Redefining high resolution and low noise in Delta-Sigma ADC applications
Redefining high resolution and low noise in Delta-Sigma ADC applications

- How do Precision Delta-Sigma (ΔΣ) ADCs work?
- Introduction to the ADS1262 & ADS1263
- Common Application Circuits using the ADS126xEVM
  - 3-/4-Wire RTDs
  - 3-/4-Wire RTD Pitfalls
  - Load Cells
  - Load Cell Pitfalls
- How to use the ADS1262 and ADS1263 monitoring and diagnostic features
- Coming Soon… PLC reference design
- Additional Information
Precision Delta-Sigma ADC Basics

Why is this a high resolution, low noise ADC architecture?
First, what do Precision ΔΣ ADCs do?

• High resolution + low noise
• Offer wide dynamic range
• Measure slow-moving signals
• Often application-specific
How Do Precision Delta-Sigma ADC’s Work?

ADC Architecture Overview

What’s inside a Delta-Sigma ADC core?
How Do Precision Delta-Sigma ADC’s Work?

The Delta-Sigma Modulator – Time Domain

- Digital output is equal to the input plus the quantization noise
- Goal is to minimize error due to quantization noise

\[ y_i = x_{i-1} + (e_i - e_{i-1}) \]
How Do Precision Delta-Sigma ADC’s Work?

The Delta-Sigma Modulator – Frequency Domain

How do we lower inband quantization noise?

Oversampling!

Noise floor is lower in Frequency Band of interest

Same total noise, but spread over more frequencies

New noise floor (w/ oversampling)

Power

Frequency

FS / 2  kFS / 2  FS  kFS
How Do Precision Delta-Sigma ADC’s Work?

The Digital Filter – Ideal Response

How do we remove out-of-band noise?

Filtering!

Noise removed by filter
How Do Precision Delta-Sigma ADC’s Work?

The Digital Filter – Actual Response

For a real-world SINC³ filter, the actual response and noise attenuation looks like this:

![SINC3 Frequency Response (DR = 60 Hz)](image)
How Do Precision Delta-Sigma ADC’s Work?

The Decimator

- Decimate the output by averaging several samples
- Often accomplish both filtering & decimation with SINC filter
How Do Precision Delta-Sigma ADC’s Work?
Low Noise, High Resolution... & Beyond

 Mostly digital

Are there other advantages to this architecture?

Let’s look at an example.

More room for integration
How Do Precision Delta-Sigma ADC’s Work?

Lots of digital = lots of room for integration!

- Delta-Sigma Core

[Diagram showing the components and connections of a Precision Delta-Sigma ADC, including Test DAC, MUX, PGA, 32-bit ΔΣ ADC, Internal Reference, Reference MUX / Detect / Buffer, Programmable Digital Filter & SPI Control, System/Self Calibration, Low Drift Oscillator, Temp Sensor, GPIO, Level Shift, AVDD, AVSS.]
ADS1262 and ADS1263
ADS1262/3
Best-in-class Industrial ΔΣ ADC w/ Ultra Low Noise | 32-bit | 10/5 SE/Diff Channels

Features

- **Highest Resolution ADC:**
  - 27 bit ENOB, 7nV Noise (@2.5SPS)

- **11 Flexible, Multiplexed Inputs:**
  - 10 Single-Ended OR 5 Differential

- **Highly Specified Performance:**
  - Offset Drift: 1nV/°C
  - Gain Drift: 0.5ppm/°C
  - INL: 3ppm

- **Highly Integrated Device:**
  - Low Drift Internal Reference: 2.5V
  - GPIOs (8)
  - Internal Clock: 7.3728MHz
  - High Impedance PGA: 1/2/4/8/16/32
  - SINC + 50/60Hz Digital Filter

- **Fault Detection/Input Diagnostics**

Benefits

- Wide dynamic range 32-bit ADC enables direct digitization of low level sensors
- High-resolution, low-drift architecture provides the industry’s best performing ADC
- A high level of integration eliminates the need for several typical discrete components, decreasing necessary PCB space and reducing costs
- Wide sample rate allows this device to be adaptable to a variety of applications
- On-chip sensor bias current sources make the ADS1262 RTD-ready
- Fault detection improves system reliability

Applications

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

TI Information – Selective Disclosure
Performance development kits (PDKs)
- Daughter card, motherboard, USB cable and power supply.
- ADCPro™ evaluation software for Microsoft Windows with built-in analysis tools.
- Configurable inputs, references, supplies, and clock sources
- Getting started software available for download
ADS1262/3 – More Tools for Faster Design

Precision Weigh Scale Reference Design | Excel Configuration Calculator

TI Designs reference design for high resolution, low drift, precision weigh scale measurements with AC bridge excitation (TIPD188)

- Improve offset and offset drift performance for bridge measurements
- Accelerates time to market.
- Includes schematics, BOM and design files

Excel-based calculator for device configuration

- Check PGA input range requirements.
- Calculate CRC/checksum values.
- Evaluate different SINC filter responses.
- View a register map.
Common Application Circuits using the ADS126xEVM

3-/4-Wire RTDs
Common Apps – 3-/4-Wire RTDs

Resistance Temperature Detector (RTD) Overview

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

![Diagram of RTD connections](image)

**4-Wire RTD**

- $R_{LEAD1}$
- $R_{LEAD2}$
- $R_{LEAD3}$
- $R_{LEAD4}$
- $I_{DAC1}$
- $I_{DAC2}$
- $V_{RTD}$
- $V_{LEAD}$

**3-Wire RTD**

- $R_{LEAD1}$
- $R_{LEAD2}$
- $R_{LEAD3}$
- $I_{DAC1}$
- $I_{DAC2}$

**Graph:**

- PT-100 RTD Resistance vs. Temperature

**Texas Instruments**
Common Apps – 3-/4-Wire RTDs

4-Wire RTD Connections

- IDAC is used to excite the RTD and generate the reference voltage ("ratiometric")
Common Apps – 3-/4-Wire RTDs

4-Wire RTD Connections

- Ratiometric configuration is unaffected by changes in IDAC current.

![Diagram of 4-Wire RTD Connections]

- 4-Wire RTD (PT100) (100 Ω @ 0°C)
- 50 mV (@ 0°C)
- 1.95 V
- 500 μA
- AVSS + 50 mV (@ 0°C)
- -(100 Ω @ 0°C)

**Equation:**

\[
\frac{PGA \cdot V_{IN}}{V_{REF}} = \frac{CODE}{2^{(N-1)}}
\]
A second *(matched)* IDAC current source is used to remove the effect of RTD lead resistance from the measurement.
Common Apps – 3-/4-Wire RTDs

3-Wire RTD Connections

- A second (matched) IDAC current source is used to remove the effects of RTD lead resistance from the measurement.
Common Application Circuits using the ADS126xEVM

3-/4-Wire RTD Pitfalls
Common Apps – 3-/4-Wire RTD Pitfalls
Reference Resistor Tolerance & Drift
Common Apps – 3-/4-Wire RTD Pitfalls
Reference Resistor Tolerance & Drift

\( \Delta R_{REF} \rightarrow \text{Gain Error (GE)} \)

1. **Resistor Tolerance** Gain Error \((\text{removed by calibration})\):

\[
GE \ (\text{ppm}) = 10,000 \cdot \text{Tolerance} \ (%) \cdot \text{FSR Utilization} \ (\%)
\]

2. **Resistor Temperature Coefficient** Gain Error \((\text{remains after cal})\):

\[
GE \ (\text{ppm}) = \text{Temp Co.} \ \frac{\text{ppm}}{\text{°C}} \cdot \text{Temp Range} \ (\text{°C}) \cdot \text{FSR Utilization} \ (\%)
\]

– Example:

\[
25 \ \frac{\text{ppm}}{\text{°C}} \cdot 50 \ \text{°C} \cdot 90\% \ \text{Utilization} = 1125 \ \text{ppm} \ (9.8 \ \text{bits accuracy})
\]

👍 Use a reference resistor with a temperature coefficient \(\leq 1 \ \text{ppm/°C}\)
Common Apps – 3-/4-Wire RTD Pitfalls

IDAC Mismatch

- 3-Wire RTD
- RREF
- AIN3 (REFN)
- AIN2 (REFP)
- RREF
- AIN4 (AINP)
- AIN5 (AINN)
- IDAC1
- IDAC2
- 5 V
- 0.1 μF
- AVDD
- AVSS
- Digital Filter
- 32-bit ΔΣ ADC
- Reference Mux
- PGA
- ADS1262

Texas Instruments
Common Apps – 3-/4-Wire RTD Pitfalls
IDAC Chopping using the ADS1262/3

1) \( V_{\text{IN1}} = V_{\text{RTD}} + \Delta V_{\text{LEAD}} \)
2) \( V_{\text{IN2}} = V_{\text{RTD}} - \Delta V_{\text{LEAD}} \)

\[ \text{AVE: } \frac{1}{2} (V_{\text{IN1}} + V_{\text{IN2}}) = V_{\text{RTD}} \]
Common Apps – 3-/4-Wire RTD Pitfalls
Error Improvements using IDAC Chopping

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

<table>
<thead>
<tr>
<th>System Temperature Range</th>
<th>50 (Δ°C)</th>
<th>Before Calibration</th>
<th>After Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDAC CHOPPING = OFF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDAC Match Error</td>
<td>0.1% (%)</td>
<td>500 (ppm)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>IDAC Match Drift</td>
<td>5 (ppm/°C)</td>
<td>125 (ppm)</td>
<td>125 (ppm)</td>
</tr>
<tr>
<td>TOTAL ADC ERROR</td>
<td></td>
<td>556 (ppm)</td>
<td>127 (ppm)</td>
</tr>
<tr>
<td>IDAC CHOPPING = ON</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDAC Match Error</td>
<td>0.0% (%)</td>
<td>0 (ppm)</td>
<td></td>
</tr>
<tr>
<td>IDAC Match Drift</td>
<td>0 (ppm/°C)</td>
<td>0 (ppm)</td>
<td></td>
</tr>
<tr>
<td>TOTAL ADC ERROR</td>
<td></td>
<td>210 (ppm)</td>
<td>23 (ppm)</td>
</tr>
</tbody>
</table>

5x Accuracy Improvement!
Common Apps – 3-/4-Wire RTD Pitfalls

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!
• Resolution = Measurement Repeatability or smallest discernable unit

<table>
<thead>
<tr>
<th>ADS1262 Configuration</th>
<th>RTD (PT100 type)</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>
<tr>
<td>ADC Noise RTI</td>
<td>376.20 (nV&lt;sub&gt;P-P&lt;/sub&gt;)</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;H&lt;/sub&gt;(°C) - T&lt;sub&gt;L&lt;/sub&gt;(°C): 1050 (°C)</td>
</tr>
<tr>
<td></td>
<td>VRTD (@ -200°C): 9.260 (mV)</td>
</tr>
<tr>
<td></td>
<td>VRTD (@ +850°C): 195.241 (mV)</td>
</tr>
<tr>
<td></td>
<td>ΔVin: 185.981 (mV)</td>
</tr>
<tr>
<td></td>
<td>Noise-Free Bits: 18.9 (nV&lt;sub&gt;P-P&lt;/sub&gt;)</td>
</tr>
<tr>
<td></td>
<td>Temperature Resolution: 0.002 (°C&lt;sub&gt;P-P&lt;/sub&gt;)</td>
</tr>
</tbody>
</table>
Common Application Circuits using the ADS126xEVM

Load Cells
Common Apps – Load Cells

Introduction to Load Cells

Load Cell

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

\[ + \quad 2 \text{mV/V} \]

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

\[ + \quad 10 \text{mV} \quad (@ \text{capacity}) \]

\[ - \]

\[ R_{\text{LEAD}} \]
Common Apps – Load Cells
Connecting a Load Cell to the ADS126xEVM

- 4-/6-Wire Load Cell Connections
- ADS126x can internally use the analog supply as the reference voltage

![Diagram of Load Cell Connections](image-url)
Common Application Circuits using the ADS126xEVM

Load Cell Pitfalls
Common Apps – Load Cell Pitfalls

Offset Drift
Common Apps – Load Cell Pitfalls
Input Chopping to Remove Offset Drift using the ADS1262/3

How to remove additional offset & drift
http://www.ti.com/tool/tipd188

1) $V_{IN1} = V_{BRIDGE} + V_{OS}$
2) $V_{IN2} = -V_{BRIDGE} + V_{OS}$

$\text{SUB: } \frac{1}{2}(V_{IN1} - V_{IN2}) = V_{BRIDGE}$

ADS1262

Texas Instruments
Common Apps – Load Cell Pitfalls

Error Analysis

- Neglects load cell errors

<table>
<thead>
<tr>
<th>System Temperature Range</th>
<th>165 (Δ°C)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>ADS1262 Errors</th>
<th>Before Calibraion</th>
<th>After Calibraion</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>198.00 (nV p-p)</td>
<td>0.63 (ppm)</td>
</tr>
<tr>
<td>Offset</td>
<td>10.938 (µV)</td>
<td>35 (ppm)</td>
</tr>
<tr>
<td>Offset Drift</td>
<td>10.9 (nV/°C)</td>
<td>5.78 (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>4.99 (ppm)</td>
</tr>
<tr>
<td>INL</td>
<td>3 (ppm)</td>
<td>3 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;REF&lt;/sub&gt; Abs. Bias Current</td>
<td>100 (nA)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;REF&lt;/sub&gt; Abs. Bias Current V Coeff</td>
<td>50 (nA/V)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;REF&lt;/sub&gt; Abs. Bias Current Drift</td>
<td>0.03 (nA/°C)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;REF&lt;/sub&gt; Diff. Bias Current</td>
<td>200 (nA)</td>
<td>0.23 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;REF&lt;/sub&gt; Diff. Bias Current V Coeff</td>
<td>6 (nA/V)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;REF&lt;/sub&gt; Diff. Bias Current Drift</td>
<td>0.30 (nA/°C)</td>
<td>0.06 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;AIN&lt;/sub&gt;N/ Abs. Bias Current</td>
<td>2 (nA)</td>
<td>0.15 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;AIN&lt;/sub&gt;N/ Abs. Bias Current V Coeff</td>
<td>0.75 (nA/V)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;AIN&lt;/sub&gt;N/ Abs. Bias Current Drift</td>
<td>0.01 (nA/°C)</td>
<td>0 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;AIN&lt;/sub&gt; Diff. Bias Current</td>
<td>0.1 (nA)</td>
<td>0.260 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;AIN&lt;/sub&gt; Diff. Bias Current V Coeff</td>
<td>0.20 (nA/V)</td>
<td>0.002 (ppm)</td>
</tr>
<tr>
<td>I&lt;sub&gt;AIN&lt;/sub&gt; Diff. Bias Current Drift</td>
<td>0.01 (nA/°C)</td>
<td>5.16 (ppm)</td>
</tr>
</tbody>
</table>

**TOTAL ADC ERROR**

|                  | 36 (ppm) | 10 (ppm) |

**TOTAL ERROR**

<table>
<thead>
<tr>
<th>Total Uncorrelated System Error</th>
<th>36 (ppm)</th>
<th>10 (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.39 (±µV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.365 (±g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.097 (±g)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Common Apps – Load Cell Pitfalls

Weight Resolution

- Resolution = Measurement Repeatability or smallest discernable unit

<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>∆Vin</td>
</tr>
<tr>
<td>198.00 (nV_{p.p})</td>
<td>10 (mV)</td>
</tr>
<tr>
<td></td>
<td>Noise-Free Bits</td>
</tr>
<tr>
<td></td>
<td>15.6 (nV_{p.p})</td>
</tr>
<tr>
<td></td>
<td>Weight Resolution</td>
</tr>
<tr>
<td></td>
<td>0.198 (g_{p.p})</td>
</tr>
</tbody>
</table>
How to Use the ADS126x Monitoring and Diagnostic Features
ADS126x Monitoring & Diagnostics
Communication Error Checking

Checksum/CRC

Data byte 1
+ Data byte 2
+ Data byte 3
+ Data byte 4
+ 9Bh
= checksum byte

CRC Byte (Initialized to 0x00)

Data (MSB first)

(XOR)
Figure 92. Status Byte (STATUS)

<table>
<thead>
<tr>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC2</td>
<td>ADC1</td>
<td>EXTCLK</td>
<td>REF_ALM</td>
<td>PGAL_ALM</td>
<td>PGAH_ALM</td>
<td>PGAD_ALM</td>
<td>RESET</td>
</tr>
</tbody>
</table>
ADS126x Monitoring & Diagnostics
Burnout Detection with ADC2

The diagram shows the connection of ADS1263 to the measurement points. The 4-Wire RTD is used for measuring temperature. The 32-bit ΔΣ ADC and 24-bit ΔΣ ADC are used for digital signal processing. The Digital Filter is applied to the output of each ADC.
Universal Input for Programmable Logic Controllers using the ADS1262
Upcoming Universal Input Module for PLC
Best-in-class Industrial ΔΣ ADC w/ Ultra Low Noise | 32-bit | 10/5 SE/Diff Channels

New Reference Design for Programmable Logic Controllers (PLC)

Coming soon…

[Diagram of input module with 4-Wire RTD, 3-Wire RTD, and Thermocouple inputs]
Additional Information
Redefining high resolution and low noise in Delta-Sigma ADC applications

General Delta-Sigma ADC information:
- Understanding the Delta-Sigma modulator
- Delta-Sigma basics: how the digital filter works
- How Delta-Sigma ADCs work (Part 1)
- How Delta-Sigma ADCs work (Part 2)

ADS1262 & ADS1263 Information:
- ADS1262 Product Folder
- ADS1262EVM
- ADS1262/3 precision weigh scale reference design
- ADS1262/3 configuration calculator
- Buy or sample the ADS1262/3
Thanks!

Any Questions?