Typical Signal chain solutions for Industrial
Agenda

• Industrial Signal Chain Overview

• Industrial Signal Conditioning and Acquisition
  – Unipolar Signal
  – Bipolar Signals
  – Multi-Channel Signal

• Industrial Signal Transmission
  – 4~20mA
TI Offers the Complete Signal Processing Chain

- OP AMP
- MUX
- FILTER
- A/D
- Voltage Reference Source

- Sensor Interface
- Voltage Reference Source
- Buffer
- Gain
- Difference Amplifier
- Instrumentation Amplifier
- Filter
- Level Shift

- Anti-Alias Filter
- Band-pass Filter
- Programmable Gain Amp
- Instrumentation Amp
- A/D Converter Driver

- Voltage Reference Source
- DDS Synthesis

- µC or µP

- POWER AMP

- Actuator Driver
- Line Driver
- 4-20mA Driver

- Valve
Unipolar Signal Conditioning and Acquisition
One of Sensors: Bridge Sensor

Measure the Followings:

- Pressure
- Temperature
- Humidity
- Acceleration
- Torque
# Temperature Measurement Sensors

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Resistance-Temperature Detector (RTD)</th>
<th>Thermistor</th>
<th>Thermocouple (TC)</th>
<th>Integrated Circuit Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature Range</strong></td>
<td>-70°C to 500°C</td>
<td>0°C to 100°C</td>
<td>-270°C to 1820°C</td>
<td>-40°C to 150°C</td>
</tr>
<tr>
<td><strong>Linearity</strong></td>
<td>High (limited)</td>
<td>Low (Non Linear)</td>
<td>Non-linear</td>
<td>Very Linear</td>
</tr>
<tr>
<td><strong>Power Consumption</strong></td>
<td>External Current/Voltage Source</td>
<td>External Current Source</td>
<td>Self Power</td>
<td>System Power (uA)</td>
</tr>
<tr>
<td><strong>Output Range</strong></td>
<td>100 to 1kΩ</td>
<td>100 to 40MΩ</td>
<td>Low Voltage (mv)</td>
<td>Digital Output</td>
</tr>
<tr>
<td><strong>Self Heating</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>Low : +0.4Ω/°C</td>
<td>High: -3.9%/° C to -6.4%/° C</td>
<td>10μV /° C</td>
<td>0.5 ° C</td>
</tr>
<tr>
<td><strong>Operation</strong></td>
<td>2-4Wire, Signal Conditioning</td>
<td>2 Wire, Signal Conditioning</td>
<td>Cold Junction Compensation + Signal Amplifier</td>
<td>Power Supply, Self Contained</td>
</tr>
</tbody>
</table>
Temperature: Why an RTD?

Table Comparing Advantages and Disadvantages of Temp Sensors

<table>
<thead>
<tr>
<th></th>
<th>Thermocouple</th>
<th>RTD</th>
<th>Thermistor</th>
<th>I. C. Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-powered</td>
<td></td>
<td>Most stable</td>
<td>High output</td>
<td>Most linear</td>
</tr>
<tr>
<td>Simple</td>
<td></td>
<td>Most accurate</td>
<td>Fast</td>
<td>Highest output</td>
</tr>
<tr>
<td>Rugged</td>
<td></td>
<td>More linear than thermocouple</td>
<td>Two-wire ohms measurement</td>
<td>Inexpensive</td>
</tr>
<tr>
<td>Inexpensive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide variety</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide temperature range</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□</td>
<td></td>
<td></td>
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<tr>
<td>□</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **Disadvantages** | | | |
| Non-linear | Expensive | Non-linear | T<200°C |
| Low voltage | Current source required | Limited temperature range | Power supply required |
| Reference required | Small ΔR | Fragile | Slow |
| Least stable | Low absolute resistance | Current source required | Self-heating |
| Least sensitive | Self-heating | Self-heating | Self-heating |
| □            |            |            |            |
| □            |            |            |            |
| □            |            |            |            |
| □            |            |            |            |
| □            |            |            |            |
| □            |            |            |            |
OPA333, OPA2333
Micro Power, Zerø-Drift Operational Amplifier

Features

- Low Quiescent Current: 25µA (max)
- Low Offset Voltage: 10µV (max)
- Offset Voltage Drift: 0.05µV/°C (max)
- Low Voltage Noise: 1.1 µV_P-P
- Bandwidth: 350kHz
- Rail-to-Rail Input and Output
- 1.8V to 5.5V Supply Voltage
- Specified Temperature Range:
  - -40° C to +125° C
- OPA333: SC70-5, SOT23-5, SO-8
- OPA2333: QFN-8, SO-8

Applications

- Battery-Powered Instruments
- Temperature Measurement
- Precision Strain Gages
- Precision Sensor Applications
- Handheld Test Equipment

Benefits

- Lowest Power Increases Battery Life
- Low Offset and Drift Removes Need for Calibration in Application
- RRIO Increases Dynamic Range
- 1.8V Supply Excellent for Battery Devices
- Micro SC70 Package Saves Board Space
Example: EMI Cell Phone Disturbance

Offset voltage variation due to an interfering from cell phone.
Performance Improvement by EMI hardened Amplifier

Given:

- Disturbing RF = 100 mVp at 900 MHz
- Op amp gain = 101x
- ADC: 10-bit resolution, 5V input range -> 1 bit = 4.88 mV

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Typical</th>
<th>LMV851 EMI hardened</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMIRR</td>
<td>50 dB</td>
<td>80 dB</td>
</tr>
<tr>
<td>Input referred voltage shift</td>
<td>0.32 mV</td>
<td>10 μV</td>
</tr>
<tr>
<td>Output shift</td>
<td>32 mV</td>
<td>1 mV</td>
</tr>
<tr>
<td>Signal path inaccuracy due EMI</td>
<td>7 bit</td>
<td>0.2 bit only</td>
</tr>
</tbody>
</table>
EMI Hardened Product Family

**LMV831**
- BW = 3 MHz
- EMIRR = 120 dB
- \( I_s = 0.24 \text{ mA per channel} \)

**LMV832**
- BW = 3 MHz
- EMIRR = 120 dB
- \( I_s = 0.4 \text{ mA per channel} \)

**LMV834**
- BW = 3 MHz
- EMIRR = 120 dB
- \( I_s = 0.4 \text{ mA per channel} \)

**LMV851**
- BW = 8 MHz
- EMIRR = 87 dB

**LMV852**
- BW = 8 MHz
- EMIRR = 87 dB
- \( I_s = 0.4 \text{ mA per channel} \)

**LMV854**
- BW = 8 MHz
- EMIRR = 87 dB
- \( I_s = 0.4 \text{ mA per channel} \)

**LMV861**
- BW = 30 MHz
- EMIRR = 105 dB
- \( I_s = 2.25 \text{ mA per channel} \)

**LMV862**
- BW = 30 MHz
- EMIRR = 105 dB
- \( I_s = 2.25 \text{ mA per channel} \)

**LMP2021**
- ZDNN Low Noise Amplifier

**LMP2022**
- ZDNN Low Noise Amplifier
Key Advantages of the 24-bit AFEs LMP90100 and ADS1248

- Continuous Background Calibration Engine (no drift over time or temperature)
- Non-invasive Sensor Diagnostics
- Robust Data Transmission (CRC)

- Sample rate up to 2k SPS
- Integrated Reference
- Internal VBIAS
- Flexible internal routing of IBIAS
# Product Comparison

<table>
<thead>
<tr>
<th>Key Specifications</th>
<th>LMP90100 Family</th>
<th>ADS1248 Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully Integrated AFE</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Single Cycle Settling Time</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Flex Routing of Inputs</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Self-Calibration</td>
<td>Continuous Background and System</td>
<td>System Calibration</td>
</tr>
<tr>
<td>Sensor Diagnostics</td>
<td>✔ (Non-invasive)</td>
<td>✔</td>
</tr>
<tr>
<td>Serial Interface</td>
<td>SPI with Error Detection</td>
<td>SPI</td>
</tr>
<tr>
<td>Variable Data Rate</td>
<td>Up to 214 SPS</td>
<td>Up to 2k SPS</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>400 µA</td>
<td>230 µA</td>
</tr>
<tr>
<td>ENOB</td>
<td>21.5 bits</td>
<td>21.8 bits</td>
</tr>
<tr>
<td>Analog Supply Voltage</td>
<td>2.85V to 5.5V</td>
<td>2.7V to 5.25V</td>
</tr>
<tr>
<td>Small form factor</td>
<td>TSSOP - 28</td>
<td>TSSOP – 28</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-40°C to 125°C</td>
<td>-40°C to 125°C</td>
</tr>
</tbody>
</table>
ADS1247/48
24-Bit, Complete Temperature Measurement ADC

**Features**

*Device Features:*
- 2/4 Differential or 3/7 Single-Ended
- True Bipolar ± 2.5V or Unipolar 5V
- Max Data Rate – 2kSPS
- Low Noise PGA: 40\(\eta\)V @ G = 128
- 50/60Hz Simultaneous Rejection Mode (20SPS)

*On-Chip Integration:*
- Low Drift Internal Reference (10 ppm/°C Max)
- Dual Matched Current DACs (50 – 1500 \(\mu\)A)
- Oscillator, Temp Sensor, Burnout Detect
- 4/8 General Purpose I/Os
- 16-Bit Upgrade upcoming ADS1147/48

**Applications**
- Temperature Management
  - RTDs, Thermocouples, Thermistors
- Flow/Pressure Measurement
- Industrial Process Control

**Benefits**

- Ultimate Temperature Sensor Measurement Solution
- Most Flexible Front End for a Wide Range of Industrial Sensors
- High Integration Without Compromising Performance
- Scalable Upgrades

EVM:ADS1248EVM

20/28-Pin TSSOP
3-Wire RTD Measurement

Note: $R_{BIAS}$ should be as close to the ADC as possible.
**LMP90100**

**Multi-Channel, Low Power 24-Bit Sensor AFE with True Continuous Background Calibration**

**Features**

- 24-Bit Low Power Sigma Delta ADC
- 4 Diff or 7 SE inputs (mix and match)
- True Continuous Background Calibration and Background Diagnostics at all gains
- Low-Noise 1x to 128x PGA
- Part of Pin - Compatible Family

**Benefits**

- LMP90100 supported with Web Design Tool and Bench-top Development System
- Single board layout supports multiple resolutions and Configurations
- Performance stated for each gain/speed combination (Web Design tool and datasheet)
- Very Low Power

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Current Sources</th>
<th>4 Diff. / 7SE</th>
<th>2 Diff. / 4SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 Bit</td>
<td>Yes</td>
<td>LMP90100</td>
<td>LMP90098</td>
</tr>
<tr>
<td>24 Bit</td>
<td>No</td>
<td>LMP90099</td>
<td>LMP90097</td>
</tr>
<tr>
<td>16 Bit</td>
<td>Yes</td>
<td>LMP90080</td>
<td>LMP90078</td>
</tr>
<tr>
<td>16 Bit</td>
<td>No</td>
<td>LMP90079</td>
<td>LMP90077</td>
</tr>
</tbody>
</table>

**Applications**

- Transducers and Transmitters
- RTD, Thermocouple, Temperature Sensors
- Pressure, Load and Force Sensing
- Data Acquisition

**EVM PART # LMP90100EB**

![EVM NEW!](image-url)
Continuous Calibration Advantages

• Primary benefit of continuous calibration is excellent drift compensation for both drift components
  – Drift over temperature
  – Drift over time

• Current methods for compensating for drift are:
  – Chopping for offset drift
  – Monitoring the temperature and re-calibrating if temperature changes
  – Budgeting drift error in system errors and re-calibrating at fixed time intervals

• None of the existing methods are perfect for drift compensation. Continuous calibration offers the best results
Background Offset Correction


\[ c_{est} = \frac{(y[1] + y[2])}{2} \quad if \quad x[1] = x[2] \]

• Offset Estimation:
  – Alternate input samples to the ADC are inverted and the two digital output codes are averaged

• Offset Correction:
  – All the subsequent conversions can use \( c_{est} \) to eliminate the offset

• \( c_{est} \) is continuously updated to eliminate drift errors
Offset Error without Background Calibration

Waveform Graph

Mean (μ) = -5.95 μV.
Std. Dev. (σ) = 7.585 μV.
Offset Error with Background Calibration

Waveform Graph 2

Mean ($\mu$) = -0.0311 $\mu$V.
Std. Dev. ($\sigma$) = 4.563 $\mu$V.
Background Gain Correction

\[ A'_{\text{est}} = (y[2] - y[1]) / \Delta x \quad \text{if} \quad x[2] = x[1] + \Delta x \]

• Gain Estimation:
  – A known value \( \Delta x \) is added to alternate analog input samples and the difference between the digital codes is used to estimate the gain

• Gain Correction:
  – All the subsequent conversions can use \( A'_{\text{est}} \) to eliminate the gain error

• \( A'_{\text{est}} \) is continuously updated to eliminate drift errors
Two separate 24-bit registers for Gain & Offset Correction factors

User has read & write access to these registers
Sensor Diagnostics – What is required

- Comprehensive solution to detect various fault conditions
- Should work for various sensors (RTD, Thermistors, Thermocouple)
- Should work for various configurations (2, 3, 4 wire)
- Provide information about possible cause of failure.
- Background no User intervention required.
- Continuous, monitors all the time
- Should not interfere with the input
Sensor Diagnostics – Existing Solution

**Open Circuit Detection**

- **LTC**
- **Maxim**
- **ADI**
- **TI**

**RTC Introduces Offset**

**Burnout Detection**

- Fault detection using “Current injection” fail in most of the cases
Sensor Diagnostics – Existing Solution

Issues with Current Injection:
- Can’t detect all the Fault conditions, only on demand
- Slows down the total conversion rate as ADC O/P is used.
- Interfere with the main measurement.
- Small current sources for open/short detection is not usable by temperature transmitters. This is because RC filters are connected to every input linked with the outside world need a lot of time to charge the capacitor and is therefore not usable.
- Once enabled as shown below all the channels are effected.

![Diagram](image)

Current injection is not channel specific.
Current scan

- Current Injection
  - Helps to detect Floating inputs.
  - Channel Specific Current Injection.

<table>
<thead>
<tr>
<th>Existing Solution</th>
<th>Proposed Solution</th>
</tr>
</thead>
</table>

From nA to 10μA
Current scan modes

• Single Channel Current Injection

  Frame-1: CH1 is Evaluated

  Frame-2: CH2 is Evaluated

  Frame-3: CH3 is Evaluated

• Automated Scan injection.
  – Current is not injected into the channel that is being evaluated.
  – Idea is to minimize the interference with Signal.
## Sensor Diagnostics – Advantages

- Multiple Methods to detect different kind of fault Conditions
- Burnout Current Source Scan.

<table>
<thead>
<tr>
<th>Detection Method</th>
<th>Competitors</th>
<th>National</th>
<th>Interference to Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shorted Input</td>
<td>Pump Burnout Current. Change in Resistance {should store history .i.e μC}</td>
<td>RTD/TC: Same as Existing (Or) Using of Threshold Register [Window Comparison].</td>
<td>Yes/ No</td>
</tr>
<tr>
<td>Floating Input</td>
<td>No</td>
<td>Inject Burnout Current. Near rail detect comparators detect a Float.</td>
<td>No</td>
</tr>
<tr>
<td>Over Load Detection</td>
<td>No</td>
<td>With Modulator overflow detection we can easily detect if input exceed the allowed range. Also we can detect if Reference is open/short</td>
<td>No</td>
</tr>
</tbody>
</table>
ADS1118
World’s Smallest 16-bit ADC, w/0.5°C (max) Accurate Temp Sensor

**Features**

- Complete set of integrated functions:
  - Four multiplexed analog inputs
  - Four digital I/O
  - PGA (gains: 0.33, x0.5, x1, x2, x4 or x8)
  - Precision ADC with data rates from 8 to 860 SPS
  - Internal temperature sensor (0.5°C max)
  - Small QFN package (2.05mm x 1.55mm x 0.4mm)

- Versatile supply range and low power consumption
  - Low supply current: 150uA typ
  - Supply 2.0V – 5.5V

**Applications**

- Temperature Measurement
- Battery Pack
- Portable Instrumentation
- Industrial Process Control
- Gas Monitoring
- Consumer Goods
- Embedded ADC Upgrade

**Benefits**

- A single ADS1118 can perform data acquisition of multiple signals from a wide variety of sensors.

- Small package that readily senses ambient temperature to perform cold junction compensation in thermocouple applications.

- Its size and low power consumption make the ADS1118 a great device for portable applications where extended battery life is critical

**Diagram**

Tiny QFN(RUG) or MSOP(DGS) Package

ADS1118 EVM Available
**AMC1200**

4kV\textsubscript{PEAK} Isolated Amplifier

**Features**

- $\pm 250$ mV input voltage range
- Fixed gain: 8
- Gain error: 1% max; drift: $\pm 40$ ppm/°C
- Input bandwidth: 60 kHz min
- Input offset voltage: $\pm 2$ mV max; drift: $\pm 10$ $\mu$V/°C max
- Non-linearity: $\pm 0.05$% max
- Transient immunity: 10 kV/μs min
- Specified Temp range: -40..105°C
- Package: Gullwing-8

**Benefits**

- Pin-to-pin performance upgrade for HCPL7800 & HCPL7840
- 50% lower power dissipation on VDD1

**Applications**

- Current measurement in:
  - Motor Control
  - Isolated Power Supplies

![Diagrams showing voltage levels and current measurement](image)
LMP91000 Application Diagram
Toxic Gas Sensor
LMP91000 Product Overview

Features

• Low Power (<10μA)

• TIA Gain ranges (KΩ): 2.75, 3.5, 7, 14, 35, 120, 350, external resistor

• Reference Electrode Bias Current: 900pA (max)

• Cell conditioning currents: up to 10mA

• Output Drive Current: > 750 μA

• Internal Temp Acc: +/- 3°C
## LMP91000 Product Overview

### Features

<table>
<thead>
<tr>
<th>Area</th>
<th>TI</th>
<th>Discrete Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single solution addresses multiple gases</td>
<td>✅</td>
<td>✗</td>
</tr>
<tr>
<td>Small footprint</td>
<td>✅</td>
<td>✗</td>
</tr>
<tr>
<td>One solution across multiple types of sensors</td>
<td>✅</td>
<td>✗</td>
</tr>
<tr>
<td>One solution across varying gas concentration</td>
<td>✅</td>
<td>✗</td>
</tr>
<tr>
<td>Integral Temperature Sensor</td>
<td>✅</td>
<td>✗</td>
</tr>
<tr>
<td>Quick Design /Prototype evaluation</td>
<td>✅</td>
<td>✗</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>✅</td>
<td>✗</td>
</tr>
<tr>
<td>System Reliability</td>
<td>Improved</td>
<td>-</td>
</tr>
<tr>
<td>Low Power Consumption</td>
<td>✅</td>
<td>✗*</td>
</tr>
<tr>
<td>Superior EMI Protection</td>
<td>✅</td>
<td>✗*</td>
</tr>
</tbody>
</table>

* Requires special op amps
**LMP91000**

Configurable AFE Potentiostat for Low-Power Chemical Sensing Applications

### Features

- Programmable transimpedance gain
- Programmable cell bias voltage
- Supply current (Average over time) <10μA
- On board sensor test
- On board temperature sensor
- Low bias voltage drift
- Operating supply range: 2.7V to 5.5 V
- Cell conditioning currents up to 10mA
- Reference Electrode Bias Current 1000pA (max)
- Output Drive Current 670μA (min)
- Sink and source capability
- I2C® compatible digital interface

### Applications

- Toxic gas detection platforms
- Amperometric applications
- Chemical species detection

---

**Benefits**

- Industry’s low power complete potentiostat circuit which interfaces to most of today’s single channel chemical cells. Programmability enables
  - A modular approach for our customers
  - One solution for multiple devices
  - Offers the proper amount of integration which makes smaller solutions for the customer
  - Lower assembly and handling cost
  - And finally helps them get their products to market faster!

---

**EVM PART # LMP91000SDE/NOPB**
LMP91200
Fully Integrated Analog Front End for pH Analyzer Sensor Platforms

Features

 Complete integrated front end for pH sensing
 Ultra low input bias current: 0.45 pA at 85°C
 Programmable Output Common Mode Voltage
 Active guard pins
 Easy RTD hookup for temperature measurement
 Supported by Webench Sensor AFE Designer

Benefits

 World’s first single chip solution helps reduce design time, cost and board space
 99% lower bias vs. competition allows reliable measurement with high impedance pH electrodes
 Provides flexibility to use with several pH sensor output ranges
 Provide high parasitic impedance wiring to eliminate leakage
 Allows calibration of temp. drifts over time
 Online & Hardware evaluation tools enable quick evaluation, prototyping and faster time to market

Applications

 pH Sensor Platforms
   Chemical/Petrochemical Plants
   Refining & Gas production
   Emission Monitoring
   Steam & Water quality monitoring

EVM PART # LMP91200EVAL

1ku pricing=$4.50
LMP91200 Application Diagram

**pH sensing**

- **Precision resistor for high accuracy temp. calibration**
- **Guard pins to prevent leakage currents**
- **CM o/p for differential o/p measurement**
- **Diagnostic features to detect sensor and check sensor connection**
- **Adjustable VCM: Vref/8, 2Vref/8 to 7Vref/8**
- **Excitation currents for RTD: 100uA to 1mA**
- **Through SPI, one can switch b/w pH measurement mode and temp. measurement mode**

- **High impedance CM o/p if needed**
Bipolar Signal Conditioning and Acquisition
OPA188 / OPA2188 / OPA4188
0.03µV/°C, 25µV Vos, 36V Zerø-Drift™ Operational Amplifier

Features

• Very Low Offset and Drift
  • Offset Voltage: 25µV (max)
  • Offset Voltage Drift: 0.085µV/°C max
  • CMRR, PSRR, Aol = 130dB (min)
• Noise Voltage: 8.8nV/√Hz at 1kHz
  • GBW : 2MHz
• Low Quiescent Current: 475µA (max)
• Low Bias Current: 160pA (typ)

• Supply Range: +4.0V to +36V or ±2V to ±18V
  • Rail to Rail Output
  • EMI/RFI Filtered Inputs

Benefits

• Improved high accuracy and stability over the previous generation OPA277
  • Offset drift 75% lower than the nearest competitor
• Allows for high sensitivity, high resolution systems across a wide frequency range
• Well suited for battery powered operation
• Minimizes errors on the output due to current noise
• Flexibility in design, enabling low power 5V supply systems
  • Improved Noise Immunity

Applications

• Electronic Weigh Scales
• Bridge Amplifier
• Strain Gauge
• Automated Test Equipment
• Transducer amplifier
• Medical Instrumentation
• Resistor Thermal Detector

Packaging options:
Single: SO-8, MSOP-8, SOT-23
Dual: SO-8, MSOP-8
Quad: SO-14, TSSOP-14

OPA188
1ku: $0.80
RTM 1Q’12

OPA2188
1ku: $1.40
RTM 8/2011

OPA4188
1ku: $2.45
RTM 4Q’11
## HV Low BW Amplifier – Competitive Analysis

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Vmin</td>
<td>2.7V</td>
<td>4V</td>
<td>4V</td>
<td>5V</td>
<td>5V</td>
<td>8V</td>
<td>6V</td>
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<tr>
<td>Vmax</td>
<td>36V</td>
<td>36V</td>
<td>36V</td>
<td>30V</td>
<td>36V</td>
<td>36V</td>
<td>36V</td>
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<tr>
<td>Iq / channel (max)</td>
<td>595uA</td>
<td>475uA</td>
<td>825uA</td>
<td>TBD</td>
<td>600uA</td>
<td>1.3mA</td>
<td>5mA</td>
</tr>
<tr>
<td>Vos (max)</td>
<td>1.8mV</td>
<td>25uV</td>
<td>25uV</td>
<td>10uV</td>
<td>60uV</td>
<td>130uV</td>
<td>150uV</td>
</tr>
<tr>
<td>Offset Drift (typ)</td>
<td>0.3uV/C</td>
<td>0.03uV/C</td>
<td>0.1uV/C</td>
<td>0.04uV/C</td>
<td>0.2uV/C</td>
<td>0.5uV/C</td>
<td>0.5uV/C</td>
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<tr>
<td>Ib (max)</td>
<td>15pA</td>
<td>850pA</td>
<td>1000pA</td>
<td>TBD</td>
<td>2000pA</td>
<td>1nA</td>
<td>7nA</td>
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<tr>
<td>GBW (typ)</td>
<td>3MHz</td>
<td>2MHz</td>
<td>1MHz</td>
<td>TBD</td>
<td>1.3MHz</td>
<td>600kHz</td>
<td>600kHz</td>
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<tr>
<td>Slew Rate (typ)</td>
<td>1.5V/us</td>
<td>0.8V/us</td>
<td>0.8V/us</td>
<td>2</td>
<td>0.7V/us</td>
<td>0.2V/us</td>
<td>0.3V/us</td>
</tr>
<tr>
<td>CMRR (min)</td>
<td>104dB</td>
<td>130dB</td>
<td>130dB</td>
<td>120dB</td>
<td>120dB</td>
<td>120dB</td>
<td>100dB</td>
</tr>
<tr>
<td>Vn @ 1kHz</td>
<td>14nV/√Hz</td>
<td>8.8nV/√Hz</td>
<td>8nV/√Hz</td>
<td>60nV/√Hz</td>
<td>7.9nV/√Hz</td>
<td>10nV/√Hz</td>
<td>9.8nV/√Hz</td>
</tr>
<tr>
<td>Rail to Rail</td>
<td>Out</td>
<td>Out</td>
<td>NA</td>
<td>Out</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Package (Single)</td>
<td>8MSOP</td>
<td>8VSSOP</td>
<td>8MSOP</td>
<td>8SOIC</td>
<td>8MSOP</td>
<td>5SOT23</td>
<td>8SOIC, 8PDIP</td>
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<tr>
<td></td>
<td>8SOIC</td>
<td>5SOIC</td>
<td>8SOIC</td>
<td>8DFN</td>
<td>8SOIC</td>
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<tr>
<td>Price @1ku</td>
<td>$0.6</td>
<td>$1.40</td>
<td>$1.65</td>
<td>TBD</td>
<td>$1.5</td>
<td>$0.76</td>
<td>$0.4</td>
</tr>
</tbody>
</table>
Newer Op-amps have built-in EMI filtering

Simplified CMOS Op-amp

Built-in input EMI Filter

Filter response
OPA209, OPA2209, & OPA4209
Low Noise, Low Ib Op Amp with RRO in SOT23

**Features**
- Low Noise : 2.2nV/√Hz max
- 130nVpp Noise, 0.1Hz – 10Hz
- Low Ib: 12nA max
- Low Supply Current: 2.3mA/Amp max
- Low Offset Voltage: 100µV max
- Gain Bandwidth Product: 18MHz
- Slew Rate: 6V/µs
- Wide Supply Range ±2.25 to ±18V, 4.5 to 36V
- Rail-to-Rail Output
- Single - SOT23-5, MSOP-8, SO-8
- Dual – MSOP-8, SO-8
- Quad – TSSOP-14, QFN-16

**Applications**
- PLL Loop Filter
- Low Noise, Low Power Signal Processing
- High Performance ADC Driver
- High Performance DAC Output Amplifier.
- Active Filters
- Low Noise Instrumentation Amplifiers

**Benefits**
- Improved Dynamic Range
- Lower Power Dissipation
- Space Savings
OPA171, OPA2171, OPA4171
36 Volt SOT-563 Amplifier

Features
- Offset Voltage: 2mV (max)
- Offset Voltage Drift: 3µV/°C
- Noise Voltage: 15nV/√Hz
- Input Range Includes the Negative Supply
- Input Range Operates to the Positive Supply
- RFI Filtered Inputs
- Slew Rate: 1.5V/µs
- GBW: 3 MHz
- High Common-Mode Rejection: 90dB
- Low Bias Current: 10pA (max)
- Supply Range: +2.7V to +36V, ±1.35V to ±18V
- Low Quiescent Current: 500µA (max)
- Single, Dual. Quad Versions
- MicroPackages: Single in SOT-563, Dual in VSSOP-8

Benefits
- Precision
- Stability
- Clean Signal Conditioning
- Single Supply Operation
- Wide Common Mode Range
- Improved Noise Immunity
- Fast Response
- Wide Signal sources
- High Stability
- Low Errors
- Versatility
- Battery Operation
- Multi Channel Options
- Smallest Board Footprint

Applications
- Transducer Amplifier
- Bridge Amplifier
- Temperature Measurements
- Strain Gauge Amplifier
- Precision Integrator
- Battery Powered Instruments
- Test Equipment

Small Size

<table>
<thead>
<tr>
<th>SOT23-5</th>
<th>SC70-5</th>
<th>SOT-563</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 x 3 x 1.45</td>
<td>2 x 2 x 1.1</td>
<td>1.6 x 1.6 x 0.6</td>
</tr>
</tbody>
</table>

65%
INA826
Low Power RRIO Precision Instrumentation Amp

**Features**

- Wide Common Mode Input Range
  - Input voltage swing $V_-$ to $V_+(-1V)$
  - $+/ -50V$ Input Protection
- Precision Input:
  - Low Offset Voltage: $40uV$
  - EMI Hardened
  - CMRR ($G = 1$): $84$ dB min
  - Input noise: $18$ nV/$\sqrt{Hz}$
- Low Power and Wide Supply:
  - Max supply current: $250 \mu A$
  - Supply: $+2.7$ to $+36V$, $\pm 1.35V$ to $\pm 18V$
  - Rail-to-Rail Output
- Standard and Micro Packages
  - MSOP-8, SOIC-8, & SON-8 (3x3)

**Applications**

- Industrial process controls
- Circuit Breakers
- Current Measurement
- Medical instrumentation
- Portable data acquisition

**Benefits**

- Maximum input signal range with a single device for both single or bipolar supply industrial applications
- Achieve precision measurement with high EMI robustness.
- High performance on Low or High Vs
- DFN saves 30% of Space vs MSOP-8

**Diagram**

IN826 precision instrumentation amplifier schematic diagram.
Multi-channel Signal Conditioning and Acquisition
Multi-Channel signal acquisition

>75% Lower Cost
>75% Less PWB Space
>75% Lower Power
>75% Less Components
**Features**

- Internal High-performance PGA (G=1,2,4,8)
  - Bit Effective resolution up to 14-bits
  - Gain/Channel mapping function. Specific gains can be set for each channel selected for conversion
- Onboard 8X1 FIFO
- Eight single ended/four differential channel MUX onboard
- \( I_q \) (typ)=800\,\mu A
- Deep Power-Down Mode
- Excellent DC performance:
  - INL : +/-1.5\,\text{lsb}; DNL : +/-1.0\,\text{lsb}
- Up to 100kHz throughput rate
- \( V_{dd} \) = 2.2 to 5V
- \( I_q \) (typ)=800\,\mu A
- 24 pin, 4X4 QFN

**Benefits**

- Internal PGA-14 bit resolution for 12-bit cost!
- Conversion results can be saved and read back later with the addition of an onboard FIFO!
- Power and Board Space Savings all in one!
- No competition at such low power with such integration

**Applications**

- Portable Communications
- Transducer Interface
- Portable Medical Instruments
- GPS based applications
- Sensor data acquisition systems
**Features**

- **Flexible, Cost-Saving, Design**
  - SW selectable input ranges selection
    - ± 10, ± 5, ± 2.5V, 0-5V, 0-10V
  - Wide Digital Supply 1.65 to 5.25V

- **Integration and Precision**
  - Internal reference and temperature sensor
  - Two programmable alarm thresholds / channel
  - Alarm / temp threshold output

- **Small Footprint Product Family**
  - Pin compatible with ADS7951
  - SPI Serial Interface
  - 4x4 QFN
  - -40 to 125 Specified Temperature Range

**Applications**

- Industrial Process Controls (PLC)
- High-Speed Data Acquisition Systems
- High-Speed Closed-Loop Applications
  - Digital Power Supply

**Benefits**

- Single chip solution for wide range of inputs; and direct interface with low voltage processors without the need for level shifting

- Integration reduces system cost and complexity; while threshold detection reduces the number of accesses required by host processor in monitoring applications

- Enables designers to change resolution without redesigning their board or control software

---

**ADS8638**

12-Bit, 1MSPS, 8-Ch, True Bipolar, μ-power, serial, SAR ADC

- **Features**
  - **Flexible, Cost-Saving, Design**
    - SW selectable input ranges selection
      - ± 10, ± 5, ± 2.5V, 0-5V, 0-10V
    - Wide Digital Supply 1.65 to 5.25V
  - **Integration and Precision**
    - Internal reference and temperature sensor
    - Two programmable alarm thresholds / channel
    - Alarm / temp threshold output
  - **Small Footprint Product Family**
    - Pin compatible with ADS7951
    - SPI Serial Interface
    - 4x4 QFN
    - -40 to 125 Specified Temperature Range

- **Applications**
  - Industrial Process Controls (PLC)
  - High-Speed Data Acquisition Systems
  - High-Speed Closed-Loop Applications
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---

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- Integration reduces system cost and complexity; while threshold detection reduces the number of accesses required by host processor in monitoring applications

- Enables designers to change resolution without redesigning their board or control software

---

**EVM Available**
**Features**

- Low power, flexible supply range
  - 2.7V~5.5V Analog Supply
  - Only 6.75mW (250KHz, +VA=2.7V, VBD=1.8V)
  - Only 10mW (500KHz, +VA=2.7V, VBD=1.8V)
- Up to 500KHz Sampling Rate
- Excellent DC Performance
  - ±1.2LSB TYP, ±2LSB MAX INL
  - ±1LSB TYP, -1.5/±2LSB MAX DNL
  - 16 Bit NMC Over Temperature
  - ±0.5mV Offset Error @ 2.7V
  - ±1mV Offset Error @ 5V
- Excellent AC Performance @fi=10KHz
  - 91dB SNR
  - 100dB SFDR
  - -96dB THD
- Flexible analog input arrangement
  - Unipolar Input Range 0 ~ Vref
  - Onchip 4/8 channel MUX with breakout
  - Auto/Manual channel select & trigger
- Other built hardware features
  - Onchip Conversion clock (CCLK)
  - Hardware/Software Reset
  - Onchip temperature sensor
  - Programmable Status/polarity EOC/INT-
- Multi-Chip ready and fully automated
  - Daisy Chain Mode
  - Programmable Tag Bit Output
  - Global CONVST- (Independent of CS-)
- Friendly I/O
  - SPI/DSP Compatible Serial interface
  - Separate I/O Supply 1.65V~1.5*(+VA)
  - SCLK up to 50MHz
- Comprehensive Powerdown Modes:
  - DEEP Power-down
  - NAP Power-down
  - AUTONAP Power-down
- 24 Pin 4X4 QFN & TSSOP Packages

**Benefits**

- Low Power
- Automatic
- Small Size, 4X4 QFN package
- High Speed SPI Serial Interfaces
- Compatible Upgrade/Downgrade paths
- 16 SCLK cycle (comparing to ADS8344)
- Scan Range Select
- Daisy Chain
- Programmable Status Output

**Applications**

- GPS Sensor Conditioning
- Portable Data Logging with multiple Inputs
- Battery Powered Equipment (i.e., PDA, PCA, Cellular)
- Isolated Data Acquisition
- Transducer Interface
ADS8556
16-Bit, 630/450kSPS, 6ch Simultaneous Sampling SAR w/ Bipolar Inputs

**Features**

- **Best In Class AC/DC Performance**
  - 16-Bit, 3 LSB MAX INL
  - 91.5db SNR (typ)

- True bipolar inputs with software selectable input ranges up to ±12V and Selectable parallel or serial interface

- Pin Compatible 14-/12-Bit Versions

- LQFP-64 Package pin compatible with AD7656
  - Only 122mW @ 250kSPS

- Excellent performance and external conversion clock for synchronization of multiple devices enables flexible and expandable systems

- Allows easy connectivity to a wide range of inputs, sensors, and host processors

- Allows for an easy upgrade / downgrade path for future designs

- Improved second source to ADI device with >2x faster sampling rate and 3.5db better SNR

**Applications**

- Power quality and automation
- Protection relays
- Closed loop servo control
- Robotics

**Diagram**

[Diagram of ADS8556]
ADS8568
16-Bit, 500/400kSPS, 8-ch Simultaneous Sampling SAR w/ Bipolar Inputs

**Features**

- 8 True bipolar inputs support up to ±12V
- Small, Integrated Industrial Solution
  - 2.5V programmable reference
  - Fully specified from -40 to 125°C
  - QFN-64 & TQFP-64 Packages
  - Supports internal and external conversion clock
  - Supports parallel and serial data interface
- Pin Compatible 14-/12-Bit Versions
  - 600/450kSPS @ 14-bits
  - 650/480kSPS @ 12-bits
- Enables 20% wider voltage input range than competing devices resulting in easy connectivity to a wide range of inputs and sensors
- External conversion clock for synchronization of multiple devices enables flexible and expandable systems at up to 500kSPS for parallel and 400kSPS serial interfaces
- Easy upgrade / downgrade path for all designs

**Applications**

- Power Automation:
  - Protection Relays
  - Power performance measuring and monitoring devices (PMD)
- Multiphase Motor Control
- Multi-axis positioning systems
- Industrial automation and Data Acquisition
Industrial Signal Transmission
Industrial Signal Transmission Approach

**Option 1**

- Noise
- Circuit diagram with symbols indicating current flow and resistance.
- Notes: 4mA = 0% level, >20mA can flag fault conditions.

**Option 2**

- Noise
- Circuit diagram with symbols indicating current flow and resistance.
- Notes: 4mA = 0% level, >20mA can flag fault conditions.

**Option 3**

- Circuit diagram with symbols indicating current flow and resistance.
- Notes: 4mA = 0% level, 20mA = 100% output, <4mA can flag fault conditions.

Footnote: TEXAS INSTRUMENTS
Why Use Current Transmitters?

• Immunity to noise (50/60Hz)
  – Industrial locations can make voltage transmission unusable
  – Unknown noise sources in between transmitter and receiver

• Long distance transmission
  – Distance determined by supply and loads present on communication line
  – Transmission distance can reach several miles based on application conditions
4-20mA Overview

- 4mA represents 0% input level
  - Allows up to 4mA to power external input circuitry
  - 4mA zero level allows underscale settings and fault detection

- 20mA represents 100% input level
  - Provides sufficient current to power electromechanical devices
  - Overscale can also be used to detect fault conditions
Transmitter Type Diagrams

Two-Wire Transmitter

Three-Wire Transmitter
2-Wire vs. 3-Wire Transmitter

• 2-Wire Transmitter (Receiver powered)
  – Referred to as Loop Powered
  – Transmitter and sensor remotely located
  – Local power supply not practical
  – Input circuitry floats with respect to loop supply ground

• 3-Wire Transmitter (Transmitter powered)
  – Referred to as Locally Powered
  – Transmitter located close to power supply
  – Input is referenced to power supply ground
  – Also referred to as voltage to current converters
Implementation Of Current Transmitters

- **2-Wire Transmitter**
  - Submersible temperature sensor
  - Remote location prevents local power supply
  - Sends data back to control station

- **3-Wire Transmitter**
  - Sends control signal to element at remote location
  - Local power supply is available
XTR117 Typical Input Scaling (2 Wires)

- 4-20mA span is 16mA
- XTR117 has current gain of 100
- Input span is 160uA
- Offset needed if input signal reaches zero

\[ I_O = 100 \times I_{IN} \]
XTR117 Typical Input Interface
XTR111 Typical Input Interface (3 Wire)
DAC161P997
16bit DAC with Single Wire Interface and “4-20mA” current loop drive

Features

- 16 bit DAC
- Low Power
- Single Wire Interface (SWI), with handshake
- Programmable start up condition
- Self adjusts over wide baud rate range
- Error detection and reporting
- Programmable output Error Level
- Auxiliary HART input
- Internal Reference

Benefits

- Fully Integrated Solution with well defined specification
  - Easy reuse of design & reduces logistics cost
  - No additional high accuracy components needed
- Satisfies system needs of total power consumption < 30mW
- SWIF interface – saves upto 3 digital isolators
- SWIF interface – low noise
- Defined Start-Up Condition 3.375mA or 21.75mA & pin programmable
- Flexible update-rate/power-consumption trade-off
- Automatic detection of error conditions

Applications

- 4to20mA loop transmitter platforms
  - 2-wire sensor systems
    - Process Control
    - Factory automation
    - Building automation

1ku pricing = $4.00
## Competitive Information

<table>
<thead>
<tr>
<th>Solution</th>
<th>AD421</th>
<th>TI - DAC161P997</th>
<th>Customer Importance</th>
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<tbody>
<tr>
<td>Single Wire Interface</td>
<td>NO</td>
<td>Yes</td>
<td>Saves 2 or 3 digital isolators</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>NO</td>
<td>Yes</td>
<td>Enhances system reliability</td>
</tr>
<tr>
<td>Start Up Condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Better</td>
</tr>
<tr>
<td>Total TC</td>
<td>Typ Numbers Only</td>
<td>29ppm/°C max</td>
<td>Achieves higher system accuracy with user calibration of offset &amp; gain</td>
</tr>
<tr>
<td>HART Interface</td>
<td>No</td>
<td>Yes</td>
<td>HART input to chip eliminates need of external mixing</td>
</tr>
<tr>
<td>Total Size</td>
<td>60mm²</td>
<td>30mm²</td>
<td>Reduces system size</td>
</tr>
<tr>
<td>Internal Sense Resistor</td>
<td>Only larger TC</td>
<td>Yes</td>
<td>Reduces system size &amp; cost</td>
</tr>
<tr>
<td>Comp Adv</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meets need</td>
<td>Doesn't meet</td>
<td>Don't care</td>
</tr>
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</table>
Perfect complimentary addition to the TI's Analog family 4-20mA Conditioning

<table>
<thead>
<tr>
<th>Receiver</th>
<th>3-Wire</th>
<th>2-Wire</th>
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<tbody>
<tr>
<td>RCV420</td>
<td>XTR110</td>
<td>XTR116</td>
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<tr>
<td>Precision Loop Rev: 0 to 5V</td>
<td>13.5V to 40V Selectable Ranges</td>
<td>7.5V to 35V 4.096V Ref.</td>
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<tr>
<td></td>
<td>XTR111</td>
<td>XTR115</td>
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<tr>
<td></td>
<td>8V to 40V Configurable Ranges</td>
<td>7.5V to 35V 2.5V Ref.</td>
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<tr>
<td></td>
<td>XTR300</td>
<td>XTR117</td>
</tr>
<tr>
<td></td>
<td>10V to 40V</td>
<td>7.5V to 40V</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

DAC161P997
Ref + Sense Resistor

XTR101
11.1V to 40V
Two 1mA I-Src.

XTR114
7.5V to 38V
Two 1000uA I-Src.

XTR105
7.5V to 30V
Two 800uA I-Scr.

XTR108
7.5V to 24V
Two 600uA I-Scr. Frg. Signal Condition.

XTR106
7.5V to 36V
Bridge Linearization.

National – New!  Existing  New  Preview

Diagnostics
- No Voltage Regulator
- Voltage Regulator
- Excitation & Linearization

16-bit ΣΔDAC
- Single-Wire Interface
  Easy Isolation Interface
DAC8411 Family
8 to 16-Bit, SC-70 package, Ultra-low glitch, low power DAC

**Features**
- Tiny SC-70 package
- Wide supply range: 1.8V – 5.5V
- Ultra Low Power: 80µA
- Pin compatible from 8 to 16 bits
- 0.15nV-sec output glitch energy
- Settling Time: 6 µs (typ)
- Temp Range -40° C to +125° C

**Benefits**
- Small size and low power operation ideal for battery-operated portable applications
- Provides design and cost flexibility
- Low cost application can now have high accuracy and best in class glitch performance
- Guaranteed performance over extended Industrial Temp Range

<table>
<thead>
<tr>
<th>Model</th>
<th>Resolution</th>
<th>INL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAC5311</td>
<td>8 Bit</td>
<td>±0.25 LSB</td>
</tr>
<tr>
<td>DAC6311</td>
<td>10 Bit</td>
<td>±0.5 LSB</td>
</tr>
<tr>
<td>DAC7311</td>
<td>12 bit</td>
<td>±1 LSB</td>
</tr>
<tr>
<td>DAC8311</td>
<td>14 Bit</td>
<td>±4 LSB</td>
</tr>
<tr>
<td>DAC8411</td>
<td>16 Bit</td>
<td>±8 LSB</td>
</tr>
</tbody>
</table>
**Features**

- Integrated 2.5V Internal Reference
- Temp Drift 2 ppm/°C (typ); 5 ppm/°C (max)
- Initial accuracy of 0.004% (typ) 0.02% (max)
- DNL: ±0.5 LSB (typ); INL: ±4 LSB (typ)

- Low Glitch: 0.15nV-Sec

- Temp Range -40° C to +105° C
- Compatible with DAC8534 and DAC8554/55
- DAC8564 - Binary input and POR to zero
- DAC8565 - Binary or 2’s complement input and Programmable POR with reset to zero or mid-scale

**Benefits**

- Lower Component Count
- Improved System Accuracy with Reduced Calibration Requirements
- More Efficient Closed-Loop Control
- Reduction of Undesired Transients and Noise leads to Lower THD when Generating Waveforms
- Performs in Extreme Environment
- Standard footprint for flexible design options

**Applications**

- Portable Instrumentation
- Industrial Process Control
- Machine and Motion control
- Waveform Generation
Thanks!