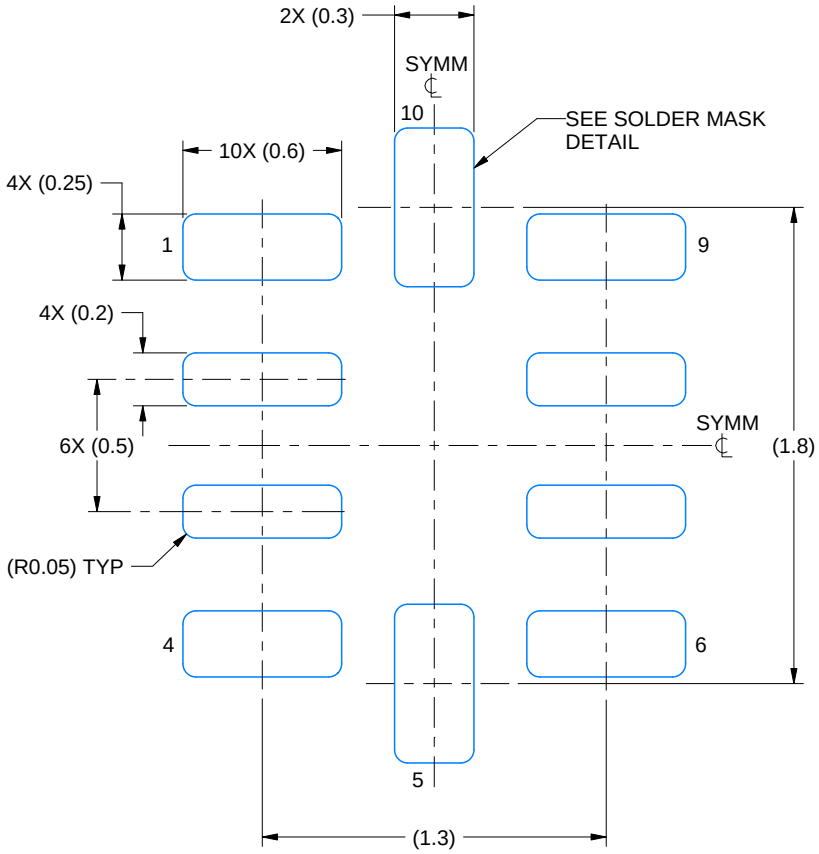
X2QFN - 0.4 mm max height

PLASTIC QUAD FLATPACK - NO LEAD

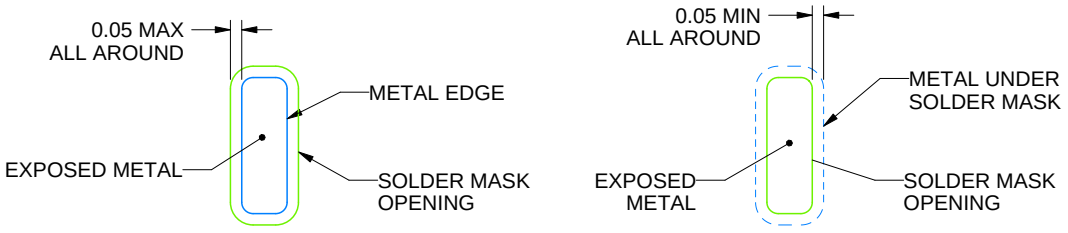


NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Minimum 0.1 mm solder wetting on pin side wall. Available for wettable flank version only.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 35X

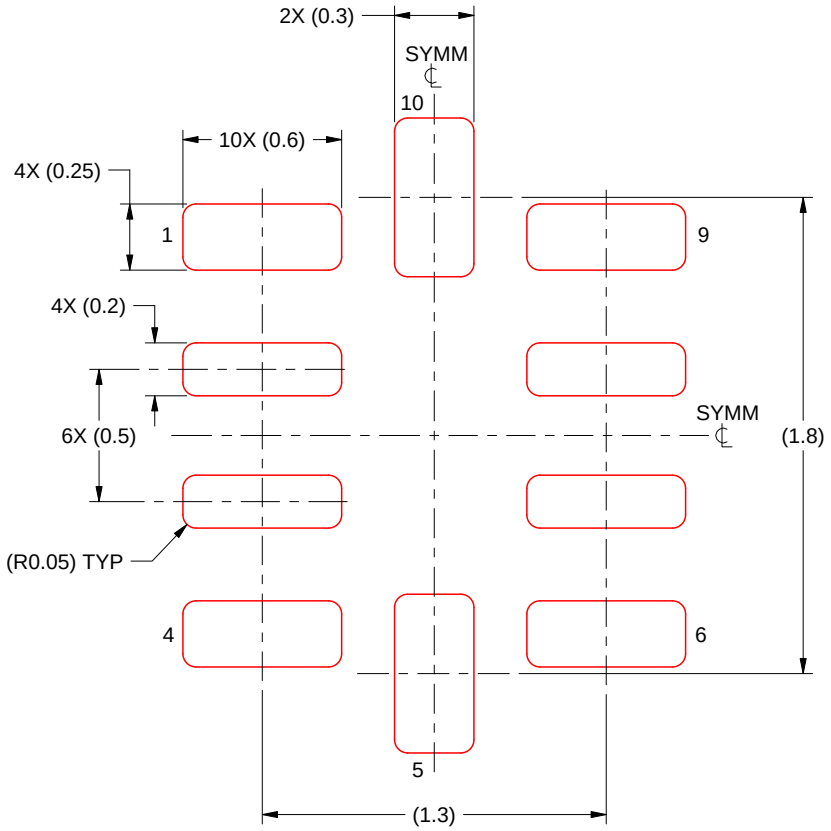


SOLDER MASK DETAILS

4220582/B 05/2025

NOTES: (continued)

4. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).



SOLDER PASTE EXAMPLE
BASED ON 0.125 MM THICK STENCIL
SCALE: 35X

4220582/B 05/2025

NOTES: (continued)

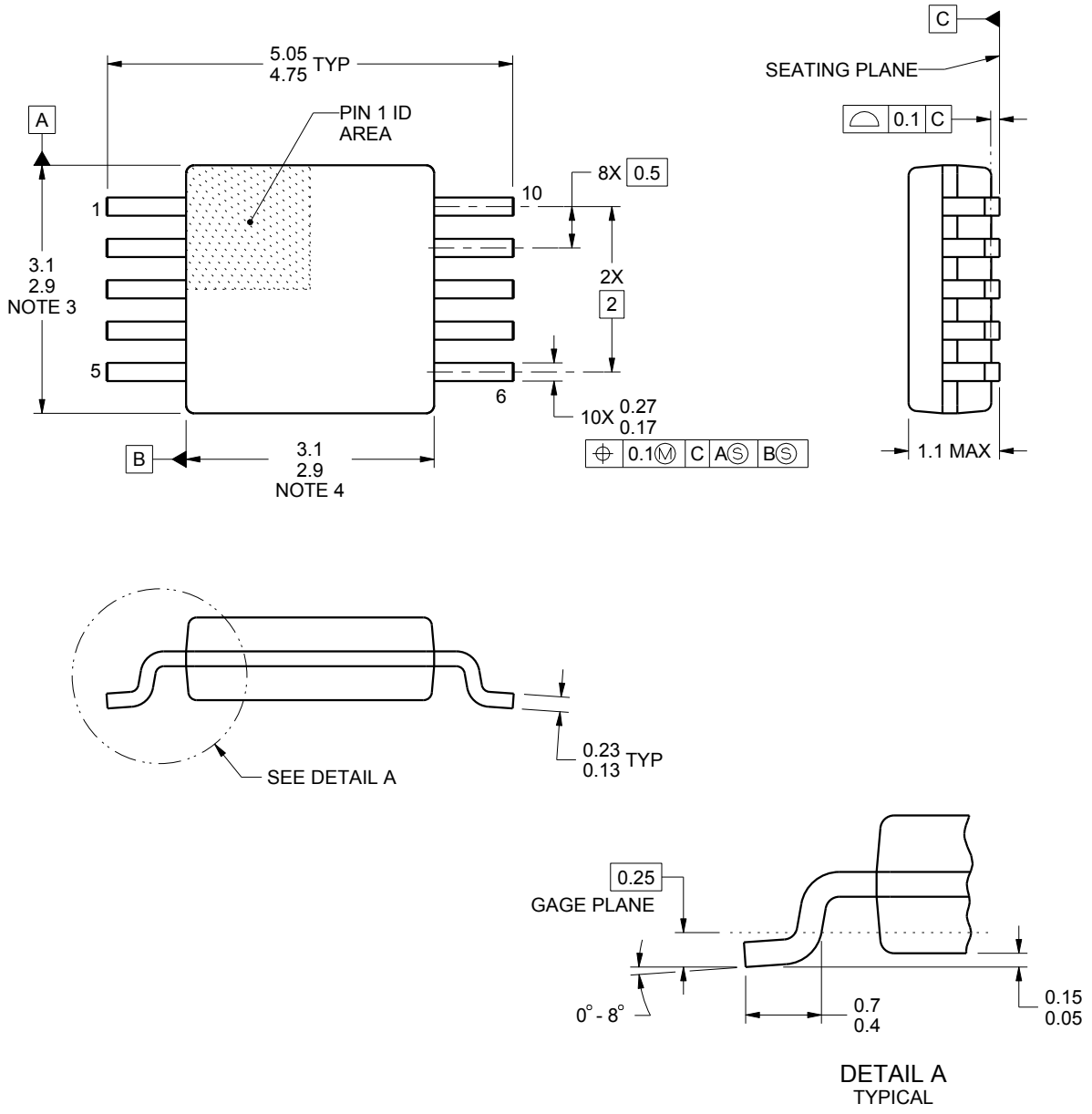
5. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

PACKAGE OUTLINE

DGS0010A

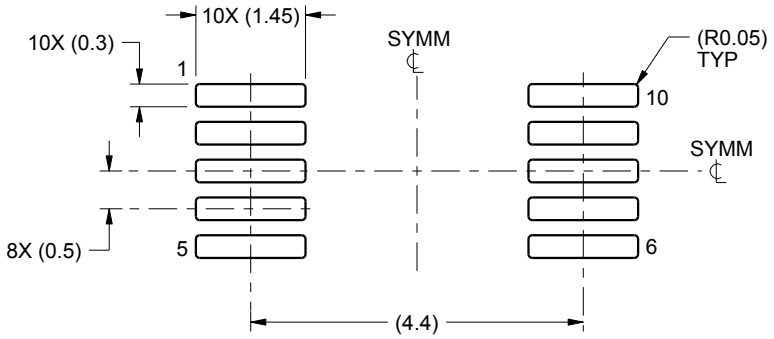
VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE

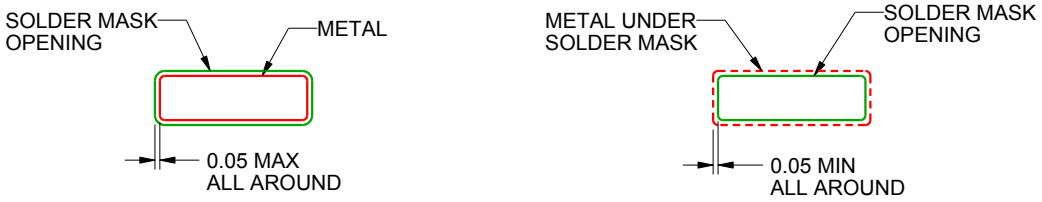


NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-187, variation BA.



LAND PATTERN EXAMPLE
SCALE:10X

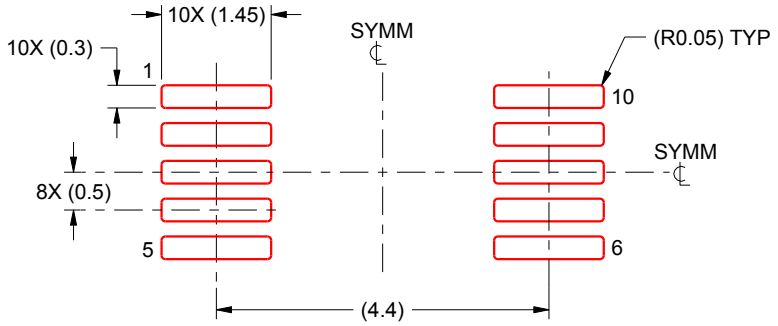


SOLDER MASK DETAILS
NOT TO SCALE

4221984/A 05/2015

NOTES: (continued)

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



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

4221984/A 05/2015

NOTES: (continued)

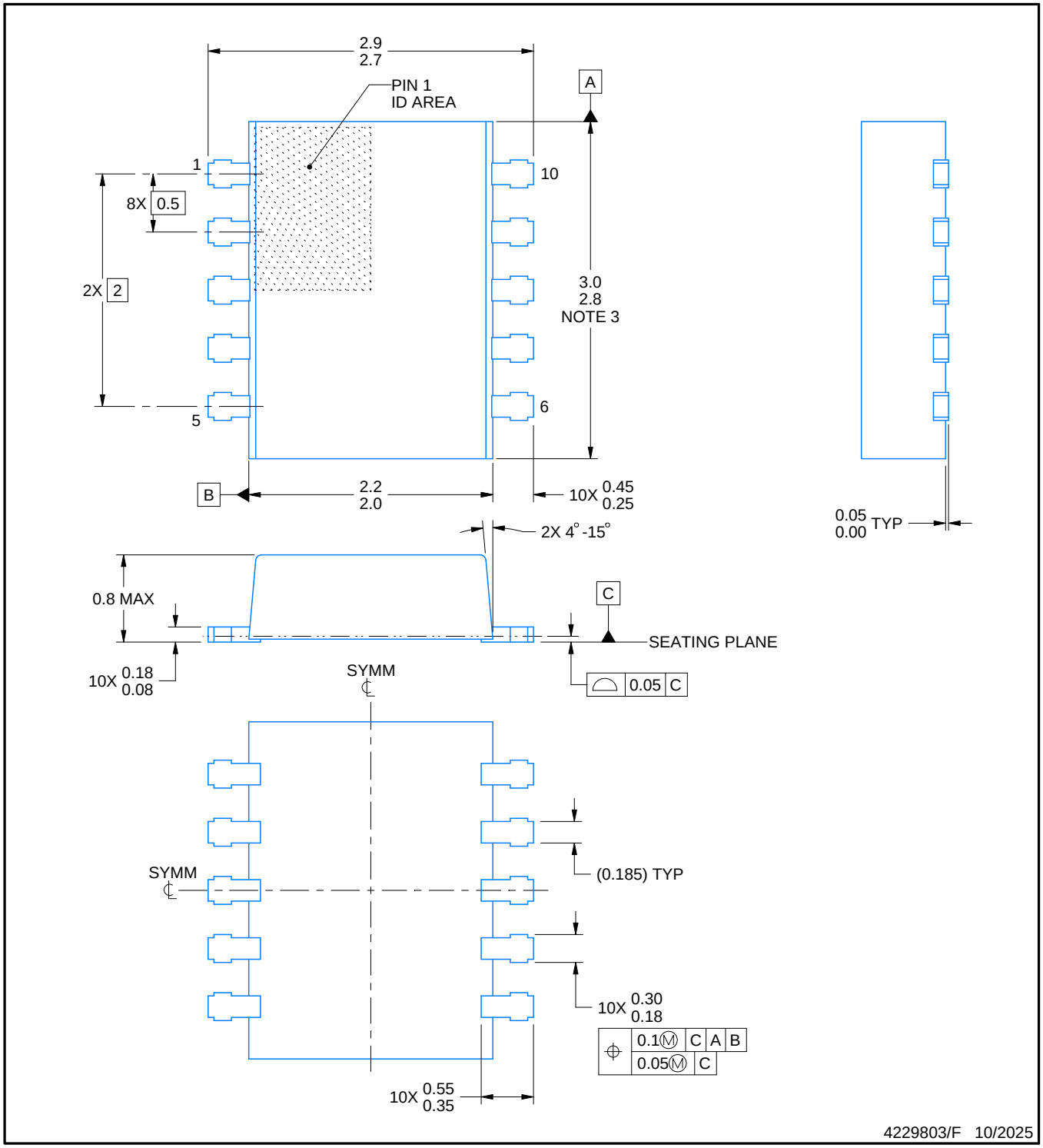
8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

DYN0010A

PACKAGE OUTLINE

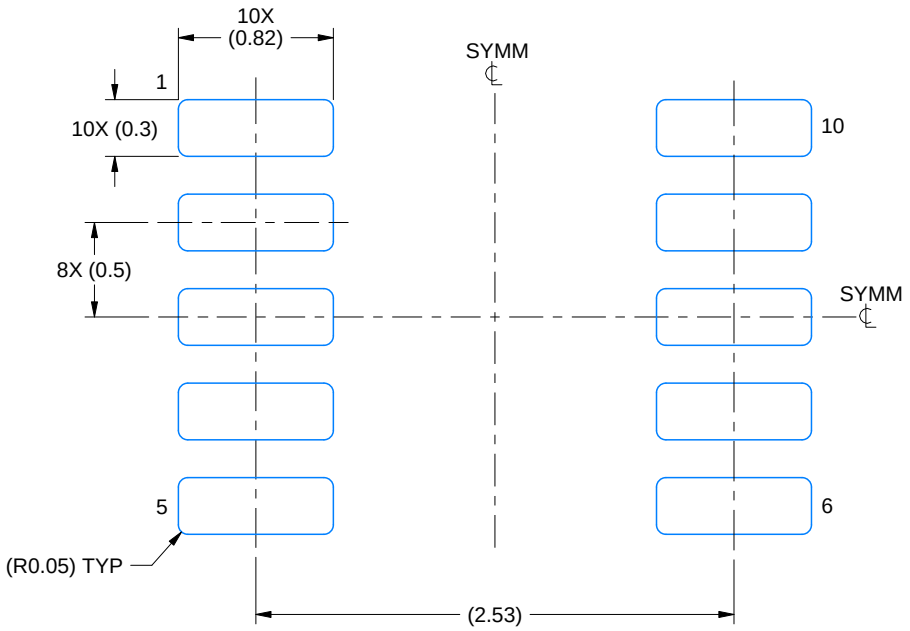
SOT - 0.8 mm max height

PLASTIC SMALL OUTLINE

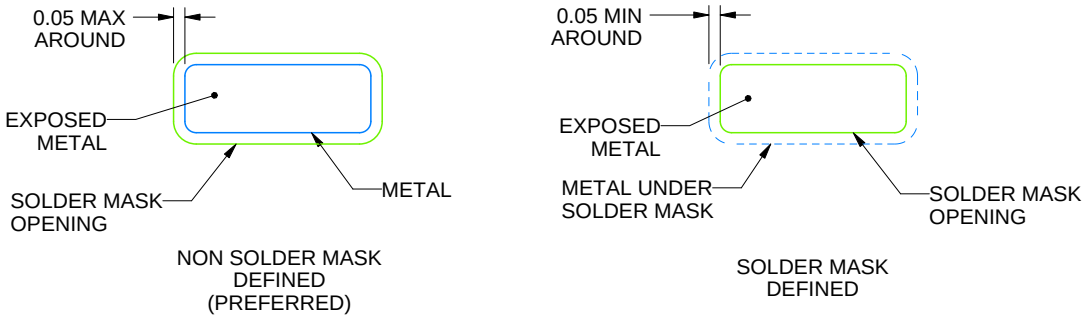


NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. Reference JEDEC MO-368, variation AA.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:25X

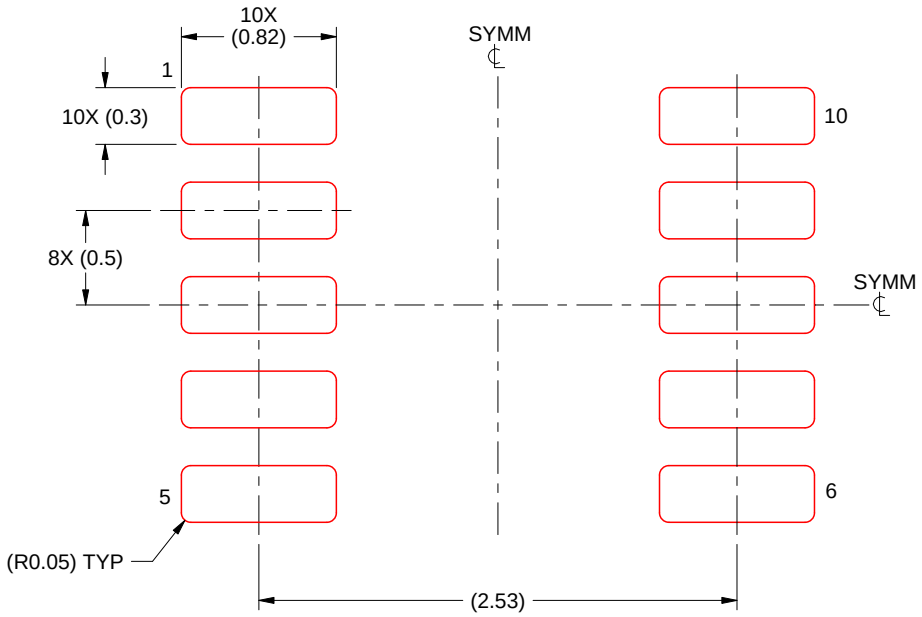


SOLDERMASK DETAILS

4229803/F 10/2025

NOTES: (continued)

5. Publication IPC-7351 may have alternate designs.
6. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
7. Land pattern design aligns to IPC-610, Bottom Termination Component (BTC) solder joint inspection criteria.



SOLDER PASTE EXAMPLE
BASED ON 0.1 mm THICK STENCIL
SCALE:25X

4229803/F 10/2025

NOTES: (continued)

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

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