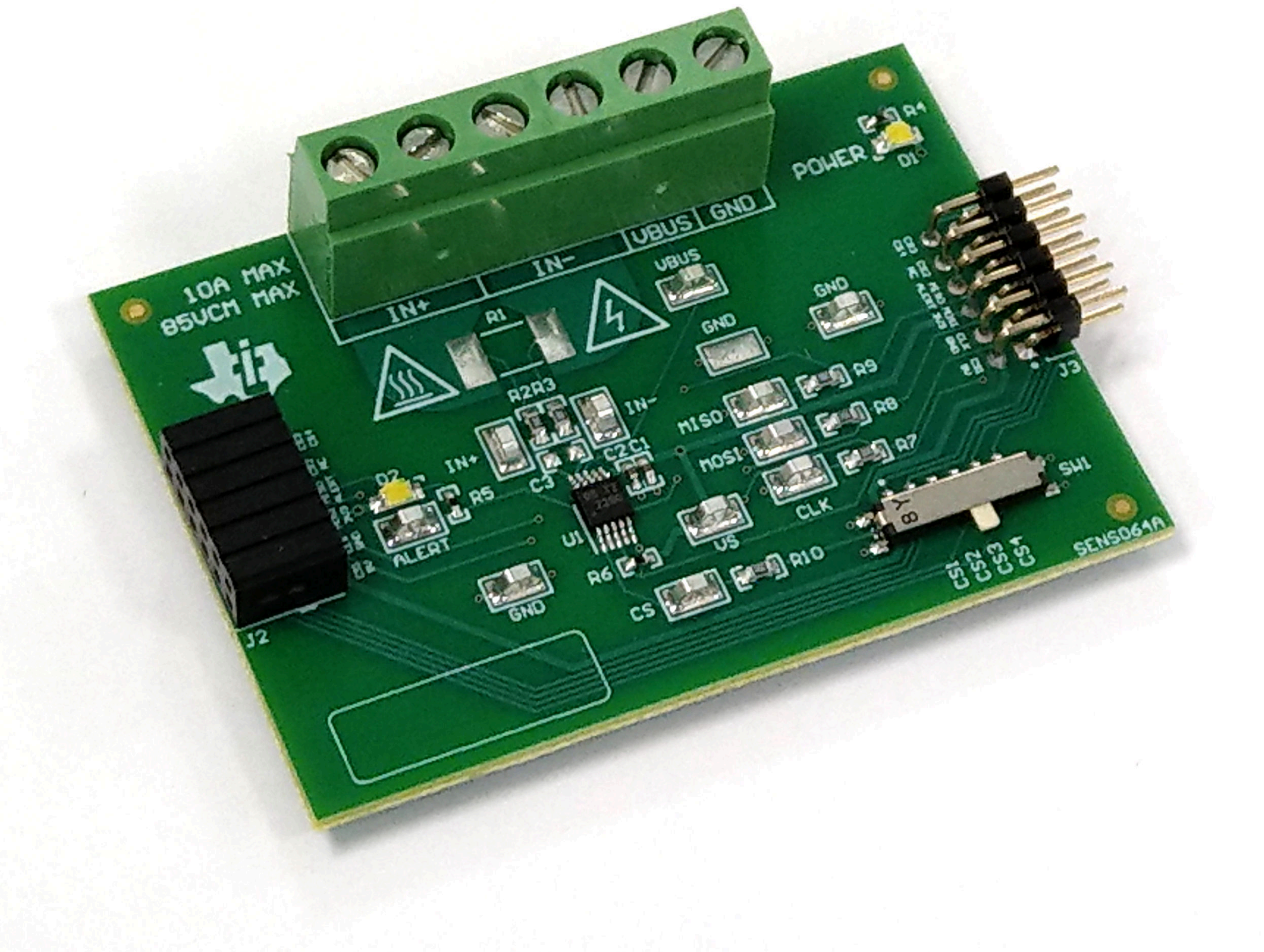
User's Guide

INA228, INA229, INA237, INA238, and INA239 EVM User's Guide

ABSTRACT

This user's guide describes the characteristics, operation, and use of the INA228, INA229, INA237, INA238, and INA239 evaluation modules (EVMs). These EVMs are designed to evaluate the performance of the INA228, INA229, INA237, INA238, and INA239. Throughout this document, the terms evaluation board, evaluation module, and EVM are synonymous with the INA228EVM, INA229EVM, INA237EVM, INA238EVM, and INA239EVM. 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.

General Texas Instruments High Voltage Evaluation (TI HV EMV) User Safety Guidelines

WARNING

Always follow TI's set-up and application instructions, including use of all interface components within their recommended electrical rated voltage and power limits. Always use electrical safety precautions to help ensure your personal safety and those working around you. Contact TI's Product Information Center http://ti.com/customer support for further information.

Save all warnings and instructions for future reference.

> **WARNING**
>
> Failure to follow warnings and instructions may result in personal injury, property damage or death due to electrical shock and burn hazards.

The term TI HV EVM refers to an electronic device typically provided as an open framed, unenclosed printed circuit board assembly. It is *intended strictly for use in development laboratory environments, solely for qualified professional users having training, expertise and knowledge of electrical safety risks in development and application of high voltage electrical circuits. Any other use and/or application are strictly prohibited by Texas Instruments.* If you are not suitable qualified, you should immediately stop from further use of the HV EVM.

1. Work Area Safety:
   a. Keep work area clean and orderly.
   b. Qualified observer(s) must be present anytime circuits are energized.
   c. Effective barriers and signage must be present in the area where the TI HV EVM and its interface electronics are energized, indicating operation of accessible high voltages may be present, for the purpose of protecting inadvertent access.
   d. All interface circuits, power supplies, evaluation modules, instruments, meters, scopes, and other related apparatus used in a development environment exceeding 50Vrms/75VDC must be electrically located within a protected Emergency Power Off EPO protected power strip.
   e. Use stable and non-conductive work surface.
   f. Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.
2. Electrical Safety:
   a. As a precautionary measure, it is always good engineering practice to assume that the entire EVM may have fully accessible and active high voltages.
   b. De-energize the TI HV EVM and all its inputs, outputs and electrical loads before performing any electrical or other diagnostic measurements. Revalidate that TI HV EVM power has been safely de-energized.
   c. With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment hook-ups and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
   d. Once EVM readiness is complete, energize the EVM as intended.

WARNING

While the EVM is energized, never touch the EVM or its electrical circuits, as they could be at high voltages capable of causing electrical shock hazard.

3. Personal Safety
   a. Wear personal protective equipment e.g. latex gloves or safety glasses with side shields or protect EVM in an adequate lucent plastic box with interlocks from accidental touch.

Limitation for safe use:

EVMs are not to be used as all or part of a production unit.

2 Overview

The INA228, INA229, INA237, INA238, and INA239 devices are digital power monitors with integrated 20-bit (INA229 and INA228) and 16-bit (INA237, INA238, and INA239) delta-sigma ADCs specifically designed for current-sensing applications. The devices can measure a selectable full-scale differential input of ±163.84 mV or ±40.96 mV across the shunt with common-mode voltage support from –0.3 V to +85 V. For the INA228 and INA229, built-in digital accumulation calculates average power, internal die temperature, energy, and charge accumulation. For the INA237, INA238, and INA239, built-in digital accumulation calculates average power and internal die temperature. All devices also have built-in diagnostics to indicate system health accessible through a digital output pin, ALERT. The devices operate from a single supply of 2.7 V to 5.5 V, drawing < 1.1-mA current during operation and < 5-µA current during shutdown. The output can be interfaced with a multitude of microcontrollers (MCUs) with a standard 4-wire SPI interface (INA229 and INA239) or with a standard I2C interface (INA228, INA237, and INA238).

Table 2-1. Device Summary

PRODUCT	DIGITAL PROTOCOL	ADC RESOLUTION	MAX GAIN ERROR	MAX OFFSET VOLTAGE
INA228	I2C	20-bit	0.05%	±1 µV
INA229	SPI	20-bit	0.05%	±1 µV
INA237	I2C	16-bit	0.3%	±50 µV
INA238	I2C	16-bit	0.1%	±5 µV
INA239	SPI	16-bit	0.1%	±5 µV

2.1 Kit Contents

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

Table 2-2. Kit Contents

ITEM	QUANTITY
INA228EVM, INA229EVM, INA237EVM, INA238EVM, OR INA239EVM 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 SBOU241. 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
INA228 data sheet	SLYS021
INA228-Q1 data sheet	SLYS022
INA229 data sheet	SLYS023
INA229-Q1 data sheet	SLYS024
INA237 data sheet	SBOSA20
INA237-Q1 data sheet	SBOSA27
INA238 data sheet	SLYS025
INA238-Q1 data sheet	SLYS026
INA239 data sheet	SLYS027
INA239-Q1 data sheet	SLYS028
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 INA228, INA229, INA237, INA238, or INA239. 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 either the INA228, INA229, INA237, INA238, or INA239 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 Section 4.2.5.
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/4910879/INA228_229_237_238_239EVM_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.

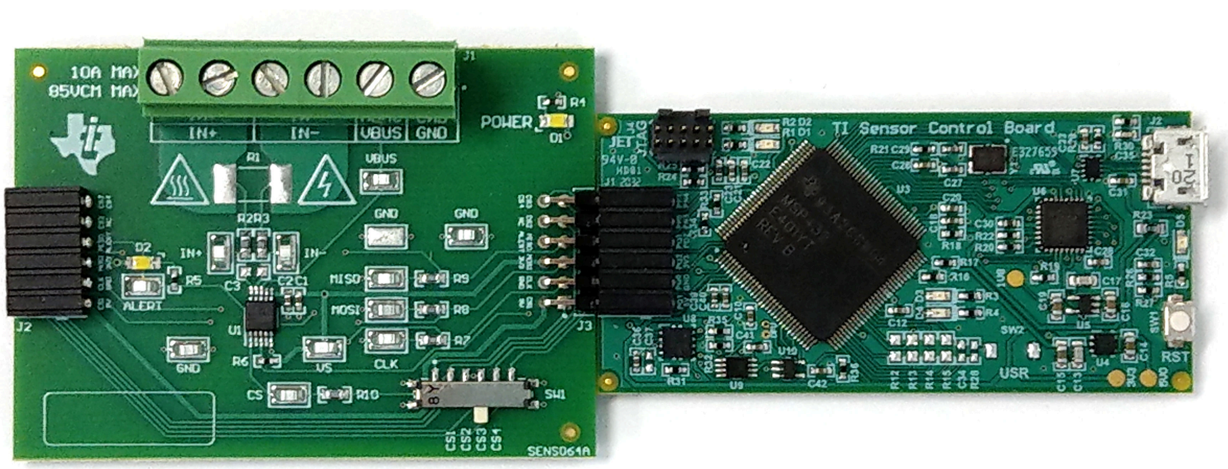


Figure 4-1. EVM (Left) Connected to SCB Controller (Right)

If using multiple EVMs, connect them as shown in Figure 4-2. Make sure to use a different chip select/address for each device. The GUI only supports one EVM/device type at a time, up to 4 EVMs total.

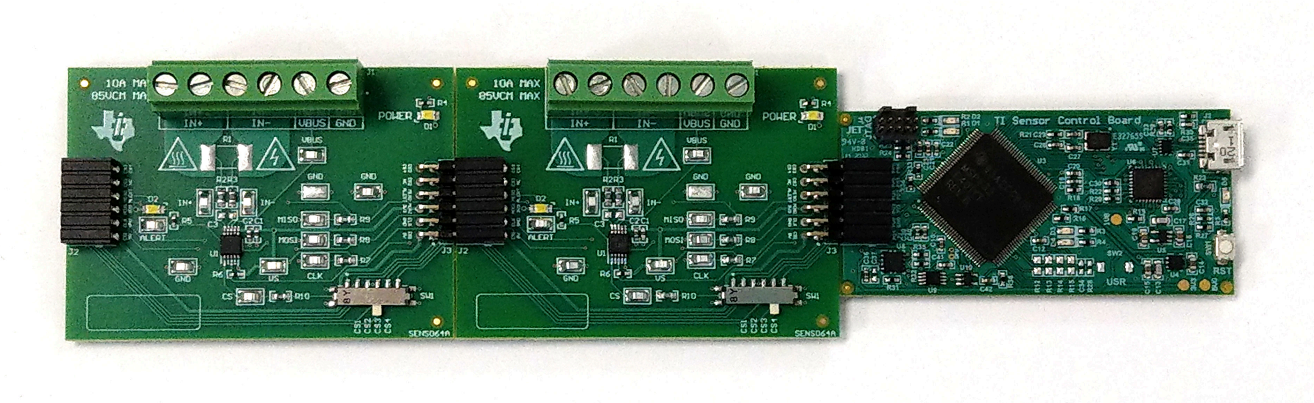


Figure 4-2. Multiple EVMs Connected to SCB Controller

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 (requires previous driver to be 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.

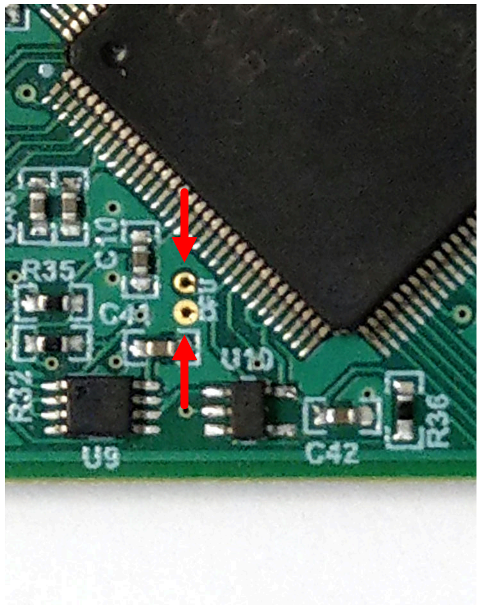


Figure 4-3. Test Points Used to Enter DFU Mode Manually

- 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

The GUI can be accessed from this link in either Chrome, Firefox, or Safari: https://dev.ti.com/gallery/info/4910879/INA228_229_237_238_239EVM_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. Click the **GUI Composer** application (see Figure 4-4) to launch the GUI from the web browser.

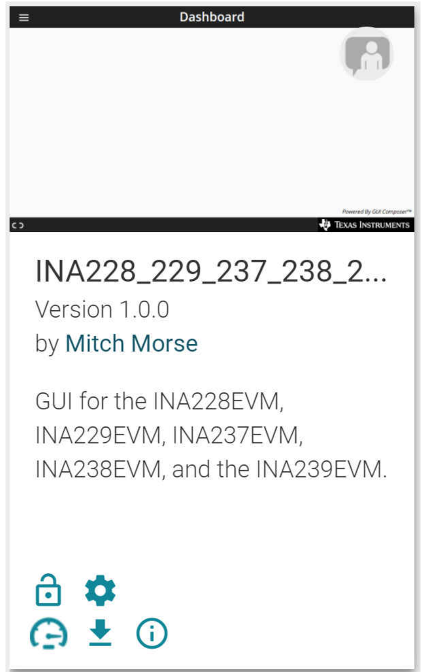


Figure 4-4. GUI Composer Application

a. The GUI link will bring up all versions of the GUI, it is recommended 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 shown in Figure 4-5. These prompts will appear after you close the README.md dialog.

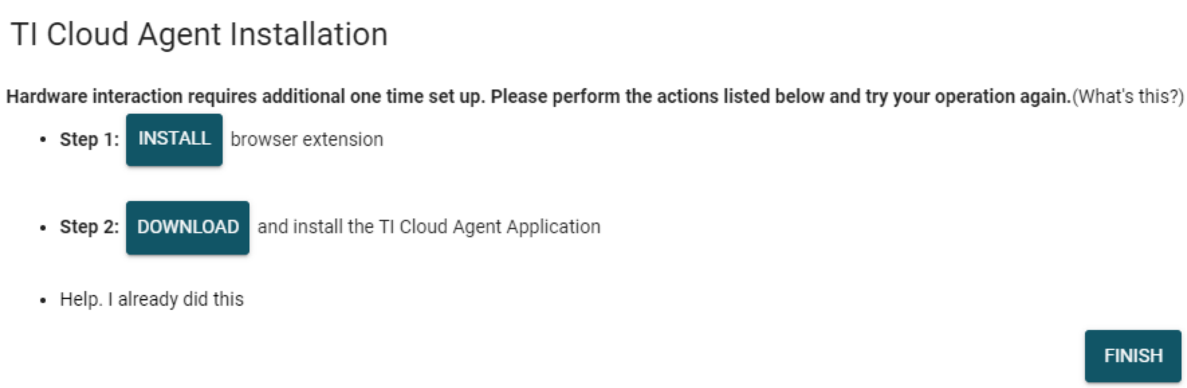


Figure 4-5. TI Cloud Agent

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

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, "Hardware Connected" should be visible near the bottom left corner of the GUI as in Figure 4-6.

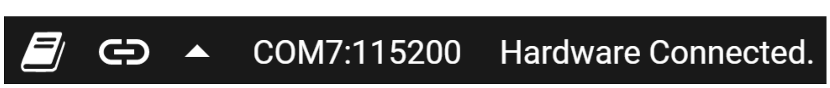


Figure 4-6. Hardware Connected

a. A green indicator with the device type and the text "DEVICE CONNECTED" should also be visible near the top left of the GUI, as shown in Figure 4-7.

Figure 4-7. Device Connected

b. If "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 doesn't work, check different hardware COM ports under **Options >> Serial Port**, as shown in Figure 4-8.

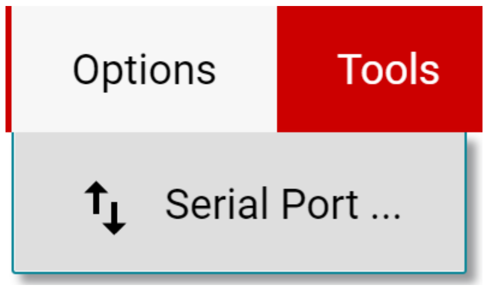


Figure 4-8. Change Serial Port

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 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. To get back to this page from anywhere, just click the (Home) icon on the menu on the left.

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, shown in Figure 4-9.

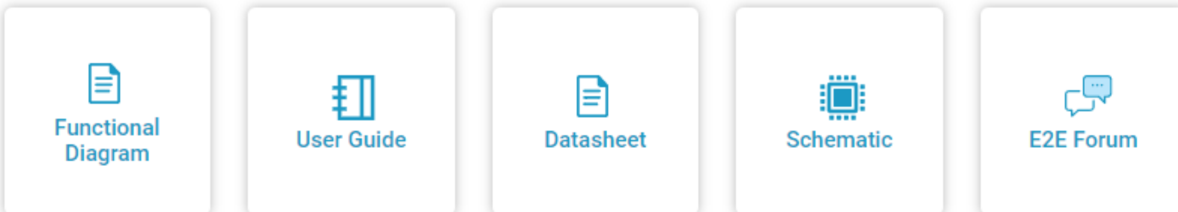


Figure 4-9. Home Tab Links

4.2.2.2 Configuration Tab

To do the initial setup for each connected EVM, click the (Configuration) icon on the menu on the left. An example of the configuration tool is shown in Figure 4-10, which may change based on the device connected.

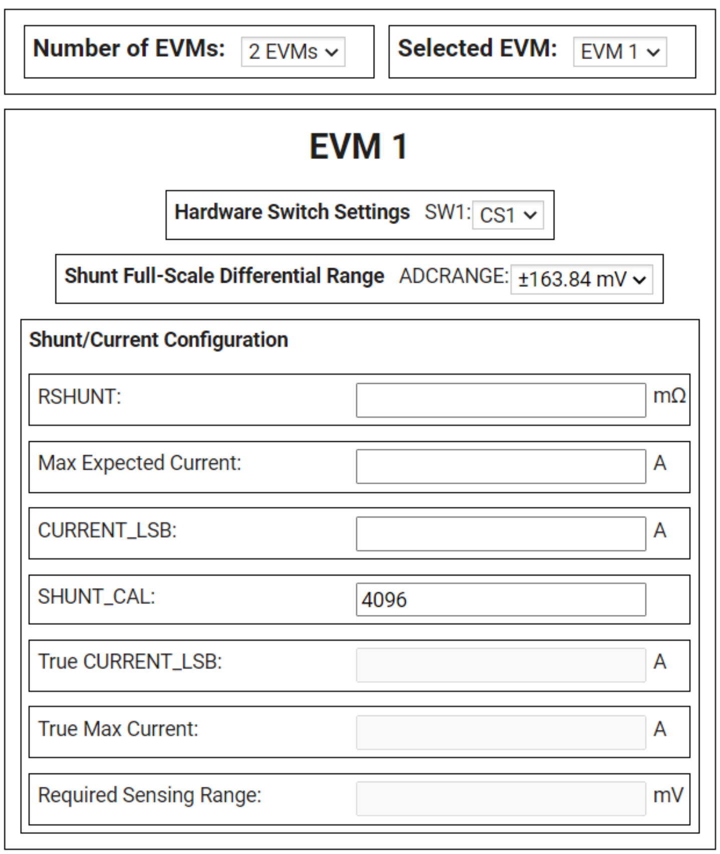


Figure 4-10. Configuration Tool

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 EVMs at a time with the same device on each EVM.
  - 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 page.
- 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 Full-Scale Differential Range
  - This is a shortcut to the ADCRANGE setting from the registers page, placed here for convenience.
  - Both this setting and the ADCRANGE setting from the register page change together.
- Shunt/Current Configuration
  - This section is used to input shunt information as well as to help calculate the CURRENT_LSB and set the SHUNT_CAL 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 SHUNT_CAL 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.
    - SHUNT_CAL
      - Calculated value for SHUNT_CAL based off of RSHUNT and CURRENT_LSB. When this field changes, the value is automatically written to the SHUNT_CAL register.
      - When CURRENT_LSB is specified, changing ADCRANGE will adjust this value automatically per data sheet equations.
        - This will happen if ADCRANGE is changed from either the configuration page or the register map.
        - If CURRENT_LSB is not specified, this value will remain unchanged, but the fields below will adjust to the new ADCRANGE.
      - 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 SHUNT_CAL 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 on the left. The registers tab will look similar to the one shown in Figure 4-11, depending on the device connected.

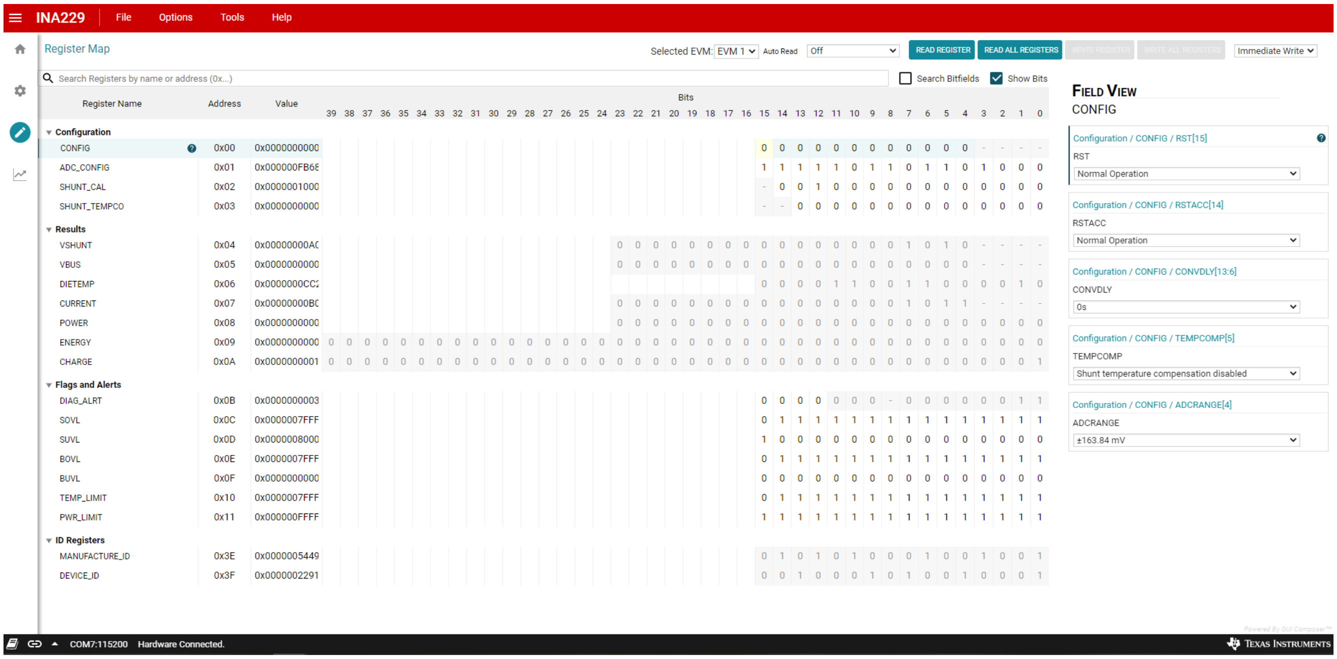


Figure 4-11. GUI Registers Tab

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

- Use the Selected EVM drop box at the 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 button 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.

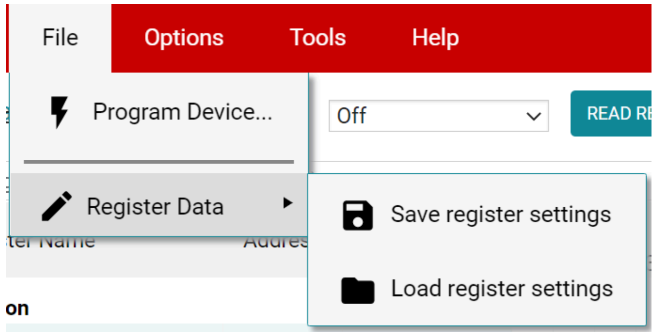


Figure 4-12. Save and Load Register Settings

– It is recommended to press the "Read All Registers" button after loading data to update the register map with the actual device values, in case the loaded registers were not compatible with the connected device.

4.2.2.4 Results Data Tab

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

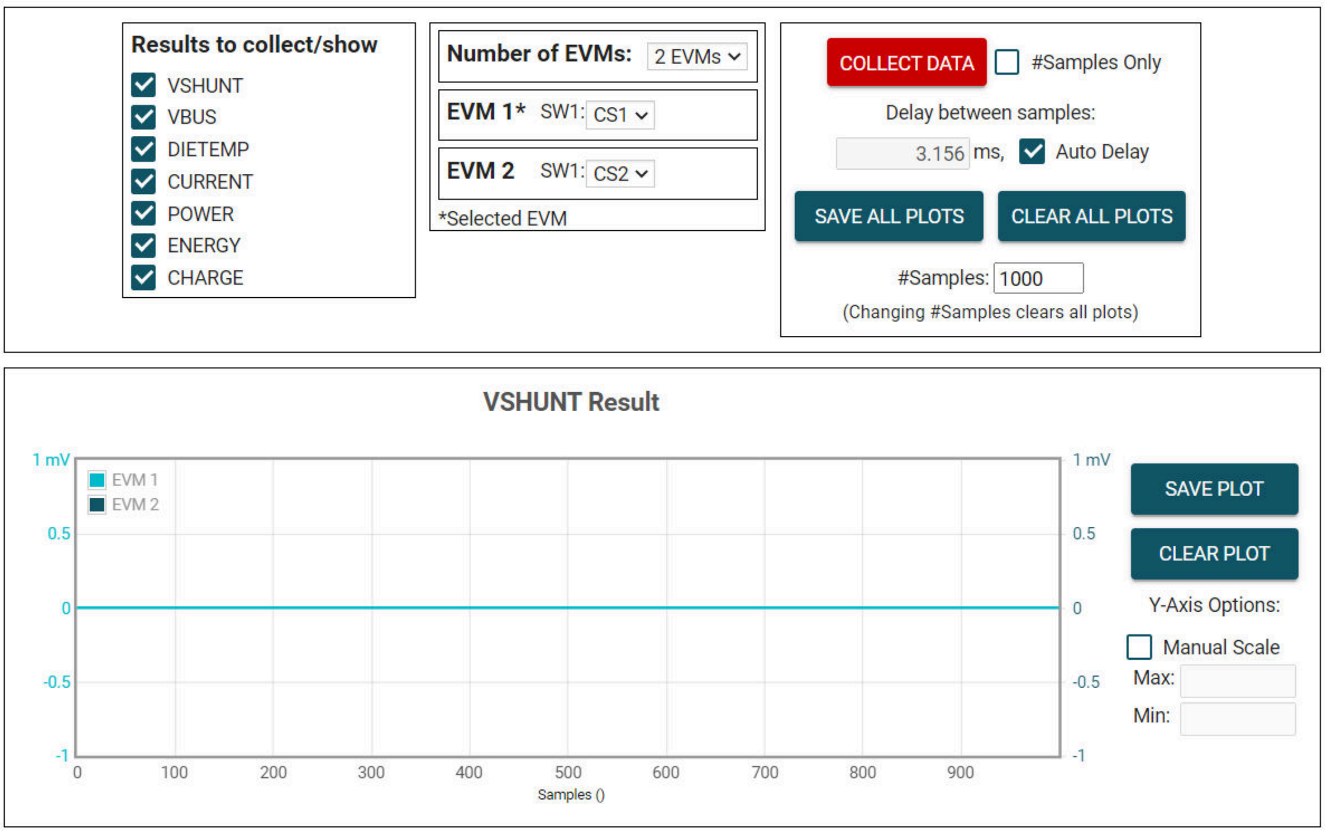


Figure 4-13. Results Page and Settings

Below is a description of how to use the buttons and settings at the top of the results data page 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, then the plot below will not show the data and the EVM will not try to read this value during the collect cycle.
  – 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 one EVM/device type at a time, up to 4 EVMs total.
  - Switch settings
    - Use the onboard switch(es) to select a different address/chip select 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 "*" 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
    - Use 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.
    - Use 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
    - Use the "SAVE ALL PLOTS" button to save the data for each currently selected result from the "Results to collect/show" section in a spreadsheet.
    - Use the "SAVE PLOT" button next to each plot to save just the data from that plot in a spreadsheet.
  - Clear All Plots
    - Use the "CLEAR ALL PLOTS" button to clear the data from all plots together.
    - Use 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.
      - For the DIETEMP Result, the units can also be toggled between °C and °F.

    - This processes the existing data in the plots, and converts new data coming in. If receiving new data while changing units, it is possible that a datapoint gets missed or duplicated.
- 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 via 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.

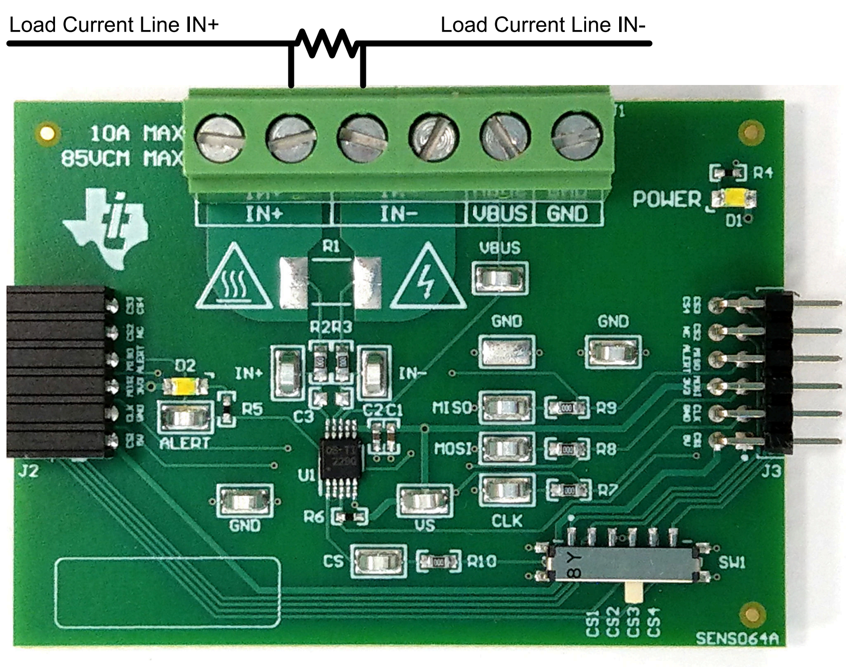


Figure 4-14. IN+ and IN– Wiring for More Than 10A

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.

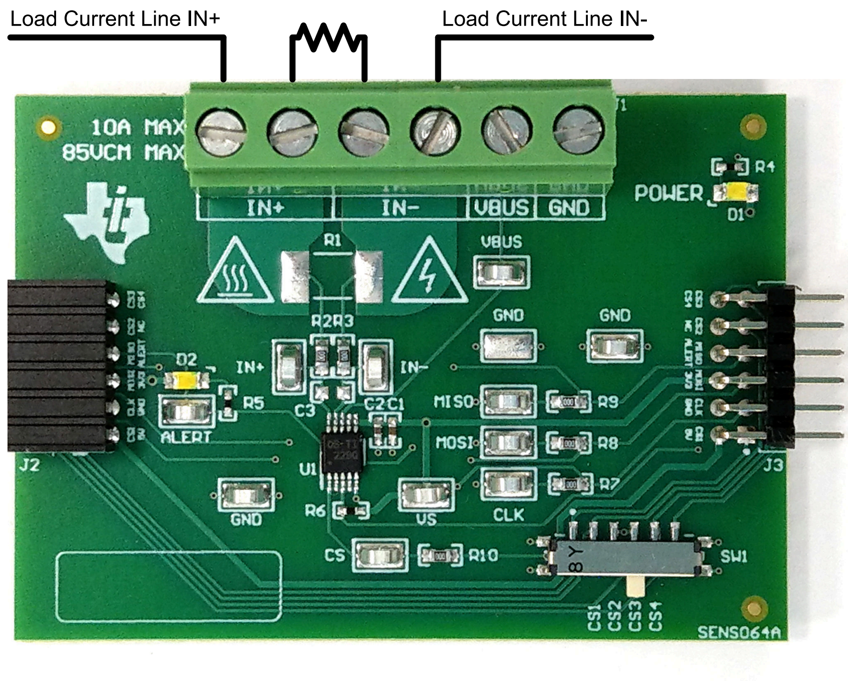


Figure 4-15. IN+ and IN– Wiring for 10A or Less

> **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.
>
> Do not touch high voltage terminals.
>
> 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:
    - SPI
      - The chip select number. Ex, for chip select of 3, use 3.

    - I2C
        - 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/chip select 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 an I2C device 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 0xB, some valid commands include:
    - rreg b
    - rreg 0B
    - rreg 0x0B
      - 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 0x0B"}
{"register":{"address":11,"value":3}}
{"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 0xfb69, some valid commands include:
    - wreg 1 fb69
    - wreg 01 0xfb69
    - wreg 0x01 0xFB69
      - 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 0x01 0xfb69"}
{"console":"Writing 0xfb69 to ADC_CONFIG 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 = 0b1000000
        - VBUS = 0b0100000
        - DIETEMP = 0b0010000
        - CURRENT = 0b0001000
        - POWER = 0b0000100
        - ENERGY = 0b0000010
        - CHARGE = 0b0000001
    - channelAddressIDs
      - SPI
        - Each 4 bits is the chip select (CS) value for each EVM chained together starting with the LSBs (each CS can either be 1, 2, 3 or 4).
          - For example, if EVM 1 is on channel 1 and EVM 2 is on channel 3, the value here would be 0b00110001.
      - I2C
        - This is the 4 LSBs of each address chained together, starting with the LSBs.
          - For example, if EVM 1 is on channel 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, VBUS, and DIETEMP every 3.156 ms, for two INA229s with EVM 1 CS = 1 and EVM 2 CS = 3, you would send: collect 3156 112 49 2
    - For this example, the EVM would return the acknowledgment and state in JSON format:

      {"acknowledge":"collect 3156 112 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 CS set to 1, and 2 if reading from EVM 2 which had a CS set to 3.
      - 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.

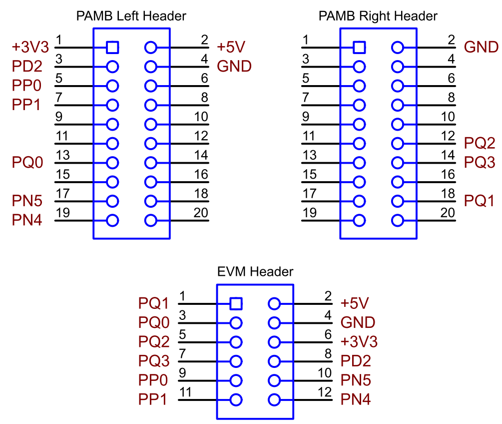


Figure 4-16. EVM to PAMB Connection

The new GUI and firmware can also be used with the SENS063A and SENS064A and PAMB Controller. If the firmware does not update automatically, DFU mode may need to be entered manually. See *Firmware Debug*.

When using SENS064A on the PAMB with the new GUI/Firmware, only 1 device can be used at a time, with SW1 on the EVM set to CS3, and the GUI switch setting set to CS1.

5 Circuitry

This section summarizes the EVM subsystems and their components.

5.1 Current Sensing IC

This section describes the main INA device and supporting components.

U1 is the main INA current-sensing device (either the INA228, INA229, INA237, INA238, or INA239). 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.

5.3.1 I2C (INA228, INA237, INA238)

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.

5.3.2 SPI (INA229, INA239)

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. R7–R10 are 0-Ω resistors in series with the main digital IO pins. Optionally, these resistor spaces can be used to provide inline filtering on the digital lines, or the resistors can be removed to disconnect the digital pins from the header pins.

SW1 is used to redirect the control signal line (CS) to 1 of 4 pins on J2 and J3. 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 EVM at a time. (Note, if using the PAMB Controller and the SENS064A EVM, you can only use one EVM at a time, with SW1 on the EVM set to CS3, and the GUI switch setting set to CS1.)

R6 is used as a pullup resistor for the ALERT pin, which is routed to J2 and J3. LED D2 and current limiting resistor R5 are used to indicate when the ALERT has triggered.

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

This section shows the schematics separately for the SENS063 and SENS064

6.1.1 SENS063 (INA228EVM, INA237EVM, INA238EVM)

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

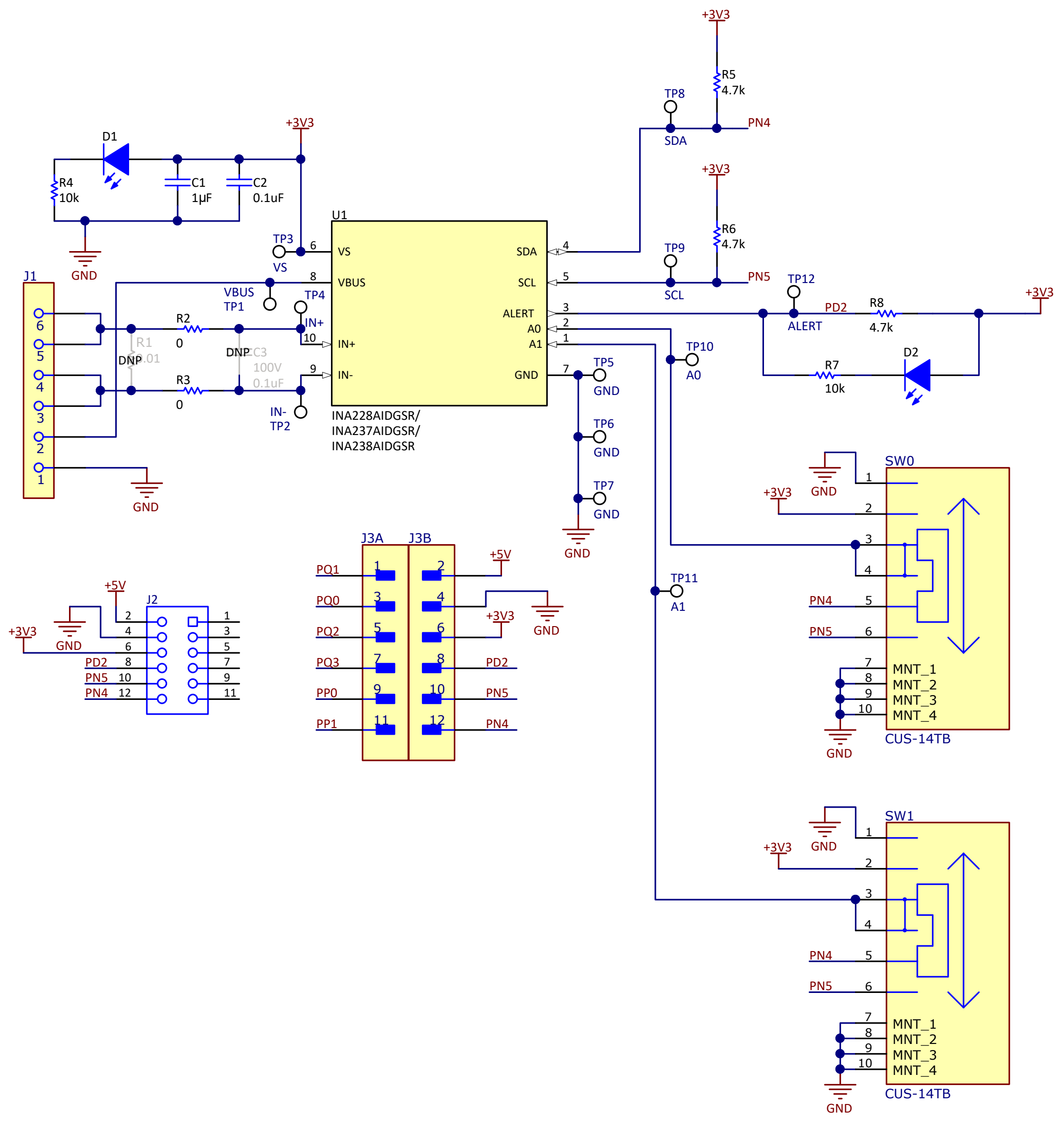
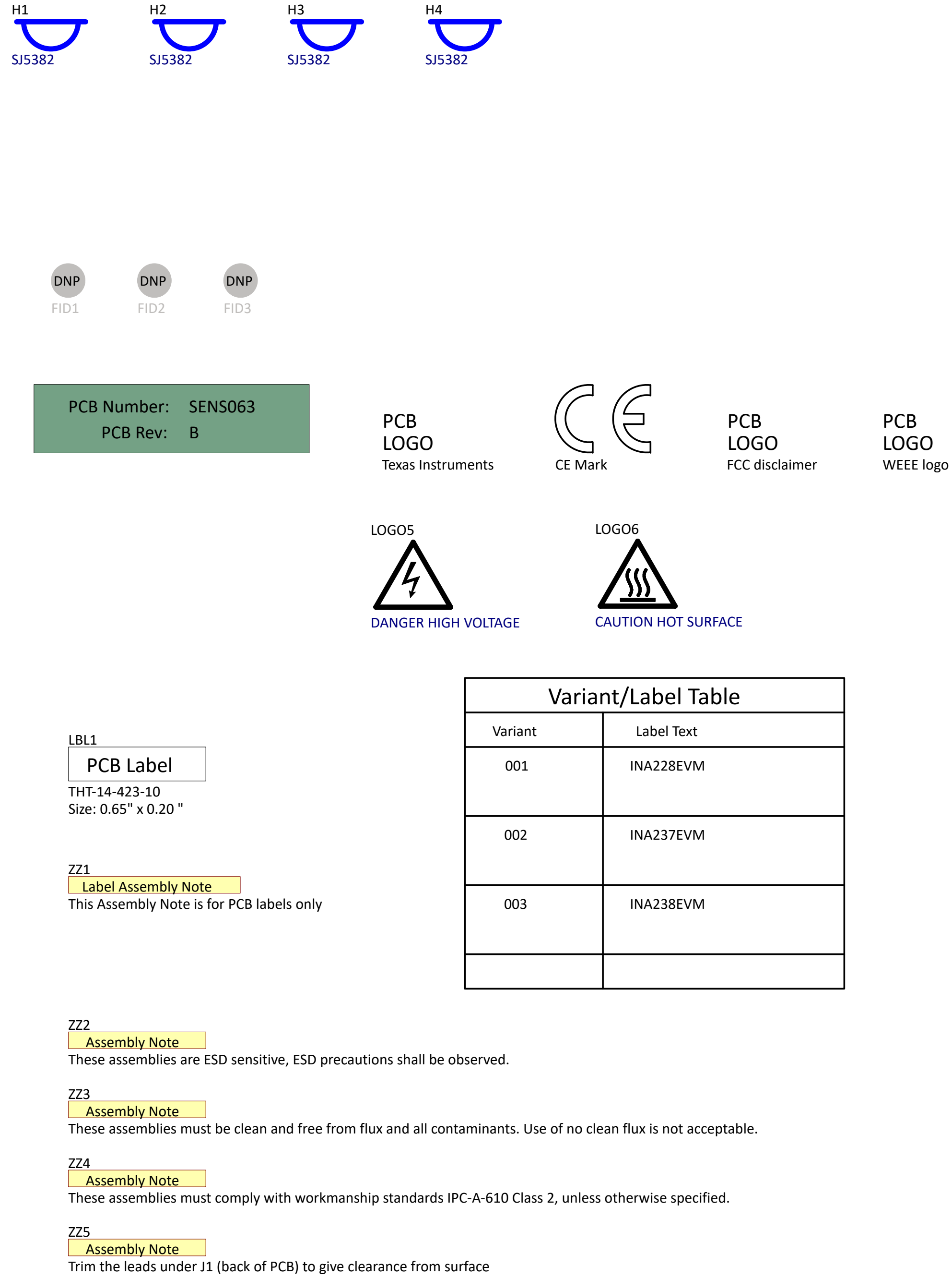


Figure 6-1. SENS063 Schematic



Variant/Label Table

Variant	Label Text
001	INA228EVM
002	INA237EVM
003	INA238EVM

Figure 6-2. SENS063 Hardware Schematic

6.1.2 SENS064 (INA229EVM, INA239EVM)

Figure 6-3 and Figure 6-4 show the schematic of the EVM. Figure 6-3 shows the circuitry for the EVM. Figure 6-4 shows the mechanical components included with the EVM.

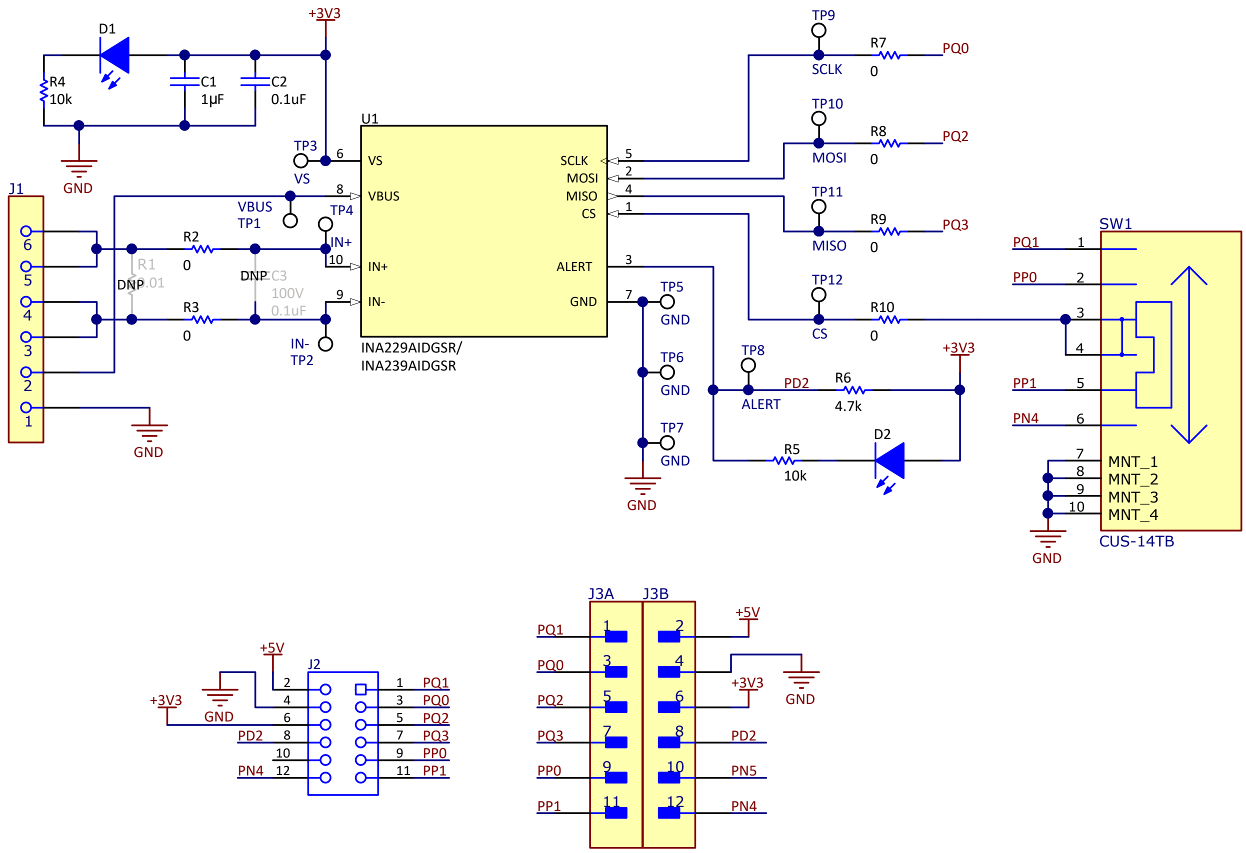
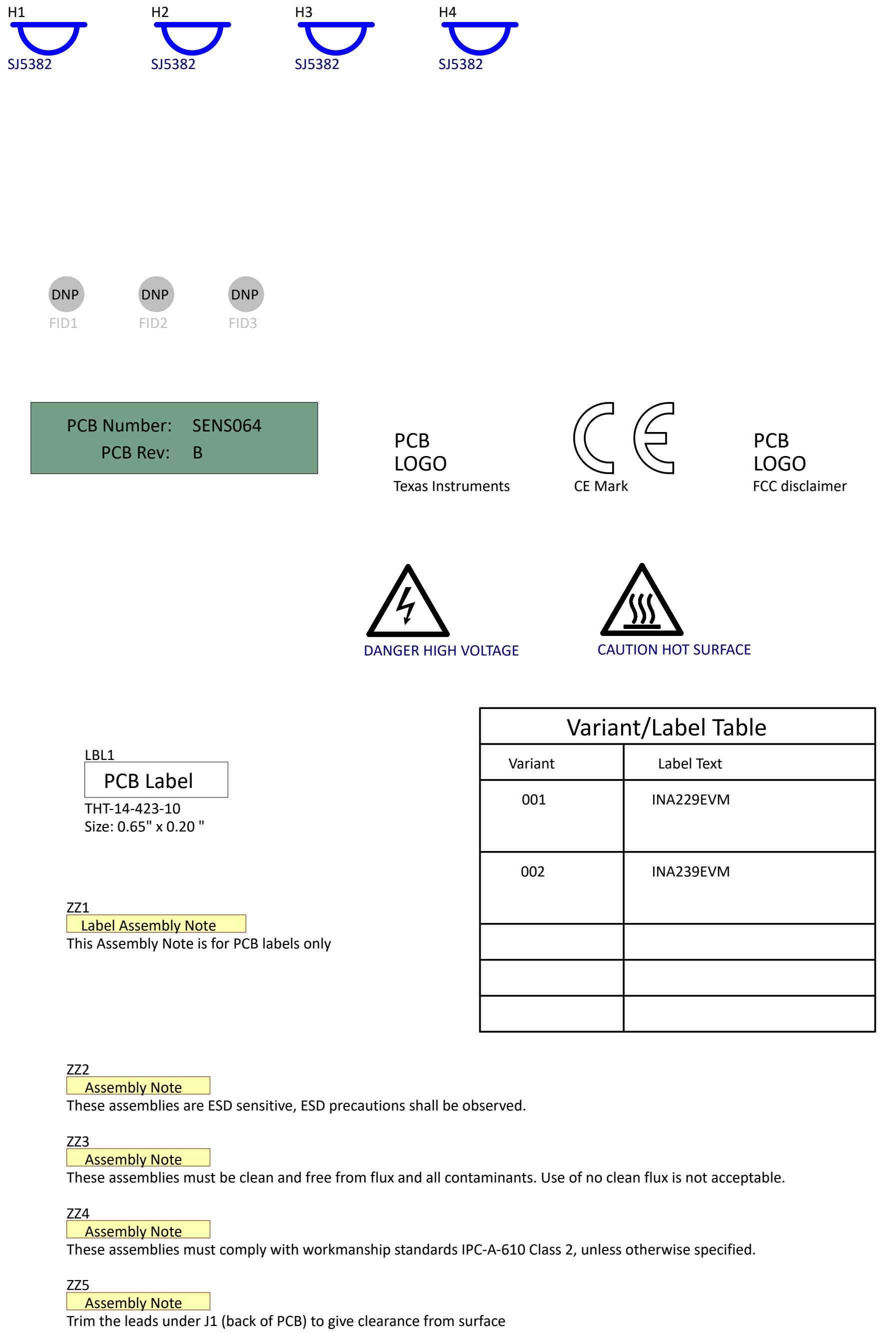


Figure 6-3. SENS064 Schematic



Variant	Label Text
001	INA229EVM
002	INA239EVM

Figure 6-4. SENS064 Hardware Schematic

6.2 PCB Layout

6.2.1 SENS063 (INA228EVM, INA237EVM, INA238EVM)

Figure 6-5 through Figure 6-8 illustrate the PCB layers of the EVM.

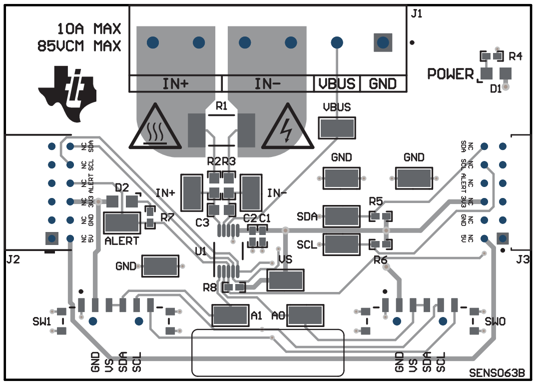


Figure 6-5. SENS063 Top View

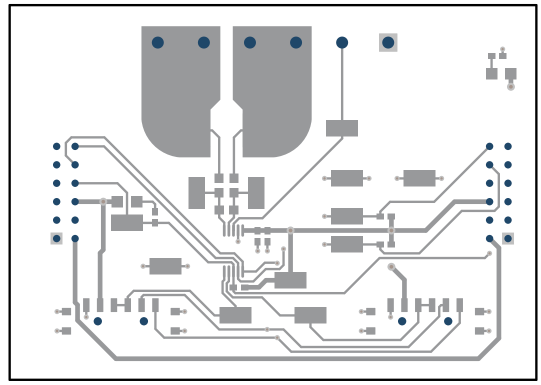


Figure 6-6. SENS063 Top Layer

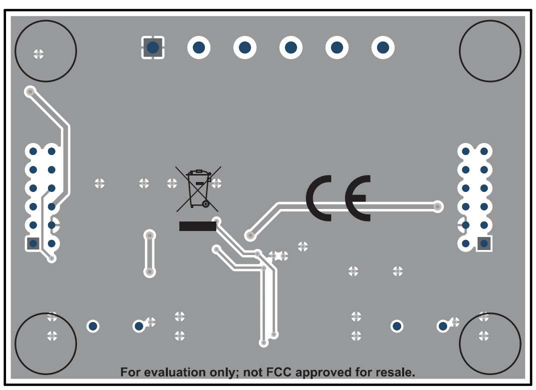


Figure 6-7. SENS063 Bottom View

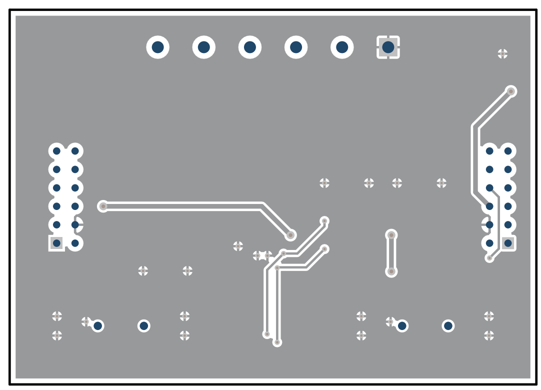


Figure 6-8. SENS063 Bottom Layer

6.2.2 SENS064 (INA229EVM, INA239EVM)

Figure 6-9 through Figure 6-12 illustrate the PCB layers of the EVM.

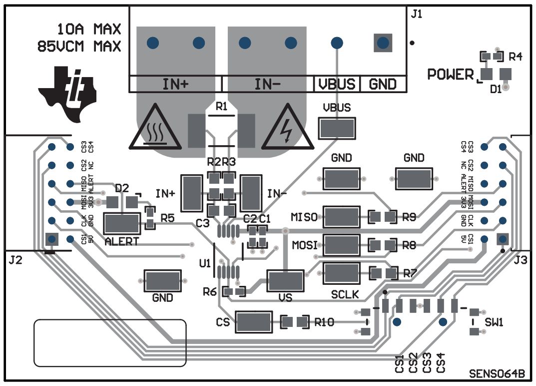


Figure 6-9. SENS064 Top View

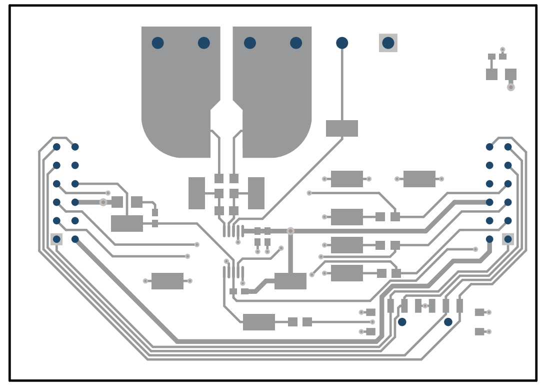


Figure 6-10. SENS064 Top Layer

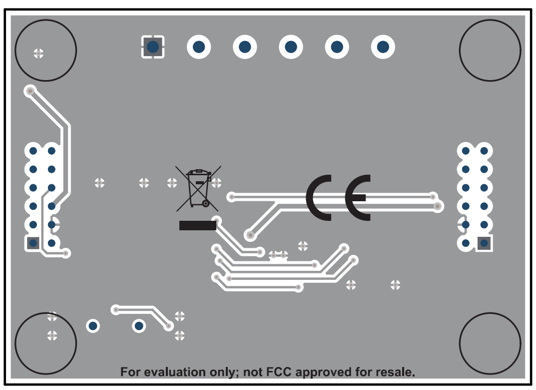


Figure 6-11. SENS064 Bottom View

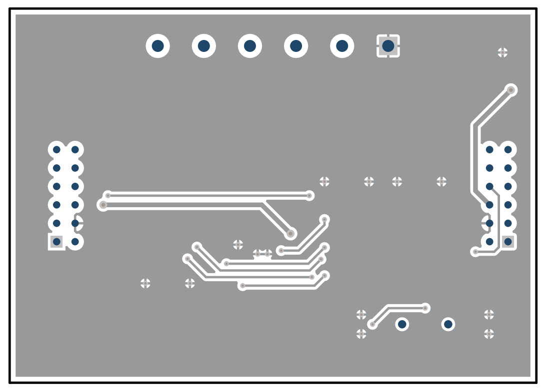


Figure 6-12. SENS064 Bottom Layer

6.3 Bill of Materials

This section shows the bill of materials separately for the SENS063 and SENS064

6.3.1 SENS063 (INA228EVM, INA237EVM, INA238EVM)

Table 6-1 through Table 6-4 provide the parts list for the EVM. Table 6-1 through Table 6-3 are variant specific, while Table 6-4 shows the parts common to all SENS063 variants.

Table 6-1. INA228EVM Exclusive Bill of Materials

Designator	QTY	Value	Description	Package Reference	Part Number	Manufacturer
U1	1		85-V, High-Voltage, Zero-Drift, 20-Bit ADC, I2C, Bidirectional Shunt Current, Bus Voltage, Power, Temperature, Energy and Charge Monitor, DGS0010A (VSSOP-10)	DGS0010A	INA228AIDGSR	Texas Instruments

Table 6-2. INA237EVM Exclusive Bill of Materials

Designator	QTY	Value	Description	Package Reference	Part Number	Manufacturer
U1	1		85-V, High-Voltage, Zero-Drift, 16-Bit ADC, I 2C, Bidirectional Shunt Current, Bus Voltage, Power, and Temperature Monitor	DGS0010A	INA237AIDGSR	Texas Instruments

Table 6-3. INA238EVM Exclusive Bill of Materials

Designator	QTY	Value	Description	Package Reference	Part Number	Manufacturer
U1	1		85-V, High-Voltage, Zero-Drift, 16-Bit ADC, I 2C, Bidirectional Shunt Current, Bus Voltage, Power, and Temperature Monitor	DGS0010A	INA238AIDGSR	Texas Instruments

Table 6-4. SENS063 Variants Bill of Materials

Designator	QTY	Value	Description	Package Reference	Part Number	Manufacturer
!PCB1	1		Printed Circuit Board		SENS063	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 PCBASSEMBLY 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
LBL1	1		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
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
SW0, SW1	2		Slide Switch SP4T Surface Mount, Right Angle	SMT_SW_11MM3_4MM1	CUS-14TB	Nidec Copal Electronics

Table 6-4. SENS063 Variants Bill of Materials (continued)

Designator	QTY	Value	Description	Package Reference	Part Number	Manufacturer
TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12	12		Test Point, Miniature, SMT	Testpoint_Keystone_Miniature	5015	Keystone
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
R1	0		10 mOhms ±0.5% 2W Chip Resistor 2512 (6432 Metric) Automotive AEC-Q200, Current Sense, Moisture Resistant Metal Film	2512	PCS2512DR0100ET	Ohmite

6.3.2 SENS064 (INA229EVM, INA239EVM)

Table 6-5 through Table 6-7 provide the parts list for the EVM. Table 6-5 and Table 6-6 are variant specific, while Table 6-7 shows the parts common to all SENS064 variants.

Table 6-5. INA229EVM Exclusive Bill of Materials

Designator	QTY	Value	Description	Package Reference	Part Number	Manufacturer
U1	1		85-V, High-Voltage, Zero-Drift, 20-Bit ADC, SPI, Bidirectional Shunt Current, Bus Voltage, Power, and Temperature, Energy and Charge Monitor, DGS0010A (VSSOP-10)	DGS0010A	INA229AIDGSR	Texas Instruments

Table 6-6. INA239EVM Exclusive Bill of Materials

Designator	QTY	Value	Description	Package Reference	Part Number	Manufacturer
U1	1		85-V, High-Voltage, Zero-Drift, 16-Bit ADC, SPI, Bidirectional Shunt Current, Bus Voltage, Power, and Temperature Monitor	DGS0010A	INA239AIDGSR	Texas Instruments

Table 6-7. SENS046 Variants Bill of Materials

Designator	QTY	Value	Description	Package Reference	Part Number	Manufacturer
!PCB1	1		Printed Circuit Board		SENS064	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 PCBASSEMBLY 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
LBL1	1		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
R2, R3, R7, R8, R9, R10	6	0	RES, 0, 5%, 0.125 W, 0603	0603	MCT06030Z0000ZP500	Vishay/Beyschlag

Table 6-7. SENS046 Variants Bill of Materials (continued)

Designator	QTY	Value	Description	Package Reference	Part Number	Manufacturer
R4, R5	2	10k	RES, 10 k, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040210K0JNED	Vishay-Dale
R6	1	4.7k	RES, 4.7 k, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW04024K70JNED	Vishay-Dale
SW1	1		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
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
R1	0		10 mOhms ±0.5% 2W Chip Resistor 2512 (6432 Metric) Automotive AEC-Q200, Current Sense, Moisture Resistant Metal Film	2512	PCS2512DR0100ET	Ohmite

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision C (July 2021) to Revision D (February 2022) **Page**

- Removed SCB as a kitted item....................5

Changes from Revision B (December 2020) to Revision C (July 2021) **Page**

- Updated GUI setup and operation instructions after software update....................5

Changes from Revision A (June 2020) to Revision B (December 2020) **Page**

- Updated from preview EVM to full production EVM....................1
- Updated the numbering format for tables, figures, and cross-references throughout the document....................5

Changes from Revision * (April 2020) to Revision A (June 2020) **Page**

- Updated document to add support for the INA228EVM, INA237EVM, and INA238EVM....................1
- Added *Direct EVM Serial Communication* section to explain how to communicate with the EVM via direct serial communication....................18