TI Signal Chain Products for Medical Applications

Rudye McGlothlin
Product Marketing, Precision Analog
Texas Instruments
What is the Purpose of Precision Analog in Medical Applications?

- Provide Gain
- Level Shifting
- Buffering
- Filtering
- Impedance Matching
- Additional Signal Conditioning
- Sensor Muxing
- Conversion to Digital
- Conversion to Analog
- Sensor Bias
- System Calibrations

To connect biological sensors to a processor!
Precision Analog Requires Great Processes

**High-Performance Analog CMOS (HPAxx):**
- Low Transistor Noise
- High Quality Passives (TFR)
- 3V / 5V CMOS
- Linear Cap
- Low Parasitics

**High-Performance BiCMOS (BiCom):**
- Complementary Vertical Bipolar
- PolySi Emitter ~Equal & High Ft
- CMOS
- Low Parasitics, Good Passives (TFR)
- SOI & SiGe

**Analog CMOS (Axx):**
- Logic & Analog CMOS
- Low Vt CMOS
- Density
- Passives
- DECMOS 20-30V

**Power BiCMOS (LBC):**
- Bipolar and Dual Gate CMOS
- LDMOS & Thick Cu Enablers
- Multi-Voltage Capability
- 20V, 60V, and 100V* Branches
- Voltage-Scaled DECMOS

---

Power and Feature Richness

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Texas Instruments
Slides for process technologies removed.

Please see your Arrow sales representative for information about TI’s process technologies.
Great Processes Lead to Innovative Architectures!
e-Trim Technology

What is e-Trim?

- Digitally trim offset after packaging device
  - Ultra low drift and offset voltage
  - Excellent output swing to rail
  - Offers new level of CMOS amplifier performance

Before e-Trim, offset shift after packaging made ultra-low offset difficult...

Offset shift due to packaging stress

e-Trim Solves This Problem!
What Parameters are Trimmed?

Trimmed Parameters
- Tail Current
- Offset
- Offset Drift over Temperature

Why is low Drift Important?
- Static Offset often Calibrated
- Temperature Drift often not Calibrated
Conventional Chopper Op Amp

Figure 1. Low-speed zero-offset path (10,000x gain of high-speed path)
New Synchronous Notch Filter Technology – Zero-Drift!

Figure 1. Switched-capacitor notch filter with synchronous integration included

Synchronous clocking assures that notches align with harmonics

Synchronous Filter Response

Log Frequency
Rail-to-Rail Input Comparison

Standard Two-Stage Input

Zero-Crossover Input Stage

OFFSET VOLTAGE vs COMMON-MODE VOLTAGE

OFFSET VOLTAGE vs COMMON-MODE VOLTAGE
FFT of Typical 2-Stage Input Topology
Harmonic Distortion

Frequency Spectrum (16384 Point FFT)
Fs = 262.1440 kHz  Fin = 10.448000 kHz

Typical Two Stage Input
Introduces harmonics caused by cross-over region

SNR = 89.817  SINAD = 86.838  SFDR = 95.384  THD (9) = -89.879  ARL = 84.288
OPA365 Zero Crossover Input Harmonic Distortion

Frequency Spectrum (16384 Point FFT)
Fs = 262.1440 kHz  Fin = 10.448000 kHz

-160 -140 -120 -100 -80 -60 -40 -20 0 20 dB

Zero-Crossover Single Stage input does not introduce additional harmonics

SNR = 90.143  SINAD = 89.905  SFDR = 103.068  THD (9) = -102.634  ARL = 84.288
Competitive Comparison OPA365

Gain +1, Supply 5V, Signal 10kHz
Measurement bandwidth 20Hz-30kHz

THD + Noise Ratio [dB]

OPA365
MAX4475
MAX410
LT1800
LMH6645
LMH6645
AD8651

Voltage [Vpp]

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Glitch Improvement

• **Main Cause of Glitch**
  – Charge in the Switch Causes Node Voltage to Change Temporarily
  – More Number of Switches Toggling when Code Changes – More Glitch!!

• **Competitor’s Process Products**
  Use Row-Column Decoding– 30~40 Switches Can Toggle at Any Code Change

• **HPA07 Products Use Single Decoder**
  – Maximum of Two Switches Toggling at Any Time

• **Results in typ 1/10 the Glitch of Competitive Parts**

![Diagram of a circuit with labels V\text{IN}, V\text{OUT}, R\text{fb}, R\text{t}, V\text{N}, a, V\text{JT}, fb, R, and Charge Q gets split.](image)
Glitch Improvement

DAC8532

Code-to-code Glitch: (32768-32767-32768)

DAC8552

V_D = 5V
V_REF = 4.096V
From Code: 8000
To Code: 7FFF
Glitch: 0.16nV-s
Measured Worst Case

Time (400ns/div)
Medical Applications

Consumer Medical Devices
– Digital thermometers
– Blood glucose monitor
– Blood pressure monitor
– Insulin Pumps
– Heart rate monitors
– Audiology (digital hearing aids)
– Other home, portable & consumer devices

Diagnostic, Patient Monitoring & Therapy
– Electrocardiogram (ECG)
– Electroencephalogram (EEG)
– Blood oxygen (pulse oximeter)
– Blood pressure
– Temperature
– Ventilation / respiration
– Defibrillators
– Other diagnostic, monitoring & therapeutic equipment

Medical Instruments
– Laboratory equipment
– Dialysis machine
– Analytical instruments
– Surgical instruments
– Dental instruments
– Other medical instruments

Medical Imaging
– Ultrasound
– Computed tomography
– Magnetic resonance imaging
– X-Ray
– Other imaging (nuclear, positron emission tomography)
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Thermopile Amplifier

Thermopile:
Multiple thermocouples in series

Radiant Energy

Cold junction measurement (thermistor)

R1 20k
R2 1k

OPA333

Ear Thermometer

• Low Power
• 1.8V Operation
• SC70 Pkg
OPA333, OPA2333
Very Low Power Zero-Drift Operational Amplifier

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

Benefits
- Lowest Power Increases Battery Life
- Low Offset and Drift Removes Need for Calibration
- RRIO Increases Dynamic Range
- 1.8V Supply Excellent for Battery Devices
- Micro SC70 Package Saves Board Space

Applications
- Battery-Powered Instruments
- Temperature Measurement
- Precision Strain Gages
- Precision Sensor Applications
- Medical Instrumentation
- Handheld Test Equipment
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What is Pulse Oximetry?

- Pulse Oximetry measures blood oxygenation by sensing the infrared and red light absorption properties of deoxygenated and oxygenated hemoglobin.
  - Deoxygenated hemoglobin allows more infrared light to pass through and absorbs more red light
  - Highly oxygenated hemoglobin allows more red light to pass through and absorbs more infrared light
- The oximeter senses and calculates an amount of light at those wavelengths proportional to the oxygen saturation (or desaturation) of the hemoglobin.
- The designer needs a true “light-to-voltage” conversion, a photodiode.
  - Amplifiers suitable for pulse oximetry applications are the classical resistor-feedback transimpedance amplifier; or
  - the capacitor-feedback switched integrator

\[
R = \frac{I_{940\text{nm}}}{I_{660\text{nm}}}
\]

\[
S_{\text{aO}_2} = \frac{[O_2-Hb]}{[O_2-Hb] + [Hb]}
\]
Pulse Oximetry – Transimpedance Amp

Amp Requirements
- Low input bias current
- Low input capacitance relative to photodiode capacitance
- High gain bandwidth product
- Low voltage noise
- Low offset drift over temperature

12-bit ADC

x2: Red Light and IR

OPA376
OPA827
OPA380
OPA376

Low Offset & Noise For Single Supply Applications

**Features**

- Low Bias Current: **10pA** (max)
- Low Offset Voltage: **25µV** (max)
- Low Noise: **7.5nV/√Hz** at 1kHz
- 0.1Hz to 10Hz Noise: **0.8µVPP**
- Quiescent Current: **950µA** (max)
- Wide Bandwidth: **5.5MHz**
- Supply Voltage: 2.2V to 5.5V
- Space Saving Packages:
  - SC70, SOT23, MSOP
- Multi Channel Availability:
  - OPA376 (single)
  - OPA2376 (dual)
  - OPA4376 (quad)

**Applications**

- Single Supply Data Acquisition Systems
- Sensors and Signal Conditioning
- Transimpedance Amplifier
- Medical Instrumentation
- Handheld Test Equipment

**Benefits**

- eTrim combines excellent AC AND DC specifications on <1mA current consumption!
- Low frequency noise (**4x lower than nearest competition**) benefits dc precision measurement and sensor applications
- Wide bandwidth and low noise density benefit single supply data acquisition systems

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OPA827
Lowest Noise, JFET, 36V Op Amp

Features
• Low Noise Voltage: 4nV/√Hz at 1kHz
• Low Offset Voltage: 150µV max
• JFET Input: IB = 15pA typ
• Low Quiescent Current: 4.8mA typ
• Wide Supply Range: ±4V to ±18V
• Low Distortion: -128dB THD+N
• Wide Bandwidth: 22MHz
• Packaging: MSOP-8, SO-8

Benefits
• Improves Signal to Noise Ratio
• Accurate Signal Reproduction
• Supports High Impedance Sources
• Provides System Power Savings
• Meets Standard Supply Voltages ±5V, ±12V, ±15V
• Excellent AC Reproduction
• Provides for a Wide Range of Signal Sources
• MSOP Offers Smallest Package Size/Performance
• Sets a New Price Point at this Performance Node

Applications
• Data Acquisition
• Instrumentation
• Automated Test Equipment
• High-End Audio
• Imaging
• And many more

Released!
1ku: $5.75

0.1Hz to 10Hz NOISE

Low Errors and Noise with High-Z Sources or fast Input Transients

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Pulse Oximetry – Additional Integration

OPA380
High-Speed Precision Transimpedance Amplifier

• Wide Bandwidth: 90MHz
• Bias Current: 50pA (Max)
• Offset Voltage: 25µV (Max)
• Drift: 0.1µV/°C
• Excellent Long-term Vos Stability
• Output Swings to 0V
• Overload Recovery Circuit
• Supply Range: 2.7V To 5.5V
• Microsize Package: MSOP-8
• Available in Dual
Pulse Oximetry – Switched Cap Integrator

**IVC102**
Precision Switched Integrator
Transimpedance Amplifier

- On-Chip Integrating Capacitors
- Gain Programmed by Timing
- Bias Current: 750fA max
- Low Noise
- Low Switch Charge Injection
- Fast Pulse Integration
- Low Nonlinearity: 0.005% typ

![Diagram of IVC102 Precision Switched Integrator Transimpedance Amplifier](image)
Pulse Oximetry – Ultimate Integration

**DDC112**
Dual Current Input 20-Bit Analog-To-Digital Converter

- Directly measures currents from fAs to μAs
- Excellent linearity
  - ±1ppm FSR
  - ±0.025% of reading
- Dual Switched Integrator
  - No charge is lost during measurement period
  - Allows for offset correction before each integration
- Very low noise: 4ppm of FSR
- High data rate: up to 3.125kSPS
- Adjustable full-scale range
  - 50pC to 1000pC
Medical Applications

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What is Bispectral Index? (BIS)

- A Bispectral index (BIS) monitor is a neurophysiological monitoring device which continually analyses a patient's electroencephalograms during general anaesthesia to assess the level of consciousness during anaesthesia.

- BIS measures micro-volts of AC signal in the presence of hundreds of millivolts of DC signals, making the primary concern of the BIS designer input referred noise.
  - **For the Amplifier:** An instrumentation amplifier is key for the analog front end of a BIS system. It determines the input-referred noise and input CMRR which must be a minimum of 80 dB.
  - **For the ADC:** CMRR is as important for the ADC as it is for the amplifier and multiplexer. In EEG applications a typical CMRR of 85dB or higher is required to maintain signal integrity. Low input noise as well as high resolution allow for accurate signal readings which are critical in monitoring a patient under anesthesia.
TI Solution:
Bispectral Analog to Digital Front End

8 EEG Sensors

Human Body

Analog Front End

ADS1258
INA129
INA333
INA822

Micro-controller
MSP430x
/2xx

ISO72xx

DSP
C67xx
0r
C55xx

Analog Input Supply

TPS62200
TPS3809
TPS780xx

Interface to host

Wireless device
CC25xx

TPS780xx

ADS1258

Referenced to
REF3325

Interface to host

ADS1258

Interface to host

Interface to host

Interface to host
ADS1258

Fastest Settling / Lowest Latency 24-bit ADC

Features

• Best in class latency - 42μs per channel
  • Measures all 16 inputs in < 675μs!
• Programmable filter/data rate:
  • 125kSPS with 20 effective bits (fixed ch.)
  • 24kSPS per/ch with 19.3 effective bits
  • 1.8kSPS per/ch with 21.6 effective bits
• Flexible input multiplexer - 16 SE / 8 Diff
  • Auto scan mode (low software overhead)
• Outstanding performance
  • 0.02 μV/°C offset drift & 0.4ppm/°C gain drift
  • 0.0003% INL & 2.8μV_RMS noise @ 1.8kSPS
• Unipolar (5V) or bipolar (+/-2.5V)
• Low power dissipation (42mW)

Benefits

• Industry-Leading In Low Latency, Speed, and Noise Performance
• Reduces System Cost and Complexity
  • Post Mux Access for Shared Signal Conditioning
  • Onboard Oscillator and Internal Monitoring

Applications

• Multi-channel data acquisition
• Medical monitoring / ECG
• Industrial process control

7mm x 7mm QFN packaging (-40°C to +105°C temp Range)

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REF33xx
Lowest Power Series Voltage Reference in SC70

**Features**
- SC70 package
- Extremely low power consumption: $I_Q = 3.9 \mu A$
- Voltages: 1.25V, 1.8V, 2.048V, 2.5V, 3.0V, 3.3V
- High Initial Accuracy: 0.15% (max)
- Super low dropout (25mV @ 25°C & 1mA $I_{OUT}$)
- Robust Output Current Drive: ±5 mA
- ±30 ppm/°C Temp Drift (max)
- Extended industrial temp range: -40°C to 125°C

**Benefits**
- SC70 package saves board space
- Low $I_Q$ increases battery life
- Low dropout allows wide supply range
- Output drive capability allows spot power management

**Applications**
- Handheld applications
- Data acquisition systems
- Battery-operated, portable consumer products
- Low-power precision voltage regulation

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**INA333**

Zero Drift, Low Power, Single Supply Instrumentation Amp

**Features**

- Low offset and drift: **25µV (max)** with **50nV/C**
- **75µA** max Supply Current
- Wide Supply Range **+1.8V To +5.5V**
- Input Bias Current: **200pA** Max
- Input Voltage Noise: 50nV/rt-Hz, 1kHz
- CMRR **106db Min** at G=100

**Benefits**

- Creates excellent accuracy: Gain Error < 0.1%
- Ideal for maximum power efficiency
- Easy compatibility for battery powered apps
- Great for high impedance applications
- Low Noise 1.6µV p-p (0.1 to 10Hz)
- Enables highest accuracy possible
- Enhances noise immunity

**Applications**

- Medical Instrumentation
- Data Acquisition
- Bridge Amplifier
- Weigh Scales
- Thermocouple Amplifier
- RTD Sensor Amplifier

**MSOP-8, DFN-8 Package**

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What is Electrocardiogram?

- An electrocardiogram measures the electrical signals that drive the heart.
  - The heartbeat is initiated by a small electrical pulse of the Sinus Node (P-Wave).
  - This energy travels through conduction pathways and gets the ventricles to contract.
  - The QRS- complex is the actual contraction of the left and right ventricles.
- These electrical pulses are detected on the surface (skin) of the human body.
Signal Characteristics

1.5V

+/−300mV

Electrode offset

Common mode, 50/60Hz

0V

Input Referred noise specs

Portable / Monitoring ECG : 20uV pk-pk
Diagnostic ECG : 10uV pk-pk
Fetal ECG : 200nV pk-pk
Typical 3-Channel ECG System Solution
ADS8331/32
16-Bit, 500KSPS, Low Power, 4/8 Channel Precision ADCs

Features

• Precision SAR ADC Performance
  • 1 MSPS - 16-Bit Resolution
  • ±1.75 LSB MAX INL
  • ±1 LSB MAX DNL
• Excellent AC Performance at 100Khz
  • 92db SNR
  • 102db SFDR
  • -102db THD
• Simple To Use Interface
  • Global CONVST Independent of CS
  • Programmable Status EOC/INT
• 4x4mm QFN Package

Benefits

• Precision 16-Bit performance for multi-channel applications

• Allows for systems with an improved dynamic range

• Global synchronization of ADCs allows for coherent signal acquisition.
• Increases channel densities and reduces system footprint

Applications

• Portable Data Logging
• Battery Powered Equipment
• Isolated Data Acquisition
• Transducer Interface
Using Low Resolution ADC (SAR/pipeline) Vs High Resolution ADC (Delta-Sigma)

a) Using a low resolution ADC

- High Gain with low noise amplifiers
- Noise free Dynamic range

b) Using a high resolution ADC

- Low gain
- Noise free Dynamic range

Amplitude vs Signal Chain

ADC Noise

≈200

≈5
System Benefits of Using Delta-Sigma (24 bit) ADC Vs Low Resolution (16 bit) ADC

- Reduced hardware
- Filter of Electro Surgery interference
- Lower power
- Lower system cost
- Electrode offset info is retained

ADS1258

Del Sig.
Why Sequential Vs Simultaneous Sampling

• A single ADC in a tapped approach does not necessarily mean lower power because of the higher speed needed to do the muxing.

• If only a low power simultaneous Delta Sigma device solution existed...?
Slides for new ADS1x9x family removed.

Please see your Arrow sales representative for information about these exciting new products.
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Medical Functions
- Calibration
- Monitoring
- Compensation
4-Quadrant Multiplying DAC
High Voltage and Bipolar Output Capable

DAC8821 / DAC8804

DAC8820 / DAC8806

OPA211

REF5010

D0
D15
/WR
/RS
/LDAC
/RSTSEL

R1
R2
R_COM
R_OFS
R_FB

I_OUT

-V_{REF} to +V_{REF}

V_{OUT}

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TENAS INSTRUMENTS
**DAC8820**

16-Bit Single, Parallel Interface, Multiplying DAC

**Features**

- +/-1 LSB INL (max)
- Power Supply: +2.7V to +5.5V
- *microPOWER* operation: 5μA @ 5V
- Settling Time: 0.5μS
- Wide Reference: ±15V, 10MHz
- SSOP-28 package
- Provides the flexibility to configure output circuit to match customer requirements.

**Benefits**

- Industry-Standard Pin Configuration
- Highest Accuracy for demanding apps
- Supports both 3.3V and 5V applications
- Very low power consumption
- Supports High Speed Applications
- Supports HV Bipolar and AC Output

**Applications**

- Industrial Process Control
- Automatic Test Equipment
- Medical Instrumentation
- Digitally controlled calibration

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DAC8820 Register

<table>
<thead>
<tr>
<th>Parallel Bus</th>
<th>Input Register</th>
<th>DAC Register</th>
<th>Control Logic</th>
<th>DAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0</td>
<td>R1</td>
<td>R2</td>
<td>R1</td>
<td>RFB</td>
</tr>
<tr>
<td>D15</td>
<td>RCOM</td>
<td>REF</td>
<td>RCOM</td>
<td>RFB</td>
</tr>
<tr>
<td>WR</td>
<td>REF</td>
<td>R2</td>
<td>RFB</td>
<td>RFB</td>
</tr>
<tr>
<td>/RST</td>
<td>R1</td>
<td>R1</td>
<td>R1</td>
<td>RFB</td>
</tr>
</tbody>
</table>

Power Supply: VDD

- Settling Time: 0.5μS
- Wide Reference: ±15V, 10MHz
- SSOP-28 package
- Provides the flexibility to configure output circuit to match customer requirements.

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Multiplying DAC Portfolio

- 16-Bit: DAC8820, DAC8822, DAC8811, DAC8812
- 14-Bit: DAC8806, DAC8805, DAC8801, DAC8802
- 12-Bit: DAC7821, DAC7822, DAC7811

Resolution: Bits

Channels: Single, Dual, Quad

= Parallel

= Serial
### MDAC, Op Amp and Reference Cross Table

<table>
<thead>
<tr>
<th></th>
<th>2 Quadrant Multiplying - Negative Output</th>
<th>2 Quadrant Multiplying - Positive output</th>
<th>4 Quadrant Multiplying</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vout Range</strong></td>
<td>0 to -2.5V</td>
<td>0 to 2.5V</td>
<td>±2.5V</td>
</tr>
<tr>
<td><strong>Low Power</strong></td>
<td>OPA703, OPA735</td>
<td>OPA344, OPA703, OPA348</td>
<td>OPA735</td>
</tr>
<tr>
<td><strong>Fast Settling</strong></td>
<td>OPA727</td>
<td>OPA350</td>
<td>OPA727</td>
</tr>
<tr>
<td><strong>Reference</strong></td>
<td>REF5025</td>
<td>REF5025</td>
<td>REF5025</td>
</tr>
<tr>
<td><strong>Voltage Range</strong></td>
<td>0 to -5V</td>
<td>0 to 5V</td>
<td>±5V</td>
</tr>
<tr>
<td><strong>Low Power</strong></td>
<td>OPA703, OPA735</td>
<td>OPA334/5, OPA333, OPA376</td>
<td>OPA703, OPA735</td>
</tr>
<tr>
<td><strong>Fast Settling</strong></td>
<td>OPA727</td>
<td>OPA350, OPA727</td>
<td>OPA727</td>
</tr>
<tr>
<td><strong>Reference</strong></td>
<td>REF5050</td>
<td>REF5050</td>
<td>REF5050</td>
</tr>
<tr>
<td><strong>Voltage Range</strong></td>
<td>0 to -10V</td>
<td>0 to 10V</td>
<td>±10V</td>
</tr>
<tr>
<td><strong>Low Power</strong></td>
<td>OPA177, OPA277</td>
<td>OPA177, OPA277</td>
<td>OPA177, OPA277</td>
</tr>
<tr>
<td><strong>Fast Settling</strong></td>
<td>OPA211, OPA227</td>
<td>OPA211, OPA227, OPA727</td>
<td>OPA211, OPA227</td>
</tr>
<tr>
<td><strong>Reference</strong></td>
<td>REF5010</td>
<td>REF5010</td>
<td>REF5010</td>
</tr>
</tbody>
</table>
REF50xx
3ppm/°C, Precision Voltage Reference

Features
- LOW NOISE: 3uVpp/V
- HIGH ACCURACY:
  - High Grade: 0.05% (max)
  - Standard Grade: 0.1% (max)
- LOW TEMPERATURE DRIFT:
  - High Grade: 3ppm/°C (max)
  - Standard Grade: 8ppm/°C
- HIGH OUTPUT CURRENT: ±10mA
- TEMP RANGE: -40°C to +125°C
- Output Voltages: 2.048V, 2.5V, 3.0V, 4.096V, 4.5V, 5V
- Wide Supply: 2.2V to 18V

Key Benefits
- High Accuracy and Low Noise for High Resolution Precision Applications
- Minimize system error over temperature
- Directly provide accurate voltage reference to ADC without additional op amp buffer
- Industrial 5V Voltage References

Applications
- Precision Data Acquisition
- ATE Equipment
- Industrial Process Control
- Medical Instrumentation

medicalolutions@arrow.com
OPA211

Lowest Power, 1nV/√Hz, 36V Op Amp

**OPA211 Features**
- Low Noise Bipolar Input: 1.1nV/√Hz at 1kHz
- THD+N: 136dB (G=1, 1kHz)
- Low Offset Voltage: 30µV (typ)
- Low Quiescent Current: 3.6mA (typ)
- Wide Gain Bandwidth: 45MHz
- Wide Supply Range: ±2.25 to ±18V
- Rail-to-Rail Output
- Packaging: DFN-8 (3x3mm), MSOP-8, SO-8
- Pricing: $3.45 in 1k units
- Specified 125°C, Operating 150°C

**Benefits**
- Provides Minimal Signal Distortion
- Amplify Small Signals above the Noise Floor
- Very High Signal Accuracy
- Lowest Power at this Noise Level
- Fastest G=1 stable 36V Op Amp @ 1nV/√Hz
- Spans 5V to Full Industrial Range
- Very Wide Dynamic Range
- Smallest Package at Performance Node
- Lowest Priced 36V 1nV/√Hz Amplifier

**Applications**
- PLL Loop Filter
- 16-bit ADC Driver
- Reference Buffer
- DAC Output Amplifier
- Low Noise Instrumentation
- Pro Audio Preamp
- Hydrophone
- Medical

![Input Voltage Noise Density vs Frequency](image)

[Image of Op Amp Noise vs Resistance (R) Noise]

medicalsolutions@arrow.com
TMP112
Digital Alternative for High Accuracy Thermistor Designs

**Features**

- High 1.0°C Accuracy Over Entire Specified Temp Range: 
  -40°C to +125°C
- NEW SPEC! 0.5°C (Max @ 25°C) Initial Accuracy plus Temp Slope Error Specification
- Vs=1.4V to 3.6V; Lowest available supply voltage for high accuracy digital temp sensors
- Industries Lowest Power 1°C I2C Temp: 10μA Active, 1μA Shutdown
- True 12 Bit Resolution Measures Temp changes to 0.0625°C
- Highly accurate PSR through supply range: 0.0625°C/V (typ)
- Tiny SOT563 Package

**Benefits**

- Maximize system accuracy for broad range thermal management applications
- Allows best-in-class accuracy for application-specific temp ranges (better than 1.0°C) and thermistor competitive design without additional calibration
- Minimizes impact on overall power budget and brings new level of accuracy to low voltage and battery powered applications
- Pairs with processors for minimal power consumption in battery applications
- Optimizes precision of temperature measurement for overall system performance
- Reduces need for additional LDO – saves board space and cost in many applications
- 68% size reduction over SOT23 reduces PCB area

**Applications**

- Thermistor Applications (Digital Alternative)
- Portable Medical & Metering
- Cold Junction Compensation
- Green Energy Controls
- Gaming and CPU Thermal Management
- Pharmaceutical and Food Monitoring

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Replaces Full Thermistor Conditioning Circuit
What is the Temp Slope Error Specification?

TMP112 Slope Error Can Be Used to Calculate Accuracy Over User-Specified Temperature Ranges:

\[ \text{Accuracy} = \text{Error}_{25^\circ C} + \Delta T \cdot \text{slope} \]

- **Slope_1** = -40 to 25°C
- **Slope_2** = 25 to 85°C
- **Slope_3** = 85 to 125°C

.5°C Accuracy Guarantee at 25°C
**TI medical product portfolio**

**Commercial/Catalog**
- High Performance Analog
- DSPs/Embedded Processors
  - MSP430
  - DaVinci
  - OMAP
  - High-performance DSPs
- Low Power Wireless
- Power Management
- Hundreds of new products introduced each year

**Enhanced**
- Specification
- Test
- Qualification
- Product Flow
- Product Lifetime

**Custom**
- High-performance custom mixed-signal solutions
- Application specific design SoC
- Advanced digital custom solutions

TI process technology, libraries, IP, circuit & system design delivers best-in-class: speed, performance and precision

medicalsolutions@arrow.com
Contact Information

To learn more about technology solutions for medical applications from Arrow, Texas Instruments, contact the Arrow Electronics Medical Group at 866-260-1401, or email medicalesolutions@arrow.com.