

## TLA202x Cost-Optimized, Ultra-Small, 12-Bit, System-Monitoring ADCs

### 1 Features

- Industry's Lowest-Cost 12-Bit Delta-Sigma ADCs
- Ultra-Small X2QFN Package: 2 mm × 1.5 mm
- Highly Integrated:
  - 4 Single-Ended or 2 Differential Inputs Make the TLA2024 the Industry's Highest Channel Density ADC (0.75 mm<sup>2</sup> per Channel)
  - PGA (TLA2022 and TLA2024 Only)
  - Voltage Reference
  - Oscillator
- Low Current Consumption: 150  $\mu$ A
- Wide Supply Range: 2 V to 5.5 V
- Programmable Data Rate: 128 SPS to 3.3 kSPS
- I<sup>2</sup>C<sup>TM</sup> Compatible Interface:
  - Supports Standard-Mode and Fast-Mode
  - Three Pin-Selectable I<sup>2</sup>C Addresses
- Operating Temperature Range: -40°C to +85°C

### 2 Applications

- Personal Electronics:
  - TVs, Tablets, Cell Phones
  - Wearables
  - Drones, Toys
- Home and Kitchen Appliances
- Building Automation:
  - HVACs, Smoke Detectors
- Battery Voltage and Current Monitoring
- Temperature Sensing
- Battery-Powered, Portable Instrumentation

### 3 Description

The TLA2021, TLA2022, and TLA2024 devices (TLA202x) are easy-to-use, low-power, 12-bit delta-sigma ( $\Delta\Sigma$ ) analog-to-digital converters (ADCs) targeted for any type of system-monitoring applications (such as supply or battery voltage supervision, current sensing, or temperature measurements). Offered in an ultra-small, leadless, 10-pin X2QFN package, the TLA2021 and TLA2022 are single-channel ADCs while the TLA2024 features a flexible input multiplexer (MUX) with two differential or four single-ended input measurement options.

The TLA202x integrate a voltage reference and oscillator. Additionally, the TLA2022 and TLA2024 include a programmable gain amplifier (PGA) with selectable input ranges from  $\pm 256$  mV to  $\pm 6.144$  V, enabling both large- and small-signal measurements.

The TLA202x communicate via an I<sup>2</sup>C-compatible interface and operate in either continuous or single-shot conversion mode. The devices automatically power down after one conversion in single-shot conversion mode, significantly reducing power consumption during idle periods.

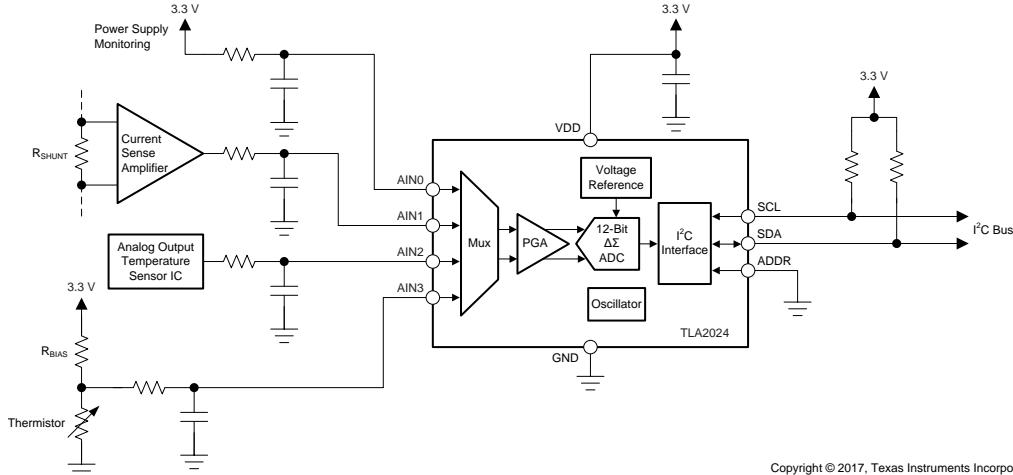
All of these features, along with a wide operating supply voltage range, make the TLA202x suitable for power- and space-constrained, system-monitoring applications.

#### Device Information<sup>(1)</sup>

| PART NUMBER | PACKAGE    | BODY SIZE (NOM)   |
|-------------|------------|-------------------|
| TLA2021     | X2QFN (10) | 1.50 mm × 2.00 mm |
| TLA2022     |            |                   |
| TLA2024     |            |                   |

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

### System-Monitoring Application Example



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## 4 Revision History

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

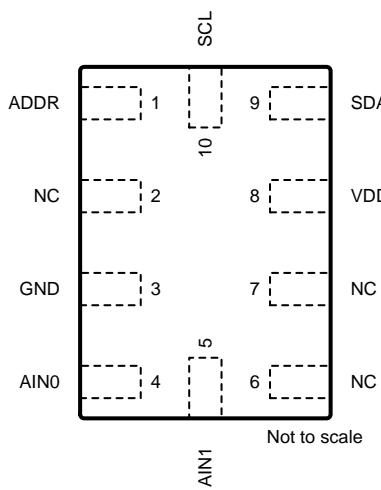
| DATE          | REVISION | NOTES            |
|---------------|----------|------------------|
| November 2017 | *        | Initial release. |

## 5 Device Comparison Table

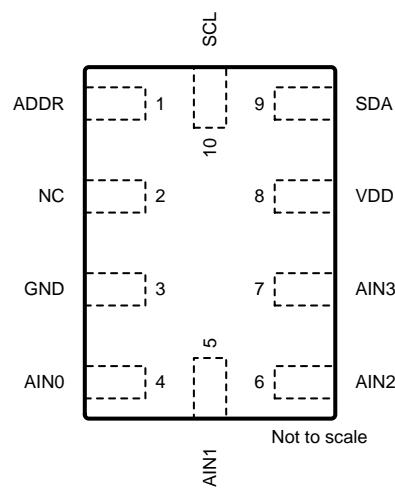
| DEVICE  | RESOLUTION<br>(Bits) | MAXIMUM SAMPLE<br>RATE<br>(SPS) | INPUT CHANNELS,<br>DIFFERENTIAL<br>(Single-Ended) | PGA | INTERFACE        |
|---------|----------------------|---------------------------------|---|-----|------------------|
| TLA2021 | 12                   | 3300                            | 1 (1)   | No  | I <sup>2</sup> C |
| TLA2022 | 12                   | 3300                            | 1 (1)   | Yes | I <sup>2</sup> C |
| TLA2024 | 12                   | 3300                            | 2 (4)   | Yes | I <sup>2</sup> C |

## 6 Pin Configuration and Functions

**TLA2021 and TLA2022 RUG Package  
10-Pin X2QFN  
Top View**



**TLA2024 RUG Package  
10-Pin X2QFN  
Top View**



### Pin Functions

| NAME | PIN                 |         | TYPE          | DESCRIPTION  |
|------|---------------------|---------|---------------|--|
|      | TLA2021,<br>TLA2022 | TLA2024 |               |  |
| ADDR | 1                   | 1       | Digital input | I <sup>2</sup> C slave address select pin. See the <a href="#">I<sup>2</sup>C Address Selection</a> section for details. |
| AIN0 | 4                   | 4       | Analog input  | Analog input 0 <sup>(1)</sup>  |
| AIN1 | 5                   | 5       | Analog input  | Analog input 1 <sup>(1)</sup>  |
| AIN2 | —                   | 6       | Analog input  | Analog input 2 <sup>(1)</sup>  |
| AIN3 | —                   | 7       | Analog input  | Analog input 3 <sup>(1)</sup>  |
| GND  | 3                   | 3       | Supply        | Ground   |
| NC   | 2, 6, 7             | 2       | —             | No connect; always leave floating  |
| SCL  | 10                  | 10      | Digital input | Serial clock input. Connect to VDD using a pullup resistor.  |
| SDA  | 9                   | 9       | Digital I/O   | Serial data input and output. Connect to VDD using a pullup resistor.  |
| VDD  | 8                   | 8       | Supply        | Power supply. Connect a 0.1- $\mu$ F, power-supply decoupling capacitor to GND.  |

(1) Float unused analog inputs, or tie unused analog inputs to GND.

## 7 Specifications

### 7.1 Absolute Maximum Ratings<sup>(1)</sup>

|                       |  | MIN       | MAX       | UNIT |
|-----------------------|--|-----------|-----------|------|
| Power-supply voltage  | VDD to GND                                   | -0.3      | 7         |      |
| Analog input voltage  | AIN0, AIN1, AIN2, AIN3                       | GND - 0.3 | VDD + 0.3 | V    |
| Digital input voltage | SDA, SCL, ADDR                               | GND - 0.3 | 7         |      |
| Input current         | Continuous, any pin except power-supply pins | -10       | 10        | mA   |
| Temperature           | Junction, $T_J$                              | -40       | 125       | °C   |
|                       | Storage, $T_{stg}$                           | -60       | 125       |      |

(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.

### 7.2 ESD Ratings

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

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

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

### 7.3 Recommended Operating Conditions

over operating ambient temperature range (unless otherwise noted)

|   | MIN    | NOM    | MAX    | UNIT |
|---|--------|--------|--------|------|
| <b>POWER SUPPLY</b>   |        |        |        |      |
| VDD to GND  | 2      | 5.5    | 5.5    | V    |
| <b>ANALOG INPUTS<sup>(1)</sup></b>  |        |        |        |      |
| FSR Full-scale input voltage range <sup>(2)</sup><br>( $V_{IN} = V_{AINP} - V_{AINN}$ ) | ±0.256 | ±6.144 | ±6.144 | V    |
| $V_{(AINx)}$ Absolute input voltage   | GND    | VDD    | VDD    | V    |
| <b>DIGITAL INPUTS</b>   |        |        |        |      |
| Digital input voltage   | GND    | 5.5    | 5.5    | V    |
| <b>TEMPERATURE</b>  |        |        |        |      |
| $T_A$ Operating ambient temperature   | -40    | 85     | 85     | °C   |

(1)  $AIN_P$  and  $AIN_N$  denote the selected positive and negative inputs. On the TLA2024,  $AIN_x$  denotes one of the four available analog inputs.

(2) This parameter expresses the full-scale range of the ADC scaling. No more than VDD + 0.3 V or 5.5 V (whichever is smaller) must be applied to this device. See the [Full-Scale Range \(FSR\) and LSB Size](#) section more information.

### 7.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup>  | TLA202x     | UNIT |
|--|-------------|------|
|  | RUG (X2QFN) |      |
|  | 10 PINS     |      |
| $R_{\theta JA}$ Junction-to-ambient thermal resistance                   | 245.2       | °C/W |
| $R_{\theta JC(\text{top})}$ Junction-to-case (top) thermal resistance    | 69.3        | °C/W |
| $R_{\theta JB}$ Junction-to-board thermal resistance                     | 172.0       | °C/W |
| $\Psi_{JT}$ Junction-to-top characterization parameter                   | 8.2         | °C/W |
| $\Psi_{JB}$ Junction-to-board characterization parameter                 | 170.8       | °C/W |
| $R_{\theta JC(\text{bot})}$ Junction-to-case (bottom) thermal resistance | N/A         | °C/W |

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

## 7.5 Electrical Characteristics

minimum and maximum specifications apply from  $T_A = -40^\circ\text{C}$  to  $+85^\circ\text{C}$ ; typical specifications are at  $T_A = 25^\circ\text{C}$ ; all specifications are at  $VDD = 3.3\text{ V}$ , data rate = 128 SPS, and  $\text{FSR} = \pm 2.048\text{ V}$  (unless otherwise noted)

| PARAMETER                                | TEST CONDITIONS   | MIN                                  | TYP     | MAX | UNIT             |
|--|---|--------------------------------------|---------|-----|------------------|
| <b>ANALOG INPUT</b>                      |   |                                      |         |     |                  |
| Common-mode input impedance              | $\text{FSR} = \pm 6.144\text{ V}^{(1)}$                                     | 10                                   |         |     | $\text{M}\Omega$ |
|  | $\text{FSR} = \pm 4.096\text{ V}^{(1)}$ , $\text{FSR} = \pm 2.048\text{ V}$ | 6                                    |         |     |                  |
|  | $\text{FSR} = \pm 1.024\text{ V}$   | 3                                    |         |     |                  |
|  | $\text{FSR} = \pm 0.512\text{ V}$ , $\text{FSR} = \pm 0.256\text{ V}$       | 100                                  |         |     |                  |
| Differential input impedance             | $\text{FSR} = \pm 6.144\text{ V}^{(1)}$                                     | 22                                   |         |     | $\text{M}\Omega$ |
|  | $\text{FSR} = \pm 4.096\text{ V}^{(1)}$                                     | 15                                   |         |     |                  |
|  | $\text{FSR} = \pm 2.048\text{ V}$   | 4.9                                  |         |     |                  |
|  | $\text{FSR} = \pm 1.024\text{ V}$   | 2.4                                  |         |     |                  |
|  | $\text{FSR} = \pm 0.512\text{ V}$ , $\pm 0.256\text{ V}$                    | 710                                  |         |     | $\text{k}\Omega$ |
| <b>SYSTEM PERFORMANCE</b>                |   |                                      |         |     |                  |
| Resolution (no missing codes)            |   | 12                                   |         |     | Bits             |
| DR Data rate                             |   | 128, 250, 490, 920, 1600, 2400, 3300 |         |     | SPS              |
| Data rate variation                      | All data rates  | −10%                                 |         | 10% |                  |
| INL Integral nonlinearity <sup>(2)</sup> |   | 1                                    |         |     | LSB              |
| Offset error                             |   | $\pm 1$                              |         |     | LSB              |
| Offset drift                             |   | 0.01                                 |         |     | LSB/°C           |
| Gain error <sup>(3)</sup>                |   | 0.05%                                |         |     |                  |
| Gain drift <sup>(3)</sup>                |   | 10                                   |         |     | ppm/°C           |
| PSRR Power-supply rejection ratio        |   | 85                                   |         |     | dB               |
| CMRR Common-mode rejection ratio         |   | 90                                   |         |     | dB               |
| <b>DIGITAL INPUT/OUTPUT</b>              |   |                                      |         |     |                  |
| $V_{IL}$ Logic input level, low          |   | GND                                  | 0.3 VDD |     | V                |
| $V_{IH}$ Logic input level, high         |   | 0.7 VDD                              |         | 5.5 | V                |
| $V_{OL}$ Logic output level, low         | $I_{OL} = 3\text{ mA}$  | GND                                  | 0.15    | 0.4 | V                |
| Input leakage current                    | $\text{GND} < V_{\text{Digital Input}} < \text{VDD}$                        | −10                                  |         | 10  | $\mu\text{A}$    |
| <b>POWER SUPPLY</b>                      |   |                                      |         |     |                  |
| $I_{VDD}$ Supply current                 | Power-down  | 0.5                                  |         |     | $\mu\text{A}$    |
|  | Operating   | 150                                  |         |     |                  |
| $P_D$ Power dissipation                  | $VDD = 5\text{ V}$  | 0.9                                  |         |     | $\text{mW}$      |
|  | $VDD = 3.3\text{ V}$  | 0.5                                  |         |     |                  |
|  | $VDD = 2\text{ V}$  | 0.3                                  |         |     |                  |
|  |   |                                      |         |     |                  |

(1) This parameter expresses the full-scale range of the ADC scaling. No more than  $VDD + 0.3\text{ V}$  or  $5.5\text{ V}$  (whichever is smaller) must be applied to this device. See the [Full-Scale Range \(FSR\) and LSB Size](#) section for more information.

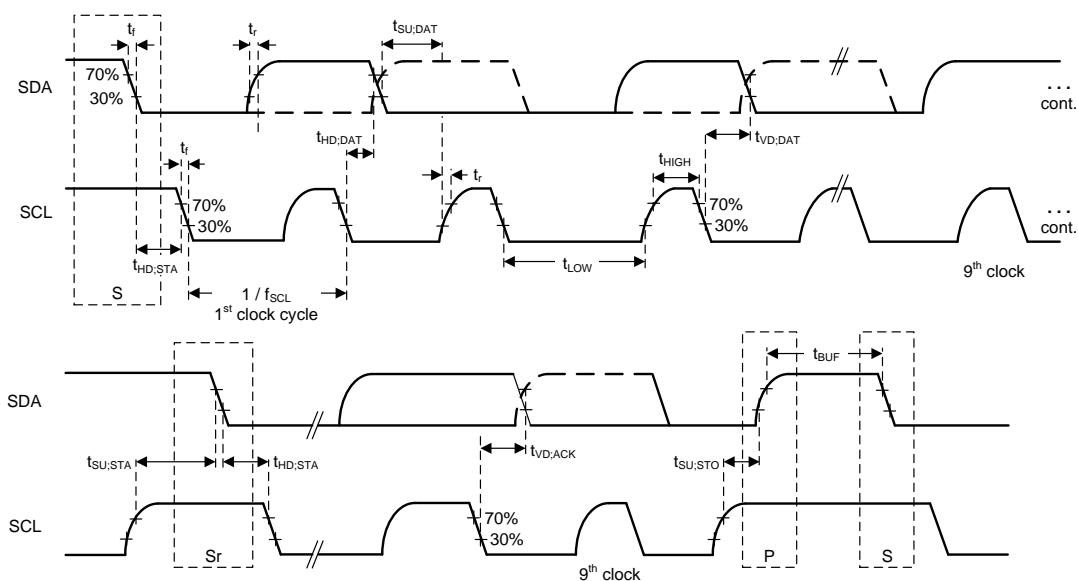
(2) Best-fit INL; covers 99% of full-scale.

(3) Includes all errors from onboard PGA and voltage reference.

## 7.6 I<sup>2</sup>C Timing Requirements

over operating ambient temperature range and VDD = 2 V to 5.5 V (unless otherwise noted)

|                      |  | MIN | MAX  | UNIT |
|----------------------|--|-----|------|------|
| <b>STANDARD-MODE</b> |  |     |      |      |
| $f_{SCL}$            | SCL clock frequency  | 10  | 100  | kHz  |
| $t_{LOW}$            | Pulse duration, SCL low  | 4.7 |      | μs   |
| $t_{HIGH}$           | Pulse duration, SCL high   | 4.0 |      | μs   |
| $t_{HD:STA}$         | Hold time, (repeated) START condition.<br>After this period, the first clock pulse is generated. | 4   |      | μs   |
| $t_{SU:STA}$         | Setup time, repeated START condition   | 4.7 |      | μs   |
| $t_{HD:DAT}$         | Hold time, data  | 0   |      | μs   |
| $t_{SU:DAT}$         | Setup time, data   | 250 |      | ns   |
| $t_r$                | Rise time, SCL, SDA  |     | 1000 | ns   |
| $t_f$                | Fall time, SCL, SDA  |     | 250  | ns   |
| $t_{SU:STO}$         | Setup time, STOP condition   | 4.0 |      | μs   |
| $t_{BUF}$            | Bus free time, between STOP and START condition  | 4.7 |      | μs   |
| $t_{VD:DAT}$         | Valid time, data   |     | 3.45 | μs   |
| $t_{VD:ACK}$         | Valid time, acknowledge  |     | 3.45 | μs   |
| <b>FAST-MODE</b>     |  |     |      |      |
| $f_{SCL}$            | SCL clock frequency  | 10  | 400  | kHz  |
| $t_{LOW}$            | Pulse duration, SCL low  | 1.3 |      | μs   |
| $t_{HIGH}$           | Pulse duration, SCL high   | 0.6 |      | μs   |
| $t_{HD:STA}$         | Hold time, (repeated) START condition.<br>After this period, the first clock pulse is generated. | 0.6 |      | μs   |
| $t_{SU:STA}$         | Setup time, repeated START condition   | 0.6 |      | μs   |
| $t_{HD:DAT}$         | Hold time, data  | 0   |      | μs   |
| $t_{SU:DAT}$         | Setup time, data   | 100 |      | ns   |
| $t_r$                | Rise time, SCL, SDA  | 20  | 300  | ns   |
| $t_f$                | Fall time, SCL, SDA  |     | 300  | ns   |
| $t_{SU:STO}$         | Setup time, STOP condition   | 0.6 |      | μs   |
| $t_{BUF}$            | Bus free time, between STOP and START condition  | 1.3 |      | μs   |
| $t_{VD:DAT}$         | Valid time, data   |     | 0.9  | μs   |
| $t_{VD:ACK}$         | Valid time, acknowledge  |     | 0.9  | μs   |



**Figure 1. I<sup>2</sup>C Timing Requirements**

## 7.7 Typical Characteristics

at FSR =  $\pm 2.048$  V and DR = 128 SPS (unless otherwise noted)

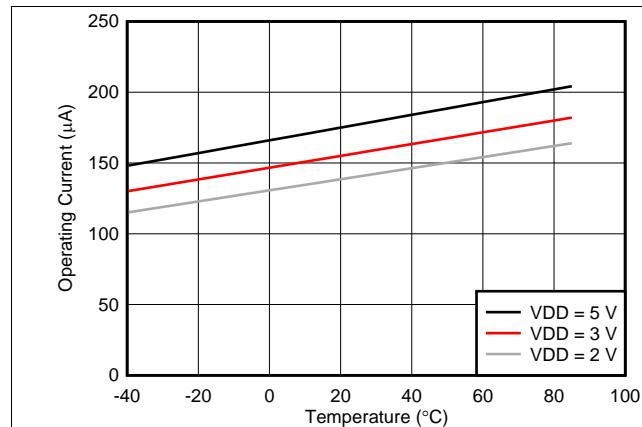


Figure 2. Operating Current vs Temperature

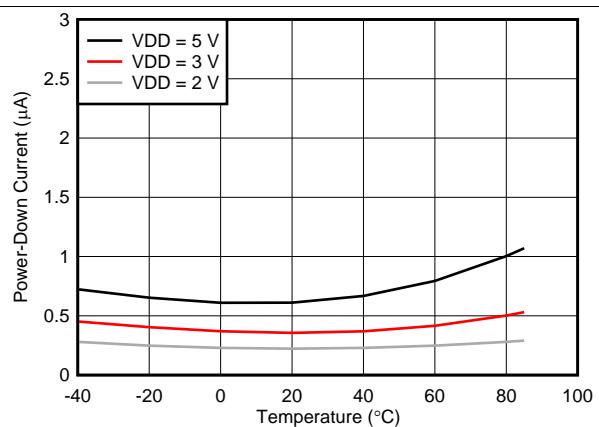


Figure 3. Power-Down Current vs Temperature

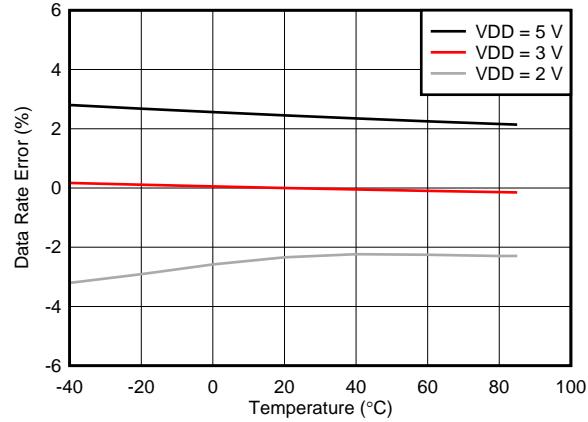


Figure 4. Data Rate vs Temperature

## 8 Detailed Description

### 8.1 Overview

The TLA202x are a family of very small, low-power, 12-bit, delta-sigma ( $\Delta\Sigma$ ) analog-to-digital converters (ADCs). The TLA202x consist of a  $\Delta\Sigma$  ADC core with an internal voltage reference, a clock oscillator, and an I<sup>2</sup>C interface. The TLA2022 and TLA2024 also integrate a programmable gain amplifier (PGA). Figure 5, Figure 6, and Figure 7 show the functional block diagrams of the TLA2024, TLA2022, and TLA2021, respectively.

The TLA202x ADC core measures a differential signal,  $V_{IN}$ , that is the difference of  $V_{A_{INP}}$  and  $V_{A_{INN}}$ . 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 TLA202x have two available conversion modes: single-shot and continuous-conversion. In single-shot conversion 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 complete. The rate of continuous conversion is equal to the programmed data rate. Data can be read at any time and always reflect the most recently completed conversion.

### 8.2 Functional Block Diagrams

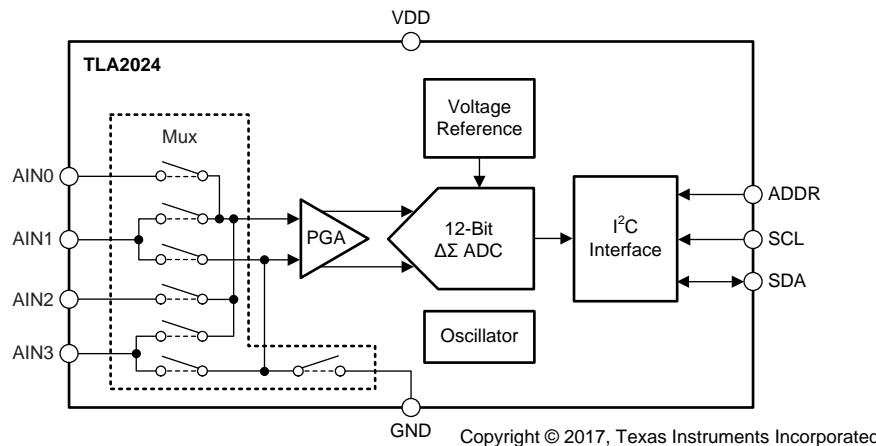


Figure 5. TLA2024 Block Diagram

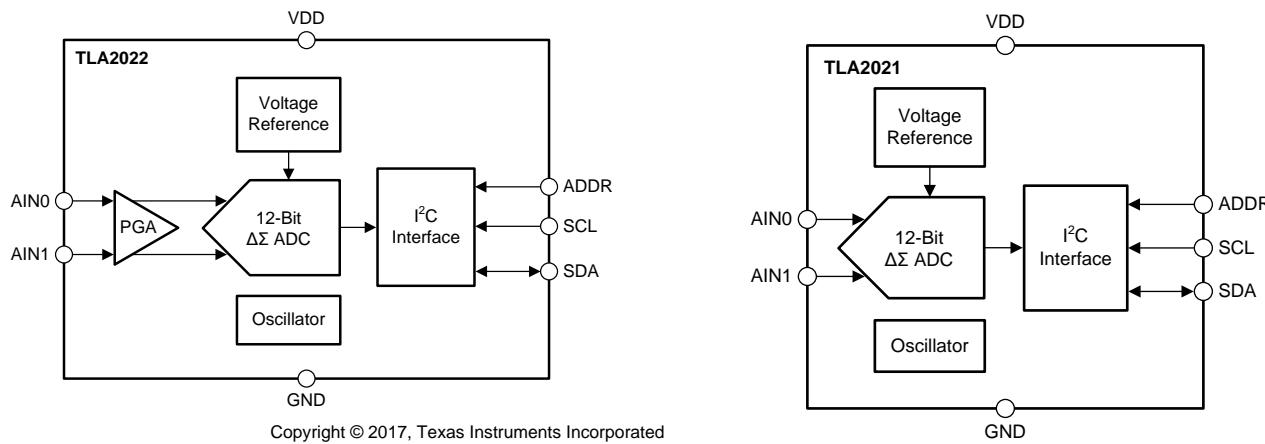


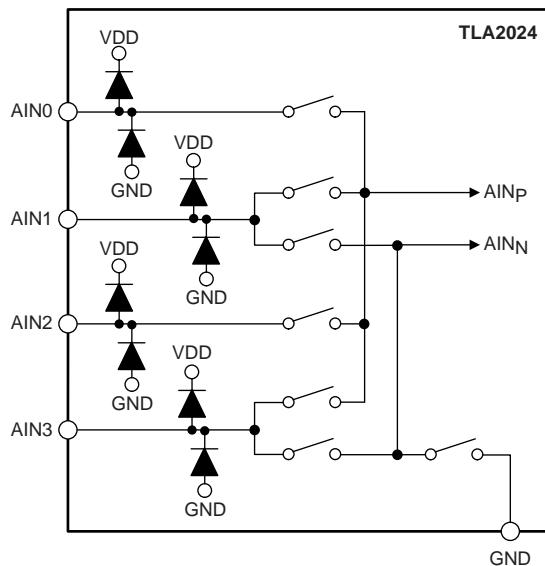
Figure 6. TLA2022 Block Diagram

Figure 7. TLA2021 Block Diagram

## 8.3 Feature Description

### 8.3.1 Multiplexer

Figure 8 shows that the TLA2024 contains an analog input multiplexer (MUX). 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 [configuration register](#). When single-ended signals are measured, the negative input of the ADC is internally connected to GND by a switch within the multiplexer.



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**Figure 8. Input Multiplexer**

The TLA2021 and TLA2022 do not have an input multiplexer and can either measure 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<sub>P</sub> refers to AIN0 and AIN<sub>N</sub> refers to AIN1 for the TLA2021 and TLA2022.

Electrostatic discharge (ESD) diodes connected to VDD and GND protect the TLA202x analog inputs. Keep the absolute voltage on any input within the range shown in [Equation 1](#) to prevent the ESD diodes from turning on.

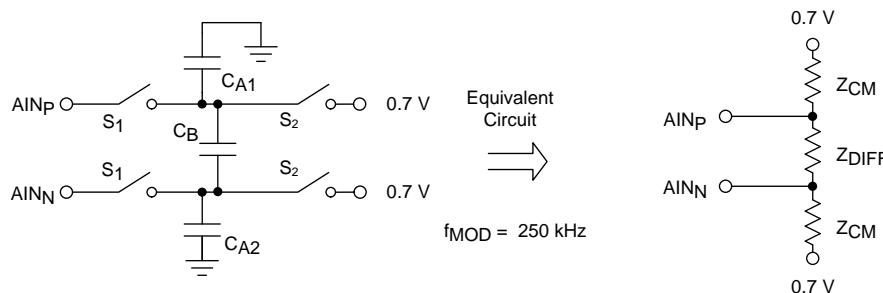
$$\text{GND} - 0.3 \text{ V} < V_{(\text{AIN}X)} < \text{VDD} + 0.3 \text{ V} \quad (1)$$

If the voltages on the analog 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).

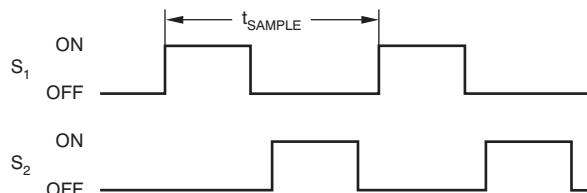
## Feature Description (continued)

### 8.3.2 Analog Inputs

The TLA202x 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 referred to as the *sampling frequency* or the *modulator frequency* ( $f_{MOD}$ ). The TLA202x have a 1-MHz internal oscillator that is further divided by a factor of 4 to generate  $f_{MOD}$  at 250 kHz. The capacitors used in this input stage are small, and to external circuitry, the average loading appears resistive. [Figure 9](#) shows this structure. The capacitor values set the resistance and switching rate. [Figure 10](#) shows the timing for the switches in [Figure 9](#). 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.  $C_{A1}$  and  $C_{A2}$  then discharge to approximately 0.7 V and  $C_B$  discharges to 0 V. This charging draws a very small transient current from the source driving the TLA202x analog inputs. The average value of this current can be used to calculate the effective impedance ( $Z_{eff}$ ), where  $Z_{eff} = V_{IN} / I_{AVERAGE}$ .



**Figure 9. Simplified Analog Input Circuit**



**Figure 10.  $S_1$  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  $6 \text{ M}\Omega$  for the default full-scale range. In [Figure 9](#), the common-mode input impedance is  $Z_{CM}$ .

The differential input impedance is measured by applying a differential signal to the  $AIN_P$  and  $AIN_N$  inputs where one input is held at 0.7 V. The current that flows through the pin connected to 0.7 V is the differential current and scales with the full-scale range. In [Figure 9](#), the differential input impedance is  $Z_{DIFF}$ .

Consider the typical value of the input impedance. Unless the input source has a low impedance, the TLA202x input impedance may affect the measurement accuracy. For sources with high-output impedance, buffering may be necessary. Active buffers introduce noise, 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.

## Feature Description (continued)

### 8.3.3 Full-Scale Range (FSR) and LSB Size

A programmable gain amplifier (PGA) is implemented before the  $\Delta\Sigma$  ADC of the TLA2022 and TLA2024. The full-scale range is configured by bits PGA[2:0] in the *configuration register* and can be set to  $\pm 6.144$  V,  $\pm 4.096$  V,  $\pm 2.048$  V,  $\pm 1.024$  V,  $\pm 0.512$  V, or  $\pm 0.256$  V. **Table 1** shows the FSR together with the corresponding LSB size. **Equation 2** shows how to calculate the LSB size from the selected full-scale range.

$$\text{LSB} = \text{FSR} / 2^{12} \quad (2)$$

**Table 1. Full-Scale Range and Corresponding LSB Size**

| FSR                          | LSB SIZE |
|------------------------------|----------|
| $\pm 6.144$ V <sup>(1)</sup> | 3 mV     |
| $\pm 4.096$ V <sup>(1)</sup> | 2 mV     |
| $\pm 2.048$ V                | 1 mV     |
| $\pm 1.024$ V                | 0.5 mV   |
| $\pm 0.512$ V                | 0.25 mV  |
| $\pm 0.256$ V                | 0.125 mV |

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

The FSR of the TLA2021 is fixed at  $\pm 2.048$  V.

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

### 8.3.4 Voltage Reference

The TLA202x have an integrated voltage reference. An external reference cannot be used with these devices. 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.

### 8.3.5 Oscillator

The TLA202x have an integrated oscillator running at 1 MHz. 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.

### 8.3.6 Output Data Rate and Conversion Time

The TLA202x offer programmable output data rates. Use the DR[2:0] bits in the *configuration register* to select output data rates of 128 SPS, 250 SPS, 490 SPS, 920 SPS, 1600 SPS, 2400 SPS, or 3300 SPS.

Conversions in the TLA202x settle within a single cycle, which means the conversion time equals 1 / DR.

## 8.4 Device Functional Modes

### 8.4.1 Reset and Power-Up

The TLA202x reset on power-up and set all bits in the [configuration register](#) to the respective default settings. The TLA202x 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 TLA202x relieves systems with tight power-supply requirements from encountering a surge during power-up.

The TLA202x respond to the I<sup>2</sup>C general-call reset command. When the TLA202x receive a general-call reset command (06h), an internal reset is performed as if the device is powered up.

### 8.4.2 Operating Modes

The TLA202x operate in one of two modes: continuous-conversion or single-shot. The MODE bit in the configuration register selects the respective operating mode.

#### 8.4.2.1 Single-Shot Conversion Mode

When the MODE bit in the configuration register is set to 1, the TLA202x enter a power-down state, and operate in single-shot conversion mode. This power-down state is the default state for the TLA202x when power is first applied. Although powered down, the devices respond to commands. The TLA202x remain in this power-down state until a 1 is written to the operational status (OS) bit in the configuration register. When the OS bit is asserted, the device powers up in approximately 25  $\mu$ s, resets the OS bit to 0, and starts a single conversion. When conversion data are ready for retrieval, the OS bit is set to 1 and the device powers down again. Writing a 1 to the OS bit while a conversion is ongoing has no effect. To switch to continuous-conversion mode, write a 0 to the MODE bit in the configuration register.

#### 8.4.2.2 Continuous-Conversion Mode

In continuous-conversion mode (MODE bit set to 0), the TLA202x perform conversions continuously. When a conversion is complete, the TLA202x place the result in the [conversion data 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 1 to the MODE bit in the configuration register or reset the device.

## 8.5 Programming

### 8.5.1 I<sup>2</sup>C Interface

The TLA202x use an I<sup>2</sup>C-compatible (inter-integrated circuit) interface for serial communication. I<sup>2</sup>C is a 2-wire, open-drain communication interface that allows communication of a master device with multiple slave devices on the same bus through the use of device addressing. Each slave device on an I<sup>2</sup>C bus must have a unique address. Communication on the I<sup>2</sup>C bus always takes place between two devices: one acting as the master and the other as the slave. Both the master and slave can receive and transmit data, but the slave can only read or write under the direction of the master. The TLA202x always act as I<sup>2</sup>C slave devices.

An I<sup>2</sup>C bus consists of two lines: SDA and SCL. SDA carries data and SCL provides the clock. Devices on the I<sup>2</sup>C bus drive the bus lines low by connecting the lines to ground; the devices never drive the bus lines high. Instead, the bus wires are pulled high by pullup resistors; thus, the bus wires are always high when a device is not driving the lines low. As a result of this configuration, two devices do not conflict. If two devices drive the bus simultaneously, there is no driver contention.

See the [I<sup>2</sup>C-Bus Specification and User Manual](#) from NXP Semiconductors™ for more details.

#### 8.5.1.1 I<sup>2</sup>C Address Selection

The TLA202x have one address pin (ADDR) that configures the I<sup>2</sup>C address of the device. The ADDR pin can connect to GND, VDD, or SCL (as shown in [Table 2](#)), which allows three different addresses to be selected with one pin. At the start of every transaction, that is between the START condition (first falling edge of SDA) and the first falling SCL edge of the address byte, the TLA202x decode its address configuration again.

**Table 2. ADDR Pin Connection and Corresponding Slave Address**

| ADDR PIN CONNECTION | SLAVE ADDRESS |
|---------------------|---------------|
| GND                 | 1001 000      |
| VDD                 | 1001 001      |
| SCL                 | 1001 011      |

#### 8.5.1.2 I<sup>2</sup>C Interface Speed

The TLA202x support I<sup>2</sup>C interface speeds up to 400 kbit/s. Standard-mode (Sm) with bit rates up to 100 kbit/s, and fast-mode (Fm) with bit rates up to 400 kbit/s are supported. Fast-mode plus (Fm+) and high-speed mode (Hs-mode) are not supported.

#### 8.5.1.3 Serial Clock (SCL) and Serial Data (SDA)

The serial clock (SCL) line is used to clock data in and out of the device. The master always drives the clock line. The TLA202x cannot act as a master and as a result can never drive SCL.

The serial data (SDA) line allows for bidirectional communication between the host (the master) and the TLA202x (the slave). When the master reads from a TLA202x, the TLA202x drives the data line; when the master writes to a TLA202x, the master drives the data line.

Data on the SDA line must be stable during the high period of the clock. The high or low state of the data line can only change when the SCL line is low. One clock pulse is generated for each data bit transferred. When in an idle state, the master should hold SCL high.

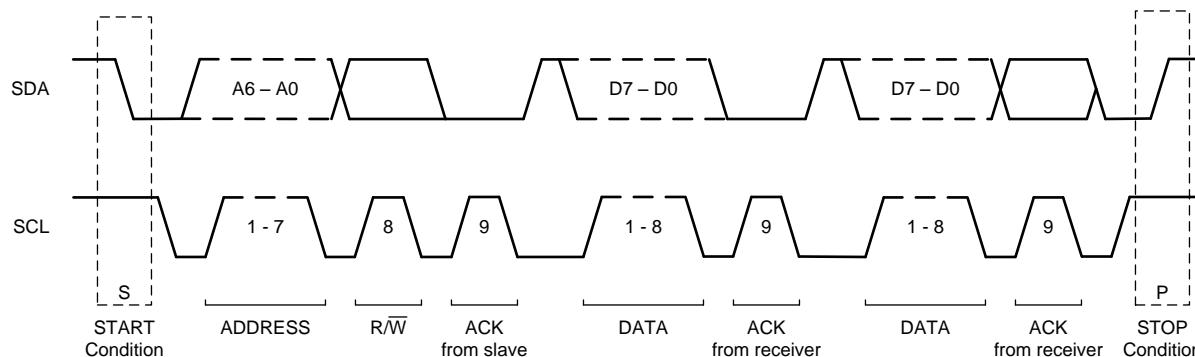
### 8.5.1.4 I<sup>2</sup>C Data Transfer Protocol

Figure 11 shows the format of the data transfer. The master initiates all transactions with the TLA202x by generating a START (S) condition. A high-to-low transition on the SDA line while SCL is high defines a START condition. The bus is considered to be busy after the START condition.

Following the START condition, the master sends the 7-bit slave address corresponding to the address of the TLA202x that the master wants to communicate with. The master then sends an eighth bit that is a data direction bit (R/W). An R/W bit of 0 indicates a write operation, and an R/W bit of 1 indicates a read operation. After the R/W bit, the master generates a ninth SCLK pulse and releases the SDA line to allow the TLA202x to acknowledge (ACK) the reception of the slave address by pulling SDA low. In case the device does not recognize the slave address, the TLA202x holds SDA high to indicate a not acknowledge (NACK) signal.

Next follows the data transmission. If the transaction is a read (R/W = 1), the TLA202x outputs data on SDA. If the transaction is a write (R/W = 0), the host outputs data on SDA. Data are transferred byte-wise, most significant bit (MSB) first. The number of bytes that can be transmitted per transfer is unrestricted. Each byte must be acknowledged (via the ACK bit) by the receiver. If the transaction is a read, the master issues the ACK. If the transaction is a write, the TLA202x issues the ACK.

The master terminates all transactions by generating a STOP (P) condition. A low-to-high transition on the SDA line while SCL is high defines a STOP condition. The bus is considered free again  $t_{BUF}$  (bus-free time) after the STOP condition.



**Figure 11. I<sup>2</sup>C Data Transfer Format**

### 8.5.1.5 Timeout

The TLA202x offer a I<sup>2</sup>C timeout feature that can be used to recover communication when a serial interface transmission is interrupted. If the host initiates contact with the TLA202x but subsequently remains idle for 25 ms before completing a command, the TLA202x interface is reset. If the TLA202x interface resets because of a timeout condition, the host must abort the transaction and restart the communication again by issuing a new START condition.

### 8.5.1.6 I<sup>2</sup>C General-Call (Software Reset)

The TLA202x respond to the I<sup>2</sup>C general-call address (0000 000) if the R/W bit is 0. The devices acknowledge the general-call address and, if the next byte is 06h, the TLA202x reset the internal registers and enter a power-down state.

### 8.5.2 Reading and Writing Register Data

The host can read the *conversion data register* from the TLA202x, or read and write the *configuration register* from and to the TLA202x, respectively. The value of the register pointer (RP), which is the first data byte after the slave address of a write transaction ( $R/W = 0$ ), determines the register that is addressed. **Table 3** shows the mapping between the register pointer value and the register that is addressed.

Register data are sent with the most significant byte first, followed by the least significant byte. Within each byte, data are transmitted most significant bit first.

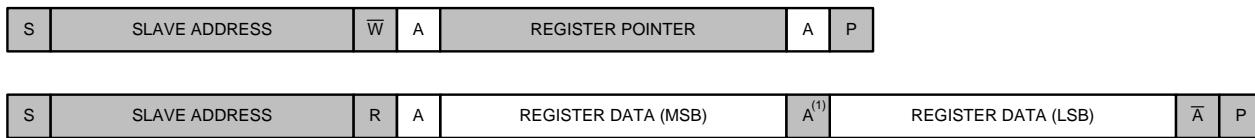
**Table 3. Register Pointer (RP)**

| REGISTER POINTER<br>(Hex) | REGISTER                 |
|---------------------------|--------------------------|
| 00h                       | Conversion data register |
| 01h                       | Configuration register   |

#### 8.5.2.1 Reading Conversion Data or the Configuration Register

Read the *conversion data register* or *configuration register* as shown in [Figure 12](#) by using two I<sup>2</sup>C communication frames. The first frame is an I<sup>2</sup>C write operation where the R/W bit at the end of the slave address is 0 to indicate a write. In this frame, the host sends the register pointer that points to the register to read from. The second frame is an I<sup>2</sup>C read operation where the R/W bit at the end of the slave address is 1 to indicate a read. The TLA202x transmits the contents of the register in this second I<sup>2</sup>C frame. The master can terminate the transmission after any byte by not acknowledging or issuing a START or STOP condition.

When repeatedly reading the same register, the register pointer does not need to be written every time again because the TLA202x store the value of the register pointer until a write operation modifies the value.

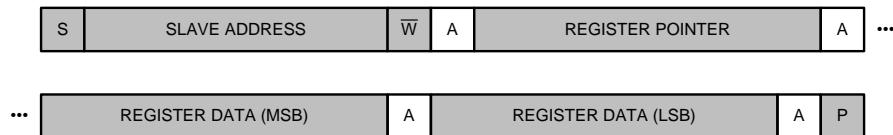


(1) The master can terminate the transmission after the first byte by not acknowledging.

**Figure 12. Reading Register Data**

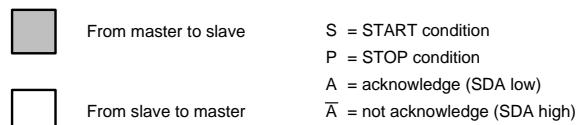
#### 8.5.2.2 Writing the Configuration Register

Write the *configuration register* as shown in [Figure 13](#) using a single I<sup>2</sup>C communication frame. The R/W bit at the end of the slave address is 0 to indicate a write. The host first sends the register pointer that points to the configuration register, followed by two bytes that represent the register content to write. The TLA202x acknowledge each received byte.



**Figure 13. Writing Register Data**

[Figure 14](#) provides a legend for [Figure 12](#) and [Figure 13](#).



**Figure 14. Legend for the I<sup>2</sup>C Sequence Diagrams**

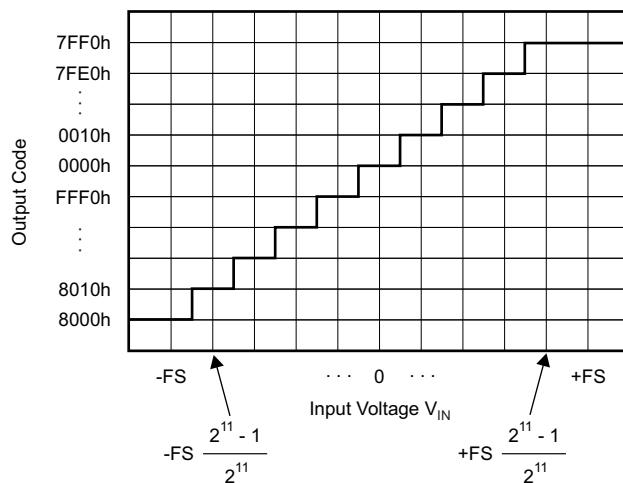
### 8.5.3 Data Format

The TLA202x provide 12 bits of data in binary two's-complement format that is left-justified within the 16-bit data word. A positive full-scale (+FS) input produces an output code of 7FF0h 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. [Table 4](#) summarizes the ideal output codes for different input signals. [Figure 15](#) shows code transitions versus input voltage.

**Table 4. Input Signal Versus Ideal Output Code**

| INPUT SIGNAL<br>$V_{IN} = (V_{AINP} - V_{AINN})$ | IDEAL OUTPUT CODE <sup>(1)</sup> |
|--|----------------------------------|
| $\geq +FS (2^{11} - 1) / 2^{11}$                 | 7FF0h                            |
| $+FS / 2^{11}$                                   | 0010h                            |
| 0  | 0000h                            |
| $-FS / 2^{11}$                                   | FFF0h                            |
| $\leq -FS$                                       | 8000h                            |

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



**Figure 15. Code Transition Diagram**

#### NOTE

Single-ended signal measurements, where  $V_{AINN} = 0$  V and  $V_{AINP} = 0$  V to +FS, only use the positive code range from 0000h to 7FF0h. However, because of device offset, the TLA202x can still output negative codes in case  $V_{AINP}$  is close to 0 V.

## 8.6 Register Maps

The TLA202x have two registers that are accessible through the I<sup>2</sup>C interface using the register pointer (RP). The *conversion data register* contains the result of the last conversion and the *configuration register* changes the TLA202x operating modes and queries the status of the device. **Table 5** lists the access codes for the TLA202x.

**Table 5. TLA202x Access Type Codes**

| Access Type | Code | Description                            |
|-------------|------|--|
| R           | R    | Read                                   |
| R-W         | R/W  | Read or write                          |
| W           | W    | Write                                  |
| -n          |      | Value after reset or the default value |

### 8.6.1 Conversion Data Register (RP = 00h) [reset = 0000h]

The 16-bit conversion data register contains the result of the last conversion in binary two's-complement format. Following power-up, the conversion data register clears to 0, and remains at 0 until the first conversion is complete.

**Figure 16. Conversion Data Register**

| 15   | 14   | 13   | 12   | 11       | 10   | 9    | 8    |
|------|------|------|------|----------|------|------|------|
| D11  | D10  | D9   | D8   | D7       | D6   | D5   | D4   |
| R-0h | R-0h | R-0h | R-0h | R-0h     | R-0h | R-0h | R-0h |
| 7    | 6    | 5    | 4    | 3        | 2    | 1    | 0    |
| D3   | D2   | D1   | D0   | RESERVED |      |      |      |
| R-0h | R-0h | R-0h | R-0h | R-0h     |      |      |      |

**Table 6. Conversion Data Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description              |
|------|----------|------|-------|--------------------------|
| 15:4 | D[11:0]  | R    | 000h  | 12-bit conversion result |
| 3:0  | Reserved | R    | 0h    | Always reads back 0h     |

### 8.6.2 Configuration Register (RP = 01h) [reset = 8583h]

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

**Figure 17. Configuration Register**

| 15      | 14       | 13 | 12       | 11       | 10 | 9 | 8      |
|---------|----------|----|----------|----------|----|---|--------|
| OS      | MUX[2:0] |    |          | PGA[2:0] |    |   | MODE   |
| R/W-1h  | R/W-0h   |    |          | R/W-2h   |    |   | R/W-1h |
| 7       | 6        | 5  | 4        | 3        | 2  | 1 | 0      |
| DR[2:0] |          |    | RESERVED |          |    |   |        |
| R/W-4h  |          |    | R/W-03h  |          |    |   |        |

**Table 7. Configuration Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description   |
|-------|----------|------|-------|---|
| 15    | OS       | R/W  | 1h    | <p><b>Operational Status or Single-Shot Conversion Start</b></p> <p>This bit determines the operational status of the device. OS can only be written when in a power-down state and has no effect when a conversion is ongoing.</p> <p>When writing:</p> <p>0 : No effect</p> <p>1 : Start a single conversion (when in a power-down state)</p> <p>When reading:</p> <p>0 : The device is currently performing a conversion</p> <p>1 : The device is not currently performing a conversion (default)</p>  |
| 14:12 | MUX[2:0] | R/W  | 0h    | <p><b>Input Multiplexer Configuration (TLA2024 only)</b></p> <p>These bits configure the input multiplexer.</p> <p>These bits serve no function on the TLA2021 and TLA2022 and are always set to 000.</p> <p>000 : <math>AIN_P = AIN_0</math> and <math>AIN_N = AIN_1</math> (default)</p> <p>001 : <math>AIN_P = AIN_0</math> and <math>AIN_N = AIN_3</math></p> <p>010 : <math>AIN_P = AIN_1</math> and <math>AIN_N = AIN_3</math></p> <p>011 : <math>AIN_P = AIN_2</math> and <math>AIN_N = AIN_3</math></p> <p>100 : <math>AIN_P = AIN_0</math> and <math>AIN_N = GND</math></p> <p>101 : <math>AIN_P = AIN_1</math> and <math>AIN_N = GND</math></p> <p>110 : <math>AIN_P = AIN_2</math> and <math>AIN_N = GND</math></p> <p>111 : <math>AIN_P = AIN_3</math> and <math>AIN_N = GND</math></p> |
| 11:9  | PGA[2:0] | R/W  | 2h    | <p><b>Programmable Gain Amplifier Configuration (TLA2022 and TLA2024 Only)</b></p> <p>These bits set the FSR of the programmable gain amplifier.</p> <p>These bits serve no function on the TLA2021 and are always set to 010.</p> <p>000 : FSR = <math>\pm 6.144</math> V<sup>(1)</sup></p> <p>001 : FSR = <math>\pm 4.096</math> V<sup>(1)</sup></p> <p>010 : FSR = <math>\pm 2.048</math> V (default)</p> <p>011 : FSR = <math>\pm 1.024</math> V</p> <p>100 : FSR = <math>\pm 0.512</math> V</p> <p>101 : FSR = <math>\pm 0.256</math> V</p> <p>110 : FSR = <math>\pm 0.256</math> V</p> <p>111 : FSR = <math>\pm 0.256</math> V</p>  |
| 8     | MODE     | R/W  | 1h    | <p><b>Operating Mode</b></p> <p>This bit controls the operating mode.</p> <p>0 : Continuous-conversion mode</p> <p>1 : Single-shot conversion mode or power-down state (default)</p>  |
| 7:5   | DR[2:0]  | R/W  | 4h    | <p><b>Data Rate</b></p> <p>These bits control the data rate setting.</p> <p>000 : DR = 128 SPS</p> <p>001 : DR = 250 SPS</p> <p>010 : DR = 490 SPS</p> <p>011 : DR = 920 SPS</p> <p>100 : DR = 1600 SPS (default)</p> <p>101 : DR = 2400 SPS</p> <p>110 : DR = 3300 SPS</p> <p>111 : DR = 3300 SPS</p>  |
| 4:0   | Reserved | R/W  | 03h   | Always write 03h  |

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

## 9 Application and Implementation

### NOTE

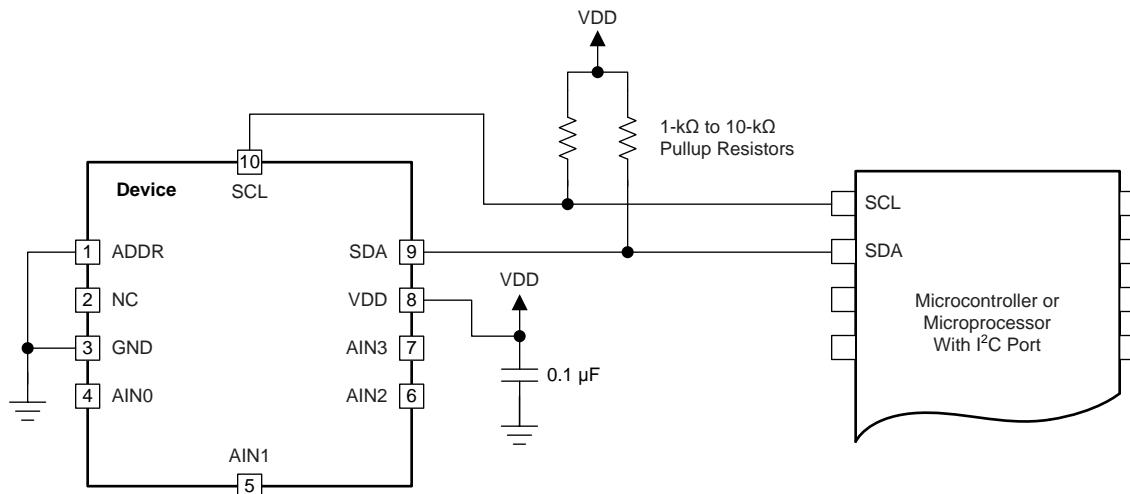
Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation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

### 9.1 Application Information

The following sections give example circuits and suggestions for using the TLA202x in various applications.

#### 9.1.1 Basic Interface Connections

Figure 18 shows the principle I<sup>2</sup>C connections for the TLA202x.



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**Figure 18. Typical Interface Connections of the TLA202x**

The TLA202x interface directly to standard-mode or fast-mode I<sup>2</sup>C controllers. Any microcontroller I<sup>2</sup>C peripheral, including master-only and single-master I<sup>2</sup>C peripherals, operates with the TLA202x. The TLA202x do not perform clock-stretching (that is, the devices never pull the clock line low), so this function does not need to be provided for unless other clock-stretching devices are present on the same I<sup>2</sup>C bus.

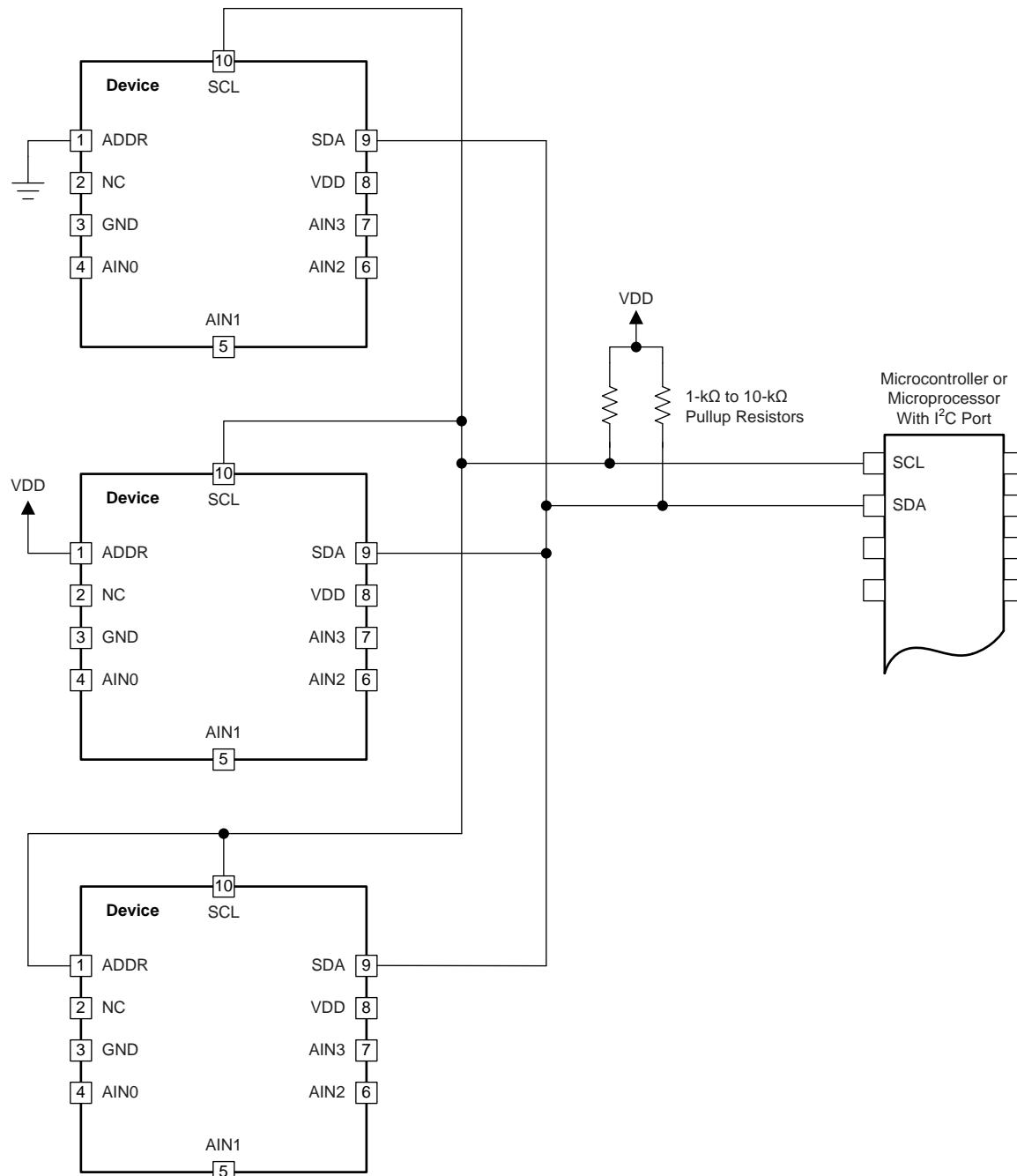
Pullup resistors are required on both the SDA and SCL lines because I<sup>2</sup>C bus drivers are open-drain. The size of these resistors depends on the bus operating speed and capacitance of the bus lines. Higher-value resistors yield lower power consumption when the bus lines are pulled low, but increase the transition times on the bus, which limits the bus speed. Lower-value resistors allow higher interface speeds, but at the expense of higher power consumption when the bus lines are pulled low. Long bus lines have higher capacitance and require smaller pullup resistors to compensate. Do not use resistors that are too small because the bus drivers may be unable to pull the bus lines low.

See the [I<sup>2</sup>C-Bus Specification and User Manual](#) from NXP Semiconductors for more details on pullup resistor sizing.

## Application Information (continued)

### 9.1.2 Connecting Multiple Devices

Up to three TLA202x devices can be connected to a single I<sup>2</sup>C bus by using different address pin configurations for each device. Use the address pin to set the TLA202x to one of three different I<sup>2</sup>C addresses. [Figure 19](#) shows an example with three TLA202x devices on the same I<sup>2</sup>C bus. One set of pullup resistors is required per bus line. The pullup resistor values may need to decrease to compensate for the additional bus capacitance presented by multiple devices and increased line length.



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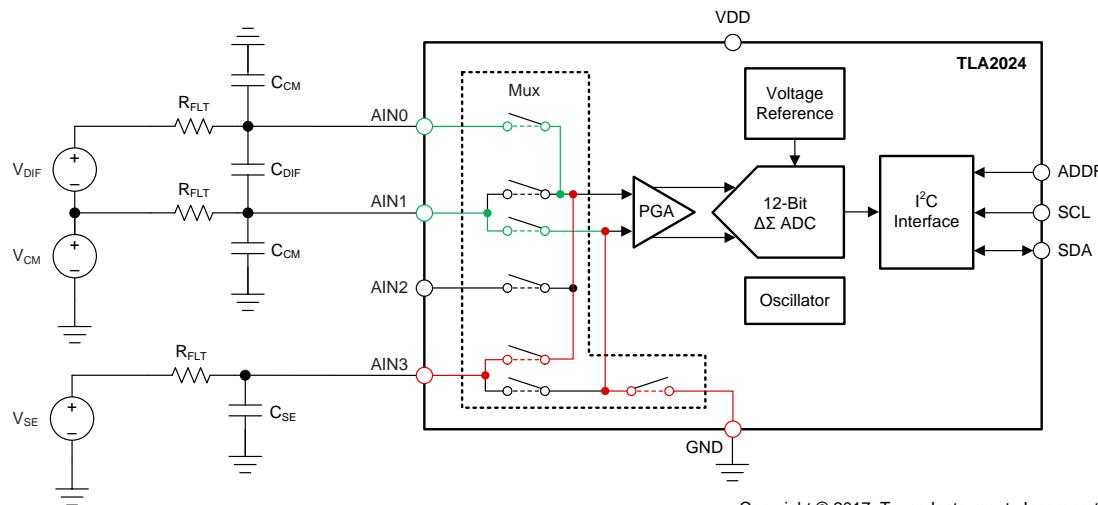
NOTE: The TLA202x power and input connections are omitted for clarity. The ADDR pin selects the I<sup>2</sup>C address.

**Figure 19. Connecting Multiple TLA202x Devices**

## Application Information (continued)

### 9.1.3 Single-Ended Signal Measurements

The TLA2021 and TLA2022 can measure one single-ended signal, and the TLA2024 up to four single-ended signals. To measure single-ended signals with the TLA2021 and TLA2022, connect AIN1 to GND externally. The TLA2024 measures single-ended signals by properly configuring the MUX[2:0] bits (settings 100 to 111) in the [configuration register](#). [Figure 20](#) shows a single-ended connection scheme for the TLA2024 highlighted in red (a differential connection scheme is shown in green). The single-ended signal range is from 0 V up to the positive supply or +FS (whichever is lower). Negative voltages cannot be applied to these devices because the TLA202x can only accept positive voltages with respect to ground. Only the code range from 0000h to 7FF0h (or a subset thereof in case +FS > VDD) is used in this case.



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**Figure 20. Filter Implementation for Single-Ended and Differential Signal Measurements**

The TLA2024 also allows AIN3 to serve as a common point for measurements by appropriately setting the MUX[2:0] bits. AIN0, AIN1, and AIN2 can all be measured with respect to AIN3. In this configuration, the usable voltage and code range, respectively, is increased over the single-ended configuration because negative differential voltages are allowed when  $GND < V_{(AIN3)} < VDD$ . Assume the following settings for example:  $VDD = 5\text{ V}$ ,  $FSR = \pm 2.048\text{ V}$ ,  $AIN_P = AIN0$ , and  $AIN_N = AIN3 = 2.5\text{ V}$ . In this case, the voltage at AIN0 can swing from  $V_{(AIN0)} = 2.5\text{ V} - 2.048\text{ V}$  to  $2.5\text{ V} + 2.048\text{ V}$  using the entire full-scale range.

### 9.1.4 Analog Input Filtering

Analog input filtering serves two purposes:

1. Limits the effect of aliasing during the ADC sampling process
2. Attenuates unwanted noise components outside the bandwidth of interest

In most cases, a first-order resistor capacitor (RC) filter is sufficient to completely eliminate aliasing or to reduce the effect of aliasing to a level within the noise floor of the sensor. A good starting point for a system design with the TLA202x is to use a differential RC filter with a cutoff frequency set somewhere between the selected output data rate and 25 kHz. Make the series resistor values as small as possible to reduce voltage drops across the resistors caused by the device input currents to a minimum. However, the resistors should be large enough to limit the current into the analog inputs to less than 10 mA in the event of an overvoltage. Then choose the differential capacitor value to achieve the target filter cutoff frequency. Common-mode filter capacitors to GND can be added as well, but should always be at least ten times smaller than the differential filter capacitor.

[Figure 20](#) shows an example of filtering a differential signal (AIN0, AIN1), and a single-ended signal (AIN3). [Equation 3](#) and [Equation 4](#) show how to calculate the filter cutoff frequencies ( $f_{CO}$ ) in the differential and single-ended cases, respectively.

$$f_{CO\ DIF} = 1 / (2\pi \cdot 2 \cdot R_{FLT} \cdot C_{DIF}) \quad (3)$$

$$f_{CO\ SE} = 1 / (2\pi \cdot R_{FLT} \cdot C_{SE}) \quad (4)$$

## Application Information (continued)

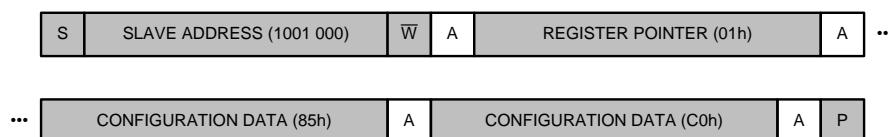
### 9.1.5 Duty Cycling To Reduce Power Consumption

For applications where power consumption is critical, the TLA202x support duty cycling that yield significant power savings by periodically requesting high data rate readings at an effectively lower data rate. For example, an TLA202x in power-down state with a data rate set to 3300 SPS can be operated by a microcontroller that instructs a single-shot conversion every 7.81 ms (128 SPS). A conversion at 3300 SPS requires approximately 0.3 ms, so the TLA202x enters power-down state for the remaining 7.51 ms. In this configuration, the TLA202x consume approximately 1/25th the power that is otherwise consumed in continuous-conversion mode. The duty cycling rate is arbitrary and is defined by the master controller.

### 9.1.6 I<sup>2</sup>C Communication Sequence Example

This section provides an example of an I<sup>2</sup>C communication sequence between a microcontroller (the master) and a TLA2024 (the slave) configured with a slave address of 1001 000 to start a single-shot conversion and subsequently read the conversion result.

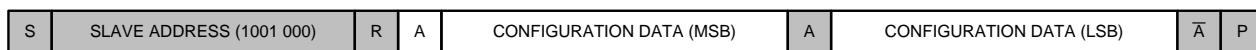
1. Write the configuration register as shown in [Figure 21](#) to configure the device (for example, write MUX[2:0] = 000, PGA[2:0] = 010, MODE = 1, and DR[2:0] = 110) and start a single-shot conversion (OS = 1):



**Figure 21. Write the Configuration Register**

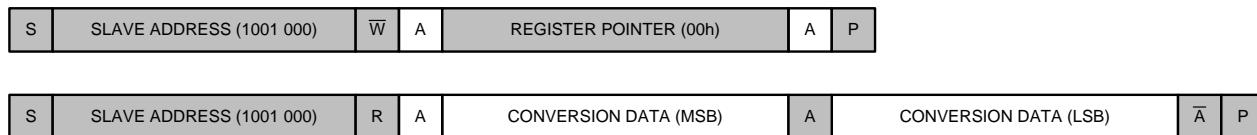
2. Wait at least  $t = 1 / DR \pm 10\%$  for the conversion to complete.

Alternatively, poll the OS bit for a 1 as shown in [Figure 22](#) to determine when the conversion result is ready for retrieval. This option does not work in continuous-conversion mode because the OS bit always reads 0.



**Figure 22. Read the Configuration Register to Check for OS = 1**

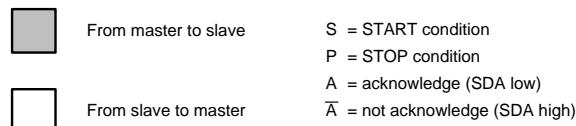
3. Then, as shown in [Figure 23](#), read the conversion data register:



**Figure 23. Read the Conversion Data Register**

4. Start a new single-shot conversion by writing a 1 to the OS bit in the configuration register.

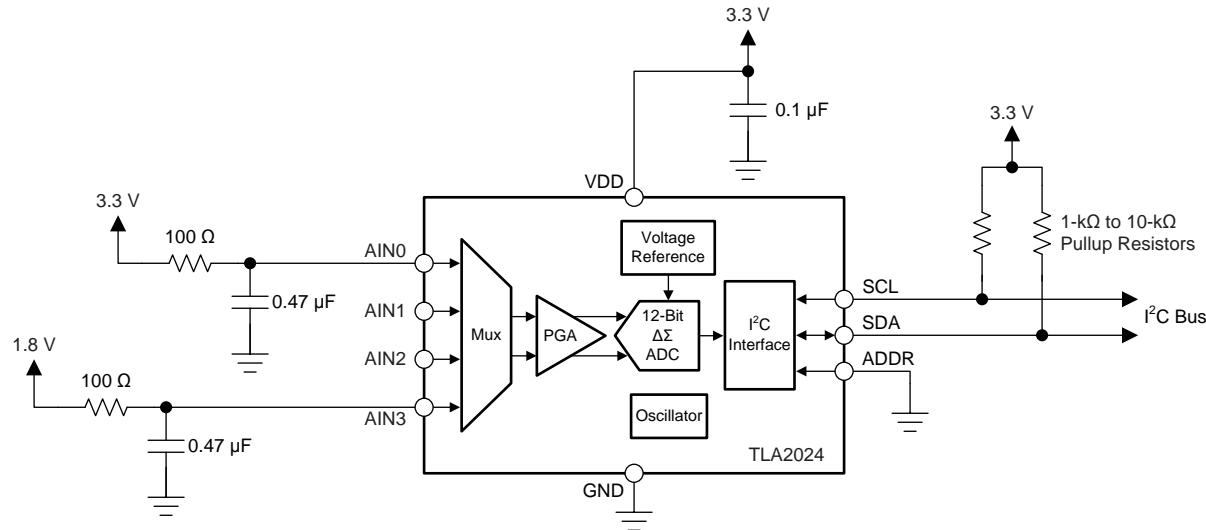
To save time, a new conversion can also be started (step 4) before reading the conversion result (step 3). [Figure 24](#) lists a legend for [Figure 21](#) to [Figure 23](#).



**Figure 24. Legend for the I<sup>2</sup>C Sequence Diagrams**

## 9.2 Typical Application

This application example describes how to use the TLA2024 to monitor two different supply voltage rails in a system. [Figure 25](#) shows a typical implementation for monitoring two supply voltage rails.



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**Figure 25. Monitoring Two Supply Voltage Rails Using the TLA2024**

### 9.2.1 Design Requirements

[Table 8](#) lists the design requirements for this application.

**Table 8. Design Requirements**

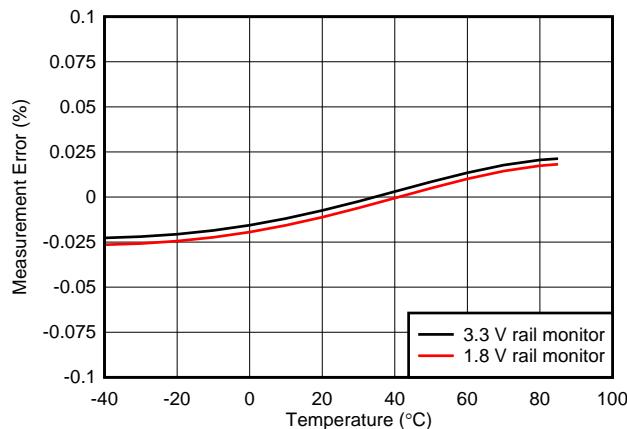
| DESIGN PARAMETER         | VALUE         |
|--------------------------|---------------|
| Device supply voltage    | 3.3 V         |
| Voltage rails to monitor | 1.8 V, 3.3 V  |
| Measurement accuracy     | $\pm 0.5\%$   |
| Update rate              | 1 ms per rail |

### 9.2.2 Detailed Design Procedure

The analog inputs, AIN0 and AIN3, connect directly to the supply voltage rails that are monitored through RC filter resistors. Small filter resistor values of  $100\ \Omega$  are chosen to reduce voltage drops, and therefore offset errors, caused by the input currents of the TLA2024 to a minimum. Filter capacitors of  $0.47\ \mu F$  are chosen to set the filter cutoff frequencies at  $3.39\ kHz$ . In order to get one reading from each of the two supplies within  $2\ ms$ , a data rate of  $2400\ SPS$  is selected. The device is set up for single-ended measurements using MUX[2:0] settings 100 and 101. A FSR =  $\pm 4.096\ V$  is selected to measure the  $3.3\text{-}V$  rail. The same FSR can also be used to measure the  $1.8\text{-}V$  rail or the FSR can be set to FSR =  $\pm 2.048\ V$ .

### 9.2.3 Application Curve

The measurement results in [Figure 26](#) show that the two supplies can be measured with  $\pm 0.5\%$  accuracy over the complete operating ambient temperature range without any offset or gain calibration.



**Figure 26. Measurement Error vs Temperature**

## 10 Power Supply Recommendations

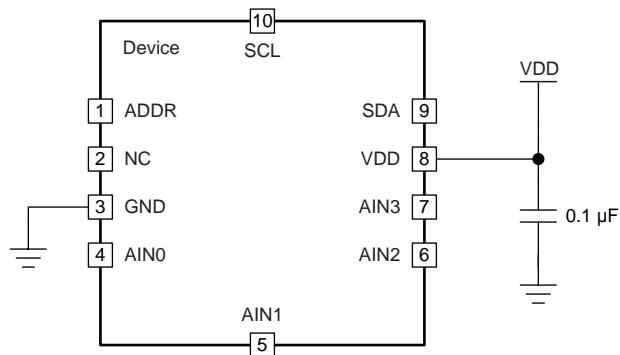
The device requires a single unipolar supply (VDD) to power the analog and digital circuitry of the device.

### 10.1 Power-Supply Sequencing

Wait approximately 50  $\mu$ s 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. As shown in [Figure 27](#), VDD must be decoupled with at least a 0.1- $\mu$ F capacitor to GND. The 0.1- $\mu$ 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 to connect the capacitors to the device pins for better noise immunity. The use of multiple vias in parallel lowers the overall inductance and is beneficial for connections to ground planes.

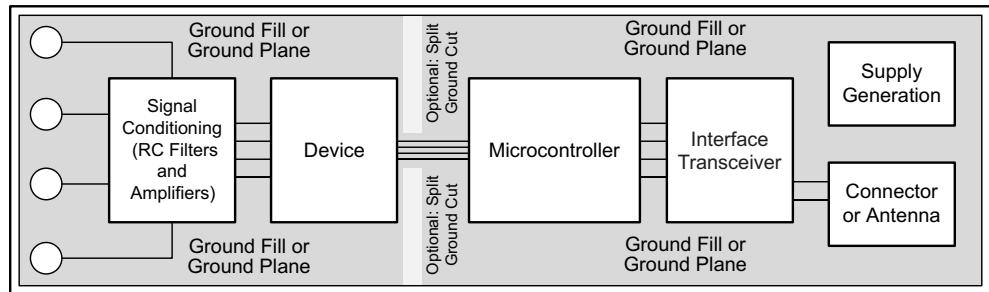


**Figure 27. TLA202x Power-Supply Decoupling**

## 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. [Figure 28](#) shows an example of good component placement. Although [Figure 28](#) provides a good example of component placement, the best placement for each application is unique to the geometries, components, and PCB fabrication capabilities. That is, there is no single layout that is perfect for every design and careful consideration must always be used when designing with any analog component.

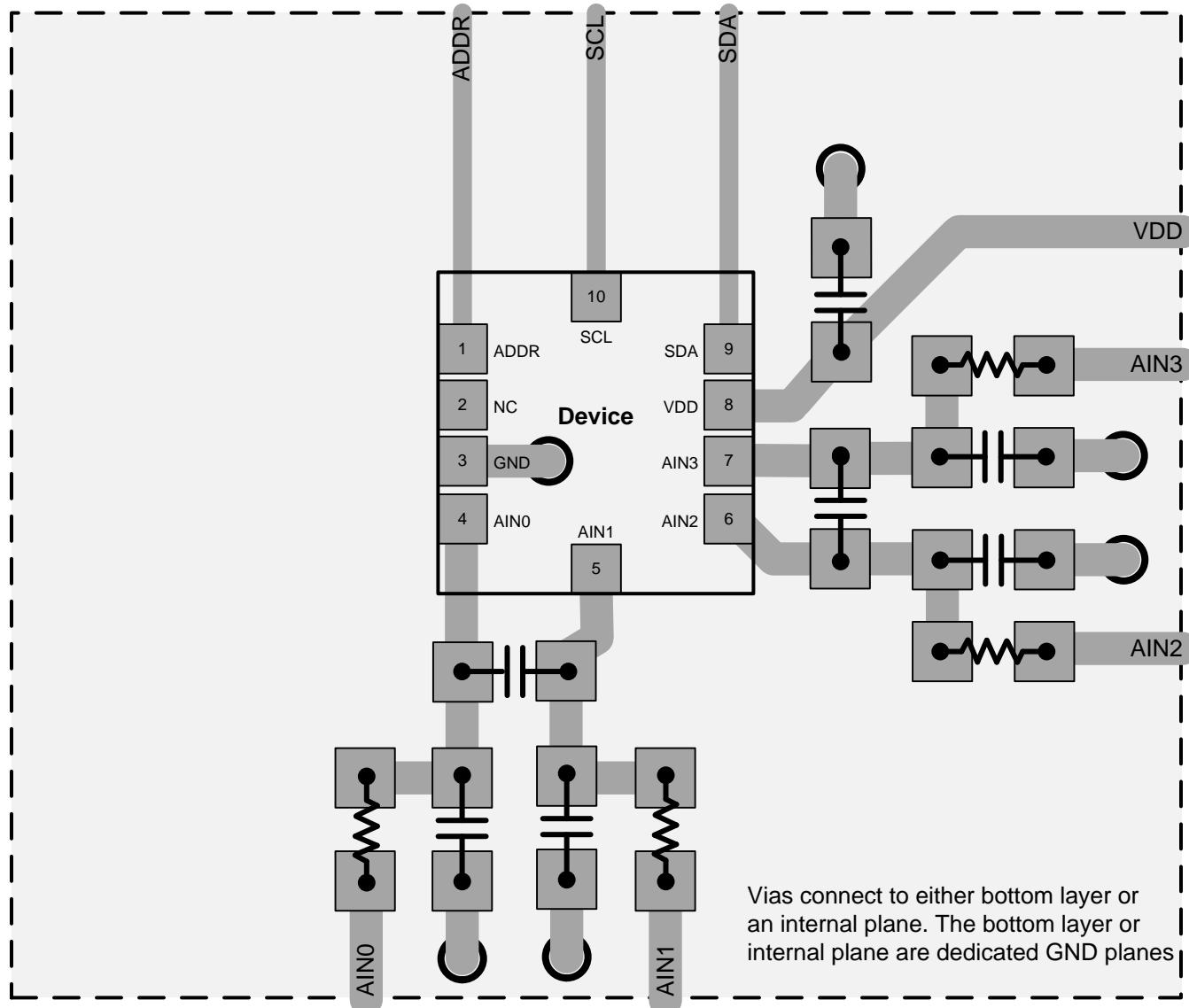


**Figure 28. System Component Placement**

The following points outline some basic recommendations for the layout of the TLA202x to get the best possible performance of the ADC. A good design can be ruined with a bad circuit layout.

- Separate the 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 to prevent 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 ground plane must find another path to return to the source and complete the circuit. If the ground plane is forced into a larger path, there is an increased chance of signal radiation. Sensitive signals are more susceptible to EMI interference.
- Use bypass capacitors on supplies to minimize high-frequency noise. Do not place vias between bypass capacitors and the active device. For best results, place the bypass capacitors on the same layer as close as possible to the active device.
- Consider the resistance and inductance of the routing. Input traces often 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 to minimize the inductance in the path.
- For best input combinations with 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) capacitors, which have stable properties and low-noise characteristics.

## 11.2 Layout Example



**Figure 29. TLA2024 X2QFN Package**

## 12 Device and Documentation Support

### 12.1 Device Support

#### 12.1.1 Third-Party Products Disclaimer

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### 12.2 Related Links

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

**Table 9. Related Links**

| PARTS   | PRODUCT FOLDER             | ORDER NOW                  | TECHNICAL DOCUMENTS        | TOOLS & SOFTWARE           | SUPPORT & COMMUNITY        |
|---------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| TLA2021 | <a href="#">Click here</a> |
| TLA2022 | <a href="#">Click here</a> |
| TLA2024 | <a href="#">Click here</a> |

### 12.3 Receiving Notification of Documentation Updates

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

### 12.4 Community Resources

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

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

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

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I<sup>2</sup>C, NXP Semiconductors are trademarks of NXP Semiconductors.

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### 12.6 Electrostatic Discharge Caution

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

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

### 12.7 Glossary

[SLYZ022](#) — *TI Glossary*.

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

## 13 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<br>(1) | Material type<br>(2) | Package   Pins   | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|-----------------------|---------------|----------------------|------------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| TLA2021IRUGR          | Active        | Production           | X2QFN (RUG)   10 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 9AZ                 |
| TLA2021IRUGR.B        | Active        | Production           | X2QFN (RUG)   10 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 9AZ                 |
| TLA2021IRUGT          | Active        | Production           | X2QFN (RUG)   10 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 9AZ                 |
| TLA2021IRUGT.B        | Active        | Production           | X2QFN (RUG)   10 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 9AZ                 |
| TLA2022IRUGR          | Active        | Production           | X2QFN (RUG)   10 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 19J                 |
| TLA2022IRUGR.B        | Active        | Production           | X2QFN (RUG)   10 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 19J                 |
| TLA2022IRUGT          | Active        | Production           | X2QFN (RUG)   10 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 19J                 |
| TLA2022IRUGT.B        | Active        | Production           | X2QFN (RUG)   10 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 19J                 |
| TLA2024IRUGR          | Active        | Production           | X2QFN (RUG)   10 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 9IJ                 |
| TLA2024IRUGR.B        | Active        | Production           | X2QFN (RUG)   10 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 9IJ                 |
| TLA2024IRUGRG4        | Active        | Production           | X2QFN (RUG)   10 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 9IJ                 |
| TLA2024IRUGRG4.B      | Active        | Production           | X2QFN (RUG)   10 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 9IJ                 |
| TLA2024IRUGT          | Active        | Production           | X2QFN (RUG)   10 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 9IJ                 |
| TLA2024IRUGT.B        | Active        | Production           | X2QFN (RUG)   10 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 9IJ                 |

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

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

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

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

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

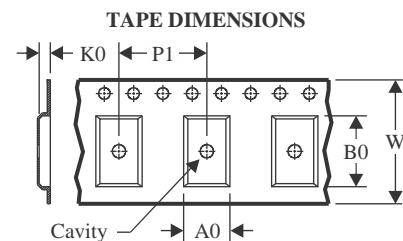
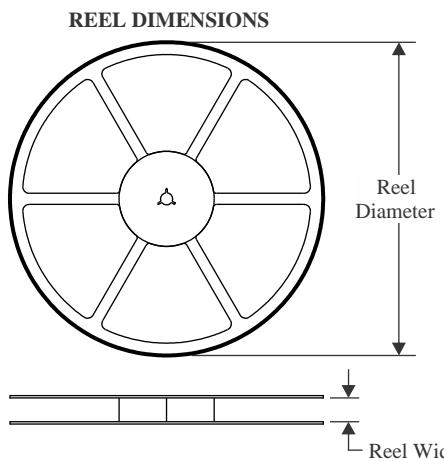
<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

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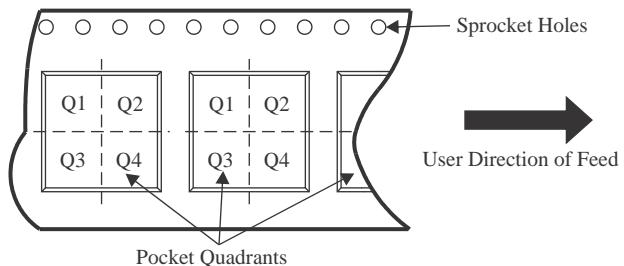
Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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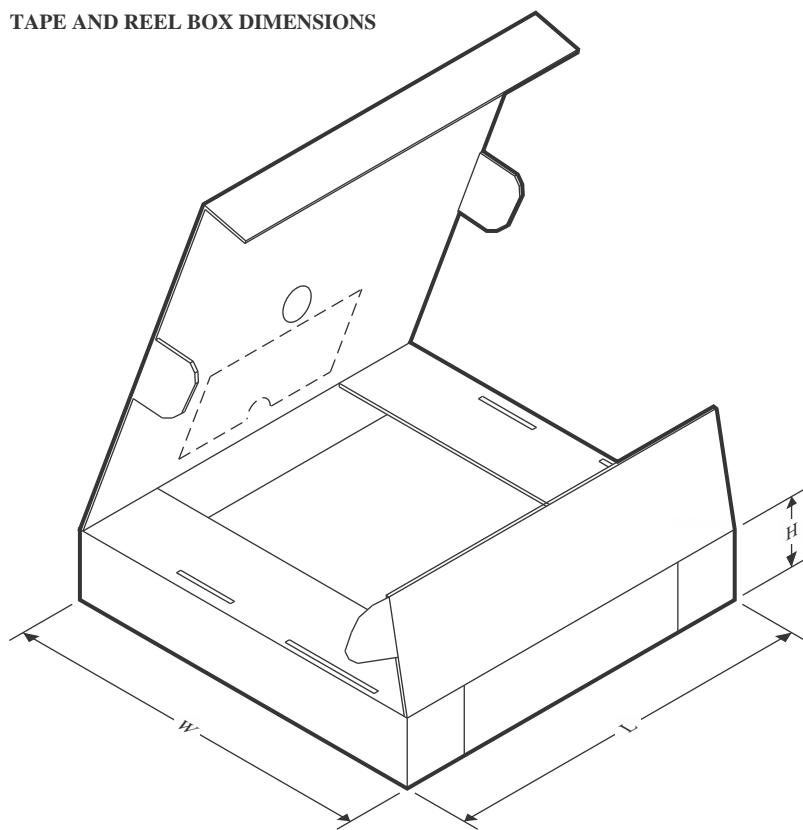
**TAPE AND REEL INFORMATION**


|    |   |
|----|---|
| 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 |
|----------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| TLA2021IRUGR   | X2QFN        | RUG             | 10   | 3000 | 180.0              | 8.4                | 1.75    | 2.25    | 0.55    | 4.0     | 8.0    | Q1            |
| TLA2021IRUGT   | X2QFN        | RUG             | 10   | 250  | 180.0              | 8.4                | 1.75    | 2.25    | 0.55    | 4.0     | 8.0    | Q1            |
| TLA2022IRUGR   | X2QFN        | RUG             | 10   | 3000 | 180.0              | 8.4                | 1.75    | 2.25    | 0.55    | 4.0     | 8.0    | Q1            |
| TLA2022IRUGT   | X2QFN        | RUG             | 10   | 250  | 180.0              | 8.4                | 1.75    | 2.25    | 0.55    | 4.0     | 8.0    | Q1            |
| TLA2024IRUGR   | X2QFN        | RUG             | 10   | 3000 | 180.0              | 8.4                | 1.75    | 2.25    | 0.55    | 4.0     | 8.0    | Q1            |
| TLA2024IRUGRG4 | X2QFN        | RUG             | 10   | 3000 | 180.0              | 8.4                | 1.75    | 2.25    | 0.55    | 4.0     | 8.0    | Q1            |
| TLA2024IRUGT   | 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) |
|----------------|--------------|-----------------|------|------|-------------|------------|-------------|
| TLA2021IRUGR   | X2QFN        | RUG             | 10   | 3000 | 210.0       | 185.0      | 35.0        |
| TLA2021IRUGT   | X2QFN        | RUG             | 10   | 250  | 210.0       | 185.0      | 35.0        |
| TLA2022IRUGR   | X2QFN        | RUG             | 10   | 3000 | 210.0       | 185.0      | 35.0        |
| TLA2022IRUGT   | X2QFN        | RUG             | 10   | 250  | 210.0       | 185.0      | 35.0        |
| TLA2024IRUGR   | X2QFN        | RUG             | 10   | 3000 | 210.0       | 185.0      | 35.0        |
| TLA2024IRUGRG4 | X2QFN        | RUG             | 10   | 3000 | 210.0       | 185.0      | 35.0        |
| TLA2024IRUGT   | X2QFN        | RUG             | 10   | 250  | 210.0       | 185.0      | 35.0        |

## GENERIC PACKAGE VIEW

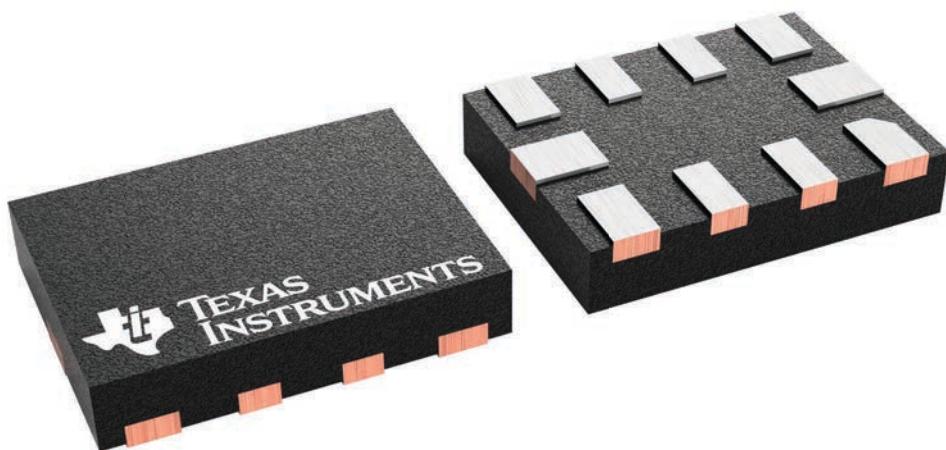
### RUG 10

1.5 x 2, 0.5 mm pitch

X2QFN - 0.4 mm max height

PLASTIC QUAD FLATPACK - NO LEAD

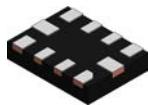
This image is a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.



4231768/A

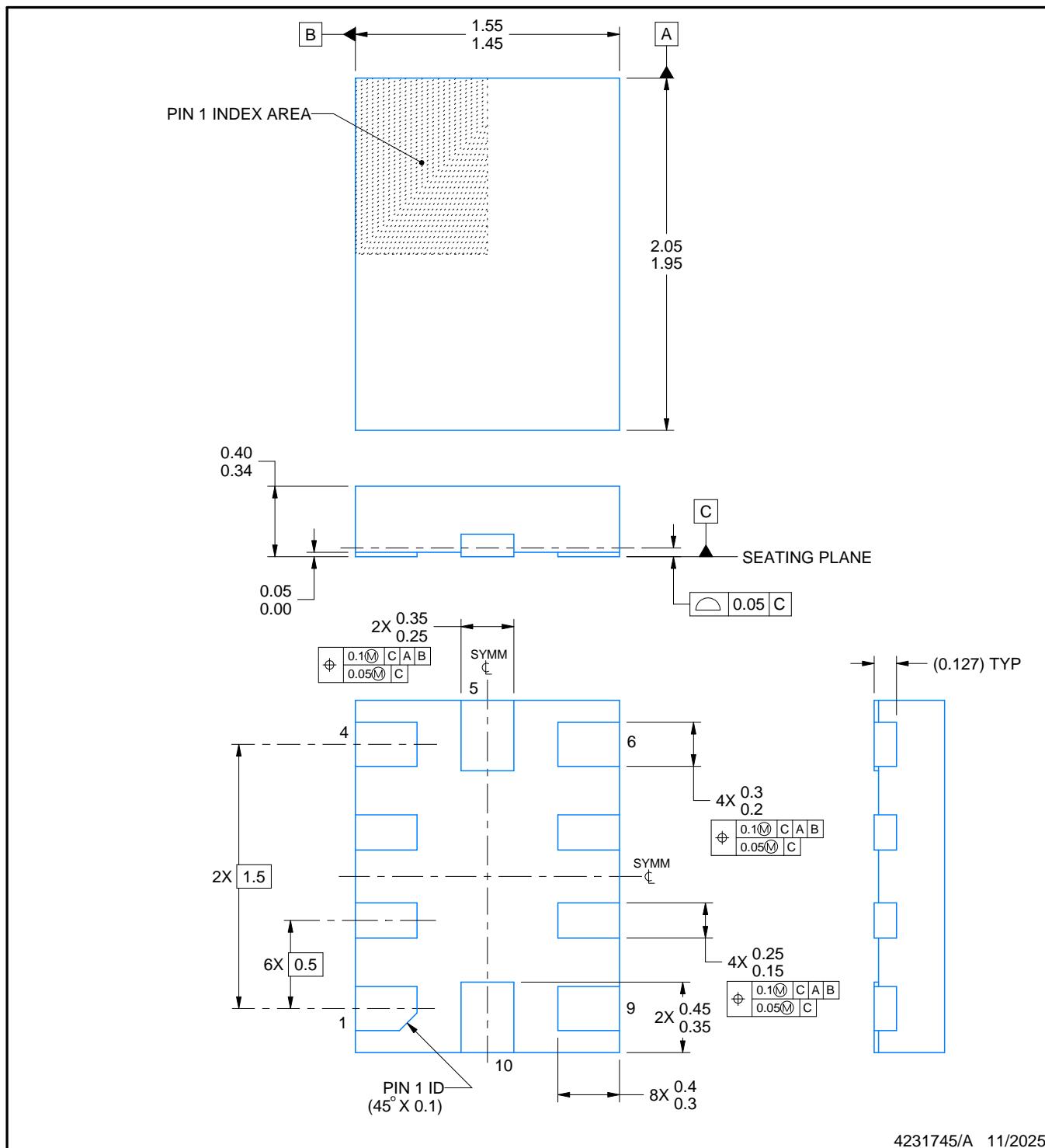
# PACKAGE OUTLINE

RUG0010A



X2QFN - 0.4 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



4231745/A 11/2025

## NOTES:

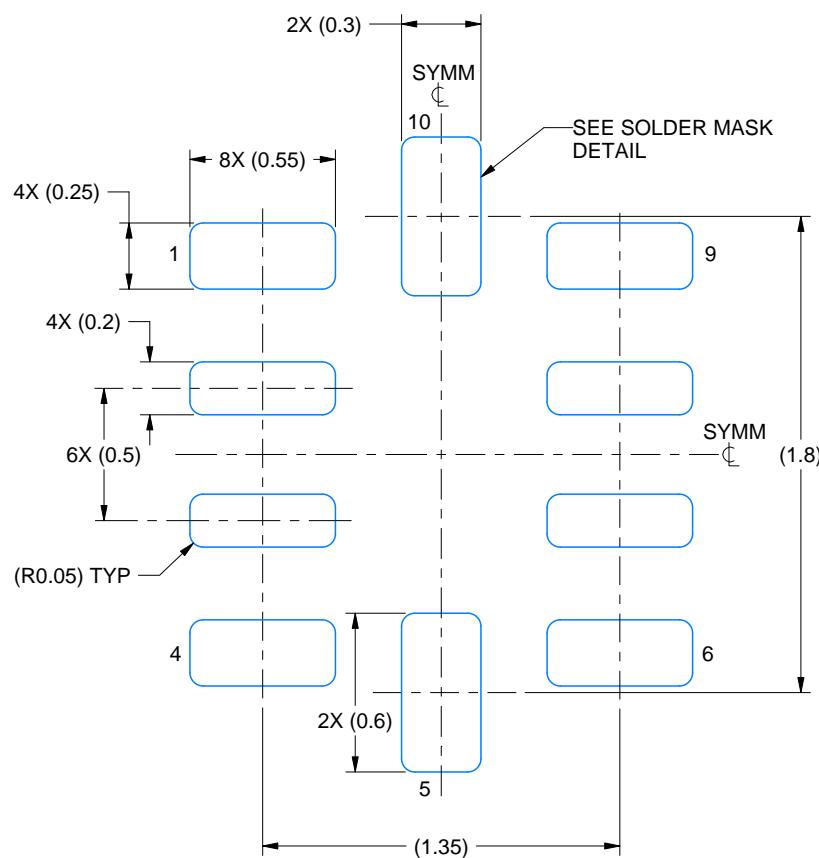
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.

# EXAMPLE BOARD LAYOUT

RUG0010A

X2QFN - 0.4 mm max height

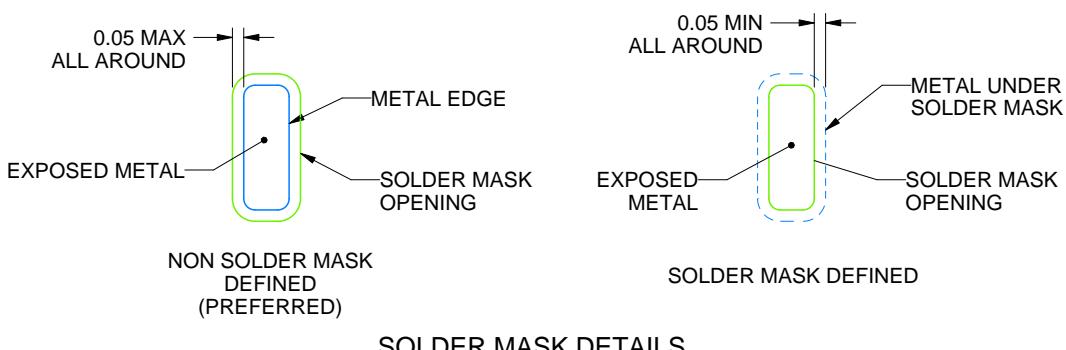
PLASTIC QUAD FLATPACK - NO LEAD



## LAND PATTERN EXAMPLE

EXPOSED METAL SHOWN

SCALE: 35X



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NOTES: (continued)

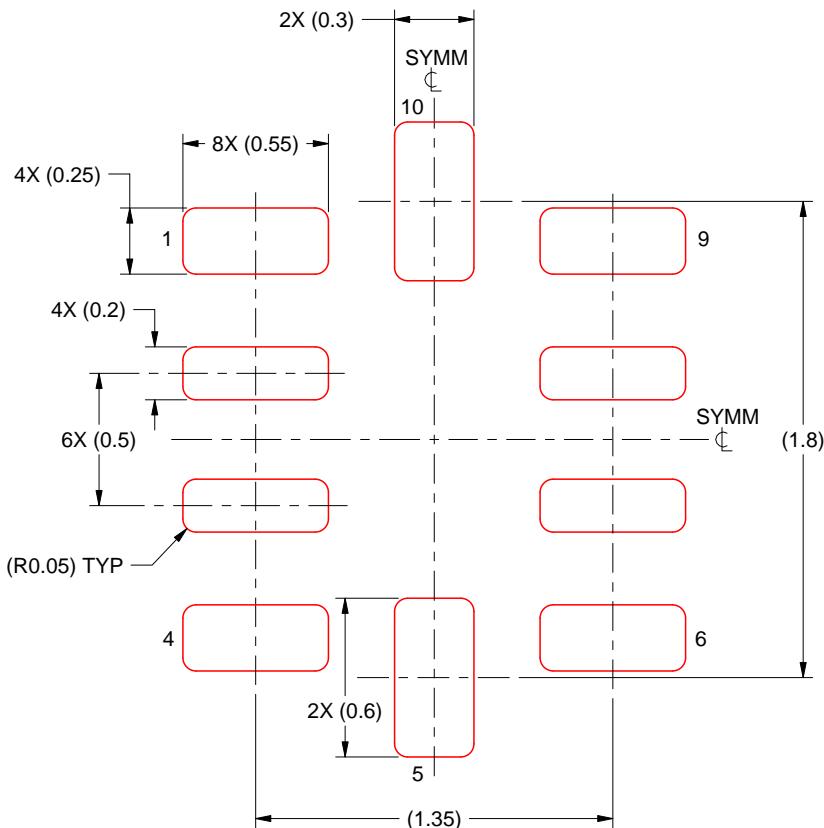
3. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/slua271](http://www.ti.com/lit/slua271)).

# EXAMPLE STENCIL DESIGN

RUG0010A

X2QFN - 0.4 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



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

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NOTES: (continued)

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

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Last updated 10/2025