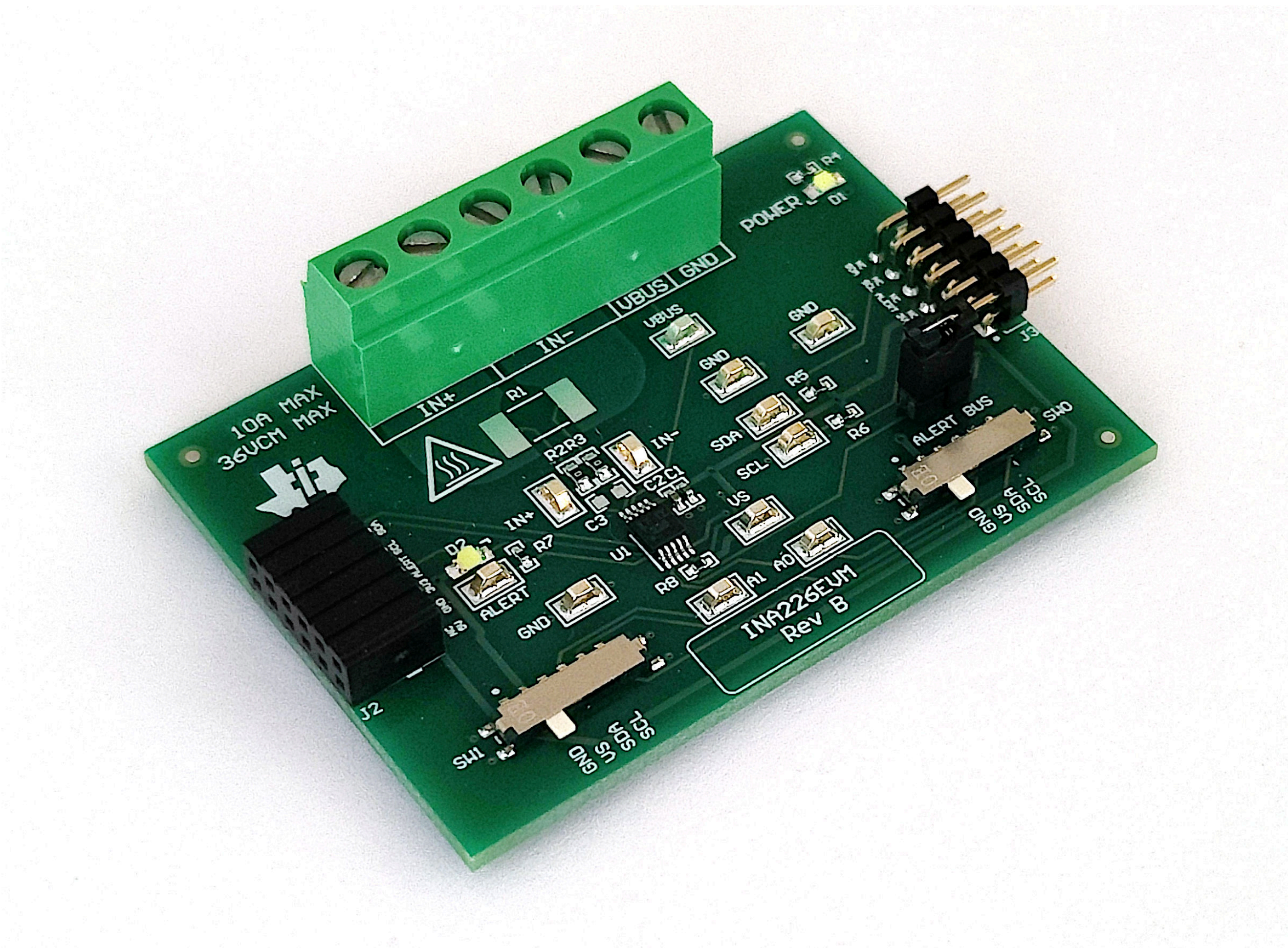
User's Guide

INA226EVM User's Guide

ABSTRACT

This user's guide describes the characteristics, operation, and use of the INA226 evaluation module (EVM). This EVM is designed to evaluate the performance of the INA226. Throughout this document, the terms evaluation board, evaluation module, and EVM are synonymous with the INA226EVM. This document includes a schematic, reference printed circuit board (PCB) layouts, and a complete bill of materials (BOM).



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1 Trademarks

All trademarks are the property of their respective owners.

2 Overview

The INA226 is a current shunt and power monitor with an I2C or SMBUS-compatible interface. The device 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 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. The device is specified over the operating temperature range between -40°C and 125°C and features up to 16 programmable addresses on the I2C-compatible interface.

Table 2-1. Device Summary

PRODUCT	DIGITAL PROTOCOL	ADC RESOLUTION	MAX GAIN ERROR	MAX OFFSET VOLTAGE
INA226	I2C	16-bit	0.1%	±10 µV

2.1 Kit Contents

Table 2-2 lists the contents of the EVM kit. Contact your nearest Texas Instruments Product Information Center if any component is missing.

Table 2-2. Kit Contents

ITEM	QUANTITY
INA226EVM test board	1

Note that this EVM requires the TI Sensor Control Board (SCB), which is sold separately.

2.2 Related Documentation From Texas Instruments

This user's guide is available from the TI website under literature number SBOU276. Any letter appended to the literature number corresponds to the document revision that is current at the time of the writing of this document. Newer revisions are available from www.ti.com or the Texas Instruments' Literature Response Center at (800) 477-8924 or the Product Information Center at (972) 644-5580. When ordering, identify the document by both title and literature number. Table 2-3 lists documentation related to the EVM. Click the links in Table 2-3 for further information. The device name links to the product web folder on www.ti.com. The literature number links to the document PDF.

Table 2-3. Related Documentation

DOCUMENT TITLE	DOCUMENT LITERATURE NUMBER
INA226 data sheet	SBOS547
INA226-Q1 data sheet	SBOS743
Getting Started with Digital Power Monitors	SBOA511

3 Hardware

The EVM is an easy-to-use platform for evaluating the main features and performance of the INA226. The EVM supports current measurements up to 10 amps through the PCB, and includes a graphical user interface (GUI) used to read and write device registers as well as view and save results data.

The EVM is intended to provide basic functional evaluation of the devices. The layout is not intended to be a model for the target circuit, nor is it laid out for electromagnetic compatibility (EMC) testing. The EVM consists of two printed-circuit boards (PCBs). The larger PCB is referred to as the EVM, and has the INA226 installed. The smaller PCB is referred to as the SCB Controller, and is used to interface the EVM with the GUI.

3.1 Features

- GUI support to read and write device registers as well as view and save results data
- EVM detached from SCB for custom use cases
- Multiple EVM support with single SCB/GUI
- Conveniently powered from a common micro-USB connector through the SCB

4 Operation

4.1 Quick Start Setup

The following instructions describe how to set up and use the EVM.

1. Purchase an SCB if you do not already have one.
   a. To use a PAMB Controller instead, see *PAMB Compatibility*.
2. Download this driver and install it **as an administrator**: https://www.ti.com/lit/zip/sbac253.
   a. Follow the download prompts, a myTI account will be required.
   b. Note that this driver is labeled as a PAMB driver, but is also used for the SCB.
3. Attach the EVM to the SCB Controller as shown in Figure 4-1.
   a. Refer to Figure 4-2 when connecting multiple EVMs of the same type together.
4. Connect the EVM to the PC using the provided USB cable.
   a. Insert the micro USB cable into the SCB Controller onboard USB receptacle J2.
   b. Plug the other end of the USB cable into a PC.
5. Access the GUI from this link in either Chrome, Firefox, or Safari: https://dev.ti.com/gallery/info/CurrentSensing/INA226EVM_GUI/.
6. Connect the GND reference of the external system to the GND node of the EVM (pin 1 of J1).
7. Provide a differential input voltage signal to the IN+ and IN– nodes by connecting the signal leads to J1 pin 5 or 6 and J1 pin 3 or 4 on the EVM as explained in *Current Sensing Operation*.

4.2 EVM Operation

To use the EVM with the SCB Controller (sold separately), connect the EVM as shown in Figure 4-1.

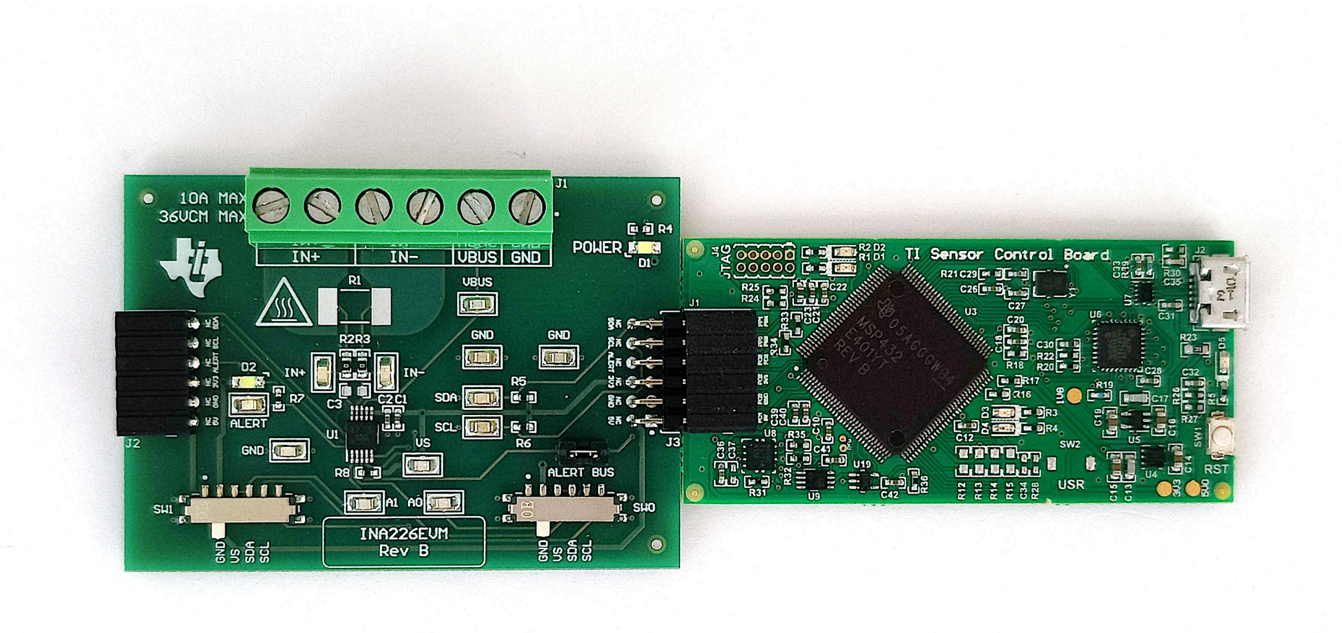

Figure 4-1. EVM (Left) Connected to SCB Controller (Right)

If using multiple EVMs, connect them as shown in Figure 4-2. Make sure to use a different I2C address for each device. The GUI only supports up to 4 EVMs total.

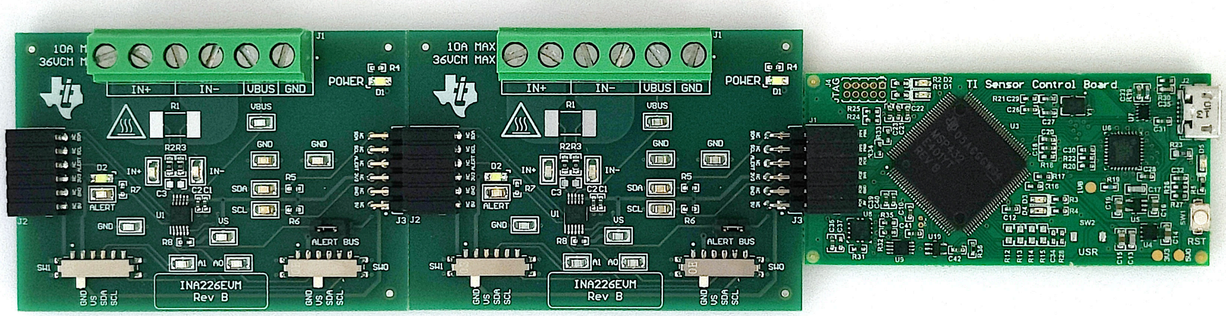

Figure 4-2. Multiple EVMs Connected to SCB Controller

4.2.1 Setup

4.2.1.1 Driver Installation

Download and install this driver: https://www.ti.com/lit/zip/sbac253. This is a one-time step per computer, and will require a myTI account. Note that this driver is labeled as a PAMB driver, but is also used for the SCB. Unzip the folder and **run the .exe file with administrator privileges**.

4.2.1.2 Firmware

Firmware updates will be pushed through the GUI if the previous driver was installed. Downloaded offline GUIs will only update the SCB Controller with the latest firmware available at the time of download. To check for the latest GUI or Firmware updates, launch the latest GUI version from the web browser.

4.2.1.2.1 Firmware Debug

If the firmware must be manually reinstalled for any reason, follow these steps to reinstall the firmware. Make sure the EVM is connected to the SCB.

1. First, see if the GUI can program the firmware manually.
   a. Plug in the SCB controller to the PC
   b. Launch the GUI
   c. It is possible that the MCU has already entered Device Firmware Update (DFU) mode. If so, the GUI may notify you and try to update the firmware to the latest version.
   d. If it does not update automatically, go to *File* > *Program Device...*
2. If step 1 is unsuccessful (or if the *Program Device* button is grayed out), manually configure the MCU on the SCB Controller to be in DFU Mode. This can be done through either of the below methods with the SCB Controller powered on:
   a. Through software:
      - Send the command 'bsl' on the SCB's USB Serial (COM) port.
   b. Though hardware:
      - For safety, **turn off and disconnect all load sources and external voltages**.
      - While shorting the two test points labeled *DFU* (shown in Figure 4-3) with a pair of tweezers (or wire), press and release the RESET button.

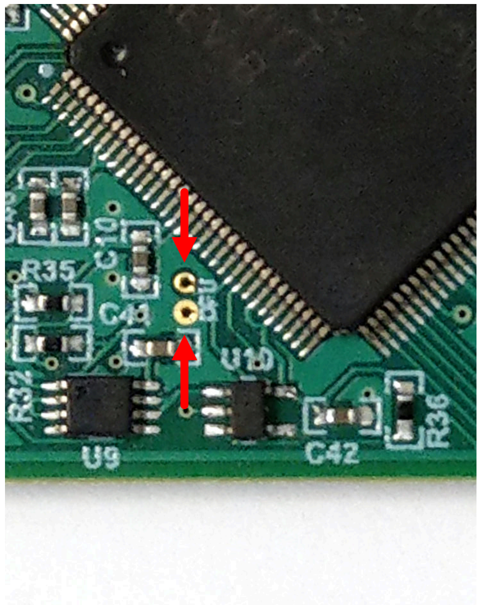

Figure 4-3. Test Points Used to Enter DFU Mode Manually

- If the PAMB board is being used instead, these test points are located near PK1 and PK2.

With the MCU in DFU mode, the firmware can now be uploaded through the method outlined in Step 1.

4.2.1.3 GUI Setup and Connection

You can access the GUI from this link in either Chrome, Firefox, or Safari: https://dev.ti.com/gallery/info/CurrentSensing/INA226EVM_GUI/.

4.2.1.3.1 Initial Setup

To set up the GUI the first time:

1. Make sure that the previously mentioned driver was installed successfully to ensure that everything works properly and that the GUI can update the EVM firmware, if necessary.
2. Check to make sure the EVM/SCB Controller unit is plugged into the PC, then go to the previously-provided GUI link.
3. Open the *GUI Composer* application to launch the GUI from the web browser (see Figure 4-4).

Figure 4-4. GUI Composer Application

a. The GUI link will bring up all versions of the GUI. TI recommends to launch the newest version available.
b. For first-time GUI Composer setup, follow the prompts to download the *TI Cloud Agent* and browser extension (see Figure 4-5). These prompts will appear after you close the *README.md* dialog box.

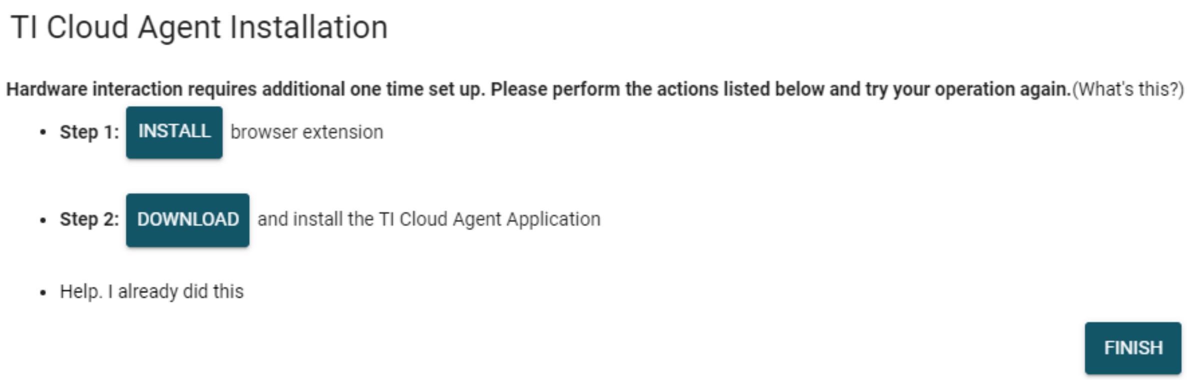

Figure 4-5. TI Cloud Agent

4. To download the GUI for offline use, click the icon in the GUI Composer application and follow the prompts (see Figure 4-4).

4.2.1.3.2 GUI to EVM Connection

To connect the GUI to the EVM, follow these steps:

1. Setup and launch the GUI as described in *Initial Setup*.
2. Check to make sure that the EVM connected to the GUI, then close the README.md file page to initiate the connection. If successful, the text *Hardware Connected* should be visible near the bottom left corner of the GUI.

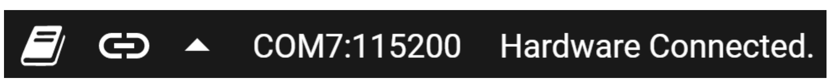

Figure 4-6. Hardware Connected

a. A green indicator with the device type and the text *DEVICE CONNECTED* should also be visible near the top left of the GUI.

Figure 4-7. Device Connected

b. If the text *Hardware Connected* and *DEVICE CONNECTED* do not show in the GUI, long-press the RESET button on the EVM to try again.
   i. If that option does not work, check different hardware COM ports under *Options* > *Serial Port*.

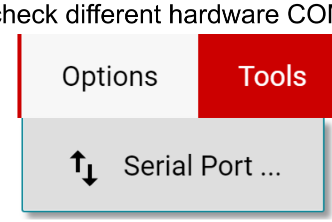

Figure 4-8. Change Serial Port

c. If the hardware still does not connect, make sure you are using the correct GUI/EVM combination.
   i. If you are using the correct GUI/EVM combination, you may need to reprogram the firmware of the SCB, as described in *Firmware Debug*.
   ii. Many connectivity issues can be addressed by doing one of the following:
      1. Long-press the RESET button on the EVM with the EVM and SCB connected to each other.

- Refreshing the GUI can also sometimes help this.

2. Connect the EVM to a different USB port.
    - Avoid using long cables and USB hubs.
    - If you are using a desktop PC, try a USB port on the back.

4.2.2 GUI Operation

Setup, launch, and connect the GUI to the EVM per *GUI Setup and Connection*. Refer to the sections below for a description on how to use each page of the GUI.

4.2.2.1 Homepage Tab

The GUI starts out on the homepage tab. Click the (Home) icon on the menu to the left to return to the homepage tab at any time.

From the homepage, you can easily confirm successful GUI to EVM connection (see *GUI to EVM Connection*), as well as access helpful resources through the buttons on the bottom (see Figure 4-9).

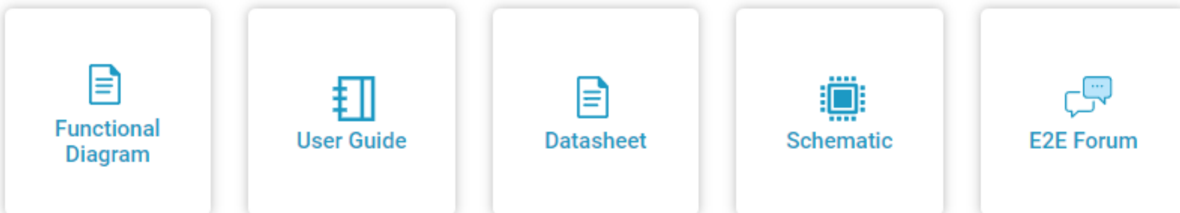

Figure 4-9. Home Tab Links

4.2.2.2 Configuration Tab

To do the initial setup for each connected EVM, click the (Configuration) icon on the menu to the left. Figure 4-10 shows an example of the configuration tool.

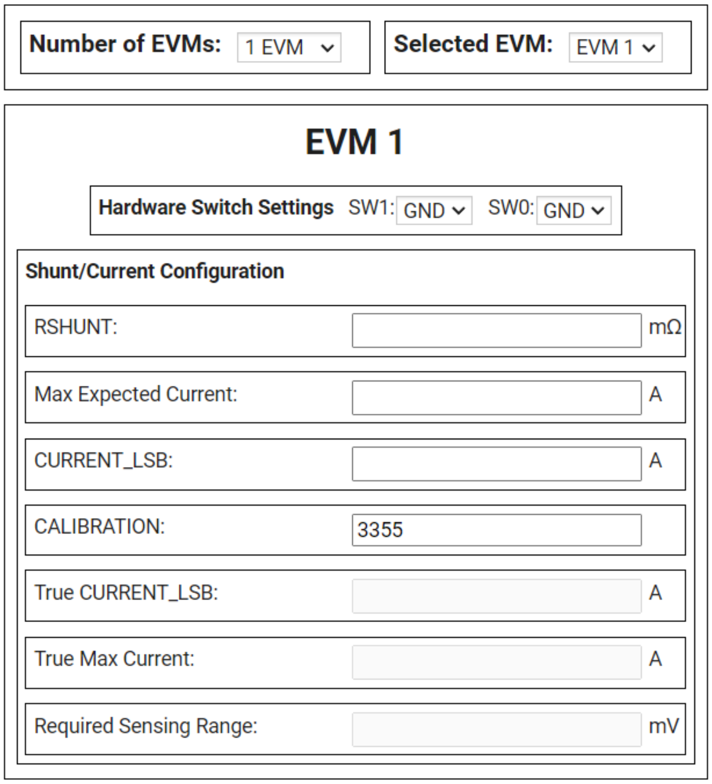

Figure 4-10. Configuration Tool

From this page you can set the number of EVMs you are using, and then for each EVM you can indicate the physical hardware switch settings and configure your shunt and CURRENT_LSB. Below is a description of each option and field on this page:

- Number of EVMs
  - This setting is used to tell the GUI how many EVMs are connected to the SCB.
  - Note, the SCB and GUI only support up to 4 INA226EVMs at a time.
  - Changing this here also changes the same setting in the Results Data tab.
- Selected EVM
  - This setting indicates which EVM you are currently changing settings for.
  - This also selects the EVM that is connected to the Registers tab.
- Hardware Switch Settings
  - Set these settings to match the physical switch settings on the EVM.
  - Note, this setting needs to be set before changing any other settings on this page. The GUI will block the other settings until this is set.
  - Changing this here also changes the same setting in the Results Data tab.
- Shunt/Current Configuration
  - This section is used to input shunt information as well as to help calculate the CURRENT_LSB and set the CALIBRATION register. Here is a description of how to use each field:
    - RSHUNT
      - Input the value of the used shunt resister in mΩ.
    - Max Expected Current
      - Input the value of the maximum expected current across the shunt resistor in Amps.

- – If the Max Expected Current field is left blank, then CALIBRATION can be adjusted manually, and the tool will tell you the True Max Current that can be measured with the EVM.
- CURRENT_LSB
  - – This is the calculated CURRENT_LSB value in Amps. This field gets populated automatically from the Max Expected Current field.
  - – This field can be changed manually if desired, and changes will filter downward.
- CALIBRATION
  - – Calculated value for CALIBRATION based off of RSHUNT and CURRENT_LSB. When this field changes, the value is automatically written to the CALIBRATION register.
  - – This field can be changed manually if desired, and changes will filter downward.
  - – Changing this value from the register map page also changes it here.
- True CURRENT_LSB
  - – This is the actual CURRENT_LSB value in Amps back calculated from the CALIBRATION register with the given shunt resistor value.
  - – This is the value used for calculations in the Results Data section.
- True Max Current
  - – This is the maximum measurable current in Amps based off of the VSHUNT and CURRENT registers, using RSHUNT and the True CURRENT_LSB for calculations.
- Required Sensing Range
  - – This shows the required sensing range to measure the Max Expected Current with the specified shunt resistor.
  - – If a Max Expected Current is not specified, then the True Max Current field will be used instead.

4.2.2.3 Registers Tab

To view and edit the device registers, click the (Registers) icon on the menu to the left. The Registers tab will look like the one shown in Figure 4-11.

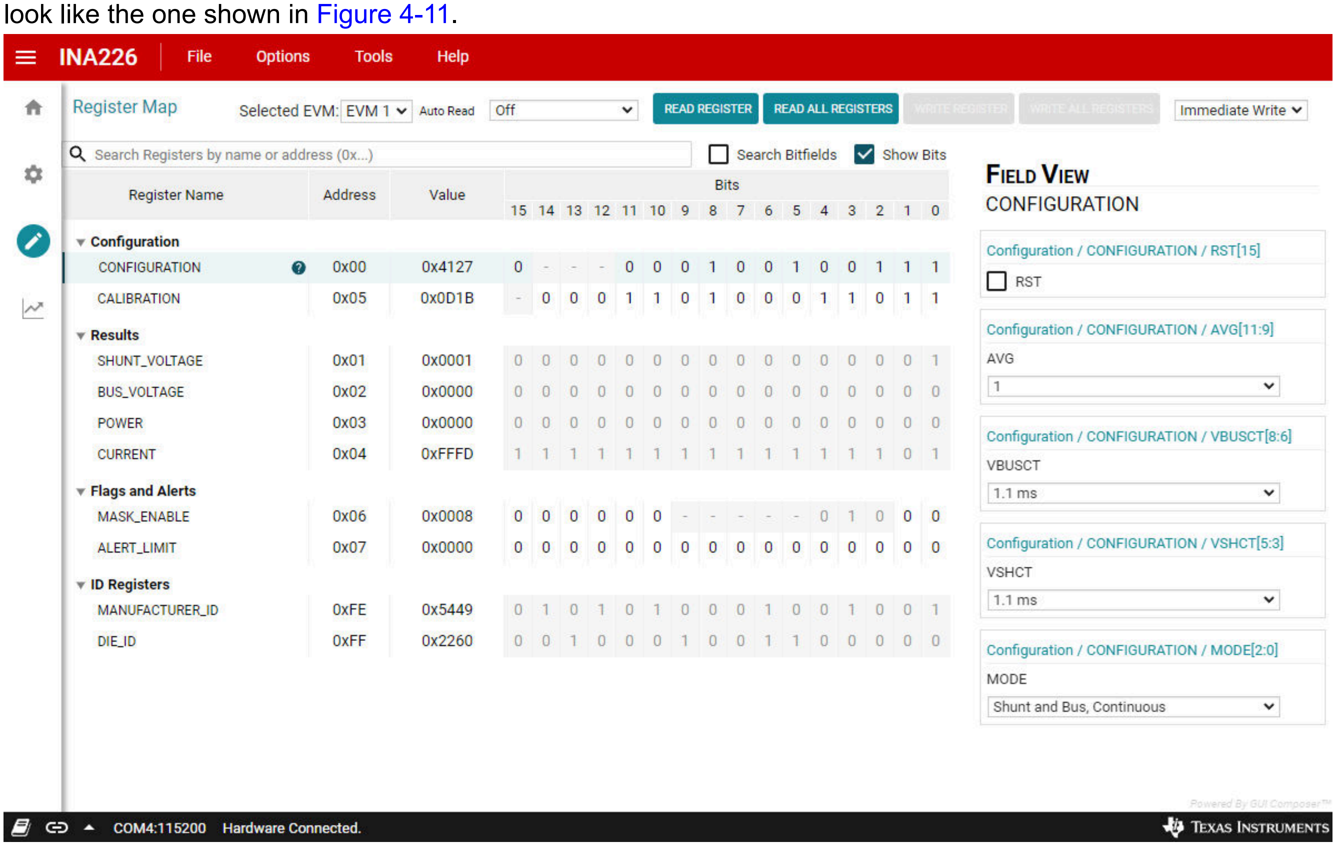

Figure 4-11. GUI Registers Tab

From this page, you can read and write device registers on the EVM. Here are some important notes:

- Use the *Selected EVM* drop-down menu at the top to choose which device to work with on the register map.
  - Note, changing this here also changes the same setting for the Configuration tab.
  - Functionally, this setting sets the default read/write address in the MCU and then reads all register values back to update the register map. Note that if data is being collected at a high frequency, then this may cause a minor delay in the data collection. For optimal performance, set device settings before you start collecting data.
- By default, all changes are automatically written to the device. If desired, you can change the *Immediate Write* setting to *Deferred Write* to only allow writing when you are ready.
  - You can modify writable register values from any of these methods:
    - Through the widget settings in the *Field View* section on the right.
    - Changing the *Value* directly with either hex or decimal values.
    - Double-clicking on any individual bit.
- Turning on *Auto Read* will only update registers in the register map, and not the plots in the *Results Data* section.
  - Leaving *Auto Read* on while collecting data for plots can interfere with data collection timing.
- For questions about a register or register bit field, select the  icon.
  - For even more questions about registers, check the data sheet.
- For convenience, register settings can be saved and loaded back later to any device with the same register map. To do this, go to *File* > *Register Data*, as shown in Figure 4-12.

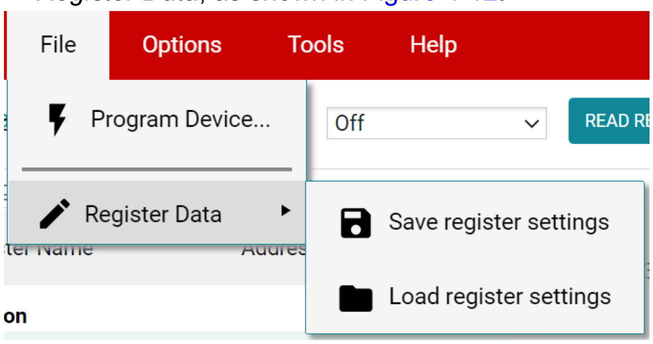

Figure 4-12. Save and Load Register Settings

  - TI recommends to press the *Read All Registers* button after loading data to update the register map with the actual device values.

4.2.2.4 Results Data Tab

To view and collect results data over time, click the  (Results Data) icon on the menu to the left. Figure 4-13 shows part of the results data page for reference, which may look different depending on the number of connected EVMs.

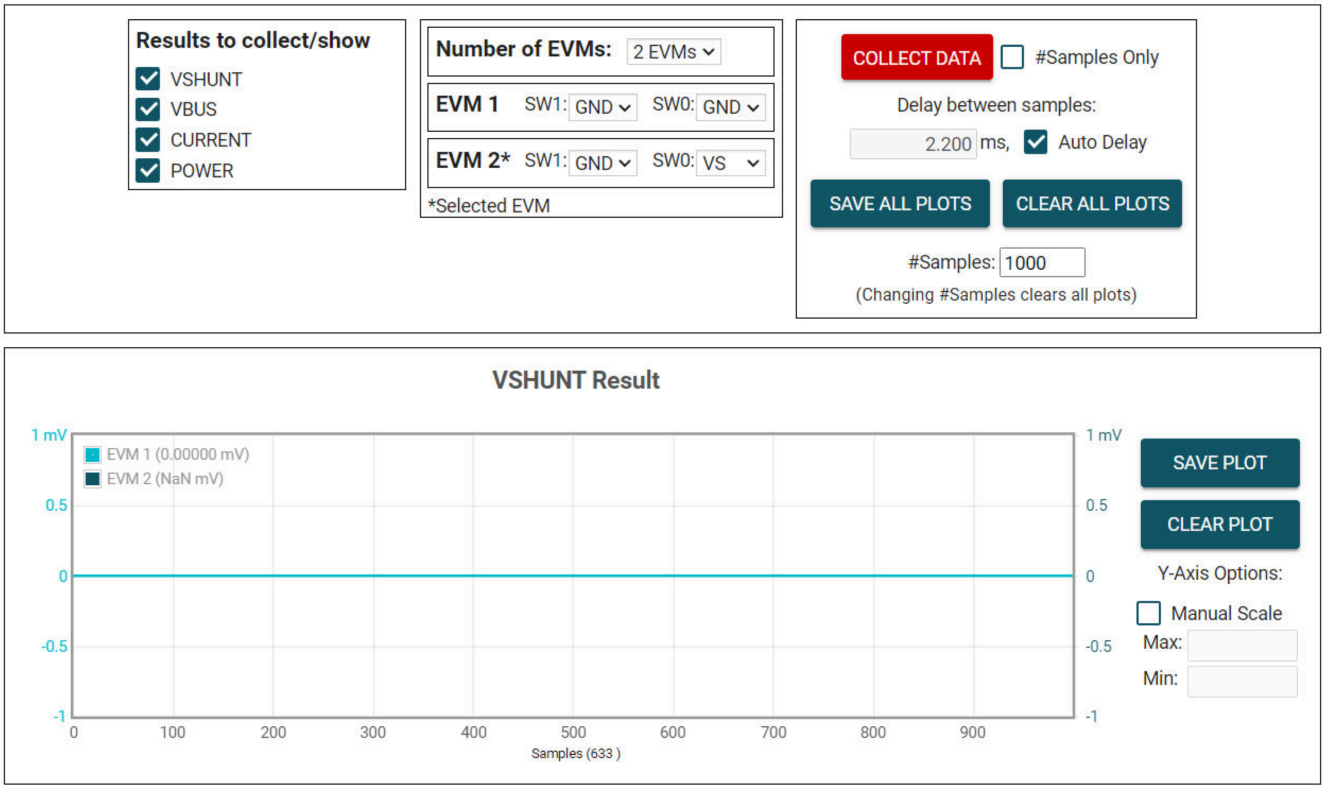

Figure 4-13. Results Page and Settings

Below is a description of how to use the buttons and settings at the top of the Results Data tab and next to each plot:

- Results to collect/show
  - Use this section to select which register values to collect data for. If a results register is unselected before the *COLLECT DATA* button is pressed, then the plot below will be hidden and the EVM will not try to read this register during the collect cycle (even if the conversion is enabled).
  - If you disable one of these settings while the EVM is collecting data, then the plot will not show, but data will still be collected and the plot will update in the background. Simply reselect to show data.
- Number of EVMs
  - Set the *Number of EVMs* drop-down menu to the number of EVMs currently in use.
    - See Figure 4-2 for how to attach multiple EVMs together.
    - Changing this here also changes the same setting in the Configuration tab.
  - The GUI only supports up to 4 INA226EVMs at a time.
  - Switch settings
    - Use the onboard switches to select a different address for each EVM.
    - Set the switch settings in the GUI to match the setting for each connected EVM.
      - *EVM 1* will automatically populate with the lowest addressed device unless a setting has already been selected.
      - Changing this here also changes the same setting in the Configuration tab.
    - If more than one device is being used, a * symbol will appear next to the selected EVM that is being used on the register map and configuration tabs.
      - Changing the switch settings of any EVM sets that EVM as the selected EVM.
- Collect/Plots settings

- Collect Data
  - Press the *COLLECT DATA* button to start data collection.
  - In this mode, the MCU reads and sends the selected result values for each device over a USB BULK channel. All results from one device are read before moving on to the next device.
    - All result values from all EVMs together are considered one "sample set".
  - Although you can read and write to other registers through the register map page while collecting data, it is possible that this adds a delay to the data being collected.
  - Press the *STOP COLLECT* button to stop collecting data.
- #Samples Only
  - If this checkbox is selected, then the GUI will automatically stop collecting data after the number of samples specified in the #Samples box have been collected.
  - If not selected, the GUI will continue collecting data and only store the most recent #Samples.
- Delay between samples
  - Sets the delay between the start of each sample set.
  - Desired delay time may not be obtainable if it is set faster than the read loop, which depends on the number of results being collected, the number of EVMs, and your CPU.
  - Although you can read and write to other registers through the register map page while collecting data, it is possible that this adds a delay to the data being collected.
- Auto Delay
  - Sets delay based on conversion times, averaging, and number of channels being converted.
  - If multiple EVMs are being used, the time put in the delay box will be from the EVM with the shortest calculated delay value.
- Save All Plots
  - Press the *SAVE ALL PLOTS* button to save the data for each currently selected result from the *Results to collect/show* section in a spreadsheet.
  - Press the *SAVE PLOT* button next to each plot to save just the data from that plot in a spreadsheet.
- Clear All Plots
  - Press the *CLEAR ALL PLOTS* button to clear the data from all plots together.
  - Press the *CLEAR PLOT* button next to each plot to clear the data from just that plot.
- #Samples
  - Change the number in this box to change the number of samples shown in each plot.
    - Changing this number clears out the plot buffers, so the plots will be cleared on the next read.
- Y-Axis Options
  - Manual Scale
    - Checking this box will set all EVM results in this plot to the same scale value specified by the Max and Min fields.
    - When this is not selected, each EVM will have it's own Y-axis scale based on the min and max value for that EVM's result values.
  - Max
    - The maximum Y-axis value to use for all EVMs in this plot.
    - If this field is empty when Manual Scale is selected, then it will auto populate with the maximum value currently in the plot.
  - Min
    - The minimum Y-axis value to use for all EVMs in this plot.
    - If this field is empty when *Manual Scale* is selected, then it will auto populate with the minimum value currently in the plot.

4.2.3 Current Sensing Operation

The EVM can be used with either an onboard or external shunt resistor. To use the onboard shunt resister, solder a 2512 surface-mount technology (SMT) shunt resistor across the pads of R1, and connect it in series with the external system and load current through J1. An external shunt can be connected directly across the terminals of J1. There are two terminals each for IN+ (J1 pins 5 and 6) and IN– (J1 pins 3 and 4) for convenience.

4.2.3.1 Detailed Setup

To configure a measurement evaluation, follow these steps:

1. Connect a shunt resister by doing either of the following:
    a. Solder a 2512 resistor across the pads of R1 that connects the IN+ and IN– inputs.
    b. Connect an external shunt across the IN+ and IN– terminals of J1, preferably across pins 4 and 5, as shown in Figure 4-14 and Figure 4-15.
        i. If an external shunt is being used, make the connections such that the sensing location is across the shunt and there will be no high current on the sensing path. See the *TI Precision Labs - Current Sense Amplifiers: Shunt Resistor Layout* video for more information.
2. Connect the IN+ and IN– terminals in series with the load while powered off.
    a. When measuring more than 10 A, make sure the high current path does not go through the EVM (including the terminal block J1), as shown in Figure 4-14.

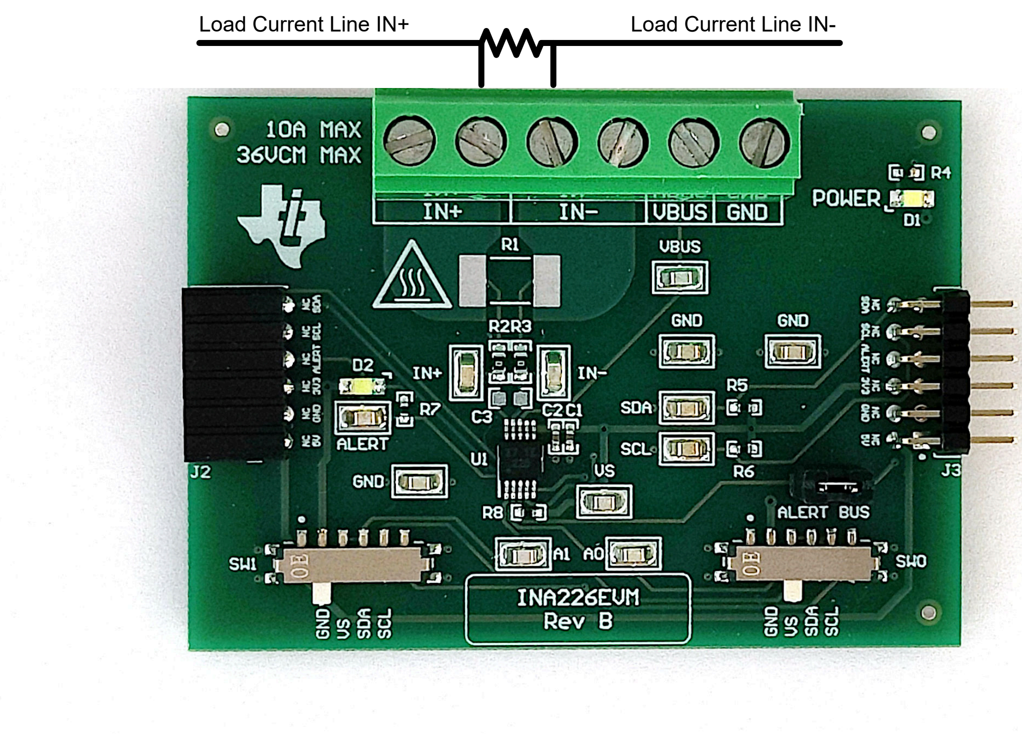

Figure 4-14. IN+ and IN– Wiring for More Than 10A

    b. When using 10 A or less with either an onboard or external shunt, the current path can be passed through the EVM. Figure 4-15 shows a convenient way to use the multiple IN+ and IN- terminals with an external shunt for this use case.

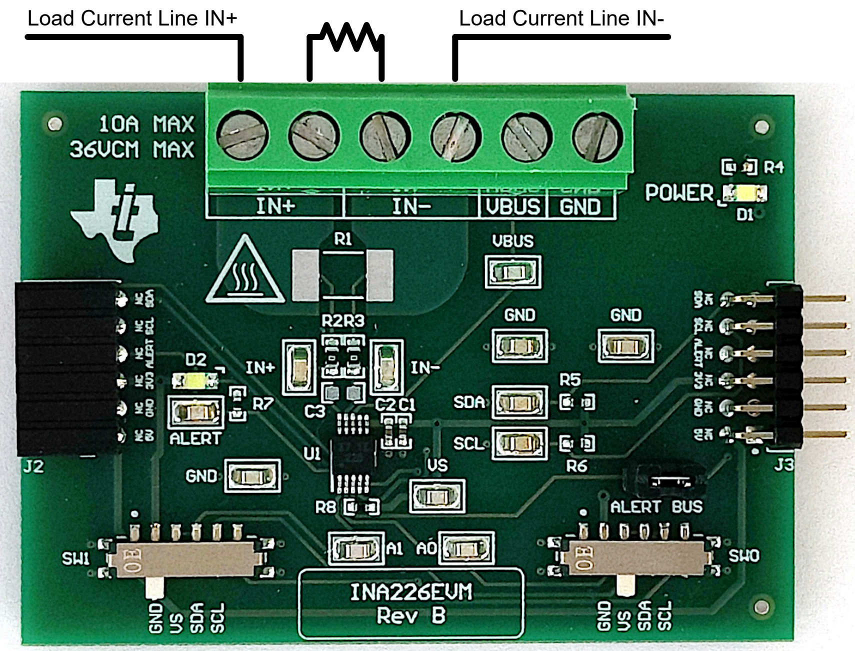

Figure 4-15. IN+ and IN– Wiring for 10A or Less

> **WARNING**
>
> When measuring current, first make sure that the equipment (shunt resistor, wires, connectors, and so on) can support the amperage and power dissipation. Secondly, make sure that the current flowing through J1 does not exceed 10 A. Failure to do so can result in damage to the EVM, or personal injury.
>
> The EVM may get hot.

3. Connect the VBUS terminal (J1 pin 2) to the desired bus voltage (likely either IN+ or IN–).
   a. If VBUS and dependent features are not being used, this channel can be used as an ADC input for another voltage.
4. Connect the system ground to the GND terminal (J1 pin 1).
5. Power on the system, and observe the device states and outputs through the GUI.

4.2.4 Direct EVM USB Communication

If desired, the EVM can be communicated with directly without the use of the GUI through the USB port. This is done by sending the desired command string over the serial COM port and receiving the results either through the COM port or the USB BULK channel, based on the mode. This is useful for interfacing the EVM with custom setups, scripts, or GUIs.

4.2.4.1 Standard USB Read and Write Operations

Use the serial COM port to read and write registers through USB commands using the following format:

- Set device address format: setdevice DEVID
  - Where setdevice is always lower case, and DEVID is defined as:
    - The 4 LSBs of the address in decimal format. Ex, for an address of 0x4A, use 10.
  - Note, when the SCB is reset while one or more EVMs are connected, the address will default to the lowest address found.
    - The SCB checks for I2C or SPI at start up, if no device is attached, it will default to SPI. Reset the SCB with an I2C EVM connected to use I2C.
  - For example, to set the INA226 with a register address of 0x4A you could send the command: setdevice 10
  - For this example, the EVM would return the acknowledgment and state ("idle" or "collecting") in JSON format:

{"acknowledge":"setdevice 10"}
{"evm_state":"idle"}

- Read register format: rreg ADR
  - Where ADR is the address in hex, and rreg is always lower case.
  - Register addresses can be in upper or lower case, and do not need to be led by '0x'. 0 padding register addresses is also optional. For example, to read register address 0xFF, some valid commands include:
    - rreg ff
    - rreg 00ff
    - rreg 0xFF
      - When '0x' is used, the 'x' must be lower case.
  - For this example, the EVM would return the results and state ("idle" or "collecting") in JSON format:

{"acknowledge":"rreg 0xFF"}
{"register":{"address":255,"value":8800}}
{"evm_state":"idle"}

- Write register format: wreg ADR VAL
  - Where ADR and VAL are in hex, and wreg is always lower case.
  - Register addresses and values can be in upper or lower case, and do not need to be led by '0x'. 0 padding register addresses and values is also optional. For example, to write register address 0x1 with the value 0x436f, some valid commands include:
    - wreg 0 436f
    - wreg 00 0x436f
    - wreg 0x00 0x436F
      - When '0x' is used, the 'x' must be lower case.
  - For this example, the EVM would return the results and state ("idle" or "collecting") in JSON format:

{"acknowledge":"wreg 0x00 0x436f"}
{"console":"Writing 0x436f to CONFIGURATION register"}
{"evm_state":"idle"}

4.2.4.2 Collect Data Through the USB BULK Channel

The *Collect Data* function reads the desired result registers and sends the data based on the specified settings. This function works best with continuous conversion mode and does not configure the EVM or associated register settings for you. Collect mode started and stopped via the serial COM port, however the results will be sent over the USB BULK channel. To use this mode, use the following format:

- Start collecting data format: collect timerPeriod collectFlags channelAddressIDs numDevices
  - Where collect is always lower case, and each parameter is the decimal representation of the value in the following format:
    - timerPeriod
      - The timer delay used in the MCU to allow data collection sample sets (in µs, unsigned 32bit value).
    - collectFlags
      - a byte of data that has a 1 to collect and a 0 to not collect each register value type, according to the following definitions (note to only use energy and charge flags when the device supports that, otherwise set to 0):
        - VSHUNT = 0b1000
        - VBUS = 0b0100
        - CURRENT = 0b0010
        - POWER = 0b0001
    - channelAddressIDs
      - This is the 4 LSBs of each I2C address chained together, starting with the LSBs.
        - For example, if EVM 1 is at address 0x41 and EVM 2 is on ox43, the value here would be 0b00110001
    - NumDevices
      - The number of EVMs chained together (1-4).
  - For example, to start data collection for VSHUNT and VBUS every 2.2 ms, for two INA226EVMs with EVM 1 address = 0x41 and EVM 2 address = 0x43, you would send: collect 2200 12 49 2
    - For this example, the EVM would return the acknowledgment and state in JSON format:

      {"acknowledge":"collect 2200 12 49 2"}
      {"evm_state":"collecting"}
  - The USB BULK channel receives data in the format: frameID deviceNumID address registerSize data
    - Where each parameter is the decimal representation of the value in the following format:
      - frameID (1 byte)
        - Always reads 0. Used to ensure data is aligned.
      - deviceNumID (1 byte)
        - An ID number corresponding to the EVM number.
          - From the above example, this will be 1 if reading from EVM 1 which had address set to 0x41, and 2 if reading from EVM 2 which had a address set to 0x43.
      - address (1 byte)
        - The register address that was read from the device.
      - registerSize (1 byte)
        - The number of bytes that the following data will have.
      - data (1 byte at a time)
        - The register data value, given in bytes with the most significant byte first.
- Stop collecting data format: stop
  - Where stop is always lower case.
  - The EVM will return the acknowledgment and state in JSON format:

    {"acknowledge":"stop"}
    {"evm_state":"idle"}

4.2.5 PAMB Compatibility

If desired, this EVM and GUI can be used with the PAMB Controller (DC081A) by jumper wiring the pin headers of the PAMB to the EVM. Figure 4-16 shows which pins on the PAMB correspond to the EVM header pins. Note not to add too much resistance in the jumper wire connection setup or the signal may degrade and cause communication errors.

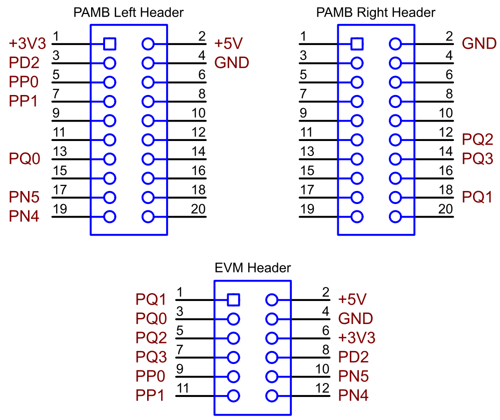

Figure 4-16. EVM to PAMB Connection

5 Circuitry

This section summarizes the EVM subsystems and their components.

5.1 Current Sensing IC

This section describes the INA226 and supporting components.

U1 is the INA226 current-sensing device. C1 and C2 are bypass capacitors that are placed near the sensor to help mitigate power supply noise and provide current quickly to the device when needed. LED D1 with current limiting resistor R4 are used to indicate when the EVM is powered on.

The device pins can be monitored directly through the test points TP1 – TP12. Note that there are two extra test points on GND for convenience.

5.2 Input Signal Path

This section describes the circuitry of the input signal path.

J1 is the main connection terminal. Pin 1 of J1 is used to tie the system ground to the EVM ground. Pin 2 of J1 is used for the VBUS measurement within the sensor. Pins 3 and 4 are tied to IN–, and Pins 5 and 6 are tied to IN+. There are two pins each for IN– and IN+ for convenience.

R1 can be used for an optional onboard shunt resistor with a 2512 footprint. Alternatively, a shunt can be placed across the IN+ and IN– terminals of J1. If desired, a differential voltage can be applied directly for measurement tests.

C3, R2, and R3 combine to make an optional input filter. R2 and R3 are populated with 0-Ω resistors by default. When using input filtering, take into account the input bias current of the device. C3 can also be used without R2 and R3 to reduce noise. See the data sheet for more info on input filtering.

5.3 Digital Circuitry

This section describes the digital circuitry around the device.

J2 and J3 are the main header pins that connect the digital and power pins to the SCB Controller or other EVMs. J3 connects to the EVM/SCB on the right, while J2 connects to more EVMs on the left. R5 and R6 are used as pullup resistors for the main digital IO pins.

SW0 and SW1 set the I2C address of the device. This can be useful when using the EVM with a custom controller (other than the SCB Controller), or when connecting multiple EVMs together. Currently the SCB Controller and GUI are set up to use four EVMs at a time.

R8 is used as a pullup resistor for the ALERT pin, which is routed to both J2 and J3. LED D2 and current limiting resistor R7 are used to indicate when the ALERT has triggered. Header J4 and jumper SH-J4 are used to disconnect the ALERT pin from the EVM ALERT bus by disconnecting from J3. This is primarily used when working with multiple EVMs, so that the individual ALERT LEDs can be seen on each EVM when the ALERT bus is not needed.

6 Schematics, PCB Layout, and Bill of Materials

Note

Board layouts are not to scale. These figures are intended to show how the board is laid out. The figures are not intended to be used for manufacturing EVM PCBs.

6.1 Schematics

Figure 6-1 and Figure 6-2 show the schematic of the INA226EVM. Figure 6-1 shows the circuitry for the EVM. Figure 6-2 shows the mechanical components included with the EVM.

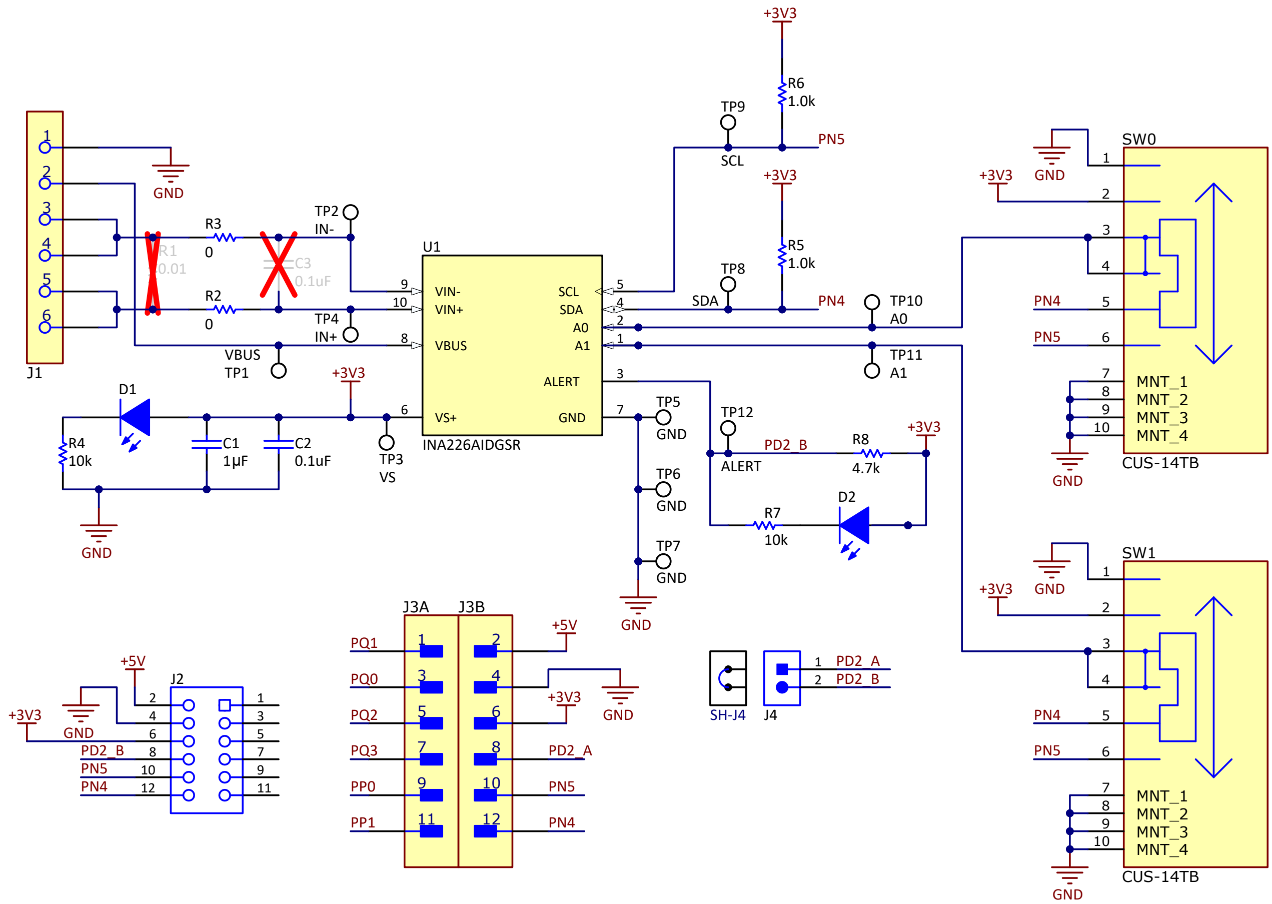

Figure 6-1. Schematic Circuitry

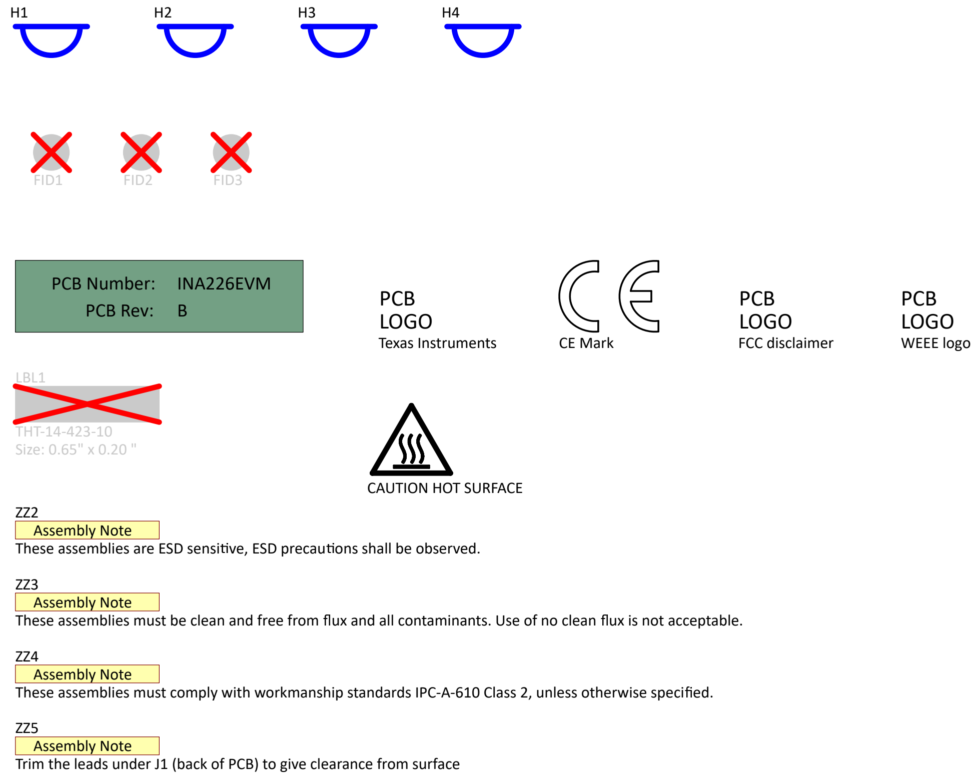

Figure 6-2. Hardware Schematic

6.2 PCB Layout

Figure 6-3 through Figure 6-6 illustrate the PCB layers of the INA226EVM.

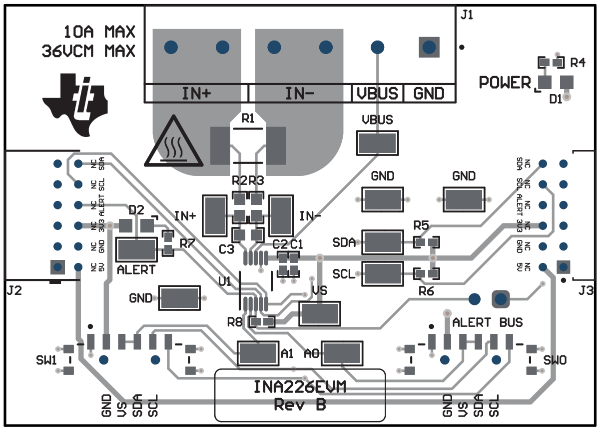

Figure 6-3. Top View

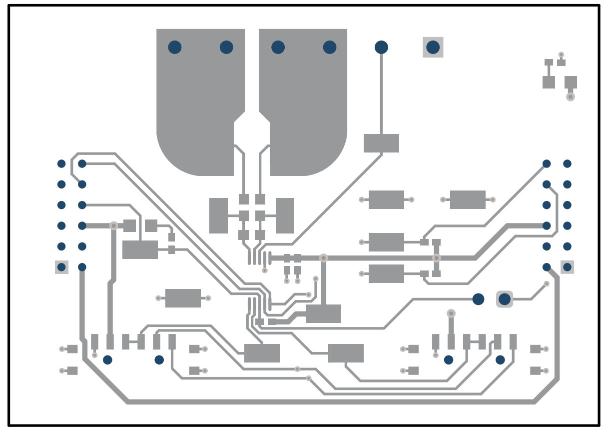

Figure 6-4. Top Layer

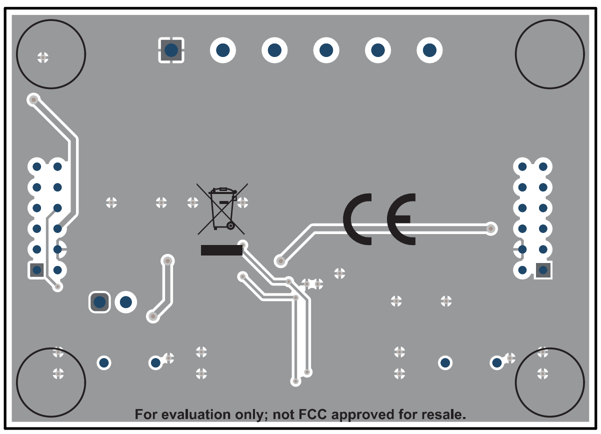

Figure 6-5. Bottom View

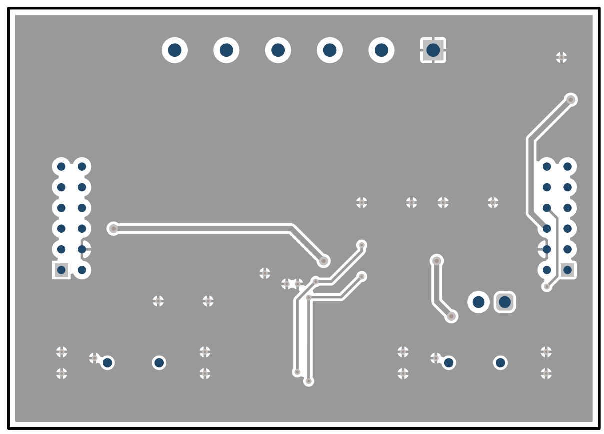

Figure 6-6. Bottom Layer

6.3 Bill of Materials

Table 6-1 provides the parts list for the INA226EVM.

Table 6-1. Bill of Materials

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer
!PCB1	1		Printed Circuit Board		INA226EVM	Any
C1	1	1uF	CAP, CERM, 1 µF, 16 V,+/- 20%, X5R, 0402	0402	GRM155R61C105MA12D	MuRata
C2	1	0.1uF	CAP, CERM, 0.1 uF, 50 V, +/- 20%, X7R, 0402	0402	GRM155R71H104ME14D	MuRata
D1, D2	2	White	LED, White, SMD	0805	VAOL-S8WR4	Visual Communications Company, LLC
H1, H2, H3, H4	4		Bumpon, Hemisphere, 0.25 X 0.075, Clear	75x250 mil	SJ5382	3M
J1	1		TERM BLK 6POS SIDE ENTRY 5MM PCB ASSEMBLY NOTE: Trim leads per ZZ5	HDR6	691137710006	Wurth Electronics
J2	1		Receptacle, 2mm, 6x2, Gold, R/A, TH	Receptacle, 2mm, 6x2, R/A, TH	NPPN062FJFN-RC	Sullins Connector Solutions
J3	1		Connector Header Through Hole, Right Angle 12 position 0.079" (2.00mm)	HDR12	NRPN062PARN-RC	Sullins Connector Solutions
J4	1		Header, 2.54 mm, 2x1, Gold, TH	Header, 2.54mm, 2x1, TH	61300211121	Wurth Elektronik
R2, R3	2	0	RES, 0, 5%, 0.125 W, 0603	0603	MCT06030Z0000ZP500	Vishay/Beyschlag
R4, R7	2	10k	RES, 10 k, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040210K0JNED	Vishay-Dale
R5, R6, R8	3	4.7k	RES, 4.7 k, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW04024K70JNED	Vishay-Dale
SH-J4	1		Shunt, 2.54mm, Gold, Black	Shunt, 2.54mm, Black	60900213421	Wurth Elektronik
SW0, SW1	2		Slide Switch SP4T Surface Mount, Right Angle	SMT_SW_11MM3_4MM1	CUS-14TB	Nidec Copal Electronics
TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12	12		Test Point, Miniature, SMT	Testpoint_Keystone_Miniature	5015	Keystone
U1	1		High-Side Measurement, Bi-Directional Current / Power Monitor with I2C Interface, 2.7 to 5.5 V, -40 to 125 degC, 10-pin SOP (DGS10), Green (RoHS & no Sb/Br)	DGS0010A	INA226AIDGSR	Texas Instruments
C3	0	0.1uF	CAP, CERM, 0.1 uF, 100 V, +/- 10%, X7S, AEC-Q200 Grade 1, 0603	0603	CGA3E3X7S2A104K080AB	TDK
FID1, FID2, FID3	0		Fiducial mark. There is nothing to buy or mount.	N/A	N/A	N/A
LBL1	0		Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	PCB Label 0.650 x 0.200 inch	THT-14-423-10	Brady
R1	0	10m Ω	10 mOhms ±0.5% 2W Chip Resistor 2512 (6432 Metric) Automotive AEC-Q200, Current Sense, Moisture Resistant Metal Film	2512	PCS2512DR0100ET	Ohmite

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   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

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NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *Regulatory Notices:*

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3.1.1 *Notice applicable to EVMs not FCC-Approved:*

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d’usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

3.3.2 *Notice for Users of EVMs Considered “Radio Frequency Products” in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry’s Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

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4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

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7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVMS , REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, , EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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