

24-BIT ANALOG-TO-DIGITAL CONVERTER

Check for Samples: [ADS1243-HT](#)

FEATURES

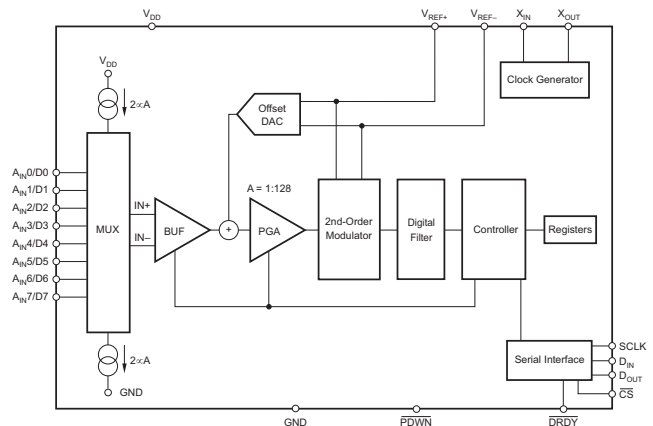
- 24-Bits No Missing Codes
- Simultaneous 50-Hz and 60-Hz Rejection (–90 dB Minimum)
- 0.0025% INL
- PGA Gains From 1 to 128
- Single-Cycle Settling
- Programmable Data Output Rates
- External Differential Reference of 0.1 V to 5 V
- On-Chip Calibration
- SPI™ Compatible
- 2.7 V to 5.25 V Supply Range
- 600- μ W Power Consumption
- Up to Eight Input Channels
- Up to Eight Data I/O

APPLICATIONS

- Down-Hole Drilling
- High Temperature Environments
- Vibration/Modal Analysis
- Multi-Channel Data Acquisition
- Acoustics/Dynamic Strain Gauges
- Pressure Sensors

SUPPORTS EXTREME TEMPERATURE APPLICATIONS

- Controlled Baseline
- One Assembly/Test Site
- One Fabrication Site
- Available in Extreme (–55°C/210°C) Temperature Range⁽¹⁾
- Extended Product Life Cycle
- Extended Product-Change Notification
- Product Traceability
- Texas Instruments' high temperature products utilize highly optimized silicon (die) solutions with design and process enhancements to maximize performance over extended temperatures. All devices are characterized and qualified for 1000 hours of continuous operating life at maximum rated temperatures.



(1) Custom temperature ranges available

DESCRIPTION

The ADS1243 is a precision, wide dynamic range, delta-sigma, analog-to-digital (A/D) converter with 24-bit resolution operating from 2.7-V to 5.25-V supplies. This delta-sigma, A/D converter provides up to 24 bits of no missing code performance and effective resolution of 21 bits.

The input channels are multiplexed. Internal buffering can be selected to provide a very high input impedance for direct connection to transducers or low-level voltage signals. Burnout current sources are provided that allow for the detection of an open or shorted sensor. An 8-bit digital-to-analog converter (DAC) provides an offset correction with a range of 50% of the FSR (Full-Scale Range).



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

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The Programmable Gain Amplifier (PGA) provides selectable gains of 1 to 128 with an effective resolution of 19 bits at a gain of 128. The A/D conversion is accomplished with a second-order delta-sigma modulator and programmable FIR filter that provides a simultaneous 50-Hz and 60-Hz notch. The reference input is differential and can be used for ratiometric conversion.

The serial interface is SPI compatible. Up to eight bits of data I/O are also provided that can be used for input or output. The ADS1243 is designed for high-resolution measurement applications in smart transmitters, industrial process control, weight scales, chromatography and portable instrumentation.

ORDERING INFORMATION⁽¹⁾

| T _A | PACKAGE | ORDERABLE PART NUMBER | TOP-SIDE MARKING |
|----------------|---------|-----------------------|------------------|
| -55°C to 210°C | JD | ADS1243SJD | ADS1243SJD |
| | KGD | ADS1243SKGD1 | NA |

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI Web site at www.ti.com.

ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range (unless otherwise noted) ⁽¹⁾

| | VALUE | UNIT |
|-------------------------------|------------------------------------|------|
| V _{DD} to GND | -0.3 to 6 | V |
| Input Current | 100, Momentary | mA |
| Input Current | 10, Continuous | mA |
| A _{IN} | GND - 0.5 to V _{DD} + 0.5 | V |
| Digital Input Voltage to GND | -0.3V to V _{DD} + 0.3 | V |
| Digital Output Voltage to GND | -0.3V to V _{DD} + 0.3 | V |
| Maximum Junction Temperature | 215 | °C |
| Operating Temperature Range | -55 to 210 | °C |
| Storage Temperature Range | -65 to 100 | °C |

(1) Stresses above those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. Exposure to absolute maximum conditions for extended periods may affect device reliability.

THERMAL CHARACTERISTICS

over operating free-air temperature range (unless otherwise noted)

| PARAMETER | | | MIN | TYP | MAX | UNIT |
|-----------------|-------------------------------------|-------------|-----|-----|-----|------|
| θ _{JC} | Junction-to-case thermal resistance | HKJ package | | | 8.1 | °C/W |

DIGITAL CHARACTERISTICS

V_{DD} 2.7 V to 5.25 V

| PARAMETER | TEST CONDITIONS | T _A = -55°C to 125°C | | | T _A = 210°C | | | UNIT | |
|-------------------------------------|--------------------------------|----------------------------------|-----------------------|-----|------------------------|-----------------------|-----|------|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | | |
| Digital Input/Output | | | | | | | | | |
| Logic Family | | CMOS | | | CMOS | | | | |
| Logic Level | V _{IH} | 0.8 • V _{DD} | | | 0.8 • V _{DD} | | | V | |
| | V _{IL} ⁽¹⁾ | GND | | | GND | | | V | |
| | V _{OH} | I _{OH} = 1 mA | V _{DD} - 0.4 | | | V _{DD} - 0.4 | | | V |
| | V _{OL} | I _{OL} = 1 mA | GND | | | GND + 0.4 | | | V |
| Input Leakage | I _{IH} | V _I = V _{DD} | | | 10 | | | μA | |
| | I _{IL} | V _I = 0 | | | -10 | | | μA | |
| Master Clock Rate: f _{OSC} | | 1 | | | 5 | | | MHz | |

(1) V_{IL} for X_{IN} is GND to GND + 0.05 V.

DIGITAL CHARACTERISTICS (continued)
 V_{DD} 2.7 V to 5.25 V

| PARAMETER | TEST CONDITIONS | $T_A = -55^\circ\text{C to } 125^\circ\text{C}$ | | | $T_A = 210^\circ\text{C}$ | | | UNIT |
|-----------------------------------|-----------------|---|-----|------|---------------------------|-----|------|------|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Master Clock Period: t_{OSC} | $1/f_{OSC}$ | 200 | | 1000 | 200 | | 1000 | ns |

ELECTRICAL CHARACTERISTICS: $V_{DD} = 5\text{ V}$

 All specifications $V_{DD} = 5\text{ V}$, $f_{MOD} = 19.2\text{ kHz}$, $PGA = 1$, Buffer ON, $f_{DATA} = 15\text{ Hz}$,
 $V_{REF} \equiv (\text{REF IN+}) - (\text{REF IN-}) = 2.5\text{ V}$, unless otherwise specified.

| PARAMETER | TEST CONDITIONS | $T_A = -55^\circ\text{C to } 125^\circ\text{C}$ | | | $T_A = 210^\circ\text{C}$ | | | UNIT |
|--|--|---|-----|-------------------------------|---------------------------|-----|-------------------------------|-----------------------------|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| ANALOG INPUT ($A_{IN0} - A_{IN7}$) | | | | | | | | |
| Analog Input Range | Buffer OFF | GND – 0.1 | | $V_{DD} + 0.1$ | GND – 0.1 | | $V_{DD} + 0.1$ | V |
| | Buffer ON | GND + 0.05 | | $V_{DD} - 1.5$ | GND + 0.05 | | $V_{DD} - 1.5$ | V |
| Full-Scale Input Range | (In+) – (In–), See Block Diagram, RANGE = 0 | | | $\pm V_{REF}/PGA$ | | | $\pm V_{REF}/PGA$ | V |
| | RANGE = 1 | | | $\pm V_{REF}/(2 \bullet PGA)$ | | | $\pm V_{REF}/(2 \bullet PGA)$ | V |
| Differential Input Impedance | Buffer OFF | | | 5/PGA | | | 12/PGA | M Ω |
| | Buffer ON | | | 5 | | | 8 | G Ω |
| Bandwidth | $f_{DATA} = 3.75\text{ Hz}$ | –3 dB | | 1.65 | | | | Hz |
| | $f_{DATA} = 7.50\text{ Hz}$ | –3 dB | | 3.44 | | | | Hz |
| | $f_{DATA} = 15\text{ Hz}$ | –3 dB | | 14.6 | | | | Hz |
| Programmable Gain Amplifier | User-Selectable Gain Ranges | 1 | | 128 | 1 | | 128 | |
| Input Capacitance | | | | 9 | | | 25 | pF |
| Input Leakage Current | Modulator OFF, $T = 25^\circ\text{C}$ | | | 5 | | | 6 | pA |
| Burnout Current Sources | | | | 2 | | | | μA |
| OFFSET DAC | | | | | | | | |
| Offset DAC Range | RANGE = 0 | | | $\pm V_{REF}/(2 \bullet PGA)$ | | | $\pm V_{REF}/(2 \bullet PGA)$ | V |
| | RANGE = 1 | | | $\pm V_{REF}/(4 \bullet PGA)$ | | | $\pm V_{REF}/(4 \bullet PGA)$ | V |
| Offset DAC Monotonicity | | | | 8 | | | 8 | Bits |
| Offset DAC Gain Error | | | | ± 10 | | | ± 15 | % |
| Offset DAC Gain Error Drift | | | | 1 | | | 2.2 | ppm/ $^\circ\text{C}$ |
| SYSTEM PERFORMANCE | | | | | | | | |
| Resolution | No Missing Codes | | | 24 | | | 24 | Bits |
| Integral Nonlinearity | End Point Fit | | | ± 0.0015 | | | ± 0.0018 | % of FS |
| Offset Error ⁽¹⁾ | | | | 7.5 | | | 15 | ppm of FS |
| Offset Drift ⁽¹⁾ | | | | 0.02 | | | 0.04 | ppm of FS/ $^\circ\text{C}$ |
| Gain Error ⁽¹⁾ | | | | 0.005 | | | 0.100 | % |
| Gain Error Drift ⁽¹⁾ | | | | 0.5 | | | 1.118 | ppm/ $^\circ\text{C}$ |
| Common-Mode Rejection | at DC | | | 100 | | | 94 | dB |
| | $f_{CM} = 60\text{ Hz}$, $f_{DATA} = 15\text{ Hz}$ | | | 130 | | | 100 | dB |
| | $f_{CM} = 50\text{ Hz}$, $f_{DATA} = 15\text{ Hz}$ | | | 120 | | | 100 | dB |
| Normal-Mode Rejection | $f_{SIG} = 50\text{ Hz}$, $f_{DATA} = 15\text{ Hz}$ | | | 100 | | | 95 | dB |
| | $f_{SIG} = 60\text{ Hz}$, $f_{DATA} = 15\text{ Hz}$ | | | 100 | | | 95 | dB |
| Output Noise | | | | See Typical Characteristics | | | | |

(1) Calibration can minimize these errors.

ELECTRICAL CHARACTERISTICS: V_{DD} = 5 V (continued)

All specifications V_{DD} = 5 V, f_{MOD} = 19.2 kHz, PGA = 1, Buffer ON, f_{DATA} = 15 Hz, V_{REF} ≡ (REF IN+) – (REF IN–) = 2.5 V, unless otherwise specified.

| PARAMETER | TEST CONDITIONS | T _A = –55°C to 125°C | | | T _A = 210°C | | | UNIT | |
|----------------------------------|---|---------------------------------|-----|-----------------|------------------------|------|-----------------|-----------------|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | | |
| Power-Supply Rejection | at DC, dB = –20 log(ΔV _{OUT} /V _{DD}) ⁽²⁾ | 80 | 95 | | 79 | 95 | | dB | |
| VOLTAGE REFERENCE INPUT | | | | | | | | | |
| Reference Input Range | REF IN+, REF IN– | 0 | | | 0 | | | V _{DD} | V |
| V _{REF} | V _{REF} ≡ (REF IN+) – (REF IN–), RANGE = 0 | 0.1 | 2.5 | 2.6 | 0.1 | 2.5 | 2.6 | V | |
| | RANGE = 1 | 0.1 | | V _{DD} | 0.1 | | V _{DD} | V | |
| Common-Mode Rejection | at DC | 120 | | | 98 | | | dB | |
| Common-Mode Rejection | f _{VREFCM} = 60 Hz, f _{DATA} = 15 Hz | 120 | | | 95 | | | dB | |
| Bias Current ⁽³⁾ | V _{REF} = 2.5 V | 1.3 | | | 10 | | | μA | |
| POWER-SUPPLY REQUIREMENTS | | | | | | | | | |
| Power-Supply Voltage | V _{DD} | 4.75 | | 5.25 | 4.75 | | 5.25 | V | |
| Current | PGA = 1, Buffer OFF | | 240 | 375 | | 250 | 480 | μA | |
| | PGA = 128, Buffer OFF | | 450 | 800 | | 630 | 940 | μA | |
| | PGA = 1, Buffer ON | | 290 | 425 | | 350 | 585 | μA | |
| | PGA = 128, Buffer ON | | 960 | 1400 | | 1200 | 2050 | μA | |
| | SLEEP Mode | | 60 | | | 80 | | μA | |
| | Read Data Continuous Mode | | 230 | | | 350 | | μA | |
| | PDWN | | 0.5 | | | 10 | | nA | |
| Power Dissipation | PGA = 1, Buffer OFF | | 1.2 | 1.9 | | 1.3 | 2.52 | mW | |

(2) ΔV_{OUT} is a change in digital result.

(3) 12-pF switched capacitor at f_{SAMP} clock frequency.

ELECTRICAL CHARACTERISTICS: V_{DD} = 3 V

All specifications V_{DD} = 3 V, f_{MOD} = 19.2 kHz, PGA = 1, Buffer ON, f_{DATA} = 15 Hz, V_{REF} ≡ (REF IN+) – (REF IN–) = 1.25 V, unless otherwise specified.

| PARAMETER | TEST CONDITIONS | T _A = –55°C to 125°C | | | T _A = 210°C | | | UNIT | |
|---|---|---------------------------------|-----|-----|------------------------------|-----|-----|------------------------------|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | | |
| ANALOG INPUT (A_{IN0} – A_{IN7}) | | | | | | | | | |
| Analog Input Range | Buffer OFF | GND – 0.1 | | | GND – 0.1 | | | V _{DD} + 0.1 | V |
| | Buffer ON | GND + 0.05 | | | GND + 0.05 | | | V _{DD} – 1.5 | V |
| Full-Scale Input Voltage Range | (In+) – (In–), See Block Diagram, RANGE = 0 | | | | ±V _{REF} /PGA | | | ±V _{REF} /PGA | V |
| | RANGE = 1 | | | | ±V _{REF} /(2 • PGA) | | | ±V _{REF} /(2 • PGA) | V |
| Input Impedance | Buffer OFF | 5/PGA | | | 10/PGA | | | MΩ | |
| | Buffer ON | 5 | | | 8 | | | GΩ | |
| Bandwidth | f _{DATA} = 3.75 Hz | –3 dB | | | 1.65 | | | Hz | |
| | f _{DATA} = 7.50 Hz | –3 dB | | | 3.44 | | | Hz | |
| | f _{DATA} = 15 Hz | –3 dB | | | 14.6 | | | Hz | |
| Programmable Gain Amplifier | User-Selectable Gain Ranges | 1 | | 128 | 1 | | 128 | | |
| Input Capacitance | | 9 | | | 25 | | | pF | |
| Input Leakage Current | Modulator OFF, T = 25°C | 5 | | | 6 | | | pA | |
| Burnout Current Sources | | 2 | | | | | | μA | |
| OFFSET DAC | | | | | | | | | |
| Offset DAC Range | RANGE = 0 | ±V _{REF} /(2 • PGA) | | | ±V _{REF} /(2 • PGA) | | | V | |
| | RANGE = 1 | ±V _{REF} /(4 • PGA) | | | ±V _{REF} /(4 • PGA) | | | V | |

ELECTRICAL CHARACTERISTICS: $V_{DD} = 3\text{ V}$ (continued)

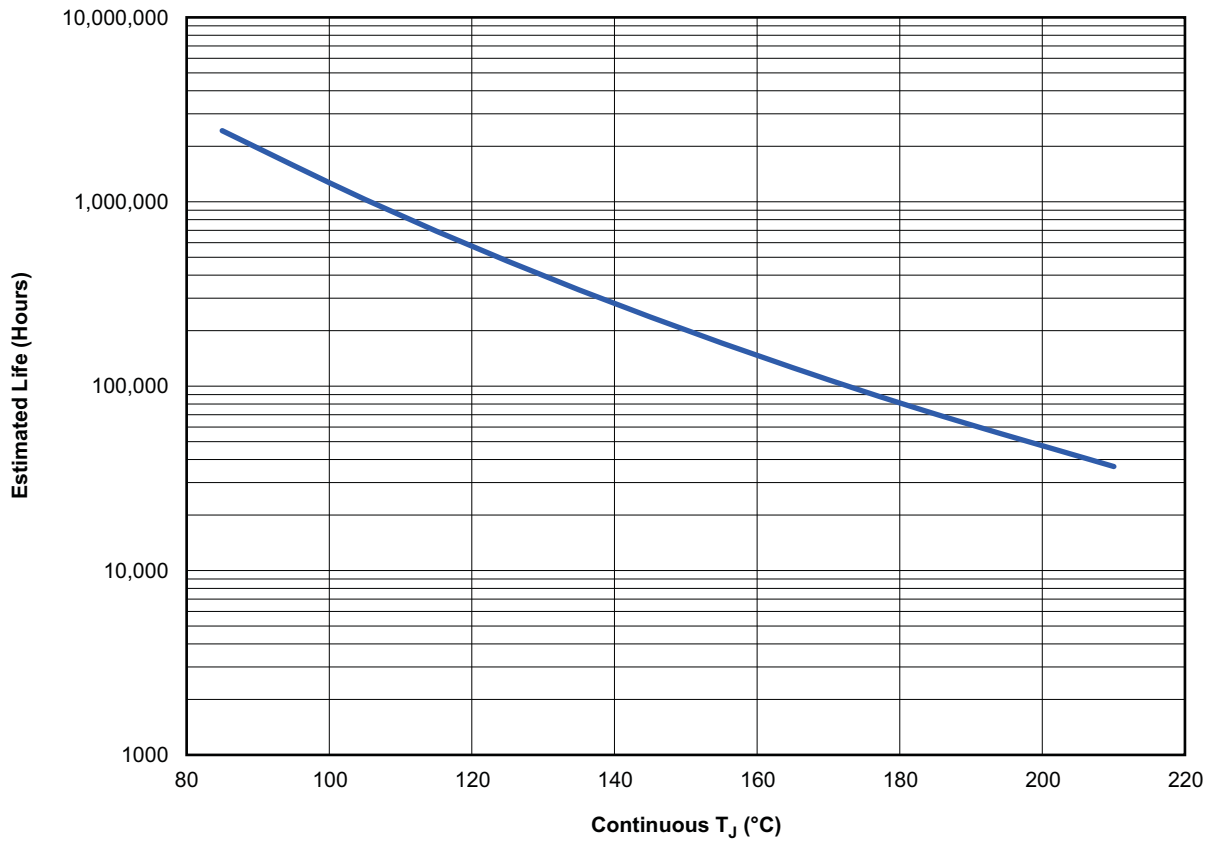
All specifications $V_{DD} = 3\text{ V}$, $f_{MOD} = 19.2\text{ kHz}$, $PGA = 1$, Buffer ON, $f_{DATA} = 15\text{ Hz}$,
 $V_{REF} \equiv (\text{REF IN+}) - (\text{REF IN-}) = 1.25\text{ V}$, unless otherwise specified.

| PARAMETER | TEST CONDITIONS | $T_A = -55^\circ\text{C to } 125^\circ\text{C}$ | | | $T_A = 210^\circ\text{C}$ | | | UNIT |
|----------------------------------|---|---|------|----------|---------------------------|------|------|--------------|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Offset DAC Monotonicity | | 8 | | | 8 | | | Bits |
| Offset DAC Gain Error | | ±10 | | | ±12 | | | % |
| Offset DAC Gain Error Drift | | 1 | | | 2 | | | ppm/°C |
| SYSTEM PERFORMANCE | | | | | | | | |
| Resolution | No Missing Codes | 24 | | | 24 | | | Bits |
| Integral Nonlinearity | End Point Fit | ±0.0015 | | | ±0.0025 | | | % of FS |
| Offset Error ⁽¹⁾ | | 75 | | | 40 | | | ppm of FS |
| Offset Drift ⁽¹⁾ | | 0.02 | | | 0.20 | | | ppm of FS/°C |
| Gain Error ⁽¹⁾ | | 0.005 | | | 0.1 | | | % |
| Gain Error Drift ⁽¹⁾ | | 0.5 | | | 1.118 | | | ppm/°C |
| Common-Mode Rejection | at DC | 100 | | | 87 | | | dB |
| | $f_{CM} = 60\text{ Hz}$, $f_{DATA} = 15\text{ Hz}$ | 130 | | | 98 | | | dB |
| | $f_{CM} = 50\text{ Hz}$, $f_{DATA} = 15\text{ Hz}$ | 120 | | | 95 | | | dB |
| Normal-Mode Rejection | $f_{SIG} = 50\text{ Hz}$, $f_{DATA} = 15\text{ Hz}$ | 100 | | | 90 | | | dB |
| | $f_{SIG} = 60\text{ Hz}$, $f_{DATA} = 15\text{ Hz}$ | 100 | | | 90 | | | dB |
| Output Noise | | See Typical Characteristics | | | | | | |
| Power-Supply Rejection | at DC, dB = $-20 \log(\Delta V_{OUT} / V_{DD})$ ⁽²⁾ | 80 | 95 | | 75 | 90 | | dB |
| VOLTAGE REFERENCE INPUT | | | | | | | | |
| Reference Input Range | REF IN+, REF IN- | 0 V_{DD} | | | 0 V_{DD} | | | V |
| V_{REF} | $V_{REF} \equiv (\text{REF IN+}) - (\text{REF IN-})$, RANGE = 0 | 0.1 | 1.25 | 1.30 | 0.1 | 1.25 | 1.30 | V |
| | RANGE = 1 | 0.1 | | V_{DD} | 0.1 | | 2.6 | V |
| Common-Mode Rejection | at DC | 120 | | | 95 | | | dB |
| Common-Mode Rejection | $f_{VREFCM} = 60\text{ Hz}$, $f_{DATA} = 15\text{ Hz}$ | 120 | | | 93 | | | dB |
| Bias Current ⁽³⁾ | $V_{REF} = 1.25\text{ V}$ | 1.3 | | | 8 | | | μA |
| POWER-SUPPLY REQUIREMENTS | | | | | | | | |
| Power-Supply Voltage | V_{DD} | 2.7 3.3 | | | 2.7 3.3 | | | V |
| Current | PGA = 1, Buffer OFF | 190 375 | | | 200 480 | | | μA |
| | PGA = 128, Buffer OFF | 460 700 | | | 600 940 | | | μA |
| | PGA = 1, Buffer ON | 240 375 | | | 350 585 | | | μA |
| | PGA = 128, Buffer ON | 870 1325 | | | 1200 1800 | | | μA |
| | SLEEP Mode | 75 | | | 110 | | | μA |
| | Read Data Continuous Mode | 113 | | | 250 | | | μA |
| | $\overline{\text{PDWN}} = 0$ | 0.5 | | | 7.5 | | | nA |
| Power Dissipation | PGA = 1, Buffer OFF | 0.6 1.2 | | | 0.66 1.58 | | | mW |

(1) Calibration can minimize these errors.

(2) ΔV_{OUT} is a change in digital result.

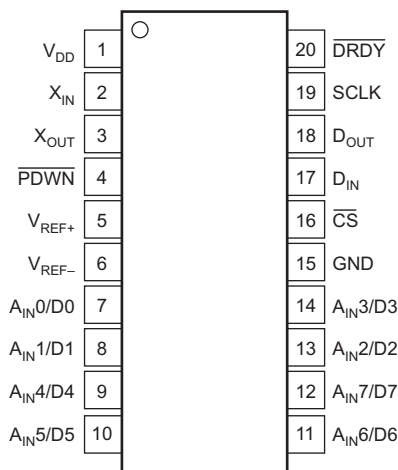
(3) 12-pF switched capacitor at f_{SAMP} clock frequency.



- (1) See data sheet for absolute maximum and minimum recommended operating conditions.
- (2) Silicon operating life design goal is 10 years at 105°C junction temperature (does not include package interconnect life).
- (3) The predicted operating lifetime vs. junction temperature is based on reliability modeling using electromigration as the dominant failure mechanism affecting device wearout for the specific device process and design characteristics.

Figure 1. ADS1243-HT Operating Life Derating Chart

PIN CONFIGURATION

**CDIP PACKAGE
(TOP VIEW)**


PIN ASSIGNMENTS

| PIN # | NAME | DESCRIPTION |
|-------|--------------------------|---|
| 1 | V _{DD} | Power Supply |
| 2 | X _{IN} | Clock Input |
| 3 | X _{OUT} | Clock Output, used with crystal or ceramic resonator. |
| 4 | $\overline{\text{PDWN}}$ | Active LOW. Power Down. The power down function shuts down the analog and digital circuits. |
| 5 | V _{REF+} | Positive Differential Reference Input |
| 6 | V _{REF-} | Negative Differential Reference Input |
| 7 | A _{IN0} /D0 | Analog Input 0/Data I/O 0 |
| 8 | A _{IN1} /D1 | Analog Input 1/Data I/O 1 |
| 9 | A _{IN4} /D4 | Analog Input 4/Data I/O 4 |
| 10 | A _{IN5} /D5 | Analog Input 5/Data I/O 5 |
| 11 | A _{IN6} /D6 | Analog Input 6/Data I/O 6 |
| 12 | A _{IN7} /D7 | Analog Input 7/Data I/O 7 |
| 13 | A _{IN2} /D2 | Analog Input 2/Data I/O 2 |
| 14 | A _{IN3} /D3 | Analog Input 3/Data I/O 3 |
| 15 | GND | Ground |
| 16 | $\overline{\text{CS}}$ | Active LOW, Chip Select |
| 17 | D _{IN} | Serial Data Input, Schmitt Trigger |
| 18 | D _{OUT} | Serial Data Output |
| 19 | SCLK | Serial Clock, Schmitt Trigger |
| 20 | $\overline{\text{DRDY}}$ | Active LOW, Data Ready |

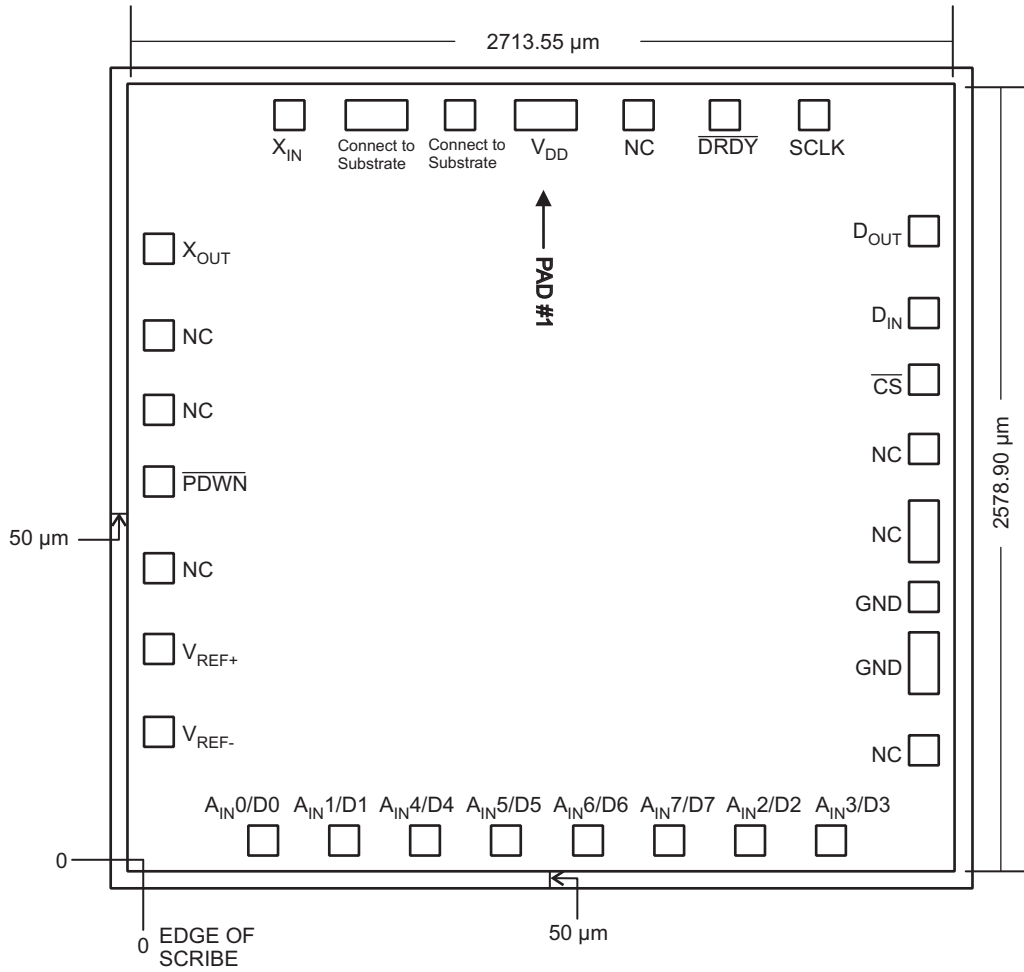
BARE DIE INFORMATION

| DIE THICKNESS | BACKSIDE FINISH | BACKSIDE POTENTIAL | BOND PAD METALLIZATION COMPOSITION |
|---------------|------------------------|--------------------|------------------------------------|
| 15 mils | Silicon with backgrind | GND | AlCu |

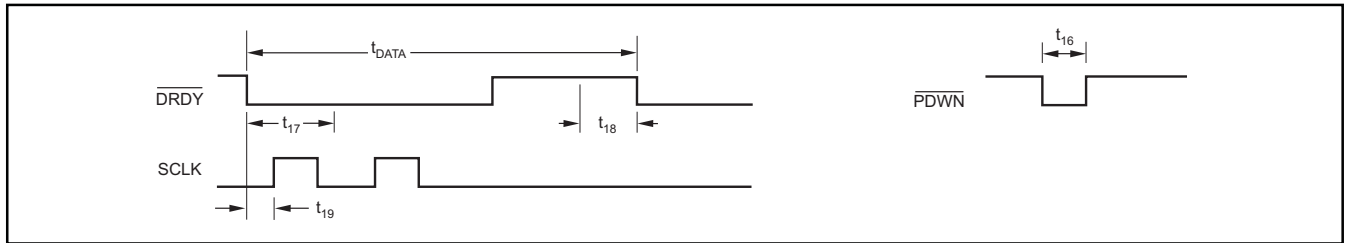
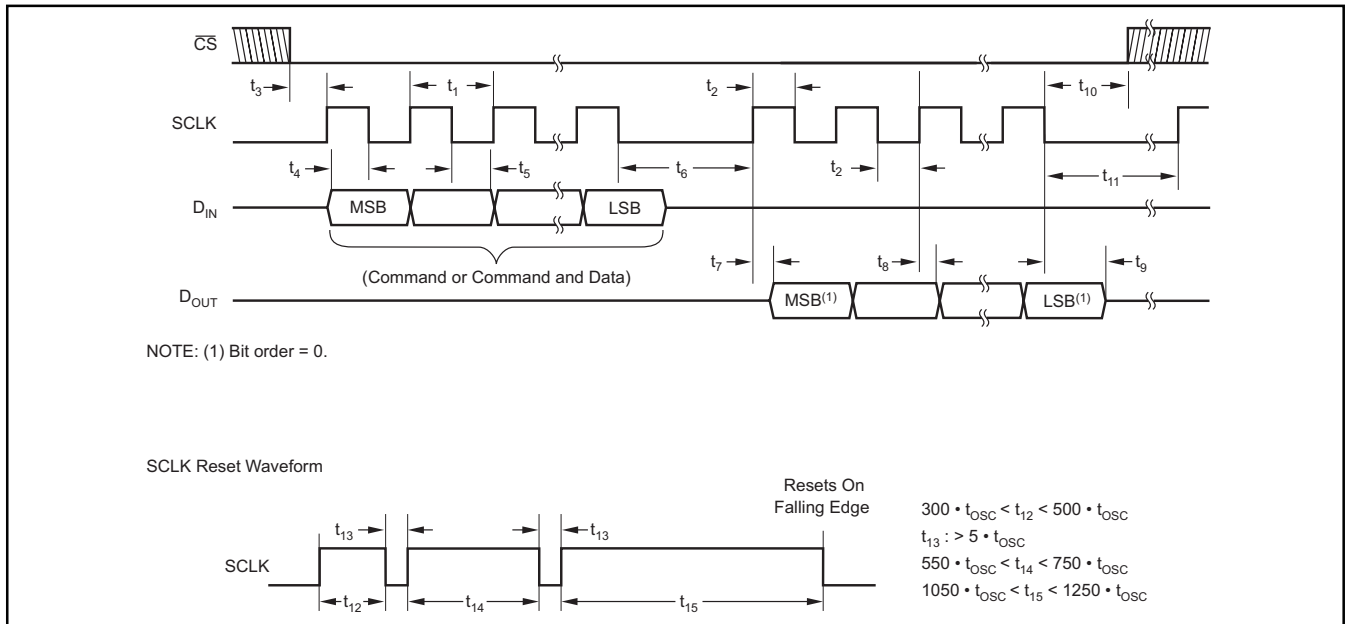
Table 1. Bond Pad Coordinates in Microns⁽¹⁾

| DISCRIPTION | PAD NUMBER | X MIN | Y MIN | X MAX | Y MAX |
|--------------------------|------------|---------|---------|---------|---------|
| V _{DD} | 1 | 1268.55 | 2471.55 | 1478.15 | 2572.55 |
| Connect to substrate | 2 | 1030.45 | 2471.55 | 1132.45 | 2572.55 |
| Connect to substrate | 3 | 692.45 | 2471.55 | 902.05 | 2572.55 |
| X _{IN} | 4 | 450.05 | 2471.55 | 552.05 | 2572.55 |
| X _{OUT} | 5 | 6.45 | 2016.65 | 107.45 | 2118.65 |
| NC | 6 | 6.45 | 1721.75 | 107.45 | 1823.75 |
| NC | 7 | 6.45 | 1468.60 | 107.45 | 1570.60 |
| $\overline{\text{PDWN}}$ | 8 | 6.45 | 1224.80 | 107.45 | 1326.80 |
| NC | 9 | 6.45 | 929.95 | 107.45 | 1031.95 |
| V _{REF+} | 10 | 6.45 | 655.20 | 107.45 | 757.20 |
| V _{REF-} | 11 | 6.45 | 373.25 | 107.45 | 475.25 |
| A _{IN} 0/D0 | 12 | 361.15 | 3.55 | 462.15 | 105.55 |
| A _{IN} 1/D1 | 13 | 636.45 | 3.55 | 737.45 | 105.55 |
| A _{IN} 4/D4 | 14 | 911.70 | 3.55 | 1012.70 | 105.55 |
| A _{IN} 5/D5 | 15 | 1186.85 | 3.55 | 1287.85 | 105.55 |
| A _{IN} 6/D6 | 16 | 1466.25 | 3.55 | 1567.25 | 105.55 |
| A _{IN} 7/D7 | 17 | 1742.50 | 3.55 | 1843.50 | 105.55 |
| A _{IN} 2/D2 | 18 | 2017.60 | 3.55 | 2118.60 | 105.55 |
| A _{IN} 3/D3 | 19 | 2292.75 | 3.55 | 2393.75 | 105.55 |
| NC | 20 | 2608.70 | 310.50 | 2709.70 | 412.50 |
| GND | 21 | 2608.75 | 553.25 | 2709.75 | 762.85 |
| GND | 22 | 2608.70 | 832.20 | 2709.70 | 934.20 |
| NC | 23 | 2608.75 | 1001.60 | 2709.75 | 1211.20 |
| NC | 24 | 2608.70 | 1335.65 | 2709.70 | 1437.65 |
| $\overline{\text{CS}}$ | 25 | 2608.70 | 1571.45 | 2709.70 | 1673.45 |
| D _{IN} | 26 | 2608.70 | 1797.90 | 2709.70 | 1899.90 |
| D _{OUT} | 27 | 2608.70 | 2076.55 | 2709.70 | 2178.55 |
| SCLK | 28 | 2234.80 | 2471.55 | 2336.80 | 2572.55 |
| $\overline{\text{DRDY}}$ | 29 | 1931.10 | 2471.55 | 2033.10 | 2572.55 |
| NC | 30 | 1637.90 | 2471.55 | 1739.90 | 2572.55 |

(1) For signal descriptions see the Pin Assignments table.



TIMING DIAGRAMS



TIMING REQUIREMENTS

| PARAMETER | TEST CONDITIONS | | MIN | MAX | UNIT |
|-------------------------------|--|---|-----|------|-------------------------------------|
| t ₁ | SCLK Period | | 4 | | t _{osc} Periods |
| | | | | 3 | $\overline{\text{DRDY}}$ Periods |
| t ₂ | SCLK Pulse Width, HIGH and LOW | | 200 | | ns |
| t ₃ | $\overline{\text{CS}}$ low to first SCLK Edge; Setup Time ⁽¹⁾ | | 0 | | ns |
| t ₄ | D _{IN} Valid to SCLK Edge; Setup Time | | 50 | | ns |
| t ₅ | Valid D _{IN} to SCLK Edge; Hold Time | | 50 | | ns |
| t ₆ | Delay between last SCLK edge for D _{IN} and first SCLK edge for D _{OUT} : RDATA, RDATA _C , RREG, WREG | | 50 | | t _{osc} Periods |
| t ₇ ⁽²⁾ | SCLK Edge to Valid New D _{OUT} | | | 50 | ns |
| t ₈ ⁽²⁾ | SCLK Edge to D _{OUT} , Hold Time | | 0 | | ns |
| t ₉ | Last SCLK Edge to D _{OUT} Tri-State NOTE: D _{OUT} goes tri-state immediately when CS goes HIGH. | | 6 | 10 | t _{osc} Periods |
| t ₁₀ | $\overline{\text{CS}}$ LOW time after final SCLK edge. | Read from the device | 0 | | t _{osc} Periods |
| | | Write to the device | 8 | | t _{osc} Periods |
| t ₁₁ | Final SCLK edge of one command until first edge SCLK of next command: | RREG, WREG, DSYNC, SLEEP, RDATA, RDATA _C , STOPC | 4 | | t _{osc} Periods |
| | | SELFGCAL, SELFOCAL, SYSOCAL, SYSGCAL | 2 | | $\overline{\text{DRDY}}$ Periods |
| | | SELFCAL | 4 | | $\overline{\text{DRDY}}$ Periods |
| | | RESET (also SCLK Reset) | 16 | | t _{osc} Periods |
| t ₁₆ | Pulse Width | | 4 | | t _{osc} Periods |
| t ₁₇ | Allowed analog input change for next valid conversion. | | | 5000 | t _{osc} Periods |
| t ₁₈ | DOR update, DOR data not valid. | | 4 | | t _{osc} Periods |
| t ₁₉ | First SCLK after $\overline{\text{DRDY}}$ goes LOW: | RDATA _C Mode | 10 | | t _{osc} Periods |
| | | Any other mode | 0 | | t _{osc} Periods |

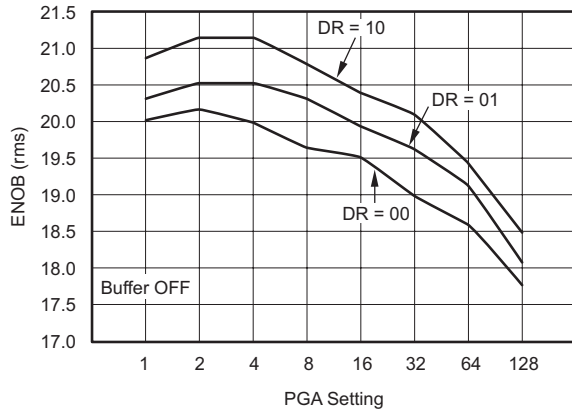
(1) $\overline{\text{CS}}$ may be tied LOW.

(2) Load = 20 pF || 10 kΩ to GND.

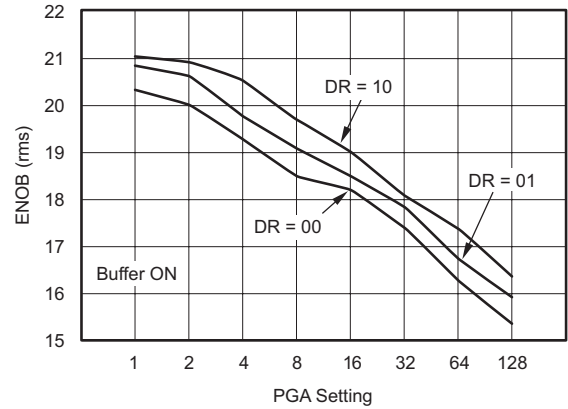
TYPICAL CHARACTERISTICS

All specifications $V_{DD} = 5\text{ V}$, $f_{OSC} = 2.4576\text{ MHz}$, $PGA = 1$, $f_{DATA} = 15\text{ Hz}$, and $V_{REF} \equiv (\text{REF IN+}) - (\text{REF IN-}) = 2.5\text{ V}$, unless otherwise specified.

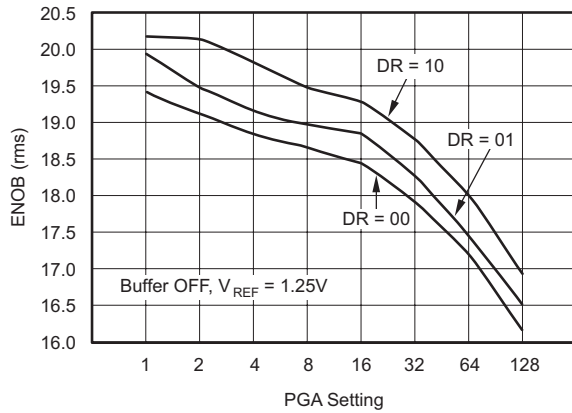
**EFFECTIVE NUMBER OF BITS
vs
PGA SETTING**



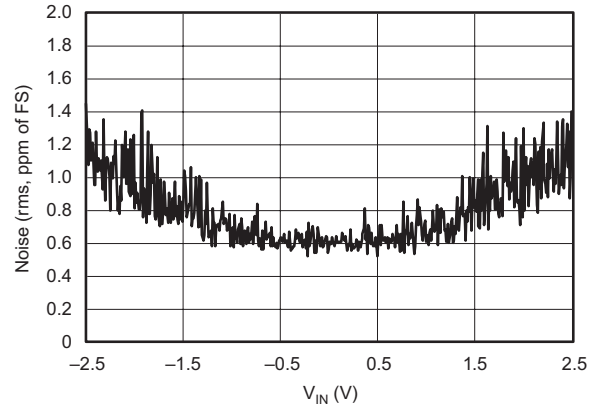
**EFFECTIVE NUMBER OF BITS
vs
PGA SETTING**



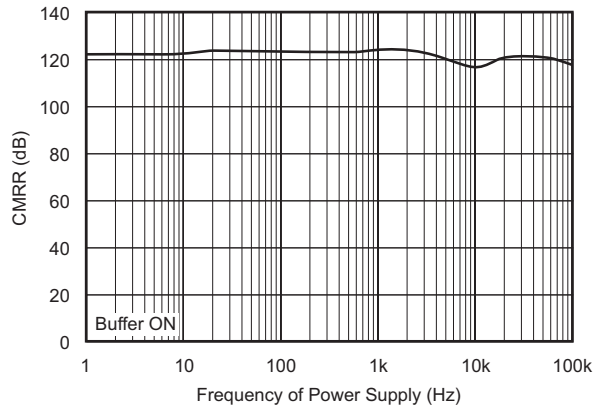
**EFFECTIVE NUMBER OF BITS
vs
PGA SETTING**



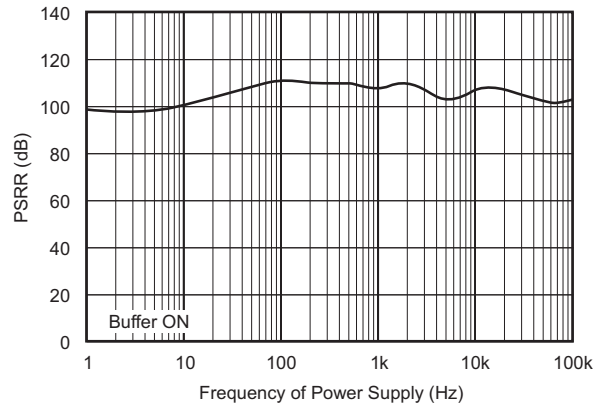
**NOISE
vs
INPUT SIGNAL**



**COMMON-MODE REJECTION RATIO
vs
FREQUENCY**

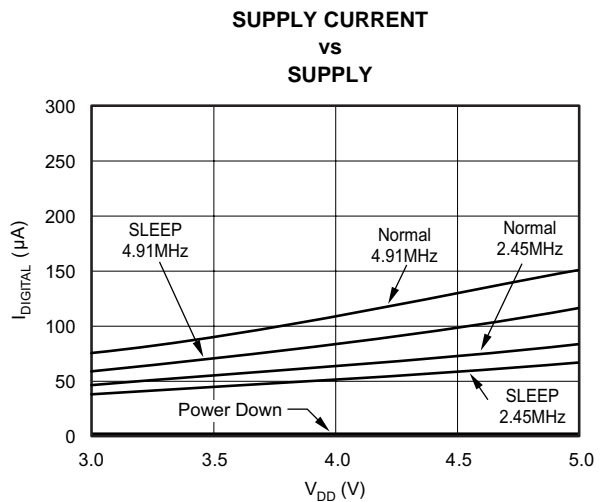
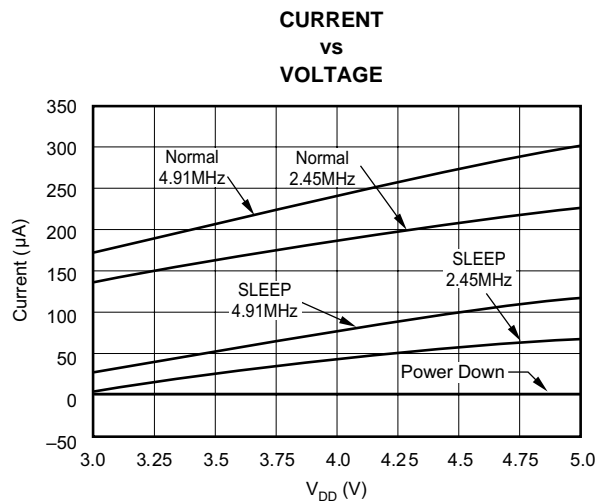
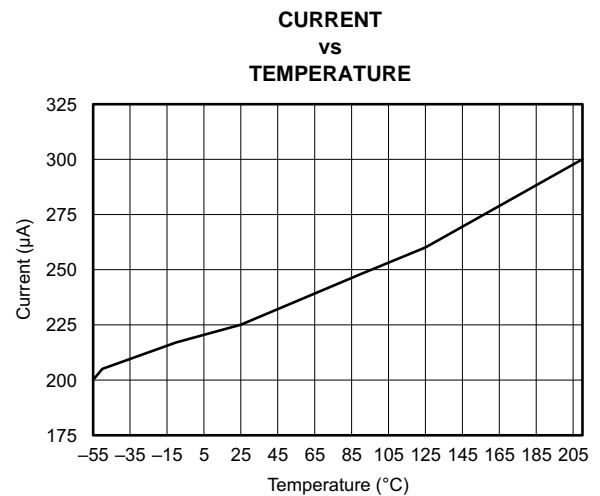
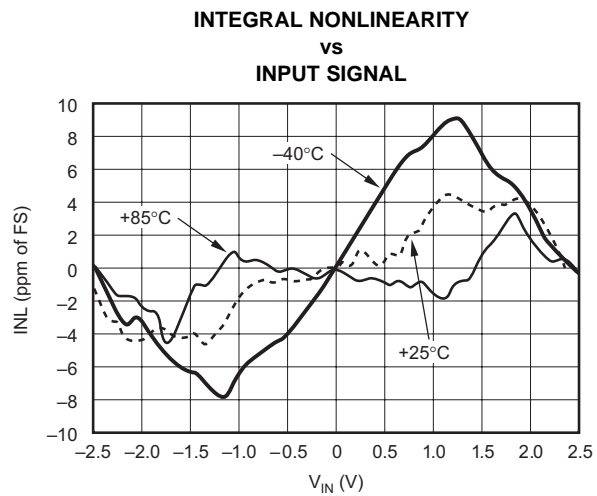
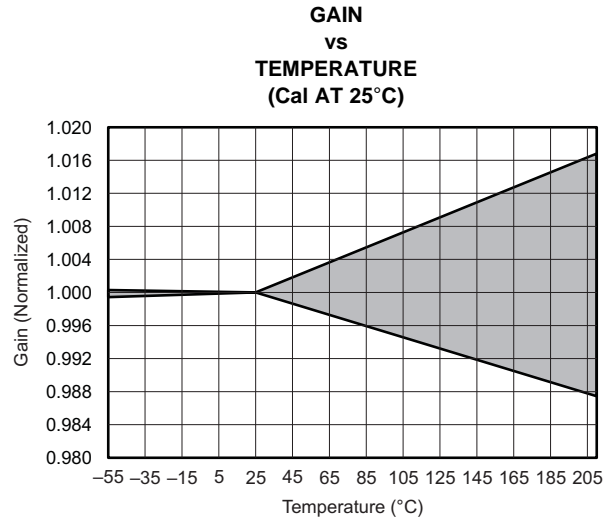
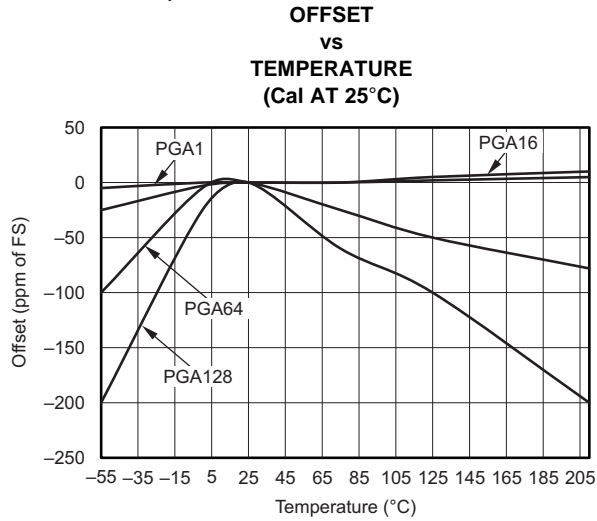


**POWER SUPPLY REJECTION RATIO
vs
FREQUENCY**



TYPICAL CHARACTERISTICS (continued)

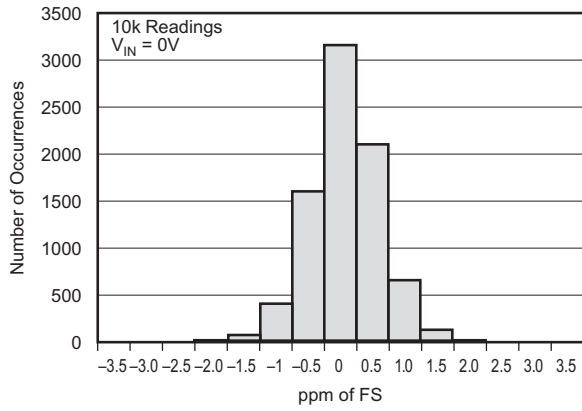
All specifications $V_{DD} = 5\text{ V}$, $f_{OSC} = 2.4576\text{ MHz}$, $PGA = 1$, $f_{DATA} = 15\text{ Hz}$, and $V_{REF} \equiv (\text{REF IN+}) - (\text{REF IN-}) = 2.5\text{ V}$, unless otherwise specified.



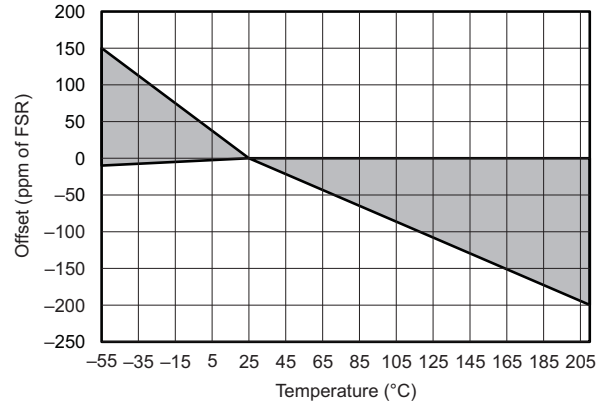
TYPICAL CHARACTERISTICS (continued)

All specifications $V_{DD} = 5\text{ V}$, $f_{OSC} = 2.4576\text{ MHz}$, $PGA = 1$, $f_{DATA} = 15\text{ Hz}$, and $V_{REF} \equiv (\text{REF IN+}) - (\text{REF IN-}) = 2.5\text{ V}$, unless otherwise specified.

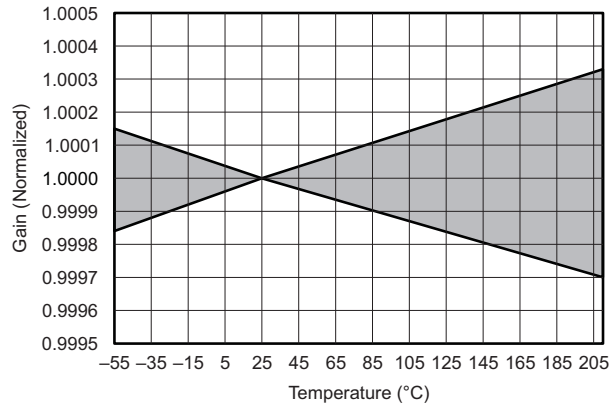
NOISE HISTOGRAM



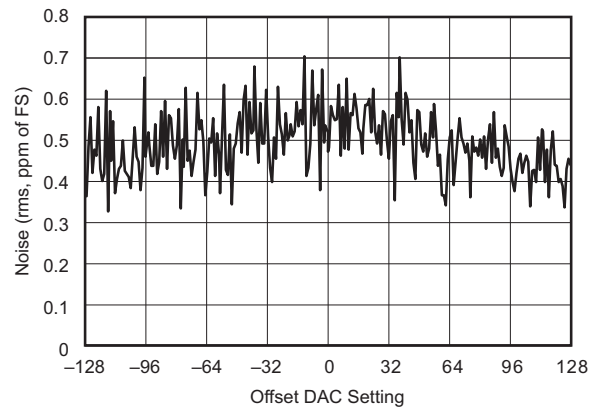
**OFFSET DAC OFFSET
vs
TEMPERATURE
(Cal AT 25°C)**



**OFFSET DAC GAIN
vs
TEMPERATURE
(Cal AT 25°C)**



**OFFSET DAC NOISE
vs
SETTING**



OVERVIEW

INPUT MULTIPLEXER

The input multiplexer provides for any combination of differential inputs to be selected on any of the input channels, as shown in Figure 2. For example, if $A_{IN}0$ is selected as the positive differential input channel, any other channel can be selected as the negative terminal for the differential input channel. With this method, it is possible to have up to seven single-ended input channels or four independent differential input channels for the ADS1243.

The ADS1243 features a single-cycle settling digital filter that provides valid data on the first conversion after a new channel selection. In order to minimize the settling error, synchronize MUX changes to the conversion beginning, which is indicated by the falling edge of \overline{DRDY} . In other words, issuing a MUX change through the WREG command immediately after \overline{DRDY} goes LOW minimizes the settling error. Increasing the time between the conversion beginning (\overline{DRDY} goes LOW) and the MUX change command (t_{DELAY}) results in a settling error in the conversion data, as shown in Figure 3.

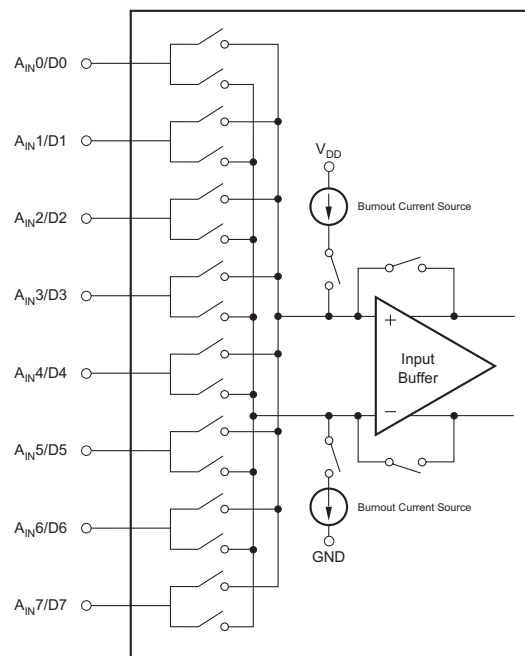


Figure 2. Input Multiplexer Configuration

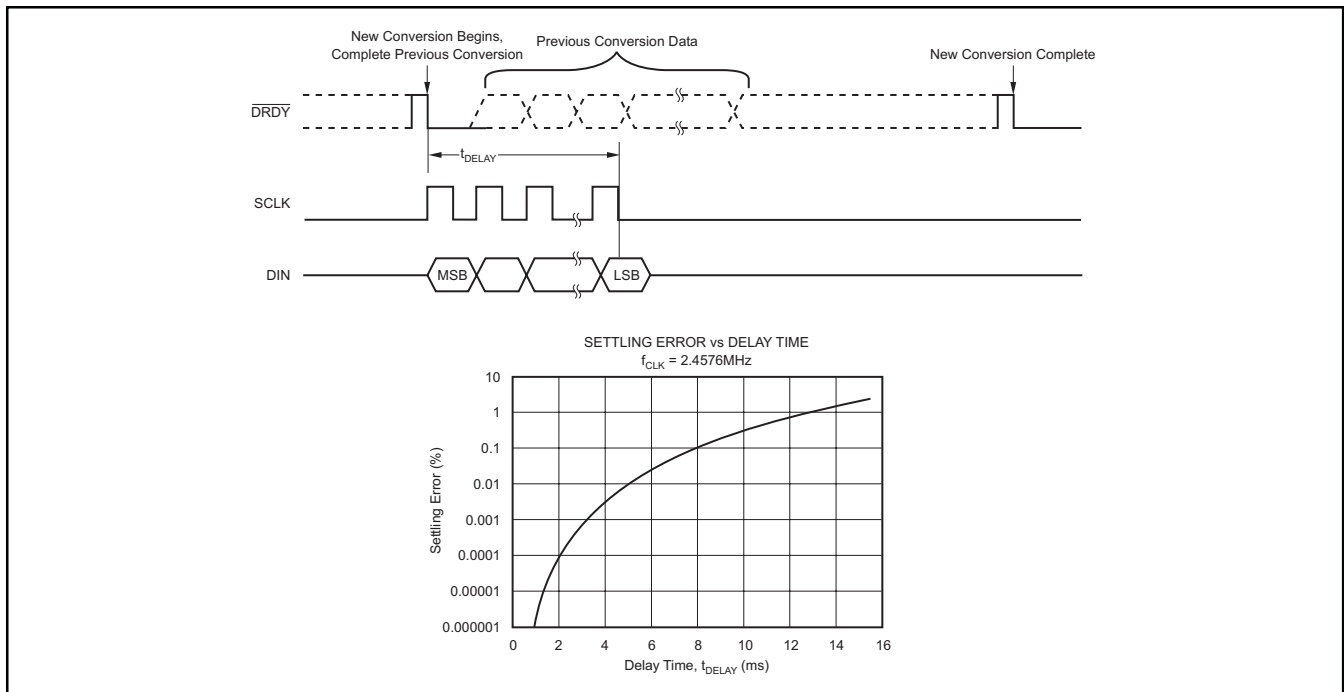


Figure 3. Input Multiplexer Configuration

BURNOUT CURRENT SOURCES

The Burnout Current Sources can be used to detect sensor short-circuit or open-circuit conditions. Setting the Burnout Current Sources (BOCS) bit in the SETUP register activates two 2µA current sources called burnout current sources. One of the current sources is connected to the converter’s negative input and the other is connected to the converter’s positive input.

Figure 4 shows the situation for an open-circuit sensor. This is a potential failure mode for many kinds of remotely connected sensors. The current source on the positive input acts as a pull-up, causing the positive input to go to the positive analog supply, and the current source on the negative input acts as a pull-down, causing the negative input to go to ground. The ADS1243 therefore outputs full-scale (7FFFFFF Hex).

Figure 5 shows a short-circuited sensor. Since the inputs are shorted and at the same potential, the ADS1243 signal outputs are approximately zero. (Note that the code for shorted inputs is not exactly zero due to internal series resistance, low-level noise and other error sources.)

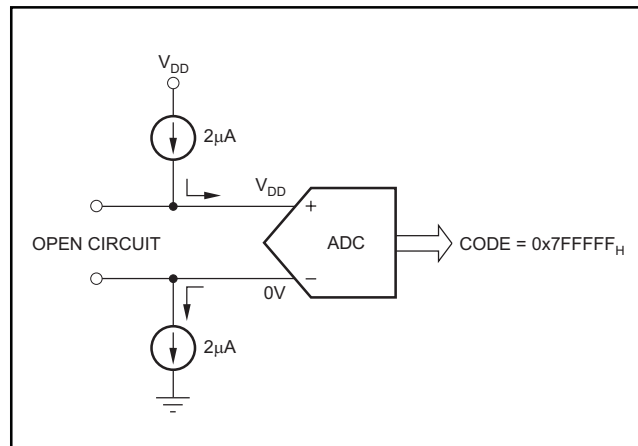


Figure 4. Burnout Detection While Sensor is Open-Circuited.

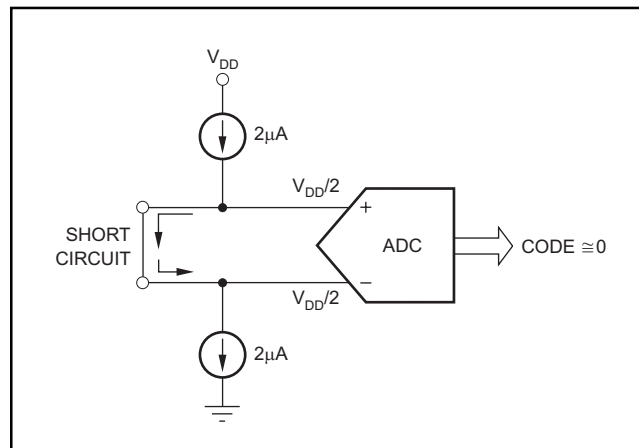


Figure 5. Burnout Detection While Sensor is Short-Circuited.

INPUT BUFFER

The input impedance of ADS1243 without the buffer enabled is approximately $5\text{M}\Omega/\text{PGA}$. For systems requiring very high input impedance, the ADS1243 provides a chopper-stabilized differential FET-input voltage buffer. When activated, the buffer raises the ADS1243 input impedance to approximately $5\text{G}\Omega$.

The buffer's input range is approximately 50mV to $V_{\text{DD}} - 1.5\text{V}$. The buffer's linearity will degrade beyond this range. Differential signals should be adjusted so that both signals are within the buffer's input range.

The buffer can be enabled using the BUFEN pin or the BUFEN bit in the ACR register. The buffer is on when the BUFEN pin is high and the BUFEN bit is set to one. If the BUFEN pin is low, the buffer is disabled. If the BUFEN bit is set to zero, the buffer is also disabled.

The buffer draws additional current when activated. The current required by the buffer depends on the PGA setting. When the PGA is set to 1, the buffer uses approximately $50\text{ }\mu\text{A}$; when the PGA is set to 128, the buffer uses approximately $500\text{ }\mu\text{A}$.

PGA

The Programmable Gain Amplifier (PGA) can be set to gains of 1, 2, 4, 8, 16, 32, 64, or 128. Using the PGA can improve the effective resolution of the A/D converter. For instance, with a PGA of 1 on a 5-V full-scale signal, the A/D converter can resolve down to $1\text{ }\mu\text{V}$. With a PGA of 128 and a full-scale signal of 39 mV , the A/D converter can resolve down to 75 nV . V_{DD} current increases with PGA settings higher than 4.

OFFSET DAC

The input to the PGA can be shifted by half the full-scale input range of the PGA using the Offset DAC (ODAC) register. The ODAC register is an 8-bit value; the MSB is the sign and the seven LSBs provide the magnitude of the offset. Using the offset DAC does not reduce the performance of the A/D converter. For more details on the ODAC in the ADS1243, please refer to TI application report SBAA077 (available through the TI website).

MODULATOR

The modulator is a single-loop second-order system. The modulator runs at a clock speed (f_{MOD}) that is derived from the external clock (f_{OSC}). The frequency division is determined by the SPEED bit in the SETUP register, as shown in [Table 2](#).

Table 2. Output Configuration

| f _{osc} | SPEED BIT | f _{MOD} | DR BITS | | | 1st NOTCH FREQUENCY |
|------------------|-----------|------------------|---------|---------|----------|---------------------|
| | | | 00 | 01 | 10 | |
| 2.4576 MHz | 0 | 19,200 Hz | 15 Hz | 7.5 Hz | 3.75 Hz | 50/60 Hz |
| | 1 | 9,600 Hz | 7.5 Hz | 3.75 Hz | 1.875 Hz | 25/30 Hz |
| 4.9152 MHz | 0 | 38,400 Hz | 30 Hz | 15 Hz | 7.5 Hz | 100/120 Hz |
| | 1 | 19,200 Hz | 15 Hz | 7.5 Hz | 3.75 Hz | 50/60 Hz |

CALIBRATION

The offset and gain errors can be minimized with calibration. The ADS1243 supports both self and system calibration.

Self-calibration of the ADS1243 corrects internal offset and gain errors and is handled by three commands: SELFCAL, SELFGAL, and SELFOCAL. The SELFCAL command performs both an offset and gain calibration. SELFGAL performs a gain calibration and SELFOCAL performs an offset calibration, each of which takes two t_{DATA} periods to complete. During self-calibration, the ADC inputs are disconnected internally from the input pins. The PGA must be set to 1 prior to issuing a SELFCAL or SELFGAL command. Any PGA is allowed when issuing a SELFOCAL command. For example, if using PGA = 64, first set PGA = 1 and issue SELFGAL. Afterwards, set PGA = 64 and issue SELFOCAL. For operation with a reference voltage greater than (V_{DD} – 1.5) volts, the buffer must also be turned off during gain self-calibration to avoid exceeding the buffer input range.

System calibration corrects both internal and external offset and gain errors. While performing system calibration, the appropriate signal must be applied to the inputs. The system offset calibration command (SYSOCAL) requires a zero input differential signal (see Table 5). It then computes the offset that nullifies the offset in the system. The system gain calibration command (SYSGCAL) requires a positive full-scale input signal. It then computes a value to nullify the gain error in the system. Each of these calibrations takes two t_{DATA} periods to complete. System gain calibration is recommended for the best gain calibration at higher PGAs.

Calibration should be performed after power on, a change in temperature, or a change of the PGA. The RANGE bit (ACR bit 2) must be zero during calibration.

Calibration removes the effects of the ODAC; therefore, disable the ODAC during calibration, and enable again after calibration is complete.

At the completion of calibration, the $\overline{\text{DRDY}}$ signal goes low, indicating the calibration is finished. The first data after calibration should be discarded since it may be corrupt from calibration data remaining in the filter. The second data is always valid.

EXTERNAL VOLTAGE REFERENCE

The ADS1243 requires an external voltage reference. The selection for the voltage reference value is made through the ACR register.

The external voltage reference is differential and is represented by the voltage difference between the pins: +V_{REF} and –V_{REF}. The absolute voltage on either pin, +V_{REF} or –V_{REF}, can range from GND to V_{DD}. However, the following limitations apply:

- For V_{DD} = 5 V and RANGE = 0 in the ACR, the differential V_{REF} must not exceed 2.5 V.
- For V_{DD} = 5 V and RANGE = 1 in the ACR, the differential V_{REF} must not exceed 5 V.
- For V_{DD} = 3 V and RANGE = 0 in the ACR, the differential V_{REF} must not exceed 1.25 V.
- For V_{DD} = 3 V and RANGE = 1 in the ACR, the differential V_{REF} must not exceed 2.5 V.

CLOCK GENERATOR

The clock source for ADS1243 can be provided from a crystal, oscillator, or external clock. When the clock source is a crystal, external capacitors must be provided to ensure start-up and stable clock frequency. This is shown in both Figure 6 and Table 3. X_{OUT} is only for use with external crystals and it should not be used as a clock driver for external circuitry.

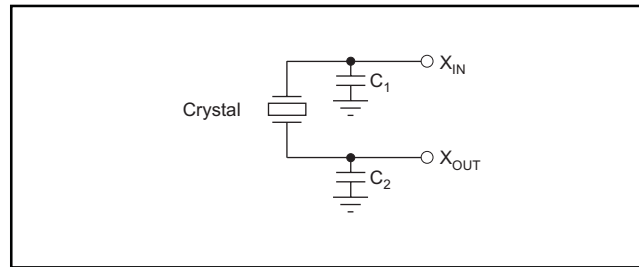


Figure 6. Crystal Connection.

Table 3. Recommended Crystals

| CLOCK SOURCE | FREQUENCY | C ₁ | C ₂ | PART NUMBER |
|--------------|-----------|----------------|----------------|---------------------|
| Crystal | 2.4576 | 0-20 pF | 0-20 pF | ECS, ECSD 2.45 – 32 |
| Crystal | 4.9152 | 0-20 pF | 0-20 pF | ECS, ECSD 4.91 |
| Crystal | 4.9152 | 0-20 pF | 0-20 pF | ECS, ECSD 4.91 |
| Crystal | 4.9152 | 0-20 pF | 0-20 pF | CTS, MP 042 4M9182 |

DIGITAL FILTER

The ADS1243 has a 1279 tap linear phase Finite Impulse Response (FIR) digital filter that a user can configure for various output data rates. When a 2.4576-MHz crystal is used, the device can be programmed for an output data rate of 15 Hz, 7.5 Hz, or 3.75 Hz. Under these conditions, the digital filter rejects both 50Hz and 60Hz interference. Figure 7 shows the digital filter frequency response for data output rates of 15 Hz, 7.5 Hz, and 3.75 Hz.

If a different data output rate is desired, a different crystal frequency can be used. However, the rejection frequencies shift accordingly. For example, a 3.6864-MHz master clock with the default register condition has:

$$(3.6864 \text{ MHz} / 2.4576 \text{ MHz}) \bullet 15 \text{ Hz} = 22.5 \text{ Hz data output rate}$$

and the first and second notch is:

$$1.5 \bullet (50 \text{ Hz and } 60 \text{ Hz}) = 75 \text{ Hz and } 90 \text{ Hz}$$

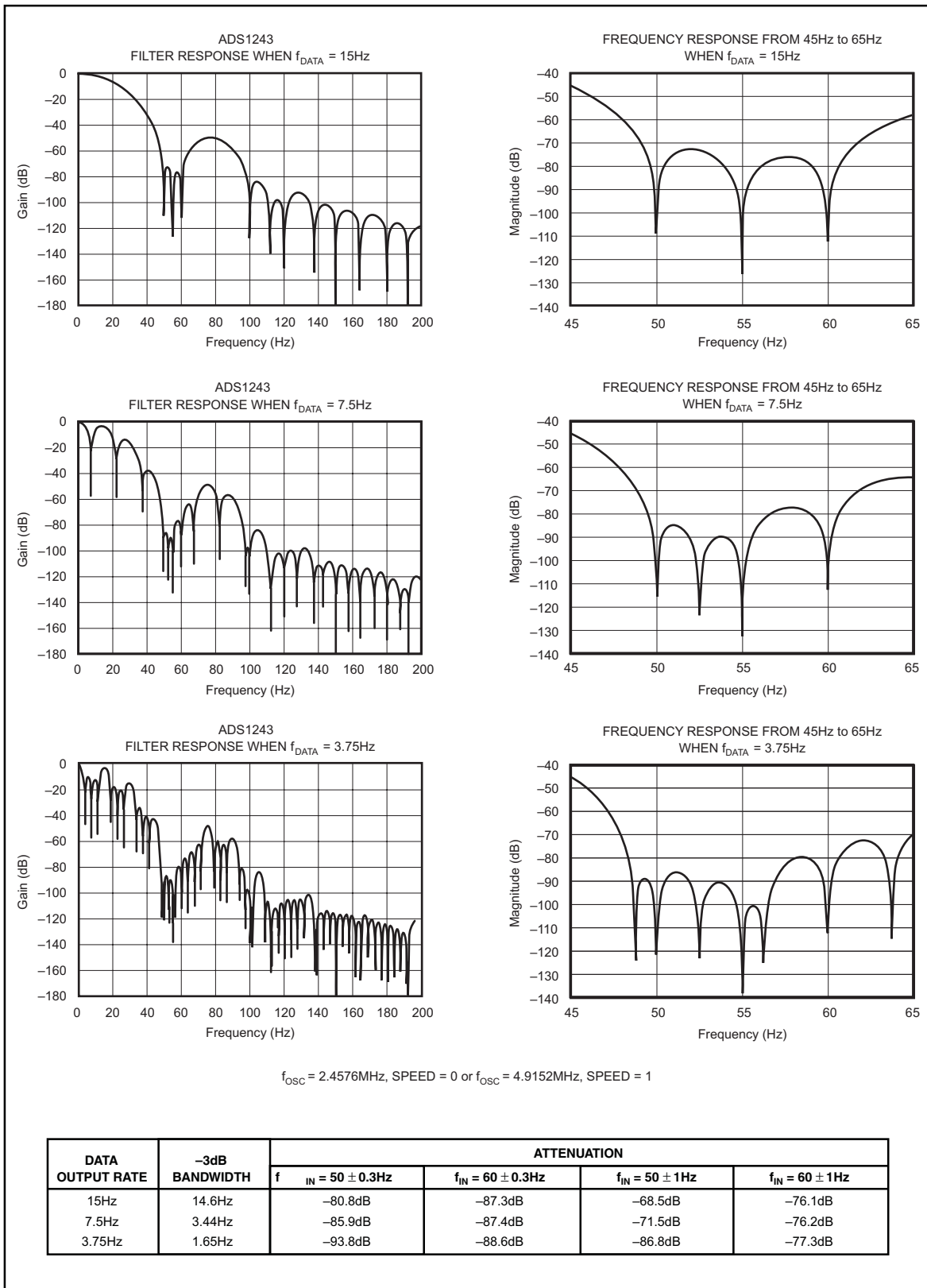


Figure 7. Filter Frequency Responses

DATA I/O INTERFACE

The ADS1243 has eight pins that serve a dual purpose as both analog inputs and data I/O. These pins are configured through the IOCON, DIR, and DIO registers and can be individually configured as either analog inputs or data I/O. See Figure 8 for the equivalent schematic of an Analog/Data I/O pin.

The IOCON register defines the pin as either an analog input or data I/O. The power-up state is an analog input. If the pin is configured as an analog input in the IOCON register, the DIR and DIO registers have no effect on the state of the pin.

If the pin is configured as data I/O in the IOCON register, then DIR and DIO are used to control the state of the pin. The DIR register controls the direction of the data pin, either as an input or output. If the pin is configured as an input in the DIR register, then the corresponding DIO register bit reflects the state of the pin. Make sure the pin is driven to a logic one or zero when configured as an input to prevent excess current dissipation. If the pin is configured as an output in the DIR register, then the corresponding DIO register bit value determines the state of the output pin (0 = GND, 1 = V_{DD}).

It is still possible to perform A/D conversions on a pin configured as data I/O. This may be useful as a test mode, where the data I/O pin is driven and an A/D conversion is done on the pin.

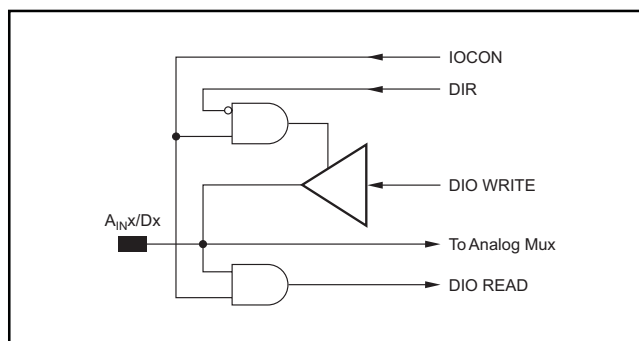


Figure 8. Analog/Data Interface Pin

SERIAL PERIPHERAL INTERFACE

The Serial Peripheral Interface (SPI) allows a controller to communicate synchronously with the ADS1243. The ADS1243 operates in slave-only mode. The serial interface is a standard four-wire SPI (\overline{CS} , SCLK, D_{IN} and D_{OUT}) interface.

Chip Select (\overline{CS})

The chip select (\overline{CS}) input must be externally asserted before communicating with the ADS1243. \overline{CS} must stay LOW for the duration of the communication. Whenever \overline{CS} goes HIGH, the serial interface is reset. \overline{CS} may be hard-wired LOW.

Serial Clock (SCLK)

The serial clock (SCLK) features a Schmitt-triggered input and is used to clock D_{IN} and D_{OUT} data. Make sure to have a clean SCLK to prevent accidental double-shifting of the data. If SCLK is not toggled within three \overline{DRDY} pulses, the serial interface resets on the next SCLK pulse and starts a new communication cycle. A special pattern on SCLK resets the entire chip; see the RESET section for additional information.

Data Input (D_{IN}) and Data Output (D_{OUT})

The data input (D_{IN}) and data output (D_{OUT}) receive and send data from the ADS1243. D_{OUT} is high impedance when not in use to allow D_{IN} and D_{OUT} to be connected together and driven by a bidirectional bus. Note: the Read Data Continuous Mode (RDATAC) command should not be issued when D_{IN} and D_{OUT} are connected. While in RDATAC mode, D_{IN} looks for the STOPC or RESET command. If either of these 8-bit bytes appear on D_{OUT} (which is connected to D_{IN}), the RDATAC mode ends.

DATA READY ($\overline{\text{DRDY}}$) PIN

The $\overline{\text{DRDY}}$ line is used as a status signal to indicate when data is ready to be read from the internal data register. $\overline{\text{DRDY}}$ goes LOW when a new data word is available in the DOR register. It is reset HIGH when a read operation from the data register is complete. It also goes HIGH prior to the updating of the output register to indicate when not to read from the device to ensure that a data read is not attempted while the register is being updated.

The status of $\overline{\text{DRDY}}$ can also be obtained by interrogating bit 7 of the ACR register (address 2_{H}). The serial interface can operate in 3-wire mode by tying the $\overline{\text{CS}}$ input LOW. In this case, the SCLK, D_{IN} , and D_{OUT} lines are used to communicate with the ADS1243. This scheme is suitable for interfacing to microcontrollers. If $\overline{\text{CS}}$ is required as a decoding signal, it can be generated from a port bit of the microcontroller.

DSYNC OPERATION

Synchronization can be achieved through the DSYNC command. When the DSYNC command is sent, the digital filter is reset on the edge of the last SCLK of the DSYNC command. The modulator is held in RESET until the next edge of SCLK is detected. Synchronization occurs on the next rising edge of the system clock after the first SCLK following the DSYNC command.

POWER-UP—SUPPLY VOLTAGE RAMP RATE

The power-on reset circuitry was designed to accommodate digital supply ramp rates as slow as 1 V/10 ms. To ensure proper operation, the power supply should ramp monotonically.

ADS1243 REGISTERS

The operation of the device is set up through individual registers. Collectively, the registers contain all the information needed to configure the part, such as data format, multiplexer settings, calibration settings, data rate, etc. The 16 registers are shown in [Table 4](#).

Table 4. Registers

| ADDRESS | REGISTER | BIT 7 | BIT 6 | BIT 5 | BIT 4 | BIT 3 | BIT 2 | BIT 1 | BIT 0 |
|-----------------|----------|--------------------------|--------------------------------|-------|-------|-----------|-------|-------|-------|
| 00 _H | SETUP | ID | ID | ID | ID | BOCS | PGA2 | PGA1 | PGA0 |
| 01 _H | MUX | PSEL3 | PSEL2 | PSEL1 | PSEL0 | NSEL3 | NSEL2 | NSEL1 | NSEL0 |
| 02 _H | ACR | $\overline{\text{DRDY}}$ | $\text{U}/\overline{\text{B}}$ | SPEED | BUFEN | BIT ORDER | RANGE | DR1 | DR0 |
| 03 _H | ODAC | SIGN | OSET6 | OSET5 | OSET4 | OSET3 | OSET2 | OSET1 | OSET0 |
| 04 _H | DIO | DIO_7 | DIO_6 | DIO_5 | DIO_4 | DIO_3 | DIO_2 | DIO_1 | DIO_0 |
| 05 _H | DIR | DIR_7 | DIR_6 | DIR_5 | DIR_4 | DIR_3 | DIR_2 | DIR_1 | DIR_0 |
| 06 _H | IOCON | IO7 | IO6 | IO5 | IO4 | IO3 | IO2 | IO1 | IO0 |
| 07 _H | OCR0 | OCR07 | OCR06 | OCR05 | OCR04 | OCR03 | OCR02 | OCR01 | OCR00 |
| 08 _H | OCR1 | OCR15 | OCR14 | OCR13 | OCR12 | OCR11 | OCR10 | OCR09 | OCR08 |
| 09 _H | OCR2 | OCR23 | OCR22 | OCR21 | OCR20 | OCR19 | OCR18 | OCR17 | OCR16 |
| 0A _H | FSR0 | FSR07 | FSR06 | FSR05 | FSR04 | FSR03 | FSR02 | FSR01 | FSR00 |
| 0B _H | FSR1 | FSR15 | FSR14 | FSR13 | FSR12 | FSR11 | FSR10 | FSR09 | FSR08 |
| 0C _H | FSR2 | FSR23 | FSR22 | FSR21 | FSR20 | FSR19 | FSR18 | FSR17 | FSR16 |
| 0D _H | DOR2 | DOR23 | DOR22 | DOR21 | DOR20 | DOR19 | DOR18 | DOR17 | DOR16 |
| 0E _H | DOR1 | DOR15 | DOR14 | DOR13 | DOR12 | DOR11 | DOR10 | DOR09 | DOR08 |
| 0F _H | DOR0 | DOR07 | DOR16 | FSR21 | DOR04 | DOR03 | DOR02 | DOR01 | DOR00 |

DETAILED REGISTER DEFINITIONS

Setup

(Address 00_H) Setup Register

Reset Value = iiiii0000

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| ID | ID | ID | ID | BOCS | PGA2 | PGA1 | PGA0 |

bit 7–4 Factory Programmed Bits

bit 3 BOCS: Burnout Current Source

0 = Disabled (default)

1 = Enabled

bit 2–0 PGA2: PGA1: PGA0: Programmable Gain Amplifier

Gain Selection

000 = 1 (default)

001 = 2

010 = 4

011 = 8

100 = 16

101 = 32

110 = 64

111 = 128

MUX

(Address 01_H) Multiplexer Control Register

Reset Value = 01_H

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
| PSEL3 | PSEL2 | PSEL1 | PSEL0 | NSEL3 | NSEL2 | NSEL1 | NSEL0 |

bit 7–4 PSEL3: PSEL2: PSEL1: PSEL0: Positive Channel

Select

- 0000 = A_{IN}0 (default)
- 0001 = A_{IN}1
- 0010 = A_{IN}2
- 0011 = A_{IN}3
- 0100 = A_{IN}4
- 0101 = A_{IN}5
- 0110 = A_{IN}6
- 0111 = A_{IN}7
- 1111 = Reserved

bit 3–0 NSEL3: NSEL2: NSEL1: NSEL0: Negative Channel

Select

- 0000 = A_{IN}0
- 0001 = A_{IN}1 (default)
- 0010 = A_{IN}2
- 0011 = A_{IN}3
- 0100 = A_{IN}4
- 0101 = A_{IN}5
- 0110 = A_{IN}6
- 0111 = A_{IN}7
- 1111 = Reserved

ACR

(Address 02_H) Analog Control Register

Reset Value = X0_H

| | | | | | | | |
|--------------------------|--------------------------|-------|-------|-----------|-------|-------|-------|
| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
| $\overline{\text{DRDY}}$ | U/ $\overline{\text{B}}$ | SPEED | BUFEN | BIT ORDER | RANGE | DR1 | DR0 |

bit 7 $\overline{\text{DRDY}}$: Data Ready (Read Only)
This bit duplicates the state of the $\overline{\text{DRDY}}$ pin.

bit 6 U/B: Data Format
0 = Bipolar (default)
1 = Unipolar

| U/ $\overline{\text{B}}$ | ANALOG INPUT | DIGITAL OUTPUT (Hex) |
|--------------------------|--------------|----------------------|
| 0 | +FSR | 0x7FFFFFFF |
| | Zero | 0x000000 |
| | –FSR | 0x800000 |
| 1 | +FSR | 0xFFFFFFFF |
| | Zero | 0x000000 |
| | –FSR | 0x000000 |

- bit 5 **SPEED:** Modulator Clock Speed
 0 = $f_{MOD} = f_{OSC}/128$ (default)
 1 = $f_{MOD} = f_{OSC}/256$
- bit 4 **BUFEN:** Buffer Enable
 0 = Buffer Disabled (default)
 1 = Buffer Enabled
- bit 3 **BIT ORDER:** Data Output Bit Order
 0 = Most Significant Bit Transmitted First (default)
 1 = Least Significant Bit Transmitted First
 Data is always shifted in or out MSB first.
- bit 2 **RANGE:** Range Select
 0 = Full-Scale Input Range equal to $\pm V_{REF}$ (default).
 1 = Full-Scale Input Range equal to $\pm 1/2 V_{REF}$
NOTE: This allows reference voltages as high as V_{DD} , but even with a 5V reference voltage the calibration must be performed with this bit set to 0.
- bit 1–0 **DR1: DR0:** Data Rate
 ($f_{OSC} = 2.4576\text{MHz}$, $SPEED = 0$)
 00 = 15 Hz (default)
 01 = 7.5 Hz
 10 = 3.75 Hz
 11 = Reserved

ODAC

(Address 03) Offset DAC

 Reset Value = 00_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| SIGN | OSET6 | OSET5 | OSET4 | OSET3 | OSET2 | OSET1 | OSET0 |

- bit 7 **Sign**
 0 = Positive
 1 = Negative

$$\text{Offset} = \frac{V_{REF}}{2 \cdot \text{PGA}} \cdot \left(\frac{\text{OSET}[6:0]}{127} \right) \text{ RANGE} = 0$$

$$\text{Offset} = \frac{V_{REF}}{4 \cdot \text{PGA}} \cdot \left(\frac{\text{OSET}[6:0]}{127} \right) \text{ RANGE} = 1$$

NOTE: The offset DAC must be enabled after calibration or the calibration nullifies the effects.

DIO

 (Address 04_H) Data I/O

 Reset Value = 00_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| DIO 7 | DIO 6 | DIO 5 | DIO 4 | DIO 3 | DIO 2 | DIO 1 | DIO 0 |

If the IOCON register is configured for data, a value written to this register appears on the data I/O pins if the pin is configured as an output in the DIR register. Reading this register returns the value of the data I/O pins.

DIR

(Address 05_H) Direction Control for Data I/O

Reset Value = FF_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| DIR7 | DIR6 | DIR5 | DIR4 | DIR3 | DIR2 | DIR1 | DIR0 |

Each bit controls whether the corresponding data I/O pin is an output (= 0) or input (= 1). The default power-up state is as inputs.

IOCON

(Address 06_H) I/O Configuration Register

Reset Value = 00_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| IO7 | IO6 | IO5 | IO4 | IO3 | IO2 | IO1 | IO0 |

bit 7-0 IO7: IO0: Data I/O Configuration

0 = Analog (default)

1 = Data

Configuring the pin as a data I/O pin allows it to be controlled through the DIO and DIR registers.

ORC0

(Address 07_H) Offset Calibration Coefficient

(Least Significant Byte)

Reset Value = 00_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| OCR07 | OCR06 | OCR05 | OCR04 | OCR03 | OCR02 | OCR01 | OCR00 |

OCR1

(Address 08_H) Offset Calibration Coefficient

(Middle Byte)

Reset Value = 00_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| OCR15 | OCR14 | OCR13 | OCR12 | OCR11 | OCR10 | OCR09 | OCR08 |

OCR2

(Address 09_H) Offset Calibration Coefficient

(Most Significant Byte)

Reset Value = 00_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| OCR23 | OCR22 | OCR21 | OCR20 | OCR19 | OCR18 | OCR17 | OCR16 |

FSR0

(Address 0A_H) Full-Scale Register

(Least Significant Byte)

Reset Value = 59_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| FSR07 | FSR06 | FSR05 | FSR04 | FSR03 | FSR02 | FSR01 | FSR00 |

FSR1

 (Address 0B_H) Full-Scale Register

(Middle Byte)

 Reset Value = 55_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| FSR15 | FSR14 | FSR13 | FSR12 | FSR11 | FSR10 | FSR09 | FSR08 |

FSR2

 (Address 0C_H) Full-Scale Register

(Most Significant Byte)

 Reset Value = 55_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| FSR23 | FSR22 | FSR21 | FSR20 | FSR19 | FSR18 | FSR17 | FSR16 |

DOR2

 (Address 0D_H) Data Output Register

(Most Significant Byte) (Read Only)

 Reset Value = 00_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| DOR23 | DOR22 | DOR21 | DOR20 | DOR19 | DOR18 | DOR17 | DOR16 |

DOR1

 (Address 0E_H) Data Output Register

(Middle Byte) (Read Only)

 Reset Value = 00_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| DOR15 | DOR14 | DOR13 | DOR12 | DOR11 | DOR10 | DOR09 | DOR08 |

DOR0

 (Address 0F_H) Data Output Register

(Least Significant Byte) (Read Only)

 Reset Value = 00_H

| bit 7 | bit 6 | bit 5 | bit 4 | bit 3 | bit 2 | bit 1 | bit 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| DOR07 | DOR06 | DOR05 | DOR04 | DOR03 | DOR02 | DOR01 | DOR00 |

ADS1243 CONTROL COMMAND DEFINITIONS

The commands listed in Table IV control the operations of ADS1243. Some of the commands are stand-alone commands (for example, RESET) while others require additional bytes (for example, WREG requires the count and data bytes).

Operands:

- n = count (0 to 127)
- r = register (0 to 15)
- x = don't care

Table 5. Command Summary

| COMMANDS | DESCRIPTION | OP CODE | 2nd COMMAND BYTE |
|--------------|-------------------------------|---------------------------------|-------------------------|
| | Read Data | 0000 0001 (01 _H) | — |
| | Read Data Continuously | 0000 0011 (03 _H) | — |
| | Stop Read Data Continuously | 0000 1111 (0F _H) | — |
| RDATA RDATAc | Read from REG “rrrr” | 0001 r r r r (1x _H) | xxxx_nnnn (# of regs-1) |
| STOPC RREG | Write to REG “rrrr” | 0101 r r r r (5x _H) | xxxx_nnnn (# of regs-1) |
| WREG SELFCAL | Offset and Gain Self Cal | 1111 0000 (F0 _H) | — |
| SELFOCAL | Self Offset Cal | 1111 0001 (F1 _H) | — |
| SELFGCAL | Self Gain Cal | 1111 0010 (F2 _H) | — |
| SYSOCAL | Sys Offset Cal | 1111 0011 (F3 _H) | — |
| SYSGCAL | Sys GainCal | 1111 0100 (F4 _H) | — |
| WAKEUP | Wakeup from SLEEP Mode | 1111 1011 (FB _H) | — |
| DSYNC SLEEP | Sync $\overline{\text{DRDY}}$ | 1111 1100 (FC _H) | — |
| RESET | Put in SLEEP Mode | 1111 1101 (FD _H) | — |
| | Reset to Power-Up Values | 1111 1110 (FE _H) | — |

NOTE: The received data format is always MSB first; the data out format is set by the BIT ORDER bit in the ACR register.

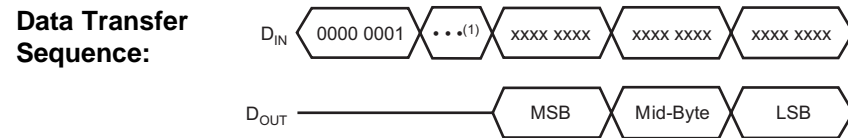
RDATA–Read Data

Description: Read the most recent conversion result from the Data Output Register (DOR). This is a 24-bit value.

Operands: None

Bytes: 1

Encoding: 0000 0001



(1) For wait time, refer to timing specification.

RDATAc–Read Data Continuous

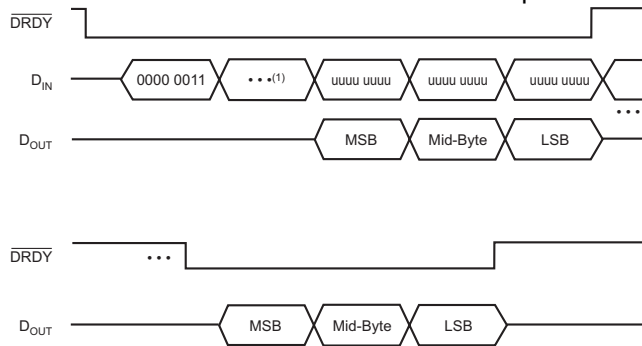
Description: Read Data Continuous mode enables the continuous output of new data on each $\overline{\text{DRDY}}$. This command eliminates the need to send the Read Data Command on each $\overline{\text{DRDY}}$. This mode may be terminated by either the STOPC command or the RESET command. Wait at least 10 f_{OSC} after $\overline{\text{DRDY}}$ falls before reading.

Operands: None

Bytes: 1

Encoding: 0000 0011

Data Transfer Sequence: Command terminated when “uuuu uuuu” equals STOPC or RESET.



(1)For wait time, refer to timing specification.

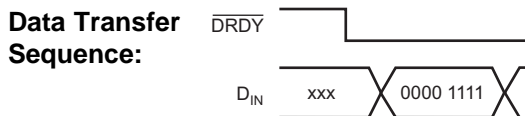
STOPC–Stop Continuous

Description: Ends the continuous data output mode. Issue after \overline{DRDY} goes LOW.

Operands: None

Bytes: 1

Encoding: 0000 1111



RREG–Read from Registers

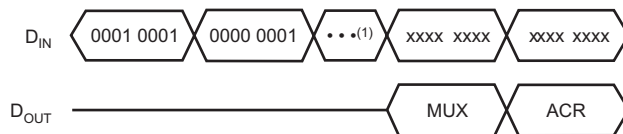
Description: Output the data from up to 16 registers starting with the register address specified as part of the instruction. The number of registers read will be one plus the second byte count. If the count exceeds the remaining registers, the addresses wrap back to the beginning.

Operands: r, n

Bytes: 2

Encoding: 0001 rrrr xxxx nnnn

Data Transfer Sequence: Read Two Registers Starting from Register 01_H (MUX)



(1)For wait time, refer to timing specification.

WREG–Write to Registers

Description: Write to the registers starting with the register address specified as part of the instruction. The number of registers that will be written is one plus the value of the second byte.

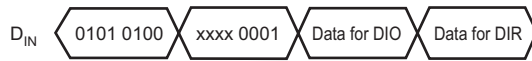
Operands: r, n

Bytes: 2

Encoding: 0101 rrrr xxxx nnnn

Data Transfer Write Two Registers Starting from 04_H (DIO)

Sequence:



SELFCAL–Offset and Gain Self Calibration

Description: Starts the process of self calibration. The Offset Calibration Register (OCR) and the Full-Scale Register (FSR) are updated with new values after this operation.

Operands: None

Bytes: 1

Encoding: 1111 0000

Data Transfer Sequence: D_{IN} { 1111 0000 }

SELFOCAL–Offset Self Calibration

Description: Starts the process of self-calibration for offset. The Offset Calibration Register (OCR) is updated after this operation.

Operands: None

Bytes: 1

Encoding: 1111 0001

Data Transfer Sequence: D_{IN} { 1111 0001 }

SELFGCAL–Gain Self Calibration

Description: Starts the process of self-calibration for gain. The Full-Scale Register (FSR) is updated with new values after this operation.

Operands: None

Bytes: 1

Encoding: 1111 0010

Data Transfer Sequence: D_{IN} { 1111 0010 }

SYSOCAL–System Offset Calibration

Description: Initiates a system offset calibration. The input should be set to 0V, and the ADS1243 computes the OCR value that compensates for offset errors. The Offset Calibration Register (OCR) is updated after this operation. The user must apply a zero input signal to the appropriate analog inputs. The OCR register is automatically updated afterwards.

Operands: None

Bytes: 1

Encoding: 1111 0011

Data Transfer Sequence: D_{IN} { 1111 0011 }

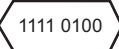
SYSGCAL–System Gain Calibration

Description: Starts the system gain calibration process. For a system gain calibration, the input should be set to the reference voltage and the ADS1243 computes the FSR value that will compensate for gain errors. The FSR is updated after this operation. To initiate a system gain calibration, the user must apply a full-scale input signal to the appropriate analog inputs. FCR register is updated automatically.

Operands: None

Bytes: 1

Encoding: 1111 0100

Data Transfer Sequence: D_{IN} 

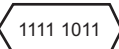
WAKEUP

Description: Wakes the ADS1243 from SLEEP mode.

Operands: None

Bytes: 1

Encoding: 1111 1011

Data Transfer Sequence: D_{IN} 

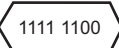
DSYNC–Sync \overline{DRDY}

Description: Synchronizes the ADS1243 to an external event.

Operands: None

Bytes: 1

Encoding: 1111 1100

Data Transfer Sequence: D_{IN} 

SLEEP–Sleep Mode

Description: Puts the ADS1243 into a low power sleep mode. To exit sleep mode, issue the WAKEUP command.

Operands: None

Bytes: 1

Encoding: 1111 1101

Data Transfer Sequence: D_{IN} 

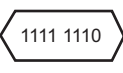
RESET–Reset to Default Values

Description: Restore the registers to their power-up values. This command stops the Read Continuous mode.

Operands: None

Bytes: 1

Encoding: 1111 1110

Data Transfer Sequence: D_{IN} A diagram showing a data transfer sequence. It consists of a hexagonal shape with a pointed right side. Inside the hexagon, the binary sequence '1111 1110' is written. To the left of the hexagon, the label 'D_{IN}' is positioned.

APPLICATION INFORMATION

GENERAL-PURPOSE WEIGHT SCALE

Figure 9 shows a typical schematic of a general-purpose weight scale application using the ADS1243. In this example, the internal PGA is set to either 64 or 128 (depending on the maximum output voltage of the load cell) so that the load cell output can be directly applied to the differential inputs of ADS1243.

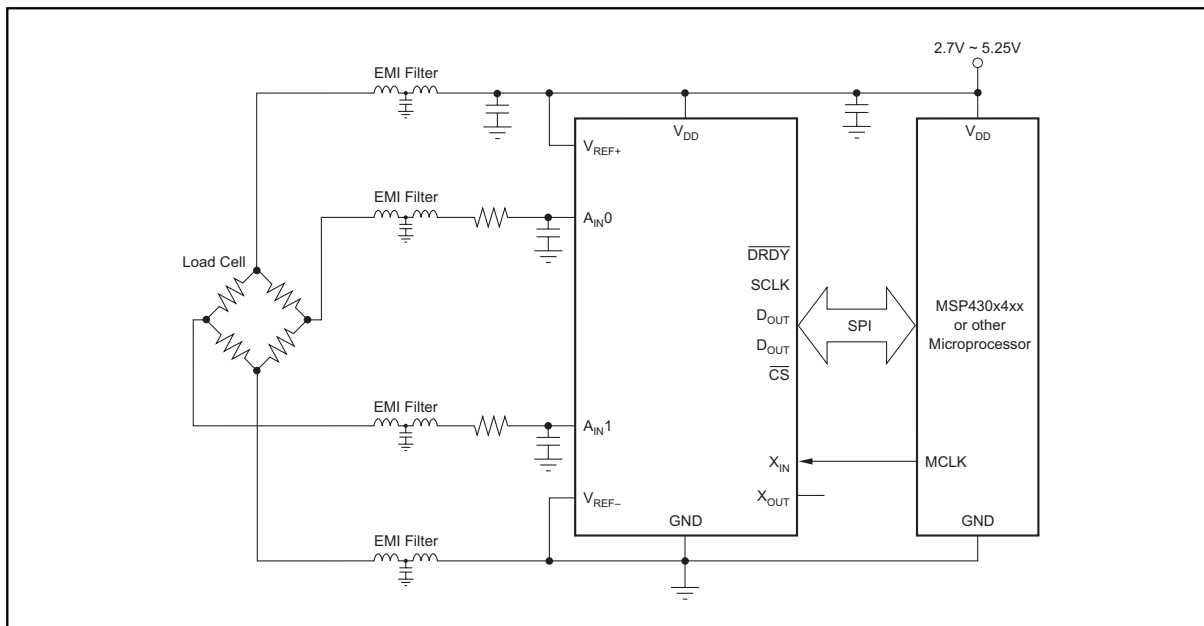


Figure 9. Schematic of a General-Purpose Weight Scale.

HIGH PRECISION WEIGHT SCALE

Figure 10 shows the typical schematic of a high-precision weight scale application using the ADS1243. The front-end differential amplifier helps maximize the dynamic range.

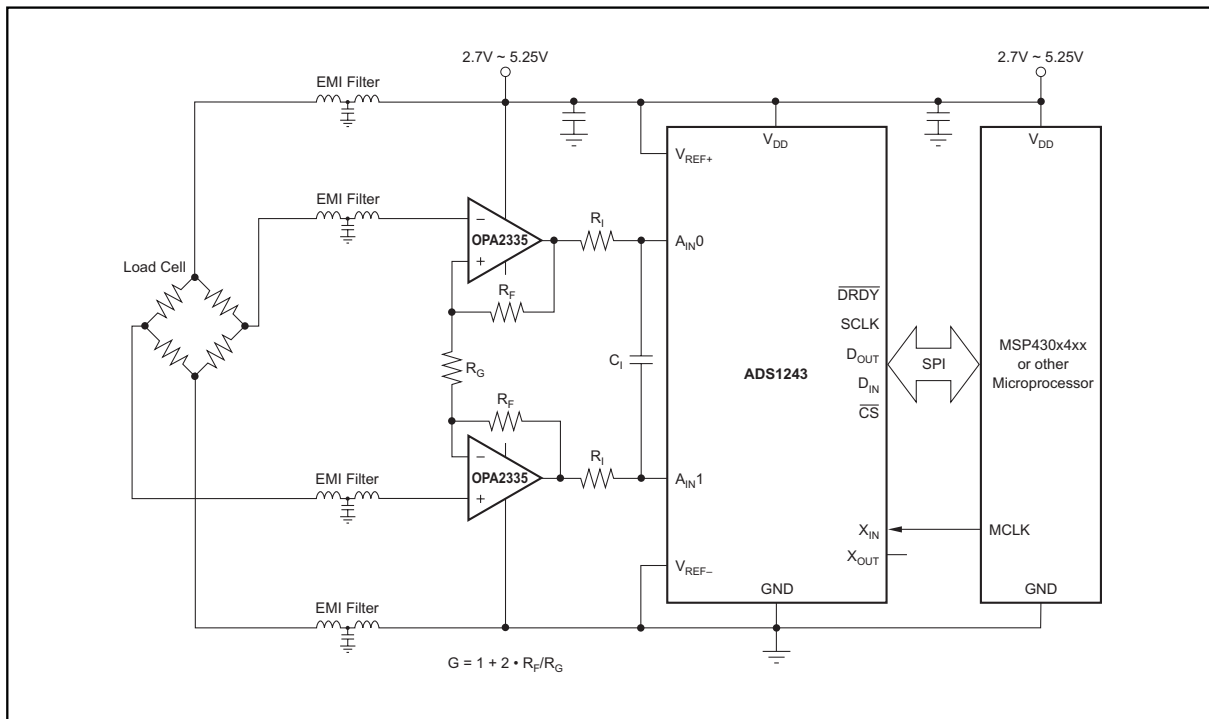


Figure 10. Block Diagram for a High-Precision Weight Scale.

DEFINITION OF TERMS

An attempt has been made to be consistent with the terminology used in this data sheet. In that regard, the definition of each term is given as follows:

Analog Input Voltage – the voltage at any one analog input relative to GND.

Analog Input Differential Voltage – given by the following equation: (IN+) – (IN–). Thus, a positive digital output is produced whenever the analog input differential voltage is positive, while a negative digital output is produced whenever the differential is negative.

For example, when the converter is configured with a 2.5-V reference and placed in a gain setting of 1, the positive full-scale output is produced when the analog input differential is 2.5 V. The negative full-scale output is produced when the differential is –2.5 V. In each case, the actual input voltages must remain within the GND to V_{DD} range.

Conversion Cycle – the term conversion cycle usually refers to a discrete A/D conversion operation, such as that performed by a successive approximation converter. As used here, a conversion cycle refers to the t_{DATA} time period.

Data Rate – The rate at which conversions are completed. See definition for f_{DATA} .

$$f_{DATA} = \frac{f_{OSC}}{128 \cdot 2^{SPEED} \cdot 1280 \cdot 2^{DR}}$$

SPEED = 0, 1
DR = 0, 1, 2

f_{OSC} – the frequency of the crystal oscillator or CMOS compatible input signal at the X_{IN} input of the ADS1243.

f_{MOD} – the frequency or speed at which the modulator of the ADS1243 is running. This depends on the SPEED bit as given by the following equation:

| | SPEED = 0 | SPEED = 1 |
|---------|-----------|-----------|
| mfactor | 128 | 256 |

$$f_{MOD} = \frac{f_{OSC}}{mfactor} = \frac{f_{OSC}}{128 \cdot 2^{SPEED}}$$

| PGA SETTING | SAMPLING FREQUENCY |
|-------------|--|
| 1, 2, 4, 8 | $f_{SAMP} = \frac{f_{OSC}}{mfactor}$ |
| 16 | $f_{SAMP} = \frac{f_{OSC} \cdot 2}{mfactor}$ |
| 32 | $f_{SAMP} = \frac{f_{OSC} \cdot 4}{mfactor}$ |
| 64, 128 | $f_{SAMP} = \frac{f_{OSC} \cdot 8}{mfactor}$ |

f_{SAMP} – the frequency, or switching speed, of the input sampling capacitor. The value is given by one of the following equations:

f_{DATA} – the frequency of the digital output data produced by the ADS1243, f_{DATA} is also referred to as the Data Rate.

Full-Scale Range (FSR) – as with most A/D converters, the full-scale range of the ADS1243 is defined as the input, that produces the positive full-scale digital output minus the input, that produces the negative full-scale digital output.

For example, when the converter is configured with a 2.5-V reference and is placed in a gain setting of 2, the full-scale range is: [1.25 V (positive full-scale) minus –1.25 V (negative full-scale)] = 2.5 V.

Least Significant Bit (LSB) Weight – this is the theoretical amount of voltage that the differential voltage at the analog input has to change in order to observe a change in the output data of one least significant bit. It is computed as follows:

$$\text{LSBWeight} = \frac{\text{Full-Scale Range}}{2^N - 1}$$

where N is the number of bits in the digital output.

t_{DATA} – the inverse of f_{DATA}, or the period between each data output.

Table 6. Full-Scale Range versus PGA Setting

| GAIN SETTING | 5V SUPPLY ANALOG INPUT ⁽¹⁾ | | | GENERAL EQUATIONS | | |
|--------------|---------------------------------------|--|------------------|-----------------------|--|-----------------------------------|
| | FULL-SCALE RANGE | DIFFERENTIAL INPUT VOLTAGES ⁽²⁾ | PGA OFFSET RANGE | FULL-SCALE RANGE | DIFFERENTIAL INPUT VOLTAGES ⁽²⁾ | PGA SHIFT RANGE |
| 1 | 5 V | ±2.5 V | ±1.25 V | RANGE = 0 | | |
| 2 | 2.5 V | ±1.25 V | ±0.625 V | $\frac{V_{REF}}{PGA}$ | $\frac{\pm V_{REF}}{2 \cdot PGA}$ | $\frac{\pm V_{REF}}{4 \cdot PGA}$ |
| 4 | 1.25 V | ±0.625 V | ±312.5 mV | | | |
| 8 | 0.625 V | ±312.5 mV | ±156.25 mV | RANGE = 1 | | |
| 16 | 312.5 mV | ±156.25 mV | ±78.125 mV | | | |
| 32 | 156.25 mV | ±78.125 mV | ±39.0625 mV | | | |
| 64 | 78.125 mV | ±39.0625 mV | ±19.531 mV | | | |
| 128 | 39.0625 mV | ±19.531 mV | ±9.766 mV | | | |

(1) With a 2.5-V reference.

(2) Refer to electrical specification for analog input voltage range.

PACKAGING INFORMATION

| Orderable Device | Status ⁽¹⁾ | Package Type | Package Drawing | Pins | Package Qty | Eco Plan ⁽²⁾ | Lead/Ball Finish | MSL Peak Temp ⁽³⁾ | Samples (Requires Login) |
|------------------|-----------------------|--------------|-----------------|------|-------------|-------------------------|------------------|------------------------------|--------------------------|
| ADS1243SJD | ACTIVE | CDIP SB | JD | 20 | 1 | TBD | AU | N / A for Pkg Type | |
| ADS1243SKGD1 | ACTIVE | XCEPT | KGD | 0 | 121 | TBD | Call TI | N / A for Pkg Type | |

⁽¹⁾ The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSELETE: TI has discontinued the production of the device.

⁽²⁾ Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

⁽³⁾ MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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OTHER QUALIFIED VERSIONS OF ADS1243-HT :

- Catalog: [ADS1243](#)

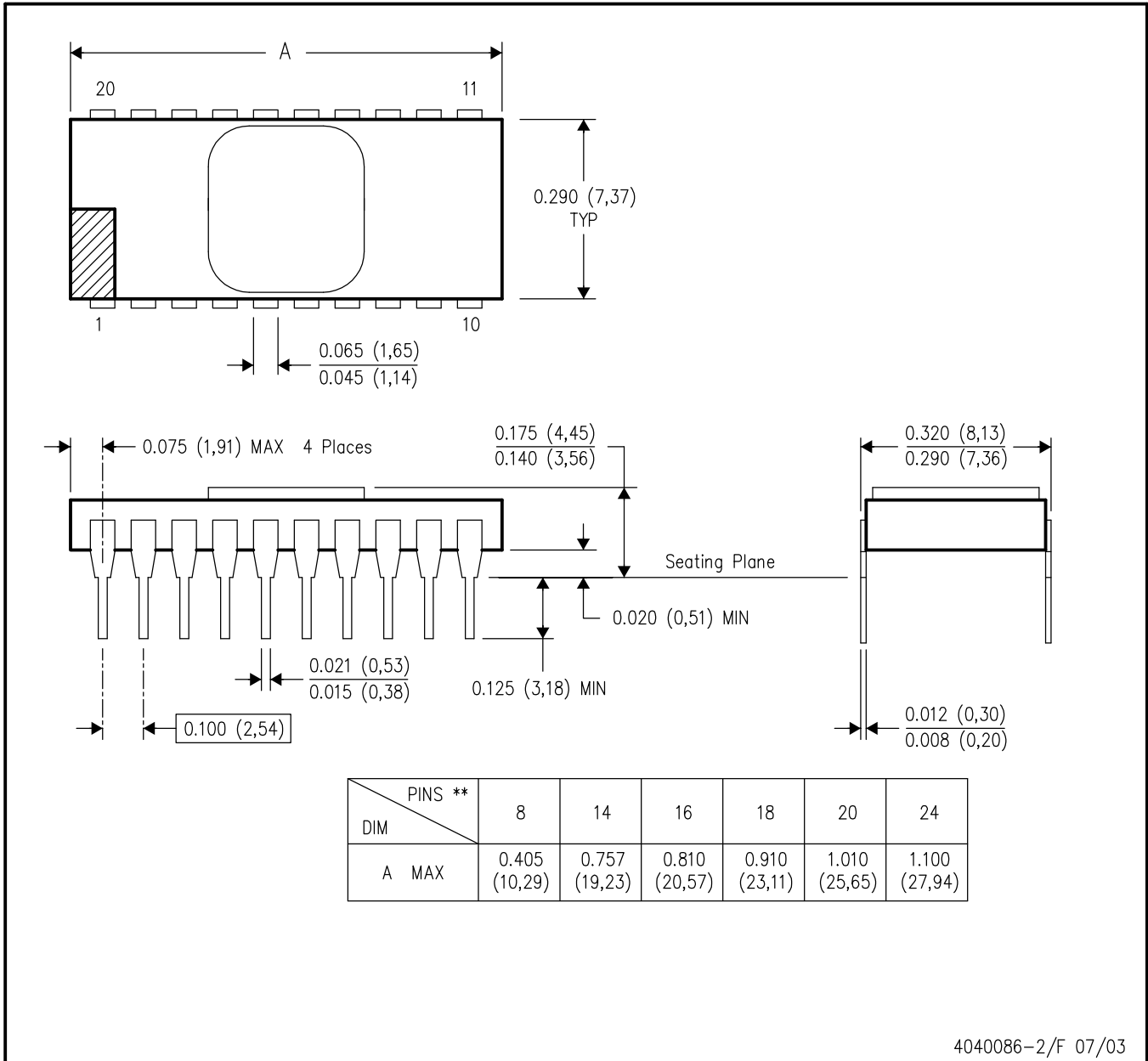
NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product

JD (R-CDIP-T**)

CERAMIC SIDE-BRAZE DUAL-IN-LINE PACKAGE

20 PINS SHOWN



4040086-2/F 07/03

- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 - C. This package is hermetically sealed with a metal lid.
 - D. The terminals are gold plated.
 - E. Falls within MIL STD 1835 CDIP2 - T8, T14, T16, T18, T20 and T24 respectively.

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