*Application Note*

# *Monitoring Bus Voltage and Power Measurement on AM263x MCU Using INA226/INA228*


**ABSTRACT**

This application note describes the usage of current shunt and power monitor INA226/INA228 with the AM263x MCU. The two devices can use the Inter-Integrated Circuit (I2C) interface for communication. This document provides an example of using the AM263x control card evaluation module (EVM) to evaluate this usage, along with an excel tool that provides the programming values and the I2C driver to program them.

The spreadsheet mentioned in this document can be downloaded from the following URL: https://www.ti.com/lit/zip/sprad70.


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## Trademarks

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# 1 Introduction

Current shunt monitors are a simple and easy way to measure current. The INA226/INA228 is a current shunt and power monitor with an I2C- or SMBUS-compatible interface. It measures the voltage across a sense resistor placed in the conduction path between a power source and a load. The device can monitor both shunt voltage drops 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 reports current, bus voltage and power on common-mode bus voltages that can vary from 0 V to 36 V, independent of the supply voltage. The device operates from a single 2.7-V to 5.5-V supply, drawing a typical of 330 μA of supply current. It can measure a full-scale differential input of ±81.92 mV across a resistive shunt sense element.

The INA228 reports current, bus voltage, temperature, power, energy and charge accumulation on common-mode bus voltages that can vary from 0 V to 85 V, independent of the supply voltage. The device operates from a single 2.7-V to 5.5-V supply, drawing a typical of 640 μA of supply current. It can measure a full-scale differential input of ±163.84 mV or ±40.96 mV across a resistive shunt sense element with common-mode voltage support from –0.3 V to +85 V. The integrated temperature sensor is ±1°C accurate for die temperature measurement and is useful in monitoring the system ambient temperature.

The devices are specified over the operating temperature range between –40°C and 125°C and features up to 16 programmable addresses on the I2C-compatible interface. See the respective device datasheets for more information.

# 2 Applications

The INA226/INA228 can be used as a simple on-board device for added safety and protection, feedback control and system monitoring in applications such as battery management systems (BMS) in hybrid electric vehicles (HEV) and electric vehicles (EV), battery test equipment, motor current measurements in industrial drives and automotive applications, and so forth. It can help in monitoring/ measuring the following:

- Total system current and power consumption
- Battery charge-discharge current
- Current/power consumed by the connected peripherals
- Current/power consumed in different operating modes and use cases
- Any unforeseen rise or fall in current/power consumption
- Overcurrent protection/monitoring

# 3 Usage With AM263X

The AM263x Control Card Evaluation Module (EVM) has 2x INA226/INA228 (in E1/E2 respectively) current monitors that can be used to evaluate this usage. The two current monitors are used to measure the power on the two voltage rails, 1.2V and 3.3V, respectively.

As an example, consider the monitoring and measurement of power on the 1.2V voltage rail. Follow sections 3.1 and 3.2 if you are using the control card with INA226 or sections 3.3 and 3.4 if it has the INA228.

## 3.1 Obtaining the Register Values to Program in INA226

1. Determine the maximum current that needs to be sensed on each of the voltage rails, from the *AM263x Sitara™ Microcontrollers Data Sheet*. (For 1.2 V, it is VDD + VDDARn = 2.5A).
2. Input this value in the cell “Max Expected Current” on the excel tool.
3. Based on the input from the previous step, the tool calculates the smallest allowable Current_LSB value “Recommended value of CURRENT_LSB”.
   a. While this value yields the highest resolution, it is common to select a value for the Current_LSB to the nearest round number above this value to simplify the conversion of the Current Register (04h) and Power Register (03h) to amperes and watts, respectively.
4. Input the desired CURRENT_LSB in “Value of CURRENT_LSB to be used”. Here it is chosen to be 0.0001 (100 μA).
5. The recommended Shunt Resistor value (Rshunt) from the maximum expected current is provided in “Recommended Rshunt Value should be less than <”.

6. Choose the nearest available resistor value and input the value in “Actual value of Rshunt used in design”. In this example, 10mΩ resistor is chosen.
7. The tool calculates the value of the Calibration Register (05h) based on the above inputs and provides it in “Calibration register value in Hex”.
8. The default value of 0x4127 for Configuration Register (00h) is chosen here, which configures Continuous shunt and bus measurement mode, Shunt voltage conversion time and Bus voltage conversion time to 1.1 ms each and Number of Averages to 1.

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**Note**

The project can also be modified to monitor multiple voltage rails by defining the I2C Slave addresses of the Instrumentation Amplifier (INA) devices monitoring the other rails and using those addresses in the I2C transactions.

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**Note**

The Alert pin of the INA device can be connected to a GPIO on the AM263x, which provides a response to a single user-defined event or to a Conversion Ready notification, if desired.

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## 3.2 Programming the Register Values Using the Provided I2C Code in INA226

1. Input the INA part being used (INA226/INA228) as shown below:

```
#define INA226      (0X01) //1 - INAA26 is used, 0 - INA228 is used
```

2. Input the voltage rail that needs to be monitored as shown below:

```
#define RAIL_1V2 (0x01) //1 - 1.2V rail to be monitored, 0 - 3.3V rail to be monitored
```

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**Note**

In this example, 1.2V voltage rail is being monitored using the INA with I2C device address 0x41.

To monitor the 3.3V rail, the INA with the device address 0x40 needs to be used.

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3. Input the value of the Calibration Register value obtained in the previous section under the macros “INA226_REG_CALIBRATION_MSB_VALUE” (with the Most significant Byte) and “INA226_REG_CALIBRATION_LSB_VALUE” (with the Least Significant Byte).

```
#define INA226_REG_CALIBRATION_MSB_VALUE    (0x14)  /* Input from user */
#define INA226_REG_CALIBRATION_MSB_VALUE    (0x00)  /* Input from user */
```

4. Configuration Register is programmed with the default value of 0x4127 as explained in the previous step.
5. Run the provided project on CCS and obtain the Current, Shunt Voltage and Bus Voltage and Power value on the console output as shown in the image below.

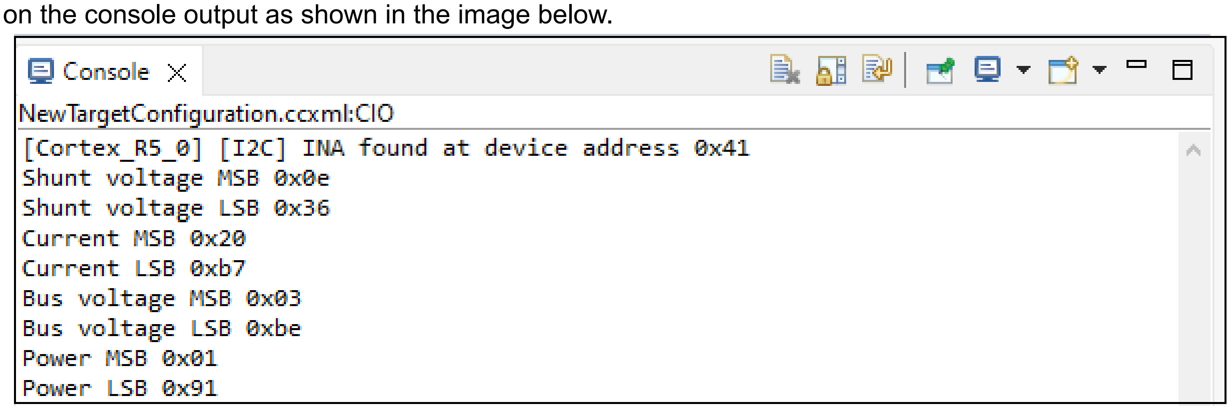


**Figure 3-1. CCS Console Output**

6. Input these values in the excel to calculate the actual Current, Shunt Voltage and Bus Voltage and Power values by multiplying with the corresponding LSB values.

7. In Figure 3-2, the following output values were obtained:

| Type | Description | Values | Units |
|---|---|---|---|
| INA226 Parameters | Shunt voltage input range max | 0.08192 | V |
| | Shunt voltage LSB | 2.5 | µV/LSB |
| | Bus voltage input range max | 40.96 | V |
| | Bus voltage LSB | 1.250000 | mV/LSB |
| **Input from User ->** | Max Expected current | **2.5** | A |
| Recommendation for design | Recommended value of CURRENT_LSB | 7.62939E-05 | A/LSB |
| **Input from User ->** | Value of CURRENT_LSB to be used | **0.0001** | A/LSB |
| Recommendation for design | Recommended Rshunt Value should be less than < | 0.032768 | Ω |
| **Input from User ->** | Actual value of Rshunt used in design | **0.01** | Ω |
| | Calibration register(CAL) value | 5120 | |
| **To be programmed into INA226 Calibration Register - 05h ->** | Calibration register(CAL) value in Hex | **1400** | |
| Parameters to check proper usage | Max voltage drop across the shunt resistor | 0.025 | V |
| | % of ADC range used based on shunt resistor used | 30.51757813 | |

**Yellow highlighted cells are inputs required from user used by this excel.**
**Orange highlighted cells are INA226 register values to be programmed.**
**Green highlighted cells are INA226 register values read for a programmed calibration register.**

| | Registers read from INA226 | Returned Value(in Hex) | LSB Value | Unit |
|---|---|---|---|---|
| **Input from User -> Read 01h to 04h registers from INA226 and enter in C20, C22, C23, C21.** | Shunt voltage - 01h | **0E36** | 2.500000000 | µV/LSB |
| | Current (A) - 04h | **20B7** | 100.000000000 | µA/LSB |
| | Bus voltage (V) - 02h | **03BE** | 1.250000000 | mV/LSB |
| | Power (W) - 03h | **0191** | Current LSB x 25 | W/LSB |

| Value measured by INA226 | | | | |
|---|---|---|---|---|
| Description | Calculated Value | Unit | Calculated Value | Unit |
| Shunt voltage across INA+ and INA- pins | 9095 | µV | **0.009095** | V |
| Current through the Shunt resistor | 837500 | µA | **0.8375** | A |
| Bus voltage as measured by VBUS pin | 1197.5 | mV | **1.1975** | V |
| Total power delivered through the Shunt resistor | 1002.5 | mW | **1.0025** | W |

INA226 | INA228

**Figure 3-2. Measurements Obtained Highlighted**

## 3.3 Obtaining the Register Values to Program in INA228

1. Determine the maximum current that needs to be sensed on each of the voltage rails, from the *AM263x Sitara™ Microcontrollers Data Sheet*. (For 1.2 V, it is VDD + VDDARn = 2.5A).
2. Input this value in the cell “Max Expected Current” on the excel tool.
3. Based on the input from the previous step, the tool calculates the smallest allowable Current_LSB value “Recommended value of CURRENT_LSB”.
   a. While this value yields the highest resolution, it is common to select a value for the Current_LSB to the nearest round number above this value to simplify the conversion of the Current Register (07h) and Power Register (08h) to amperes and watts, respectively.
4. Input the desired shunt voltage input range based on the expected maximum current and precision required in "ADCRANGE". Selecting 0 sets it to ±163.84 mV, while selecting 1 sets it to ±40.96 mV.

   Here it is set to "0".
5. Input the desired CURRENT_LSB in “Value of CURRENT_LSB to be used”. Here it is chosen to be 0.0001A/LSB.
6. The recommended Shunt Resistor value (Rshunt) from the maximum expected current is provided in “Recommended Rshunt Value should be less than <”.
7. Choose the nearest available resistor value and input the value in “Actual value of Rshunt used in design”. In this example, 10mΩ resistor is chosen.
8. The tool calculates the value of the Shunt Calibration Register (02h) based on the above inputs and provides it in “SHUNT_CAL[14:0] in Hex”.
9. The default value of 0xFB68 for ADC Configuration (01h) is chosen here, which configures Continuous bus voltage, shunt voltage and temperature mode, Shunt voltage conversion time, temperature conversion time and Bus voltage conversion time to 1052 µs each and Number of Averages to 1.

## 3.4 Programming the Register Values Using the Provided I2C Code in INA228

1. Input the INA part being used (INA226/INA228) as shown below:

```
#define INA226     (0X00) //1 - INAA26 is used, 0 - INA228 is used
```

2. Input the voltage rail that needs to be monitored as shown below:

```
#define RAIL_1V2 (0x01) //1 - 1.2V rail to be monitored, 0 - 3.3V rail to be monitored
```

**Note**

In this example, 1.2V voltage rail is being monitored using the INA with I2C device address 0x41.

To monitor the 3.3V rail, the INA with the device address 0x40 needs to be used.

3. Input the value of the Configuration Register obtained in the previous section under the macros “INA228_REG_CONFIG_MSB_VALUE” (with the Most significant Byte) and “INA228_REG_CONFIG_LSB_VALUE” (with the Least Significant Byte).

```
#define INA228_REG_CONFIG_MSB_VALUE        (0x00) /* Input from the user */
#define INA228_REG_CONFIG_LSB_VALUE        (0x00) /* Input from the user */
```

   Note: The value of Configuration Register (00h) in this example is "0x0000" which is it's default value, and in case the value of "ADCRANGE" needs to be "1", the register then needs to be programmed with "0x0010".

4. Input the value of the Calibration Register value obtained in the previous section under the macros “#define: INA228_REG_SHUNT_CAL_MSB_VALUE” (with the Most significant Byte) and “#define INA228_REG_SHUNT_CAL_LSB_VALUE” (with the Least Significant Byte).

```
#define INA228_REG_SHUNT_CAL_MSB_VALUE     (0x33) /* Input from the user */
#define INA228_REG_SHUNT_CAL_LSB_VALUE     (0x33) /* Input from the user */
```

5. ADC Configuration Register is programmed with the default value of 0xFB68 as explained in the previous section.

```
#define INA228_REG_ADC_CONFIG_MSB_VALUE   (0xFB) /* Default value */
#define INA228_REG_ADC_CONFIG_LSB_VALUE   (0x68) /* Default value */
```

6. Run the provided project on Code Composer Studio™ (CCS) and obtain the Current, Shunt Voltage and Bus Voltage, Die temperature, Energy, Charge and Power values on the console output as shown in the image below.

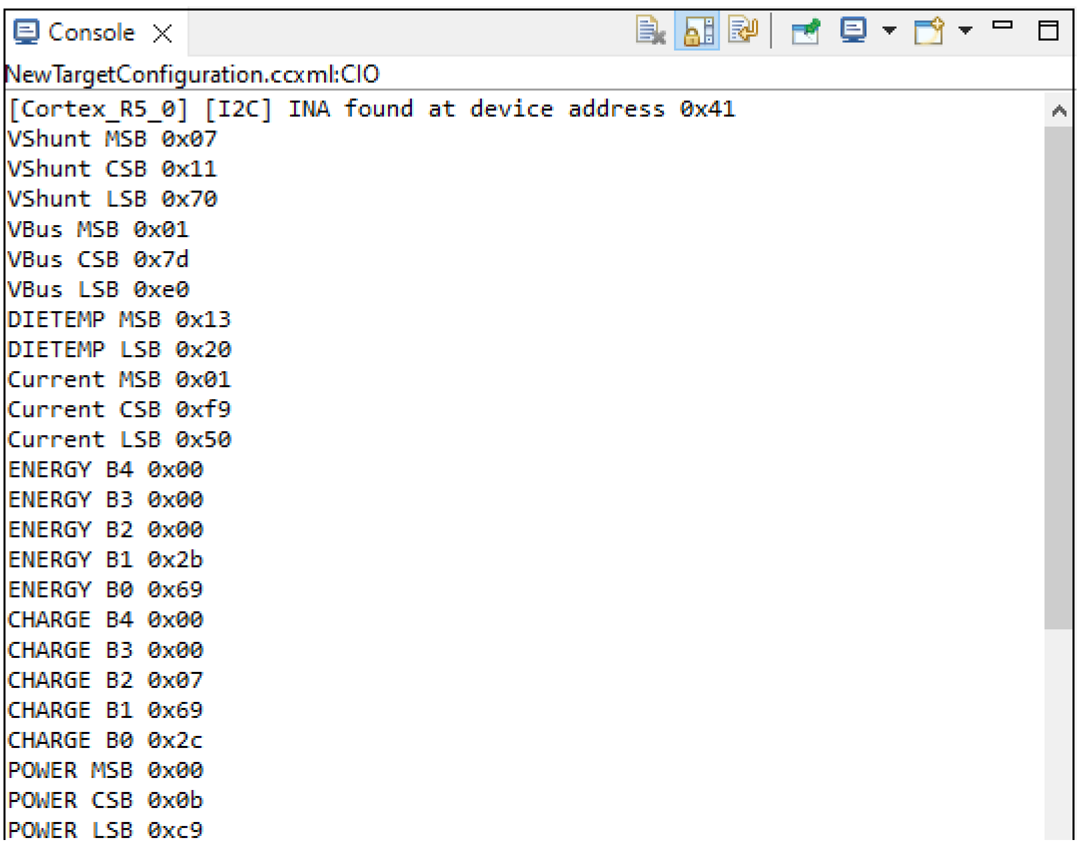


**Figure 3-3. CCS Console Output**

7. Input these values in the excel in the column "Returned Value(in Hex)" to calculate the actual Current, Shunt Voltage and Bus Voltage, Die temperature, Energy, Charge and Power values by multiplying with the corresponding LSB values.
8. In Figure 3-4, the following output values were obtained.

| Type | Description | Values | Units |
|---|---|---|---|
| INA228 Parameters | Shunt voltage input range max | 0.16384 | V |
| | Shunt voltage LSB | 312.5 | nV/LSB |
| | Bus voltage input range max | 85 | V |
| | Bus voltage LSB | 195.312500 | µV/LSB |
| ADCRANGE used | ADCRANGE bit in CONFIG[4] register | 0 | 0h = ±163.84 mV<br>1h = ± 40.96 mV |
| **Input from User ->** | Max Expected current | **2.5** | A |
| Recommendation for design | Recommended value of CURRENT_LSB | 4.76837E-06 | A/LSB |
| **Input from User ->** | Value of CURRENT_LSB to be used | **0.0001** | A/LSB |
| | SHUNT_CAL[14:0] in Decimal | 13107 | A/LSB |
| **To be programmed into INA228 SHUNT_CAL Register - 2h ->** | SHUNT_CAL[14:0] in Hex | **3333** | A/LSB |
| Recommendation for design | Recommended Rshunt Value should be less than < | 0.065536 | Ω |
| **Input from User ->** | Actual value of Rshunt used in design | **0.01** | Ω |
| Parameters to check proper usage | Max voltage drop across the shunt resistor | 0.025 | V |
| | % of ADC range used based on shunt resistor used | 15.25878906 | |

**Yellow highlighted cells are inputs required from user used by this excel.**
**Orange highlighted cells are INA228 register values to be programmed.**
**Green highlighted cells are INA228 register values read for a programmed calibration register.**

| | Registers read from INA228 | Returned Value(in Hex) | Required register bits | Required Value(in Hex) | LSB Value | Unit |
|---|---|---|---|---|---|---|
| **Input from User -> Read registers from INA228 and enter in C19 to C25.** | VSHUNT[23:0] - 4h | **071170** | VSHUNT[23:4] - 4h | **07117** | 312.5000 | nV/LSB |
| | VBUS[23:0] - 5h | **017DE0** | VBUS[23:4] - 5h | **017DE** | 195.3125 | µV/LSB |
| | DIETEMP[15:0] - 6h | **1320** | DIETEMP[15:0] - 6h | **1320** | 7.8125 | m°C/LSB |
| | CURRENT[23:0] - 7h | **01F950** | CURRENT[23:4] - 7h | **01F95** | 100.0000 | µA/LSB |
| | POWER[23:0] - 8h | **000BC9** | POWER[23:0] - 8h | **000BC9** | 3.2 x Current LSB | W/LSB |
| | ENERGY[39:0] - 9h | **0000002B69** | ENERGY[39:0] - 9h | **0000002B69** | 16 x 3.2 x Current LSB | J/LSB |
| | CHARGE[39:0] - Ah | **000007692C** | CHARGE[39:0] - Ah | **000007692C** | Current LSB | µC/LSB |

| Value measured by INA228 | | | | |
|---|---|---|---|---|
| Description | Calculated Value | Unit | Calculated Value | Unit |
| Shunt voltage across INA+ and INA- pins | 9047187.5 | nV | **0.009047188** | **V** |
| Bus voltage as measured by VBUS pin | 1193359.375 | µV | **1.193359375** | **V** |
| On die temperature measured | 38250 | m°C | **38.25** | **°C** |
| Current through the Shunt resistor | 808500 | µA | **0.8085** | **A** |
| Total power delivered through the Shunt resistor | 965.44 | mW | **0.96544** | **W** |
| Total power delivered through the Shunt resistor | 56898.56 | mJ | **56.89856** | **J** |
| Total power delivered through the Shunt resistor | 48567600 | µC | **48.5676** | **C** |

INA226 | INA228

**Figure 3-4. Measurements Obtained Highlighted**

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**Note**

The Alert pin of the INA device can be connected to a general-purpose input/output (GPIO) on the AM263x, which provides a response to a single user-defined event or to a Conversion Ready notification, if desired.

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## 4 References


- Texas Instruments: *AM263x Sitara™Microcontrollers Data Sheet*
- Texas Instruments: *AM263x Sitara™ Microcontroller Technical Reference Manual*
- MCU-PLUS-SDK-AM263X - AM263x software development kit (SDK) for Sitara™ microcontrollers
- Texas Instruments: *INA226 High-Side or Low-Side Measurement, Bi-Directional Current and Power Monitor with I2C Compatible Interface Data Sheet*
- Texas Instruments: *INA226-Q1 AEC-Q100, 36-V, 16-Bit, Ultra-Precise, I2C Output Current, Voltage, and Power Monitor with Alert Data Sheet*
- Texas Instruments: *Simplifying Current Sensing*
- Texas Instruments: *AM263x Sitara Control Card Hardware User's Guide*

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