High-or Low-Side Measurement,
Bi-Directional CURRENT/POWER MONITOR with I^{2}C™ Interface

Check for Samples: INA226

FEATURES

- **SENSES BUS VOLTAGES FROM 0V TO +36V**
- **HIGH- OR LOW-SIDE SENSING**
- **REPORTS CURRENT, VOLTAGE, AND POWER**
- **HIGH ACCURACY:**
  - **0.1% Gain Error (Max)**
  - **10μV Offset (Max)**
- **CONFIGURABLE AVERAGING OPTIONS**
- **16 PROGRAMMABLE ADDRESSES**
- **OPERATES FROM 2.7 to 5.5V POWER SUPPLY**
- **MSOP-10 PACKAGE**

APPLICATIONS

- **SERVERS**
- **TELECOM EQUIPMENT**
- **COMPUTERS**
- **POWER MANAGEMENT**
- **BATTERY CHARGERS**
- **POWER SUPPLIES**
- **TEST EQUIPMENT**

DESCRIPTION

The INA226 is a current shunt and power monitor with an I^{2}C interface. The INA226 monitors both a shunt voltage drop and bus supply voltage. Programmable calibration value, conversion times, and averaging, combined with an internal multiplier, enable direct readouts of current in amperes and power in watts.

The INA226 senses current on buses that can vary from 0V to +36V, while the device obtains its power from a single +2.7V to +5.5V supply, drawing a typical of 330μA of supply current. The INA226 is specified over the operating temperature range of –40°C to +125°C. The I^{2}C interface features 16 programmable addresses.

RELATED PRODUCTS

DESCRIPTION	DEVICE
Current/Power Monitor with Watchdog, Peak-Hold, and Fast Comparator Functions	INA209
Zerø-Drift, Low-Cost, Analog Current Shunt Monitor Series in Small Package	INA210, INA211, INA212, INA213, INA214
Zerø-Drift, Bi-Directional Current Power Monitor with Two-Wire Interface	INA219
High or Low Side, Bi-Directional Current/Power Monitor with Two-Wire Interface	INA220
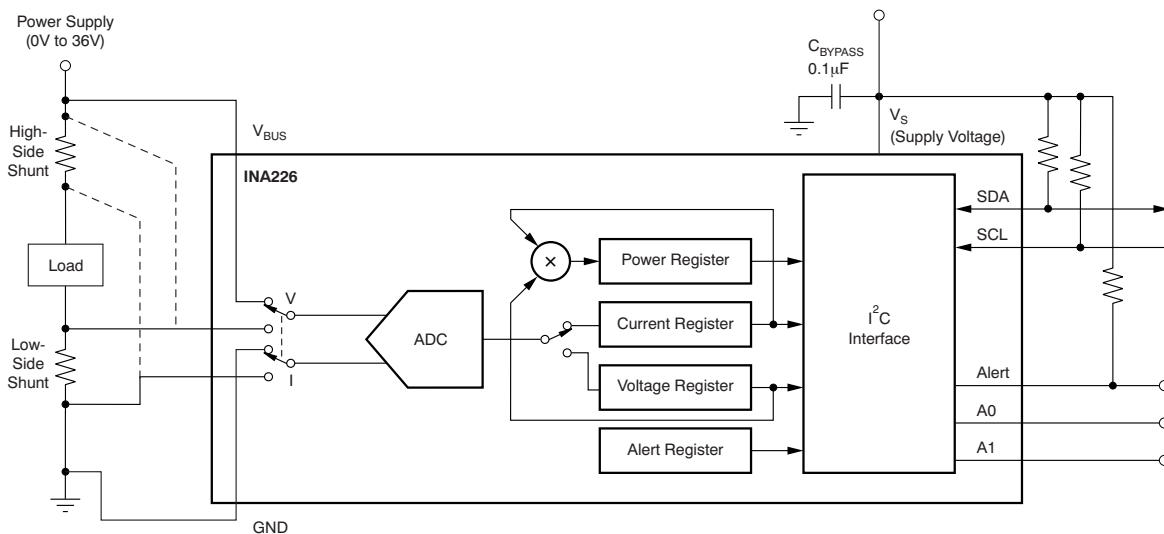
High-or Low-Side Sensing

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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.

PACKAGING INFORMATION[1]

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	PACKAGE MARKING
INA226AIDGS	MSOP-10	DGS	226

(1) For the most current package and ordering information see the Package Option Addendum at the end of this document, or see the INA226 product folder at www.ti.com.

ABSOLUTE MAXIMUM RATINGS[1]

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

		INA226	UNIT
Supply Voltage, V_S		6	V
Analog Inputs, VIN+, VIN–	Differential (VIN+) – (VIN–)[2]	–40 to +40	V
	Common-Mode	–0.3 to +40	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
Storage Temperature		–65 to +150	°C
Junction Temperature		+150	°C
ESD Ratings	Human Body Model (HBM)	2500	V
	Charged-Device Model (CDM)	1000	V
	Machine Model (MM)	150	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) VIN+ and VIN– may have a differential voltage of –40V to +40V; however, the voltage at these pins must not exceed the range –0.3V to +40V.

ELECTRICAL CHARACTERISTICS: V_S = +3.3V

Boldface limits apply over the specified temperature range, T_A = **−40°C to +125°C.**

At T_A = +25°C, VIN+ = 12V, V_{SENSE} = (VIN+ − VIN−) = 0mV, V_{BUS} = 12V, unless otherwise noted.

PARAMETER		CONDITIONS	INA226			UNIT
			MIN	TYP	MAX	
INPUT						
Shunt voltage input range			-81.9175		81.92	mV
Bus voltage input range[1]			0		36	V
Common-mode rejection	CMRR	VIN+ = 0V to +36V	126	140		dB
Shunt offset voltage, RTI[2]	V_{OS}			±2.5	±10	μV
vs Temperature				**0.02**	**0.1**	**μV/°C**
vs Power supply	PSRR	V_S = +2.7V to +5.5V		2.5		μV/V
Bus offset voltage, RTI[2]	V_{OS}			±1.25	±7.5	mV
vs Temperature				**10**	**40**	**μV/°C**
vs Power supply	PSRR			0.5		mV/V
Input bias current	I_{IN+}, I_{IN-}			10		μA
V_{BUS} input impedance				830		kΩ
Input leakage[3]		(VIN+ Pin) + (VIN− Pin), Power-down mode		0.1	0.5	μA
DC ACCURACY						
ADC native resolution				16		Bits
1 LSB step size		Shunt voltage		2.5		μV
		Bus voltage		1.25		mV
Shunt voltage gain error				0.02	0.1	%
vs Temperature				**10**	**50**	**ppm/°C**
Bus voltage gain error				0.02	0.1	%
vs Temperature				**10**	**50**	**ppm/°C**
Differential nonlinearity				±0.1		LSB
ADC conversion time		CT bit = 000		140	154	μs
		CT bit = 001		204	224	μs
		CT bit = 010		332	365	μs
		CT bit = 011		588	646	μs
		CT bit = 100		1.1	1.21	ms
		CT bit = 101		2.116	2.328	ms
		CT bit = 110		4.156	4.572	ms
		CT bit = 111		8.244	9.068	ms
SMBus						
SMBus timeout[4]				28	35	ms
DIGITAL INPUT/OUTPUT						
Input capacitance				3		pF
Leakage input current		0 ≤ V_{IN} ≤ V_S		0.1	1	μA
Input logic levels:						
V_{IH}			0.7(V_S)		6	V
V_{IL}			−0.5		0.3(V_S)	V
Output logic level						
V_{OL} SDA, alert		I_{OL} = 3mA	0		0.4	V
Hysteresis				500		mV

(1) While the input range is 36V, the full-scale range of the ADC scaling is 40.96V. See the *Basic ADC Functions* section. Do not apply more than 36V.
(2) RTI = Referred-to-input.
(3) Input leakage is positive (current flowing into the pin) for the conditions shown at the top of this table. Negative leakage currents can occur under different input conditions.
(4) SMBus timeout in the INA226 resets the interface any time SCL is low for more than 28ms.

ELECTRICAL CHARACTERISTICS: V_S = +3.3V (continued)

Boldface limits apply over the specified temperature range, **T_A = −40°C to +125°C.**
At T_A = +25°C, VIN+ = 12V, V_{SENSE} = (VIN+ − VIN−) = 0mV, V_{BUS} = 12V, unless otherwise noted.

PARAMETER	CONDITIONS	INA226			UNIT
		MIN	TYP	MAX	
POWER SUPPLY					
Operating supply range		+2.7		+5.5	V
Quiescent current			330	420	µA
Quiescent current, power-down mode			0.5	2	µA
Power-on reset threshold			2		V
TEMPERATURE RANGE					
Specified range		−40		+125	°C

THERMAL INFORMATION

THERMAL METRIC[1]		INA226	UNITS
		DGS	
		10 PINS	
θ_{JA}	Junction-to-ambient thermal resistance	171.4	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance	42.9	
θ_{JB}	Junction-to-board thermal resistance	91.8	
ψ_{JT}	Junction-to-top characterization parameter	1.5	
ψ_{JB}	Junction-to-board characterization parameter	90.2	
θ_{JCbot}	Junction-to-case (bottom) thermal resistance	n/a	

(1)   For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

PIN CONFIGURATIONS

**DGS PACKAGE
MSOP-10
(Top View)**

A1	1	10	VIN+
A0	2	9	VIN–
Alert	3	8	V_{BUS}
SDA	4	7	GND
SCL	5	6	V_{S+}
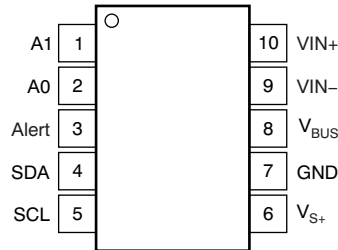
PIN DESCRIPTIONS

<table>
<tr><th colspan="2">MSOP-10
(DGS)</th><th rowspan="2"></th></tr>
<tr><th>PIN NO</th><th>NAME</th><th>DESCRIPTION</th></tr>
<tr><td>1</td><td>A1</td><td>Address pin. Connect to GND, SCL, SDA, or V_S. Table 7 shows pin settings and corresponding addresses.</td></tr>
<tr><td>2</td><td>A0</td><td>Address pin. Connect to GND, SCL, SDA, or V_S. Table 7 shows pin settings and corresponding addresses.</td></tr>
<tr><td>3</td><td>Alert</td><td>Multi-functional alert, open-drain output.</td></tr>
<tr><td>4</td><td>SDA</td><td>Serial bus data line, open-drain input/output.</td></tr>
<tr><td>5</td><td>SCL</td><td>Serial bus clock line, open-drain input.</td></tr>
<tr><td>6</td><td>V_{S+}</td><td>Power supply, 2.7V to 5.5V.</td></tr>
<tr><td>7</td><td>GND</td><td>Ground.</td></tr>
<tr><td>8</td><td>V_{BUS}</td><td>Bus voltage input.</td></tr>
<tr><td>9</td><td>VIN–</td><td>Negative differential shunt voltage. Connect to negative side of shunt resistor.</td></tr>
<tr><td>10</td><td>VIN+</td><td>Positive differential shunt voltage. Connect to positive side of shunt resistor.</td></tr>
</table>

REGISTER BLOCK DIAGRAM
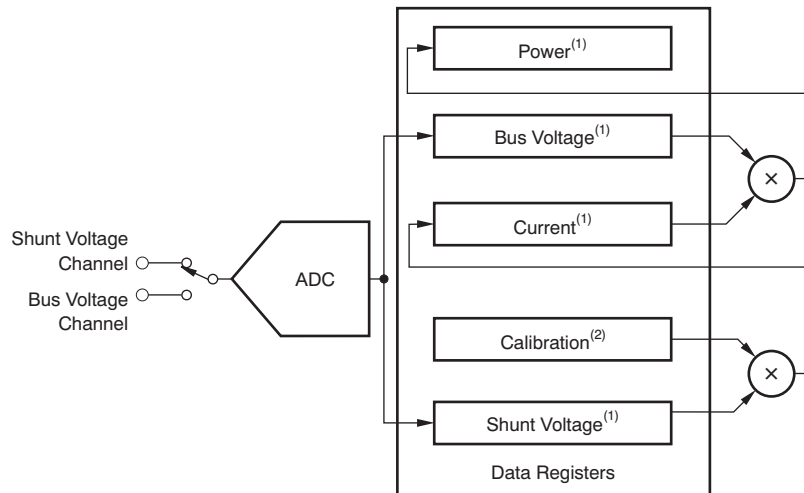
(1)   Read-only

(2)   Read/write

Figure 1. INA226 Register Block Diagram

INA226

TEXAS INSTRUMENTS

TYPICAL CHARACTERISTICS

At T_A = +25°C, V_S = +3.3V, VIN+ = 12V, V_{SENSE} = (VIN+ − VIN−) = 0mV, V_{BUS} = 12V, unless otherwise noted.

FREQUENCY RESPONSE

Figure 2.

**SHUNT INPUT OFFSET VOLTAGE
PRODUCTION DISTRIBUTION**

Figure 3.

**SHUNT INPUT OFFSET VOLTAGE
vs TEMPERATURE**

Figure 4.

**SHUNT INPUT COMMON-MODE REJECTION RATIO
vs TEMPERATURE**

Figure 5.

SHUNT INPUT GAIN ERROR PRODUCTION DISTRIBUTION
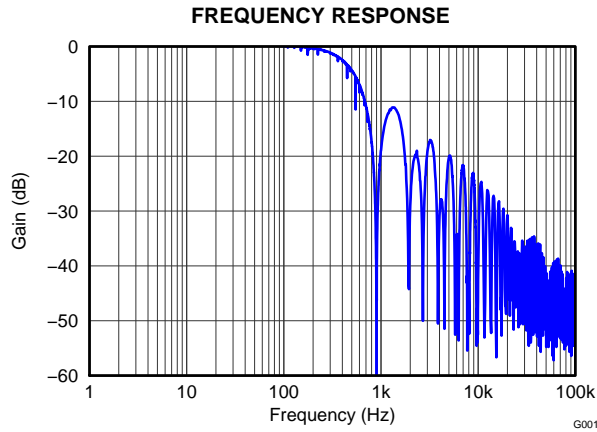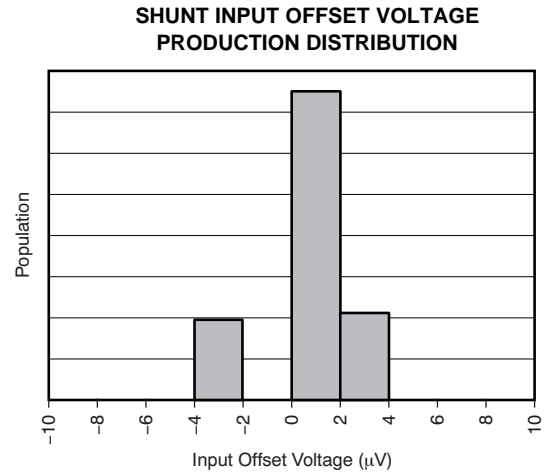
Figure 6.
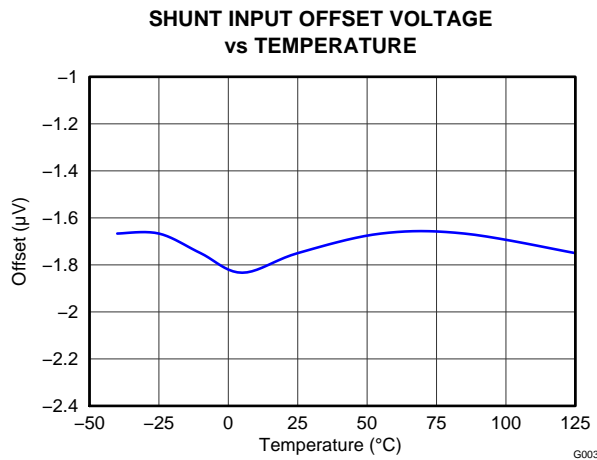
SHUNT INPUT GAIN ERROR vs TEMPERATURE
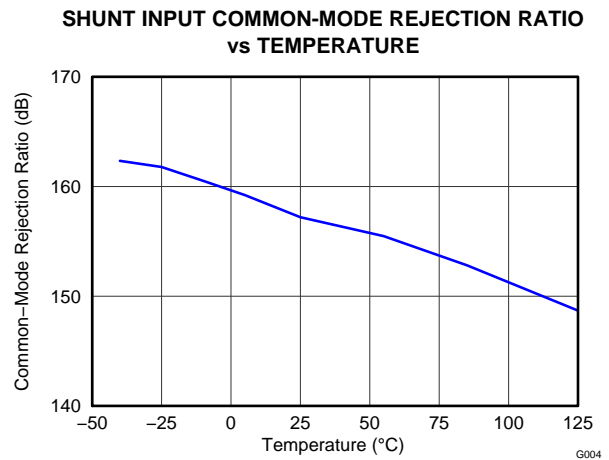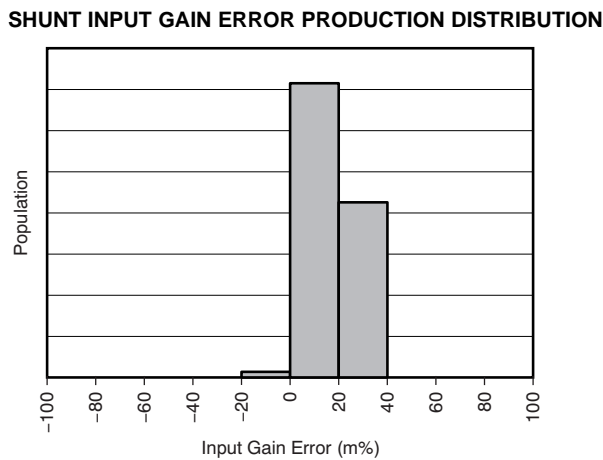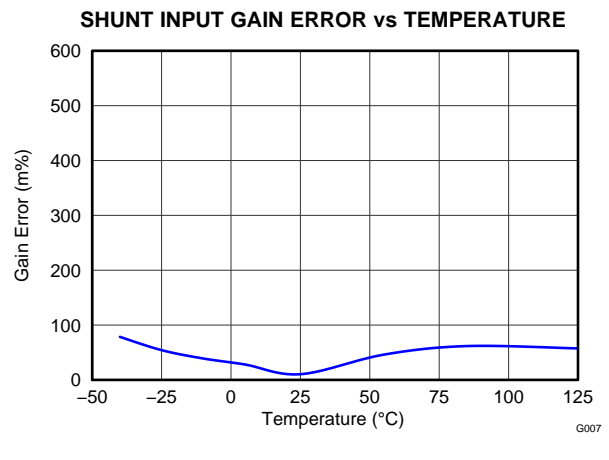
Figure 7.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = +3.3V, VIN+ = 12V, V_{SENSE} = (VIN+ − VIN−) = 0mV, V_{BUS} = 12V, unless otherwise noted.

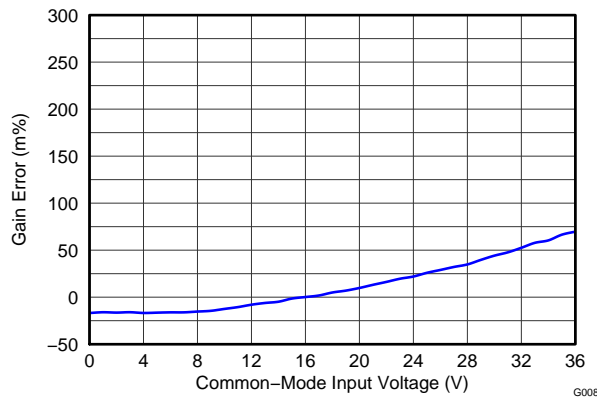**SHUNT INPUT GAIN ERROR
vs COMMON-MODE VOLTAGE**

Figure 8.
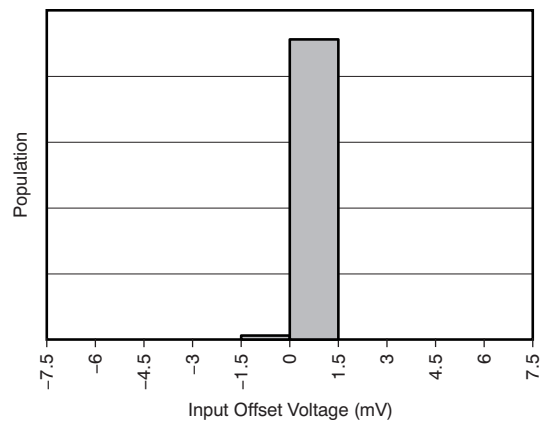
**BUS INPUT OFFSET VOLTAGE
PRODUCTION DISTRIBUTION**

Figure 9.
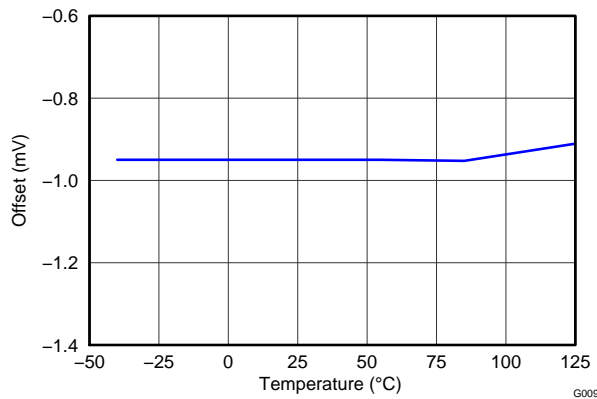
BUS INPUT OFFSET VOLTAGE vs TEMPERATURE

Figure 10.
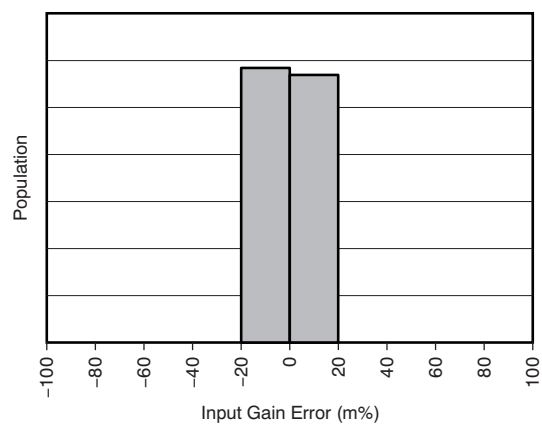
BUS INPUT GAIN ERROR PRODUCTION DISTRIBUTION

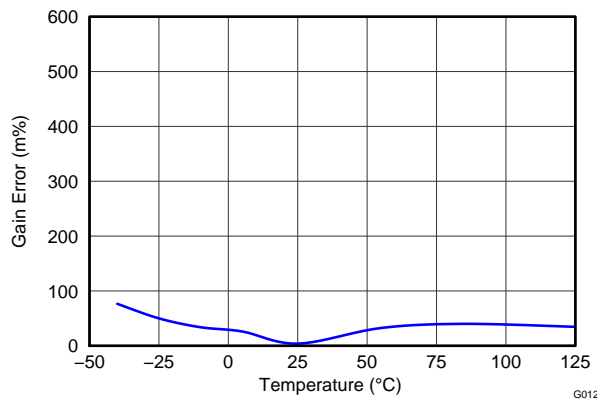**Figure 11.**

BUS INPUT GAIN ERROR vs TEMPERATURE

Figure 12.
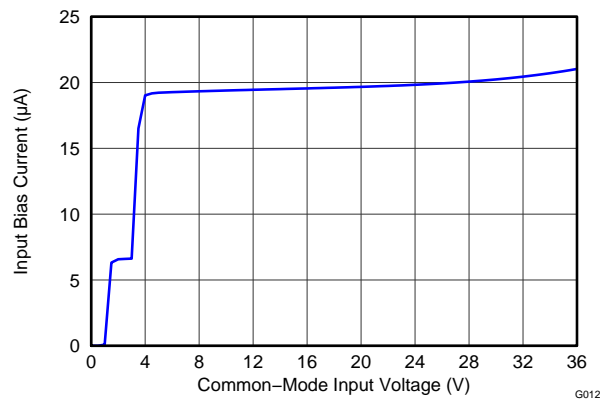
INPUT BIAS CURRENT vs COMMON-MODE VOLTAGE

Figure 13.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = +3.3V, VIN+ = 12V, V_{SENSE} = (VIN+ − VIN−) = 0mV, V_{BUS} = 12V, unless otherwise noted.

INPUT BIAS CURRENT vs TEMPERATURE

Figure 14.

INPUT BIAS CURRENT vs TEMPERATURE, SHUTDOWN

Figure 15.

ACTIVE I_Q vs TEMPERATURE

Figure 16.

SHUTDOWN I_Q vs TEMPERATURE

Figure 17.

ACTIVE I_Q vs I²C CLOCK FREQUENCY

Figure 18.

SHUTDOWN I_Q vs I²C CLOCK FREQUENCY

Figure 19.

Product Folder Link(s): *INA226*
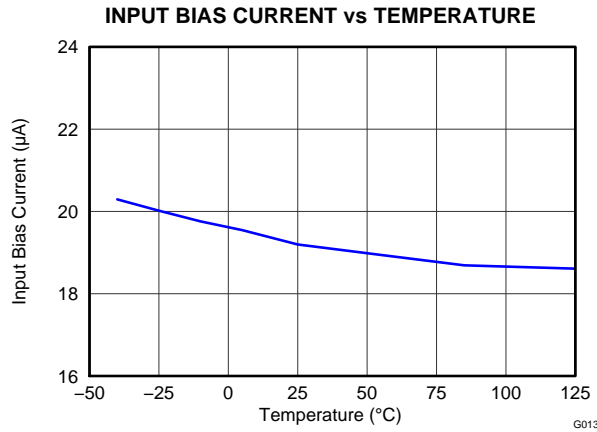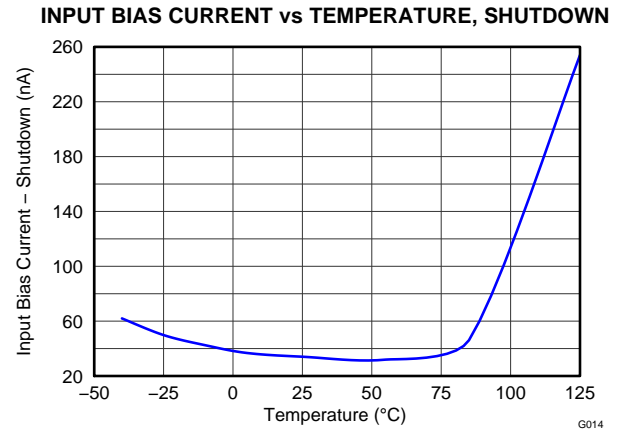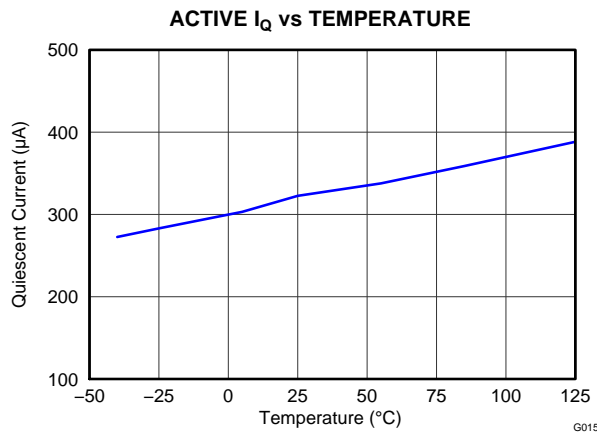
APPLICATION INFORMATION

The INA226 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 as well as 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 INA226.

INA226 TYPICAL APPLICATION

The front-page figure shows a typical application circuit for the INA226. Use a 0.1µF ceramic capacitor for power-supply bypassing, placed as closely as possible to the supply and ground pins.
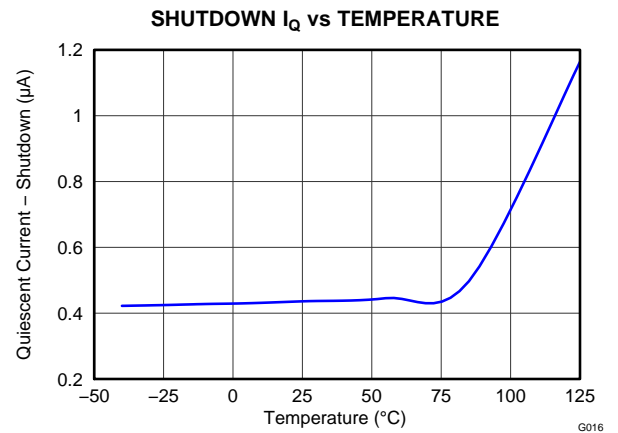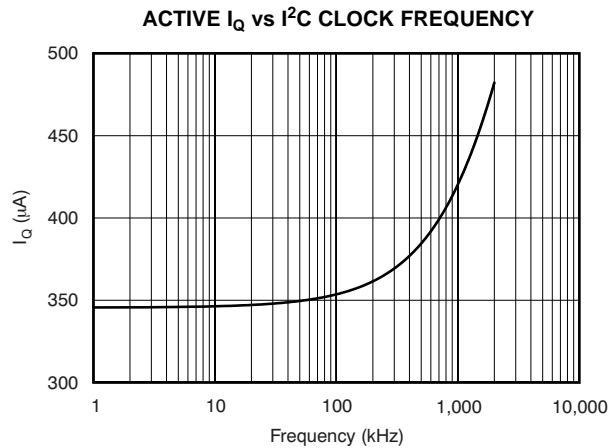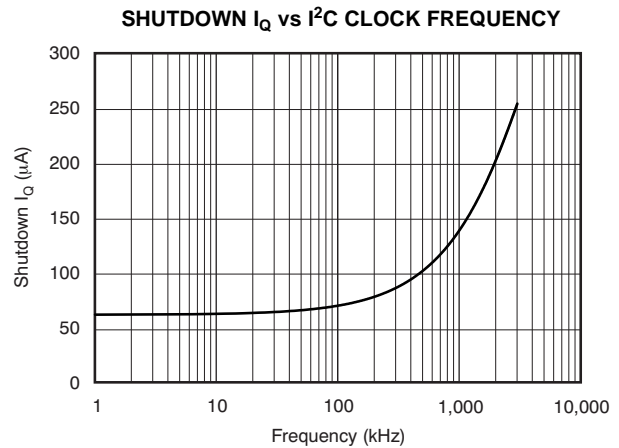
BASIC ADC FUNCTIONS

The INA226 performs two measurements on the power-supply bus of interest. The voltage developed from the load current that flows through a shunt resistor creates a shunt voltage that is measured at the VIN+ and VIN– pins. The device can also measure the power supply bus voltage by connecting this voltage to the V_{BUS} pin. The differential shunt voltage is measured with respect to the VIN– pin while the bus voltage is measured with respect to ground.

The INA226 is typically powered by a separate supply that can range from 2.7V to 5.5V. The bus that is being monitored can range in voltage from 0V to 36V. It is important to note here that based on the fixed 1.25mV LSB for the bus voltage register that a full-scale register would result in a 40.96V value. **The actual voltage that is applied to the input pins of the INA226 should not exceed 36V.** There are no special considerations for power-supply sequencing because the common-mode input range and power-supply voltage are independent of each other; therefore, the bus voltage can be present with the supply voltage off, and vice-versa.

As noted, the INA226 takes two measurements, shunt voltage and bus voltage. It then converts these measurements to current, based on the Calibration Register value, and then calculates power. Refer to the Configure/Measure/Calculate Example section for additional information on programming the Calibration Register.

INA226 имеет два режима работы, непрерывный и запускаемый, которые определяют, как работает АЦП после этих преобразований. Когда INA226 находится в нормальном рабочем режиме (то есть биты MODE регистра конфигурации установлены на «111»), он непрерывно преобразует показания напряжения шунта, а затем показания напряжения шины.
После считывания напряжения шунта рассчитывается текущее значение (на основании уравнения 3). Это текущее значение затем используется для расчета результата мощности (с использованием уравнения 4). Эти значения впоследствии сохраняются в аккумуляторе, и последовательность измерений / вычислений повторяется до тех пор, пока не будет достигнуто число средних значений, установленных в Регистре конфигурации. После каждой последовательности текущий набор измеренных и рассчитанных значений

The Mode control in the Configuration Register also permits selecting modes to convert only the shunt voltage or the bus voltage in order to further allow the user to configure the monitoring function to fit the specific application requirements.

All current and power calculations are performed in the background and do not contribute to conversion time.

Управление режимом в Регистре конфигурации также позволяет выбирать режимы для преобразования только напряжения шунта или напряжения шины, чтобы дополнительно позволить пользователю настроить функцию мониторинга в соответствии с конкретными требованиями приложения. Все расчеты тока и мощности выполняются в фоновом режиме и не влияют на время преобразования.
В запущенном режиме запись любого из запущенных режимов преобразования в регистр конфигурации (т. Е. Биты MODE регистра конфигурации установлены в «001», «010» или «011») запускает однократное преобразование. Это действие производит один набор измерений; таким образом, чтобы инициировать другое однократное преобразование, регистр конфигурации должен быть записан во второй раз, даже если режим не изменяется.
    В дополнение к двум рабочим режимам (непрерывный и триггерный) INA226 также имеет режим отключения питания, который уменьшает ток покоя и отключает ток на входах INA226, уменьшая влияние источника питания, когда устройство не используется. Полное восстановление из режима выключения требует 40 мс. Регистры INA226 могут записываться и считываться, когда устройство находится в режиме отключения питания. Устройство остается в режиме отключения до тех пор, пока один из параметров активных режимов не будет записан в регистр конфигурации.
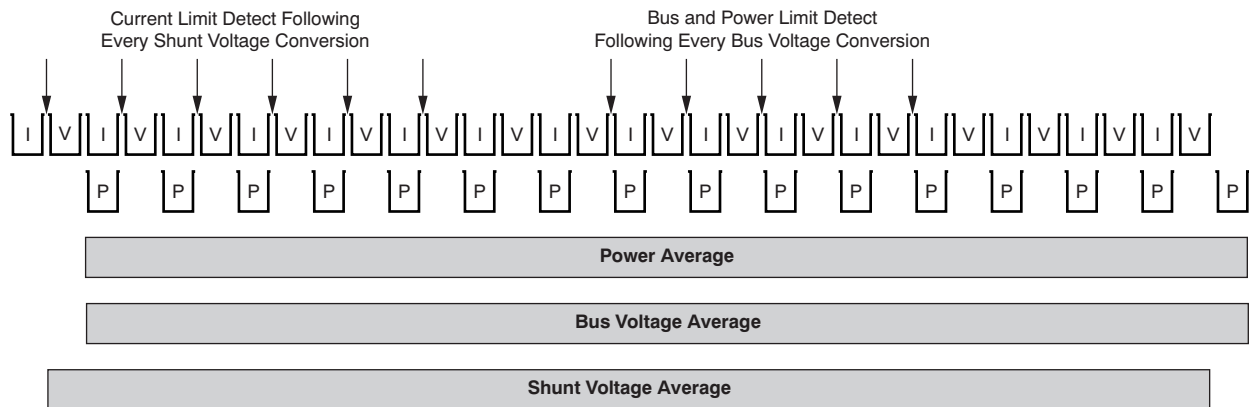
INA226 имеет программируемое время преобразования для измерения напряжения шунта и напряжения шины. Время преобразования для этих измерений может быть выбрано от 140 мкс до 8,244 мс. Настройки времени преобразования, наряду с программируемым режимом усреднения, позволяют INA226 быть настроенным на оптимизировать доступные временные требования в данном приложении. Например, если система требует, чтобы данные были считывать каждые 5 мсек, INA226 может быть настроен с временем преобразования 588 мкс и режимом усреднения 4. Эта конфигурация приводит к обновлению данных примерно каждые 4,7 мс. INA226 также может быть настроен с другой настройкой времени преобразования для измерений напряжения на шунте и шине. Этот тип подхода распространен в приложениях, где напряжение на шине имеет тенденцию быть относительно стабильным. Эта ситуация может позволить уменьшить время, сфокусированное на измерении напряжения на шине, относительно измерения напряжения на шунте.

Время преобразования шунтирующего напряжения может быть установлено равным 4,156 мс, а время преобразования напряжения шины - 588 мкс, а режим усреднения - 1. Эта конфигурация также приводит к обновлению данных приблизительно каждые 4,7 мс. Есть компромиссы, связанные с настройками времени конвертации и используемого режима усреднения. Функция усреднения может значительно повысить точность измерения за счет эффективной фильтрации сигнала. Такой подход позволяет INA226 уменьшить любой шум в измерении, который может быть вызван шумовой связью в сигнале. Большее число средних значений позволяет INA226 быть более эффективным в снижении шумовой составляющей измерения. Выбранные времена преобразования также могут влиять на точность измерений. Этот эффект можно увидеть на рисунке 21. Здесь показано несколько времен преобразования, чтобы проиллюстрировать влияние шума на измерение. Чтобы достичь максимально возможного измерения точности, следует использовать комбинацию самых длинных допустимых времен преобразования и наибольшего числа средних значений в зависимости от требований системы к синхронизации.
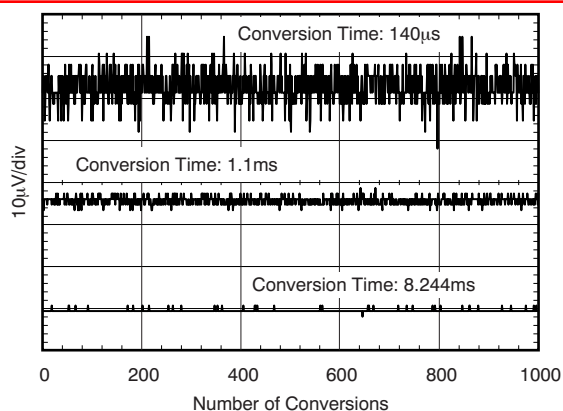
Figure 21. Noise vs Conversion Time

Product Folder Link(s): *INA226*

Filtering and Input Considerations

Measuring current is often noisy, and such noise can be difficult to define. The INA226 offers several options for filtering by allowing the conversion times and number of averages to be selected independently in the Configuration Register. The conversion times can be set independently for the shunt voltage and bus voltage measurements to allow added flexibility in configuring the monitoring of the power-supply bus.

The internal ADC is based on a delta-sigma ($\Delta\Sigma$) front-end with a 500kHz (±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 managed by incorporating filtering at the input of the INA226. The high frequency enables the use of low-value series resistors on the filter with negligible effects on measurement accuracy. In general, filtering the INA226 input is only necessary if there are transients at exact harmonics of the 500kHz (±30%) sampling rate (greater than 1MHz). Filter using the lowest possible series resistance (typically 10Ω or less) and a ceramic capacitor. Recommended values for this capacitor are 0.1µF to 1.0µF. Figure 22 shows the INA226 with an additional filter added at the input.

Overload conditions are another consideration for the INA226 inputs. The INA226 inputs are specified to tolerate 40V 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). Keep in mind that removing a short to ground can result in inductive kickbacks that could exceed the 40V differential and common-mode rating of the INA226. Inductive kickback voltages are best controlled 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 INA226 in systems where large currents are available. Testing has demonstrated that the addition of 10Ω resistors in series with each input of the INA226 sufficiently protect the inputs against this dV/dt failure up to the 40V rating of the INA226. Selecting these resistors in the range noted has minimal effect on accuracy.
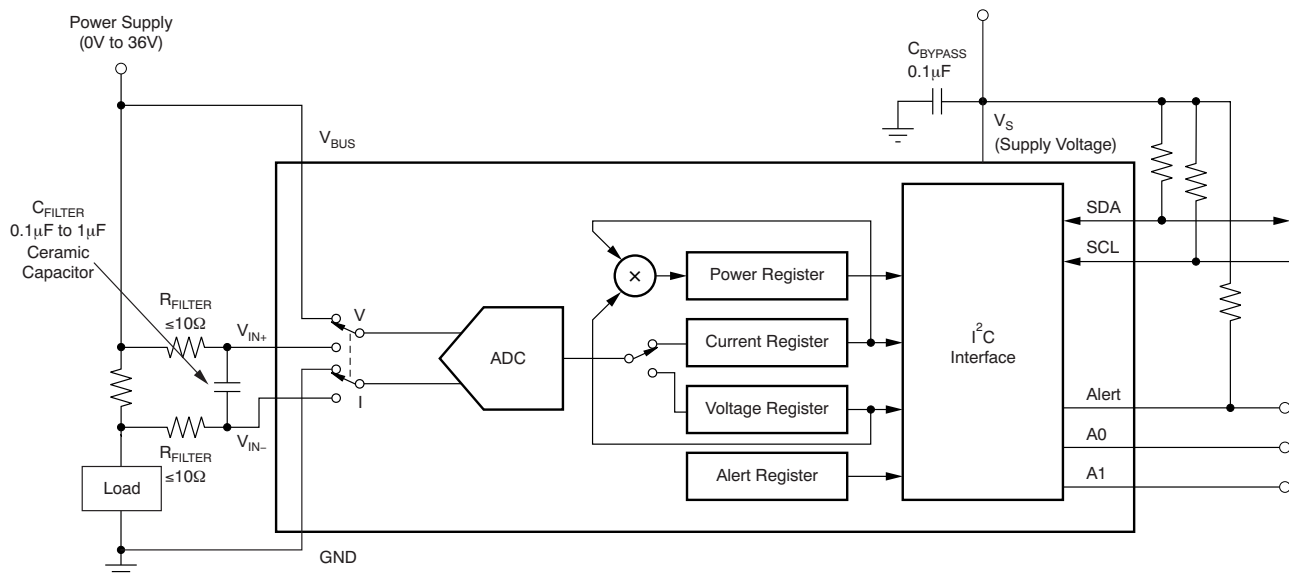
Figure 22. INA226 with Input Filtering

INA226 имеет единственный регистр предела оповещения, 07h, который позволяет запрограммировать вывод оповещения для ответа на одно пользовательское событие или на уведомление о готовности к преобразованию, если это необходимо. Регистр «Маска / Разрешение» позволяет пользователю выбрать одну из пяти доступных функций для контроля и / или установить бит готовности к преобразованию для управления реакцией контакта «Предупреждение». Основываясь на отслеживаемой функции, пользователь затем вводит значение в регистр предела оповещения, чтобы установить соответствующее пороговое значение, которое устанавливает вывод оповещения. Вывод оповещения позволяет контролировать одну из нескольких доступных функций оповещения, чтобы определить, превышен ли определенный пользователем порог. Пять функций оповещения, которые можно отслеживать:
• Превышение предела напряжения шунта (SOL)
• Напряжение шунта под лимитом (SUL)
• Превышение предела напряжения шины (BOL)
• Напряжение шины ниже предела (BUL)
• Power Over Limit (POL)

Контакт Alert является выходом с открытым стоком. Этот вывод активируется, когда функция оповещения, выбранная в регистре «Маска / Разрешение», превышает значение, запрограммированное в регистре предела оповещения. Только одна из этих функций оповещения может быть включена и отслеживаться одновременно. Если включено несколько функций оповещения, выбранная функция в старшей значащей битовой позиции имеет приоритет и реагирует на значение регистра предела оповещения. Например, если выбраны оба параметра: «Предел превышения напряжения шунта» и «Ограничение напряжения шунта», вывод оповещения срабатывает, когда регистр превышения шунта напряжения превышает значение в регистре предела оповещения.

The Conversion Ready state of the device can also be monitored at the Alert pin to inform the user when the device has completed the previous conversion and is ready to begin a new conversion. Conversion Ready can be monitored at the Alert pin along with one of the alert functions. If an alert function and the Conversion Ready are both enabled to be monitored at the Alert pin, after the Alert pin is asserted, the Mask/Enable register must be read following the alert to determine the source of the alert. By reading the Conversion Ready Flag (CVRF), bit D3, and the Alert Function Flag (AFF), bit D4 in the Mask/Enable register, the source of the alert can be determined. If the conversion ready feature is not desired, and the CNVR bit is not set, the Alert pin only responds to an exceeded alert limit based on the alert function enabled.

If the Alert function is not used, the Alert pin can be left floating without impacting the operation of the device.

Refer to Figure 20 to see the relative timing of when the value in the Alert Limit Register is compared to the corresponding converted value. For example, if the alert function that is enabled is Shunt Voltage Over Limit (SOL), following every shunt voltage conversion the value in the Alert Limit Register is compared to the measured shunt voltage to determine if the measurements has exceeded the programmed limit. The AFF, bit 4 of the Mask/Enable Register, asserts high any time the measured voltage exceeds the value programmed into the Alert Limit Register. In addition to the AFF being asserted, the Alert pin is asserted based on the Alert Polarity Bit (APOL, bit 1 of the Mask/Enable Register). If the Alert Latch is enabled, the AFF and Alert pin remain asserted until either the Configuration Register is written to or the Mask/Enable Register is read.

The Bus Voltage alert functions compare the measured bus voltage to the Alert Limit Register following every bus voltage conversion and assert the AFF bit and Alert pins if the limit threshold is exceeded.

The Power Over Limit alert function is also compared to the calculated power value following every bus voltage measurement conversion and asserts the AFF bit and Alert pins if the limit threshold is exceeded.

ПРОГРАММИРОВАНИЕ INA226
Важным аспектом INA226 является то, что он не обязательно измеряет ток или мощность. INA226 измеряет как дифференциальное напряжение, подаваемое между входными контактами VIN + и VIN-, так и напряжение, подаваемое на контакт VBUS. Чтобы INA226 мог сообщать значения тока и мощности, пользователь должен запрограммировать разрешение регистра тока и значение шунтирующего резистора, присутствующего в приложении, для создания дифференциального напряжения, приложенного между входными контактами. Внутренний регистр питания установлен в 25 раз больше запрограммированный Current_LSB. И значение Current_LSB, и значение шунтирующего резистора используются при расчете значения регистра калибровки, который INA226 использует для вычисления соответствующих значений тока и мощности на основе измеренных напряжений шунта и шины.

Регистр калибровки рассчитывается на основе уравнения 1. Это уравнение включает в себя термин Current_LSB. Это запрограммированное значение для LSB для текущего регистра. Это значение, которое пользователь будет использовать для преобразования значения в регистре тока в фактический ток в амперах. Наивысшее разрешение для регистра тока можно получить, используя наименьшее допустимое значение Current_LSB на основе максимального ожидаемого тока, как показано в уравнении 2. Хотя это значение даст самое высокое разрешение, обычно выбирают значение для Current_LSB с точностью до ближайшего округлите число выше этого значения, чтобы упростить преобразование регистра тока и регистра мощности в амперы и ватты соответственно. Термин RSHUNT - это значение внешнего шунта,

$$CAL = \frac{0.00512}{Current\_LSB \cdot R_{SHUNT}}$$

(1)

$$Current\_LSB = \frac{Maximum\ Expected\ Current}{2^{15}}$$

(2)

После того, как регистр калибровки запрограммирован, регистр тока и регистр мощности будут соответственно обновляться на основе соответствующих измерений напряжения шунта и напряжения шины. Пока не запрограммирован регистр калибровки, регистры тока и мощности остаются на нуле.

CONFIGURE/MEASURE/CALCULATE EXAMPLE

В этом примере, показанном на рисунке 23, номинальная нагрузка 10 А создает дифференциальное напряжение 20 мВ на шунтирующем резисторе 2 мОм. Напряжение на шине для INA226 измеряется на входном выводе внешней шины V, который в этом примере подключен к выводу VIN– для измерения уровня напряжения, подаваемого на нагрузку. В этом примере вывод V BUS измеряет менее 12 В, поскольку напряжение на выводе VIN– составляет 11,98 В в результате падения напряжения на шунтирующем резисторе.
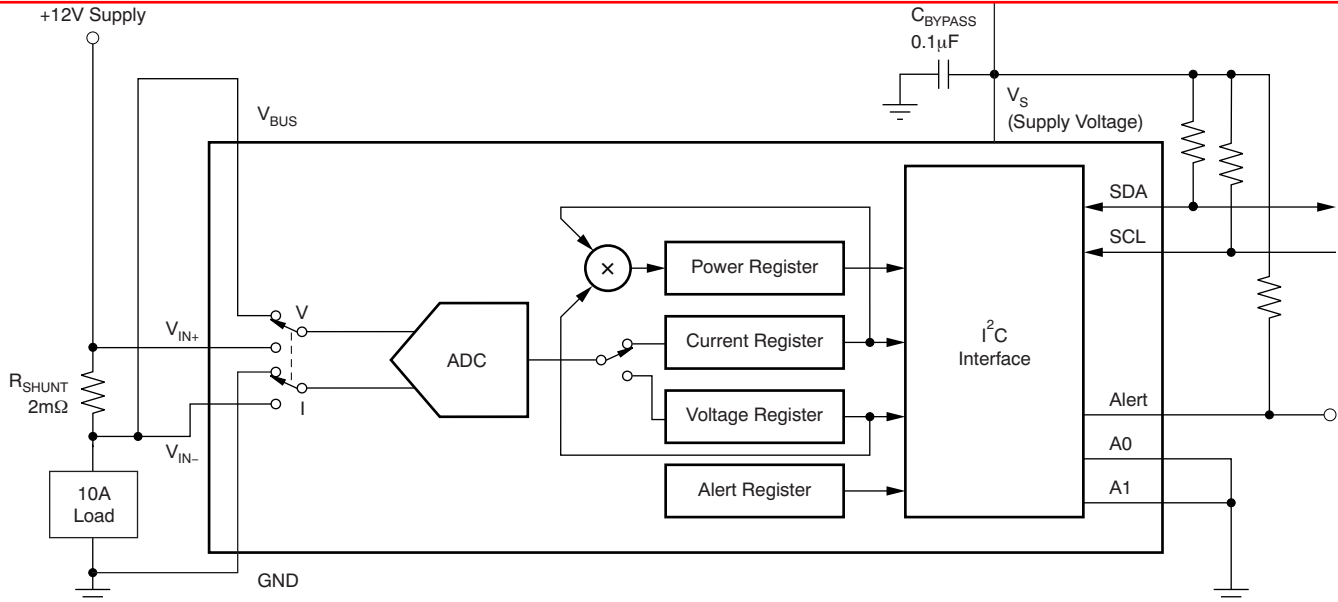
Для этого примера, предполагая, что максимальный ожидаемый ток 15A, Current_LSB рассчитывается как 457,7 мкА / бит с использованием уравнения 2. Использование значения Current_LSB в 500 мкА / бит или 1 мА / бит значительно упростит преобразование из регистра тока и Регистр мощности для ампер и ватт. В этом примере для текущего LSB было выбрано значение 1 мА / бит. Использование этого значения для Current_LSB обменивает небольшое разрешение на упрощение процесса преобразования на стороне пользователя. Использование уравнения 1 в этом примере с текущим LSB 1 мА / бит и шунтирующим резистором 2 мОм приводит к значению регистра калибровки 2560 или A00h.

Current Register (04h) затем рассчитывается путем умножения десятичного значения содержимого регистра шунтового напряжения на десятичное значение регистра калибровки, а затем деления на 2048, как показано в уравнении 3. Для этого примера регистр напряжения шунта содержит значение 8000, которое умножается на значение регистра калибровки 2560, а затем делится на 2048, чтобы получить десятичное значение для текущего регистра 10000 или 2710h. Умножение этого значения на 1 мА / бит приводит к исходному уровню 10 А, указанному в примере.

$$Current = \frac{ShuntVoltage \cdot CalibrationRegister}{2048}$$

(3)

LSB для регистра напряжения шины (02h) - это фиксированный 1,25 мВ / бит, что означает, что 11,98 В, присутствующие на выводе V BUS, приводят к значению регистра 2570h или десятичному эквиваленту 9584. Обратите внимание, что MSB Регистр напряжения шины всегда равен нулю, поскольку вывод V BUS может измерять только положительные напряжения.

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Регистр мощности (03h) затем рассчитывается путем умножения десятичного значения регистра тока 10000 на десятичное значение регистра напряжения шины 9584, а затем деления на 20000, как определено в уравнении 4. Для этого примера результат для регистра мощности равен 12B8h, или десятичный эквивалент 4792. Умножение этого результата на LSB мощности (в 25 раз превышающее [1 × 10–3 Current LSB]) приводит к вычислению мощности (4792 × 25 мВт / бит) или 119,82 Вт. Мощность LSB имеет фиксированное отношение к текущему LSB от 25 Вт / бит до 1 А / бит. В этом примере запрограммированный LSB тока 1 мА / бит приводит к тому, что LSB мощности составляет 25 мВт / бит. Это соотношение внутренне запрограммировано, чтобы гарантировать, что масштаб вычисления мощности находится в допустимом диапазоне. Ручной расчет для мощности, подаваемой на нагрузку, будет использовать напряжение шины 11,98 В (12 В СМ - падение шунта 20 мВ), умноженное на ток нагрузки 10 А, чтобы получить результат 119,8 Вт.

$$Power = \frac{Current \bullet BusVoltage}{20,000}$$

(4)

Table 1 shows the steps for configuring, measuring, and calculating the values for current and power for this device.

Table 1. Configure/Measure/Calculate Example[1]

STEP #	REGISTER NAME	ADDRESS	CONTENTS	DEC	LSB	VALUE
Step 1	Configuration	00h	4127h	—	—	—
Step 2	Shunt	01h	1F40h	8000	2.5µV	20mV
Step 3	Bus	02h	2570h	9584	1.25mV	11.98V
Step 4	Calibration	05h	A00h	2560	—	—
Step 5	Current	04h	2710	10000	1mA	10A
Step 6	Power	03h	12B8h	4792	25mW	119.82W

(1)   Conditions: Load = 10A, V_{CM} = 12V, R_{SHUNT} = 2mΩ, and V_{BUS} = 12V.

PROGRAMMING THE INA226 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 would yield the highest resolution based using the previously calculated minimum current LSB in the equation for the Calibration Register. 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 value for each corresponding register. After these choices have been made, the Calibration Register also offers possibilities for end user system-level calibration. By physically measuring the current with an external ammeter, the exact current is known. The value of the Calibration Register can then be adjusted based on the measured current result of the INA226 to cancel the total system error as shown in Equation 5.

$$Corrected\_Full\_Scale\_Cal = trunc\left[\frac{Cal \times MeasShuntCurrent}{INA226\_Current}\right]$$

(5)

Simple Current Shunt Monitor Usage
(No Programming Necessary)

The INA226 can be used without any programming if it is only necessary to read a shunt voltage drop and bus voltage with the default power-on reset configuration and continuous conversion of shunt and bus voltage.

Without programming the INA226 Calibration Register, the device is unable to provide either a valid current or power value, because these outputs are both derived using the values loaded into the Calibration Register.

Default INA226 Settings

The default power-up states of the registers are shown in the INA226 Register Descriptions section of this data sheet. These registers are volatile, and if programmed to a value other than the default values shown in Table 2, they must be re-programmed at every device power-up. Detailed information on programming the Calibration Register specifically is given in the Configure/Measure/Calculate Example section and calculated based on Equation 1.

REGISTER INFORMATION

The INA226 uses a bank of registers for holding configuration settings, measurement results, minimum/maximum limits, and status information. Table 2 summarizes the INA226 registers; refer to Figure 1 for an illustration of the registers.

Table 2. Summary of Register Set Резюме набора регистров

POINTER ADDRESS			POWER-ON RESET		
HEX	REGISTER NAME	FUNCTION	BINARY	HEX	TYPE[1]
0	Configuration Register	All-register reset, shunt voltage and bus voltage ADC conversion times and averaging, operating mode.	01000001 00100111	4127	R/$\overline{W}$
1	Shunt Voltage	Shunt voltage measurement data.	00000000 00000000	0000	R
2	Bus Voltage	Bus voltage measurement data.	00000000 00000000	0000	R
3	Power[2]	Contains the value of the calculated power being delivered to the load.	00000000 00000000	0000	R
4	Current[2]	Contains the value of the calculated current flowing through the shunt resistor.	00000000 00000000	0000	R
5	Calibration	Sets full-scale range and LSB of current and power measurements. Overall system calibration.	00000000 00000000	0000	R/$\overline{W}$
6	Mask/Enable	Alert configuration and conversion ready flag.	00000000 00000000	0000	R/$\overline{W}$
7	Alert Limit	Contains the limit value to compare to the selected Alert function.	00000000 00000000	0000	R/$\overline{W}$
FF	Die ID	Contains unique die identification number.	ASCII	ASCII	R

(1) Type: **R** = Read-Only, **R/$\overline{W}$** = Read/Write.
(2) The Current Register defaults to '0' because the Calibration Register defaults to '0', yielding a zero current and power value until the Calibration Register is programmed.

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REGISTER DETAILS

Все 16-битные регистры INA226 представляют собой два 8-битных байта через интерфейс I 2 C.

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	—	—	—	AVG2	AVG1	AVG0	$V_{BUS}CT2$	$V_{BUS}CT1$	$V_{BUS}CT0$	$V_{SH}CT2$	$V_{SH}CT1$	$V_{SH}CT0$	MODE3	MODE2	MODE1
POR VALUE	0	1	0	0	0	0	0	1	0	0	1	0	0	1	1	1

Настройки регистра конфигурации управляют режимами работы INA226. Этот регистр управляет настройками времени преобразования для измерений напряжения шунта и напряжения на шине, а также используемого режима усреднения. Режим работы, который контролирует, какие сигналы выбираются для измерения, также программируется в Регистре конфигурации. Регистр конфигурации можно прочитать в любое время, не влияя и не влияя на настройки устройства или выполняемое преобразование. Запись в регистр конфигурации остановит все выполняющиеся преобразования до записи последовательность завершена, в результате чего начинается новое преобразование на основе нового содержимого регистра конфигурации. Это предотвращает любую неопределенность в условиях,

Bit Descriptions

RST:
Bit 15

Установка этого бита в «1» приводит к сбросу системы, который аналогичен сбросу при включении питания. Сбрасывает все регистры к значениям по умолчанию; этот бит values; this bit self-clears.

AVG:
Bits 9–11

Averaging Mode

Устанавливает количество образцов, которые будут собраны и усреднены вместе. В таблице 3 приведены настройки битов AVG и соответствующее количество средних для каждого бита.

Table 3. AVG Bit Settings[11:9][1]

AVG2 D11	AVG1 D10	AVG0 D9	NUMBER OF AVERAGES
0	0	0	1
0	0	1	4
0	1	0	16
0	1	1	64
1	0	0	128
1	0	1	256
1	1	0	512
1	1	1	1024

[1] Затененные значения являются значениями по умолчанию.

V_{BUS} CT: **Bus Voltage Conversion Time**

Bits 6–8   Устанавливает время преобразования для измерения напряжения на шине. В таблице 4 показаны параметры битов VBUS CT и соответствующие времена

Table 4. V_{BUS} CT Bit Settings [8:6] [1]

V_{BUS} CT2 D8	V_{BUS} CT1 D7	V_{BUS} CT0 D6	CONVERSION TIME
0	0	0	140µs
0	0	1	204µs
0	1	0	332µs
0	1	1	588µs
1	0	0	1.1ms
1	0	1	2.116ms
1	1	0	4.156ms
1	1	1	8.244ms

(1)   Shaded values are default.

V_{SH} CT: **Shunt Voltage Conversion Time**

Bits 3–5   Устанавливает время преобразования для измерения напряжения шунта. В таблице 5 показаны параметры битов VSH CT и соответствующие времена преобразования для

Table 5. V_{SH} CT Bit Settings [5:3][1]

V_{SH} CT2 D5	V_{SH} CT1 D4	V_{SH} CT0 D3	CONVERSION TIME
0	0	0	140µs
0	0	1	204µs
0	1	0	332µs
0	1	1	588µs
1	0	0	1.1ms
1	0	1	2.116ms
1	1	0	4.156ms
1	1	1	8.244ms

(1)   Shaded values are default.

MODE: **Operating Mode**

Bits 0–2   Выбирает непрерывный, сработавший или отключенный режим работы. По умолчанию эти биты имеют режим непрерывного шунта и измерения шины. Настройки режима

Table 6. Mode Settings [2:0][1]

MODE3 D2	MODE2 D1	MODE1 D0	MODE
0	0	0	Power-Down Выключить
0	0	1	Shunt Vo Напряжение шунта, непрерывное
0	1	0	Bus Voltage, Triggered
0	1	1	Shunt and Bus, Triggered
1	0	0	Power-Down
1	0	1	Shunt Напряжение шунта, срабатывание
1	1	0	Bus Voltage, Continuous
1	1	1	Shunt and Bus, Continuous

(1)   Shaded values are default.

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РЕЗУЛЬТАТЫ ВЫХОДА ДАННЫХ
Регистр напряжения шунта 01h (только для чтения)
Регистр напряжения шунта хранит текущее значение напряжения шунта, V SHUNT. Отрицательные числа представлены в формате двойного дополнения. Создайте двойное дополнение отрицательного числа, добавив двоичное число абсолютного значения и добавив 1. Расширьте знак, обозначающий отрицательное число, установив MSB = '1'.

Example: For a value of $V_{SHUNT} = -80mV$:

1. Take the absolute value: 80mV   Возьмите абсолютное значение: 80 мВ.
2. Translate this number to a whole decimal number (80mV ÷ 2.5µV) = 32000
3. Convert this number to binary = 111 1101 0000 0000
4. Complement the binary result = 000 0010 1111 1111
5. Add '1' to the complement to create the twos complement result = 000 0011 0000 0000
6. Extend the sign and create the 16-bit word: 1000 0011 0000 0000 = 8300h

Если усреднение включено, в этом регистре отображается усредненное значение. Полный диапазон = 81,92 мВ (десятичный = 7FFF); LSB: 2,5 мкВ.

BIT #	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
BIT NAME	SIGN	SD14	SD13	SD12	SD11	SD10	SD9	SD8	SD7	SD6	SD5	SD4	SD3	SD2	SD1	SD0
POR VALUE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Bus Voltage Register 02h (Read-Only)[1] Регистр напряжения шины 02h (только чтение) (1)

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

If averaging is enabled, this register displays the averaged value. Full-scale range = 40.96V (decimal = 7FFF); LSB = 1.25mV.

BIT #	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
BIT NAME	—	BD14	BD13	BD12	BD11	BD10	BD9	BD8	BD7	BD6	BD5	BD4	BD3	BD2	BD1	BD0
POR VALUE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(1)   D15 is always zero because bus voltage can only be positive.

Power Register 03h (Read-Only)

If averaging is enabled, this register displays the averaged value.

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 LSB is internally programmed to equal 25 times the programmed value of the Current_LSB.

The Power Register records power in watts by multiplying the decimal values of the current register with the decimal value of the bus voltage register according to Equation 4.

Current Register 04h (Read-Only)

Если усреднение включено, этот регистр отображает усредненное значение.

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

Значение регистра тока рассчитывается путем умножения десятичного значения в регистре шунтового напряжения на десятичное значение регистра калибровки в соответствии с уравнением 3.

Calibration Register 05h (Read/Write)

Этот регистр обеспечивает INA226 значением шунтирующего резистора, который присутствовал для создания измеренного дифференциального напряжения. Он также устанавливает разрешение текущего регистра. Текущий LSB и LSB мощности устанавливаются посредством программирования этого регистра. Этот регистр также подходит для использования в общей калибровке системы. См. Пример конфигурации /

BIT #	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
BIT NAME	—	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

Mask/Enable 06h (Read/Write)

Регистр маски / включения выбирает функцию, которая включена для управления выводом предупреждения, а также то, как этот вывод работает. Если задействовано несколько функций, функция предупреждения о положении самого старшего бита (D11-D15) имеет приоритет и реагирует на регистр предела предупреждения.

BIT #	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
BIT NAME	SOL	SUL	BOL	BUL	POL	CNVR	—	—	—	—	—	AFF	CVRF	OVF	APOL	LEN
POR VALUE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SOL: **Shunt Voltage Over-Voltage**

Bit 15   Установка этого бита в высокий уровень конфигурирует вывод предупреждения, который будет выдан, когда регистр шунтирующего напряжения превышает значение в регистре

SUL: **Shunt Voltage Under-Voltage**

Bit 14   Setting this bit high configures the Alert pin to be asserted when the Shunt Voltage Register drops below the value in the Alert Limit Register.

BOL: **Bus Voltage Over-Voltage**

Bit 13   Setting this bit high configures the Alert pin to be asserted when the Bus Voltage Register exceeds the value in the Alert Limit Register.

BUL: **Bus Voltage Under-Voltage**

Bit 12   Setting this bit high configures the Alert pin to be asserted when the Bus Voltage Register drops below the value in the Alert Limit Register.

POL: **Over-Limit Power**

Bit 11   Setting this bit high configures the Alert pin to be asserted when the Power Register exceeds the value in the Alert Limit Register.

CNVR: **Conversion Ready**

Bit 10   Setting this bit high configures the Alert pin to be asserted when the Conversion Ready Flag, Bit 3, is asserted indicating that the device is ready for the next conversion.

AFF:	Alert Function Flag
Bit 4	While only one Alert Function can be monitored at the Alert pin at a time, the Conversion Ready can also be enabled to assert the Alert pin. Reading the Alert Function Flag following an alert allows the user to determine if the Alert Function was the source of the Alert.
	When the Alert Latch Enable bit is set to Latch mode, the Alert Function Flag clears only when the Mask/Enable Register is read. When the Alert Latch Enable bit is set to Transparent mode, the Alert Function Flag is cleared following the next conversion that does not result in an Alert condition.

CVRF:	Conversion Ready Flag
Bit 3	Although the INA226 can be read at any time, and the data from the last conversion is available, the Conversion Ready bit is provided to help coordinate one-shot or triggered conversions. The Conversion bit is set after all conversions, averaging, and multiplications are complete. Conversion Ready clears under the following conditions:
	1.) Writing to the Configuration Register (except for Power-Down or Disable selections)
	2.) Reading the Mask/Enable Register

OVF:	Math Overflow Flag
Bit 2	This bit is set to '1' if an arithmetic operation resulted in an overflow error. It indicates that current and power data may be invalid.

APOL:	Бит полярности предупреждения; устанавливает полярность контакта
Bit 1	1 = Inverted (active-high open collector)
	0 = Normal (active-low open collector) (default)

LEN:	Alert Latch Enable; configures the latching feature of the Alert pin and Flag bits.
Bit 0	1 = Latch enabled
	0 = Transparent (default)
	When the Alert Latch Enable bit is set to Transparent mode, the Alert pin and Flag bits will reset to their idle states when the fault has been cleared. When the Alert Latch Enable bit is set to Latch mode, the Alert pin and Flag bits will remain active following a fault until the Mask/Enable Register has been read.

Alert Limit 07h (Read/Write)

The Alert Limit Register contains the value used to compare to the register selected in the Mask/Enable Register to determine if a limit has been exceeded.

BIT #	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
BIT NAME	AUL15	AUL14	AUL13	AUL12	AUL11	AUL10	AUL9	AUL8	AUL7	AUL6	AUL5	AUL4	AUL3	AUL2	AUL1	AUL0
POR VALUE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

BUS OVERVIEW

The INA226 offers compatibility with both I^2C and SMBus interfaces. The I^2C and SMBus protocols are essentially compatible with one another.

The I^2C interface is used throughout this data sheet as the primary example, with SMBus protocol specified only when a difference between the two systems is discussed. Two bidirectional lines, SCL and SDA, connect the INA226 to the bus. Both SCL and SDA are open-drain connections.

The device that initiates a data 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.

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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 INA226 includes a 28ms timeout on its interface to prevent locking up the bus.

Serial Bus Address

To communicate with the INA226, 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 that indicates whether the action is to be a read or write operation.

The INA226 has two address pins, A0 and A1. Table 7 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.

Table 7. INA226 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 INA226 operates only as a slave device on both the I^{2}C bus and the 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. While there is spike suppression integrated into the digital I/O lines, proper layout should be used to minimize the amount of coupling into the communication lines. This noise introduction could occur from capacitively coupling signal edges between the two communication lines themselves or from other switching noise sources present in the system. Routing traces in parallel with ground in between layers on a printed circuit board (PCB) typically reduces the effects of coupling between the communication lines. Shielding communication lines in general is recommended to reduce to possibility of unintended noise coupling into the digital I/O lines that could be incorrectly interpreted as start or stop commands.

The INA226 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.

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WRITING TO/READING FROM THE INA226

Accessing a specific register on the INA226 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 27) is the first byte transferred after the slave address byte with the R/$\overline{W}$ bit low. Every write operation to the INA226 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/$\overline{W}$ bit low. The INA226 then acknowledges receipt of a valid address. The next byte transmitted by the master is the address of the register which data will be written to. 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 INA226 acknowledges receipt of each data byte. The master may terminate data transfer by generating a start or stop condition.

When reading from the INA226, 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/$\overline{W}$ 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/$\overline{W}$ 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 INA226 retains the register pointer value until it is changed by the next write operation.

Figure 24 and Figure 25 show the write and read operation timing diagrams, respectively. Note that register bytes are sent most-significant byte first, followed by the least significant byte.
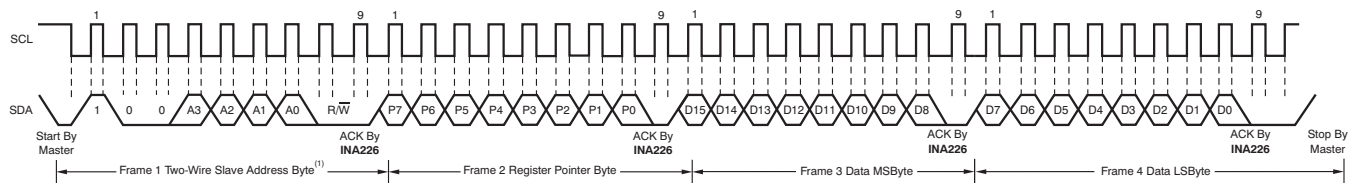
(1)   The value of the Slave Address byte is determined by the settings of the A0 and A1 pins. Refer to Table 7.

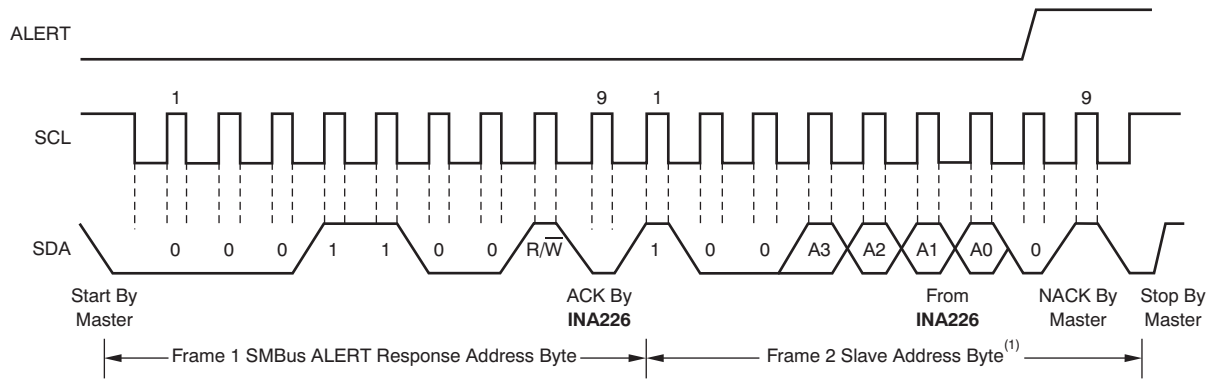**Figure 24. Timing Diagram for Write Word Format**

Байт адреса двухпроводного
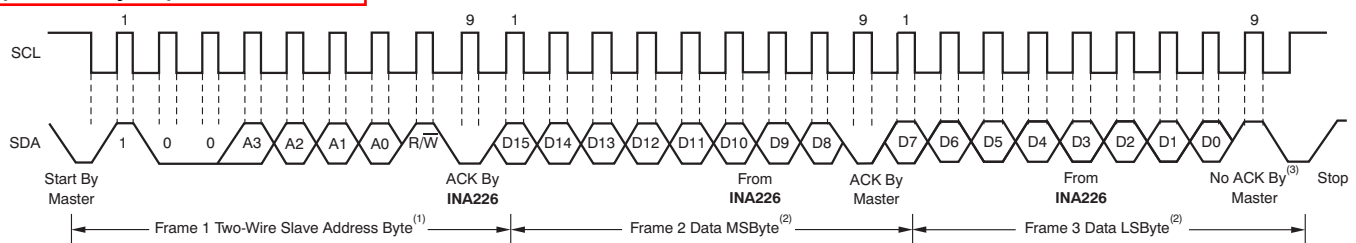
(1)   The value of the Slave Address byte is determined by the settings of the A0 and A1 pins. Refer to Table 7.

(2)   Read data is from the last register pointer location. If a new register is desired, the register pointer must be updated. See Figure 23.

(3)   ACK by Master can also be sent.

Figure 25. Timing Diagram for Read Word Format
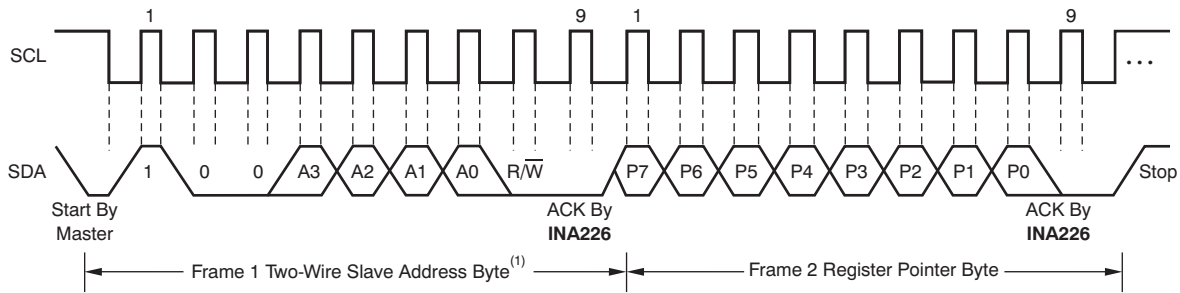
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Figure 26 shows the timing diagram for the SMBus Alert response operation. Figure 27 illustrates a typical register pointer configuration.

(1) The value of the Slave Address Byte is determined by the settings of the A0 and A1 pins. Refer to Table 7.

Figure 26. Timing Diagram for SMBus ALERT

(1) The value of the Slave Address Byte is determined by the settings of the A0 and A1 pins. Refer to Table 7.

Figure 27. 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 (400kHz) or standard (100kHz) (F/S) mode at no more than 400kHz. The INA226 does not acknowledge the HS master code, but does recognize it and switches its internal filters to support 3.4MHz 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 3.4MHz 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 INA226 to support the F/S mode.
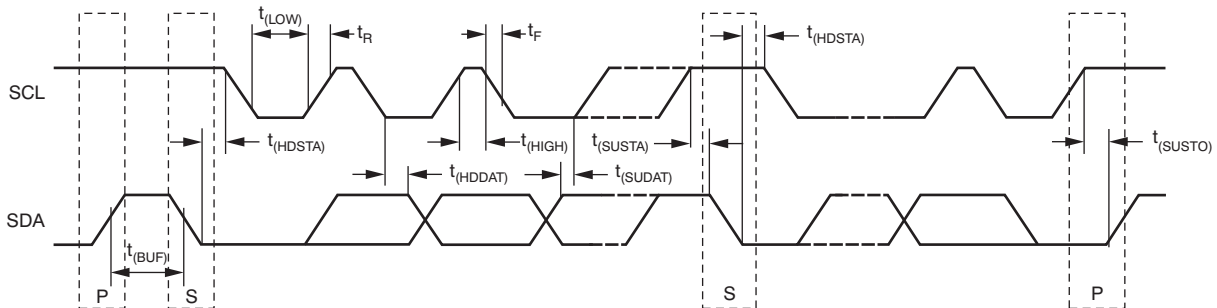

Figure 28. Bus Timing Diagram

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 conditions	$t_{(BUF)}$	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 ≤ 100kHz	t_R		1000			ns

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SMBus Alert Response

The INA226 is designed to respond to the SMBus Alert Response address. The SMBus Alert Response provides a quick fault identification for simple slave devices. When an Alert occurs, the master can broadcast the Alert Response slave address (0001 100) with the Read/Write bit set high. Following this Alert Response, any slave devices that generated an alert will identify themselves by acknowledging the Alert Response and sending their respective address on the bus.

The Alert Response can activate several different slave devices simultaneously, similar to the I^{2}C General Call. If more than one slave attempts to respond, bus arbitration rules apply. The losing device does not generate an Acknowledge and continues to hold the Alert line low until the interrupt is cleared.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/ Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
INA226AIDGSR	ACTIVE	MSOP	DGS	10	2500	TBD	Call TI	Call TI	
INA226AIDGST	ACTIVE	MSOP	DGS	10	250	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.
OBSOLETE: 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.
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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)
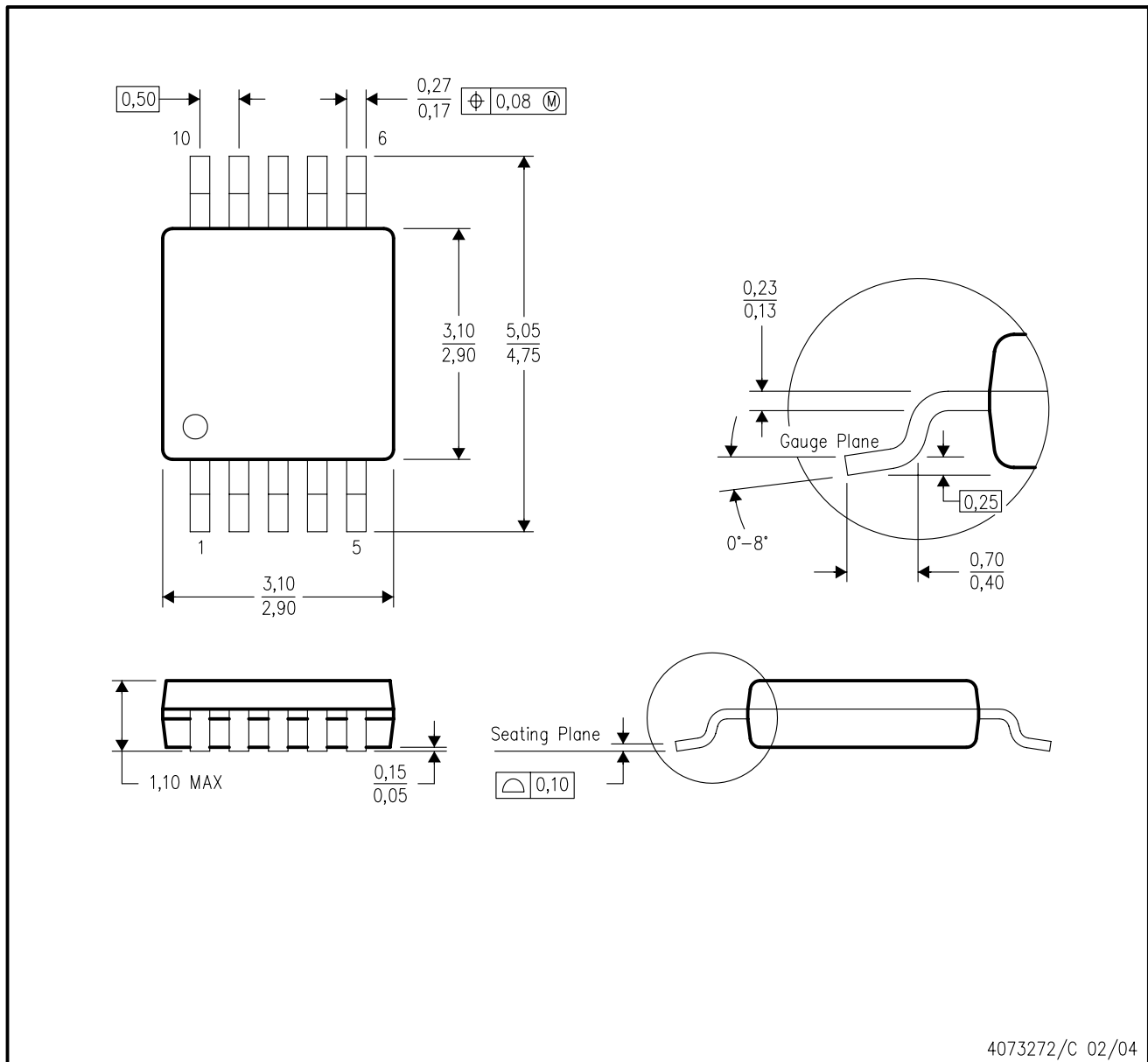
(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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DGS (S−PDSO−G10)   PLASTIC SMALL−OUTLINE PACKAGE

0,50

0,27
0,17   ⊕ 0,08 Ⓜ

10   6

3,10   5,05
2,90   4,75

1   5

3,10
2,90

1,10 MAX

0,15
0,05

0,23
0,13

Gauge Plane

0°−8°

0,25

0,70
0,40

Seating Plane

△ 0,10

4073272/C 02/04

NOTES: A. All linear dimensions are in millimeters.
         B. This drawing is subject to change without notice.
         C. Body dimensions do not include mold flash or protrusion.
         D. Falls within JEDEC MO−187 variation BA.

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