

Zero-Drift, Bi-Directional CURRENT/POWER MONITOR with I²C™ Interface

FEATURES

- SENSES BUS VOLTAGES FROM 0V TO +26V
- REPORTS CURRENT, VOLTAGE, AND POWER
- 16 PROGRAMMABLE ADDRESSES
- HIGH ACCURACY: 1% (Max) OVER TEMPERATURE
- FILTERING OPTIONS
- CALIBRATION REGISTERS
- SOT23-8 AND SO-8 PACKAGES

APPLICATIONS

- SERVERS
- TELECOM EQUIPMENT
- NOTEBOOK COMPUTERS
- POWER MANAGEMENT
- BATTERY CHARGERS
- WELDING EQUIPMENT
- POWER SUPPLIES
- TEST EQUIPMENT

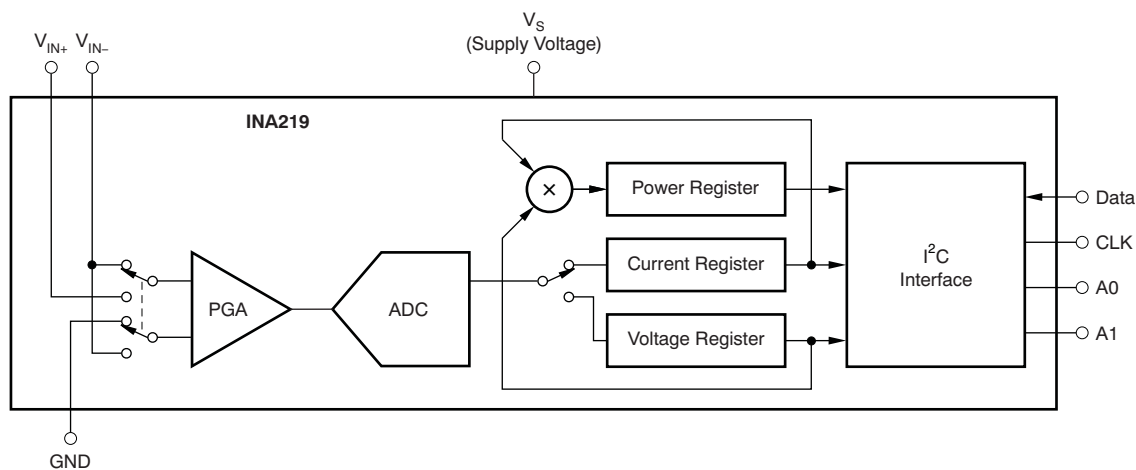
DESCRIPTION

The INA219 is a high-side current shunt and power monitor with an I²C interface. The INA219 monitors both shunt drop and supply voltage, with programmable conversion times and filtering. A programmable calibration value, combined with an internal multiplier, enables direct readouts in amperes. An additional multiplying register calculates power in watts. The I²C interface features 16 programmable addresses.

The INA219 senses across shunts on buses that can vary from 0V to 26V. The device uses a single +3V to +5.5V supply, drawing a maximum of 1mA of supply current. The INA219 operates from –40°C to +125°C.

RELATED PRODUCTS

| DESCRIPTION | DEVICE |
|---|-------------------------------|
| Current/Power Monitor with Watchdog, Peak-Hold, and Fast Comparator Functions | INA209 |
| Zero-Drift, Low-Cost, Analog Current Shunt Monitor Series in Small Package | INA210-INA214 |



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This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ORDERING INFORMATION⁽¹⁾

| PRODUCT | PACKAGE-LEAD | PACKAGE DESIGNATOR | PACKAGE MARKING |
|---------|--------------|--------------------|-----------------|
| INA219 | SO-8 | D | I219A |
| | SOT23-8 | DCN | A219 |

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

ABSOLUTE MAXIMUM RATINGS⁽¹⁾

Over operating free-air temperature range (unless otherwise noted).

| | | INA219 | UNIT |
|---|---|--------------------------|------|
| Supply Voltage, V_S | | 6 | V |
| Analog Inputs, V_{IN+} , V_{IN-} | Differential ($V_{IN+} - V_{IN-}$) ⁽²⁾ | -26 to +26 | V |
| | Common-Mode | -0.3 to +26 | V |
| SDA | | GND – 0.3 to +6 | V |
| SCL | | GND – 0.3 to $V_S + 0.3$ | V |
| Input Current Into Any Pin | | 5 | mA |
| Open-Drain Digital Output Current | | 10 | mA |
| Operating Temperature | | -40 to +125 | °C |
| Storage Temperature | | -40 to +150 | °C |
| Junction Temperature | | +150 | °C |
| ESD Ratings | Human Body Model | 4000 | V |
| | Charged-Device Model | 750 | V |
| | Machine Model (MM) | 200 | V |

- (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.
- (2) V_{IN+} and V_{IN-} may have a differential voltage of -26V to +26V; however, the voltage at these pins must not exceed the range -0.3V to +26V.

ELECTRICAL CHARACTERISTICS: $V_S = +3.3V$
Boldface limits apply over the specified temperature range, $T_A = -25^{\circ}C$ to $+85^{\circ}C$.

 At $T_A = +25^{\circ}C$, $V_{IN+} = 12V$, $V_{SENSE} = (V_{IN+} - V_{IN-}) = 32mV$, $PGA = \div 1$, and $BRNG^{(1)} = 1$, unless otherwise noted.

| PARAMETER | TEST CONDITIONS | INA219 | | | UNIT |
|--|-----------------|-----------------------|------------|---------------------------|-------------------------------------|
| | | MIN | TYP | MAX | |
| INPUT | | | | | |
| Full-Scale Current Sense (Input) Voltage Range | $PGA = \div 1$ | 0 | | ± 40 | mV |
| | $PGA = \div 2$ | 0 | | ± 80 | mV |
| | $PGA = \div 4$ | 0 | | ± 160 | mV |
| | $PGA = \div 8$ | 0 | | ± 320 | mV |
| Bus Voltage (Input Voltage) Range ⁽²⁾ | $BRNG = 1$ | 0 | | 32 | V |
| | $BRNG = 0$ | 0 | | 16 | V |
| Common-Mode Rejection | CMRR | $V_{IN+} = 0V$ to 26V | 100 | 120 | dB |
| Offset Voltage, $RTI^{(3)}$ | V_{OS} | $PGA = \div 1$ | | ± 10 | μV |
| | | $PGA = \div 2$ | | ± 20 | μV |
| | | $PGA = \div 4$ | | ± 30 | μV |
| | | $PGA = \div 8$ | | ± 40 | μV |
| vs Temperature | | | 0.1 | | $\mu V/^{\circ}C$ |
| vs Power Supply | PSRR | $V_S = 3V$ to 5.5V | | 10 | $\mu V/V$ |
| Current Sense Gain Error | | | | ± 40 | m% |
| vs Temperature | | | | 10 | ppm/$^{\circ}C$ |
| Input Impedance | | Active Mode | | | |
| V_{IN+} Pin | | | | 20 | μA |
| V_{IN-} Pin | | | | 20 320 | μA k Ω |
| Input Leakage ⁽⁴⁾ | | Power-Down Mode | | | |
| V_{IN+} Pin | | | | 0.1 | μA |
| V_{IN-} Pin | | | | 0.1 | μA |
| DC ACCURACY | | | | | |
| ADC Basic Resolution | | | | 12 | Bits |
| 1 LSB Step Size | | | | | |
| Shunt Voltage | | | | 10 | μV |
| Bus Voltage | | | | 4 | mV |
| Current Measurement Error | | | | ± 0.2 | % |
| over Temperature | | | | ± 1 | % |
| Bus Voltage Measurement Error | | | | ± 0.2 | % |
| over Temperature | | | | ± 1 | % |
| Differential Nonlinearity | | | | ± 0.1 | LSB |
| ADC TIMING | | | | | |
| ADC Conversion Time | | 12-Bit | | 532 | μs |
| | | 11-Bit | | 276 | μs |
| | | 10-Bit | | 148 | μs |
| | | 9-Bit | | 84 | μs |
| Minimum Convert Input Low Time | | | | 4 | μs |

 (1) BRNG is bit 13 of the [Configuration Register](#).

(2) This parameter only expresses the full-scale range of the ADC scaling. In no event should more than 26V be applied to this device.

(3) Referred-to-input (RTI).

(4) Input leakage is positive (current flowing into the pin) for the conditions shown at the top of the table. Negative leakage currents can occur under different input conditions.

ELECTRICAL CHARACTERISTICS: $V_S = +3.3V$ (continued)

Boldface limits apply over the specified temperature range, $T_A = -25^\circ\text{C}$ to $+85^\circ\text{C}$.

At $T_A = +25^\circ\text{C}$, $V_{IN+} = 12V$, $V_{SENSE} = (V_{IN+} - V_{IN-}) = 32mV$, $PGA = \div 1$, and $BRNG = 1$, unless otherwise noted.

| PARAMETER | TEST CONDITIONS | INA219 | | | UNIT |
|--|--------------------------|---------------|------|---------------|--------------------|
| | | MIN | TYP | MAX | |
| SMBus SMBus Timeout ⁽⁵⁾ | | | 28 | 35 | ms |
| DIGITAL INPUTS (SDA as Input, SCL, A0, A1) | | | | | |
| Input Capacitance | $0 \leq V_{IN} \leq V_S$ | | 3 | | pF |
| Leakage Input Current | | | 0.1 | 1 | μA |
| Input Logic Levels: | | | | | |
| V_{IH} | | 0.7 (V_S) | | 6 | V |
| V_{IL} | | -0.3 | | 0.3 (V_S) | V |
| Hysteresis | | | 500 | | mV |
| OPEN-DRAIN DIGITAL OUTPUTS (SDA) | | | | | |
| Logic '0' Output Level | $I_{SINK} = 3mA$ | | 0.15 | 0.4 | V |
| High-Level Output Leakage Current | $V_{OUT} = V_S$ | | 0.1 | 1 | μA |
| POWER SUPPLY | | | | | |
| Operating Supply Range | | +3 | | +5.5 | V |
| Quiescent Current | | | 0.7 | 1 | mA |
| Quiescent Current, Power-Down Mode | | | 6 | 15 | μA |
| Power-On Reset Threshold | | | 2 | | V |
| TEMPERATURE RANGE | | | | | |
| Specified Temperature Range | | -25 | | +85 | $^\circ\text{C}$ |
| Operating Temperature Range | | -40 | | +125 | $^\circ\text{C}$ |
| Thermal Resistance ⁽⁶⁾ | θ_{JA} | | | | |
| SOT23-8 | | | 142 | | $^\circ\text{C/W}$ |
| SO-8 | | | 120 | | $^\circ\text{C/W}$ |

(5) SMBus timeout in the INA219 resets the interface any time SCL or SDA is low for over 28ms.

(6) θ_{JA} value is based on JEDEC low-K board.

PIN CONFIGURATIONS



PIN DESCRIPTIONS: SOT23-8

| SOT23-8 (DCN) | | DESCRIPTION |
|------------------|-----------|---|
| PIN NO | NAME | |
| 1 | V_{IN+} | Positive differential shunt voltage. Connect to positive side of shunt resistor. |
| 2 | V_{IN-} | Negative differential shunt voltage. Connect to negative side of shunt resistor. Bus voltage is measured from this pin to ground. |
| 3 | GND | Ground. |
| 4 | V_S | Power supply, 3V to 5.5V. |
| 5 | SCL | Serial bus clock line. |
| 6 | SDA | Serial bus data line. |
| 7 | A0 | Address pin. Table 1 shows pin settings and corresponding addresses. |
| 8 | A1 | Address pin. Table 1 shows pin settings and corresponding addresses. |

PIN DESCRIPTIONS: SO-8

| SO-8 (D) | | DESCRIPTION |
|-------------|-----------|---|
| PIN NO | NAME | |
| 1 | A1 | Address pin. Table 1 shows pin settings and corresponding addresses. |
| 2 | A0 | Address pin. Table 1 shows pin settings and corresponding addresses. |
| 3 | SDA | Serial bus data line. |
| 4 | SCL | Serial bus clock line. |
| 5 | V_S | Power supply, 3V to 5.5V. |
| 6 | GND | Ground. |
| 7 | V_{IN-} | Negative differential shunt voltage. Connect to negative side of shunt resistor. Bus voltage is measured from this pin to ground. |
| 8 | V_{IN+} | Positive differential shunt voltage. Connect to positive side of shunt resistor. |

TYPICAL CHARACTERISTICS

At $T_A = +25^\circ\text{C}$, $V_{IN+} = 12\text{V}$, $V_{SENSE} = (V_{IN+} - V_{IN-}) = 32\text{mV}$, $\text{PGA} = \div 1$, and $\text{BRNG} = 1$, unless otherwise noted.

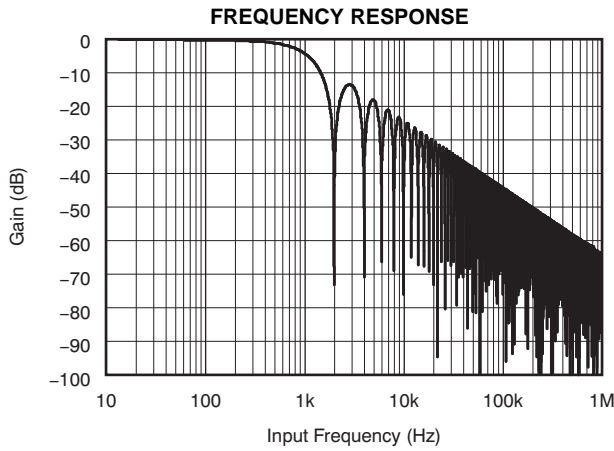


Figure 1.

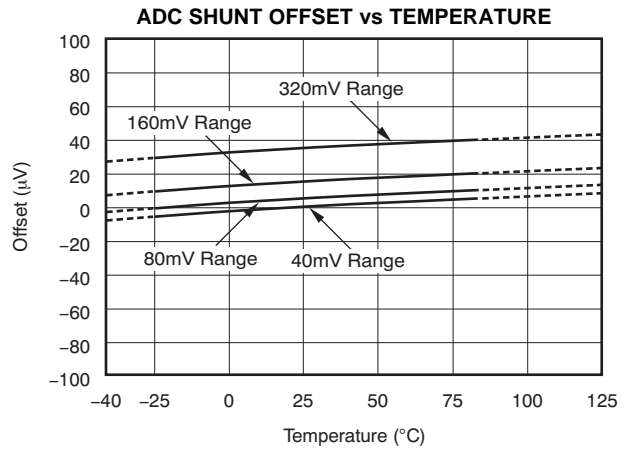


Figure 2.

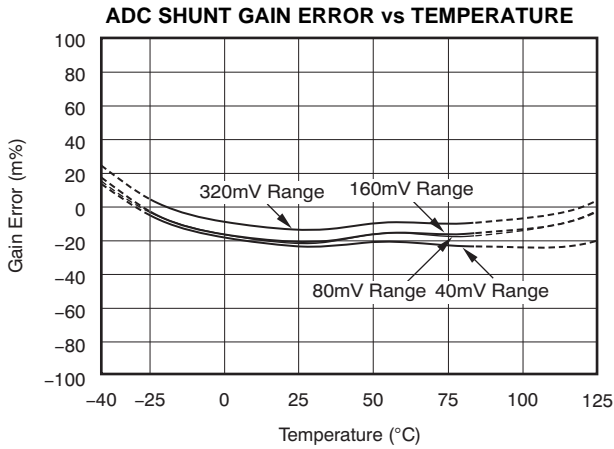


Figure 3.

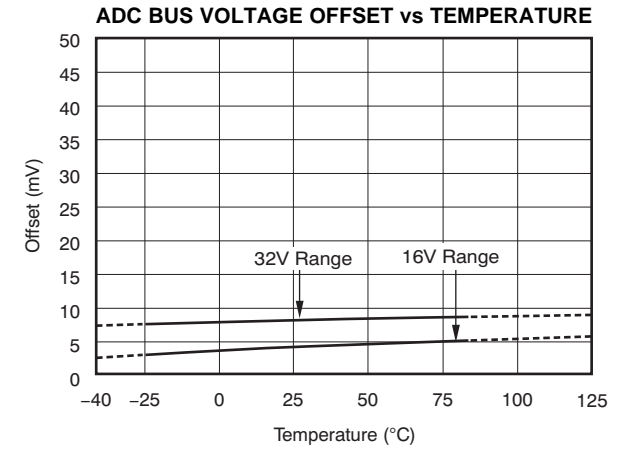


Figure 4.

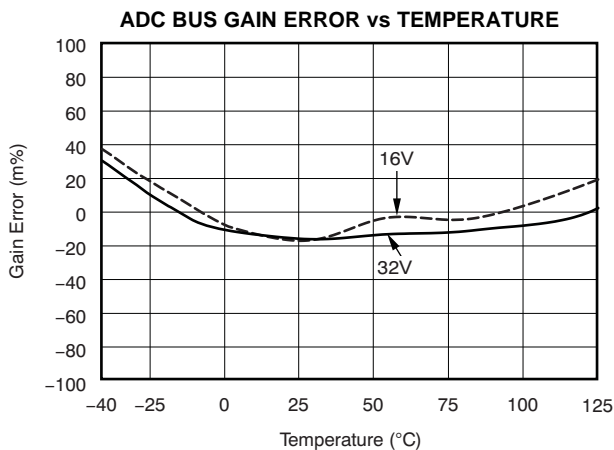


Figure 5.

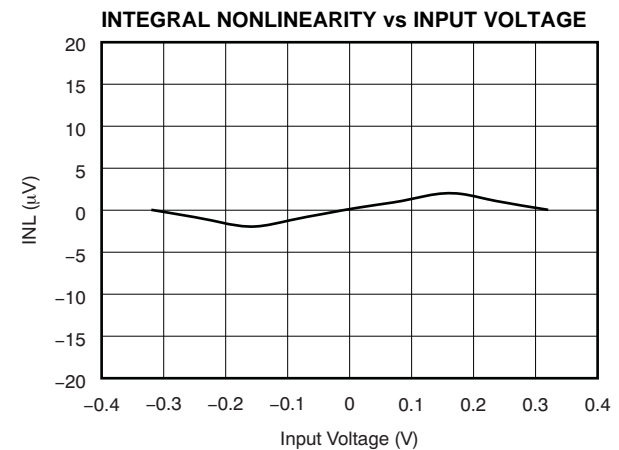


Figure 6.

TYPICAL CHARACTERISTICS (continued)

At $T_A = +25^\circ\text{C}$, $V_{IN+} = 12\text{V}$, $V_{SENSE} = (V_{IN+} - V_{IN-}) = 32\text{mV}$, $\text{PGA} = \div 1$, and $\text{BRNG} = 1$, unless otherwise noted.

INPUT CURRENTS WITH LARGE DIFFERENTIAL VOLTAGES
(V_{IN+} at 12V, Sweep of V_{IN-})

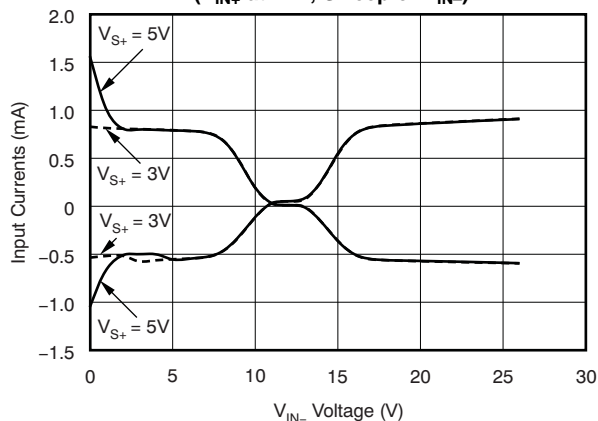


Figure 7.

ACTIVE I_Q vs TEMPERATURE

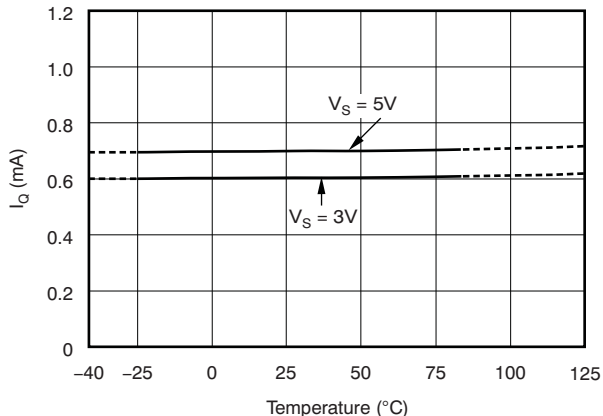


Figure 8.

SHUTDOWN I_Q vs TEMPERATURE

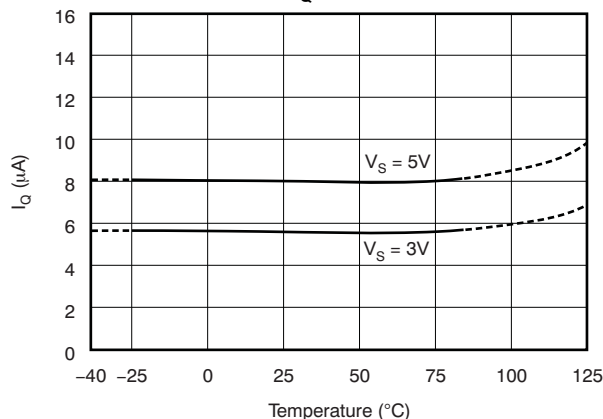


Figure 9.

ACTIVE I_Q vs I²C CLOCK FREQUENCY

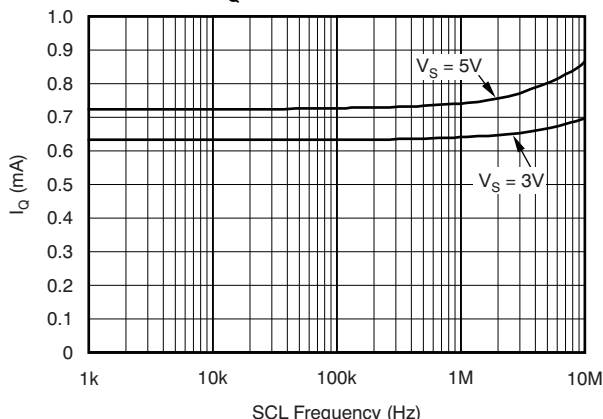


Figure 10.

SHUTDOWN I_Q vs I²C CLOCK FREQUENCY

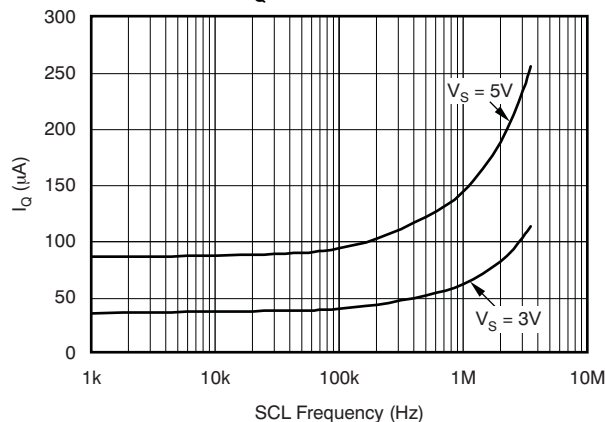


Figure 11.

REGISTER BLOCK DIAGRAM

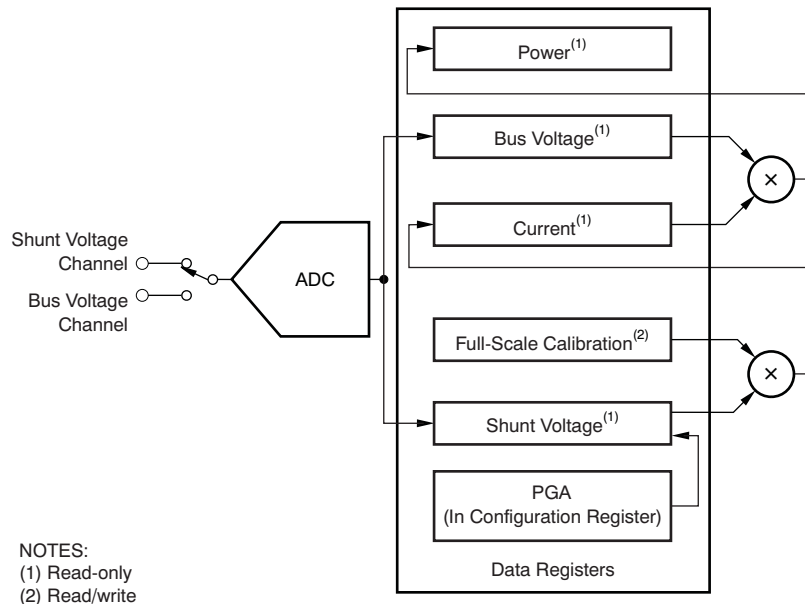


Figure 12. INA219 Register Block Diagram

APPLICATION INFORMATION

The INA219 is a digital current-shunt monitor with an I²C and SMBus-compatible interface. It provides digital current, voltage, and power readings necessary for accurate decision-making in precisely-controlled systems. Programmable registers allow flexible configuration for measurement resolution, and continuous-versus-triggered operation. Detailed register information appears at the end of this data sheet, beginning with [Table 2](#). See the [Register Block Diagram](#) for a block diagram of the INA219.

INA219 TYPICAL APPLICATION

[Figure 13](#) shows a typical application circuit for the INA219. Use a 0.1µF ceramic capacitor for power-supply bypassing, placed as closely as possible to the supply and ground pins.

The input filter circuit consisting of R_{F1}, R_{F2}, and C_F is not necessary in most applications. If the need for filtering is unknown, reserve board space for the components and install 0Ω resistors unless a filter is needed. See the [Filtering and Input Considerations](#) section.

The pull-up resistors shown on the SDA and SCL lines are not needed if there are pull-up resistors on these same lines elsewhere in the system. Resistor values shown are typical: consult either the I²C or SMBus specification to determine the acceptable minimum or maximum values.

BUS OVERVIEW

The INA219 offers compatibility with both I²C and SMBus interfaces. The I²C and SMBus protocols are essentially compatible with one another.

The I²C interface is used throughout this data sheet as the primary example, with SMBus protocol specified only when a difference between the two systems is being addressed. Two bidirectional lines, SCL and SDA, connect the INA219 to the bus. Both SCL and SDA are open-drain connections.

The device that initiates the transfer is called a *master*, and the devices controlled by the master are *slaves*. The bus must be controlled by a master device that generates the serial clock (SCL), controls the bus access, and generates START and STOP conditions.

To address a specific device, the master initiates a START condition by pulling the data signal line (SDA) from a HIGH to a LOW logic level while SCL is HIGH. All slaves on the bus shift in the slave address byte on the rising edge of SCL, with the last bit indicating whether a read or write operation is intended. During the ninth clock pulse, the slave being addressed responds to the master by generating an Acknowledge and pulling SDA LOW.

Data transfer is then initiated and eight bits of data are sent, followed by an *Acknowledge* bit. During data transfer, SDA must remain stable while SCL is HIGH. Any change in SDA while SCL is HIGH is interpreted as a START or STOP condition.

Once all data have been transferred, the master generates a STOP condition, indicated by pulling SDA from LOW to HIGH while SCL is HIGH. The INA219 includes a 28ms timeout on its interface to prevent locking up an SMBus.

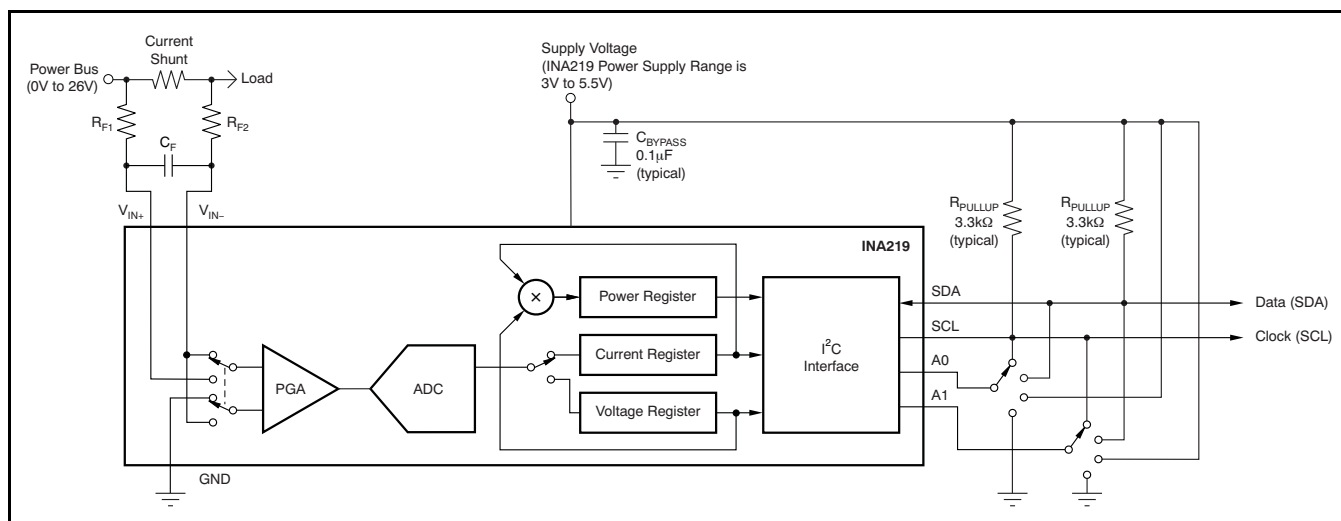


Figure 13. Typical Application Circuit

Serial Bus Address

To communicate with the INA219, the master must first address slave devices via a slave address byte. The slave address byte consists of seven address bits, and a direction bit indicating the intent of executing a read or write operation.

The INA219 has two address pins, A0 and A1. [Table 1](#) describes the pin logic levels for each of the 16 possible addresses. The state of pins A0 and A1 is sampled on every bus communication and should be set before any activity on the interface occurs. The address pins are read at the start of each communication event.

Table 1. INA219 Address Pins and Slave Addresses

| A1 | A0 | SLAVE ADDRESS |
|-----------------|-----------------|---------------|
| GND | GND | 1000000 |
| GND | V _{S+} | 1000001 |
| GND | SDA | 1000010 |
| GND | SCL | 1000011 |
| V _{S+} | GND | 1000100 |
| V _{S+} | V _{S+} | 1000101 |
| V _{S+} | SDA | 1000110 |
| V _{S+} | SCL | 1000111 |
| SDA | GND | 1001000 |
| SDA | V _{S+} | 1001001 |
| SDA | SDA | 1001010 |
| SDA | SCL | 1001011 |
| SCL | GND | 1001100 |
| SCL | V _{S+} | 1001101 |
| SCL | SDA | 1001110 |
| SCL | SCL | 1001111 |

Serial Interface

The INA219 operates only as a slave device on the I²C bus and SMBus. Connections to the bus are made via the open-drain I/O lines SDA and SCL. The SDA and SCL pins feature integrated spike suppression filters and Schmitt triggers to minimize the effects of input spikes and bus noise. The INA219 supports the transmission protocol for fast (1kHz to 400kHz) and high-speed (1kHz to 3.4MHz) modes. All data bytes are transmitted most significant byte first.

WRITING TO/READING FROM THE INA219

Accessing a particular register on the INA219 is accomplished by writing the appropriate value to the register pointer. Refer to [Table 2](#) for a complete list of registers and corresponding addresses. The value for the register pointer as shown in [Figure 17](#) is the first byte transferred after the slave address byte with the R/W bit LOW. Every write operation to the INA219 requires a value for the register pointer.

Writing to a register begins with the first byte transmitted by the master. This byte is the slave address, with the R/W bit LOW. The INA219 then acknowledges receipt of a valid address. The next byte transmitted by the master is the address of the register to which data will be written. This register address value updates the register pointer to the desired register. The next two bytes are written to the register addressed by the register pointer. The INA219 acknowledges receipt of each data byte. The master may terminate data transfer by generating a START or STOP condition.

When reading from the INA219, the last value stored in the register pointer by a write operation determines which register is read during a read operation. To change the register pointer for a read operation, a new value must be written to the register pointer. This write is accomplished by issuing a slave address byte with the R/W bit LOW, followed by the register pointer byte. No additional data are required. The master then generates a START condition and sends the slave address byte with the R/W bit HIGH to initiate the read command. The next byte is transmitted by the slave and is the most significant byte of the register indicated by the register pointer. This byte is followed by an *Acknowledge* from the master; then the slave transmits the least significant byte. The master acknowledges receipt of the data byte. The master may terminate data transfer by generating a *Not-Acknowledge* after receiving any data byte, or generating a START or STOP condition. If repeated reads from the same register are desired, it is not necessary to continually send the register pointer bytes; the INA219 retains the register pointer value until it is changed by the next write operation.

[Figure 14](#) and [Figure 15](#) show read and write operation timing diagrams, respectively. Note that register bytes are sent most-significant byte first, followed by the least significant byte. [Figure 16](#) shows the timing diagram for the SMBus Alert response operation. [Figure 17](#) illustrates a typical register pointer configuration.

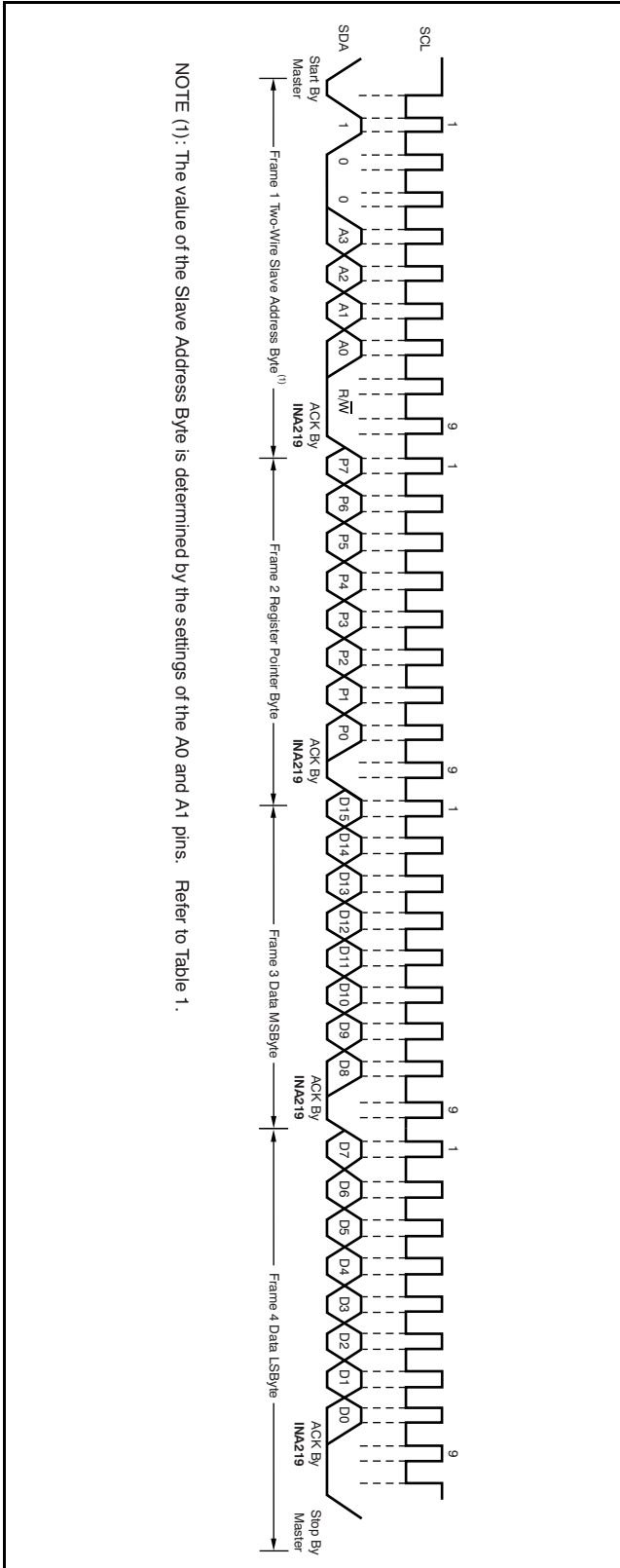


Figure 14. Timing Diagram for Write Word Format

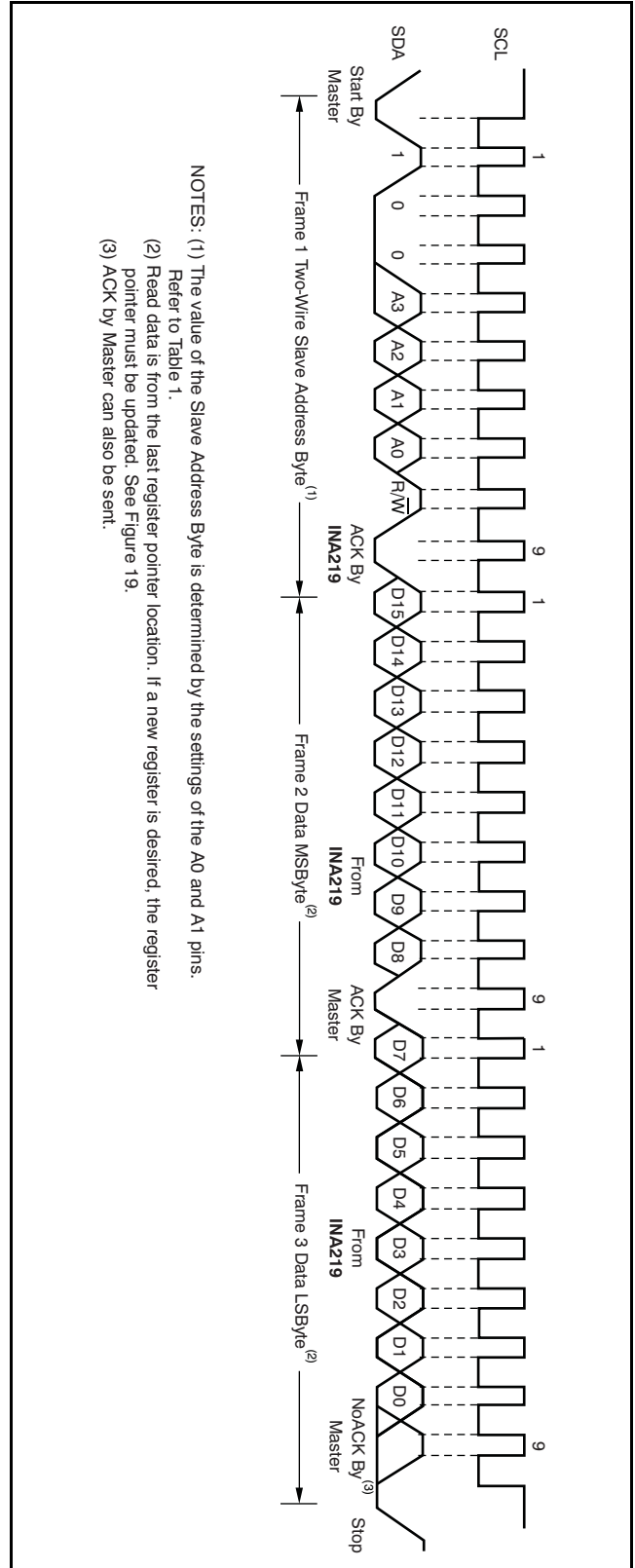


Figure 15. Timing Diagram for Read Word Format

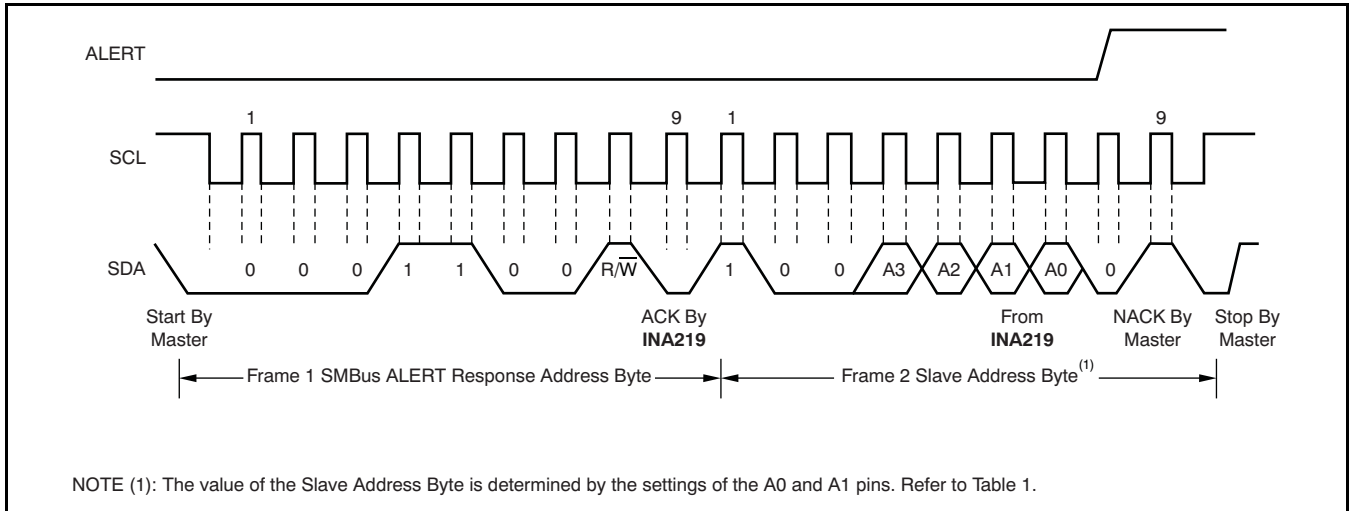


Figure 16. Timing Diagram for SMBus ALERT

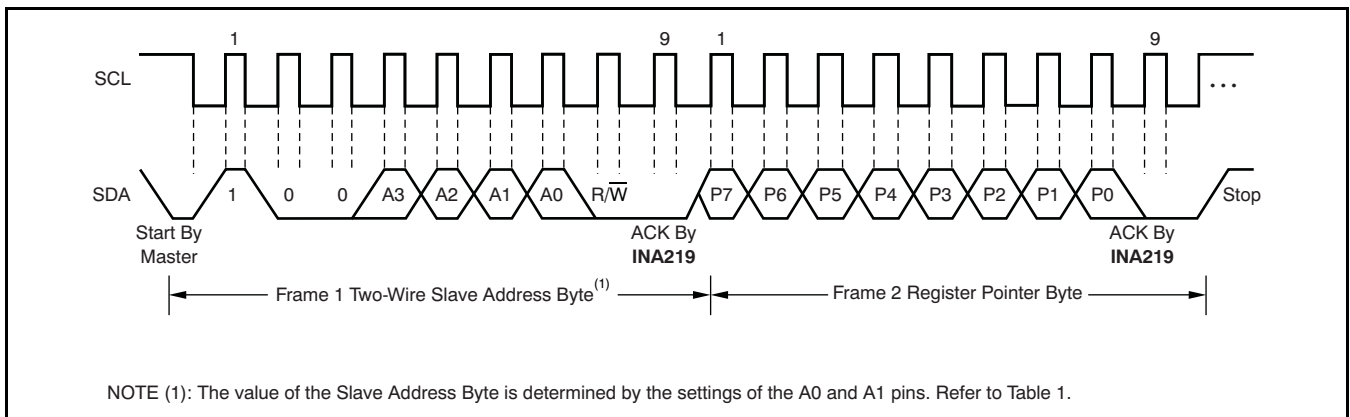


Figure 17. Typical Register Pointer Set

High-Speed I²C Mode

When the bus is idle, both the SDA and SCL lines are pulled high by the pull-up devices. The master generates a start condition followed by a valid serial byte containing High-Speed (HS) master code 00001XXX. This transmission is made in fast (400kbps) or standard (100kbps) (F/S) mode at no more than 400kbps. The INA219 does not acknowledge the HS master code, but does recognize it and switches its internal filters to support 3.4Mbps operation.

The master then generates a repeated start condition (a repeated start condition has the same timing as the start condition). After this repeated start condition, the protocol is the same as F/S mode, except that transmission speeds up to 3.4Mbps are allowed. Instead of using a stop condition, repeated start conditions should be used to secure the bus in HS-mode. A stop condition ends the HS-mode and switches all the internal filters of the INA219 to support the F/S mode.

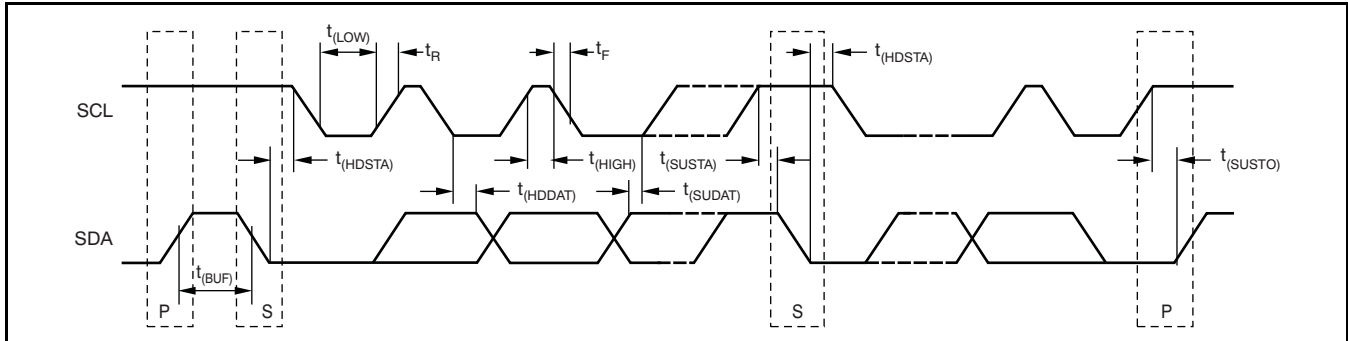


Figure 18. Bus Timing Diagram

Bus Timing Diagram Definitions

| PARAMETER | | FAST MODE | | HIGH-SPEED MODE | | UNITS |
|--|---------------|-----------|------|-----------------|-----|-------|
| | | MIN | MAX | MIN | MAX | |
| SCL Operating Frequency | $f_{(SCL)}$ | 0.001 | 0.4 | 0.001 | 3.4 | MHz |
| Bus Free Time Between STOP and START Condition | $t_{(BUF)}$ | 600 | | 160 | | ns |
| Hold time after repeated START condition. After this period, the first clock is generated. | $t_{(HDSTA)}$ | 100 | | 100 | | ns |
| Repeated START Condition Setup Time | $t_{(SUSTA)}$ | 100 | | 100 | | ns |
| STOP Condition Setup Time | $t_{(SUSTO)}$ | 100 | | 100 | | ns |
| Data Hold Time | $t_{(HDDAT)}$ | 0 | | 0 | | ns |
| Data Setup Time | $t_{(SUDAT)}$ | 100 | | 10 | | ns |
| SCL Clock LOW Period | $t_{(LOW)}$ | 1300 | | 160 | | ns |
| SCL Clock HIGH Period | $t_{(HIGH)}$ | 600 | | 60 | | ns |
| Clock/Data Fall Time | t_F | | 300 | | 160 | ns |
| Clock/Data Rise Time | t_R | | 300 | | 160 | ns |
| Clock/Data Rise Time for SCLK \leq 100kHz | t_R | | 1000 | | | ns |

Power-Up Conditions

Power-up conditions apply to a software reset via the RST bit (bit 15) in the Configuration Register, or the I²C bus General Call Reset.

BASIC ADC FUNCTIONS

The two analog inputs to the INA219, V_{IN+} and V_{IN-}, connect to a shunt resistor in the bus of interest. The INA219 is typically powered by a separate supply from +3V to +5.5V. The bus being sensed can vary from 0V to 26V. There are no special considerations for power-supply sequencing (for example, a bus voltage can be present with the supply voltage off, and vice-versa). The INA219 senses the small drop across the shunt for shunt voltage, and senses the voltage with respect to ground from V_{IN-} for the bus voltage. Figure 19 illustrates this operation.

When the INA219 is in the normal operating mode (that is, MODE bits of the Configuration Register are set to '111'), it continuously converts the shunt voltage up to the number set in the shunt voltage averaging function (Configuration Register, SADC bits). The device then converts the bus voltage up to the number set in the bus voltage averaging (Configuration Register, BADC bits). The Mode control in the Configuration Register also permits selecting modes to convert only voltage or current, either continuously or in response to an event (triggered).

All current and power calculations are performed in the background and do not contribute to conversion time; conversion times shown in the [Electrical Characteristics](#) table can be used to determine the actual conversion time.

Power-Down mode reduces the quiescent current and turns off current into the INA219 inputs, avoiding any supply drain. Full recovery from Power-Down requires 40µs. ADC Off mode (set by the Configuration Register, MODE bits) stops all conversions.

In triggered mode, the external Convert line becomes active. Convert commands are initiated by taking the Convert line low for a minimum of 4µs. The Convert line may be connected high when unused. Any re-trigger of the Convert line during a conversion is ignored, and the Convert line state is disregarded until the conversion ends. There are several available triggered modes; however, all conversions are performed repeatedly up to the number set in the Averaging function (Configuration Register, BADC and SADC bits).

If the Convert line is held low, writing any of the triggered convert modes into the Configuration Register (even if the desired mode is already programmed into the register) triggers a single-shot conversion.

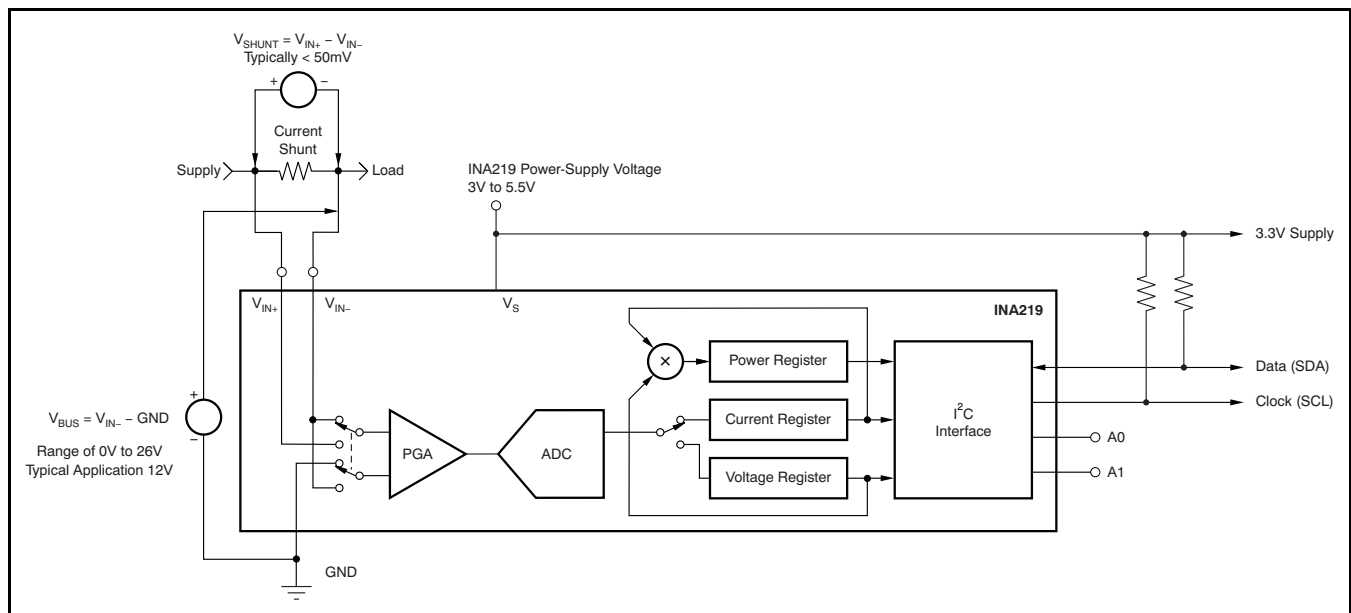


Figure 19. INA219 Configured for Shunt and Bus Voltage Measurement

Although the INA219 can be read at any time, and the data from the last conversion remain available, the Conversion Ready bit (Status Register, CNVR bit) is provided to help co-ordinate one-shot or triggered conversions. The Conversion Ready bit is set after all conversions, averaging, and multiplication operations are complete.

The Conversion Ready bit clears under these conditions:

1. Writing to the Configuration Register, except when configuring the MODE bits for Power Down or ADC off (Disable) modes;
2. Reading the Status Register; or
3. Triggering a single-shot conversion with the Convert pin.

Power Measurement

Current and bus voltage are converted at different points in time, depending on the resolution and averaging mode settings. For instance, when configured for 12-bit and 128 sample averaging, up to 68ms in time between sampling these two values is possible. Again, these calculations are performed in the background and do not add to the overall conversion time.

PGA Function

If larger full-scale shunt voltages are desired, the INA219 provides a PGA function that increases the full-scale range up to 2, 4, or 8 times (320mV). Additionally, the bus voltage measurement has two full-scale ranges: 16V or 32V.

Compatibility with TI Hot Swap Controllers

The INA219 is designed for compatibility with hot swap controllers such the TI [TPS2490](#). The TPS2490 uses a high-side shunt with a limit at 50mV; the INA219 full-scale range of 40mV enables the use of the same shunt for current sensing below this limit. When sensing is required at (or through) the 50mV sense point of the TPS2490, the PGA of the INA219 can be set to $\times 2$ to provide an 80mV full-scale range.

Filtering and Input Considerations

Measuring current is often noisy, and such noise can be difficult to define. The INA219 offers several options for filtering by choosing resolution and averaging in the Configuration Register. These filtering options can be set independently for either voltage or current measurement.

The internal ADC is based on a delta-sigma ($\Delta\Sigma$) front-end with a 500kHz ($\pm 30\%$) typical sampling rate. This architecture has good inherent noise rejection; however, transients that occur at or very close to the sampling rate harmonics can cause problems. Because these signals are at 1MHz and higher, they can be dealt with by incorporating filtering at the input of the INA219. The high frequency enables the use of low-value series resistors on the filter for negligible effects on measurement accuracy. In general, filtering the INA219 input is only necessary if there are transients at exact harmonics of the 500kHz ($\pm 30\%$) sampling rate ($>1\text{MHz}$). Filter using the lowest possible series resistance and ceramic capacitor. Recommended values are 0.1 μF to 1.0 μF . [Figure 20](#) shows the INA219 with an additional filter added at the input.

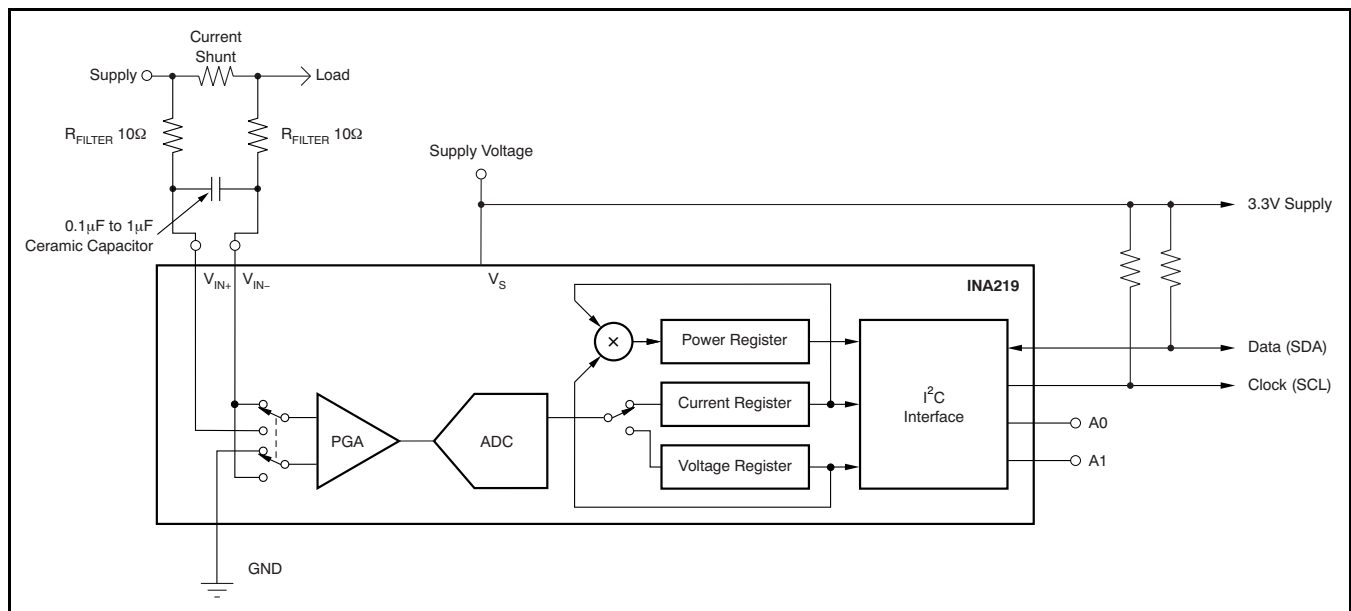


Figure 20. INA219 with Input Filtering

Overload conditions are another consideration for the INA219 inputs. The INA219 inputs are specified to tolerate 26V across the inputs. A large differential scenario might be a short to ground on the load side of the shunt. This type of event can result in full power-supply voltage across the shunt (as long the power supply or energy storage capacitors support it). It must be remembered that removing a short to ground can result in inductive kickbacks that could exceed the 26V differential and common-mode rating of the INA219. Inductive kickback voltages are best dealt with by zener-type transient-absorbing devices (commonly called *transzorbs*) combined with sufficient energy storage capacitance.

In applications that do not have large energy storage electrolytics on one or both sides of the shunt, an input overstress condition may result from an excessive dV/dt of the voltage applied to the input. A hard physical short is the most likely cause of this event, particularly in applications with no large electrolytics present. This problem occurs because an excessive dV/dt can activate the ESD protection in the INA219 in systems where large currents are available. Testing has demonstrated that the addition of 10 Ω resistors in series with each input of the INA219 sufficiently protects the inputs against dV/dt failure up to the 26V rating of the INA219. These resistors have no significant effect on accuracy.

Simple Current Shunt Monitor Usage (No Programming Necessary)

The INA219 can be used without any programming if it is only necessary to read a shunt voltage drop and bus voltage with the default 12-bit resolution, 320mV shunt full-scale range (PGA= \pm 8), 32V bus full-scale range, and continuous conversion of shunt and bus voltage.

Without programming, current is measured by reading the shunt voltage. The Current Register and Power Register are only available if the Calibration Register contains a programmed value.

Programming the INA219

The default power-up states of the registers are shown in the [INA219 register descriptions](#) section of this data sheet. These registers are volatile, and if programmed to other than default values, must be re-programmed at every device power-up. Detailed information on programming the Calibration Register specifically is given in the section, [Programming the INA219 Power Measurement Engine](#).

PROGRAMMING THE INA219 POWER MEASUREMENT ENGINE

Calibration Register and Scaling

The Calibration Register makes it possible to set the scaling of the Current and Power Registers to whatever values are most useful for a given application. One strategy may be to set the Calibration Register such that the largest possible number is generated in the Current Register or Power Register at the expected full-scale point; this approach yields the highest resolution. The Calibration Register can also be selected to provide values in the Current and Power Registers that either provide direct decimal equivalents of the values being measured, or yield a round LSB number. After these choices have been made, the Calibration Register also offers possibilities for end user system-level calibration, where the value is adjusted slightly to cancel total system error.

Below are two examples for configuring the INA219 calibration. Both examples are written so the information directly relates to the calibration setup found in the INA219EVM software.

Calibration Example 1: Calibrating the INA219 with no possibility for overflow. (Note that the numbers used in this example are the same used with the INA219EVM software as shown in [Figure 21](#).)

1. Establish the following parameters:

$$V_{\text{BUS_MAX}} = 32$$

$$V_{\text{SHUNT_MAX}} = 0.32$$

$$R_{\text{SHUNT}} = 0.5$$

2. Using [Equation 1](#), determine the maximum possible current .

$$\text{MaxPossible_I} = \frac{V_{\text{SHUNT_MAX}}}{R_{\text{SHUNT}}}$$

$$\text{MaxPossible_I} = 0.64$$

(1)

3. Choose the desired maximum current value. This value is selected based on system expectations.

$$\text{Max_Expected_I} = 0.6$$

4. Calculate the possible range of current LSBs. To calculate this range, first compute a range of LSBs that is appropriate for the design. Next, select an LSB within this range. Note that the results will have the most resolution when the minimum LSB is selected. Typically, an LSB is selected to be the nearest round number to the minimum LSB value.

$$\text{Minimum_LSB} = \frac{\text{Max_Expected_I}}{32767}$$

$$\text{Minimum_LSB} = 18.311 \times 10^{-6}$$

(2)

$$\text{Maximum_LSB} = \frac{\text{Max_Expected_I}}{4096}$$

$$\text{Maximum_LSB} = 146.520 \times 10^{-6}$$

(3)

Choose an LSB in the range: $\text{Minimum_LSB} < \text{Selected_LSB} < \text{Maximum_LSB}$

$$\text{Current_LSB} = 20 \times 10^{-6}$$

Note:

This value was selected to be a round number near the Minimum_LSB. This selection allows for good resolution with a rounded LSB.

5. Compute the Calibration Register value using [Equation 4](#):

$$\text{Cal} = \text{trunc} \left(\frac{0.04096}{\text{Current_LSB} \times R_{\text{SHUNT}}} \right)$$

$$\text{Cal} = 4096$$

(4)

6. Calculate the Power LSB, using Equation 5. Equation 5 shows a general formula; because the bus voltage measurement LSB is always 4mV, the power formula reduces to the calculated result.

$$\text{Power_LSB} = 20 \text{ Current_LSB}$$

$$\text{Power_LSB} = 400 \times 10^{-6} \quad (5)$$

7. Compute the maximum current and shunt voltage values (before overflow), as shown by Equation 6 and Equation 7. Note that both Equation 6 and Equation 7 involve an *If - then* condition:

$$\text{Max_Current} = \text{Current_LSB} \times 32767$$

$$\text{Max_Current} = 0.65534 \quad (6)$$

If $\text{Max_Current} \geq \text{Max Possible_I}$ then

$$\text{Max_Current_Before_Overflow} = \text{MaxPossible_I}$$

Else

$$\text{Max_Current_Before_Overflow} = \text{Max_Current}$$

End If

(Note that Max_Current is greater than MaxPossible_I in this example.)

$$\text{Max_Current_Before_Overflow} = 0.64 \text{ (Note: This result is displayed by software as seen in Figure 21.)}$$

$$\text{Max_ShuntVoltage} = \text{Max_Current_Before_Overflow} \times R_{\text{SHUNT}}$$

$$\text{Max_ShuntVoltage} = 0.32 \quad (7)$$

If $\text{Max_ShuntVoltage} \geq V_{\text{SHUNT_MAX}}$

$$\text{Max_ShuntVoltage_Before_Overflow} = V_{\text{SHUNT_MAX}}$$

Else

$$\text{Max_ShuntVoltage_Before_Overflow} = \text{Max_ShuntVoltage}$$

End If

(Note that Max_ShuntVoltage is greater than $V_{\text{SHUNT_MAX}}$ in this example.)

$$\text{Max_ShuntVoltage_Before_Overflow} = 0.32 \text{ (Note: This result is displayed by software as seen in Figure 21.)}$$

8. Compute the maximum power with Equation 8.

$$\text{MaximumPower} = \text{Max_Current_Before_Overflow} \times V_{\text{BUS_MAX}}$$

$$\text{MaximumPower} = 20.48 \quad (8)$$

9. (Optional second Calibration step.) Compute corrected full-scale calibration value based on measured current.

$$\text{INA219_Current} = 0.63484$$

$$\text{MeasShuntCurrent} = 0.55$$

$$\text{Corrected_Full_Scale_Cal} = \text{trunc} \left(\frac{\text{Cal} \times \text{MeasShuntCurrent}}{\text{INA219_Current}} \right)$$

$$\text{Corrected_Full_Scale_Cal} = 3548 \quad (9)$$

Figure 21 illustrates how to perform the same procedure discussed in this example using the automated INA219EVM software. Note that the same numbers used in the nine-step example are used in the software example in Figure 21. Also note that Figure 21 illustrates which results correspond to which step (for example, the information entered in Step 1 is enclosed in a box in Figure 21 and labeled).

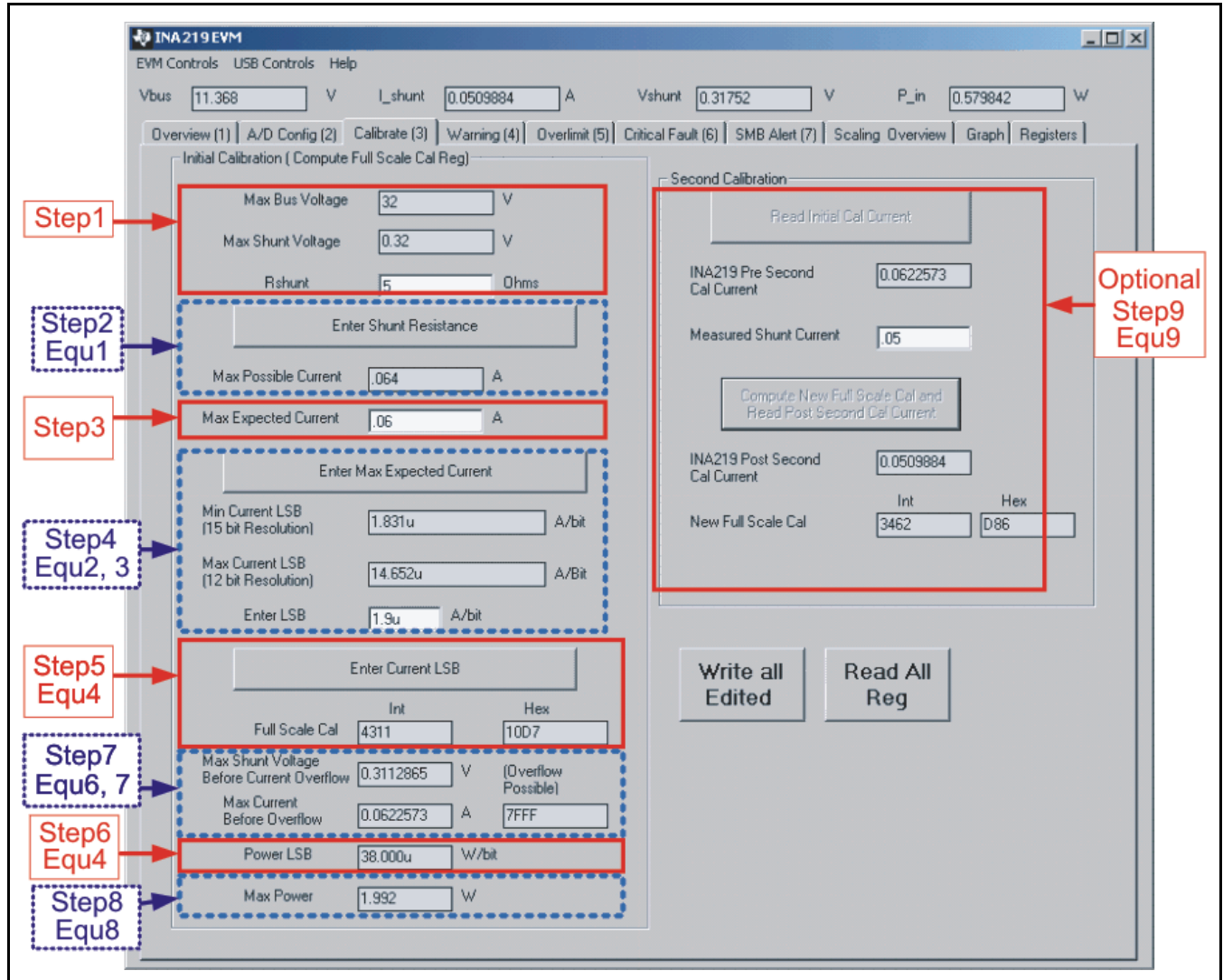


Figure 21. INA219 Calibration Software Automatically Computes Calibration Steps 1-9

Calibration Example 2 (Overflow Possible)

This design example uses the nine-step procedure for calibrating the INA219 where overflow is possible. Figure 22 illustrates how the same procedure is performed using the automated INA219EVM software. Note that the same numbers used in the nine-step example are used in the software example in Figure 22. Also note that Figure 22 illustrates which results correspond to which step (for example, the information entered in Step 1 is circled in Figure 22 and labeled).

1. Establish the following parameters:

$$V_{\text{BUS_MAX}} = 32$$

$$V_{\text{SHUNT_MAX}} = 0.32$$

$$R_{\text{SHUNT}} = 5$$

2. Determine the maximum possible current using Equation 10:

$$\text{MaxPossible_I} = \frac{V_{\text{SHUNT_MAX}}}{R_{\text{SHUNT}}}$$

$$\text{MaxPossible_I} = 0.064 \quad (10)$$

3. Choose the desired maximum current value: $\text{Max_Expected_I}, \leq \text{MaxPossible_I}$. This value is selected based on system expectations.

$$\text{Max_Expected_I} = 0.06$$

4. Calculate the possible range of current LSBs. This calculation is done by first computing a range of LSB's that is appropriate for the design. Next, select an LSB within this range. Note that the results will have the most resolution when the minimum LSB is selected. Typically, an LSB is selected to be the nearest round number to the minimum LSB.

$$\text{Minimum_LSB} = \frac{\text{Max_Expected_I}}{32767}$$

$$\text{Minimum_LSB} = 1.831 \times 10^{-6} \quad (11)$$

$$\text{Maximum_LSB} = \frac{\text{Max_Expected_I}}{4096}$$

$$\text{Maximum_LSB} = 14.652 \times 10^{-6} \quad (12)$$

Choose an LSB in the range: $\text{Minimum_LSB} < \text{Selected_LSB} < \text{Maximum_LSB}$

$$\text{Current_LSB} = 1.9 \times 10^{-6}$$

Note:

This value was selected to be a round number near the Minimum_LSB. This section allows for good resolution with a rounded LSB.

5. Compute the calibration register using Equation 13:

$$\text{Cal} = \text{trunc} \left(\frac{0.04096}{\text{Current_LSB} \times R_{\text{SHUNT}}} \right) \quad \text{Cal} = 4311 \quad (13)$$

6. Calculate the Power LSB using Equation 14. Equation 14 shows a general formula; because the bus voltage measurement LSB is always 4mV, the power formula reduces to calculate the result.

$$\text{Power_LSB} = 20 \text{ Current_LSB}$$

$$\text{Power_LSB} = 38 \times 10^{-6} \quad (14)$$

7. Compute the maximum current and shunt voltage values (before overflow), as shown by [Equation 15](#) and [Equation 16](#). Note that both [Equation 15](#) and [Equation 16](#) involve an *If - then* condition.

$$\text{Max_Current} = \text{Current_LSB} \times 32767$$

$$\text{Max_Current} = 0.06226 \tag{15}$$

If $\text{Max_Current} \geq \text{Max_Possible_I}$ then

$$\text{Max_Current_Before_Overflow} = \text{MaxPossible_I}$$

Else

$$\text{Max_Current_Before_Overflow} = \text{Max_Current}$$

End If

(Note that Max_Current is less than MaxPossible_I in this example.)

$$\text{Max_Current_Before_Overflow} = 0.06226 \text{ (Note: This result is displayed by software as seen in [Figure 22](#).)}$$

$$\text{Max_ShuntVoltage} = \text{Max_Current_Before_Overflow} \times R_{\text{SHUNT}}$$

$$\text{Max_ShuntVoltage} = 0.3113 \tag{16}$$

If $\text{Max_ShuntVoltage} \geq V_{\text{SHUNT_MAX}}$

$$\text{Max_ShuntVoltage_Before_Overflow} = V_{\text{SHUNT_MAX}}$$

Else

$$\text{Max_ShuntVoltage_Before_Overflow} = \text{Max_ShuntVoltage}$$

End If

(Note that Max_ShuntVoltage is less than $V_{\text{SHUNT_MAX}}$ in this example.)

$$\text{Max_ShuntVoltage_Before_Overflow} = 0.3113 \text{ (Note: This result is displayed by software as seen in [Figure 22](#).)}$$

8. Compute the maximum power with equation 8.

$$\text{MaximumPower} = \text{Max_Current_Before_Overflow} \times V_{\text{BUS_MAX}}$$

$$\text{MaximumPower} = 1.992 \tag{17}$$

9. (Optional second calibration step.) Compute the corrected full-scale calibration value based on measured current.

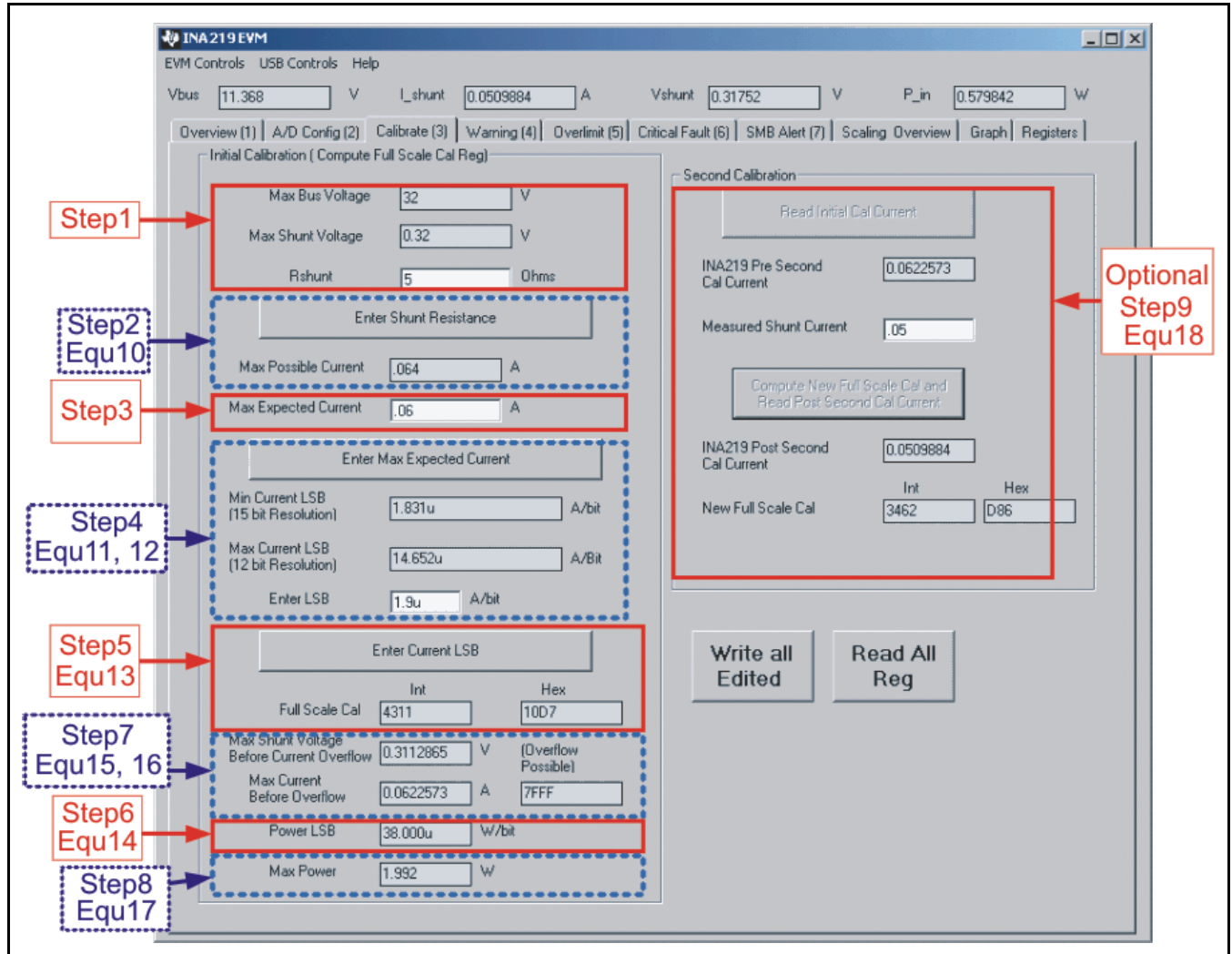
$$\text{INA219_Current} = 0.06226$$

$$\text{MeasShuntCurrent} = 0.05$$

$$\text{Corrected_Full_Scale_Cal} = \text{trunc} \left(\frac{\text{Cal} \times \text{MeasShuntCurrent}}{\text{INA219_Current}} \right)$$

$$\text{Corrected_Full_Scale_Cal} = 3462 \tag{18}$$

[Figure 22](#) illustrates how to perform the same procedure discussed in this example using the automated INA219EVM software. Note that the same numbers used in the nine-step example are used in the software example in [Figure 22](#). Also note that [Figure 22](#) illustrates which results correspond to which step (for example, the information entered in Step 1 is enclosed in a box in [Figure 22](#) and labeled).



The screenshot shows the 'INA219 EVM' calibration software interface. The main window is titled 'INA219 EVM' and contains several tabs: 'Overview (1)', 'A/D Config (2)', 'Calibrate (3)', 'Warning (4)', 'Overlimit (5)', 'Critical Fault (6)', 'SMB Alert (7)', 'Scaling Overview', 'Graph', and 'Registers'. The 'Calibrate (3)' tab is active, showing two main sections: 'Initial Calibration (Compute Full Scale Cal Reg)' and 'Second Calibration'.
The 'Initial Calibration' section includes:
- Max Bus Voltage: 32 V
- Max Shunt Voltage: 0.32 V
- Rshunt: 5 Ohms
- Enter Shunt Resistance (Step 2 Equ 10)
- Max Possible Current: .064 A
- Max Expected Current: .06 A (Step 3)
- Enter Max Expected Current (Step 4 Equ 11, 12)
- Min Current LSB (15 bit Resolution): 1.831u A/bit
- Max Current LSB (12 bit Resolution): 14.652u A/Bit
- Enter LSB: 1.9u A/bit
- Enter Current LSB (Step 5 Equ 13)
- Full Scale Cal: Int: 4311, Hex: 10D7
- Max Shunt Voltage Before Current Overflow: 0.3112865 V (Overflow Possible)
- Max Current Before Overflow: 0.0622573 A (7FFF)
- Power LSB: 38.000u W/bit (Step 6 Equ 14)
- Max Power: 1.992 W (Step 8 Equ 17)
The 'Second Calibration' section includes:
- Read Initial Cal Current
- INA219 Pre Second Cal Current: 0.0622573
- Measured Shunt Current: .05 (Optional Step 9 Equ 18)
- Compute New Full Scale Cal and Read Post Second Cal Current
- INA219 Post Second Cal Current: 0.0509884
- New Full Scale Cal: Int: 3462, Hex: D86
Buttons for 'Write all Edited' and 'Read All Reg' are located at the bottom right of the calibration area.

Figure 22. Calibration Software Automatically Computes Calibration Steps 1-9

REGISTER INFORMATION

The INA219 uses a bank of registers for holding configuration settings, measurement results, maximum/minimum limits, and status information. [Table 2](#) summarizes the INA219 registers; [Figure 12](#) illustrates registers.

Register contents are updated 4μs after completion of the write command. Therefore, a 4μs delay is required between completion of a write to a given register and a subsequent read of that register (without changing the pointer) when using SCL frequencies in excess of 1MHz.

Table 2. Summary of Register Set

| POINTER ADDRESS | REGISTER NAME | FUNCTION | POWER-ON RESET | | TYPE ⁽¹⁾ |
|-----------------|------------------------|--|-------------------|------|---------------------|
| | | | BINARY | HEX | |
| 00 | Configuration Register | All-register reset, settings for bus voltage range, PGA Gain, ADC resolution/averaging. | 00111001 10011111 | 399F | R/ \bar{W} |
| 01 | Shunt Voltage | Shunt voltage measurement data. | Shunt voltage | — | R |
| 02 | Bus Voltage | Bus voltage measurement data. | Bus voltage | — | R |
| 03 | Power ⁽²⁾ | Power measurement data. | 00000000 00000000 | 0000 | R |
| 04 | Current ⁽²⁾ | Contains the value of the current flowing through the shunt resistor. | 00000000 00000000 | 0000 | R |
| 05 | Calibration | Sets full-scale range and LSB of current and power measurements. Overall system calibration. | 00000000 00000000 | 0000 | R/ \bar{W} |

(1) Type: R = Read-Only, R/ \bar{W} = Read/Write.

(2) The Power Register and Current Register default to '0' because the Calibration Register defaults to '0', yielding a zero current value until the Calibration Register is programmed.

REGISTER DETAILS

All INA219 registers 16-bit registers are actually two 8-bit bytes via the I²C interface.

Configuration Register 00h (Read/Write)

| BIT # | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|-----------|-----|-----|------|-----|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| BIT NAME | RST | — | BRNG | PG1 | PG0 | BADC4 | BADC3 | BADC2 | BADC1 | SADC4 | SADC3 | SADC2 | SADC1 | MODE3 | MODE2 | MODE1 |
| POR VALUE | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |

Bit Descriptions

RST: **Reset Bit**

Bit 15 Setting this bit to '1' generates a system reset that is the same as power-on reset. Resets all registers to default values; this bit self-clears.

BRNG: **Bus Voltage Range**

Bit 13 0 = 16V FSR
1 = 32V FSR (default value)

PG: **PGA (Shunt Voltage Only)**

Bits 11, 12 Sets PGA gain and range. Note that the PGA defaults to ÷8 (320mV range). [Table 3](#) shows the gain and range for the various product gain settings.

Table 3. PG Bit Settings⁽¹⁾

| PG1 | PG0 | GAIN | RANGE |
|-----|-----|------|--------|
| 0 | 0 | 1 | ±40mV |
| 0 | 1 | ÷2 | ±80mV |
| 1 | 0 | ÷4 | ±160mV |
| 1 | 1 | ÷8 | ±320mV |

(1) Shaded values are default.

BADC: **BADC Bus ADC Resolution/Averaging**

Bits 7–10 These bits adjust the Bus ADC resolution (9-, 10-, 11-, or 12-bit) or set the number of samples used when averaging results for the Bus Voltage Register (02h).

SADC:
SADC Shunt ADC Resolution/Averaging

Bits 3–6

These bits adjust the Shunt ADC resolution (9-, 10-, 11-, or 12-bit) or set the number of samples used when averaging results for the Shunt Voltage Register (01h). BADC (Bus) and SADC (Shunt) ADC resolution/averaging and conversion time settings are shown in [Table 4](#).

Table 4. ADC Settings⁽¹⁾

| ADC4 | ADC3 | ADC2 | ADC1 | MODE/SAMPLES | CONVERSION TIME |
|------|------------------|------|------|--------------|-----------------|
| 0 | X ⁽²⁾ | 0 | 0 | 9-bit | 84µs |
| 0 | X ⁽²⁾ | 0 | 1 | 10-bit | 148µs |
| 0 | X ⁽²⁾ | 1 | 0 | 11-bit | 276µs |
| 0 | X ⁽²⁾ | 1 | 1 | 12-bit | 532µs |
| 1 | 0 | 0 | 0 | 12-bit | 532µs |
| 1 | 0 | 0 | 1 | 2 | 1.06ms |
| 1 | 0 | 1 | 0 | 4 | 2.13ms |
| 1 | 0 | 1 | 1 | 8 | 4.26ms |
| 1 | 1 | 0 | 0 | 16 | 8.51ms |
| 1 | 1 | 0 | 1 | 32 | 17.02ms |
| 1 | 1 | 1 | 0 | 64 | 34.05ms |
| 1 | 1 | 1 | 1 | 128 | 68.10ms |

(1) Shaded values are default.

(2) X = Don't care.

MODE:
Operating Mode

Bits 0–2

Selects continuous, triggered, or power-down mode of operation. These bits default to continuous shunt and bus measurement mode. The mode settings are shown in [Table 5](#).

Table 5. Mode Settings⁽¹⁾

| MODE3 | MODE2 | MODE1 | MODE |
|-------|-------|-------|---------------------------|
| 0 | 0 | 0 | Power-Down |
| 0 | 0 | 1 | Shunt Voltage, Triggered |
| 0 | 1 | 0 | Bus Voltage, Triggered |
| 0 | 1 | 1 | Shunt and Bus, Triggered |
| 1 | 0 | 0 | ADC Off (disabled) |
| 1 | 0 | 1 | Shunt Voltage, Continuous |
| 1 | 1 | 0 | Bus Voltage, Continuous |
| 1 | 1 | 1 | Shunt and Bus, Continuous |

(1) Shaded values are default.

DATA OUTPUT REGISTERS

Shunt Voltage Register 01h (Read-Only)

The Shunt Voltage Register stores the current shunt voltage reading, V_{SHUNT} . Shunt Voltage Register bits are shifted according to the PGA setting selected in the Configuration Register (00h). When multiple sign bits are present, they will all be the same value. Negative numbers are represented in two's complement format. Generate the two's complement of a negative number by complementing the absolute value binary number and adding 1. Extend the sign, denoting a negative number by setting the MSB = '1'. Extend the sign to any additional sign bits to form the 16-bit word.

Example: For a value of $V_{SHUNT} = -320mV$:

1. Take the absolute value (include accuracy to 0.01mV) ==> 320.00
2. Translate this number to a whole decimal number ==> 32000
3. Convert it to binary ==> 111 1101 0000 0000
4. Complement the binary result : 000 0010 1111 1111
5. Add 1 to the Complement to create the Two's Complement formatted result ==> 000 0011 0000 0000
6. Extend the sign and create the 16-bit word: 1000 0011 0000 0000 = 8300h (Remember to extend the sign to all sign-bits, as necessary based on the PGA setting.)

At PGA = ÷8, full-scale range = ±320mV (decimal = 32000, positive value hex = 7D00, negative value hex = 8300), and LSB = 10µV.

| BIT # | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|-----------|------|--------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| BIT NAME | SIGN | SD14_8 | SD13_8 | SD12_8 | SD11_8 | SD10_8 | SD9_8 | SD8_8 | SD7_8 | SD6_8 | SD5_8 | SD4_8 | SD3_8 | SD2_8 | SD1_8 | SD0_8 |
| POR VALUE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

At PGA = ÷4, full-scale range = ±160mV (decimal = 16000, positive value hex = 3E80, negative value hex = C180), and LSB = 10µV.

| BIT # | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|-----------|------|------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| BIT NAME | SIGN | SIGN | SD13_4 | SD12_4 | SD11_4 | SD10_4 | SD9_4 | SD8_4 | SD7_4 | SD6_4 | SD5_4 | SD4_4 | SD3_4 | SD2_4 | SD1_4 | SD0_4 |
| POR VALUE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

At PGA = ÷2, full-scale range = ±80mV (decimal = 8000, positive value hex = 1F40, negative value hex = E0C0), and LSB = 10µV.

| BIT # | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|-----------|------|------|------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| BIT NAME | SIGN | SIGN | SIGN | SD12_2 | SD11_2 | SD10_2 | SD9_2 | SD8_2 | SD7_2 | SD6_2 | SD5_2 | SD4_2 | SD3_2 | SD2_2 | SD1_2 | SD0_2 |
| POR VALUE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

At PGA = ÷1, full-scale range = ±40mV (decimal = 4000, positive value hex = 0FA0, negative value hex = F060), and LSB = 10µV.

| BIT # | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|-----------|------|------|------|------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| BIT NAME | SIGN | SIGN | SIGN | SIGN | SD11_1 | SD10_1 | SD9_1 | SD8_1 | SD7_1 | SD6_1 | SD5_1 | SD4_1 | SD3_1 | SD2_1 | SD1_1 | SD0_1 |
| POR VALUE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 6. Shunt Voltage Register Format⁽¹⁾

| V _{SHUNT} Reading (mV) | Decimal Value | PGA = ÷ 8 (D15.....D0) | PGA = ÷ 4 (D15.....D0) | PGA = ÷ 2 (D15.....D0) | PGA = ÷ 1 (D15.....D0) |
|------------------------------------|------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| 320.02 | 32002 | 0111 1101 0000 0000 | 0011 1110 1000 0000 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 320.01 | 32001 | 0111 1101 0000 0000 | 0011 1110 1000 0000 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 320.00 | 32000 | 0111 1101 0000 0000 | 0011 1110 1000 0000 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 319.99 | 31999 | 0111 1100 1111 1111 | 0011 1110 1000 0000 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 319.98 | 31998 | 0111 1100 1111 1110 | 0011 1110 1000 0000 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 160.02 | 16002 | 0011 1110 1000 0010 | 0011 1110 1000 0000 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 160.01 | 16001 | 0011 1110 1000 0001 | 0011 1110 1000 0000 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 160.00 | 16000 | 0011 1110 1000 0000 | 0011 1110 1000 0000 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 159.99 | 15999 | 0011 1110 0111 1111 | 0011 1110 0111 1111 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 159.98 | 15998 | 0011 1110 0111 1110 | 0011 1110 0111 1110 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 80.02 | 8002 | 0001 1111 0100 0010 | 0001 1111 0100 0010 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 80.01 | 8001 | 0001 1111 0100 0001 | 0001 1111 0100 0001 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 80.00 | 8000 | 0001 1111 0100 0000 | 0001 1111 0100 0000 | 0001 1111 0100 0000 | 0000 1111 1010 0000 |
| 79.99 | 7999 | 0001 1111 0011 1111 | 0001 1111 0011 1111 | 0001 1111 0011 1111 | 0000 1111 1010 0000 |
| 79.98 | 7998 | 0001 1111 0011 1110 | 0001 1111 0011 1110 | 0001 1111 0011 1110 | 0000 1111 1010 0000 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 40.02 | 4002 | 0000 1111 1010 0010 | 0000 1111 1010 0010 | 0000 1111 1010 0010 | 0000 1111 1010 0000 |
| 40.01 | 4001 | 0000 1111 1010 0001 | 0000 1111 1010 0001 | 0000 1111 1010 0001 | 0000 1111 1010 0000 |
| 40.00 | 4000 | 0000 1111 1010 0000 | 0000 1111 1010 0000 | 0000 1111 1010 0000 | 0000 1111 1010 0000 |
| 39.99 | 3999 | 0000 1111 1001 1111 | 0000 1111 1001 1111 | 0000 1111 1001 1111 | 0000 1111 1001 1111 |
| 39.98 | 3998 | 0000 1111 1001 1110 | 0000 1111 1001 1110 | 0000 1111 1001 1110 | 0000 1111 1001 1110 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 0.02 | 2 | 0000 0000 0000 0010 | 0000 0000 0000 0010 | 0000 0000 0000 0010 | 0000 0000 0000 0010 |
| 0.01 | 1 | 0000 0000 0000 0001 | 0000 0000 0000 0001 | 0000 0000 0000 0001 | 0000 0000 0000 0001 |
| 0 | 0 | 0000 0000 0000 0000 | 0000 0000 0000 0000 | 0000 0000 0000 0000 | 0000 0000 0000 0000 |
| -0.01 | -1 | 1111 1111 1111 1111 | 1111 1111 1111 1111 | 1111 1111 1111 1111 | 1111 1111 1111 1111 |
| -0.02 | -2 | 1111 1111 1111 1110 | 1111 1111 1111 1110 | 1111 1111 1111 1110 | 1111 1111 1111 1110 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| -39.98 | -3998 | 1111 0000 0110 0010 | 1111 0000 0110 0010 | 1111 0000 0110 0010 | 1111 0000 0110 0010 |
| -39.99 | -3999 | 1111 0000 0110 0001 | 1111 0000 0110 0001 | 1111 0000 0110 0001 | 1111 0000 0110 0001 |
| -40.00 | -4000 | 1111 0000 0110 0000 | 1111 0000 0110 0000 | 1111 0000 0110 0000 | 1111 0000 0110 0000 |
| -40.01 | -4001 | 1111 0000 0101 1111 | 1111 0000 0101 1111 | 1111 0000 0101 1111 | 1111 0000 0110 0000 |
| -40.02 | -4002 | 1111 0000 0101 1110 | 1111 0000 0101 1110 | 1111 0000 0101 1110 | 1111 0000 0110 0000 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| -79.98 | -7998 | 1110 0000 1100 0010 | 1110 0000 1100 0010 | 1110 0000 1100 0010 | 1111 0000 0110 0000 |
| -79.99 | -7999 | 1110 0000 1100 0001 | 1110 0000 1100 0001 | 1110 0000 1100 0001 | 1111 0000 0110 0000 |
| -80.00 | -8000 | 1110 0000 1100 0000 | 1110 0000 1100 0000 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| -80.01 | -8001 | 1110 0000 1011 1111 | 1110 0000 1011 1111 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| -80.02 | -8002 | 1110 0000 1011 1110 | 1110 0000 1011 1110 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| -159.98 | -15998 | 1100 0001 1000 0010 | 1100 0001 1000 0010 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| -159.99 | -15999 | 1100 0001 1000 0001 | 1100 0001 1000 0001 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| -160.00 | -16000 | 1100 0001 1000 0000 | 1100 0001 1000 0000 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| -160.01 | -16001 | 1100 0001 0111 1111 | 1100 0001 1000 0000 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| -160.02 | -16002 | 1100 0001 0111 1110 | 1100 0001 1000 0000 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| -319.98 | -31998 | 1000 0011 0000 0010 | 1100 0001 1000 0000 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| -319.99 | -31999 | 1000 0011 0000 0001 | 1100 0001 1000 0000 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| -320.00 | -32000 | 1000 0011 0000 0000 | 1100 0001 1000 0000 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| -320.01 | -32001 | 1000 0011 0000 0000 | 1100 0001 1000 0000 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |
| -320.02 | -32002 | 1000 0011 0000 0000 | 1100 0001 1000 0000 | 1110 0000 1100 0000 | 1111 0000 0110 0000 |

(1) Out-of-range values are shown in grey shading.

Bus Voltage Register 02h (Read-Only)

The Bus Voltage Register stores the most recent bus voltage reading, V_{BUS} .

At full-scale range = 32V (decimal = 8000, hex = 1F40), and LSB = 4mV.

| BIT # | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|-----------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|------|-----|
| BIT NAME | BD12 | BD11 | BD10 | BD9 | BD8 | BD7 | BD6 | BD5 | BD4 | BD3 | BD2 | BD1 | BD0 | — | CNVR | OVF |
| POR VALUE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

At full-scale range = 16V (decimal = 4000, hex = 0FA0), and LSB = 4mV.

| BIT # | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|-----------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|------|-----|
| BIT NAME | 0 | BD11 | BD10 | BD9 | BD8 | BD7 | BD6 | BD5 | BD4 | BD3 | BD2 | BD1 | BD0 | — | CNVR | OVF |
| POR VALUE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CNVR: Conversion Ready

Bit 1 Although the data from the last conversion can be read at any time, the INA219 Conversion Ready bit (CNVR) indicates when data from a conversion is available in the data output registers. The CNVR bit is set after all conversions, averaging, and multiplications are complete. CNVR will clear under the following conditions:

- 1.) Writing a new mode into the Operating Mode bits in the Configuration Register (except for Power-Down or Disable)
- 2.) Reading the Power Register

OVF: Math Overflow Flag

Bit 0 The Math Overflow Flag (OVF) is set when the Power or Current calculations are out of range. It indicates that current and power data may be meaningless.

Power Register 03h (Read-Only)

Full-scale range and LSB are set by the Calibration Register. See the [Programming the INA219 Power Measurement Engine](#) section.

| BIT # | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|-----------|------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| BIT NAME | PD15 | PD14 | PD13 | PD12 | PD11 | PD10 | PD9 | PD8 | PD7 | PD6 | PD5 | PD4 | PD3 | PD2 | PD1 | PD0 |
| POR VALUE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The Power Register records power in watts by multiplying the values of the current with the value of the bus voltage according to the equation:

$$\text{Power} = \frac{\text{Current} \times \text{BusVoltage}}{5000}$$

Current Register 04h (Read-Only)

Full-scale range and LSB depend on the value entered in the Calibration Register. See the [Programming the INA219 Power Measurement Engine](#) section. Negative values are stored in two's complement format.

| BIT # | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|-----------|-------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| BIT NAME | CSIGN | CD14 | CD13 | CD12 | CD11 | CD10 | CD9 | CD8 | CD7 | CD6 | CD5 | CD4 | CD3 | CD2 | CD1 | CD0 |
| POR VALUE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The value of the Current Register is calculated by multiplying the value in the Shunt Voltage Register with the value in the Calibration Register according to the equation:

$$\text{Current} = \frac{\text{ShuntVoltage} \times \text{Calibration Register}}{4096}$$

CALIBRATION REGISTER

Calibration Register 05h (Read/Write)

Current and power calibration are set by bits D15 to D1 of the Calibration Register. Note that bit D0 is not used in the calculation. This register sets the current that corresponds to a full-scale drop across the shunt. Full-scale range and the LSB of the current and power measurement depend on the value entered in this register. See the [Programming the INA219 Power Measurement Engine](#) section. This register is suitable for use in overall system calibration. Note that the '0' POR values are all default.

| BIT # | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 ⁽¹⁾ |
|-----------|------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------------------|
| BIT NAME | FS15 | FS14 | FS13 | FS12 | FS11 | FS10 | FS9 | FS8 | FS7 | FS6 | FS5 | FS4 | FS3 | FS2 | FS1 | FS0 |
| POR VALUE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

(1) D0 is a *void* bit and will always be '0'. It is not possible to write a '1' to D0. CALIBRATION is the value stored in D15:D1.

PACKAGING INFORMATION

| Orderable Device | Status ⁽¹⁾ | Package Type | Package Drawing | Pins | Package Qty | Eco Plan ⁽²⁾ | Lead/Ball Finish | MSL Peak Temp ⁽³⁾ |
|------------------|-----------------------|--------------|-----------------|------|-------------|-------------------------|------------------|------------------------------|
| INA219AID | PREVIEW | SOIC | D | 8 | 75 | TBD | Call TI | Call TI |
| INA219AIDCNR | ACTIVE | SOT-23 | DCN | 8 | 3000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| INA219AIDCNRG4 | ACTIVE | SOT-23 | DCN | 8 | 3000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| INA219AIDCNT | ACTIVE | SOT-23 | DCN | 8 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| INA219AIDCNTG4 | ACTIVE | SOT-23 | DCN | 8 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| INA219AIDR | PREVIEW | SOIC | D | 8 | 2500 | TBD | Call TI | Call TI |

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

ACTIVE: Product device recommended for new designs.

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

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

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

OBSELETE: TI has discontinued the production of the device.

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

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

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

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

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

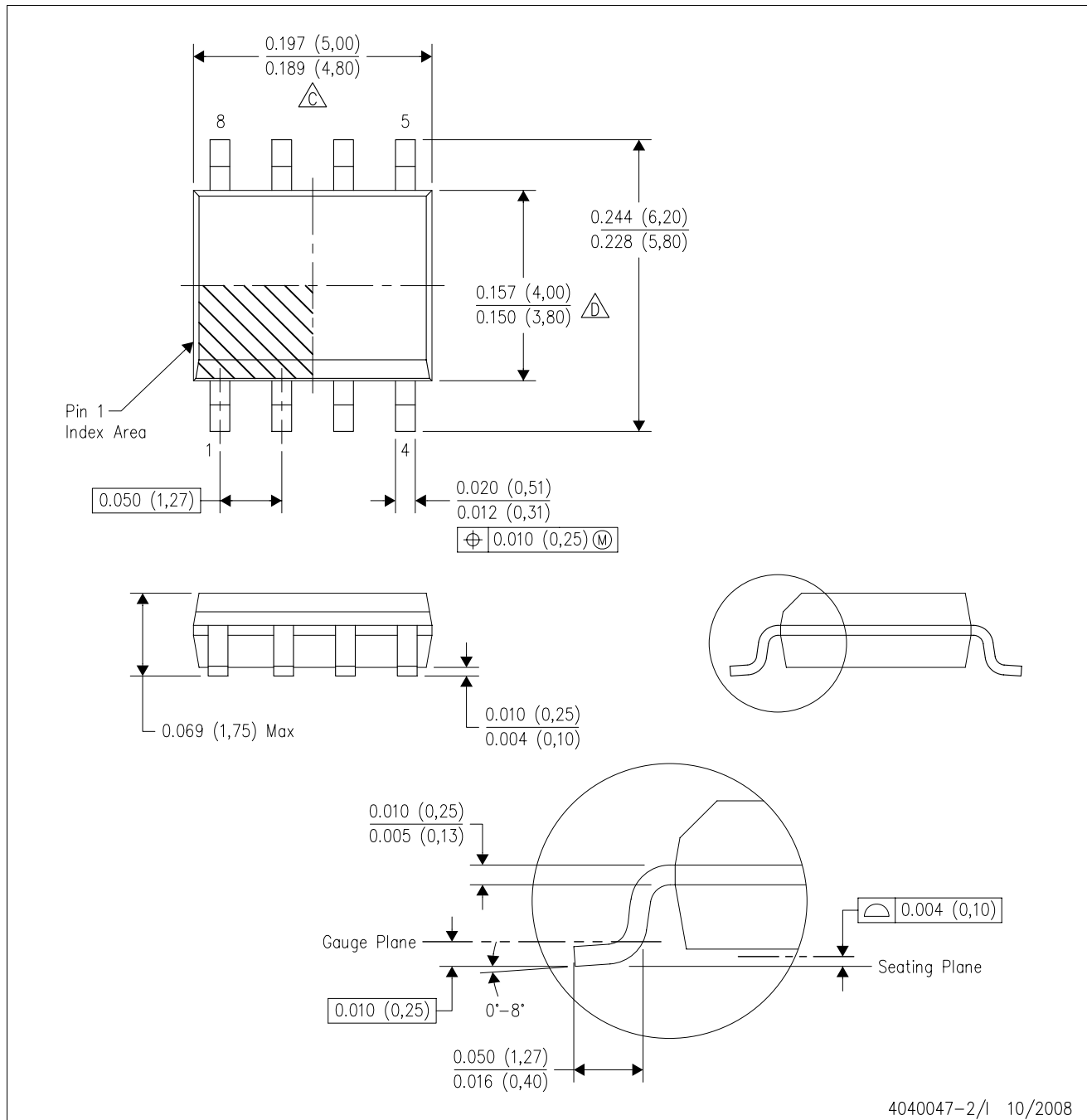
⁽³⁾ MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.



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D (R-PDSO-G8)

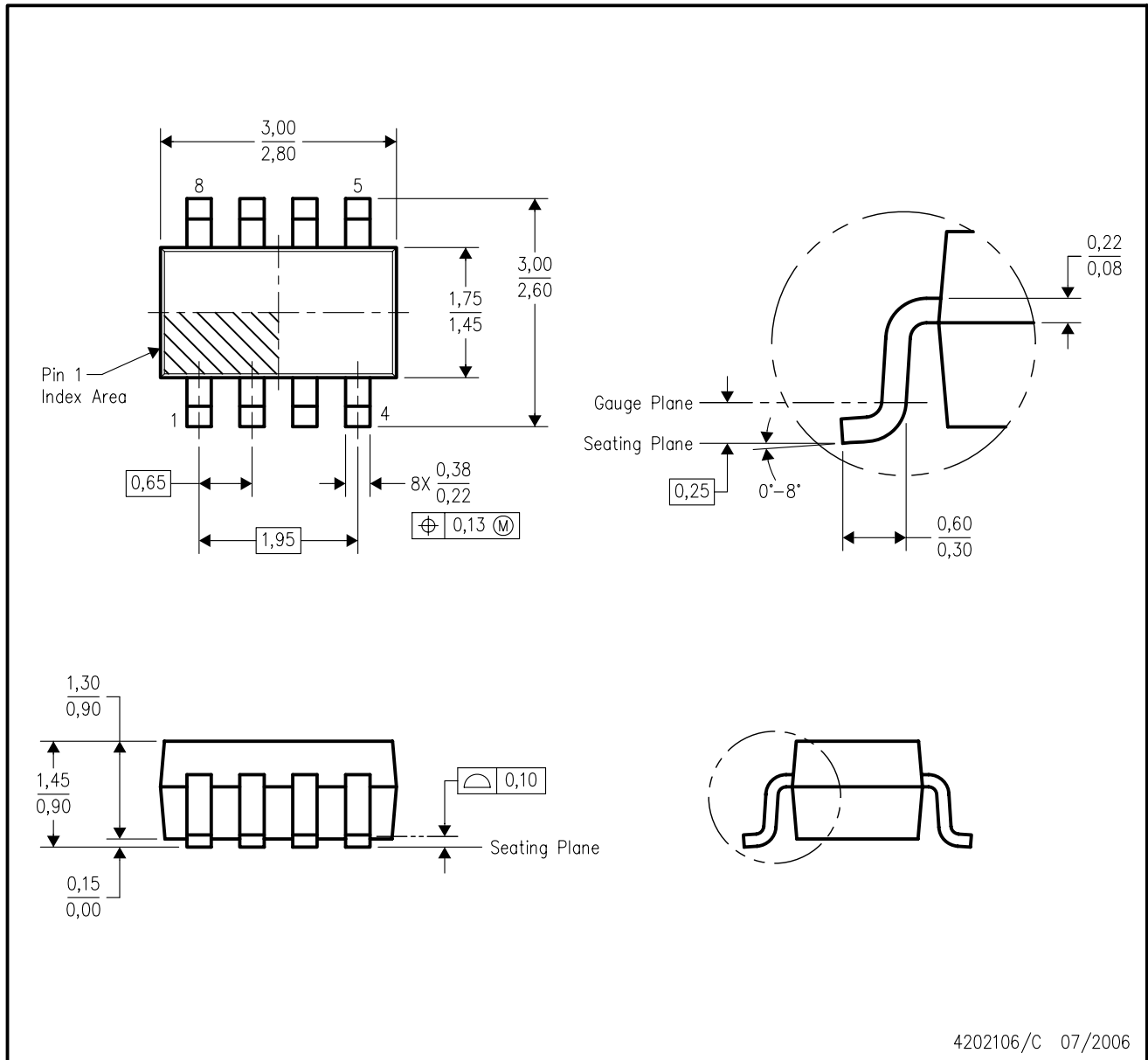
PLASTIC SMALL-OUTLINE PACKAGE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 -  Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 (0,15) per end.
 -  Body width does not include interlead flash. Interlead flash shall not exceed .017 (0,43) per side.
 - E. Reference JEDEC MS-012 variation AA.

DCN (R-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE (DIE DOWN)



- NOTES:
- All linear dimensions are in millimeters.
 - This drawing is subject to change without notice.
 - Package outline exclusive of mold flash, metal burr & dambar protrusion/intrusion.
 - Package outline inclusive of solder plating.
 - A visual index feature must be located within the Pin 1 index area.
 - Falls within JEDEC MO-178 Variation BA.

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
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