

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

1.0 General Description

The LMP90100/LMP90099/LMP90098/LMP90097 are highly integrated, multi-channel, low power 24-bit Sensor AFEs. The devices features a precision, 24-bit Sigma Delta Analog-to-Digital Converter (ADC) with a low-noise programmable gain amplifier and a fully differential high impedance analog input multiplexer. A true continuous background calibration feature allows calibration at all gains and output data rates without interrupting the signal path. The background calibration feature essentially eliminates gain and offset errors across temperature and time, providing measurement accuracy without sacrificing speed and power consumption.

Another feature of the LMP90100/LMP90099/LMP90098/LMP90097 is continuous background sensor diagnostics, allowing the detection of open and short circuit conditions and out-of-range signals, without requiring user intervention, resulting in enhanced system reliability.

Two sets of independent external reference voltage pins allow multiple ratiometric measurements. In addition, two matched programmable current sources are available in the LMP90100/LMP90098 to excite external sensors such as resistive temperature detectors and bridge sensors. Furthermore, seven GPIO pins are provided for interfacing to external LEDs and switches to simplify control across an isolation barrier.

Collectively, these features make the LMP90100/LMP90099/LMP90098/LMP90097 complete analog front-ends for low power, precision sensor applications such as temperature, pressure, strain gauge, and industrial process control. The LMP90100/LMP90099/LMP90098/LMP90097 are guaranteed over the extended temperature range of -40°C to +125°C and are available in a 28-pin TSSOP package.

2.0 Features

- 24-Bit Low Power Sigma Delta ADC
- True Continuous Background Calibration at all gains
- In-Place System Calibration using Expected Value programming

- Low-Noise programmable gain (1x - 128x)
- Continuous background open/short and out of range sensor diagnostics
- 8 output data rates (ODR) with single-cycle settling
- 2 matched excitation current sources from 100 μ A to 1000 μ A (LMP90100/LMP90098)
- 4-DIFF / 7-SE inputs (LMP90100/LMP90099)
- 2-DIFF / 4-SE inputs (LMP90098/LMP90097)
- 7 General Purpose Input/Output pins
- Chopper-stabilized buffer for low offset
- SPI 4/3-wire with CRC data link error detection
- 50 Hz to 60 Hz line rejection at ODR \leq 13.42 SPS
- Independent gain and ODR selection per channel
- Supported by Webench Sensor AFE Designer
- Automatic Channel Sequencer

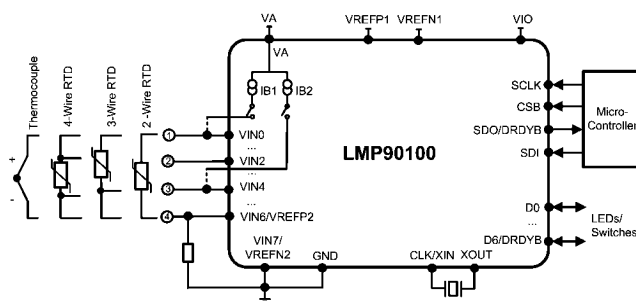
3.0 Key Specifications

| | |
|------------------------------------|-------------------------|
| ■ ENOB/NFR | Up to 21.5/19 bits |
| ■ Offset Error (typ) | 8.4 nV |
| ■ Gain Error (typ) | 7 ppm |
| ■ Total Noise | < 10 μ V-rms |
| ■ Integral Non-Linearity (INL max) | \pm 15 ppm of FSR |
| ■ Output Data Rates (ODR) | 1.6775 SPS - 214.65 SPS |
| ■ Analog Voltage, VA | +2.85V to +5.5V |
| ■ Operating Temp Range | -40°C to 125°C |
| ■ Package | 28-Pin TSSOP |

4.0 Applications

- Temperature and Pressure Transmitters
- Strain Gauge Interface
- Industrial Process Control

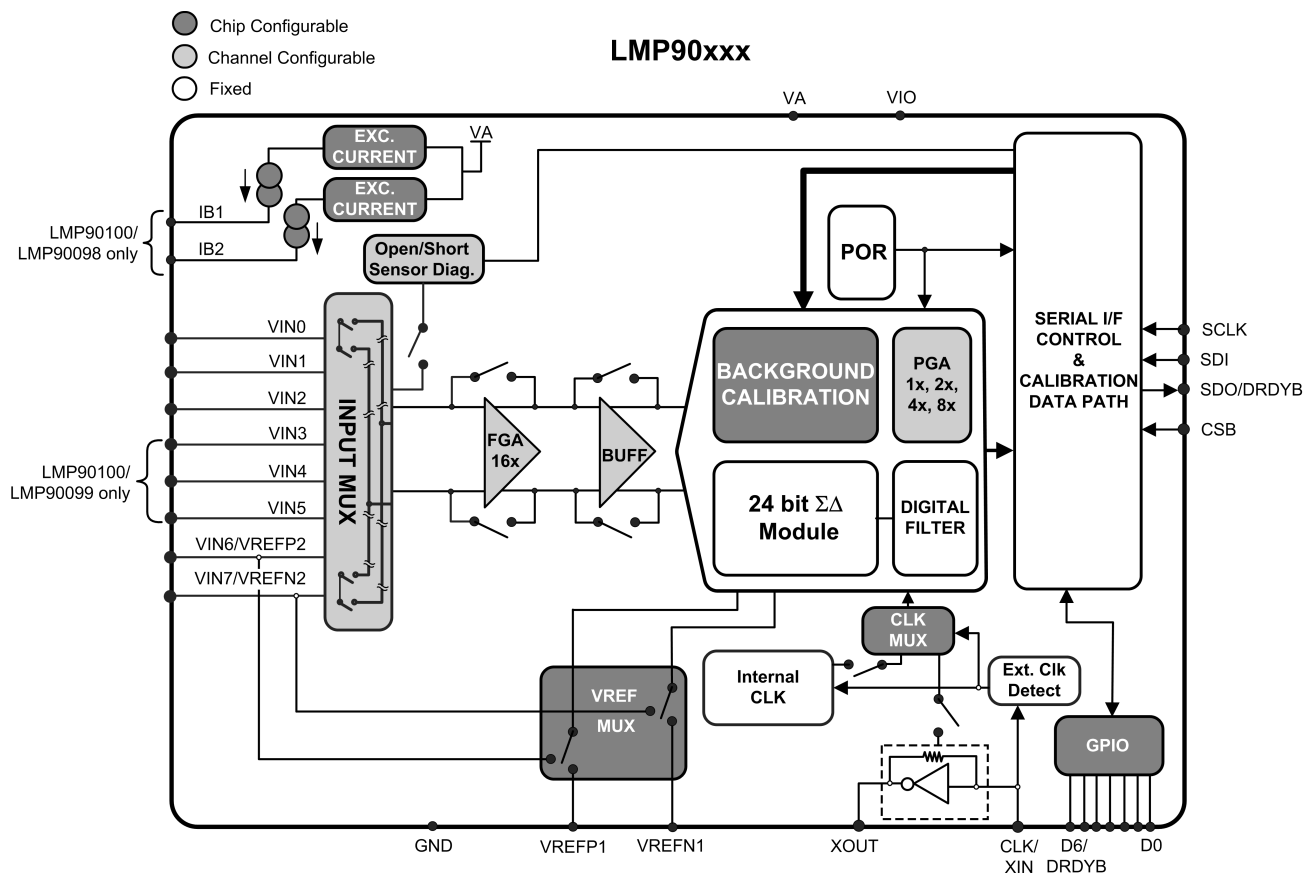
5.0 Typical Application



| LMP90xxx 24-bit Sensor AFE Family of Products | | |
|---|-------------------------------|-----------------|
| Product | Channel Configuration | Current Sources |
| LMP90100 | 4 Differential/7 Single-Ended | Yes |
| LMP90099 | 4 Differential/7 Single-Ended | No |
| LMP90098 | 2 Differential/4 Single-Ended | Yes |
| LMP90097 | 2 Differential/4 Single-Ended | No |

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6.0 Block Diagram



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FIGURE 1. Block Diagram

• True Continuous Background Calibration

The LMP90100/LMP90099/LMP90098/LMP90097 feature a 24 bit $\Sigma\Delta$ core with continuous background calibration to compensate for gain and offset errors in the ADC, virtually eliminating any drift with time and temperature. The calibration is performed in the background without user or ADC input interruption, making it unique in the industry and eliminating down time associated with field calibration required with other solutions. Having this continuous calibration improves performance over the entire life span of the end product.

• Continuous Background Sensor Diagnostics

Sensor diagnostics are also performed in the background, without interfering with signal path performance, allowing the detection of sensor shorts, opens, and out-of-range signals, which vastly improves system reliability. In addition, the fully flexible input multiplexer described below allows any input pin to be connected to any ADC input channel providing additional sensor path diagnostic capability.

• Flexible Input MUX Channels

The flexible input MUX allows interfacing to a wide range of sensors such as thermocouples, RTDs, thermistors, and

bridge sensors. The LMP90100/LMP90099's multiplexer supports 4 differential channels while the LMP90098/LMP90097 supports 2. Each effective input voltage that is digitized is $VIN = VINx - VINy$, where x and y are any input. In addition, the input multiplexer of the LMP90100/LMP90099 also supports 7 single-ended channels (LMP90098/LMP90097 supports 4), where the common ground is any one of the inputs.

• Programmable Gain Amplifiers (FGA & PGA)

The LMP90100/LMP90099/LMP90098/LMP90097 contain an internal 16x fixed gain amplifier (FGA) and a 1x, 2x, 4x, or 8x programmable gain amplifier (PGA). This allows accurate gain settings of 1x, 2x, 4x, 8x, 16x, 32x, 64x, or 128x through configuration of internal registers. Having an internal amplifier eliminates the need for external amplifiers that are costly, space consuming, and difficult to calibrate.

• Excitation Current Sources (IB1 & IB2) - LMP90100/LMP90098

Two matched internal excitation currents, IB1 and IB2, can be used for sourcing currents to a variety of sensors. The current range is from 100 μA to 1000 μA in steps of 100 μA .

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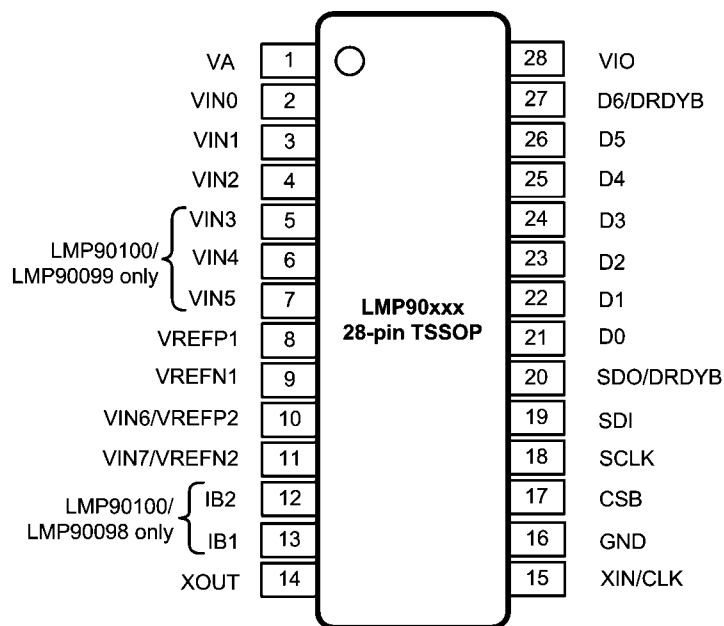
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7.0 Ordering Information

| Product | Channel Configuration | Current Sources |
|----------|---------------------------------|-----------------|
| LMP90100 | 4 Differential / 7 Single-Ended | Yes |
| LMP90099 | 4 Differential / 7 Single-Ended | No |
| LMP90098 | 2 Differential / 4 Single-Ended | Yes |
| LMP90097 | 2 Differential / 4 Single-Ended | No |

| Order Code | Temperature Range | Description |
|------------------|-------------------|-------------------------------------|
| LMP90100MH/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Rail of 48 |
| LMP90100MHE/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Reel of 250 |
| LMP90100MHX/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Reel of 2500 |
| LMP90099MH/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Rail of 48 |
| LMP90099MHE/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Reel of 250 |
| LMP90099MHX/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Reel of 2500 |
| LMP90098MH/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Rail of 48 |
| LMP90098MHE/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Reel of 250 |
| LMP90098MHX/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Reel of 2500 |
| LMP90097MH/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Rail of 48 |
| LMP90097MHE/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Reel of 250 |
| LMP90097MHX/NOPB | -40°C to +125°C | 28-Lead TSSOP Package, Reel of 2500 |

8.0 Connection Diagram



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See Pin Descriptions for specific information regarding options LMP90099, LMP90098, and LMP90097.

9.0 Pin Descriptions

| Pin # | Pin Name | Type | Function |
|------------------------------------|---------------|----------------|--|
| 1 | VA | Analog Supply | Analog power supply pin |
| 2 - 4 | VIN0 - VIN2 | Analog Input | Analog input pins |
| 5 - 7 (LMP90100, LMP90099) | VIN3 - VIN5 | Analog Input | Analog input pins |
| 5 - 7 (LMP90098, LMP90097) | VIN3 - VIN5 | No Connect | No connect: must be left unconnected |
| 8 | VREFP1 | Analog Input | Positive reference input |
| 9 | VREFN1 | Analog Input | Negative reference input |
| 10 | VIN6 / VREFP2 | Analog Input | Analog input pin or VREFP2 input |
| 11 | VIN7 / VREFN2 | Analog Input | Analog input pin or VREFN2 input |
| 12 - 13 (LMP90100, LMP90098) | IB2 & IB1 | Analog output | Excitation current sources for external RTDs |
| 12 - 13 (LMP90099, LMP90097) | IB2 & IB1 | No Connect | No connect: must be left unconnected |
| 14 | XOUT | Analog output | External crystal oscillator connection |
| 15 | XIN / CLK | Analog input | External crystal oscillator connection or external clock input |
| 16 | GND | Ground | Power supply ground |
| 17 | CSB | Digital Input | Chip select bar |
| 18 | SCLK | Digital Input | Serial clock |
| 19 | SDI | Digital Input | Serial data input |
| 20 | SDO / DRDYB | Digital Output | Serial data output and data ready bar |
| 21 - 26 | D0 - D5 | Digital IO | General purpose input/output (GPIO) pins |
| 27 | D6 / DRDYB | Digital IO | General purpose input/output pin or data ready bar |
| 28 | VIO | Digital Supply | Digital input/output supply pin |

10.0 Absolute Maximum Ratings *(Note 1, Note 2)*

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

| | |
|---|---------------------|
| Analog Supply Voltage, VA | -0.3V to 6.0V |
| Digital I/O Supply Voltage, VIO | -0.3V to 6.0V |
| Reference Voltage, VREF | -0.3V to VA+0.3V |
| Voltage on Any Analog Input Pin to GND <i>(Note 3)</i> | -0.3V to VA+0.3V |
| Voltage on Any Digital Input PIN to GND <i>(Note 3)</i> | -0.3V to VIO+0.3V |
| Voltage on SDO <i>(Note 3)</i> | -0.3V to VIO + 0.3V |
| Input Current at Any Pin <i>(Note 3)</i> | 5mA |
| Output Current Source or Sink by SDO | 3mA |
| Total Package Input and Output Current | 20mA |
| ESD Susceptibility | |
| Human Body Model (HBM) | 2500V |

| | |
|---|-----------------|
| Machine Models (MM) | 200V |
| Charged Device Model (CDM) | 1250V |
| Junction Temperature (T_{JMAX}) | +150°C |
| Storage Temperature Range | -65°C to +150°C |
| For soldering specifications: | |
| see product folder at www.national.com and www.national.com/ms/MS/MS-SOLDERING.pdf | |

11.0 Operating Ratings

| | |
|--|---|
| Analog Supply Voltage, VA | +2.85V to 5.5V |
| Digital I/O Supply Voltage, VIO | +2.7V to 5.5V |
| Full Scale Input Range, VIN | ±VREF / PGA |
| Reference Voltage, VREF | +0.5V to VA |
| Temperature Range for Electrical Characteristics | $T_{MIN} = -40^{\circ}C$ $T_{MAX} = +125^{\circ}C$ |
| Operating Temperature Range | $-40^{\circ}C \leq T_A \leq +125^{\circ}C$ |
| Junction to Ambient Thermal Resistance (θ_{JA}) <i>(Note 4)</i> | 41°C/W |

12.0 Electrical Characteristics

Unless otherwise noted, the key for the condition is (VA = VIO = VREF) / ODR (SPS) / buffer / calibration / gain . Boldface limits apply for $T_{MIN} \leq T_A \leq T_{MAX}$; the typical values apply for $T_A = +25^{\circ}C$.

| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|------------|--|--|--------|-------------------------|-------|-----------------|
| n | Resolution | | | 24 | | Bits |
| ENOB / NFR | Effective Number of Bits and Noise Free Resolution | 3V / all / ON / OFF / all. Shorted input. | | <i>Table 1</i> | | Bits |
| | | 5V / all / ON / OFF / all. Shorted input. | | <i>Table 3</i> | | Bits |
| ODR | Output Data Rates | | 1.6675 | <i>Table 1</i> | 214.6 | SPS |
| | Gain | FGA × PGA | 1 | <i>Table 1</i> | 128 | |
| INL | Integral Non-Linearity | 3V / 214.65 / ON / ON / 1 | -1 | ± 0.5 | +1 | LSB |
| | | 3V & 5V / 214.65 / ON / ON / 16 | | ± 1 | | LSB |
| | Total Noise | 3V / all / ON / ON / all. Shorted input. | | <i>Table 2</i> | | μV |
| | | 5V / all / ON / OFF / all. Shorted input. | | <i>Table 4</i> | | μV |
| OE | Offset Error | 3V & 5V / all / ON or OFF / ON / all | | Below Noise Floor (rms) | | μV |
| | | 3V / 214.65 / ON / ON / 1 | | 1.22 | 9.52 | μV |
| | | 3V / 214.65 / ON / ON / 128 | | 0.00838 | 0.70 | μV |
| | | 5V / 214.65 / ON / ON / 1 | | 1.79 | 8.25 | μV |
| | | 5V / 214.65 / ON / ON / 128 | | 0.0112 | 0.63 | μV |
| | Offset Drift Over Temp <i>(Note 5)</i> | 3V & 5V / 214.65 / ON or OFF / OFF / 1-8 | | 100 | | nV/°C |
| | | 3V & 5V / 214.65 / ON / ON / 1-8 | | 3 | | nV/°C |
| | | 3V & 5V / 214.65 / ON / OFF / 16 | | 25 | | nV/°C |
| | | 3V & 5V / 214.65 / ON / ON / 16 | | 0.4 | | nV/°C |
| | | 3V & 5V / 214.65 / ON / OFF / 128 | | 6 | | nV/°C |
| | | 3V & 5V / 214.65 / ON / ON / 128 | | 0.125 | | nV/°C |
| | Offset Drift over Time <i>(Note 5)</i> | 5V / 214.65 / ON / OFF / 1, $T_A = 150^{\circ}C$ | | 2360 | | nV / 1000 hours |
| | | 5V / 214.65 / ON / ON / 1, $T_A = 150^{\circ}C$ | | 100 | | nV / 1000 hours |

| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|------------------------------|--------------------------------------|--|------|------|------|------------------|
| GE | Gain Error | 3V & 5V / 214.65 / ON / ON / 1 | -80 | 7 | 80 | ppm |
| | | 3V & 5V / 13.42 / ON / ON / 16 | | 50 | | ppm |
| | | 3V & 5V / 13.42 / ON / ON / 64 | | 50 | | ppm |
| | | 3V & 5V / 13.42 / ON / ON / 128 | | 100 | | ppm |
| | Gain Drift over Temp (Note 5) | 3V & 5V / 214.65 / ON / ON / all | | 0.5 | | ppm/°C |
| | Gain Drift over Time (Note 5) | 5V / 214.65 / ON / OFF / 1, T _A = 150°C | | 5.9 | | ppm / 1000 hours |
| | | 5V / 214.65 / ON / ON / 1, T _A = 150°C | | 1.6 | | ppm / 1000 hours |
| CONVERTER'S CHARACTERISTIC | | | | | | |
| CMRR | Input Common Mode Rejection Ratio | DC, 3V / 214.65 / ON / ON / 1 | 70 | 117 | | dB |
| | | DC, 5V / 214.65 / OFF / OFF / 1 | 90 | 120 | | dB |
| | | 50/60 Hz, 5V / 214.65 / OFF / OFF / 1 | | 117 | | dB |
| | Reference Common Mode Rejection | VREF = 2.5V | | 101 | | dB |
| PSRR | Power Supply Rejection Ratio | DC, 3V / 214.65 / ON / ON / 1 | 75 | 115 | | dB |
| | | DC, 5V / 214.65 / ON / ON / 1 | | 112 | | dB |
| NMRR | Normal Mode Rejection Ratio (Note 5) | 47 Hz to 63 Hz, 5V / 13.42 / OFF / OFF / 1 | 78 | | | dB |
| | Cross-talk | 3V / 214.65 / OFF / OFF / 1 | 95 | 136 | | dB |
| | | 5V / 214.65 / OFF / OFF / 1 | 95 | 143 | | dB |
| POWER SUPPLY CHARACTERISTICS | | | | | | |
| VA | Analog Supply Voltage | | 2.85 | 3.0 | 5.5 | V |
| VIO | Digital Supply Voltage | | 2.7 | 3.3 | 5.5 | V |
| IVA | Analog Supply Current | 3V / 13.42 / OFF / OFF / 1, ext. CLK | | 400 | 500 | μA |
| | | 5V / 13.42 / OFF / OFF / 1, ext. CLK | | 464 | 555 | μA |
| | | 3V / 13.42 / ON / OFF / 64, ext. CLK | | 600 | 700 | μA |
| | | 5V / 13.42 / ON / OFF / 64, ext. CLK | | 690 | 800 | μA |
| | | 3V / 214.65 / ON / OFF / 64, int. CLK | | 1547 | 1700 | μA |
| | | 5V / 214.65 / ON / OFF / 64, int. CLK | | 1760 | 2000 | μA |
| | | 3V / 214.65 / OFF / OFF / 1, int. CLK | | 826 | 1000 | μA |
| | | 5V / 214.65 / OFF / OFF / 1, int. CLK | | 941 | 1100 | μA |
| | | Standby, 3V , int. CLK | | 3 | 10 | μA |
| | | Standby, 3V , ext. CLK | | 257 | | μA |
| | | Standby, 5V, int. CLK | | 5 | 15 | μA |
| | | Standby, 3V, ext. CLK | | 300 | | μA |
| | | Power-down, 3V, int/ext CLK | | 2.6 | 5 | μA |
| | | Power-down, 5V, int/ext CLK | | 4.6 | 9 | μA |

| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|--|---------------------------------------|--|-------------|-------------|-------------|-------|
| REFERENCE INPUT | | | | | | |
| VREFP | Positive Reference | | VREFN + 0.5 | | VA | V |
| VREFN | Negative Reference | | GND | | VREFP - 0.5 | V |
| VREF | Differential Reference | VREF = VREFP - VREFN | 0.5 | | VA | V |
| ZREF | Reference Impedance | 3V / 13.42 / OFF / OFF / 1 | | 10 | | MOhm |
| IREF | Reference Input | 3V / 13.42 / ON or OFF / ON or OFF / all | | ±2 | | µA |
| CREFP | Capacitance of the Positive Reference | (Note 5), gain = 1 | | 6 | | pF |
| CREFN | Capacitance of the Negative Reference | (Note 5), gain = 1 | | 6 | | pF |
| ILREF | Reference Leakage Current | Power-down | | 1 | | nA |
| ANALOG INPUT | | | | | | |
| VINP | Positive Input | Gain = 1-8, buffer ON | GND + 0.1 | | VA - 0.1 | V |
| | | Gain = 16 - 128, buffer ON | GND + 0.4 | | VA - 1.5 | V |
| | | Gain = 1-8, buffer OFF | GND | | VA | V |
| VINN | Negative Input | Gain = 1-8, buffer ON | GND + 0.1 | | VA - 0.1 | V |
| | | Gain = 16 - 128, buffer ON | GND + 0.4 | | VA - 1.5 | V |
| | | Gain = 1-8, buffer OFF | GND | | VA | V |
| VIN | Differential Input | VIN = VINP - VINN | | ±VREF / PGA | | |
| ZIN | Differential Input Impedance | ODR = 13.42 SPS | | 15.4 | | MOhm |
| CINP | Capacitance of the Positive Input | 5V / 214.65 / OFF / OFF / 1 | | 4 | | pF |
| CINN | Capacitance of the Negative Input | 5V / 214.65 / OFF / OFF / 1 | | 4 | | pF |
| IIN | Input Leakage Current | 3V & 5V / 13.42 / ON / OFF / 1-8 | | 500 | | pA |
| | | 3V & 5V / 13.42 / ON / OFF / 16 - 128 | | 100 | | pA |
| DIGITAL INPUT CHARACTERISTICS at VA = VIO = VREF = 3.0V | | | | | | |
| VIH | Logical "1" Input Voltage | | 0.7 x VIO | | | V |
| VIL | Logical "0" Input Voltage | | | | 0.3 x VIO | V |
| IIL | Digital Input Leakage Current | | -10 | | +10 | µA |
| VHYST | Digital Input Hysteresis | | | 0.1 x VIO | | V |
| DIGITAL OUTPUT CHARACTERISTICS at VA = VIO = VREF = 3.0V | | | | | | |
| VOH | Logical "1" Output Voltage | Source 300 µA | 2.6 | | | V |
| VOL | Logical "0" Output Voltage | Sink 300 µA | | | 0.4 | V |
| IOZH, IOZL | TRI-STATE® Leakage Current | | -10 | | 10 | µA |
| COUT | TRI-STATE Capacitance | (Note 5) | | 5 | | pF |

| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|--|----------------------------------|---|-------------|--|-------------|--------|
| EXCITATION CURRENT SOURCES CHARACTERISTICS (LMP90100/LMP90098 only) | | | | | | |
| IB1, IB2 | Excitation Current Source Output | | | 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 | | μA |
| | IB1/IB2 Tolerance | VA = VREF = 3V | -7 | 2.5 | 7 | % |
| | | VA = VREF = 5V | -3.5 | 0.2 | 3.5 | % |
| | IB1/IB2 Output Compliance Range | VA = 3.0V & 5.0V, IB1/IB2 = 100 μA to 1000 μA | | VA - 0.8 | | V |
| | IB1/IB2 Regulation | VA = 5.0V, IB1/IB2 = 100 μA to 1000 μA | | 0.07 | | % / V |
| IBTC | IB1/IB2 Drift | VA = 3.0V | | 95 | | ppm/°C |
| | | VA = 5.0V | | 60 | | ppm/°C |
| IBMT | IB1/IB2 Matching | 3V & 5V / 214.65 / OFF / OFF / 1, IB1/IB2 = 100 μA | | 0.34 | 1.53 | % |
| | | 3V & 5V / 214.65 / OFF / OFF / 1, IB1/IB2 = 200 μA | | 0.22 | 1 | % |
| | | 3V & 5V / 214.65 / OFF / OFF / 1, IB1/IB2 = 300 μA | | 0.2 | 0.85 | % |
| | | 3V & 5V / 214.65 / OFF / OFF / 1, IB1/IB2 = 400 μA | | 0.15 | 0.8 | % |
| | | 3V & 5V / 214.65 / OFF / OFF / 1, IB1/IB2 = 500 μA | | 0.14 | 0.7 | % |
| | | 3V & 5V / 214.65 / OFF / OFF / 1, IB1/IB2 = 600 μA | | 0.13 | 0.7 | % |
| | | 3V & 5V / 214.65 / OFF / OFF / 1, IB1/IB2 = 700 μA | | 0.075 | 0.65 | % |
| | | 3V & 5V / 214.65 / OFF / OFF / 1, IB1/IB2 = 800 μA | | 0.085 | 0.6 | % |
| | | 3V & 5V / 214.65 / OFF / OFF / 1, IB1/IB2 = 900 μA | | 0.11 | 0.55 | % |
| | | 3V & 5V / 214.65 / OFF / OFF / 1, IB1/IB2 = 1000 μA | | 0.11 | 0.45 | % |
| IBMTC | IB1/IB2 Matching Drift | VA = 3.0V & 5.0V, IB1/IB2 = 100 μA to 1000 μA | | 2 | | ppm/°C |
| INTERNAL/EXTERNAL CLK | | | | | | |
| CLKIN | Internal Clock Frequency | | | 893 | | kHz |
| CLKEXT | External Clock Frequency | (Note 5) | 1.8 | 3.5717 | 7.2 | MHz |
| | External Crystal Frequency | Input Low Voltage | | 0 | | V |
| | | Input High Voltage | | 1 | | V |
| | | Frequency | 1.8 | 3.5717 | 7.2 | MHz |
| | | Start-up time | | 7 | | ms |
| SCLK | Serial Clock | | | | 10 | MHz |

TABLE 1. ENOB (Noise Free Resolution) vs. Sampling Rate and Gain at VA = VIO = VREF = 3V

| ODR (SPS) | Gain | | | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| | 1 | 2 | 4 | 8 | 16 | 32 | 64 | 128 |
| 1.6775 | 20.5 (18) | 20.5 (18) | 19.5 (17) | 19 (16.5) | 20.5 (18) | 19.5 (17) | 19 (16.5) | 18 (15.5) |
| 3.355 | 20 (17.5) | 20 (17.5) | 19 (16.5) | 18.5 (16) | 20 (17.5) | 19 (16.5) | 18.5 (16) | 17 (14.5) |
| 6.71 | 19.5 (17) | 19.5 (17) | 18.5 (16) | 18 (15.5) | 19.5 (17) | 18.5 (16) | 17.5 (15) | 17 (14.5) |
| 13.42 | 19 (16.5) | 18.5 (16) | 18 (15.5) | 17.5 (15) | 19 (16.5) | 18 (15.5) | 17.5 (15) | 16.5 (14) |
| 26.83125 | 20.5 (18) | 20 (17.5) | 19.5 (17) | 19 (16.5) | 20 (17.5) | 19 (16.5) | 18 (15.5) | 17.5 (15) |
| 53.6625 | 20 (17.5) | 19.5 (17) | 19 (16.5) | 18.5 (16) | 19.5 (17) | 18.5 (16) | 17.5 (15) | 17 (14.5) |
| 107.325 | 19.5 (17) | 19 (16.5) | 18.5 (16) | 18 (15.5) | 19 (16.5) | 18 (15.5) | 17 (14.5) | 16.5 (14) |
| 214.65 | 19 (16.5) | 18.5 (16) | 18 (15.5) | 17.5 (15) | 18.5 (16) | 17.5 (15) | 17 (14.5) | 16 (13.5) |

TABLE 2. RMS Noise (μ V) vs. Sampling Rate and Gain at VA = VIO = VREF = 3V

| ODR (SPS) | Gain of the ADC | | | | | | | |
|-----------|-----------------|------|------|------|------|------|------|------|
| | 1 | 2 | 4 | 8 | 16 | 32 | 64 | 128 |
| 1.6775 | 3.08 | 1.90 | 1.53 | 1.27 | 0.23 | 0.21 | 0.15 | 0.14 |
| 3.355 | 4.56 | 2.70 | 2.21 | 1.67 | 0.34 | 0.27 | 0.24 | 0.26 |
| 6.71 | 6.15 | 4.10 | 3.16 | 2.39 | 0.51 | 0.40 | 0.37 | 0.35 |
| 13.42 | 8.60 | 5.85 | 4.29 | 3.64 | 0.67 | 0.54 | 0.51 | 0.49 |
| 26.83125 | 3.35 | 2.24 | 1.65 | 1.33 | 0.33 | 0.27 | 0.26 | 0.25 |
| 53.6625 | 4.81 | 3.11 | 2.37 | 1.90 | 0.44 | 0.39 | 0.37 | 0.36 |
| 107.325 | 6.74 | 4.51 | 3.38 | 2.66 | 0.63 | 0.54 | 0.52 | 0.49 |
| 214.65 | 9.52 | 6.37 | 4.72 | 3.79 | 0.90 | 0.79 | 0.72 | 0.70 |

TABLE 3. ENOB (Noise Free Resolution) vs. Sampling Rate and Gain at VA = VIO = VREF = 5V

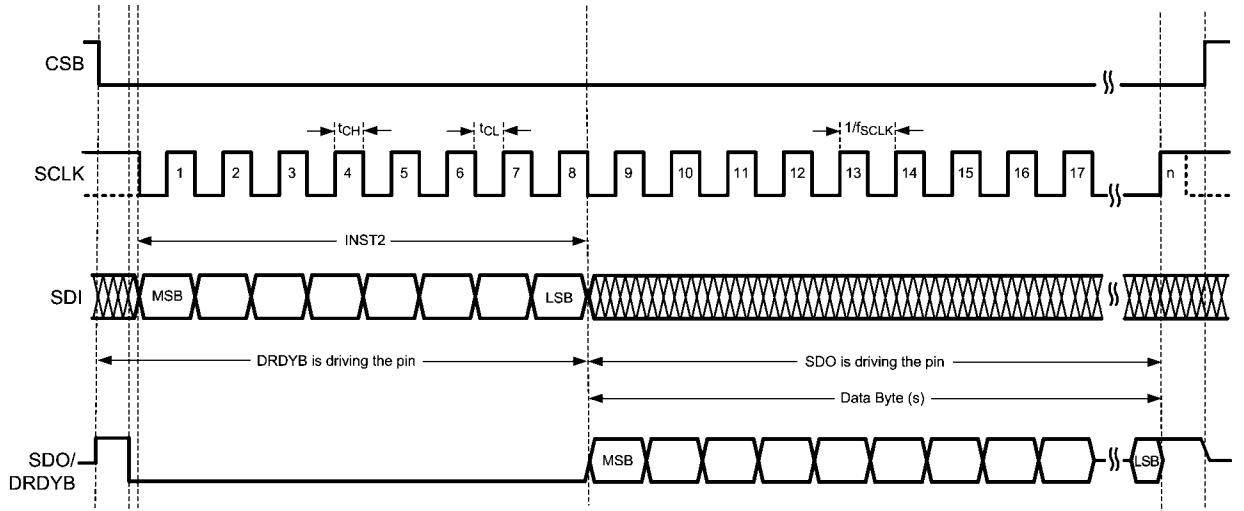
| SPS | Gain of the ADC | | | | | | | |
|----------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| | 1 | 2 | 4 | 8 | 16 | 32 | 64 | 128 |
| 1.6775 | 21.5 (19) | 21.5 (19) | 20.5 (18) | 20 (17.5) | 21 (18.5) | 20.5 (18) | 19.5 (17) | 18.5 (16) |
| 3.355 | 21 (18.5) | 21 (18.5) | 20 (17.5) | 19.5 (17) | 20.5 (18) | 20 (17.5) | 19 (16.5) | 18 (15.5) |
| 6.71 | 20.5 (18) | 20 (17.5) | 19.5 (17) | 19 (16.5) | 20 (17.5) | 19.5 (17) | 19 (16.5) | 17.5 (15) |
| 13.42 | 20 (17.5) | 19.5 (17) | 19 (16.5) | 18.5 (16) | 20 (17.5) | 19 (16.5) | 18 (15.5) | 17.5 (15) |
| 26.83125 | 21.5 (19) | 21 (18.5) | 20.5 (18) | 20 (17.5) | 21 (18.5) | 20 (17.5) | 19.5 (17) | 18 (15.5) |
| 53.6625 | 21 (18.5) | 20.5 (18) | 20 (17.5) | 19.5 (17) | 20.5 (18) | 19.5 (17) | 18.5 (16) | 17.5 (15) |
| 107.325 | 20.5 (18) | 20 (17.5) | 19.5 (17) | 19 (16.5) | 20 (17.5) | 19 (16.5) | 18 (15.5) | 17 (14.5) |
| 214.65 | 20 (17.5) | 19.5 (17) | 19 (16.5) | 18.5 (16) | 19.5 (17) | 18.5 (16) | 17.5 (15) | 16.5 (14) |

TABLE 4. RMS Noise (μ V) vs. Sampling Rate and Gain at VA = VIO = VREF = 5V

| SPS | Gain of the ADC | | | | | | | |
|----------|-----------------|------|------|------|------|------|------|------|
| | 1 | 2 | 4 | 8 | 16 | 32 | 64 | 128 |
| 1.6775 | 2.68 | 1.65 | 1.24 | 1.00 | 0.22 | 0.19 | 0.17 | 0.16 |
| 3.355 | 3.86 | 2.36 | 1.78 | 1.47 | 0.34 | 0.27 | 0.22 | 0.22 |
| 6.71 | 5.23 | 3.49 | 2.47 | 2.09 | 0.44 | 0.34 | 0.30 | 0.32 |
| 13.42 | 7.94 | 5.01 | 3.74 | 2.94 | 0.61 | 0.50 | 0.45 | 0.43 |
| 26.83125 | 2.90 | 1.86 | 1.34 | 1.08 | 0.29 | 0.24 | 0.23 | 0.23 |
| 53.6625 | 4.11 | 2.60 | 1.90 | 1.50 | 0.39 | 0.35 | 0.32 | 0.31 |
| 107.325 | 5.74 | 3.72 | 2.72 | 2.11 | 0.56 | 0.48 | 0.46 | 0.44 |
| 214.65 | 8.25 | 5.31 | 3.82 | 2.97 | 0.79 | 0.68 | 0.64 | 0.63 |

13.0 Timing Diagrams

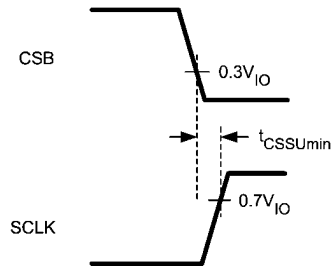
Unless otherwise noted, specified limits apply for $V_A = V_{IO} = 3.0V$. Boldface limits apply for $T_{MIN} \leq T_A \leq T_{MAX}$; the typical values apply for $T_A = +25^\circ C$.



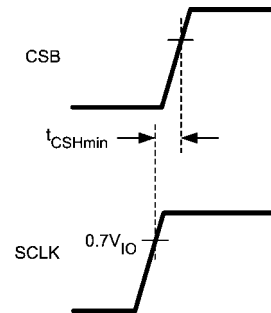
30139501

FIGURE 2. Timing Diagram

| Symbol | Parameter | Conditions | Min | Typical | Max | Units |
|------------|----------------|------------|------------------|---------|-----|-------|
| f_{SCLK} | | | | | 10 | MHz |
| t_{CH} | SCLK High time | | $0.4 / f_{SCLK}$ | | | ns |
| t_{CL} | SCLK Low time | | $0.4 / f_{SCLK}$ | | | ns |

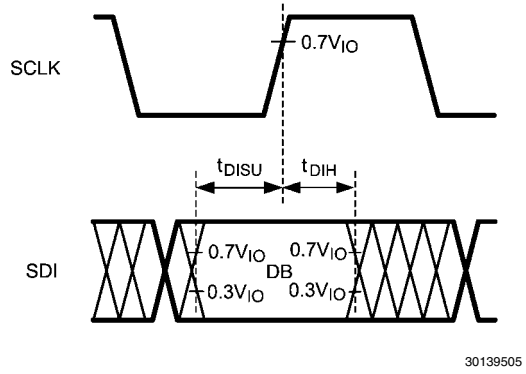
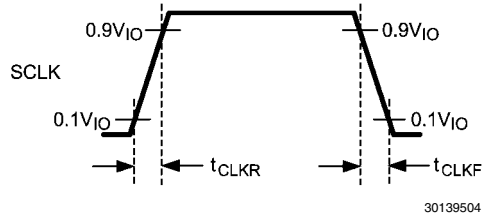


30139502

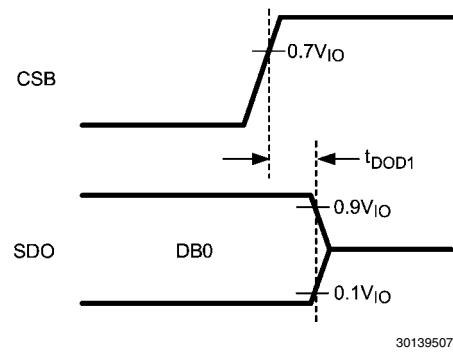
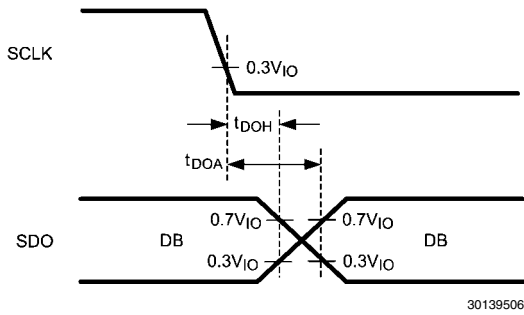


30139503

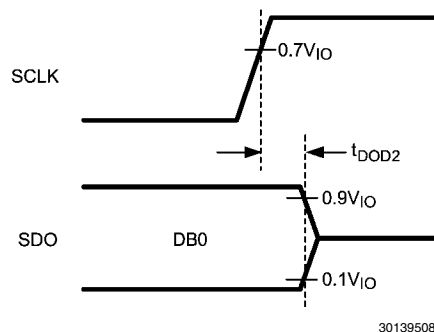
| Symbol | Parameter | Conditions | Min | Typical | Max | Units |
|------------|--|------------|-----|---------|-----|-------|
| t_{CSSU} | CSB Setup time prior to an SCLK rising edge | | 5 | | | ns |
| t_{CSH} | CSB Hold time after the last rising edge of SCLK | | 6 | | | ns |



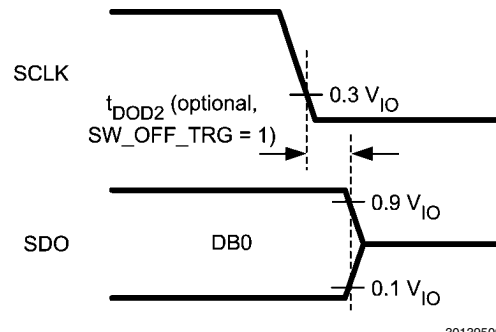
| Symbol | Parameter | Conditions | Min | Typical | Max | Units |
|------------|---|------------|-----|---------|-----|-------|
| t_{CLKR} | SCLK Rise time | | | 1.15 | | ns |
| t_{CLKF} | SCLK Fall time | | | 1.15 | | ns |
| t_{DISU} | SDI Setup time prior to an SCLK rising edge | | 5 | | | ns |
| t_{DIH} | SDI Hold time after an SCLK rising edge | | 6 | | | ns |



| Symbol | Parameter | Conditions | Min | Typical | Max | Units |
|------------|---|------------|-----|---------|-----|-------|
| t_{DOA} | SDO Access time after an SCLK falling edge | | | | 35 | ns |
| t_{DOH} | SDO Hold time after an SCLK falling edge | | 5 | | | ns |
| t_{DOD1} | SDO Disable time after the rising edge of CSB | | | | 5 | ns |

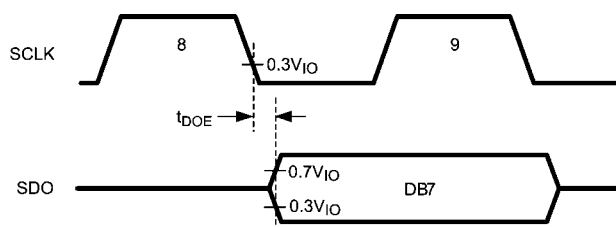


30139508

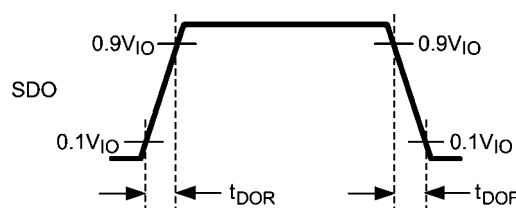


30139509

| Symbol | Parameter | Conditions | Min | Typical | Max | Units |
|------------|--|------------|-----|---------|-----|-------|
| t_{DOD2} | SDO Disable time after either edge of SCLK | | | | 27 | ns |



30139510



30139511

| Symbol | Parameter | Conditions | Min | Typical | Max | Units |
|-------------|---|-------------------------------|-----|---------|-----|---------|
| t_{DOE} | SDO Enable time from the falling edge of the 8th SCLK | | | | 35 | ns |
| t_{DOR} | SDO Rise time | (Note 5) | | 7 | | ns |
| t_{DOF} | SDO Fall time | (Note 5) | | 7 | | ns |
| t_{DRDYB} | Data Ready Bar pulse at every 1/ODR second, see Figure 21 | $ODR \leq 13.42$ SPS | | 64 | | μ s |
| | | $13.42 < ODR \leq 214.65$ SPS | | 4 | | μ s |

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

Note 2: All voltages are measured with respect to GND, unless otherwise specified

Note 3: When the input voltage (V_{IN}) exceeds the power supply ($V_{IN} < GND$ or $V_{IN} > V_A$), the current at that pin must be limited to 5mA and V_{IN} has to be within the Absolute Maximum Rating for that pin. The 20 mA package input current rating limits the number of pins that can safely exceed the power supplies with current flow to four pins.

Note 4: The maximum power dissipation is a function of $T_{J(MAX)}$ AND θ_{JA} . The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)} - T_A) / \theta_{JA}$.

Note 5: This parameter is guaranteed by design and/or characterization and is not tested in production.

14.0 Specific Definitions

COMMON MODE REJECTION RATIO is a measure of how well in-phase signals common to both input pins are rejected. To calculate CMRR, the change in output offset is measured while the common mode input voltage is changed.

$$\text{CMRR} = 20 \text{ LOG}(\Delta \text{Common Input} / \Delta \text{Output Offset})$$

EFFECTIVE NUMBER OF BITS (ENOB, or EFFECTIVE BITS) – says that the converter is equivalent to a perfect ADC of this (ENOB) number of bits. LMP90100's ENOB is a DC ENOB spec, not the dynamic ENOB that is measured using FFT and SINAD. Its equation is as follows:

$$\text{ENOB} = \log_2 \left(\frac{2 \times \text{VREF}/\text{Gain}}{\text{RMS Noise}} \right)$$

GAIN ERROR is the deviation from the ideal slope of the transfer function.

INTEGRAL NON-LINEARITY (INL) is a measure of the deviation of each individual code from a straight line through the input to output transfer function. The deviation of any given code from this straight line is measured from the center of that code value. The end point fit method is used. INL for this product is specified over a limited range, per the Electrical Tables.

NEGATIVE FULL-SCALE ERROR is the difference between the differential input voltage at which the output code transitions to negative full scale and $(-\text{VREF} + 1\text{LSB})$.

NEGATIVE GAIN ERROR is the difference between the negative full-scale error and the offset error divided by $(\text{VREF} / \text{Gain})$.

NOISE FREE RESOLUTION is a method of specifying the number of bits for a converter with noise.

$$\text{NFR} = \log_2 \left(\frac{2 \times \text{VREF}/\text{Gain}}{\text{Peak-to-Peak Noise}} \right)$$

ODR Output Data Rate.

OFFSET ERROR is the difference between the differential input voltage at which the output code transitions from code 0000h to 0001h and 1 LSB.

POSITIVE FULL-SCALE ERROR is the difference between the differential input voltage at which the output code transitions to positive full scale and $(\text{VREF} - 1\text{LSB})$.

POSITIVE GAIN ERROR is the difference between the positive full-scale error and the offset error divided by $(\text{VREF} / \text{Gain})$.

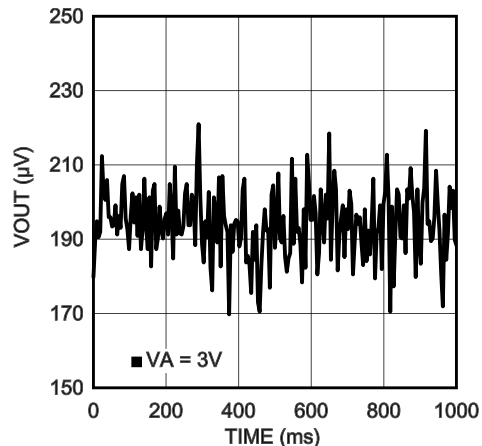
POWER SUPPLY REJECTION RATIO (PSRR) is a measure of how well a change in the analog supply voltage is rejected. PSRR is calculated from the ratio of the change in offset error for a given change in supply voltage, expressed in dB.

$$\text{PSRR} = 20 \text{ LOG} (\Delta \text{VA} / \Delta \text{Output Offset})$$

15.0 Typical Performance Characteristics

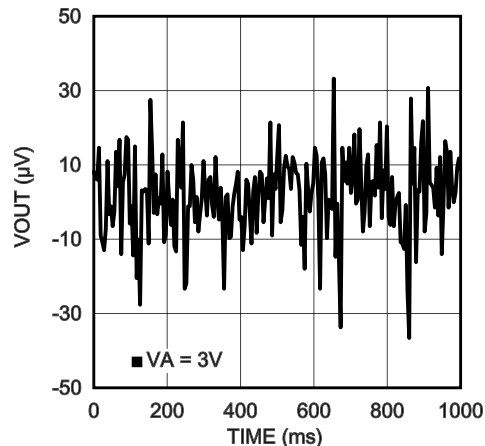
Unless otherwise noted, specified limits apply for $V_A = V_{IO} = V_{REF} = 3.0V$. The maximum and minimum values apply for $T_A = T_{MIN}$ to T_{MAX} ; the typical values apply for $T_A = +25^\circ C$.

Noise Measurement without Calibration at Gain = 1



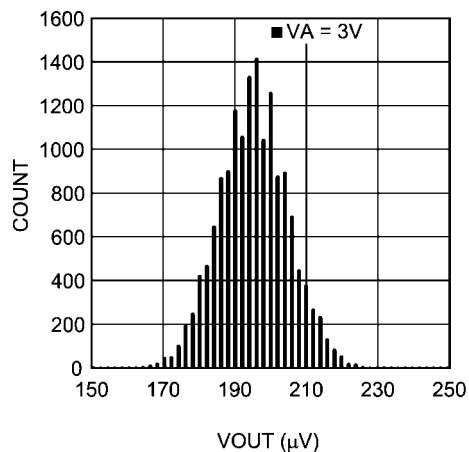
30139515

Noise Measurement with Calibration at Gain = 1



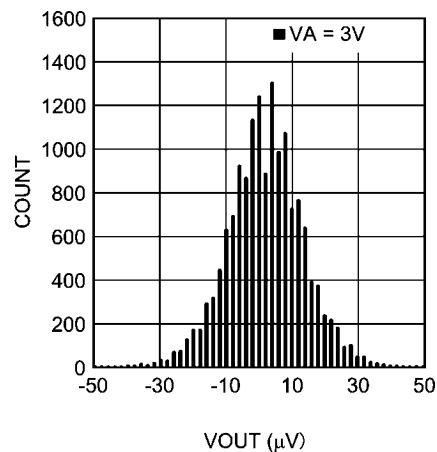
30139516

Histogram without Calibration at Gain = 1



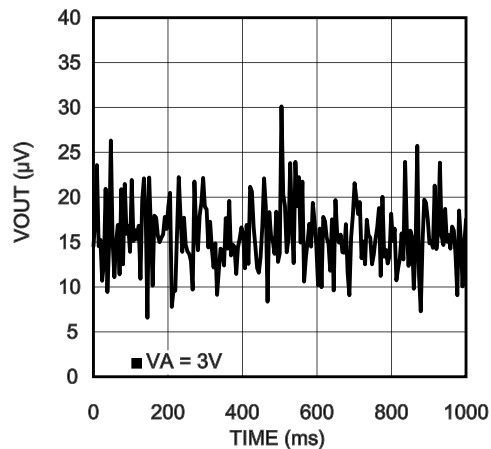
30139521

Histogram with Calibration at Gain = 1



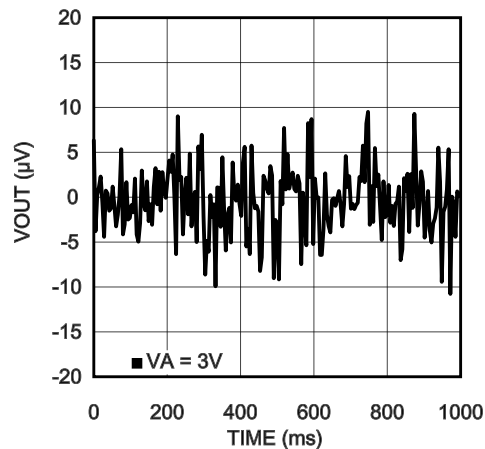
30139522

Noise Measurement without Calibration at Gain = 8

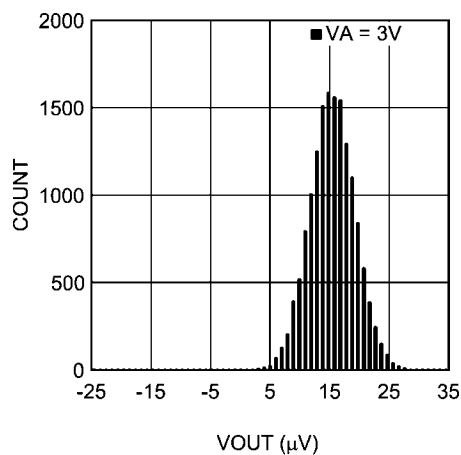


30139517

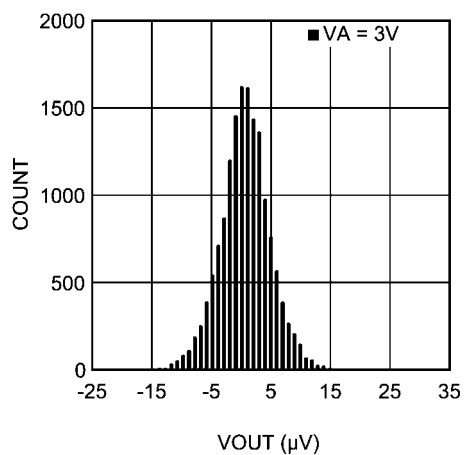
Noise Measurement with Calibration at Gain = 8



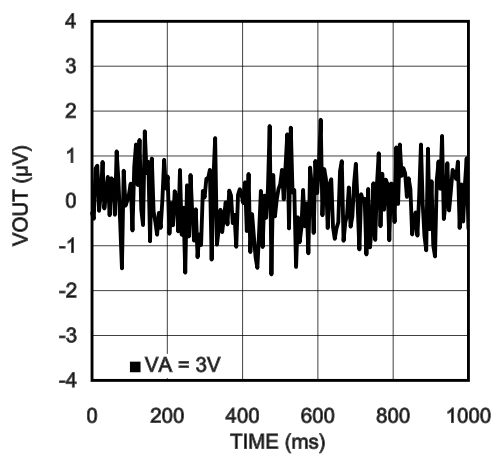
30139518

Histogram without Calibration at Gain = 8

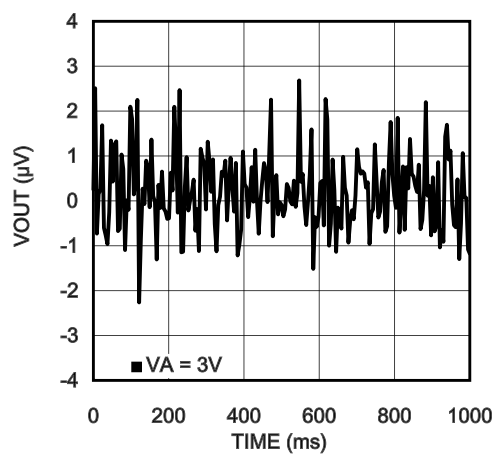
30139523

Histogram with Calibration at Gain = 8

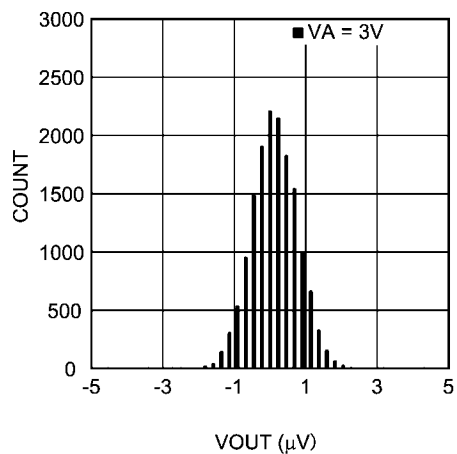
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Noise Measurement without Calibration at Gain = 128

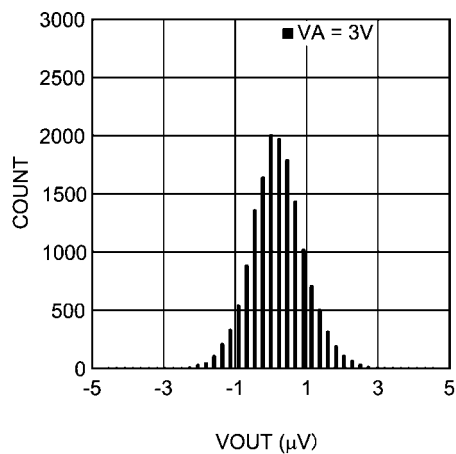
30139519

Noise Measurement without Calibration at Gain = 128

30139520

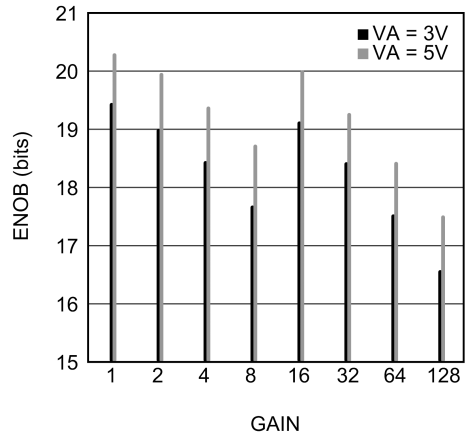
Histogram without Calibration at Gain = 128

30139525

Histogram with Calibration at Gain = 128

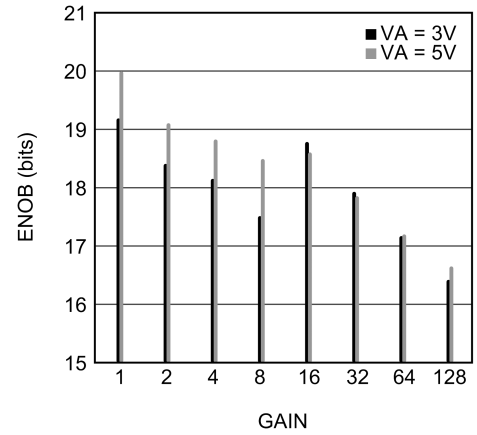
30139526

ENOB vs. Gain without Calibration at ODR = 13.42 SPS



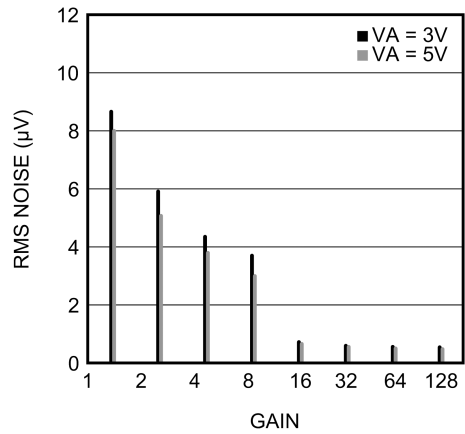
30139528

ENOB vs. Gain with Calibration at ODR = 13.42 SPS



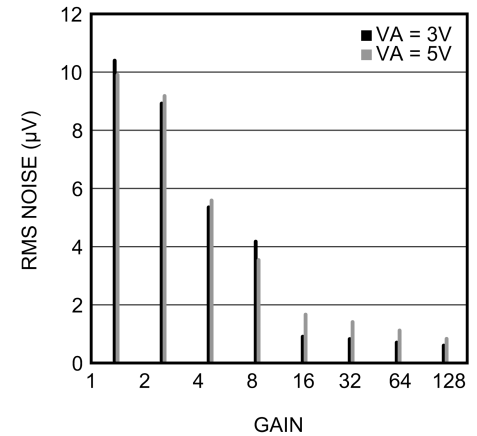
30139534

Noise vs. Gain without Calibration at ODR = 13.42 SPS



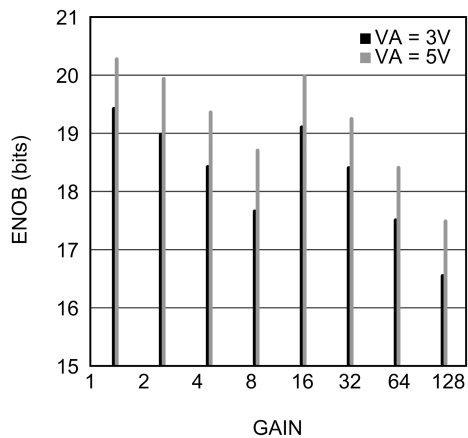
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Noise vs. Gain with Calibration at ODR = 13.42 SPS



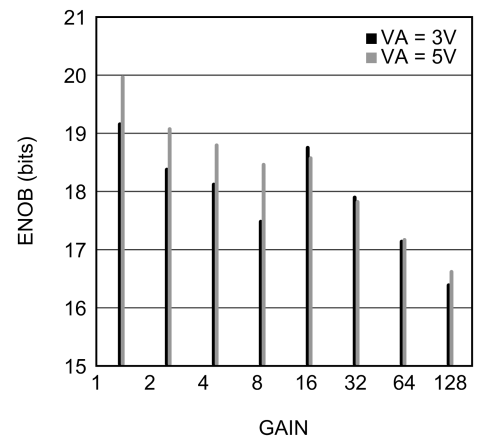
30139548

ENOB vs. Gain without Calibration at ODR = 214.65 SPS



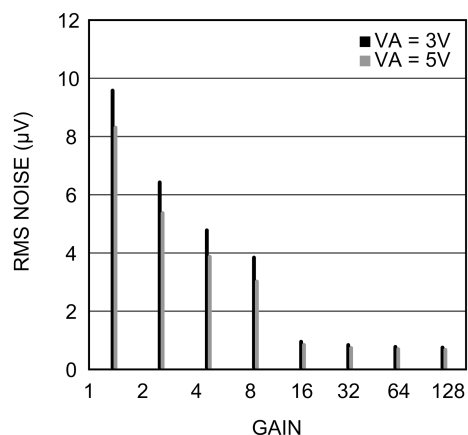
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ENOB vs. Gain with Calibration at ODR = 214.65 SPS



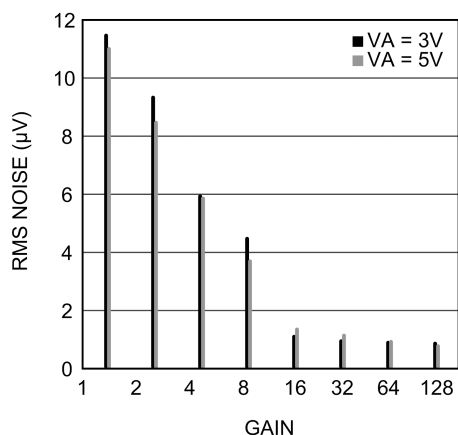
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Noise vs. Gain without Calibration at ODR = 214.65 SPS



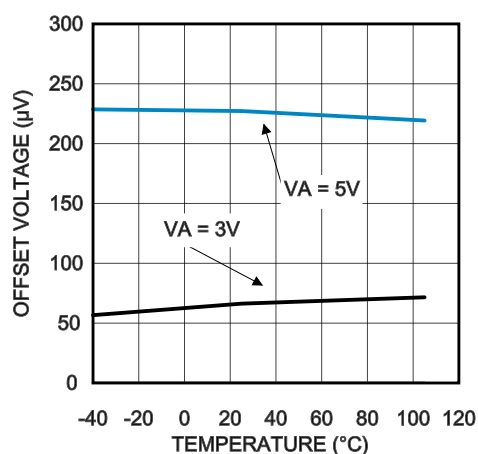
30139549

Noise vs. Gain with Calibration at ODR = 214.65 SPS



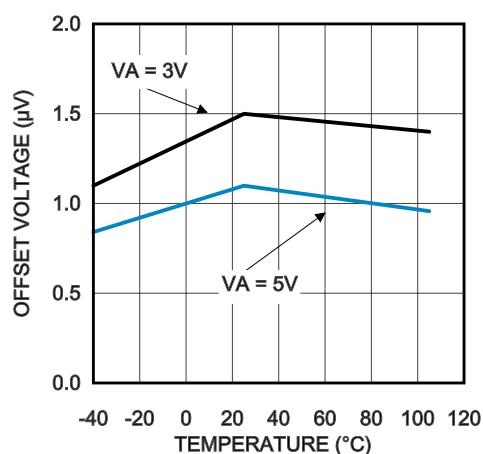
30139550

Offset Error vs. Temperature without Calibration at Gain = 1



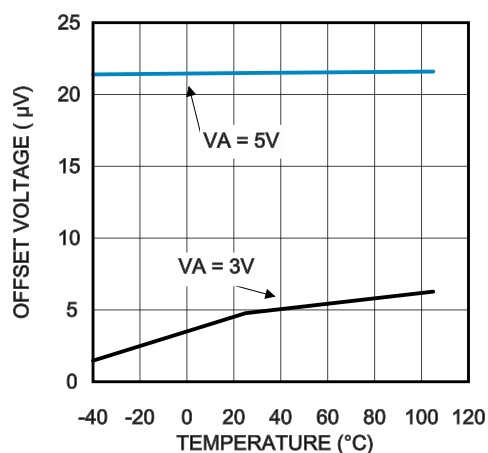
30139561

Offset Error vs. Temperature with Calibration at Gain = 1



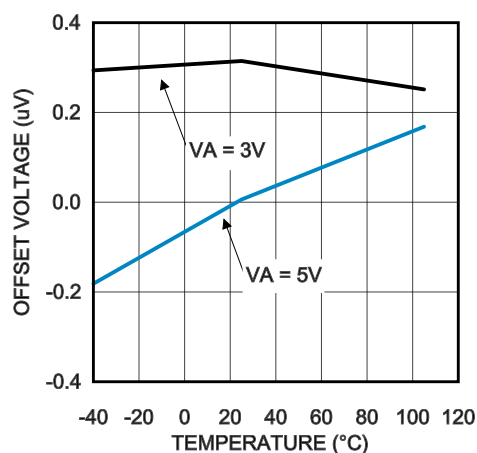
30139564

Offset Error vs. Temperature without Calibration at Gain = 8



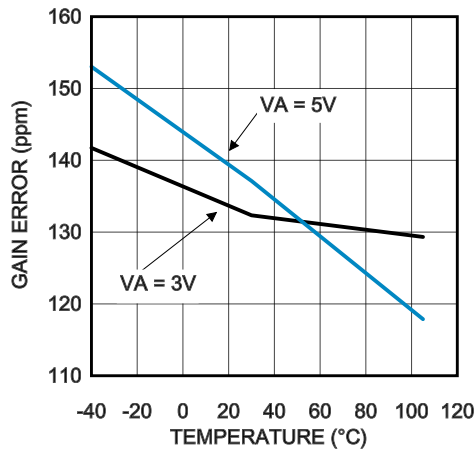
30139562

Offset Error vs. Temperature with Calibration at Gain = 8



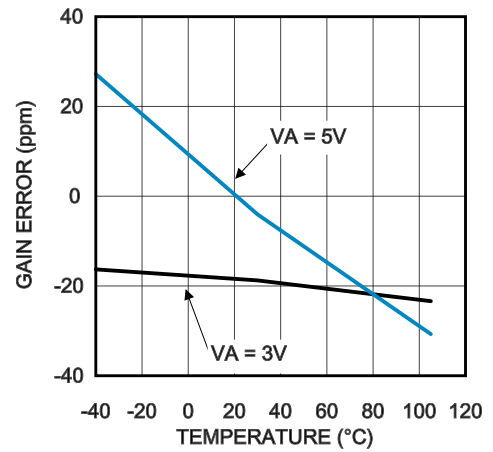
30139565

Gain Error vs. Temperature without Calibration at Gain = 1



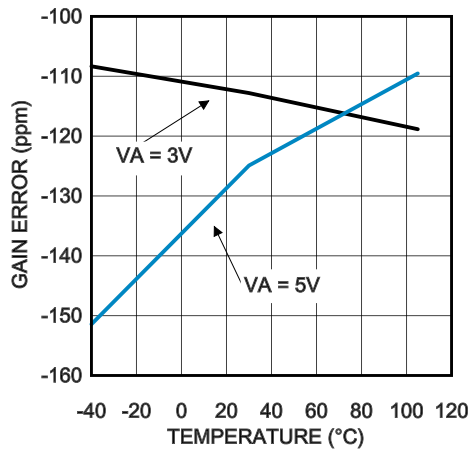
30139567

Gain Error vs. Temperature with Calibration at Gain = 1



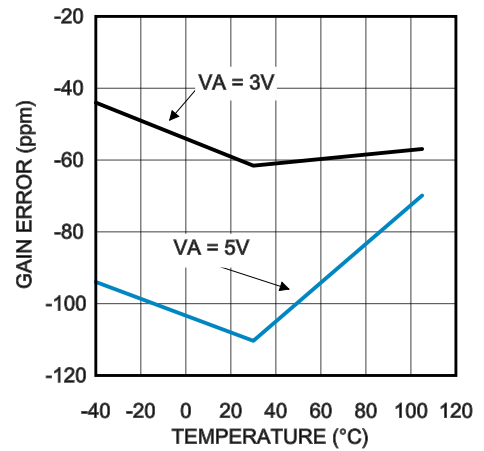
30139570

Gain Error vs. Temperature without Calibration at Gain = 8



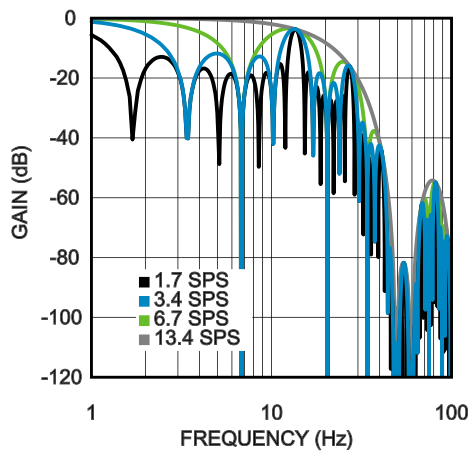
30139568

Gain Error vs. Temperature with Calibration at Gain = 8



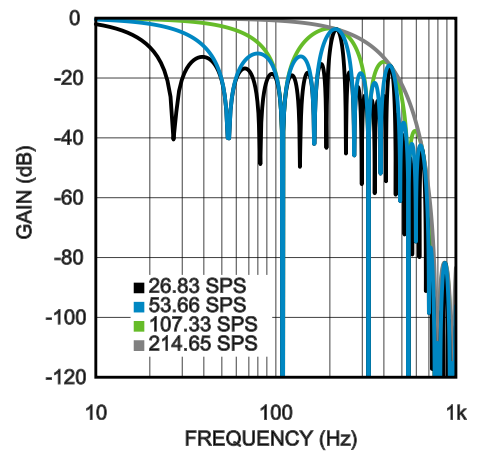
30139571

Digital Filter Frequency Response

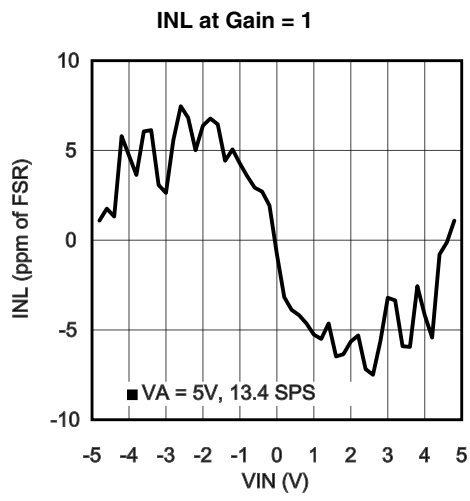


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Digital Filter Frequency Response



30139553



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16.0 Functional Description

Throughout this datasheet, the LMP90100/LMP90099/LMP90098/LMP90097 will be referred to as the LMP90xxx.

The LMP90xxx is a low-power 24-Bit $\Sigma\Delta$ ADC with 4 fully differential / 7 single-ended analog channels for the LMP90100/LMP90099 and 2 full differential / 4 single-ended for the LMP90098/LMP90097. Its serial data output is two's complement format. The output data rate (ODR) ranges from 1.6775 SPS to 214.65 SPS.

The serial communication for LMP90xxx is SPI, a synchronous serial interface that operates using 4 pins: chip select bar (CSB), serial clock (SCLK), serial data in (SDI), and serial data out / data ready bar (SDO/DRYDYB).

True continuous built-in offset and gain background calibration is also available to improve measurement accuracy. Unlike other ADCs, the LMP90xxx's background calibration can run without heavily impacting the input signal. This unique technique allows for positive as well as negative gain calibration and is available at all gain settings.

The registers can be found in [Section 18.0 Registers](#), and a detailed description of the LMP90xxx are provided in the following sections.

16.1 SIGNAL PATH

16.1.1 Reference Input (VREF)

The differential reference voltage VREF (VREFP – VREFN) sets the range for VIN.

The muxed VREF allows the user to choose between VREF1 or VREF2 for each channel. This selection can be made by

programming the VREF_SEL bit in the CHx_INPUTCN registers (CHx_INPUTCN: VREF_SEL). The default mode is VREF1. If VREF2 is used, then VIN6 and VIN7 cannot be used as inputs because they share the same pin.

Refer to [Section 17.2.2 VREF](#) for VREF applications information.

16.1.2 Flexible Input MUX (VIN)

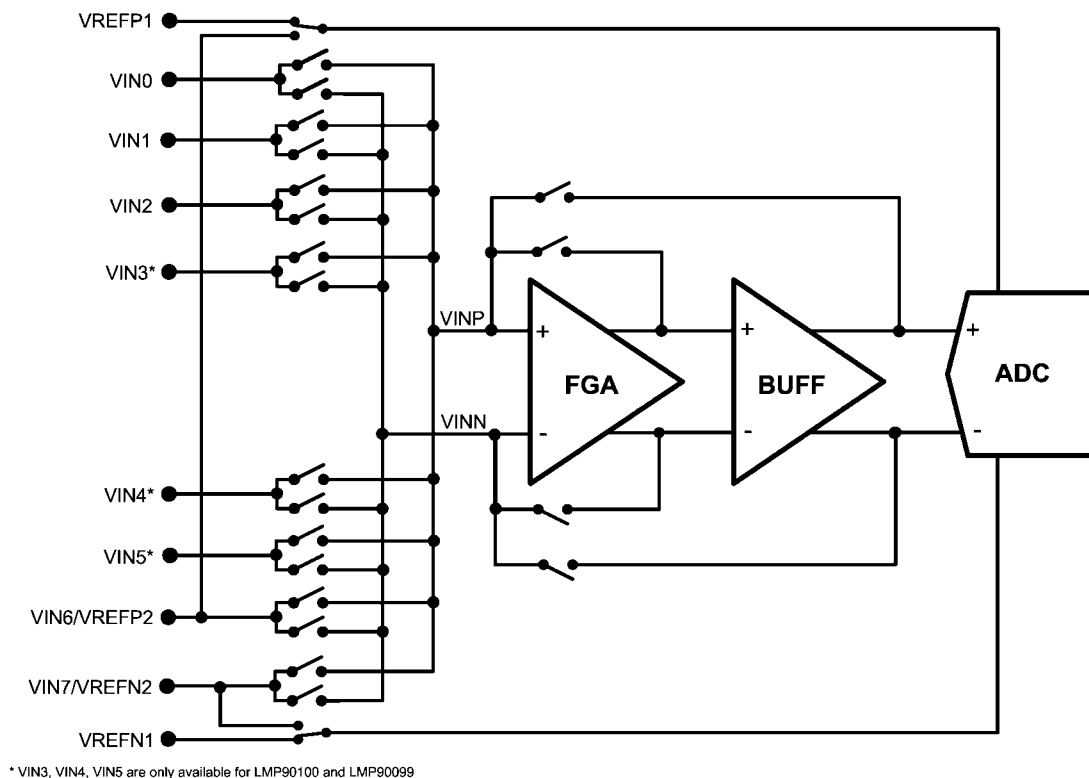
LMP90xxx provides a flexible input MUX as shown in [Figure 3](#). The input that is digitized is $VIN = VINP - VINN$; where VINP and VINN can be any available input.

The digitized input is also known as a channel, where $CH = VIN = VINP - VINN$. Thus, there are a maximum of 4 differential channels: CH0, CH1, CH2, and CH3 for the LMP90100/LMP90099. The LMP90098/LMP90097 has a maximum of 2 differential channels: CH0 and CH1 because it does not have access to the VIN3, VIN4, and VIN5 pins.

LMP90xxx can also be configured single-endedly, where the common ground is any one of the inputs. There are a maximum of 7 single-ended channels: CH0, CH1, CH2, CH3, CH4, CH5, and CH6 for the LMP90100/LMP90099 and 4: CH0, CH1, CH2, CH3 for the LMP90098/LMP90097.

The input MUX can be programmed in the CHx_INPUTCN registers. For example on the LMP90100, to program CH0 = $VIN = VIN4 - VIN1$, go to the CH0_INPUTCN register and set:

1. VINP = 0x4
2. VINN = 0x1



30139577

FIGURE 3. Simplified VIN Circuitry

16.1.3 Selectable Gains (FGA & PGA)

LMP90xxx provides two types of gain amplifiers: a fixed gain amplifier (FGA) and a programmable gain amplifier (PGA). FGA has a fixed gain of 16x or it can be bypassed, while the PGA has programmable gain settings of 1x, 2x, 4x, or 8x.

Total gain is defined as FGA x PGA. Thus, LMP90xxx provides gain settings of 1x, 2x, 4x, 8x, 16x, 32x, 64x, or 128x with true continuous background calibration.

The gain is channel specific, which means that one channel can have one gain, while another channel can have the same or a different gain.

The gain can be selected by programming the CHx_CONFIG: GAIN_SEL bits.

16.1.4 Buffer (BUFF)

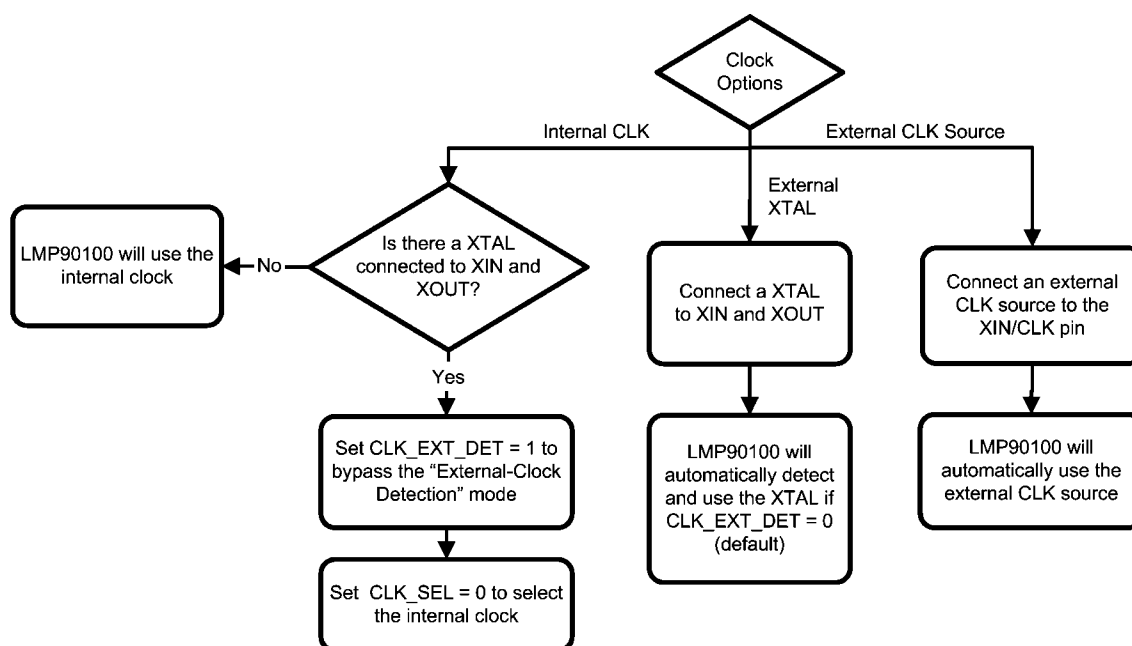
There is an internal unity gain buffer that can be included or excluded from the signal path. Including the buffer provides a high input impedance but increases the power consumption.

When gain ≥ 16 , the buffer is automatically included in the signal path. When gain < 16 , including or excluding the buffer from the signal path can be done by programming the CHX_CONFIG: BUF_EN bit.

16.1.5 Internal/External CLK Selection

LMP90xxx allows two clock options: internal CLK or external CLK (crystal (XTAL) or clock source).

There is an "External Clock Detection" mode, which detects the external XTAL if it is connected to XOUT and XIN. When operating in this mode, the LMP90xxx shuts off the internal clock to reduce power consumption. Below is a flow chart to help set the appropriate clock registers.



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FIGURE 4. CLK Register Settings

The recommended value for the external CLK is discussed in the next sections.

16.1.6 Programmable ODRs

If using the internal CLK or external CLK of 3.5717 MHz, then the output date rates (ODR) can be selected (using the ODR_SEL bit) as:

1. $13.42/8 = 1.6775$ SPS
2. $13.42/4 = 3.355$ SPS
3. $13.42/2 = 6.71$ SPS
4. 13.42 SPS
5. $214.65/8 = 26.83125$ SPS
6. $214.65/4 = 53.6625$ SPS
7. $214.65/2 = 107.325$ SPS
8. 214.65 SPS (default)

If the internal CLK is not being used and the external CLK is not 3.5717 MHz, then the ODR will be different. If this is the

case, use the equation below to calculate the new ODR values.

$$\text{ODR_Base1} = (\text{CLK}_{\text{EXT}}) / (266,240)$$

$$\text{ODR_Base2} = (\text{CLK}_{\text{EXT}}) / (16,640)$$

$$\text{ODR1} = (\text{ODR_Base1}) / n, \text{ where } n = 1, 2, 4, 8$$

$$\text{ODR2} = (\text{ODR_Base2}) / n, \text{ where } n = 1, 2, 4, 8$$

For example, a 3.6864 MHz XTAL or external clock has the following ODR values:

$$\text{ODR_Base1} = (3.6864 \text{ MHz}) / (266,240) = 13.85 \text{ SPS}$$

$$\text{ODR_Base2} = (3.6864 \text{ MHz}) / (16,640) = 221.54 \text{ SPS}$$

$$\text{ODR1} = (13.85 \text{ SPS}) / n = 13.85, 6.92, 3.46, 1.73 \text{ SPS}$$

$$\text{ODR2} = (221.54 \text{ SPS}) / n = 221.54, 110.77, 55.38, 27.69 \text{ SPS}$$

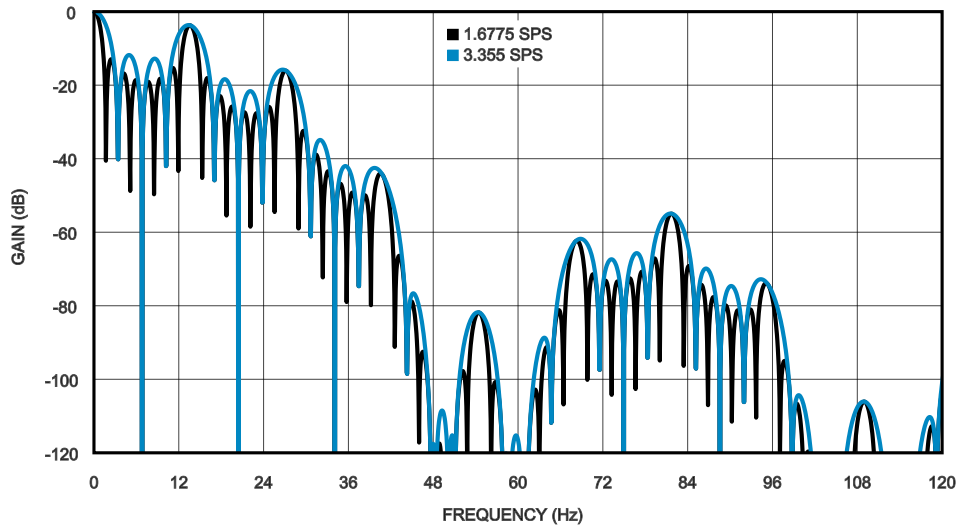
The ODR is channel specific, which means that one channel can have one ODR, while another channel can have the same or a different ODR.

Note that these ODRs are meant for a single channel conversion; the ODR needs to be divided by n for n channels

scanning. For example, if the ADC were running at 214.65 SPS and four channels are being scanned, then the ODR per channel would be $214.65/4 = 53.6625$ SPS.

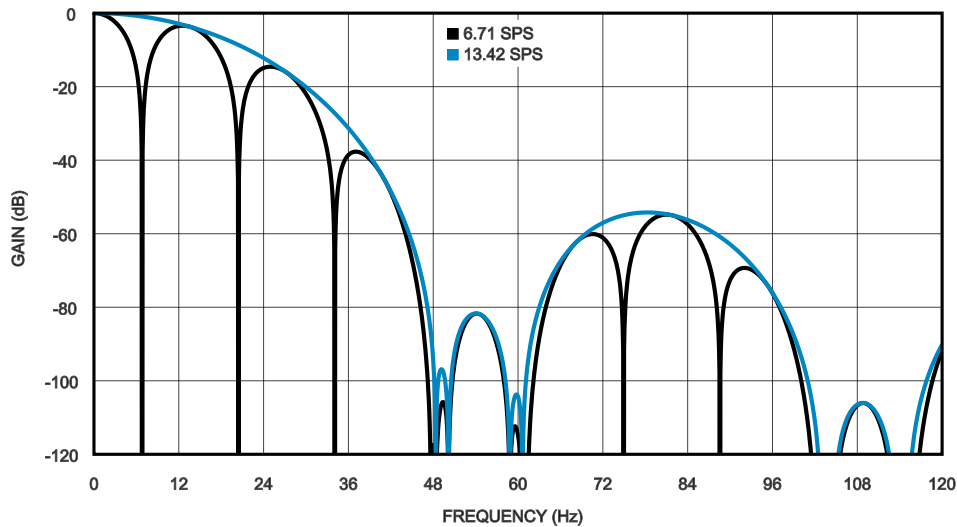
16.1.7 Digital Filter

The LMP90xxx has a fourth order rotated sinc filter that is used to configure various ODRs and to reject power supply frequencies of 50Hz and 60Hz. The 50/60 Hz rejection is only effective when the device is operating at $ODR \leq 13.42$ SPS. If the internal CLK or the external CLK of 3.5717 MHz is used, then the LMP90xxx will have the frequency response shown in [Figure 5](#) to [Figure 9](#).



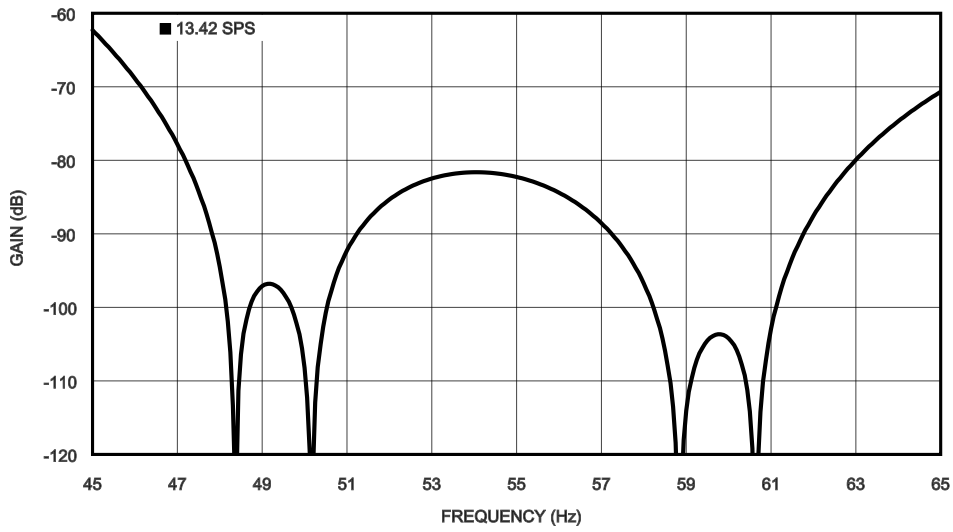
30139560

FIGURE 5. Digital Filter Response, 1.6775 SPS and 3.355 SPS



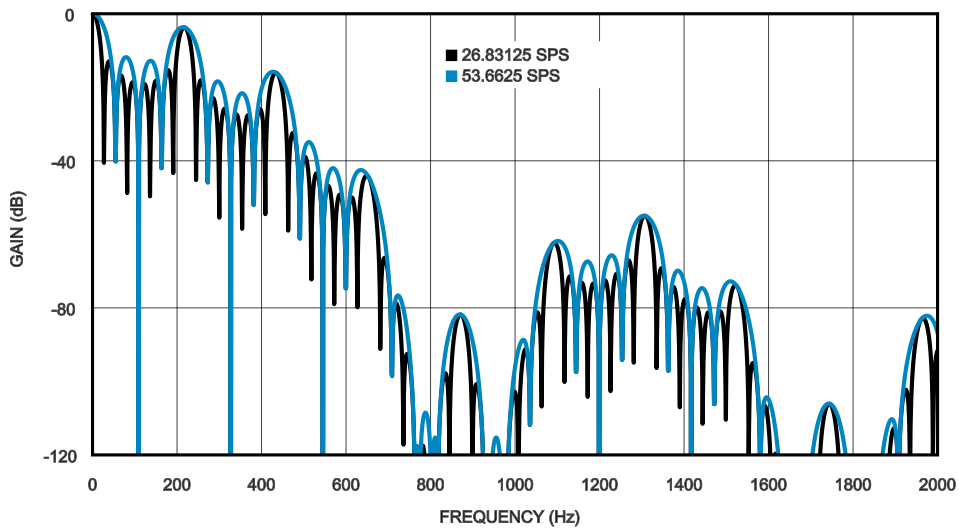
30139573

FIGURE 6. Digital Filter Response, 6.71 SPS and 13.42 SPS



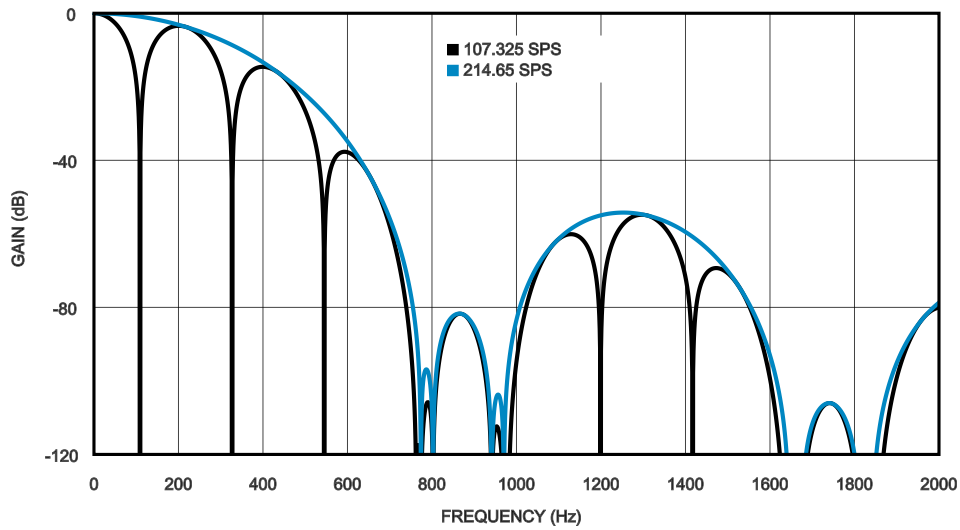
30139544

FIGURE 7. Digital Filter Response at 13.42 SPS



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FIGURE 8. Digital Filter Response, 26.83125 SPS and 53.6625 SPS



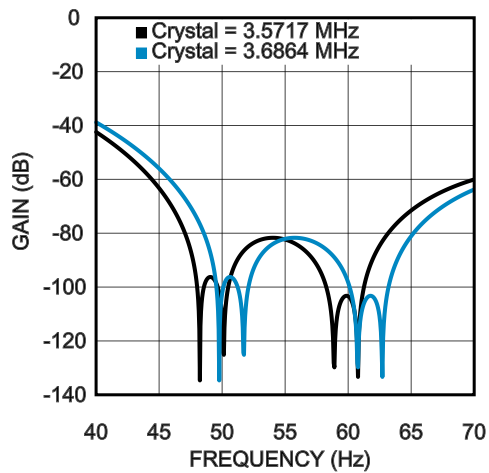
30139587

FIGURE 9. Digital Filter Response 107.325 SPS and 214.65 SPS

If the internal CLK is not being used and the external CLK is not 3.5717 MHz, then the filter response would be the same as the response shown above, but the frequency will change according to the equation:

$$f_{\text{NEW}} = [(\text{CLK}_{\text{EXT}}) / 256] \times (f_{\text{OLD}} / 13.952\text{k})$$

Using the equation above, an example of the filter response for a 3.5717 MHz XTAL versus a 3.6864 MHz XTAL can be seen in [Figure 10](#).



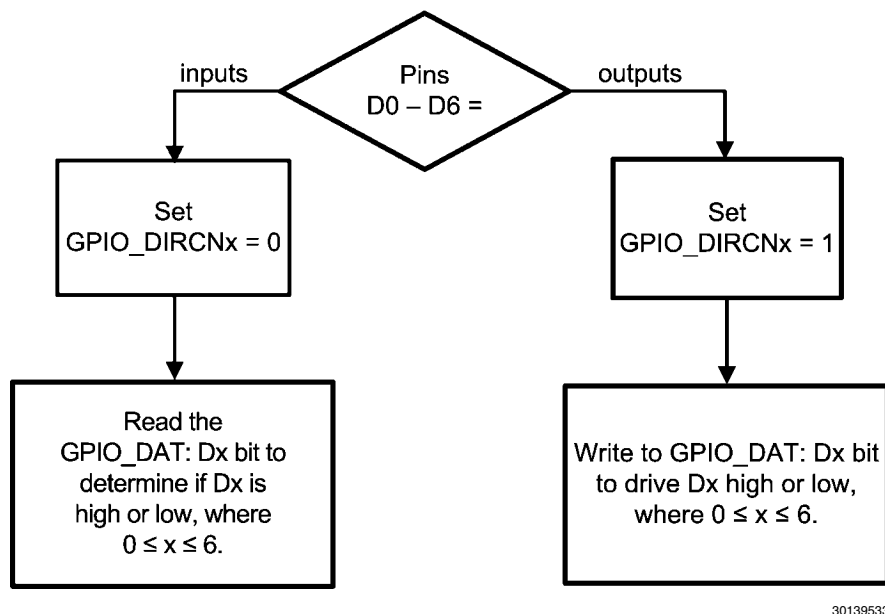
30139556

FIGURE 10. Digital Filter Response for a 3.5717MHz versus 3.6864 MHz XTAL

16.1.8 GPIO (D0–D6)

Pins D0–D6 are general purpose input/output (GPIO) pins that can be used to control external LEDs or switches. Only a high or low value can be sourced to or read from each pin.

Figure 11 shows a flowchart how these GPIOs can be programmed.

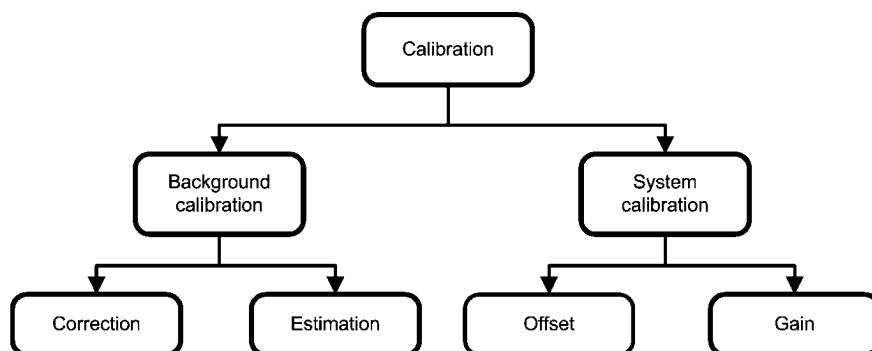


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FIGURE 11. GPIO Register Settings

16.2 CALIBRATION

As seen in Figure 12, there are two types of calibration: background calibration and system calibration. These calibrations are further described in the next sections.



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FIGURE 12. Types of Calibration

16.2.1 Background Calibration

Background calibration is the process of continuously determining and applying the offset and gain calibration coefficients to the output codes to minimize the LMP90xxx's offset and gain errors. Background calibration is a feature built into the LMP90xxx and is automatically done by the hardware without interrupting the input signal.

Four differential channels, CH0–CH3, each with its own gain and ODRs, can be calibrated to improve the accuracy.

Types of Background Calibration:

Figure 12 also shows that there are two types of background calibration:

1. Type 1: Correction - the process of continuously determining and applying the offset and gain calibration coefficients to the output codes to minimize the LMP90xxx's offset and gain errors. This method keeps track of changes in the LMP90xxx's gain and offset errors due to changes in the operating condition such as voltage, temperature, or time.
2. Type 2: Estimation - the process of determining and continuously applying the last known offset and gain

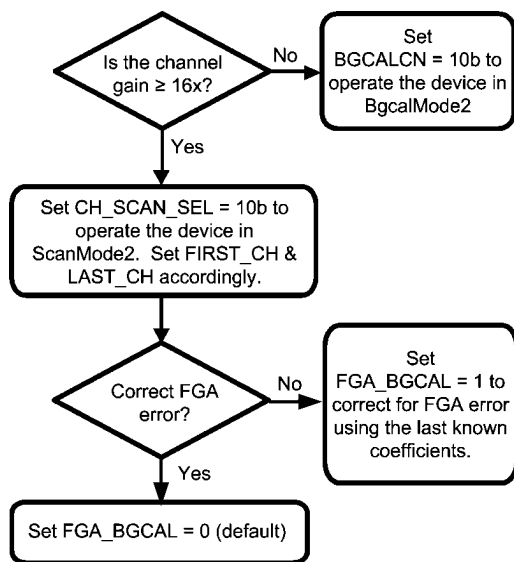
calibration coefficients to the output codes to minimize the LMP90xxx's offset and gain errors. The last known offset or gain calibration coefficients can come from two sources. The first source is the default coefficient which is pre-determined and burnt in the device's non-volatile memory. The second source is from a previous calibration run of Type 1: Correction.

The benefits of using type 2 calibration is a higher throughput, lower power consumption, and slightly better noise. The exact savings would depend on the number of channels being scanned, and the ODR and gain of each channel.

Using Background Calibration:

There are four modes of background calibration, which can be programmed using the BGALCN bits. They are as follows:

1. BgcalMode0: Background Calibration OFF
2. BgcalMode1: Offset Correction / Gain Estimation
3. BgcalMode2: Offset Correction / Gain Correction
Follow [Figure 13](#) to set other appropriate registers when using this mode.
4. BgcalMode3: Offset Estimation / Gain Estimation



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FIGURE 13. BgcalMode2 Register Settings

If operating in BgcalMode2, four channels (with the same ODR) are being converted, and FGA_BGCAL = 0 (default), then the ODR is reduced by:

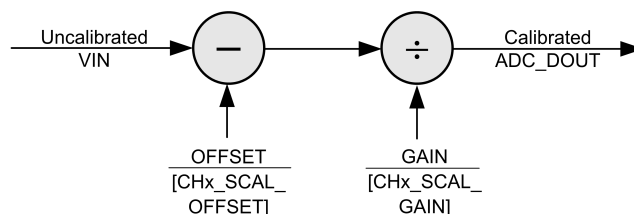
1. 0.19% of 1.6775 SPS
2. 0.39% of 3.355 SPS
3. 0.78% of 6.71 SPS
4. 1.54% of 13.42 SPS
5. 3.03% of 26.83125 SPS
6. 5.88% of 53.6625 SPS
7. 11.11% of 107.325 SPS
8. 20% of 214.65 SPS

16.2.2 System Calibration

The LMP90xxx provides some unique features to support easy system offset and system gain calibrations.

The System Calibration Offset Registers (CHx_SCAL_OFFSET) hold the System Calibration Offset Coefficients in 24-bit, two's complement binary format. The System Calibration Gain Registers (CHx_SCAL_GAIN) hold the System Calibration Gain Coefficient in 24-bit, 1.23, unsigned, fixed-point binary format. For each channel, the System Calibration Offset coefficient is subtracted from the conversion result prior to the division by the System Calibration Gain Coefficient.

A data-flow diagram of these coefficients can be seen in [Figure 14](#).



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FIGURE 14. System Calibration Data-Flow Diagram

There are four distinct sets of System Calibration Offset and System Calibration Gain Registers for use with CH0-CH3. CH4-CH6 reuse the registers of CH0-CH2, respectively.

The LMP90xxx provides two system calibration modes that automatically fill the Offset and Gain coefficients for each channel. These modes are the System Calibration Offset Coefficient Determination mode and the System Calibration Gain Coefficient Determination mode. The System Calibration Offset Coefficient Determination mode must be entered prior to the System Calibration Gain Coefficient Determination mode, for each channel.

The system zero-scale condition is a system input condition (sensor loading) for which zero (0x00_0000) system-calibrated output code is desired. It may not, however, cause a zero input voltage at the input of the ADC.

The system reference-scale condition is usually the system full-scale condition in which the system's input (or sensor's loading) would be full-scale and the desired system-calibrated output code would be 0x80_0000 (unsigned 24-bit binary). However, system full-scale condition need not cause full-scale input voltage at the input of the ADC.

The system reference-scale condition is not restricted to just the system full-scale condition. In fact, it can be any arbitrary fraction of full-scale (up to 1.25 times) and the desired system-calibrated output code can be any appropriate value (up to 0xA00000). The CHx_SCAL_GAIN register must be written with the desired system-calibrated output code (default: 0x800000) before entering the System Calibration Gain Coefficient Determination mode. This helps in in-place system calibration.

Below are the detailed procedures for using the System Calibration Offset Coefficient Determination and System Calibration Gain Coefficient Determination modes.

System Calibration Offset Coefficient Determination mode

1. Apply system zero-scale condition to the channel (CH0/CH1/CH2/CH3).

2. Enter the System Calibration Offset Coefficient Determination mode by programming 0x1 in the SCALCN register.
3. LMP90xxx starts a fresh conversion at the selected output data rate for the selected channel. At the end of the conversion, the CHx_SCAL_OFFSET register is filled-in with the System Calibration Offset coefficient.
4. The System Calibration Offset Coefficient Determination mode is automatically exited.
5. The computed calibration coefficient is accurate only to the effective resolution of the device and will probably contain some noise. The noise factor can be minimized by computing over many times, averaging (externally) and putting the resultant value back into the register. Alternatively, select the output data rate to be 26.83 sps or 1.67 sps.

System Calibration Gain Coefficient Determination mode

1. Repeat the System Calibration Offset Coefficient Determination mode to calibrate for the channel's system offset.
2. Apply the system reference-scale condition to the channel CH0/CH1/CH2/CH3.
3. In the CHx_SCAL_GAIN Register, program the expected (desired) system-calibrated output code for this condition in 24-bit unsigned format.
4. Enter the System Calibration Gain Coefficient Determination mode by programming 0x3 in the SCALCN register.
5. LMP90xxx starts a fresh conversion at the selected output data rate for the channel. At the end of the conversion, the CHx_SCAL_GAIN is filled-in (or overwritten) with the System Calibration Gain coefficient.
6. The System Calibration Gain Coefficient Determination mode is automatically exited.
7. The computed calibration coefficient is accurate only to the effective resolution of the device and will probably contain some noise. The noise factor can be minimized by computing over many times, averaging (externally) and putting the resultant value back into the register. Alternatively, select the output data rate to be 26.83 sps or 1.67 sps.

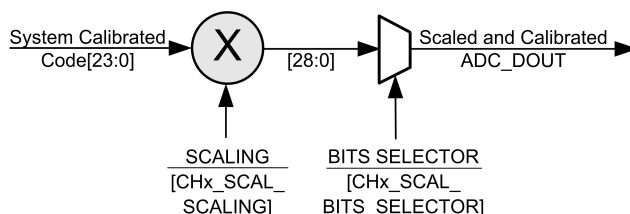
Post-calibration Scaling

LMP90xxx allows scaling (multiplication and shifting) for the System Calibrated result. This eases downstream processing, if any. Multiplication is done using the System Calibration Scaling Coefficient in the CHx_SCAL_SCALING register and shifting is done using the System Calibration Bits Selector in the CHx_SCAL_BITS_SELECTOR register.

The System Calibration Bits Selector value should ideally be the logarithm (to the base 2) of the System Calibration Scaling Coefficient value.

There are four distinct sets of System Calibration Scaling and System Calibration Bits Selector Registers for use with Channels 0-3. Channels 4-6 reuse the registers of Channels 0-2, respectively.

A data-flow diagram of these coefficients can be seen in [Figure 15](#)



30139542

FIGURE 15. Post-calibration Scaling Data-Flow Diagram

16.3 CHANNELS SCAN MODE

There are four scan modes. These scan modes are selected using the CH_SCAN: CH_SCAN_SEL bit. The first scanned channel is FIRST_CH, and the last scanned channel is LAST_CH; they are both located in the CH_SCAN register.

The CH_SCAN register is double buffered. That is, user inputs are stored in a slave buffer until the start of the next conversion during which time they are transferred to the master buffer. Once the slave buffer is written, subsequent updates are disregarded until a transfer to the master buffer happens. Hence, it may be appropriate to check the CH_SCAN_NRDY bit before programming the CH_SCAN register.

ScanMode0: Single-Channel Continuous Conversion

LMP90xxx continuously converts the selected FIRST_CH.

Do not operate in this scan mode if gain ≥ 16 and the LMP90xxx is running in background calibration modes BgcalMode1 or BgcalMode2. If this is the case, then it is more suitable to operate the device in ScanMode2 instead.

ScanMode1: Multiple-Channels Single Scan

LMP90xxx converts one or more channels starting from FIRST_CH to LAST_CH, and then enters the stand-by state.

ScanMode2: Multiple-Channels Continuous Scan

LMP90xxx continuously converts one or more channels starting from FIRST_CH to LAST_CH, and then it repeats this process.

ScanMode3: Multiple-Channels Continuous Scan with Burnout Currents

This mode is the same as ScanMode2 except that the burnout current is provided in a serially scanned fashion (injected in a channel after it has undergone a conversion). Thus it avoids burnout current injection from interfering with the conversion result for the channel.

The sensor diagnostic burnout currents are available for all four scan modes. The burnout current is further gated by the BURNOUT_EN bit for each channel. ScanMode3 is the only mode that scans multiple channels while injecting burnout currents without interfering with the signal. This is described in details in [Section 16.4.2 Burnout Currents](#).

16.4 SENSOR INTERFACE

LMP90100/LMP90098 contain two types of current sources: excitation currents (IB1 & IB2) and burnout currents. They are described in the next sections.

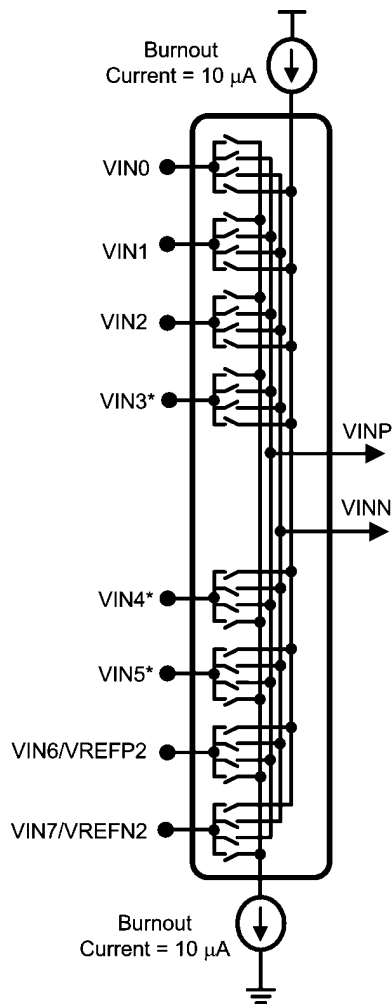
16.4.1 IB1 & IB2 - Excitation Currents

IB1 and IB2 can be used for providing currents to external sensors, such as RTDs or bridge sensors. 100 μ A to 1000 μ A, in steps of 100 μ A, can be sourced by programming the ADC_AUXCN: RTD_CUR_SEL bits.

Refer to [Section 17.6.1 3-Wire RTD](#) to see how IB1 and IB2 can be used to source a 3-wire RTD.

16.4.2 Burnout Currents

As shown in [Figure 16](#), the LMP90xxx contains two internal 10 μ A burnout current sources, one sourcing current from VA to VINP, and the other sinking current from VINN to ground. These currents are used for sensor diagnostics and can be enabled for each channel using the CHx_INPUTCN: BURNOUT_EN bit.



* VIN3, VIN4, VIN5 are only available for LMP90100 and LMP90099

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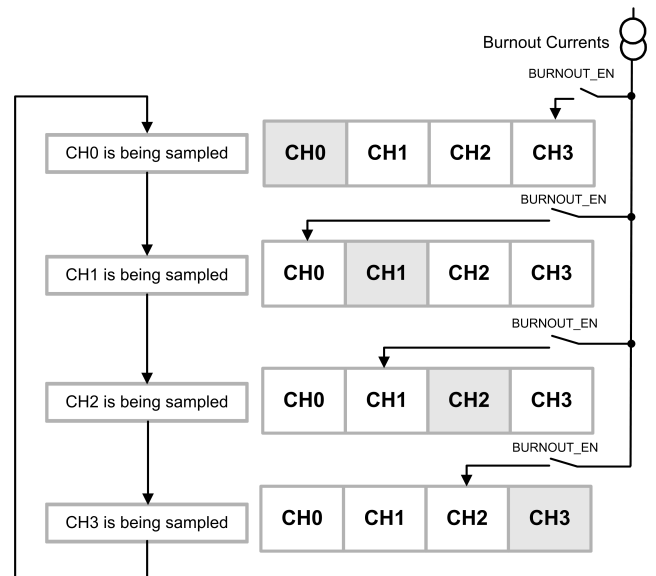
FIGURE 16. Burnout Currents

Burnout Current Injection:

Burnout currents are injected differently depending on the channel scan mode selected.

When BURNOUT_EN = 1 and the device is operating in ScanMode0, 1, or 2, the burnout currents are injected into all the channels for which the BURNOUT_EN bit is selected. This will cause problems and hence in this mode, more than one channel should not have its BURNOUT_EN bit selected. Also, the burnout current will interfere with the signal and introduce a fixed error depending on the particular external sensor.

When BURNOUT_EN = 1 and the device is operating in ScanMode3, burnout currents are injected into the last sampled channel on a cyclical basis ([Figure 17](#)). In this mode, burnout currents injection is truly done in the background without affecting the accuracy of the on-going conversion. Operating in this mode is recommended.



30139581

FIGURE 17. Burnout Currents Injection for ScanMode3

16.4.3 Sensor Diagnostic Flags

Burnout currents can be used to verify that an external sensor is still operational before attempting to make measurements on that channel. A non-operational sensor means that there is a possibility the connection between the sensor and the LMP90xxx is open circuited, short circuited, shorted to VA or GND, overloaded, or the reference may be absent. The sensor diagnostic flags diagram can be seen in [Figure 18](#).

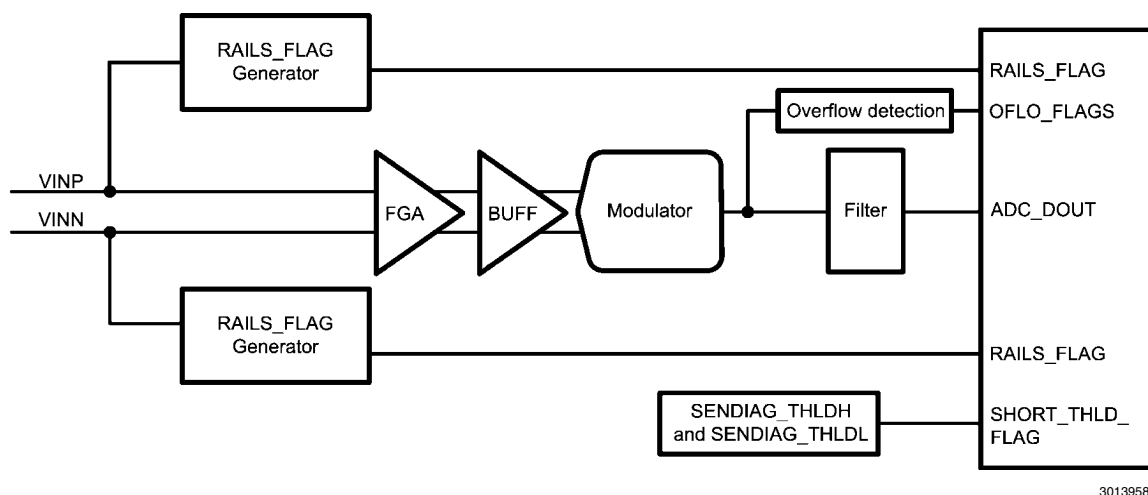


FIGURE 18. Sensor Diagnostic Flags Diagram

The sensor diagnostic flags are located in the SENDIAG_FLAGS register and are described in further details below.

SHORT_THLD_FLAG:

The short circuit threshold flag is used to report a short-circuit condition. It is set when the output voltage (VOUT) is within the absolute Vthreshold. Vthreshold can be programmed using the 8-bit SENDIAG_THLDH register concatenated with the 8-bit SENDIAG_THLDL register.

For example, assume VREF = 5V, gain = 1, SENDIAG_THLDH = 0xFA, and SENDIAG_THLDL = 0x45. In this case, Dthreshold = 0xFA45 = 64069d, and Vthreshold can be calculated as:

$$V_{\text{threshold}} = [(D_{\text{threshold}})(2)(V_{\text{REF}})] / [(Gain)(2^{24})]$$

$$V_{\text{threshold}} = [(64069)(2)(5V)] / [(1)(2^{24})]$$

$$V_{\text{threshold}} = 38.2 \text{ mV}$$

When $(-38.2\text{mV}) \leq V_{\text{OUT}} \leq (38.2\text{mV})$, then SHORT_THLD_FLAG = 1; otherwise, SHORT_THLD_FLAG = 0.

RAILS_FLAG:

The rails flag is used to detect if one of the sampled channels is within 50mV of the rails potential (VA or VSS). This can be further investigated to detect an open-circuit or short-circuit condition. If the sampled channel is near a rail, then RAILS_FLAG = 1; otherwise, RAILS_FLAG = 0.

POR_AFT_LST_RD:

If POR_AFT_LST_READ = 1, then there was a power-on-reset since the last time the SENDIAG_FLAGS register was read. This flag's status is cleared when this bit is read, unless this bit is set again on account of another power-on-reset event in the intervening period.

OFLO_FLAGS:

OFLO_FLAGS is used to indicate whether the modulator is over-ranged or under-ranged. The following conditions are possible:

1. OFLO_FLAGS = 0x0: Normal Operation
2. OFLO_FLAGS = 0x1: The modulator was not overranged, but ADC_DOUT got clamped to 0x7f_ffff (positive fullscale) or 0x80_0000 (negative full scale). For example, if VREF = 5V, VIN = 2V, and gain = 128, then OFLO_FLAGS would be 01b.
3. OFLO_FLAGS = 0x2: The modulator was over-ranged towards +VREF.
4. OFLO_FLAGS = 0x3: The modulator was over-ranged towards -VREF.

The condition of OFLO_FLAGS = 10b or 11b can be used in conjunction with the RAILS_FLAG to determine the fault condition.

SAMPLED_CH:

These three bits show the channel number for which the ADC_DOUT and SENDIAG_FLAGS are available. This does not necessarily indicate the current channel under conversion because the conversion frame and computation of results from the channels are pipelined. That is, while the conversion is going on for a particular channel, the results for the previous conversion (of the same or a different channel) are available.

16.5 SERIAL DIGITAL INTERFACE

A synchronous 4-wire serial peripheral interface (SPI) provides access to the internal registers of LMP90xxx via CSB, SCLK, SDI, SDO/DRDYB.

16.5.1 Register Address (ADDR)

All registers are memory-mapped. A register address (ADDR) is composed of an upper register address (URA) and lower register address (LRA) as shown in [ADDR Map](#). For example, ADDR 0x3A has URA=0x3 and LRA=0xA.

ADDR Map

| Bit | [6:4] | [3:0] |
|------|-------|-------|
| Name | URA | LRA |

16.5.2 Register Read/Write Protocol

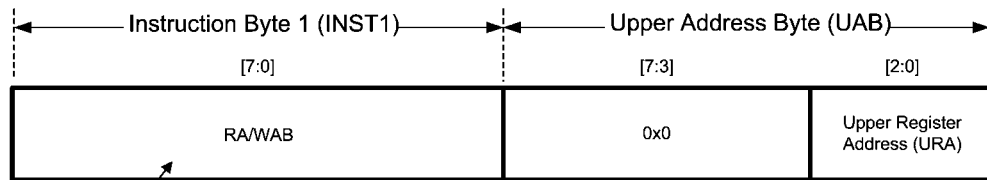
[Figure 19](#) shows the protocol how to write to or read from a register.

Transaction 1 sets up the upper register address (URA) where the user wants to start the register-write or register-read.

Transaction 2 sets the lower register address (LRA) and includes the Data Byte(s), which contains the incoming data from the master or outgoing data from the LMP90xxx.

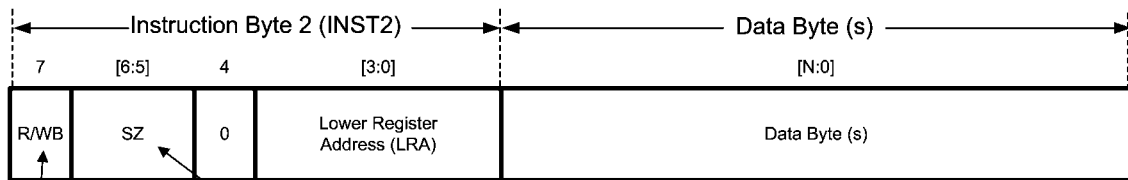
Examples of register-reads or register-writes can be found in [Section 17.4 REGISTER READ/WRITE EXAMPLES](#).

Transaction 1 – URA Setup – necessary only when the previous URA is different than the desired URA.



R/WB = Read/Write Address
 0x10: Write Address
 0x90: Read Address

Transaction 2 – Data Access



R/WB = Read/Write Data
 0: Write Data
 1: Read Data

SZ = Size
 0x0: 1 byte
 0x1: 2 bytes
 0x2: 3 bytes
 0x3: Streaming – 3+ bytes until CSB is de-asserted

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FIGURE 19. Register Read/Write Protocol

16.5.3 Streaming

When writing/reading 3+ bytes, the user must operate the device in Normal Streaming mode or Controlled Streaming mode. In the Normal Streaming mode, which is the default mode, data runs continuously starting from ADDR until CSB deasserts. This mode is especially useful when programming all the configuration registers in a single transaction. See [Section 17.5.1 Normal Streaming Example](#) for an example of the Normal Streaming mode.

In the Controlled Streaming mode, data runs continuously starting from ADDR until the data has run through all (STRM_RANGE + 1) registers. For example, if the starting ADDR is 0x1C, STRM_RANGE = 5, then data will be written to or read from the following ADDRs: 0x1C, 0x1D, 0x1E,

0x1F, 0x20, 0x21. Once the data reaches ADDR 0x21, LMP90xxx will wrap back to ADDR 0x1C and repeat this process until CSB deasserts. See [Section 17.5.2 Controlled Streaming Example](#) for an example of the Controlled Streaming mode.

If streaming reaches ADDR 0x7F, then it will wrap back to ADDR 0x00. Furthermore, reading back the Upper Register Address after streaming will report the Upper Register Address at the start of streaming, not the Upper Register Address at the end of streaming.

To stream, write 0x3 to INST2's SZ bits as seen in [Figure 19](#). To select the stream type, program the SPI_STREAMCN: STRM_TYPE bit. The STRM_RANGE can also be programmed in the same register.

16.5.4 CSB - Chip Select Bar

An SPI transaction begins when the master asserts (active low) CSB and ends when the master deasserts (active high) CSB. Each transaction might be separated by a subsequent one with a CSB deassertion, but this is optional. Once CSB is asserted, it must not pulse (deassert and assert again) during a (desired) transaction.

CSB can be grounded in systems where LMP90xxx is the only SPI slave. This frees the software from handling the CSB. Care has to be taken to avoid any false edge on SCLK, and while operating in this mode, the streaming transaction should not be used because exiting from this mode can only be done through a CSB deassertion.

16.5.5 SPI Reset

SPI Reset resets the SPI-Protocol State Machine by monitoring the SDI for at least 73 consecutive 1's at each SCLK

rising edge. After an SPI Reset, SDI is monitored for a possible Write Instruction at each SCLK rising edge.

SPI Reset will reset the Upper Address Register (URA) to 0, but the register contents are not reset.

By default, SPI reset is disabled, but it can be enabled by writing 0x01 to SPI Reset Register (ADDR 0x02).

16.5.6 DRDYB - Data Ready Bar

DRDYB is a signal generated by the LMP90xxx that indicates a fresh conversion data is available in the ADC_DOUT registers.

DRDYB is automatically asserted every (1/ODR) second and deasserts when ADC_DOUT is completely read out (LSB of ADC_DOUTL) ().



FIGURE 20. DRDYB Behavior for a Complete ADC_DOUT Reading

If ADC_DOUT is not completely read out (Figure 21) or is not read out at all, but a new ADC_DOUT is available, then

DRDYB will automatically pulse for t_{DRDYB} second. The value for t_{DRDYB} can be found in Section 13.0 Timing Diagrams.

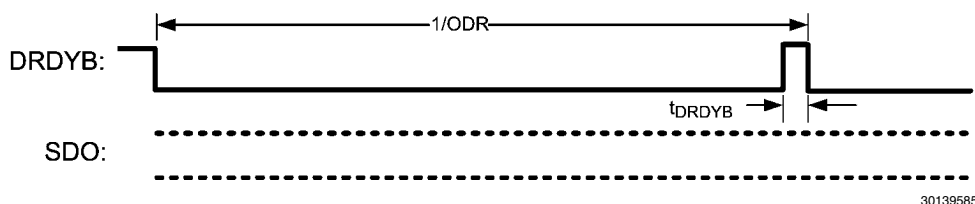


FIGURE 21. DRDYB Behavior for an ADC_DOUT not Read

If ADC_DOUT is being read, while the new ADC_DOUT becomes available, then the ADC_DOUT that is being read is still valid (Figure 22). DRDYB will be deasserted at the LSB of

the data being read, but a consecutive read on the ADC_DOUT register will fetch the newly converted data available.

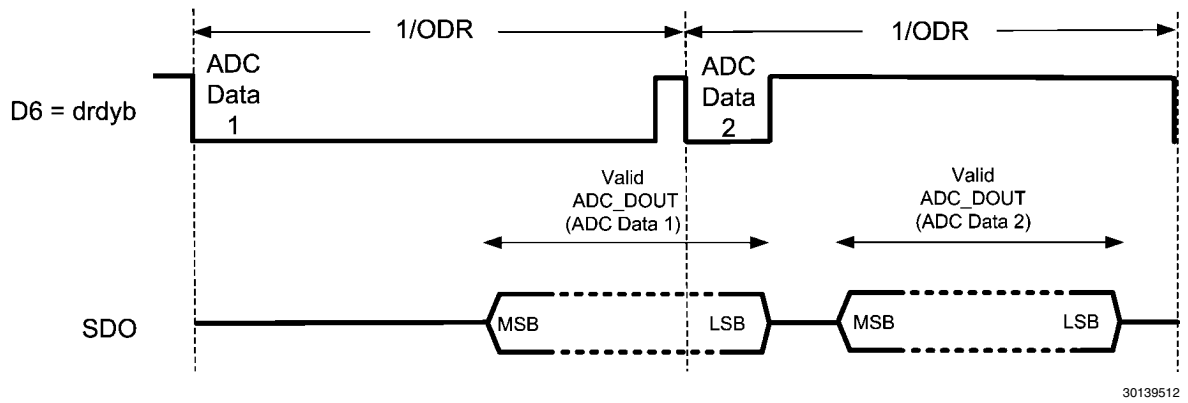


FIGURE 22. DRDYB Behavior for an Incomplete ADC_DOUT Reading

DRDYB can also be accessed via registers using the DT_AVAIL_B bit. This bit indicates when fresh conversion data is available in the ADC_DOUT registers. If new conversion data is available, then DT_AVAIL_B = 0; otherwise, DT_AVAIL_B = 1.

As opposed to the drdyb signal, a complete reading for DT_AVAIL_B occurs when the MSB of ADC_DOUTH is read

out. This bit cannot be reset even if REG_AND_CNV_RST = 0xC3.

DrdybCase1: Combining SDO/DRDYB with SDO_DRDYB_DRIVER = 0x00

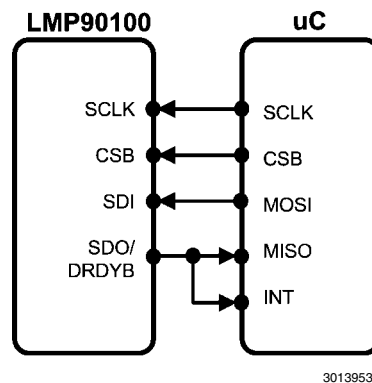


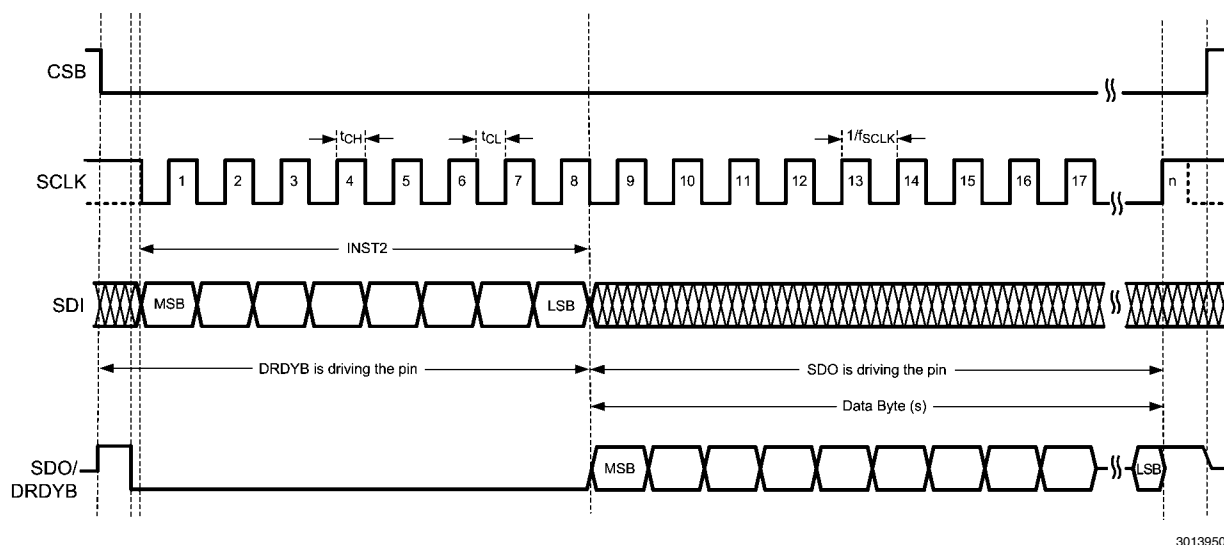
FIGURE 23. DrdybCase1 Connection Diagram

As shown in [Figure 23](#), the drdyb signal and SDO can be multiplexed on the same pin as their functions are mostly complementary. In fact, this is the default mode for the SDO/DRDYB pin.

[Figure 24](#) shows a timing protocol for DrdybCase1. In this case, start by asserting CSB first to monitor a drdyb assertion. When the drdyb signal asserts, begin writing the Instruction Bytes (INST1, UAB, INST2) to read from or write to registers.

Note that INST1 and UAB are omitted from the figure below because this transaction is only required if a new UAB needs to be implemented.

While the CSB is asserted, DRDYB is driving the SDO/DRDYB pin unless the device is reading data, in which case, SDO will be driving the pin. If CSB is deasserted, then the SDO/DRDYB pin is High-Z.



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FIGURE 24. Timing Protocol for DrdybCase1

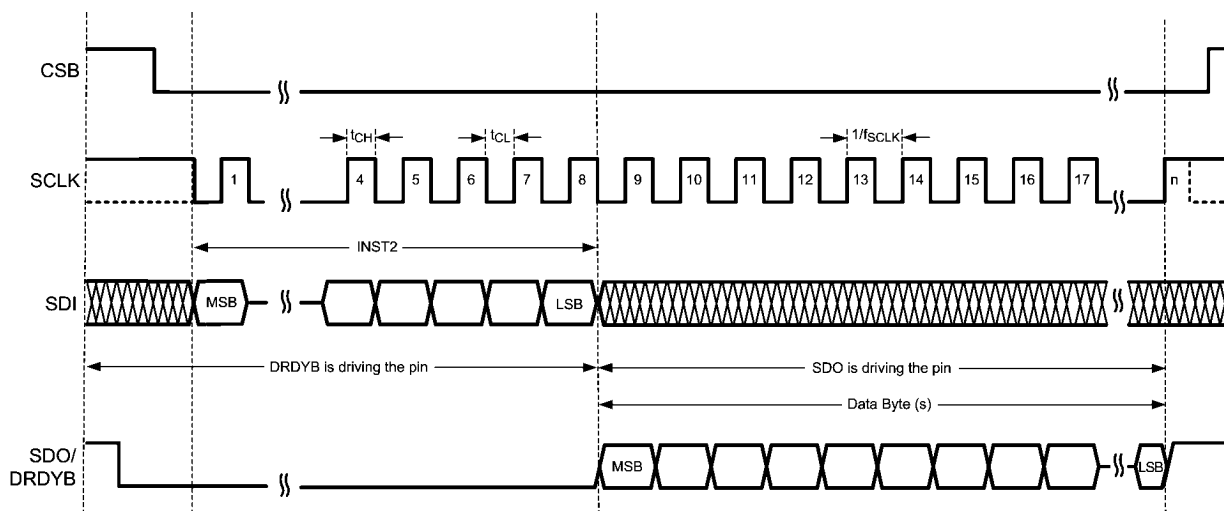
DrdybCase2: Combining SDO/DRDYB with SDO_DRDYB_DRIVER = 0x03

SDO/DRDYB can be made independent of CSB by setting SDO_DRDYB_DRIVER = 0x03 in the SPI Handshake Control register. In this case, DRDYB will drive the pin unless the device is reading data, independent of the state of CSB. SDO will drive the pin when CSB is asserted and the device is reading data.

With this scheme, one can use SDO/DRDYB as a true interrupt source, independent of the state of CSB. But this scheme

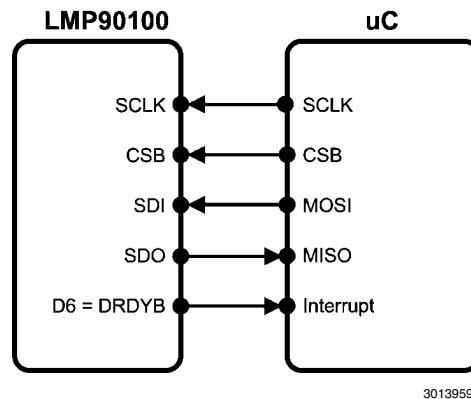
can only be used when the LMP900xx is the only device connected to the master's SPI bus because the SDO/DRDYB pin will be DRDYB even when CSB is deasserted.

The timing protocol for this case can be seen in [Figure 25](#). When drdyb asserts, assert CSB to start the SPI transaction and begin writing the Instruction Bytes (INST1, UAB, INST2) to read from or write to registers.



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FIGURE 25. Timing Protocol for DrdybCase2

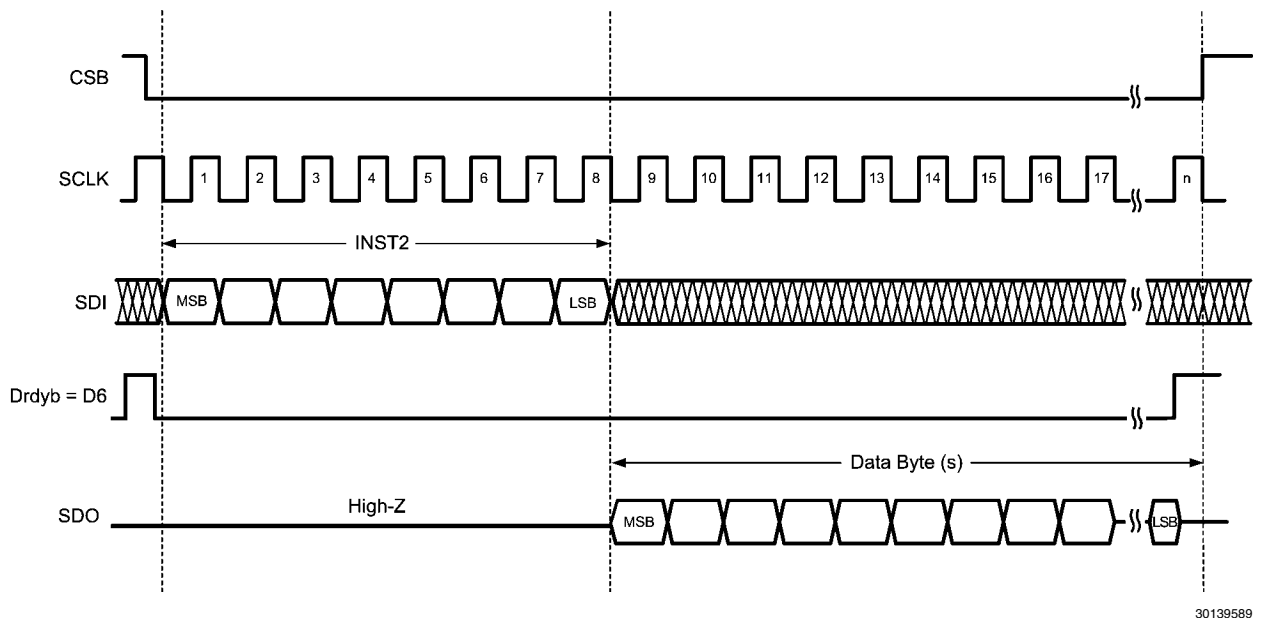
DrdybCase3: Routing DRDYB to D6

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FIGURE 26. DrdybCase3 Connection Diagram

The drdyb signal can be routed to pin D6 by setting SPI_DRDYB_D6 high and SDO_DRDYB_DRIVER to 0x4. This is the behavior for DrdybCase3 as shown in [Figure 26](#). The timing protocol for this case can be seen in [Figure 27](#). Since DRDYB is separated from SDO, it can be monitored

using the interrupt or polling method. If polled, the drdyb signal needs to be polled faster than t_{DRDYB} to detect a drdyb assertion. When drdyb asserts, assert CSB to start the SPI transaction and begin writing the Instruction Bytes (INST1, UAB, INST2) to read from or write to registers.



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FIGURE 27. Timing Protocol for DrdybCase3**16.5.7 Data Only Read Transaction**

In a data only read transaction, one can directly access the data byte(s) as soon as the CSB is asserted without having to send any instruction byte. This is useful as it brings down the latency as well as the overhead associated with the instruction byte (as well as the Upper Address Byte, if any).

In order to use the data only transaction, the device must be placed in the data first mode. The following table lists transaction formats for placing the device in and out of the data first mode and reading the mode status.

TABLE 5. Data First Mode Transactions

| | Bit[7] | Bits[6:5] | Bit[4] | Bits[3:0] | Data Bytes |
|-------------------------------------|--------|-----------|--------|-----------|------------|
| Enable Data First Mode Instruction | 1 | 11 | 1 | 1010 | None |
| Disable Data First Mode Instruction | 1 | 11 | 1 | 1011 | None |
| Read Mode Status Transaction | 1 | 00 | 1 | 1111 | One |

Note that while being in the data first mode, once the data bytes in the data only read transaction are sent out, the device is ready to start on any normal (non-data-only) transaction including the Disable Data First Mode Instruction. The current status of the data first mode (enabled/disabled status) can be read back using the Read Mode Status Transaction. This transaction consists of the Read Mode Status Instruction followed by a single data byte (driven by the device). The data first mode status is available on bit [1] of this data byte.

The data only read transaction allows reading up to eight consecutive registers, starting from any start address. Usually, the start address will be the address of the most significant byte of conversion data, but it could just as well be any other address. The start address and number of bytes to be read during the data only read transaction can be programmed using the DATA_ONLY_1 AND DATA_ONLY_2 registers respectively.

The upper register address is unaffected by a data only read transaction. That is, it retains its setting even after encountering a data only transaction. The data only transaction uses its own address (including the upper address) from the DATA_ONLY_1 register. When in the data first mode, the SCLK must stop high before entering the Data Only Read Transaction; this transaction should be completed before the next scheduled DRDYB deassertion.

16.5.8 Cyclic Redundancy Check (CRC)

CRC can be used to ensure integrity of data read from LMP90xxx. To enable CRC, set EN_CRC high. Once CRC is enabled, the CRC value is calculated and stored in SPI_CRC_DAT so that the master device can periodically read for data comparison. Conveniently, the SPI_CRC_DAT register address is located next to the ADC_DOUT register address so that the CRC value can be easily read as part of the data set. The CRC is automatically reset when CSB or DRDYB is deasserted.

The CRC polynomial is $x^8 + x^5 + x^4 + 1$. The reset value of the SPI_CRC_DAT register is zero, and the final value is ones-complemented before it is sent out. Note that CRC computation only includes the bits sent out on SDO and does not include the bits of the SPI_CRC_DAT itself; thus it is okay to read SPI_CRC_DAT repeatedly.

The drdyb signal normally deasserts (active high) every 1/ODR second or when the LSB of ADC_DOUTL is read. However, this behavior can be changed so that drdyb deassertion can occur after SPI_CRC_DAT is read, but not later than normal DRDYB deassertion which occurs at every 1/ODR seconds. This is done by setting bit DRDYB_AFT_CRC high.

The timing protocol for CRC can be found in [Figure 28](#).

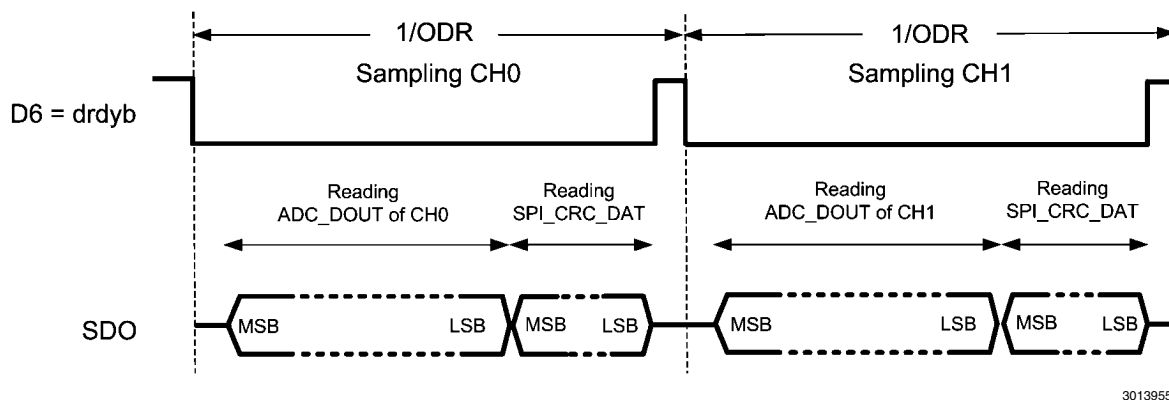


FIGURE 28. Timing Protocol for Reading SPI_CRC_DAT

If SPI_CRC_DAT read extends beyond the normal DRDYB deassertion at every 1/ODR seconds, then CRC_RST has to be set in the SPI Data Ready Bar Control Register. This is

done to avoid a CRC reset at the DRDYB deassertion. Timing protocol for reading CRC with CRC_RST set is shown in [Figure 29](#)

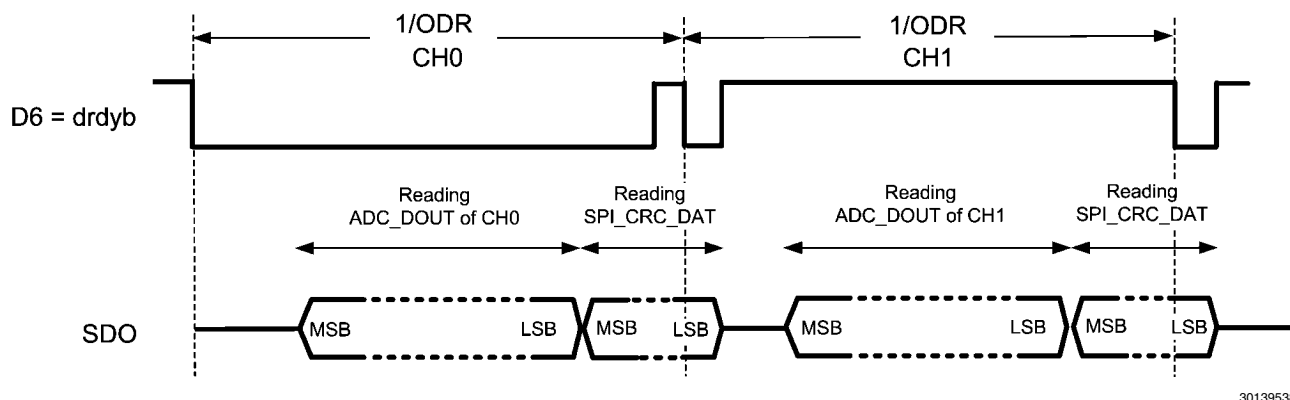


FIGURE 29. Timing Protocol for Reading SPI_CRC_DAT beyond normal DRDYB deassertion at every 1/ODR seconds

16.6 POWER MANAGEMENT

The device can be placed in Active, Power-Down, or Stand-By state.

In Power-Down, the ADC is not converting data, contents of the registers are unaffected, and there is a drastic power reduction. In Stand-By, the ADC is not converting data, but the power is only slightly reduced so that the device can quickly transition into the active state if desired.

These states can be selected using the PWRCN register. When written, PWRCN brings the device into the Active, Power-Down, or Stand-By state. When read, PWRCN indicates the state of the device.

The read value would confirm the write value after a small latency (approximately 15 μ s with the internal CLK). It may be appropriate to wait for this latency to confirm the state change. Requests not adhering to this latency requirement may be rejected.

It is not possible to make a direct transition from the power-down state to the stand-by state. This state diagram is shown below.

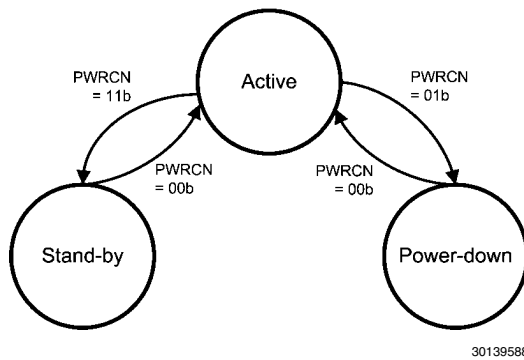


FIGURE 30. Active, Power-Down, Stand-by State Diagram

16.7 RESET and RESTART

Writing 0xC3 to the REG_AND_CNV_RST field will reset the conversion and most of the programmable registers to their default values. The only registers that will not be reset are the System Calibration Registers (CHx_SCAL_OFFSET, CHx_SCAL_GAIN) and the DT_AVAIL_B bit.

If it is desirable to reset the System Calibration Coefficient Registers, then set RESET_SYSCAL = 1 before writing 0xC3 to REG_AND_CNV_RST. If the device is operating in the "System Calibration Offset/Gain Coefficient Determination" mode (SCALCN register), then write REG_AND_CNV_RST = 0xC3 twice to get out of this mode.

After a register reset, any on-going conversions will be aborted and restarted. If the device is in the power-down state, then a register reset will bring it out of the power-down state.

To restart a conversion, write 1 to the RESTART bit. This bit can be used to synchronize the conversion to an external event.

17.0 Applications Information

17.1 QUICK START

This section shows step-by-step instructions to configure the LMP90xxx to perform a simple DC reading from CH0.

1. Apply $V_A = V_{IO} = V_{REF1} = 5V$, and ground V_{REFN1}
2. Apply $V_{INP} = \frac{3}{4}V_{REF}$ and $V_{INN} = \frac{1}{4}V_{REF}$ for CH0. Thus, set $CH0 = V_{IN} = V_{INP} - V_{INN} = \frac{1}{2}V_{REF}$ (CH0_INPUTCN register)
3. Set gain = 1 (CH0_CONFIG: GAIN_SEL = 0x0)
4. Exclude the buffer from the signal path (CH0_CONFIG: BUF_EN = 1)
5. Set the background to BgcalMode2 (BGCALCN = 0x2)
6. Select VREF1 (CH0_INPUTCN: VREF_SEL = 0)
7. To use the internal CLK, set CLK_EXT_DET = 1 and CLK_SEL = 0.
8. Follow the register read/write protocol (Figure 19) to capture ADC_DOUT from CH0.

17.2 CONNECTING THE SUPPLIES

17.2.1 VA and VIO

Any ADC architecture is sensitive to spikes on the analog voltage, V_A , digital input/output voltage, V_{IO} , and ground pins. These spikes may originate from switching power supplies, digital logic, high power devices, and other sources. To diminish these spikes, the LMP90xxx's V_A and V_{IO} pins should be clean and well bypassed. A 0.1 μF ceramic bypass capacitor and a 1 μF tantalum capacitor should be used to bypass the LMP90xxx supplies, with the 0.1 μF capacitor placed as close to the LMP90xxx as possible.

Since the LMP90xxx has both external V_A and V_{IO} pins, the user has two options on how to connect these pins. The first option is to tie V_A and V_{IO} together and power them with the same power supply. This is the most cost effective way of powering the LMP90xxx but is also the least ideal because noise from V_{IO} can couple into V_A and negatively affect performance. The second option involves powering V_A and V_{IO} with separate power supplies. These supply voltages can have the same amplitude or they can be different.

17.2.2 VREF

Operation with VREF below V_A is also possible with slightly diminished performance. As VREF is reduced, the range of acceptable analog input voltages is also reduced. Reducing the value of VREF also reduces the size of the LSB. When the LSB size goes below the noise floor of the LMP90xxx, the noise will span an increasing number of codes and performance will degrade. For optimal performance, VREF should

be the same as V_A and sourced with a clean source that is bypassed with a ceramic capacitor value of 0.1 μF and a tantalum capacitor of 10 μF .

LMP90xxx also allows ratiometric connection for noise immunity reasons. A ratiometric connection is when the ADC's V_{REFP} and V_{REFN} are used to excite the input device's (i.e. a bridge sensor) voltage references. This type of connection severely attenuates any VREF ripple seen the ADC output, and is thus strongly recommended.

17.3 ADC_DOUT CALCULATION

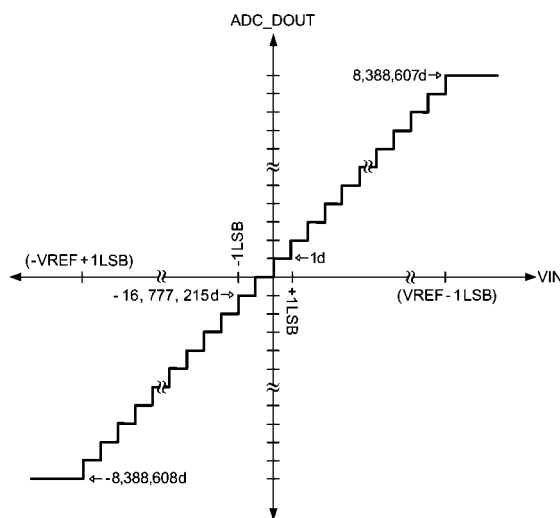
The output code of the LMP90xxx can be calculated as:

$$ADC_DOUT = \pm \left(\frac{(V_{INP} - V_{INN}) \times GAIN}{V_{REFP} - V_{REFN}} \right) \times (2^{23})$$

Equation 1 — Output Code

ADC_DOUT is in 24-bit two's complement binary format. The largest positive value is 0x7F_FFFF while the largest negative value is 0x80_0000. In case of an over range the value is automatically clamped to one of these two values.

Figure 31 shows the theoretical output code, ADC_DOUT, vs. analog input voltage, V_{IN} , using the equation above.



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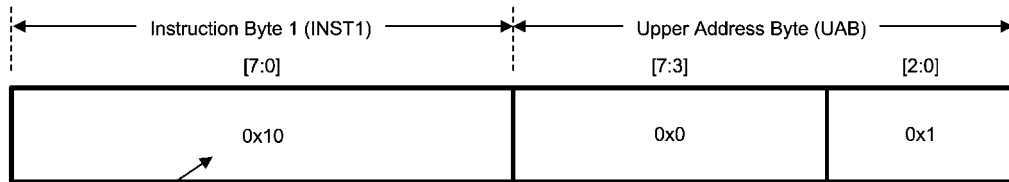
FIGURE 31. ADC_DOUT vs. V_{IN} of a 24-Bit Resolution ($V_{REF} = 5.5V$, Gain = 1).

17.4 REGISTER READ/WRITE EXAMPLES

17.4.1 Writing to Register Examples

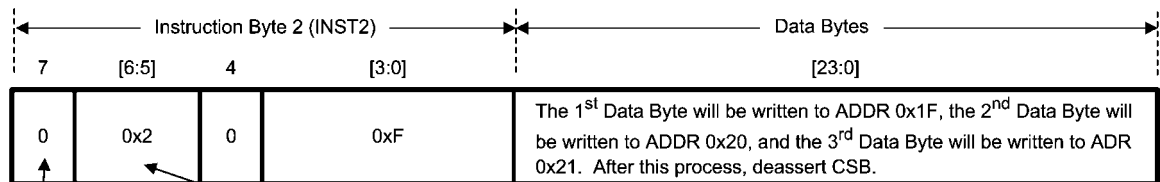
Using the register read/write protocol shown in [Figure 19](#), the following example shows how to write three data bytes starting at register address (ADDR) 0x1F. After the last byte has been written to ADDR 0x21, deassert CSB to end the register-write.

Transaction 1 – URA Setup – necessary only when the previous URA is different than the desired URA.



R/WB = Read/Write Address
 0x10: Write Address
 0x90: Read Address

Transaction 2 – Data Access



R/WB = Read/Write Data
 0: Write Data
 1: Read Data

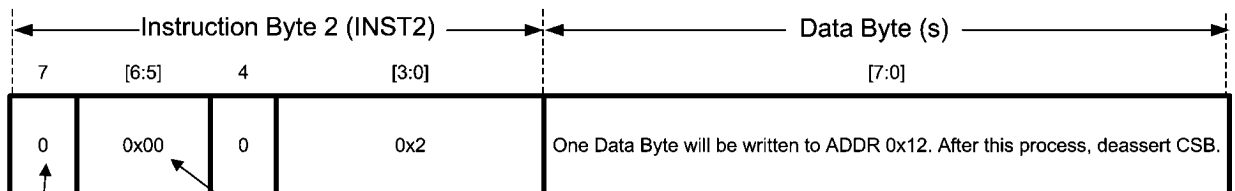
SZ = Size
 0x0: 1 byte
 0x1: 2 bytes
 0x2: 3 bytes
 0x3: Streaming – 3+ bytes until CSB is de-asserted

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FIGURE 32. Register-Write Example 1

The next example shows how to write one data byte to ADDR 0x12. Since the URA for this example is the same as the last example, transaction 1 can be omitted.

Transaction 2 – Data Access



R/WB = Read/Write Data
 0: Write Data
 1: Read Data

SZ = Size
 0x0: 1 byte
 0x1: 2 bytes
 0x2: 3 bytes
 0x3: Streaming – 3+ bytes until CSB is de-asserted

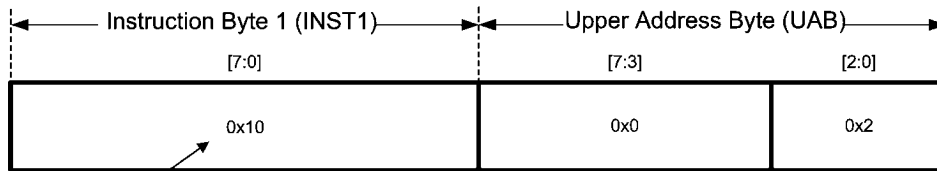
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FIGURE 33. Register-Write Example 2

17.4.2 Reading from Register Example

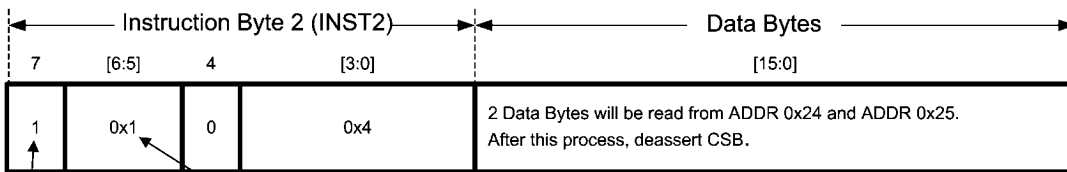
The following example shows how to read two bytes. The first byte will be read from starting ADDR 0x24, and the second byte will be read from ADDR 0x25.

Transaction 1 – URA Setup – necessary only when the previous URA is different than the desired URA.



R/WB = Read/Write Address
 0x10: Write Address
 0x90: Read Address

Transaction 2 – Data Access



R/WB = Read/Write Data SZ = Size
 0: Write Data 0x0: 1 byte
 1: Read Data 0x1: 2 bytes
 0x2: 3 bytes
 0x3: Streaming – 3+ bytes until CSB is de-asserted

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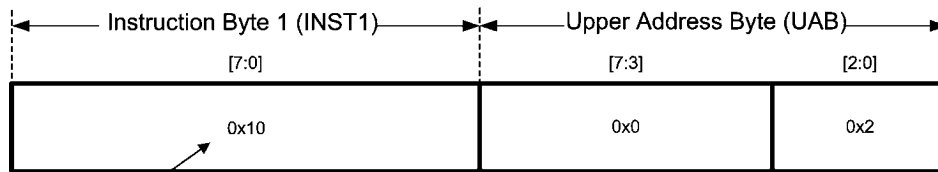
FIGURE 34. Register-Read Example

17.5 STREAMING EXAMPLES

17.5.1 Normal Streaming Example

This example shows how to write six data bytes starting at ADDR 0x28 using the Normal Streaming mode. Because the default STRM_TYPE is the Normal Streaming mode, setting up the SPI_STREAMCN register can be omitted.

Transaction 1 – URA Setup – necessary only when the previous URA is different than the desired URA.

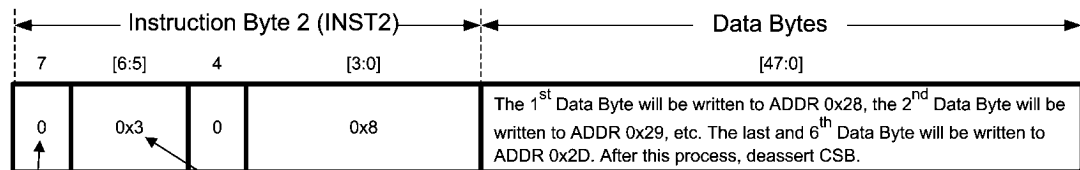


R/WB = Read/Write Address

0x10: Write Address

0x90: Read Address

Transaction 2 – Data Access



R/WB = Read/Write Data

0: Write Data

1: Read Data

SZ = Size

0x0: 1 byte

0x1: 2 bytes

0x2: 3 bytes

0x3: Streaming – 3+ bytes until CSB is de-asserted

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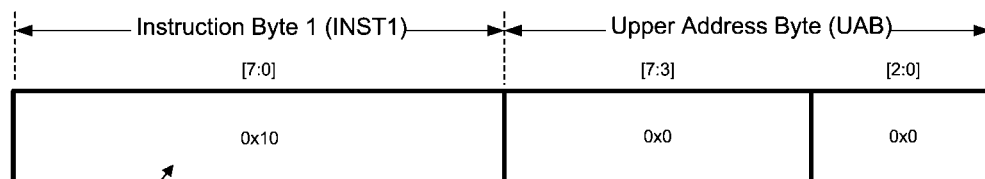
FIGURE 35. Normal Streaming Example

17.5.2 Controlled Streaming Example

This example shows how to read the 24-bit conversion data (ADC_DOUT) four times using the Controlled Streaming mode. The ADC_DOUT registers consist of ADC_DOUTH at ADDR 0x1A, ADC_DOUTM at ADDR 0x1B, and ADC_DOUTL at ADDR 0x1C.

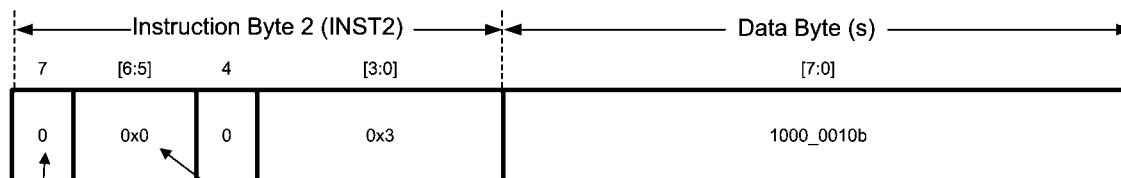
The first step ([Figure 36](#)) sets up the SPI_STREAMCN register. This step enters the Controlled Streaming mode by setting STRM_TYPE high in ADDR 0x03. Since three registers (ADDR 0x1A - 0x1C) need to be read, the STRM_RANGE is 2.

Transaction 1 – URA Setup – necessary only when the previous URA is different than the desired URA.



R/WB = Read/Write Address
 0x10: Write Address
 0x90: Read Address

Transaction 2 – Data Access



R/WB = Read/Write Data
 0: Write Data
 1: Read Data

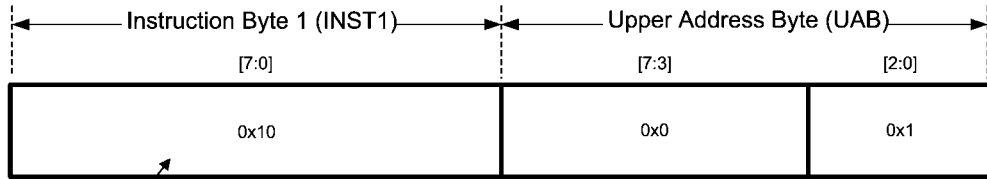
SZ = Size
 0x0: 1 byte
 0x1: 2 bytes
 0x2: 3 bytes
 0x3: Streaming – 3+ bytes until CSB is de-asserted

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FIGURE 36. Setting up SPI_STREAMCN

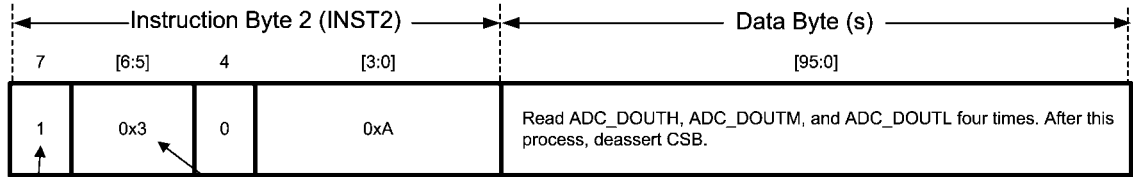
The next step shows how to perform the Controlled Streaming mode so that the master device will read ADC_DOUT from ADDR 0x1A, 0x1B, 0x1C, then wrap back to ADDR 0x1A, and repeat this process for four times. After this process, deassert CSB to end the Controlled Streaming mode.

Transaction 1 – URA Setup – necessary only when the previous URA is different than the desired URA.



R/WB = Read/Write Address
 0x10: Write Address
 0x90: Read Address

Transaction 2 – Data Access



R/WB = Read/Write Data
 0: Write Data
 1: Read Data

SZ = Size
 0x0: 1 byte
 0x1: 2 bytes
 0x2: 3 bytes
 0x3: Streaming – 3+ bytes until CSB is de-asserted

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FIGURE 37. Controlled Streaming Example

17.6 EXAMPLE APPLICATIONS

17.6.1 3-Wire RTD

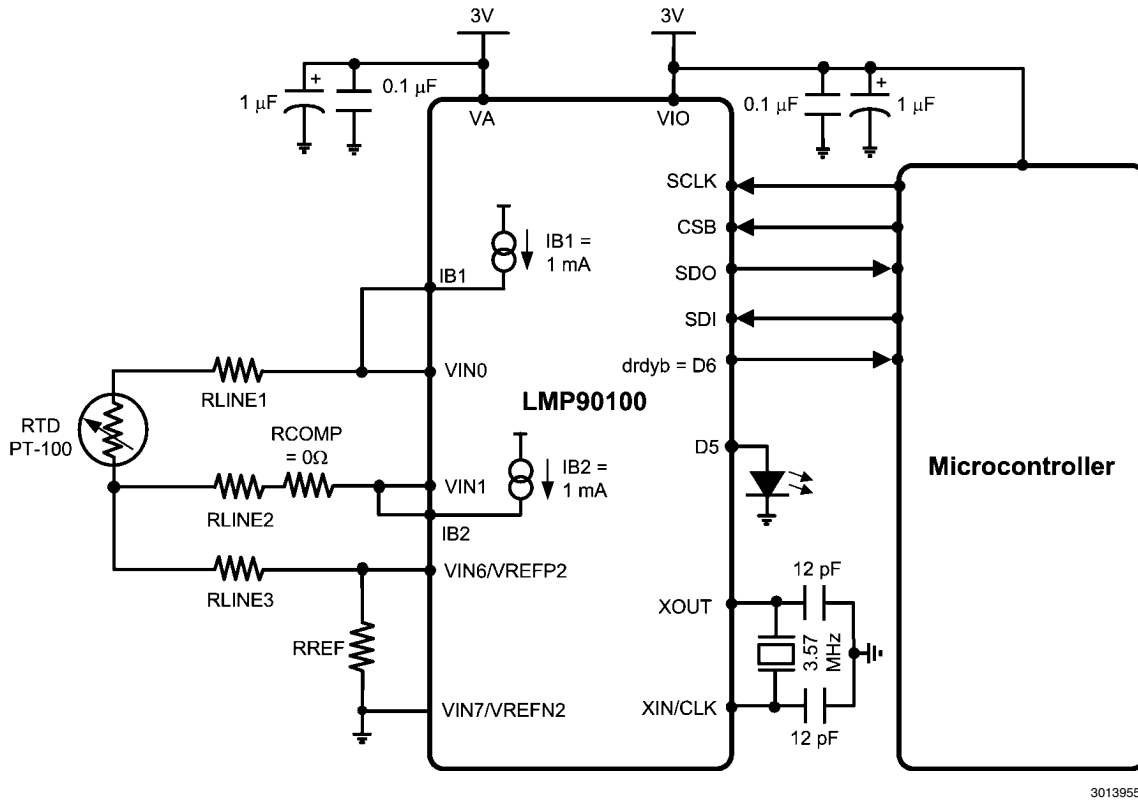


FIGURE 38. Topology #1: 3-wire RTD Using 2 Current Sources

Figure 38 shows the first topology for a 3-wire resistive temperature detector (RTD) application. Topology #1 uses two excitation current sources, IB1 and IB2, to create a differential voltage across VIN0 and VIN1. As a result of using both IB1 and IB2, only one channel (VIN0-VIN1) needs to be measured. As shown in Equation 2, the equation for this channel is $IB1 \times (RTD - RCOMP)$ assuming that $RLINE1 = RLINE2$.

$$\begin{aligned} VIN0 &= IB1 (RLINE1 + RTD) + (IB1 + IB2) (RLINE3 + RREF) \\ VIN1 &= IB2 (RLINE2 + RCOMP) + (IB1 + IB2) (RLINE3 + RREF) \\ \text{If } RLINE1 &= RLINE2, \text{ then:} \\ VIN &= (VIN0 - VIN1) = IB1 (RTD - RCOMP) \end{aligned}$$

Equation 2 — VIN Equation for Topology #1

The PT-100 changes linearly from 100 Ohm at 0°C to 146.07 Ohm at 120°C. If desired, choose a suitable compensating resistor (RCOMP) so that VIN can be virtually 0V at any desirable temperature. For example, if RCOMP = 100 Ohm, then at 0°C, VIN = 0V and thus a higher gain can be used.

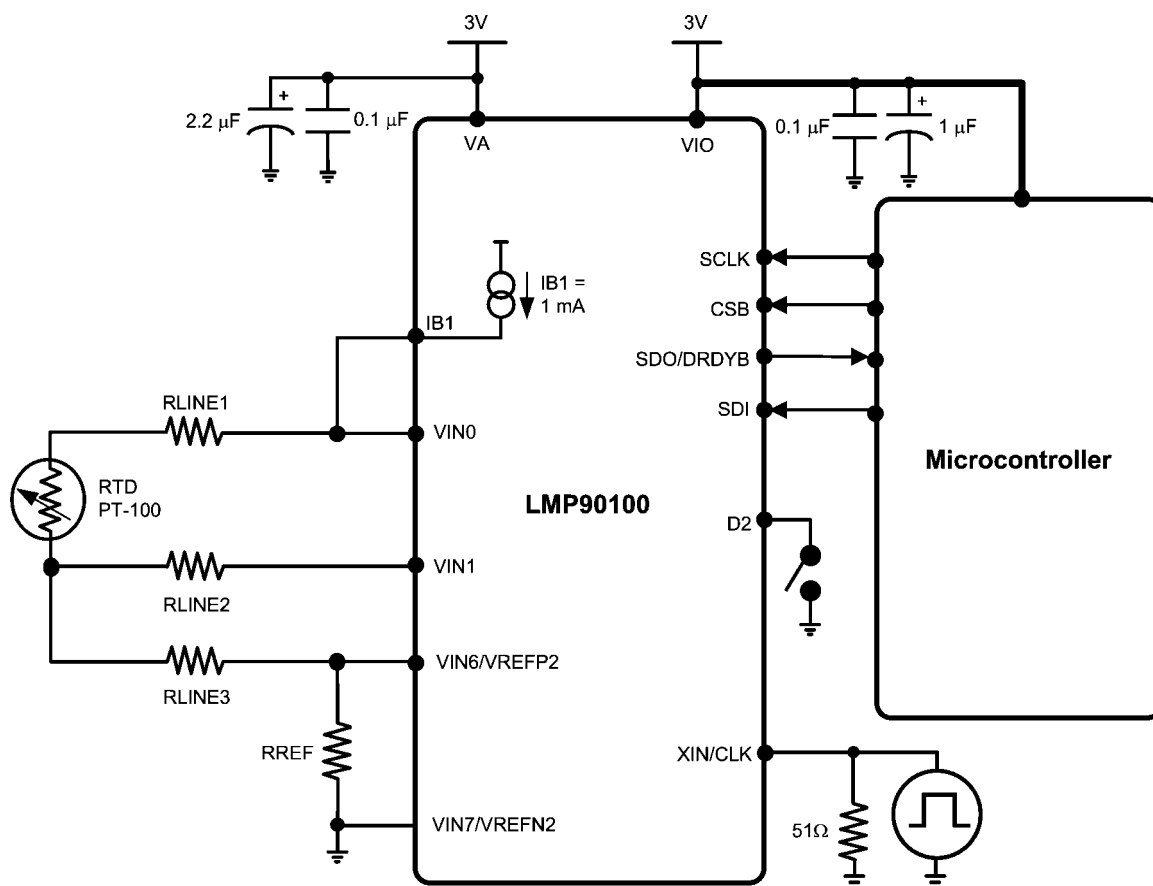
The advantage of this circuit is its ratiometric configuration, where $VREF = (IB1 + IB2) \times (RREF)$. Equation 3 shows that a ratiometric configuration eliminates IB1 and IB2 from the output equation, thus increasing the overall performance.

$$ADC_DOUT = \frac{VIN(Gain)}{2VREF} (2^n)$$

$$ADC_DOUT = \frac{[IB1(RTD - RCOMP)Gain]}{2(IB1 + IB2)RREF} (2^n)$$

$$ADC_DOUT = \frac{[(RTD - RCOMP)Gain]}{2(2)RREF} (2^n)$$

Equation 3 — ADC_DOUT Showing IB1 & IB2 Elimination



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FIGURE 39. Topology #2: 3-wire RTD Using 1 Current Source

Figure 39 shows the second topology for a 3-wire RTD application. Topology #2 shows the same connection as topology #1, but without IB2. Although this topology eliminates a current source, it requires two channel measurements as shown in Equation 4.

$$VIN0 = IB1 (RLINE1 + RTD + RLINE3 + RREF)$$

$$VIN1 = IB1 (RLINE3 + RREF)$$

$$VIN6 = IB1 (RREF)$$

$$CH0 = VIN0 - VIN1 = IB1 (RLINE1 + RTD)$$

$$CH1 = VIN1 - VIN6 = IB1 (RLINE3)$$

Assume $RLINE1 = RLINE3$, thus:

$$CH0 - CH1 = IB1 (RTD)$$

Equation 4 — VIN Equation for Topology #2



FIGURE 40. Thermocouple with CJC

Because a thermocouple can only measure a temperature difference, it does not have the ability to measure absolute temperature. To determine the absolute temperature of the measured environment (Thot), a technique known as cold junction compensation (CJC) must be used.

For example, assume $T_{cold} = 20^{\circ}\text{C}$. The equivalent voltage from a type K thermocouple look-up-table is 0.798 mV. Next, add the measured differential thermocouple voltage to the T_{cold} equivalent voltage. For example, if the thermocouple voltage is 4.096 mV, the total would be $0.798\text{ mV} + 4.096\text{ mV} = 4.894\text{ mV}$. Referring to the type K thermocouple table gives a temperature of 119.37°C for 4.894 mV.

18.0 Registers

1. If written to, RESERVED bits must be written to only 0 unless otherwise indicated.
2. Read back value of RESERVED bits and registers is unspecified and should be discarded.
3. Recommended values must be programmed and forbidden values must not be programmed where they are indicated in order to avoid unexpected results.

4. If written to, registers indicated as Reserved must have the indicated default value as shown below. Any other value can cause unexpected results.

18.1 REGISTER MAP

| Register Name | | ADDR (URA & LRA) | Type | Default |
|---|---------------------------------|---------------------|------------|---------|
| RESETCN | Reset Control | 0x00 | WO | - |
| SPI_HANDSHAKECN | SPI Handshake Control | 0x01 | R/W | 0x00 |
| SPI_RESET | SPI Reset Control | 0x02 | R/W | 0x00 |
| SPI_STREAMCN | SPI Stream Control | 0x03 | R/W | 0x00 |
| Reserved | - | 0x04 - 0x07 | - | 0x00 |
| PWRCN | Power Mode Control and Status | 0x08 | RO & WO | 0x00 |
| DATA_ONLY_1 | Data Only Read Control 1 | 0x09 | R/W | 0x1A |
| DATA_ONLY_2 | Data Only Read Control 2 | 0x0A | R/W | 0x02 |
| ADC_RESTART | ADC Restart Conversion | 0x0B | WO | - |
| Reserved | - | 0x0C - 0x0D | - | 0x00 |
| GPIO_DIRCN | GPIO Direction Control | 0x0E | R/W | 0x00 |
| GPIO_DAT | GPIO Data | 0x0F | RO & WO | - |
| BGCALCN | Background Calibration Control | 0x10 | R/W | 0x00 |
| SPI_DRDYBCN | SPI Data Ready Bar Control | 0x11 | R/W | 0x03 |
| ADC_AUXCN | ADC Auxiliary Control | 0x12 | R/W | 0x00 |
| SPI_CRC_CN | CRC Control | 0x13 | R/W | 0x02 |
| SENDIAG_THLD | Sensor Diagnostic Threshold 1,0 | 0x14 - 0x15 | R/W | 0x0000 |
| Reserved | - | 0x16 | - | 0x00 |
| SCALCN | System Calibration Control | 0x17 | R/W | 0x00 |
| ADC_DONE | ADC Data Available | 0x18 | RO | - |
| SENDIAG_FLAGS | Sensor Diagnostic Flags | 0x19 | RO | - |
| ADC_DOUT | Conversion Data 2,1,0 | 0x1A - 0x1C | RO | - |
| SPI_CRC_DAT | CRC Data | 0x1D | RO & WO | - |
| CHANNEL CONFIGURATION REGISTERS (CH4 to CH6 for LMP90100/LMP9099 only) | | | | |
| CH_STS | Channel Status | 0x1E | RO | 0x00 |
| CH_SCAN | Channel Scan Mode | 0x1F | R/W | 0x30 |
| CH0_INPUTCN | CH0 Input Control | 0x20 | R/W | 0x01 |
| CH0_CONFIG | CH0 Configuration | 0x21 | R/W | 0x70 |
| CH1_INPUTCN | CH1 Input Control | 0x22 | R/W | 0x13 |
| CH1_CONFIG | CH1 Configuration | 0x23 | R/W | 0x70 |
| CH2_INPUTCN | CH2 Input Control | 0x24 | R/W | 0x25 |
| CH2_CONFIG | CH2 Configuration | 0x25 | R/W | 0x70 |
| CH3_INPUTCN | CH3 Input Control | 0x26 | R/W | 0x37 |
| CH3_CONFIG | CH3 Configuration | 0x27 | R/W | 0x70 |
| CH4_INPUTCN | CH4 Input Control | 0x28 | R/W | 0x01 |
| CH4_CONFIG | CH4 Configuration | 0x29 | R/W | 0x70 |
| CH5_INPUTCN | CH5 Input Control | 0x2A | R/W | 0x13 |
| CH5_CONFIG | CH5 Configuration | 0x2B | R/W | 0x70 |
| CH6_INPUTCN | CH6 Input Control | 0x2C | R/W | 0x25 |

| Register Name | | ADDR (URA & LRA) | Type | Default |
|-------------------------------------|---|---------------------|------|-----------|
| CH6_CONFIG | CH6 Configuration | 0x2D | R/W | 0x70 |
| Reserved | - | 0x2E - 0x2F | - | 0x00 |
| SYSTEM CALIBRATION REGISTERS | | | | |
| CH0_SCAL_OFFSET | CH0 System Calibration Offset Coefficients | 0x30 - 0x32 | R/W | 0x00_0000 |
| CH0_SCAL_GAIN | CH0 System Calibration Gain Coefficients | 0x33 - 0x35 | R/W | 0x80_0000 |
| CH0_SCAL_SCALING | CH0 System Calibration Scaling Coefficients | 0x36 | R/W | 0x01 |
| CH0_SCAL_BITS_SELECTOR | CH0 System Calibration Bits Selector | 0x37 | R/W | 0x00 |
| CH1_SCAL_OFFSET | CH1 System Calibration Offset Coefficients | 0x38 - 0x3A | R/W | 0x00_0000 |
| CH1_SCAL_GAIN | CH1 System Calibration Gain Coefficient | 0x3B - 0x3D | R/W | 0x80_0000 |
| CH1_SCAL_SCALING | CH1 System Calibration Scaling Coefficients | 0x3E | R/W | 0x01 |
| CH1_SCAL_BITS_SELECTOR | CH1 System Calibration Bits Selector | 0x3F | R/W | 0x00 |
| CH2_SCAL_OFFSET | CH2 System Calibration Offset Coefficients | 0x40 - 0x42 | R/W | 0x00_0000 |
| CH2_SCAL_GAIN | CH2 System Calibration Gain Coefficient | 0x43 - 0x45 | R/W | 0x80_0000 |
| CH2_SCAL_SCALING | CH2 System Calibration Scaling Coefficients | 0x46 | R/W | 0x01 |
| CH2_SCAL_BITS_SELECTOR | CH2 System Calibration Bits Selector | 0x47 | R/W | 0x00 |
| CH3_SCAL_OFFSET | CH3 System Calibration Offset Coefficients | 0x48 - 0x4A | R/W | 0x00_0000 |
| CH3_SCAL_GAIN | CH3 System Calibration Gain Coefficient | 0x4B - 0x4D | R/W | 0x80_0000 |
| CH3_SCAL_SCALING | CH3 System Calibration Scaling Coefficients | 0x4E | R/W | 0x01 |
| CH3_SCAL_BITS_SELECTOR | CH3 System Calibration Bits Selector | 0x4F | R/W | 0x00 |
| Reserved | - | 0x50 - 0x7F | - | 0x00 |

18.2 POWER AND RESET REGISTERS

RESETCN: Reset Control (Address 0x00)

| Bit | Bit Symbol | Bit Description |
|-------|-----------------|--|
| [7:0] | REG_AND_CNV_RST | <p>Register and Conversion Reset</p> <p>0xC3: Register and conversion reset</p> <p>Others: Neglected</p> |

SPI_RESET: SPI Reset Control (Address 0x02)

| Bit | Bit Symbol | Bit Description |
|-----|------------|--|
| [0] | SPI_RST | <p>SPI Reset Enable</p> <p>0x0 (default): SPI Reset Disabled</p> <p>0x1: SPI Reset Enabled</p> <p>Note: Once Written, The contents of this register are sticky. That is, the content of this register cannot be changed with subsequent write. However, a Register reset clears the register as well as the sticky status.</p> |

PWRCN: Power Mode Control and Status (Address 0x08)

| Bit | Bit Symbol | Bit Description |
|-------|------------|---|
| [7:2] | Reserved | - |
| [1:0] | PWRCN | <p>Power Control</p> <p>Write Only – power down mode control</p> <p>0x0: Active Mode</p> <p>0x1: Power-down Mode</p> <p>0x3: Stand-by Mode</p> <p>Read Only – the present mode is:</p> <p>0x0 (default): Active Mode</p> <p>0x1: Power-down Mode</p> <p>0x3: Stand-by Mode</p> |

18.3 ADC REGISTERS

ADC_RESTART: ADC Restart Conversion (Address 0x0B)

| Bit | Bit Symbol | Bit Description |
|-------|------------|--|
| [7:1] | Reserved | - |
| 0 | RESTART | Restart conversion 1: Restart conversion. |

14.2.1. ADC_AUXCN: ADC Auxiliary Control (Address 0x12)

| Bit | Bit Symbol | Bit Description |
|-------|---|---|
| 7 | Reserved | - |
| 6 | RESET_SYSCAL | The System Calibration registers (CHx_SCAL_OFFSET and CHx_SCAL_GAIN) are: 0 (default): preserved even when "REG_AND_CNV_RST" = 0xC3. 1: reset by setting "REG_AND_CNV_RST" = 0xC3. |
| 5 | CLK_EXT_DET | External clock detection 0 (default): "External Clock Detection" is operational 1: "External-Clock Detection" is bypassed |
| 4 | CLK_SEL | Clock select – only valid if CLK_EXT_DET = 1 0 (default): Selects internal clock 1: Selects external clock |
| [3:0] | RTD_CUR_SEL (LMP90100 and LMP90098 only) | Selects RTD Current as follows: 0x0 (default): 0 μ A 0x1: 100 μ A 0x2: 200 μ A 0x3: 300 μ A 0x4: 400 μ A 0x5: 500 μ A 0x6: 600 μ A 0x7: 700 μ A 0x8: 800 μ A 0x9: 900 μ A 0xA: 1000 μ A |

ADC_DONE: ADC Data Available (Address 0x18)

| Bit | Bit Symbol | Bit Description |
|-------|------------|---|
| [7:0] | DT_AVAIL_B | Data Available – indicates if new conversion data is available 0x00 – 0xFE: Available 0xFF: Not available |

ADC_DOUT: 24-bit Conversion Data (two's complement) (Address 0x1A - 0x1C)

| Address | Name | Register Description |
|---------|-----------|-----------------------------|
| 0x1A | ADC_DOUTH | ADC Conversion Data [23:16] |
| 0x1B | ADC_DOUTM | ADC Conversion Data [15:8] |
| 0x1C | ADC_DOUTL | ADC Conversion Data [7:0] |

Note: Repeat reads of these registers are allowed as long as such reads are spaced apart by at least 72 μ s.

18.4 CHANNEL CONFIGURATION REGISTERS**CH_STS: Channel Status** (Address 0x1E)

| Bit | Bit Symbol | Bit Description |
|-------|-------------------|--|
| [7:2] | Reserved | - |
| 1 | CH_SCAN_NRDY | Channel Scan Not Ready – indicates if it is okay to program CH_SCAN 0: Update not pending, CH_SCAN register is okay to program 1: Update pending, CH_SCAN register is not ready to be programmed |
| 0 | INV_OR_RPT_RD_STS | Invalid or Repeated Read Status 0: ADC_DOUT just read was valid and hitherto unread 1: ADC_DOUT just read was either invalid (not ready) or there was a repeated read. |

CH_SCAN: Channel Scan Mode (Address 0x1F)

| Bit | Bit Symbol | Bit Description |
|-------|---|---|
| [7:6] | CH_SCAN_SEL | Channel Scan Select 0x0 (default): ScanMode0: Single-Channel Continuous Conversion 0x1: ScanMode1: One or more channels Single Scan 0x2: ScanMode2: One or more channels Continuous Scan 0x3: ScanMode3: One or more channels Continuous Scan with Burnout Currents |
| [5:3] | LAST_CH (CH4 to CH6 for LMP90100 and LMP90099 only) | Last channel for conversion 0x0: CH0 0x1: CH1 0x2: CH2 0x3: CH3 0x4: CH4 0x5: CH5 0x6 (default): CH6 Note: LAST_CH cannot be smaller than FIRST_CH. For example, if LAST_CH = CH5, then FIRST_CH cannot be CH6. If 0x7 is written it is ignored. |
| [2:0] | FIRST_CH (CH4 to CH6 for LMP90100 and LMP90099 only) | Starting channel for conversion 0x0 (default): CH0 0x1: CH1 0x2: CH2 0x3: CH3 0x4: CH4 0x5: CH5 0x6: CH6 Note: FIRST_CH cannot be greater than LAST_CH. For example, if FIRST_CH = CH1, then LAST_CH cannot be CH0. If 0x7 is written it is ignored. |

Note: While writing to the CH_SCAN register, if 0x7 is written to FIRST_CH or LAST_CH the write to the entire CH_SCAN register is ignored.

CHx_INPUTCN: Channel Input Control (CH4 to CH6 for LMP90100/LMP9099 only)

Register Address (hex):

- a. CH0: 0x20
- b. CH1: 0x22
- c. CH2: 0x24
- d. CH3: 0x26
- e. CH4: 0x28
- f. CH5: 0x2A
- g. CH6: 0x2C

| Bit | Bit Symbol | Bit Description |
|-------|------------|---|
| 7 | BURNOUT_EN | Enable sensor diagnostic 0 (default): Disable Sensor Diagnostics current injection for this Channel 1: Enable Sensor Diagnostics current injection for this Channel |
| 6 | VREF_SEL | Select the reference 0 (Default): Select VREFP1 and VREFN1 1: Select VREFP2 and VREFN2 |
| [5:3] | VINP | Positive input select 0x0: VIN0 0x1: VIN1 0x2: VIN2 0x3: VIN3 (LMP90100/LMP90099 only) 0x4: VIN4 (LMP90100/LMP90099 only) 0x5: VIN5 (LMP90100/LMP90099 only) 0x6: VIN6 0x7: VIN7 Note: to see the default values for each channel, refer to the table below. |
| [2:0] | VINN | Negative input select 0x0: VIN0 0x1: VIN1 0x2: VIN2 0x3: VIN3 (LMP90100/LMP90099 only) 0x4: VIN4 (LMP90100/LMP90099 only) 0x5: VIN5 (LMP90100/LMP90099 only) 0x6: VIN6 0x7: VIN7 Note: to see the default values for each channel, refer to the table below. |

Default VINx for CH0-CH6

| | VINP | VINN |
|------------|-----------------------------------|-----------------------------------|
| CH0 | VIN0 | VIN1 |
| CH1 | VIN2 | VIN3 (LMP90100/ LMP90099 only) |
| CH2 | VIN4 (LMP90100/ LMP90099 only) | VIN5 (LMP90100/ LMP90099 only) |
| CH3 | VIN6 | VIN7 |

| | | |
|--|------|------|
| CH4 (LMP90100/ LMP90099 only) | VIN0 | VIN1 |
| CH5 (LMP90100/ LMP90099 only) | VIN2 | VIN3 |
| CH6 (LMP90100/ LMP90099 only) | VIN4 | VIN5 |

CHx_CONFIG: Channel Configuration (CH4 to CH6 LMP90100/LMP90099 only)

Register Address (hex):

- a. CH0: 0x21
- b. CH1: 0x23
- c. CH2: 0x25
- d. CH3: 0x27
- e. CH4: 0x29
- f. CH5: 0x2B
- g. CH6: 0x2D

| Bit | Bit Symbol | Bit Description |
|-------|------------|---|
| 7 | Reserved | - |
| [6:4] | ODR_SEL | ODR Select 0x0: 13.42 / 8 = 1.6775 SPS 0x1: 13.42 / 4 = 3.355 SPS 0x2: 13.42 / 2 = 6.71 SPS 0x3: 13.42 SPS 0x4: 214.65 / 8 = 26.83125 SPS 0x5: 214.65 / 4 = 53.6625 SPS 0x6: 214.65 / 2 = 107.325 SPS 0x7 (default): 214.65 SPS |
| [3:1] | GAIN_SEL | Gain Select 0x0 (default): 1 (FGA OFF) 0x1: 2 (FGA OFF) 0x2: 4 (FGA OFF) 0x3: 8 (FGA OFF) 0x4: 16 (FGA ON) 0x5: 32 (FGA ON) 0x6: 64 (FGA ON) 0x7: 128 (FGA ON) |
| 0 | BUF_EN | Enable/Disable the buffer 0 (default): Include the buffer in the signal path 1: Exclude the buffer from the signal path Note: When gain ≥ 16 , the buffer is automatically included in the signal path irrespective of this bit. |

18.5 CALIBRATION REGISTERS

BGCALCN: Background Calibration Control (Address 0x10)

| Bit | Bit Symbol | Bit Description |
|-------|------------|---|
| [7:2] | Reserved | - |
| [1:0] | BGCALN | Background calibration control – selects scheme for continuous background calibration. 0x0 (default): BgcalMode0: Background Calibration OFF 0x1: BgcalMode1: Offset Correction / Gain Estimation 0x2: BgcalMode2: Offset Correction / Gain Correction 0x3: BgcalMode3: Offset Estimation / Gain Estimation |

SCALCN: System Calibration Control (Address 0x17)

| Bit | Bit Symbol | Bit Description |
|-------|------------|---|
| [7:2] | Reserved | - |
| [1:0] | SCALCN | System Calibration Control When written, set SCALCN to: 0x0 (default): Normal Mode 0x1: "System Calibration Offset Coefficient Determination" mode 0x2: "System Calibration Gain Coefficient Determination" mode 0x3: Reserved When read, this bit indicates the system calibration mode is in: 0x0: Normal Mode 0x1: "System Calibration Offset Coefficient Determination" mode 0x2: "System Calibration Gain Coefficient Determination" mode 0x3: Reserved Note: when read, this bit will indicate the current System Calibration status. Since this coefficient determination mode will only take 1 conversion cycle, reading this register will only return 0x00, unless this register is read within 1 conversion window. |

CHx_SCAL_OFFSET: CH0-CH3 System Calibration Offset Registers (Two's-Complement)

| ADDR | | | | Name | Description |
|------|------|------|------|------------------|--|
| CH0 | CH1 | CH2 | CH3 | | |
| 0x30 | 0x38 | 0x40 | 0x48 | CHx_SCAL_OFFSETH | System Calibration Offset Coefficient Data [23:16] |
| 0x31 | 0x39 | 0x41 | 0x49 | CHx_SCAL_OFFSETM | System Calibration Offset Coefficient Data [15:8] |
| 0x32 | 0x3A | 0x42 | 0x4A | CHx_SCAL_OFFSETL | System Calibration Offset Coefficient Data[7:0] |

CHx_SCAL_GAIN: CH0-CH3 System Calibration Gain Registers (Fixed Point 1.23 Format)

| ADDR | | | | Name | Description |
|------|------|------|------|----------------|--|
| CH0 | CH1 | CH2 | CH3 | | |
| 0x33 | 0x3B | 0x43 | 0x4B | CHx_SCAL_GAINH | System Calibration Gain Coefficient Data [23:16] |
| 0x34 | 0x3C | 0x44 | 0x4C | CHx_SCAL_GAINM | System Calibration Gain Coefficient Data [15:8] |
| 0x35 | 0x3D | 0x45 | 0x4D | CHx_SCAL_GAINL | System Calibration Gain Coefficient Data[7:0] |

CHx_SCAL_SCALING: CH0-CH3 System Calibration Scaling Coefficient Registers

| ADDR | | | | Name | Description |
|------|------|------|------|------------------|---|
| CH0 | CH1 | CH2 | CH3 | | |
| 0x36 | 0x3E | 0x46 | 0x4E | CHx_SCAL_SCALING | System Calibration Scaling Coefficient Data [5:0] |

CHx_SCAL_BITS_SELECTOR: CH0-CH3 System Calibration Bits Selector Registers

| ADDR | | | | Name | Description |
|------|------|------|------|------------------------|--|
| CH0 | CH1 | CH2 | CH3 | | |
| 0x37 | 0x3F | 0x47 | 0x4F | CHx_SCAL_BITS_SELECTOR | System Calibration Bits Selection Data [2:0] |

18.6 SENSOR DIAGNOSTIC REGISTERS**SENDIAG_THLD: Sensor Diagnostic Threshold** (Address 0x14 - 0x15)

| Address | Name | Register Description |
|---------|---------------|------------------------------------|
| 0x14 | SENDIAG_THLDH | Sensor Diagnostic threshold [15:8] |
| 0x15 | SENDIAG_THLDL | Sensor Diagnostic threshold [7:0] |

SENDIAG_FLAGS: Sensor Diagnostic Flags (Address 0x19)

| Bit | Bit Symbol | Bit Description |
|-------|-----------------|--|
| 7 | SHORT_THLD_FLAG | Short Circuit Threshold Flag = 1 when the absolute value of VOUT is within the absolute threshold voltage set by SENDIAG_THLDH and SENDIAG_THLDL. |
| 6 | RAILS_FLAG | Rails Flag = 1 when at least one of the inputs is near rail (VA or GND). |
| 5 | POR_AFT_LST_RD | Power-on-reset after last read = 1 when there was a power-on-reset event since the last time the SENDIAG_FLAGS register was read. |
| [4:3] | OFLO_FLAGS | Overflow flags 0x0: Normal operation 0x1: The modulator was not overranged, but ADC_DOUT got clamped to 0x7f_ffff (positive fullscale) or 0x80_0000 (negative full scale) 0x2: The modulator was over-ranged ($V_{IN} > 1.2 \cdot V_{REF}/GAIN$) 0x3: The modulator was over-ranged ($V_{IN} < -1.2 \cdot V_{REF}/GAIN$) |
| [2:0] | SAMPLED_CH | Channel Number – the sampled channel for ADC_DOUT and SENDIAG_FLAGS. |

18.7 SPI REGISTERS

SPI_HANDSHAKECN: SPI Handshake Control (Address 0x01)

| Bit | Bit Symbol | Bit Description | | | |
|-------|------------------|---|---|---|-------------------|
| [7:4] | Reserved | - | | | |
| [3:1] | SDO_DRDYB_DRIVER | SDO/DRDYB Driver – sets who is driving the SDO/DRYB pin | | | |
| | | | Whenever CSB is Asserted and the Device is Reading ADC_DOUT | Whenever CSB is Asserted and the Device is Not Reading ADC_DOUT | CSB is Deasserted |
| | | 0x0 (default) | SDO is driving | DRDYB is driving | High-Z |
| | | 0x3 | SDO is driving | DRDYB is driving | DRDYB is driving |
| | | 0x4 | SDO is driving | High-Z | High-Z |
| | | Others | Forbidden | | |
| 0 | SW_OFF_TRG | <p>Switch-off trigger - refers to the switching of the output drive from the slave to the master.</p> <p>0 (default): SDO will be high-Z after the last (16th, 24th, 32nd, etc) rising edge of SCLK. This option allows time for the slave to transfer control back to the master at the end of the frame.</p> <p>1: SDO's high-Z is postponed to the subsequent falling edge following the last (16th, 24th, 32nd, etc) rising edge of SCLK. This option provides additional hold time for the last bit, DB0, in non-streaming read transfers.</p> | | | |

SPI_STREAMCN: SPI Streaming Control (Address 0x03)

| Bit | Bit Symbol | Bit Description |
|-------|------------|--|
| 7 | STRM_TYPE | <p>Stream type</p> <p>0 (default): Normal Streaming mode</p> <p>1: Controlled Streaming mode</p> |
| [6:0] | STRM_RANGE | <p>Stream range – selects Range for Controlled Streaming mode</p> <p>Default: 0x00</p> |

DATA_ONLY_1: Data Only Read Control 1 (Address 0x09)

| Bit | Bit Symbol | Bit Description |
|-------|---------------|---|
| 7 | Reserved | - |
| [6:0] | DATA_ONLY_ADR | <p>Start address for the Data Only Read Transaction</p> <p>Default: 0x1A</p> <p>Please refer to the description of DT_ONLY_SZ in DATA_ONLY_2 register.</p> |

DATA_ONLY_2: Data Only Read Control 2 (Address 0x0A)

| Bit | Bit Symbol | Bit Description |
|-------|--------------|---|
| [7:3] | Reserved | - |
| [2:0] | DATA_ONLY_SZ | Number of bytes to be read out in Data Only mode. A value of 0x0 means read one byte and 0x7 means read 8 bytes. Default: 0x2 |

SPI_DRDYBCN: SPI Data Ready Bar Control (Address 0x11)

| Bit | Bit Symbol | Bit Description |
|-------|--------------|---|
| 7 | SPI_DRDYB_D6 | Enable DRDYB on D6 0 (default): D6 is a GPIO 1: D6 = drdyb signal |
| 6 | Reserved | - |
| 5 | CRC_RST | CRC Reset 0 (default): Enable CRC reset on DRDYB deassertion 1: Disable CRC reset on DRDYB deassertion |
| 4 | Reserved | - |
| 3 | FGA_BGCAL | Gain background calibration 0 (default): Correct FGA gain error. This is useful only if the device is operating in Bg-calMode2 and ScanMode2 or ScanMode3. 1: Correct FGA gain error using the last known coefficients. |
| [2:0] | Reserved | Default - 0x3 (do not change this value) |

SPI_CRC_CN: CRC Control (Address 0x13)

| Bit | Bit Symbol | Bit Description |
|-------|---------------|--|
| [7:5] | Reserved | - |
| 4 | EN_CRC | Enable CRC 0 (default): Disable CRC 1: Enable CRC |
| 3 | Reserved | Default - 0x1 (do not change this value) |
| 2 | DRDYB_AFT_CRC | DRDYB After CRC 0 (default): DRDYB is deasserted (active high) after ADC_DOUTL is read. 1: DRDYB is deasserted after SPI_CRC_DAT (which follows ADC_DOUTL), is read. |
| [1:0] | Reserved | - |

SPI_CRC_DAT: CRC Data (Address 0x1D)

| Bit | Bit Symbol | Bit Description |
|-------|------------|--|
| [7:0] | CRC_DAT | <p>CRC Data</p> <p>When written, this register reset CRC: Any Value: Reset CRC</p> <p>When read, this register indicates the CRC data.</p> |

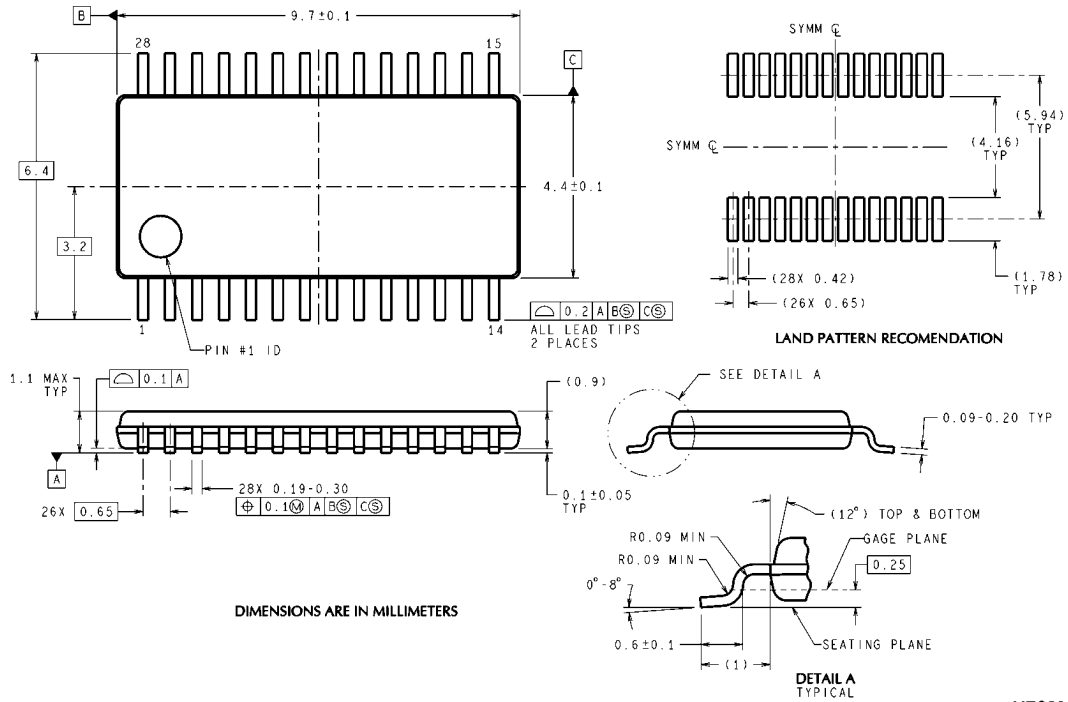
18.8 GPIO REGISTERS**GPIO_DIRCN: GPIO Direction** (Address 0x0E)

| Bit | Bit Symbol | Bit Description |
|-----|-------------|--|
| 7 | Reserved | - |
| x | GPIO_DIRCNx | <p>GPIO direction control – these bits are used to control the direction of each General Purpose Input/Outputs (GPIO) pins D0 - D6.</p> <p>0 (default): Dx is an Input 1: Dx is an Output where $0 \leq x \leq 6$.</p> <p>For example, writing a 1 to bit 6 means D6 is an Output. Note: If D6 is used for DRDYB, then it cannot be used for GPIO.</p> |

GPIO_DAT: GPIO Data (Address 0x0F)

| Bit | Bit Symbol | Bit Description |
|-----|------------|--|
| 7 | Reserved | - |
| x | Dx | <p>Write Only - when GPIO_DIRCNx = 0 0: Dx is LO 1: Dx is HI</p> <p>Read Only - when GPIO_DIRCNx = 1 0: Dx driven LO 1: Dx driven HI</p> <p>where $0 \leq x \leq 6$.</p> <p>For example, writing a 0 to bit 4 means D4 is LO. It is okay to Read the GPIOs that are configured as outputs and write to GPIOs that are configured as inputs. Reading the GPIOs that are outputs would return the current value on those GPIOs, and writing to the GPIOs that are inputs are neglected</p> |

19.0 Physical Dimensions inches (millimeters) unless otherwise noted



28-Lead Molded Plastic TSSOP
Order Number LMP90100MH/NOPB, LMP90099MH/NOPB, LMP90098MH/NOPB, LMP90097MH/NOPB
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Notes

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