Trending with Delta-Sigma ADCs

How TI’s latest Delta-Sigma ADC developments enable industrial trends

Created by
Chris Hall, Applications Engineer, Precision ADCs
Bryan Lizon, Product Marketing, Precision ADCs

Presented by
Shridhar More, Systems Engineer, Precision ADCs
Trending with Delta-Sigma ADCs

Agenda

- Introduction to Delta-Sigma ADCs
  - Key characteristics
  - Problems we solve

- Solving Design Challenges
  - Issues with digital isolation
  - Reducing digital isolation requirements

- Best Performance
  - 3-/4-Wire RTD circuit + design challenges
  - Load cell circuit analysis + design challenges

- Reliability + Autonomy
  - Monitoring and diagnostic features in the ADS124S08
Trending with Delta-Sigma ADCs

Agenda

• Introduction to Delta-Sigma ADCs
  ▪ Key characteristics
  ▪ Problems we solve

• Solving Design Challenges
  ▪ Issues with digital isolation
  ▪ Reducing digital isolation requirements

• Best Performance
  ▪ 3-/4-Wire RTD circuit + design challenges
  ▪ Load cell circuit analysis + design challenges

• Reliability + Autonomy
  ▪ Monitoring and diagnostic features in the ADS124S08
Trending with Delta-Sigma ADCs

Agenda

• Introduction to Delta-Sigma ADCs
  ▪ Key characteristics
  ▪ Problems we solve

• Solving Design Challenges
  ▪ Issues with digital isolation
  ▪ Reducing digital isolation requirements

• Best Performance
  ▪ 3-/4-Wire RTD circuit + design challenges
  ▪ Load cell circuit analysis + design challenges

• Reliability + Autonomy
  ▪ Monitoring and diagnostic features in the ADS124S08
Trending with Delta-Sigma ADCs

Agenda

• Introduction to Delta-Sigma ADCs
  ▪ Key characteristics
  ▪ Problems we solve

• Solving Design Challenges
  ▪ Issues with digital isolation
  ▪ Reducing digital isolation requirements

• Best Performance
  ▪ 3-/4-Wire RTD circuit + design challenges
  ▪ Load cell circuit analysis + design challenges

• Reliability + Autonomy
  ▪ Monitoring and diagnostic features in the ADS124S08
Trending with Delta-Sigma ADCs

Agenda

• Introduction to Delta-Sigma ADCs
  ▪ Key characteristics
  ▪ Problems we solve

• Solving Design Challenges
  ▪ Issues with digital isolation
  ▪ Reducing digital isolation requirements

• Best Performance
  ▪ 3-/4-Wire RTD circuit + design challenges
  ▪ Load cell circuit analysis + design challenges

• Reliability + Autonomy
  ▪ Monitoring and diagnostic features in the ADS124S08
Introduction to TI’s Delta-Sigma ADC portfolio
Introduction to Delta-Sigma ADCs

Key characteristics

How it works

- Oversampling converter
- Averages samples
Introduction to Delta-Sigma ADCs

Key characteristics

How it works

• Oversampling converter
• Averages samples

What it provides

• High resolution
• Low noise
Introduction to Delta-Sigma ADCs

Key characteristics

- **How it works**
  - Oversampling converter
  - Averages samples

- **What it provides**
  - High resolution
  - Low noise

- **Additional benefits**
  - Lots of integrated features
  - Often tailored for specific applications
Introduction to Delta-Sigma ADCs

Problems we solve

Sensor Measurement

Features
- DC measurement ADCs
- Low power 16-24 bit ADCs
- Small, Easy to use ADCs

Products
- ADS1115 / ADS1118
- ADS1220 / ADS122U04
- ADS124S08

Applications
- Temp/Pressure/Flow
- Sensor Conditioning
- Auto. Powertrain/HEV BMS
- General Voltage Monitoring
Introduction to Delta-Sigma ADCs

Problems we solve

Sensor Measurement

Features
• DC measurement ADCs
• Low power 16-24 bit ADCs
• Small, Easy to use ADCs

Products
• ADS1115 / ADS1118
• ADS1220 / ADS122U04
• ADS124S08

Applications
• Temp/Pressure/Flow
• Sensor Conditioning
• Auto. Powertrain/HEV BMS
• General Voltage Monitoring

High Performance

Features
• Lowest noise, highest DC precision 24-32bit ADCs
• Simultaneous sampling ADCs

Products
• ADS1262
• ADS131A04
• ADS127L01

Applications
• PLC/DCS AI Modules
• High-end Weigh Scales
• Protection Relays
• Test & Measurement
Introduction to Delta-Sigma ADCs

Problems we solve

Sensor Measurement

Features
- DC measurement ADCs
- Low power 16-24 bit ADCs
- Small, Easy to use ADCs

Products
- ADS1115 / ADS1118
- ADS1220 / ADS122U04
- ADS124S08

Applications
- Temp/Pressure/Flow
- Sensor Conditioning
- Auto. Powertrain/HEV BMS
- General Voltage Monitoring

High Performance

Features
- Lowest noise, highest DC precision 24-32bit ADCs
- Simultaneous sampling ADCs

Products
- ADS1262
- ADS131A04
- ADS127L01

Applications
- PLC/DCS AI Modules
- High-end Weigh Scales
- Protection Relays
- Test & Measurement

Isolated Converters

Features
- Isolated Amplifiers
- Isolated $\Delta \Sigma$-Modulators
- Basic & reinforced isolation

Products
- AMC1200
- AMC1301
- AMC1304 / AMC1305

Applications
- Motor Drive
- Solar Inverters
- Current Shunt Monitoring
Introduction to Delta-Sigma ADCs

Problems we solve

Sensor Measurement

Features
- DC measurement ADCs
- Low power 16-24 bit ADCs
- Small, Easy to use ADCs

Products
- ADS1115 / ADS1118
- ADS1220 / ADS122U04
- ADS124S08

Applications
- Temp/Pressure/Flow
- Sensor Conditioning
- Auto. Powertrain/HEV BMS
- General Voltage Monitoring

High Performance

Features
- Lowest noise, highest DC precision 24-32bit ADCs
- Simultaneous sampling ADCs

Products
- ADS1262
- ADS131A04
- ADS127L01

Applications
- PLC/DCS AI Modules
- High-end Weigh Scales
- Protection Relays
- Test & Measurement

Isolated Converters

Features
- Isolated Amplifiers
- Isolated ΔΣ-Modulators
- Basic & reinforced isolation

Products
- AMC1200
- AMC1301
- AMC1304 / AMC1305

Applications
- Motor Drive
- Solar Inverters
- Current Shunt Monitoring

Audio Converters

Features
- High-performance Audio ADC
- Audio Codecs w/ DSP functions

Products
- TLV320ADC3101
- PCM1860 / PCM1862
- TLV320AIC3101

Applications
- IP Phones
- Cart Audio
- Voice Recognition Systems
- Building Automation
## Introduction to Delta-Sigma ADCs

### Problems we solve

**Sensor Measurement**

**Features**
- DC measurement ADCs
- Low power 16-24 bit ADCs
- Small, Easy to use ADCs

**Products**
- ADS1115 / ADS1118
- ADS1220 / ADS122U04
- ADS124S08

**Applications**
- Temp/Pressure/Flow
- Sensor Conditioning
- Auto. Powertrain/HEV BMS
- General Voltage Monitoring

**High Performance**

**Features**
- Lowest noise, highest DC precision 24-32 bit ADCs
- Simultaneous sampling ADCs

**Products**
- ADS1262
- ADS131A04
- ADS127L01

**Applications**
- PLC/DCS AI Modules
- High-end Weigh Scales
- Protection Relays
- Test & Measurement

**Isolated Converters**

**Features**
- Isolated Amplifiers
- Isolated ΔΣ-Modulators
- Basic & reinforced isolation

**Products**
- AMC1200
- AMC1301
- AMC1304 / AMC1305

**Applications**
- Motor Drive
- Solar Inverters
- Current Shunt Monitoring

**Audio Converters**

**Features**
- High-performance Audio ADC
- Audio Codecs w/ DSP functions

**Products**
- TLV320ADC3101
- PCM1860 / PCM1862
- TLV320AIC3101

**Applications**
- IP Phones
- Cart Audio
- Voice Recognition Systems
- Building Automation
Solving design challenges using TI’s ADS122U04
Solving Design Challenges

Introduction

Typical Signal Chain

Reference

ADC

Oscillator

MUX

PGA

TC1

TC2

TC3

TC4
Solving Design Challenges

Introduction
Solving Design Challenges

Effects of ground loops

Motor

Temperature Transmitter

Delta-Sigma ADC

MSP43x

Ground Loop

100V
Solving Design Challenges

Removing ground loops w/ digital isolation

Temperature Transmitter

Delta-Sigma ADC

MSP43x

Motor

TC

ADC GND floats with TC

No Ground Loop
Solving Design Challenges
Existing solutions – direct SPI isolation

- Only requires one component
- Requires ≥3 isolation channels
Solving Design Challenges
Existing solutions – SPI to UART “Converter”

- Only requires one component
  - Requires ≥3 isolation channels

- Reduces necessary isolation lines to 2
  - Requires additional MCU on primary side
Solving Design Challenges
Using the ADS122U04

- Reduces necessary isolation lines to 2
- **Does not** require additional MCU on primary side
Solving Design Challenges
Using the ADS122U04

- Reduces necessary isolation lines to 2
- **Does not require** additional MCU on primary side

<table>
<thead>
<tr>
<th>Isolator</th>
<th>Channel Count</th>
<th>Current @ DC (mA)</th>
<th>Current @ 1Mbps (mA)</th>
<th>Cost (1kU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO7721</td>
<td>2 (1/1)</td>
<td>2</td>
<td>3.2</td>
<td>$1.45</td>
</tr>
<tr>
<td>ISO7731</td>
<td>3 (2/1)</td>
<td>2.9</td>
<td>4.6</td>
<td>$2.05</td>
</tr>
<tr>
<td>ISO7741</td>
<td>4 (3/1)</td>
<td>3.5</td>
<td>5.9</td>
<td>$2.65</td>
</tr>
</tbody>
</table>
Solving Design Challenges
Using the ADS122U04

- Reduces necessary isolation lines to 2
- **Does not require** additional MCU on primary side

### Isolator Performance

<table>
<thead>
<tr>
<th>Isolator</th>
<th>Channel Count</th>
<th>Current @ DC (mA)</th>
<th>Current @ 1Mbps (mA)</th>
<th>Cost (1kU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO7721</td>
<td>2 (1/1)</td>
<td>2</td>
<td>3.2</td>
<td>$1.45</td>
</tr>
<tr>
<td>ISO7731</td>
<td>3 (2/1)</td>
<td>2.9</td>
<td>4.6</td>
<td>$2.05</td>
</tr>
<tr>
<td>ISO7741</td>
<td>4 (3/1)</td>
<td>3.5</td>
<td>5.9</td>
<td>$2.65</td>
</tr>
</tbody>
</table>

- 30% reduction in power consumption
- 30% reduction in cost
Solving Design Challenges

Automatic Data Read Mode (ADRM)

Manual mode

Automatic mode
Solving Design Challenges

Automatic Data Read Mode (ADRM)

Manual mode

Automatic mode

RDATA command required

No read commands necessary
Solving Design Challenges

Controlling MUX on primary side

Additional 3 isolation channels required for an 8:1 MUX
Solving Design Challenges

ADS122U04’s integrated GPIOs

No additional isolation channels necessary
Best Performance

ADS122U04 Overview

Features + Benefits

- **2-wire UART interface** reduces the number of digital isolation channels between the ADC and MCU
- **Integrated features** such as VREF, PGA, Temp Sensor, and IDACs reduce PCB area and save cost for space-constrained applications
- **Configurable GPIOs** eliminate the need for additional control lines from MCU

Applications

- Temperature Sensors: RTDs | Thermocouples | Thermistors
- 4-20mA Loop-Powered Transmitters
- Pressure/Bridge Sensors
- Portable Instrumentation
Achieving the best performance with a Delta-Sigma ADC
Best Performance
Precision vs accuracy
Best Performance

Precision vs accuracy

**Precision** = ability of the ADC to provide repeatable results

- Noise (resolution)
Best Performance

Precision vs accuracy

**Precision** = ability of the ADC to provide repeatable results
- Noise (resolution)

**Accuracy** = how closely the ADC’s digital output corresponds to the analog input signal
- Offset / Gain error
- INL
- Drift (time and temperature)
Best Performance

Precision vs accuracy

**Precision** = ability of the ADC to provide repeatable results
- Noise (resolution)

**Accuracy** = how closely the ADC’s digital output corresponds to the analog input signal
- Offset / Gain error
- INL
- Drift (time and temperature)

Low precision
Low accuracy
Best Performance

Precision vs accuracy

**Precision** = ability of the ADC to provide repeatable results
- Noise (resolution)

**Accuracy** = how closely the ADC’s digital output corresponds to the analog input signal
- Offset / Gain error
- INL
- Drift (time and temperature)
Best Performance

Precision vs accuracy

**Precision** = ability of the ADC to provide repeatable results
- Noise (resolution)

**Accuracy** = how closely the ADC’s digital output corresponds to the analog input signal
- Offset / Gain error
- INL
- Drift (time and temperature)
Best Performance

**ADS1262 overview**

### Features + Benefits

- 32-bit Resolution, $7nV_{RMS}$ noise (2.5SPS, G=32)
  - Industry-leading offset drift specifications
- Highly-integrated
  - Reduce PCB area, cost, and design time with integrated VREF, OSC, IDACs, PGA, temp sensor, & GPIOs
- Host of monitoring and diagnostic features
  - Improve system reliability and functionality

### Applications

- Industrial PLC
- High-End Panel Meters and Process Controllers
- High Precision Weigh Scales
- Industrial Strain Gauge Analyzers
- Analytical Equipment
- RTD Measurement
Best Performance
Temperature measurements
Best Performance
Temperature measurements

Resolution = 0.01°C
Best Performance

Temperature measurements

Resolution = 0.01°C

Accuracy = 0.1°C
Best Performance

Introduction to resistance temperature detectors (RTDs)

- Predictable resistance change
- Mostly made of platinum
- PT100 most common device used in industry
- High accuracy, stability and repeatability
- 2-, 3-, 4-wire types
Best Performance
3-wire RTD connections
Best Performance
3-wire RTD connections

Lead-wire resistance
Best Performance
3-wire RTD connections

Lead-wire resistance
Anti-aliasing filters
Best Performance
3-wire RTD connections

- Lead-wire resistance
- Anti-aliasing filters
- Ratiometric measurement
Best Performance
Ratiometric measurements

\[
\text{Gain} \times \frac{V_{IN}}{V_{REF}} = \frac{\text{CODE}}{2^{N-1}}
\]
Best Performance
Ratiometric measurements

\[
\frac{\text{Gain} \times V_{\text{IN}}}{V_{\text{REF}}} = \frac{\text{CODE}}{2^{N-1}}
\]

\[
V_{\text{IN}} = I_{\text{IDAC}} \times R_{\text{RTD}}
\]

\[
V_{\text{REF}} = 2 \times I_{\text{IDAC}} \times R_{\text{REF}}
\]
Best Performance

Ratiometric measurements

\[
\frac{Gain \times V_{IN}}{V_{REF}} = CODE \frac{2^{N-1}}{2^{N-1}}
\]

\[
V_{IN} = I_{IDAC} \times R_{RTD}
\]

\[
V_{REF} = 2 \times I_{IDAC} \times R_{REF}
\]

\[
\frac{V_{IN}}{V_{REF}} \propto \frac{R_{RTD}}{R_{REF}}
\]
Best Performance
3-wire RTD biasing

\[ V_{IN} = AIN4 - AIN5 = \]
**Best Performance**

3-wire RTD biasing

\[ V_{IN} = AIN4 - AIN5 = I_{IDAC1} * R_{LEAD1} \]
Best Performance
3-wire RTD biasing

\[ V_{IN} = AIN4 - AIN5 = I_{IDAC1} \times R_{LEAD1} + I_{IDAC1} \times R_{RTD} \]
**Best Performance**

3-wire RTD biasing

\[ V_{IN} = AIN4 - AIN5 = \]

\[ I_{IDAC1} * R_{LEAD1} + I_{IDAC1} * R_{RTD} - I_{IDAC2} * R_{LEAD2} \]
Best Performance
3-wire RTD biasing

\[ V_{IN} = AIN4 - AIN5 = I_{IDAC1} \times R_{LEAD1} + I_{IDAC1} \times R_{RTD} - I_{IDAC2} \times R_{LEAD2} \]

\[ V_{IN} = I_{IDAC1} \times R_{RTD} \]
Best Performance
IDAC chopping
Best Performance
IDAC chopping

**Phase 1:**
\[ V_{IN1} = V_{RTD} + \Delta V_{LEAD} \]
Best Performance
IDAC chopping

**Phase 1:**
\[ V_{IN1} = V_{RTD} + \Delta V_{LEAD} \]

**Phase 2:**
\[ V_{IN2} = V_{RTD} - \Delta V_{LEAD} \]

**Average:**
\[ \frac{V_{IN1} + V_{IN2}}{2} = \frac{2 * V_{RTD} - \Delta V_{LEAD} + \Delta V_{LEAD}}{2} = V_{RTD} \]
### Best Performance

**Error improvements due to IDAC chopping**

<table>
<thead>
<tr>
<th>System Temperature Range</th>
<th>Before Calibration</th>
<th>After Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IDAC CHOPPING = OFF</td>
<td></td>
</tr>
<tr>
<td>IDAC Match Error</td>
<td>0.1% (%)</td>
<td>500 (ppm)</td>
</tr>
<tr>
<td>IDAC Match Drift</td>
<td>5 (ppm/°C)</td>
<td>125 (ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>125 (ppm)</td>
</tr>
<tr>
<td>TOTAL ADC ERROR</td>
<td>556 (ppm)</td>
<td>127 (ppm)</td>
</tr>
</tbody>
</table>

**Texas Instruments**

**(Neglecting $R_{REF}$ & RTD errors)**
## Best Performance

Error improvements due to IDAC chopping

<table>
<thead>
<tr>
<th>System Temperature Range</th>
<th>50 (Δ°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDAC Match Error</td>
<td>0.1% (%)</td>
</tr>
<tr>
<td>IDAC Match Drift</td>
<td>5 (ppm/ᵒC)</td>
</tr>
<tr>
<td>TOTAL ADC ERROR</td>
<td>556 (ppm)</td>
</tr>
</tbody>
</table>

**Before Calibration**

<table>
<thead>
<tr>
<th>IDAC CHOPPING</th>
<th>OFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDAC Match Error</td>
<td>500 (ppm)</td>
</tr>
<tr>
<td>IDAC Match Drift</td>
<td>125 (ppm)</td>
</tr>
<tr>
<td>TOTAL ADC ERROR</td>
<td>556 (ppm)</td>
</tr>
</tbody>
</table>

**After Calibration**

<table>
<thead>
<tr>
<th>IDAC CHOPPING</th>
<th>OFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDAC Match Error</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>IDAC Match Drift</td>
<td>125 (ppm)</td>
</tr>
<tr>
<td>TOTAL ADC ERROR</td>
<td>127 (ppm)</td>
</tr>
</tbody>
</table>

**4x Accuracy Improvement!**

**(Neglecting $R_{REF}$ & RTD errors)**

---

**Texas Instruments**
# Best Performance

## Error improvements due to IDAC chopping

<table>
<thead>
<tr>
<th>System Temperature Range</th>
<th>50 (Δ°C)</th>
</tr>
</thead>
</table>

### IDAC CHOPPING = OFF

<table>
<thead>
<tr>
<th>IDAC Match Error</th>
<th>0.1% (%)</th>
<th>Before Calibration</th>
<th>500 (ppm)</th>
<th>After Calibration</th>
<th>0 (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDAC Match Drift</td>
<td>5 (ppm/°C)</td>
<td></td>
<td>125 (ppm)</td>
<td></td>
<td>125 (ppm)</td>
</tr>
</tbody>
</table>

TOTAL ADC ERROR

### IDAC CHOPPING = ON

<table>
<thead>
<tr>
<th>IDAC Match Error</th>
<th>0.0% (%)</th>
<th>Before Calibration</th>
<th>0 (ppm)</th>
<th>After Calibration</th>
<th>0 (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDAC Match Drift</td>
<td>0 (ppm/°C)</td>
<td></td>
<td>0 (ppm)</td>
<td></td>
<td>0 (ppm)</td>
</tr>
</tbody>
</table>

TOTAL ADC ERROR

**(Neglecting R_{REF} & RTD errors)**
## Best Performance

Error improvements due to IDAC chopping

<table>
<thead>
<tr>
<th>System Temperature Range</th>
<th>50 (Δ°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IDAC CHOPPING = OFF</strong></td>
<td></td>
</tr>
<tr>
<td>IDAC Match Error</td>
<td>0.1% (%)</td>
</tr>
<tr>
<td>IDAC Match Drift</td>
<td>5 (ppm/ᵒC)</td>
</tr>
<tr>
<td><strong>TOTAL ADC ERROR</strong></td>
<td>556 (ppm)</td>
</tr>
<tr>
<td><strong>IDAC CHOPPING = ON</strong></td>
<td></td>
</tr>
<tr>
<td>IDAC Match Error</td>
<td>0.0% (%)</td>
</tr>
<tr>
<td>IDAC Match Drift</td>
<td>0 (ppm/ᵒC)</td>
</tr>
<tr>
<td><strong>TOTAL ADC ERROR</strong></td>
<td>210 (ppm)</td>
</tr>
</tbody>
</table>

**5x Accuracy Improvement!**

**(Neglecting \( R_{REF} \) & RTD errors)**

---

**Texas Instruments**
## Best Performance

### 3-Wire RTD error analysis

- Neglects RTD errors
- Assume all errors are linear
- Errors added as the “root-sum-of-squares” (uncorrelated errors)
- **ADS1262 data sheet provides this characterization data!**

### System Temperature Range

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Temperature Range</td>
<td>50 (Δ°C)</td>
</tr>
<tr>
<td>FSR</td>
<td>0.45 (V)</td>
</tr>
<tr>
<td>Noise RTI (@ 20 SPS, FIR)</td>
<td>266.01 (nVp-p)</td>
</tr>
<tr>
<td>Offset</td>
<td>43.75 (uV)</td>
</tr>
<tr>
<td>Offset Drift</td>
<td>13.75 (nV/°C)</td>
</tr>
<tr>
<td>Gain Error</td>
<td>50 (ppm)</td>
</tr>
<tr>
<td>Gain Error Drift</td>
<td>13.75 (ppm/°C)</td>
</tr>
<tr>
<td>INL</td>
<td>3 (ppm)</td>
</tr>
<tr>
<td>IDAC Absolute Error</td>
<td>0.7% (%), 50 (ppm/°C)</td>
</tr>
<tr>
<td>IDAC Absolute Drift</td>
<td>0.0% (%), 0 (ppm)</td>
</tr>
<tr>
<td>IDAC Match Error (Offset)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>IDAC Match Error (Gain Error)</td>
<td>0 (ppm/°C)</td>
</tr>
<tr>
<td>IRREF Abs. Bias Current</td>
<td>100 (nA)</td>
</tr>
<tr>
<td>IRREF Abs. Bias Current V Coef</td>
<td>50 (nA/V)</td>
</tr>
<tr>
<td>IRREF Abs. Bias Current Drift</td>
<td>0.03 (nA/°C)</td>
</tr>
<tr>
<td>IREF Diff. Bias Current</td>
<td>25 (nA)</td>
</tr>
<tr>
<td>IREF Diff. Bias Current V Coef</td>
<td>6 (nA/V)</td>
</tr>
<tr>
<td>IREF Diff. Bias Current Drift</td>
<td>0.06 (nA/°C)</td>
</tr>
<tr>
<td>IINFIN/N Abs. Bias Current</td>
<td>2 (nA)</td>
</tr>
<tr>
<td>IINFIN/N Abs. Bias Current V Coef</td>
<td>0.75 (nA/V)</td>
</tr>
<tr>
<td>IINFIN/N Abs. Bias Current Drift</td>
<td>0.01 (nA/°C)</td>
</tr>
<tr>
<td>IIN Diff. Bias Current</td>
<td>0.1 (nA)</td>
</tr>
<tr>
<td>IIN Diff. Bias Current V Coef</td>
<td>0.20 (nA/V)</td>
</tr>
<tr>
<td>IIN Diff. Bias Current Drift</td>
<td>0.01 (nA/°C)</td>
</tr>
<tr>
<td>Tolerance</td>
<td>0.05% (±°C)</td>
</tr>
<tr>
<td>Temp Drift</td>
<td>0.1 (±ppm/°C)</td>
</tr>
</tbody>
</table>

### ADS1262 Errors

<table>
<thead>
<tr>
<th>Before Calibraion</th>
<th>After Calibraion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset</td>
<td>97.22 (ppm)</td>
</tr>
<tr>
<td>Offset Drift</td>
<td>1.53 (ppm)</td>
</tr>
<tr>
<td>Gain Error Drift</td>
<td>43 (ppm)</td>
</tr>
<tr>
<td>Gain Error</td>
<td>21.69 (ppm)</td>
</tr>
<tr>
<td>Offset Drift</td>
<td>3 (ppm)</td>
</tr>
<tr>
<td>Gain Error Drift</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>IRREF Abs. Bias Current</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>IRREF Abs. Bias Current V Coef</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>IRREF Abs. Bias Current Drift</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>IREF Diff. Bias Current</td>
<td>45 (ppm)</td>
</tr>
<tr>
<td>IREF Diff. Bias Current V Coef</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>IREF Diff. Bias Current Drift</td>
<td>5 (ppm)</td>
</tr>
<tr>
<td>IINFIN/N Abs. Bias Current</td>
<td>7 (ppm)</td>
</tr>
<tr>
<td>IINFIN/N Abs. Bias Current V Coef</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>IINFIN/N Abs. Bias Current Drift</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>IIN Diff. Bias Current</td>
<td>0.11 (ppm)</td>
</tr>
<tr>
<td>IIN Diff. Bias Current V Coef</td>
<td>0.04 (ppm)</td>
</tr>
<tr>
<td>IIN Diff. Bias Current Drift</td>
<td>0.67 (ppm)</td>
</tr>
</tbody>
</table>

**TOTAL ADC ERROR**

<table>
<thead>
<tr>
<th>Before Calibraion</th>
<th>After Calibraion</th>
</tr>
</thead>
<tbody>
<tr>
<td>210 (ppm)</td>
<td>23 (ppm)</td>
</tr>
</tbody>
</table>
Best Performance

4-wire RTD connections
Best Performance
4-wire RTD connections

Lead-wire resistance
Best Performance
4-wire RTD connections

Lead-wire resistance

Anti-aliasing filters
Best Performance
4-wire RTD connections

- Lead-wire resistance
- Anti-aliasing filters
- Ratiometric measurement

![Diagram of 4-wire RTD connections with ADS1262 ADC]

Key Components:
- 4-Wire RTD
- AIIN1 to AIIN6
- VREF
- RREF
- PGA
- 32-bit ΔΣ ADC
- Reference Mux
- AVDD, AVSS
- 5 V
- 0.1 μF
- IDAC1, IDAC2

Texas Instruments
Best Performance

4-wire RTD biasing
Best Performance
4-wire RTD biasing

\[ V_{R_{LEAD2}} = 0V \]
\[ V_{R_{LEAD3}} = 0V \]
\[ V_{IN} = I_{IDAC} \cdot R_{RTD} \]
Best Performance
4-wire RTD biasing

\[ V_{R_{LEAD2}} = 0V \]
\[ V_{R_{LEAD3}} = 0V \]
\[ V_{IN} = I_{IDAC} \times R_{RTD} \]

\[ \frac{V_{IN}}{V_{REF}} \propto \frac{R_{RTD}}{R_{REF}} \]
**Best Performance**

Reference resistor tolerance & drift

\[
\text{Error}_{\text{Tolerance}} (\text{ppm}) = 10,000 \times \text{Tolerance} (\%) \times \text{FSR Utilization} (\%)
\]

\[
\text{Error}_{\text{Drift}} (\text{ppm}) = \text{Temp Co.} \left(\frac{\text{ppm}}{\text{°C}}\right) \times \text{Temp Range} (\text{°C}) \times \text{FSR Utilization} (\%)
\]
Best Performance
Reference resistor tolerance & drift

\[
\text{Error}_{\text{Tolerance}} (\text{ppm}) = 10,000 \times \text{Tolerance} (\%) \times \text{FSR Utilization} (\%)
\]

Can be calibrated out

\[
\text{Error}_{\text{Drift}} (\text{ppm}) = \text{Temp Co.} \left(\frac{\text{ppm}}{\degree \text{C}}\right) \times \text{Temp Range} (\degree \text{C}) \times \text{FSR Utilization} (\%)
\]
**Best Performance**

Reference resistor tolerance & drift

\[
\text{Error}_{\text{Tolerance}} (\text{ppm}) = 10,000 \times \text{Tolerance} \, (\%) \times \text{FSR Utilization} \, (\%)
\]

\[\text{Can be calibrated out}\]

\[
\text{Error}_{\text{Drift}} (\text{ppm}) = \text{Temp Co.} \left(\frac{\text{ppm}}{\degree \text{C}}\right) \times \text{Temp Range} \, (\degree \text{C}) \times \text{FSR Utilization} \, (\%)
\]

\[\text{Cannot be calibrated out}\]

\[\begin{align*}
+ & \quad \text{V}_{\text{REF}} \\
\text{V}_{\text{REF}} & \quad \text{R}_{\text{REF}} \\
- & \quad \text{VIN} \\
\text{IDAC1} & \quad \text{AVSS}
\end{align*}\]
Best Performance
Reference resistor tolerance & drift

\[ \text{Error}_{\text{Tolerance}} (\text{ppm}) = 10,000 \times \text{Tolerance} \, (\%) \times \text{FSR Utilization} \, (\%)
\]

Can be calibrated out

\[ \text{Error}_{\text{Drift}} (\text{ppm}) = \text{Temp Co.} \left( \frac{\text{ppm}}{\text{°C}} \right) \times \text{Temp Range} \, (\text{°C}) \times \text{FSR Utilization} \, (\%)
\]

Cannot be calibrated out

Example

\[ 25 \, \frac{\text{ppm}}{\text{°C}} \times 50 \, \text{°C} \times 90\% \, \text{Utilization} \]

\[ = 1125 \, \text{ppm} \, (9.8 \, \text{bits accuracy}) \]
Best Performance
Resistor drift error analysis

- Neglects RTD errors
- Assume all errors are linear
- Errors added as the “root-sum-of-squares” (uncorrelated errors)
- Assumes 50°C system temperature range
- Applicable to 3-wire RTDs as well (or any application using $R_{REF}$)

<table>
<thead>
<tr>
<th>ADS1262 Errors</th>
<th>Before Calibration</th>
<th>After Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL ADC ERROR</td>
<td>210 (ppm)</td>
<td>23 (ppm)</td>
</tr>
</tbody>
</table>
Best Performance
Resistor drift error analysis

- Neglects RTD errors
- Assume all errors are linear
- Errors added as the “root-sum-of-squares” (uncorrelated errors)
- Assumes 50°C system temperature range
- Applicable to 3-wire RTDs as well (or any application using $R_{REF}$)

<table>
<thead>
<tr>
<th></th>
<th>Before Calibration</th>
<th>After Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL ADC ERROR</td>
<td>210 (ppm)</td>
<td>23 (ppm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$R_{REF}$ Errors</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tolerance</td>
<td>±%</td>
<td>434 (ppm)</td>
</tr>
<tr>
<td>Temp Drift</td>
<td>±ppm/°C</td>
<td>4 (ppm)</td>
</tr>
<tr>
<td>TOTAL $R_{REF}$ ERROR</td>
<td>434 (ppm)</td>
<td>4 (ppm)</td>
</tr>
</tbody>
</table>
Best Performance
Resistor drift error analysis

- Neglects RTD errors
- Assume all errors are linear
- Errors added as the "root-sum-of-squares" (uncorrelated errors)
- Assumes 50°C system temperature range
- Applicable to 3-wire RTDs as well (or any application using $R_{REF}$)

<table>
<thead>
<tr>
<th></th>
<th>Before Calibration</th>
<th>After Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADS1262 Errors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL ADC ERROR</td>
<td>210 (ppm)</td>
<td>23 (ppm)</td>
</tr>
<tr>
<td>$R_{REF}$ Errors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tolerance 0.05%</td>
<td>434 (ppm)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>Temp Drift 0.1 °C</td>
<td>4 (ppm)</td>
<td>4 (ppm)</td>
</tr>
<tr>
<td>TOTAL $R_{REF}$ ERROR</td>
<td>434 (ppm)</td>
<td>4 (ppm)</td>
</tr>
<tr>
<td>TOTAL ERROR</td>
<td>482 (ppm)</td>
<td>23 (ppm)</td>
</tr>
<tr>
<td>Total Uncorrelated System Error</td>
<td>0.434 (±Ω)</td>
<td>0.021 (±Ω)</td>
</tr>
<tr>
<td></td>
<td>1.127 (±°C)</td>
<td>0.054 (±°C)</td>
</tr>
</tbody>
</table>
### Best Performance

**Temperature resolution**

<table>
<thead>
<tr>
<th>ADS1262 Configuration</th>
<th>RTD (PT100 type)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGA GAIN</td>
<td>TH(°C) - TL(°C)</td>
</tr>
<tr>
<td>Data Rate</td>
<td>1050 (°C)</td>
</tr>
<tr>
<td>Filter</td>
<td>VRTD @ -200°C</td>
</tr>
<tr>
<td>ADC Noise RTI</td>
<td>9.260 (mV)</td>
</tr>
<tr>
<td></td>
<td>VRTD @ 850°C</td>
</tr>
<tr>
<td></td>
<td>195.241 (mV)</td>
</tr>
<tr>
<td></td>
<td>$\Delta V_{IN}$</td>
</tr>
<tr>
<td></td>
<td>185.981 (mV)</td>
</tr>
</tbody>
</table>

**Ads1262 Configuration**

- PGA GAIN: 8 (V/V)
- Data Rate: 20 SPS (SPS)
- Filter: FIR
- ADC Noise RTI: 376.20 (nV<sub>p-p</sub>)

**RTD (PT100 type)**

- TH(°C) - TL(°C): 1050 (°C)
- VRTD @ -200°C: 9.260 (mV)
- VRTD @ 850°C: 195.241 (mV)
- $\Delta V_{IN}$: 185.981 (mV)
# Best Performance

## Temperature resolution

### ADS1262 Configuration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGA GAIN</td>
<td>8 (V/V)</td>
</tr>
<tr>
<td>Data Rate</td>
<td>20 SPS (SPS)</td>
</tr>
<tr>
<td>Filter</td>
<td>FIR</td>
</tr>
</tbody>
</table>

### RTD (PT100 type)

<table>
<thead>
<tr>
<th>Parameter (°C)</th>
<th>Value (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH - TL</td>
<td>1050</td>
</tr>
<tr>
<td>VRTD @ -200°C</td>
<td>9.260</td>
</tr>
<tr>
<td>VRTD @ 850°C</td>
<td>195.241</td>
</tr>
</tbody>
</table>

### ADC Noise RTI (nV_p-p)

<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>376.20</td>
</tr>
</tbody>
</table>

### Noise-Free Bits (bits)

<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.9</td>
</tr>
</tbody>
</table>

### Temperature Resolution (°C_p-p)

<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.002</td>
</tr>
</tbody>
</table>
Best Performance
Precision weigh scale
Best Performance
Precision weigh scale

Max Capacity = 10kg

Readability = 0.25g
Best Performance
Precision weigh scale

Max Capacity = 10kg

Readability = 0.25g

Noise – Free Counts = \frac{\text{Capacity}}{\text{Readability}}

Noise – Free Counts = \frac{10,000}{0.25} = 40,000
Best Performance

Introduction to load cells

4-wire bridge

6-wire bridge
Best Performance

Bridge output

Load Cell

\[ \text{Load Cell} \]

\[ V_{\text{EXC}} = 5 \] V

\[ R_{\text{LEAD}} \]

\[ + 10 \text{ mV} \]

(@ capacity)
Best Performance

Bridge output

Load Cell

$\begin{align*}
V_{EXC} &= 5V \\
R_{LEAD} &= 10 \text{ mV} \\
2 \text{ mV/V} \\
\end{align*}$
Best Performance

Bridge output

Load Cell

2 mV/V

$V_{EXC} = 5V$

$R_{LEAD}$
Best Performance

Bridge output

Load Cell

$V_{EXC} = 5V$

$2 \text{ mV/V}$

$10 \text{ mV} \ (\text{@ capacity})$

$R_{LEAD}$
Best Performance

Hooking up 4-wire bridge to the ADS1262
Best Performance
Hooking up 4-wire bridge to the ADS1262

Lead-wire resistance
Best Performance
Hooking up 4-wire bridge to the ADS1262

Lead-wire resistance

Anti-aliasing filters
Best Performance

Hooking up 4-wire bridge to the ADS1262

- Lead-wire resistance
- Anti-aliasing filters
- Ratiometric measurement

![Diagram](image)
Best Performance

Input chopping to reduce offset and drift

---

Load Cell

5 V

0.1 μF

AVIS

AVDD

ADS1262

32-bit ΔΣ ADC

PGA

Reference Mux

Reference

VIN

VOS

PGA

RLEAD

RLEAD

RLEAD

AIN4

(AINP)

AIN5

(AINN)

AIN2

(REFP)

AIN3

(REFN)

RLEAD

RLEAD

RLEAD
Best Performance
Input chopping to reduce offset and drift

Phase 1:

\[ V_{IN1} = V_{BRIDGE} + V_{OS} \]
Best Performance
Input chopping to reduce offset and drift

**Phase 1:**
\[ V_{IN1} = V_{BRIDGE} + V_{OS} \]

**Phase 2:**
\[ V_{IN2} = -V_{BRIDGE} + V_{OS} \]

**Average:**
\[ \frac{V_{IN1} - V_{IN2}}{2} = \frac{2 \cdot V_{BRIDGE} - V_{OS} + V_{OS}}{2} = V_{BRIDGE} \]
$V_{ADC} = \frac{V_{ADC}(PHASE1) - V_{ADC}(PHASE2)}{2} = \frac{(V_{Bridge} + V_{OS}) - (-V_{Bridge} + V_{OS})}{2} = V_{Bridge}$
**Best Performance**

Error improvements due to input chopping

<table>
<thead>
<tr>
<th>TOTAL ERROR - Input Chop OFF</th>
<th>36 (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Uncorrelated System Error</td>
<td>11.40 (±µV)</td>
</tr>
<tr>
<td></td>
<td>0.365 (±g)</td>
</tr>
</tbody>
</table>

- Neglects load cell errors
- Offset is the greatest error source

### ADS1262 Errors

<table>
<thead>
<tr>
<th></th>
<th>Before Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FSR</strong></td>
<td>0.3125 (V)</td>
</tr>
<tr>
<td><strong>Noise RTI (@ 20 SPS, FIR)</strong></td>
<td>198.00 (nV_{p-p})</td>
</tr>
<tr>
<td><strong>Offset</strong></td>
<td>10.9375 (µV)</td>
</tr>
<tr>
<td><strong>Offset Drift</strong></td>
<td>10.94 (nV/°C)</td>
</tr>
<tr>
<td><strong>Gain Error</strong></td>
<td>50 (ppm)</td>
</tr>
<tr>
<td><strong>Gain Error Drift</strong></td>
<td>0.5 (ppm/°C)</td>
</tr>
<tr>
<td><strong>INL</strong></td>
<td>3 (ppm)</td>
</tr>
<tr>
<td>I_{REF Abs. Bias Current}</td>
<td>100 (nA)</td>
</tr>
<tr>
<td>I_{REF Abs. Bias Current V Coeff}</td>
<td>50 (nA/V)</td>
</tr>
<tr>
<td>I_{REF Abs. Bias Current Drift}</td>
<td>0.03 (nA/°C)</td>
</tr>
<tr>
<td>I_{REF Diff. Bias Current}</td>
<td>200 (nA)</td>
</tr>
<tr>
<td>I_{REF Diff. Bias Current V Coeff}</td>
<td>6 (nA/V)</td>
</tr>
<tr>
<td>I_{REF Diff. Bias Current Drift}</td>
<td>0.30 (nA/°C)</td>
</tr>
<tr>
<td>I_{AIN Abs. Bias Current}</td>
<td>2 (nA)</td>
</tr>
<tr>
<td>I_{AIN Abs. Bias Current V Coeff}</td>
<td>0.75 (nA/V)</td>
</tr>
<tr>
<td>I_{AIN Abs. Bias Current Drift}</td>
<td>0.01 (nA/°C)</td>
</tr>
<tr>
<td>I_{AIN Diff. Bias Current}</td>
<td>0.1 (nA)</td>
</tr>
<tr>
<td>I_{AIN Diff. Bias Current V Coeff}</td>
<td>0.20 (nA/V)</td>
</tr>
<tr>
<td>I_{AIN Diff. Bias Current Drift}</td>
<td>0.01 (nA/°C)</td>
</tr>
<tr>
<td><strong>TOTAL ADC ERROR</strong></td>
<td>36 (ppm)</td>
</tr>
</tbody>
</table>

**Total Uncorrelated System Error**

- **Before Calibration** 11.40 (±µV)
- **0.365 (±g)
Best Performance

Error improvements due to input chopping

- Neglects load cell errors
- Offset/Offset drift is removed
- ADC noise decreases by 1.4

**TOTAL ERROR - Input Chop OFF**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Uncorrelated System Error</td>
<td>36 (ppm)</td>
</tr>
<tr>
<td></td>
<td>11.40 (±µV)</td>
</tr>
<tr>
<td></td>
<td>0.365 (±g)</td>
</tr>
</tbody>
</table>

**TOTAL ERROR - Input Chop ON**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Uncorrelated System Error</td>
<td>9 (ppm)</td>
</tr>
<tr>
<td></td>
<td>2.67 (±µV)</td>
</tr>
<tr>
<td></td>
<td>0.086 (±g)</td>
</tr>
</tbody>
</table>

**ADS1262 Errors**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Before Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSR</td>
<td>0.3125 (V)</td>
<td></td>
</tr>
<tr>
<td>Noise RTI (@ 20 SPS, FIR)</td>
<td>140.01 (nV_p_p)</td>
<td>0.63 (ppm)</td>
</tr>
<tr>
<td>Offset</td>
<td>0.003125 (µV)</td>
<td>0.01 (ppm)</td>
</tr>
<tr>
<td>Offset Drift</td>
<td>1.00 (nV/°C)</td>
<td>0.53 (ppm)</td>
</tr>
<tr>
<td>Gain Error</td>
<td>50 (ppm)</td>
<td>3 (ppm)</td>
</tr>
<tr>
<td>Gain Error Drift</td>
<td>0.5 (ppm/°C)</td>
<td>5.28 (ppm)</td>
</tr>
<tr>
<td>INL</td>
<td>3 (ppm)</td>
<td>3 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Abs. Bias Current</td>
<td>100 (nA)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Abs. Bias Current V Coeff</td>
<td>50 (nA/V)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Abs. Bias Current Drift</td>
<td>0.03 (nA/°C)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Diff. Bias Current</td>
<td>200 (nA)</td>
<td>0.24 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Diff. Bias Current V Coeff</td>
<td>6 (nA/V)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Diff. Bias Current Drift</td>
<td>0.30 (nA/°C)</td>
<td>0.06 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Abs. Bias Current</td>
<td>2 (nA)</td>
<td>0.14 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Abs. Bias Current V Coeff</td>
<td>0.75 (nA/V)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Abs. Bias Current Drift</td>
<td>0.01 (nA/°C)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Diff. Bias Current</td>
<td>0.1 (nA)</td>
<td>0.254 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Diff. Bias Current V Coeff</td>
<td>0.20 (nA/V)</td>
<td>0.003 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Diff. Bias Current Drift</td>
<td>0.01 (nA/°C)</td>
<td>5.03 (ppm)</td>
</tr>
<tr>
<td>TOTAL ADC ERROR</td>
<td>9 (ppm)</td>
<td></td>
</tr>
</tbody>
</table>
## Best Performance

Error improvements due to input chopping

### TOTAL ERROR - Input Chop OFF

<table>
<thead>
<tr>
<th>Total Uncorrelated System Error</th>
<th>36 (ppm)</th>
<th>11.40 (±µV)</th>
<th>0.365 (±g)</th>
</tr>
</thead>
</table>

### TOTAL ERROR - Input Chop ON

<table>
<thead>
<tr>
<th>Total Uncorrelated System Error</th>
<th>9 (ppm)</th>
<th>2.67 (±µV)</th>
<th>0.086 (±g)</th>
</tr>
</thead>
</table>

4x improvement in accuracy

### ADS1262 Errors

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Before Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSR</td>
<td>0.3125 (V)</td>
<td>0.63 (ppm)</td>
</tr>
<tr>
<td>Noise RTI (@ 20 SPS, FIR)</td>
<td>140.01 (nV p-p)</td>
<td>0.63 (ppm)</td>
</tr>
<tr>
<td>Offset</td>
<td>0.003125 (uV)</td>
<td>0.01 (ppm)</td>
</tr>
<tr>
<td>Offset Drift</td>
<td>1.00 (nV/°C)</td>
<td>0.53 (ppm)</td>
</tr>
<tr>
<td>Gain Error</td>
<td>50 (ppm)</td>
<td>3 (ppm)</td>
</tr>
<tr>
<td>Gain Error Drift</td>
<td>0.5 (ppm/°C)</td>
<td>5.28 (ppm)</td>
</tr>
<tr>
<td>INL</td>
<td>3 (ppm)</td>
<td>3 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Abs. Bias Current</td>
<td>100 (nA)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Abs. Bias Current V Coeff</td>
<td>50 (nA/V)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Abs. Bias Current Drift</td>
<td>0.03 (nA/°C)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Diff. Bias Current</td>
<td>200 (nA)</td>
<td>0.24 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Diff. Bias Current V Coeff</td>
<td>6 (nA/V)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{REF}$ Diff. Bias Current Drift</td>
<td>0.30 (nA/°C)</td>
<td>0.06 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Abs. Bias Current</td>
<td>2 (nA)</td>
<td>0.14 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Abs. Bias Current V Coeff</td>
<td>0.75 (nA/V)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Abs. Bias Current Drift</td>
<td>0.01 (nA/°C)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Diff. Bias Current</td>
<td>0.1 (nA)</td>
<td>0.254 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Diff. Bias Current V Coeff</td>
<td>0.20 (nA/V)</td>
<td>0.003 (ppm)</td>
</tr>
<tr>
<td>$I_{AIN}$ Diff. Bias Current Drift</td>
<td>0.01 (nA/°C)</td>
<td>5.03 (ppm)</td>
</tr>
</tbody>
</table>

**TOTAL ADC ERROR** | **9 (ppm)** |
# Best Performance

## Weight resolution

<table>
<thead>
<tr>
<th>ADS1262 Configuration</th>
<th>Load Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGA GAIN</td>
<td>Max Load Capacity</td>
</tr>
<tr>
<td>32 (V/V)</td>
<td>10 (kg)</td>
</tr>
<tr>
<td>Data Rate</td>
<td>Sensitivity</td>
</tr>
<tr>
<td>20 SPS (SPS)</td>
<td>2 (mV/V)</td>
</tr>
<tr>
<td>Filter</td>
<td>Excitation</td>
</tr>
<tr>
<td>FIR -</td>
<td>5 (V)</td>
</tr>
<tr>
<td>ADC Noise RTI</td>
<td>( \Delta V_{IN} )</td>
</tr>
<tr>
<td>198.00 (nV\text{P-P})</td>
<td>10 (mV)</td>
</tr>
</tbody>
</table>

\[ \downarrow \]

<table>
<thead>
<tr>
<th>Noise-Free Bits</th>
<th>( \Delta V_{IN} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.6 (bits)</td>
<td>10 (mV)</td>
</tr>
</tbody>
</table>

\[ \downarrow \]

<table>
<thead>
<tr>
<th>Weight Resolution</th>
<th>( \Delta V_{IN} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.198 (g\text{P-P})</td>
<td>10 (mV)</td>
</tr>
</tbody>
</table>
## Best Performance

### Weight resolution

<table>
<thead>
<tr>
<th>ADS1262 Configuration</th>
<th>Load Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PGA GAIN</strong></td>
<td><strong>Max Load Capacity</strong></td>
</tr>
<tr>
<td>32 (V/V)</td>
<td>10 (kg)</td>
</tr>
<tr>
<td><strong>Data Rate</strong></td>
<td><strong>Sensitivity</strong></td>
</tr>
<tr>
<td>20 SPS (SPS)</td>
<td>2 (mV/V)</td>
</tr>
<tr>
<td><strong>Filter</strong></td>
<td><strong>Excitation</strong></td>
</tr>
<tr>
<td>FIR</td>
<td>5 (V)</td>
</tr>
<tr>
<td><strong>ADC Noise RTI</strong></td>
<td><strong>ΔV_{IN}</strong></td>
</tr>
<tr>
<td>198.00 (nV_{P-P})</td>
<td>10 (mV)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Noise-Free Bits</th>
<th>Weight Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.6 (bits)</td>
<td>0.198 (g_{P-P})</td>
</tr>
</tbody>
</table>

\[ \text{Noise-Free Counts} = 2^{\text{Noise-Free Bits}} = 49,667 \]
Improving reliability and autonomy with the ADS124S08
Reliability + Autonomy

ADS124S08 overview

Key Specs
- 16 or 24-bit
- 6 or 12-channel
- 4kSPS
- 5x5 QFN or TQFP
Reliability + Autonomy

ADS124S08 overview
Reliability + Autonomy

Temperature sensor

Check ADC die temperature
Reliability + Autonomy

Power supplies

Power supply readback

<table>
<thead>
<tr>
<th>Bit</th>
<th>Field</th>
<th>Type</th>
<th>Reset</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:5</td>
<td>SYS_MON[2:0]</td>
<td>R/W</td>
<td>0h</td>
<td>System monitor configuration(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Enables a set of system monitor measurements using the ADC.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>000: Disabled (default)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>001: PGA inputs shorted to (AVDD + AVSS) / 2 and disconnected from AINx and the multiplexer; gain set by user</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>010: Internal temperature sensor measurement; PGA must be enabled; PGA EN[1:0] = 01; gain set by user(2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>011: (AVDD – AVSS) / 4 measurement; gain set to 1(3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100: DVDD / 4 measurement; gain set to 1(3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>101: Burn-out current sources enabled, 0.2-μA setting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>110: Burn-out current sources enabled, 1-μA setting</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td>3</td>
<td>CAL_SAMP[1:0]</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>2</td>
<td>TIMEOUT</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>1</td>
<td>CRC</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td>0</td>
<td>SENDSTAT</td>
</tr>
</tbody>
</table>

(1) Enables a set of system monitor measurements using the ADC.
(2) PGA EN[1:0] = 01; gain set by user.
(3) Gain set to 1.
Reliability + Autonomy

Burnout current sources

Broken sensor detection

<table>
<thead>
<tr>
<th>Bit</th>
<th>Field</th>
<th>Type</th>
<th>Reset</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-5</td>
<td>SYS_MON[2:0]</td>
<td>R/W</td>
<td>0h</td>
<td>Burn-out current sources enabled: 0.2-μA setting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>110: Burn-out current sources enabled, 1-μA setting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>111: Burn-out current sources enabled, 10-μA setting</td>
</tr>
</tbody>
</table>

System monitor configuration:

- Enables a set of system monitor measurements using the ADC.
- 000: Disabled (default)
- 001: PGA inputs shorted to (AVDD + AVSS) / 2 and disconnected from AIN and the multiplexer; gain set by user
- 010: Internal temperature sensor measurement; PGA must be enabled (PGA_EN[1:0] = 01); gain set by user
- 011: (AVDD - AVSS) / 4 measurement; gain set to 1
- 100: VDD / 4 measurement; gain set to 1
- 101: Burn-out current sources enabled, 0.2-μA setting
- 110: Burn-out current sources enabled, 1-μA setting
- 111: Burn-out current sources enabled, 10-μA setting
Reliability + Autonomy

Cyclic redundancy check (CRC)
Reliability + Autonomy
PGA monitors

<table>
<thead>
<tr>
<th>Bit</th>
<th>Field</th>
<th>Type</th>
<th>Reset</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>FL_P_POR</td>
<td>R</td>
<td>W-1h</td>
<td>Positive PGA output at positive rail flag (1)</td>
</tr>
<tr>
<td>6</td>
<td>RDY</td>
<td>R</td>
<td>0h</td>
<td>Indicates the positive PGA output is within 150 mV of AVDD.</td>
</tr>
<tr>
<td>5</td>
<td>FL_P_RAILP</td>
<td>R</td>
<td>0h</td>
<td>No error (default); 1: PGA positive output within 150 mV of AVDD</td>
</tr>
<tr>
<td>4</td>
<td>FL_P_RAILN</td>
<td>R</td>
<td>0h</td>
<td>Positive PGA output at negative rail flag (1)</td>
</tr>
<tr>
<td>3</td>
<td>FL_N_RAILP</td>
<td>R</td>
<td>0h</td>
<td>No error (default); 1: PGA negative output within 150 mV of AVDD</td>
</tr>
<tr>
<td>2</td>
<td>FL_N_RAILN</td>
<td>R</td>
<td>0h</td>
<td>Negative PGA output at positive rail flag (1)</td>
</tr>
<tr>
<td>1</td>
<td>FL_REF_L1</td>
<td>R</td>
<td>0h</td>
<td>No error (default); 1: PGA negative output within 150 mV of AVSS</td>
</tr>
<tr>
<td>0</td>
<td>FL_REF_L0</td>
<td>R</td>
<td>0h</td>
<td>Negative PGA output at positive rail flag (1)</td>
</tr>
</tbody>
</table>
Reliability + Autonomy

PGA monitors

<table>
<thead>
<tr>
<th>Bit</th>
<th>Field</th>
<th>Type</th>
<th>Reset</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>FL_P_POR</td>
<td>R</td>
<td>0h</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>RDY</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>FL_P_RAILP</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>FL_P_RAILN</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>FL_N_RAILP</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>FL_N_RAILN</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>FL_REF_L1</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>FL_REF_L0</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Reliability + Autonomy

**PGA monitors**

### PGA Input to PGA Output

- **AVDD**
- **AVDD - 0.15 V**
- **$V_{OUTP} = V_{AINP} + V_{IN} \cdot (\text{Gain} - 1) / 2$**
- **$V_{IN} = V_{AINP} - V_{ANN}$**
- **$V_{OUTN} = V_{ANN} - V_{IN} \cdot (\text{Gain} - 1) / 2$**
- **AVSS + 0.15 V**
- **AVSS**

### Table: Description of PGA Output

<table>
<thead>
<tr>
<th>Bit</th>
<th>Field</th>
<th>Type</th>
<th>Reset</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>FL_P_RAILP</td>
<td>R</td>
<td>0h</td>
<td>Positive PGA output at positive rail flag*(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Indicates the positive PGA output is within 150 mV of AVDD.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 : No error (default)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 : PGA positive output within 150 mV of AVDD</td>
</tr>
<tr>
<td>4</td>
<td>FL_P_RAILN</td>
<td>R</td>
<td>0h</td>
<td>Positive PGA output at negative rail flag*(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Indicates the positive PGA output is within 150 mV of AVSS.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 : No error (default)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 : PGA positive output within 150 mV of AVSS</td>
</tr>
<tr>
<td>3</td>
<td>FL_N_RAILP</td>
<td>R</td>
<td>0h</td>
<td>Negative PGA output at positive rail flag*(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Indicates the negative PGA output is within 150 mV of AVDD.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 : No error (default)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 : PGA negative output within 150 mV of AVDD</td>
</tr>
<tr>
<td>2</td>
<td>FL_N_RAILN</td>
<td>R</td>
<td>0h</td>
<td>Negative PGA output at negative rail flag*(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Indicates the negative PGA output is within 150 mV of AVSS.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 : No error (default)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 : PGA negative output within 150 mV of AVSS</td>
</tr>
</tbody>
</table>

### Register Bit Descriptions

<table>
<thead>
<tr>
<th>Bit</th>
<th>Field</th>
<th>Type</th>
<th>Reset</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>FL_POR</td>
<td>R/W-1h</td>
<td>R-0h</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>RDY</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>FL_P_RAILP</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>FL_P_RAILN</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>FL_N_RAILP</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>FL_N_RAILN</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>FL_REF_L1</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>FL_REF_L0</td>
<td>R-0h</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Texas Instruments*
Reliability + Autonomy

PGA monitors
Reliability + Autonomy
Voltage reference monitoring

REF5050

+ 5V -

$V_{Signal}$

ADS124S08

VREFP  VREFN

$V_{Signal}$
Reliability + Autonomy
Voltage reference monitoring

![Diagram showing REF5050 connected to ADS124S08 via voltage references VREFP and VREFN. The VREFN pin is labeled with 0V.](image)
Reliability + Autonomy
Voltage reference monitoring

![Diagram showing REF5050 and ADS124S08 with VREFP and VREFN connections]

Table:

<table>
<thead>
<tr>
<th>Bit</th>
<th>Field</th>
<th>Type</th>
<th>Reset</th>
<th>Description</th>
</tr>
</thead>
</table>
| 7   | FL_POR      | R/W-1h| 0     | Reference voltage monitor flag, level 1[2]
| 6   | RDY         | R-0h | 0     | Indicates the external reference voltage is lower than 1/3 of the analog supply voltage. |
| 5   | FL_P_RAILP  | R-0h | 0     | Indicates the reference voltage is lower than 0.3 V. Can be used to indicate a missing or floating external reference voltage. |
| 4   | FL_P_RAILN  | R-0h | 0     | Indicate the reference voltage is lower than 0.3 V. |
| 3   | FL_N_RAILP  | R-0h | 0     | Indicate the reference voltage is lower than 0.3 V. |
| 2   | FL_N_RAILN  | R-0h | 0     | Indicate the reference voltage is lower than 0.3 V. |
| 1   | FL_REF_L1   | R-0h | 0     | Indicate the reference voltage is lower than 0.3 V. |
| 0   | FL_REF_L0   | R-0h | 0     | Indicate the reference voltage is lower than 0.3 V. |
Reliability + Autonomy
Voltage reference monitoring

MISSING OR FLOATING REFERENCE VOLTAGE

<table>
<thead>
<tr>
<th>Bit</th>
<th>Field</th>
<th>Type</th>
<th>Reset</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>FL_POR</td>
<td>R</td>
<td>0h</td>
<td>Reference voltage monitor flag, level 1[1]</td>
</tr>
<tr>
<td></td>
<td>RDY</td>
<td></td>
<td></td>
<td>Indicates the external reference voltage is lower than 1/3 of the analog supply voltage.</td>
</tr>
<tr>
<td>6</td>
<td>FL_P_RAILP</td>
<td>R</td>
<td>0h</td>
<td>Can be used to detect an open-excitation lead in a 3-wire RTD application.</td>
</tr>
<tr>
<td>5</td>
<td>FL_P_RAILN</td>
<td>R</td>
<td>0h</td>
<td>1: Differential reference voltage ≤ 0.3 · (AVDD − AVSS) (default)</td>
</tr>
<tr>
<td>4</td>
<td>FL_N_RAILP</td>
<td>R</td>
<td>0h</td>
<td>1: Differential reference voltage &lt; 0.3 · (AVDD − AVSS)</td>
</tr>
<tr>
<td>3</td>
<td>FL_N_RAILN</td>
<td>R</td>
<td>0h</td>
<td>1: Differential reference voltage &gt; 0.3 · (AVDD − AVSS)</td>
</tr>
<tr>
<td>2</td>
<td>FL_REF_L1</td>
<td>R</td>
<td>0h</td>
<td>Reference voltage monitor flag, level 0[2]</td>
</tr>
<tr>
<td>1</td>
<td>FL_REF_L0</td>
<td>R</td>
<td>0h</td>
<td>Indicates the external reference voltage is lower than 0.3 V. Can be used to indicate a missing or floating external reference voltage.</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>0: Differential reference voltage ≤ 0.3 V (default)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1: Differential reference voltage &lt; 0.3 V</td>
</tr>
</tbody>
</table>

Texas Instruments
Reliability + Autonomy
Voltage reference monitoring

Detect open-excitation lead in a 3-wire RTD
Reliability + Autonomy
Diagnostic feature comparison by device

**ADS122U04**
- Temperature sensor
- Burnout current sources
- CRC
- Conversion data counter

**ADS1262**
- Temperature sensor
- Burnout current sources
- Power supply monitors
- PGA monitors
- VREF monitors
- CRC/Checksum
- Test DAC

**ADS124S08**
- Temperature sensor
- Burnout current sources
- Power supply monitors
- PGA monitors
- VREF monitors
- CRC
Reliability + Autonomy
Additional device information

**Coming Soon**

<table>
<thead>
<tr>
<th>ADS122U04</th>
<th>ADS1262</th>
<th>ADS124S08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Folder</td>
<td>Product Folder</td>
<td>Product Folder</td>
</tr>
<tr>
<td>Datasheet</td>
<td>Datasheet</td>
<td>Datasheet</td>
</tr>
<tr>
<td>Samples</td>
<td>Samples</td>
<td>Samples</td>
</tr>
<tr>
<td>EVMs</td>
<td>EVMs</td>
<td>EVMs</td>
</tr>
<tr>
<td>Configuration Calculator**</td>
<td>Configuration Calculator</td>
<td>Configuration Calculator</td>
</tr>
<tr>
<td>Isolation Tech Note**</td>
<td>Precision Weigh Scale Reference Design</td>
<td>Precision Weigh Scale Reference Design</td>
</tr>
<tr>
<td>Universal AI Module Reference Design</td>
<td>Universal AI Module Reference Design</td>
<td>Universal AI Module Reference Design</td>
</tr>
</tbody>
</table>