User's Guide

Migration From INA219 to INA232

Current Sensing

ABSTRACT

This user's guide compares the features of the INA219 and INA232 digital power monitors, and outlines key differences that need to be considered when migrating from INA219 to INA232. A design example is used to highlight both commonalities and differences between the two. The example demonstrates that there are a range of applications that can be served by both devices, either to solve a supply chain constraint issue or simply to upgrade to the latest product offerings from TI. For applications that require features unique to one device, substituting one device with the other device is not always possible.

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1 Overview

A *digital power monitor* is specially designed for current sensing applications, with an integrated analog-to-digital converter that is able to withstand common-mode voltages that are much higher than the device power supply itself. As a result, the digital power monitor can be directly interfaced with the circuit being measured.

Digital power monitors extract the small differential shunt voltage from a normally high common-mode voltage rail. This shunt voltage is proportional to the load current supplied by the voltage rail. The common mode (Bus) voltage is also measured. With these two measurements, the power monitors calculate the current, voltage, and power. These quantities are available as bit streams and available through the digital interface. Figure 1-1 shows a block diagram of a typical power monitor with I^2C digital interface.

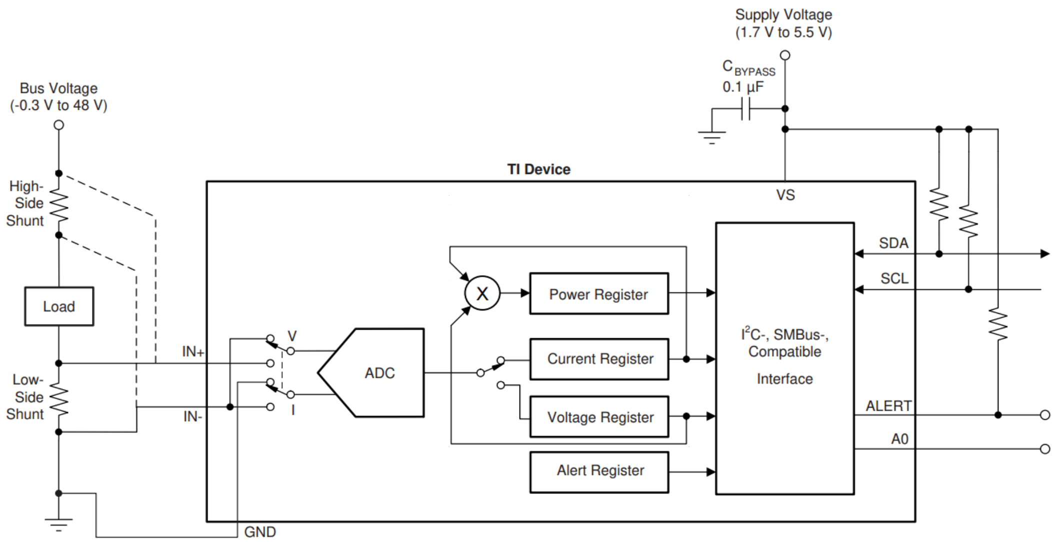

Figure 1-1. Block Diagram of a Digital Power Monitor

1.1 INA232 and INA219

The INA219 is a current shunt and power monitor with an I^2C- or SMBus-compatible interface. The device monitors both shunt voltage drop and bus supply voltage, with programmable conversion times and filtering. A programmable calibration value, combined with an internal multiplier, enables direct readouts of current in amperes. An additional multiplying register calculates power in watts. The I^2C- or SMBus-compatible interface features 16 programmable addresses. The INA219 is available in two grades: A and B. The B grade version has higher accuracy and higher precision specifications.

The INA232 device is a 16-bit digital current monitor with an I^2C- or SMBus-compatible interface that is compliant with a wide range of voltages such as 1.2 V, 1.8 V, 3.3 V, and 5.0 V. The device monitors the voltage across an external sense resistor and reports values for current, bus voltage, and power. The INA232 senses current on common-mode bus voltages that can vary from –0.3 V to 48 V, independent of the supply voltage. The device operates from a single 1.7-V to 5.5-V supply, drawing a typical supply current of 300 µA in normal operation. The device can be placed in a low-power standby mode where the typical operating current is 2.2 µA.

Figure 1-2 compares some of the key electrical specifications of INA219 and INA232

Parameter	INA232	INA219B
Operational V_{CM} Range (V)	–0.3 V to 48 V	0 V to 26 V
Surviving V_{CM} Range (V)	–0.3 V to 50 V	–0.3 V to 26 V
ADC Range Options	±20mV, ±80mV	±40mV, ±80mV, ±160mV, ±320mV
Gain Error @ 25°C (max)	0.25%	0.30%
Gain Error Drift (ppm/°C)	50	
V_{OS} @ 25°C (max µV)	20	50
V_{OS} Drift (max µV/°C)	0.1	
CMRR (min dB)	126	100
PSRR (min uV/V)	5	10
IN- pin impedance (typical)	1.05MΩ	320KΩ
BUS Offset Voltage (max mV)	10	
BUS Voltage Gain Error (max %)	0.25	0.5
BUS Voltage Gain Error Drift (max ppm)	50	
Supply Voltage Range (V)	1.7 V to 5.5 V	3 V to 5.5 V
I_Q (max mA)	0.5	1
I_B (typ µA)	300	700
I_{SD} (max µA)	3	15
Digital input Specifications		
Logic Input High (min V)	0.9	0.7*Vs
Logic Input Low (max V)	0.4	0.3*Vs
Addressing Options	4	16
Digital Output Specifications		
Number of ADC Bits	16	9, 10, 11, 12
Fastest Conversion Time	147	93 (9-bit)
Output Options	ALERT	
Output Low Level (max V)	0.3	0.4
Low-Side capable	General Call Start	

Figure 1-2. Key Features of INA232 and INA219

2 Migrating From INA219 to INA232

Since INA232 is not a drop-in replacement for INA219, certain modifications are necessary for the existing firmware to work when migrating from INA219 to INA232. Further, it is advantageous to update the firmware so that the device is backward compatible. Correct settings and math calculations can be applied depending on the device populated on the application board.

Although not entirely identical, INA219 and INA232 are highly similar in terms of package and pinout. In some migration projects, there is no need for hardware change at all; while in some, it is simply a matter of minor assembly and BOM adjustment. However, the specifics need to be decided based on the individual projects.

2.1 Package Selection and Pinout

INA219 is available in both the SOT23-8 and SOIC-8 packages, while INA232 is available in the SOT23-8 package. For an existing PCB design, the best chance of migrating from INA219 to INA232 without footprint change is with the SOT23. The two SOT23 packages are only different in height, other physical dimensions are essentially identical. Figure 2-1 shows the package and pinout of the two devices.

Pinout is also identical except pin 8, where pin 8 is the address for pin A1 for INA219, but is the ALERT output for INA232. It is common to leave address pins configurable through 0-Ω resistors. If this is the case for a design already in production, you can reconfigure this pin to enable switching between INA219 and INA232 through a

BOM change. If the A1 pin on the INA219 is connected to ground, the INA232 likely can be used without any hardware change. The ALERT pin of INA232 is an open-drain output and can be connected to ground

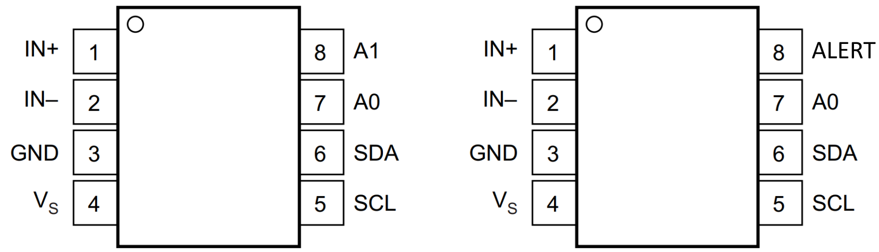

Figure 2-1. Package and Pinout

2.2 Device Address

INA219 comes with two address pins which makes it possible to have direct access to sixteen (16) unique INA219 devices in the same system. Conversely, INA232 has only one address pin, which allows direct access to only four devices.

In designs where INA219 is used and address pin A1 is connected to GND, then the addressing is compatible between INA219 and INA232.

In systems where more than four power monitors are needed, increasing the number of INA232 devices through an I^2C expander is possible.

2.3 Shunt Voltage Range

The front-end PGA in INA219 enables four shunt input voltages. The lowest range starts at ±40 mV. If larger full-scale shunt voltages are desired, the PGA function is capable of increasing the full-scale range by 2, 4, or 8 times (up to 320 mV). Additionally, the bus voltage measurement has two full-scale ranges: 16 V or 32 V, although the best practice is to limit the actual bus voltage to under 26 V to prevent damage to the device.

Two shunt input ranges are possible in INA232, namely ±20 mV and ±80 mV. INA232 has single full scale bus measurement range of up to 48 V.

As long as shunt input voltage is below the range of ±80 mV, both INA219 and INA232 can be used without changing the shunt resistor to a different value.

2.4 Power Supply and IO Voltage Levels

INA219 is powered between 3 V and 5.5 V, consuming a typical quiescent current of 700 µA under normal working conditions. In power down mode, the quiescent current decreases to 6 µA. Logic input levels are relative to power supply level. The minimum logic high is 0.7 V_S, and maximum logic low is 0.3 V_S.

INA232 has a wider working supply range, spanning 1.7 V to 5.5 V. Typical operating quiescent current is 300 µA, which decreases to 2.2 µA in shutdown mode. Logic input levels are independent of power supply. The minimum logic high and maximum logic low are 0.9 V and 0.4 V, respectively.

Power-supply levels are fully forward compatible migrating from INA219 to INA232. There are some differences in logic levels, but these differences do not pose any problem in most cases. Examine the power-supply levels to make sure of reliable communication with the controller.

2.5 Digital Interface and Data Format

Both INA219 and INA232 are equipped with an I^2C- or SMBus-compatible interface. Both devices support fast and high-speed mode communication. Timing specification is compatible migrating from INA219 to INA232.

All registers are two-bytes wide, and accessing (read and write) is done in the order of MSByte first and LSByte last. The format of communication command is compatible.

2.6 Register Set

There are six registers, from 00h to 05h, that are named and numbered identically for INA219 and INA232. These registers enable data acquisition and storage. Customize configuration register (00h) to set ADC measurement mode, range, and averaging. Program calibration register (05h) with the calibration value determined by the shunt resistor and current LSB. Only after this register is programmed, is valid data stored in the Power and Current registers (03h and 04h, respectively).

INA232 comes with four additional registers. The Mask/Enable register (06h) and Alert Limit register (07h) are to facilitate the function of the ALERT pin. Aside from selecting which comparator (shunt over-limit, shunt under-limit, bus over-limit, and so forth.) the ALERT pin responds to, the Mask/Enable register provides additional functionality such as setting the ALERT pin polarity and latch mode, as well as setting a few runtime flags which can be convenient if such information is needed.

Registers 3Eh and 3Fh in INA232 return a unique Manufacturing ID and Device ID respectively.

2.7 Accuracy

INA232 is one of the latest digital power monitors. Taking advantage of progress in technology, INA232 offers much improved electrical specifications compared with predecessors in the same class.

One of the improvements in INA232 is with higher accuracy. Figure 2-2 compares the accuracy between INA219 and INA232.

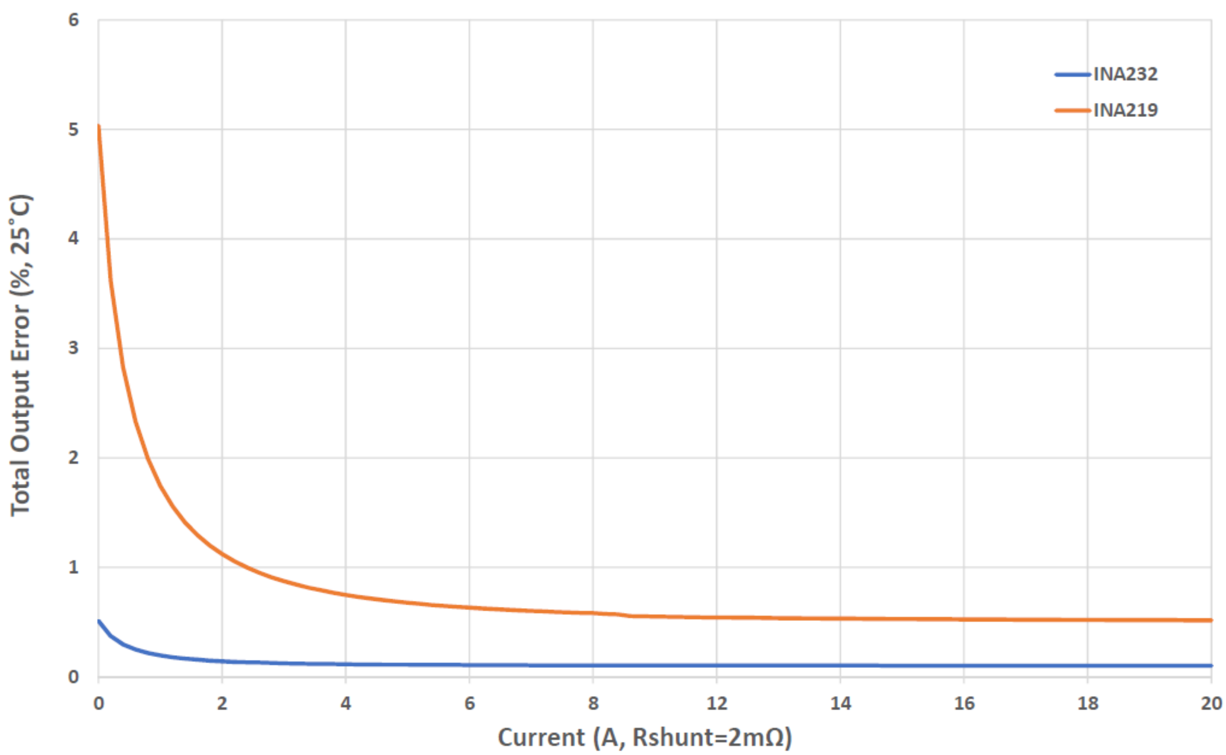

Figure 2-2. Total Output Error

2.8 Unique Features

The INA232 features very low input bias current (10-nA max) which provides several benefits. First, larger external resistors on the input pins are tolerable in terms of the impact of the resistor on measurement accuracy. The resistors are useful in implementing over- or undervoltage protection, as well as when implementing input filters. The low input bias current also reduces the current consumed by the device in both active and shutdown state.

Enabled by special input circuitry, the INA232 digital interface is compliant with a wide range of digital bus voltages such as 1.2 V, 1.8 V, 3.3 V, and 5.0 V. Because the logic levels of the device are decoupled from the device supply level, the INA232 is capable of such wide working range without level translation.

INA232 is equipped with a General Call Start command. This command consists of a single address byte 00h, with the last R/W bit set to 1. When multiple INA232 devices are present on the I^2C bus, upon receiving a General Call Start command, all INA232 devices stop activities and start a new conversion. All INA232 devices do not have to be configured identically. This command implements synchronous conversion that is standard in PMBus, where more communication overhead is necessary. For an implementation example of synchronous measurement in digital power monitors, see the *Synchronized Measurements with Digital Current Sense Monitors* application report.

3 Implementation

3.1 Identify Suitable Migration Projects

Aside from compatible footprints, the INA219 and INA232 have considerable overlapping specifications despite the fact that each has unique features. Figure 3-1 shows the key features in a Venn diagram.

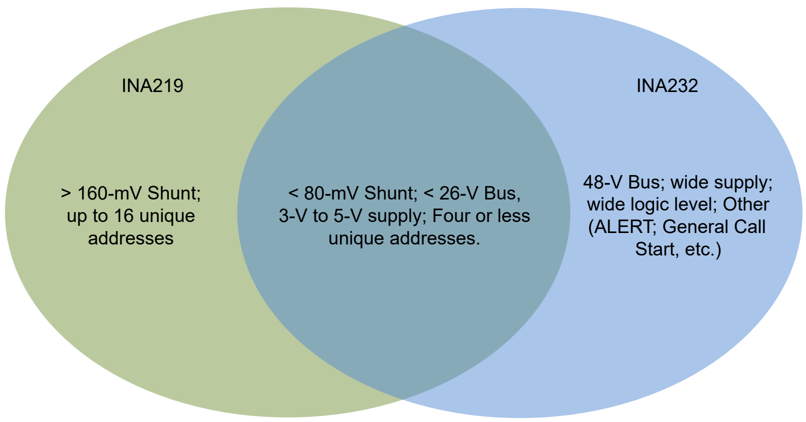

Figure 3-1. Key Features and Supported Design Parameters

In this example, an existing design with INA219 fits in the intersection region of Figure 3-1. The goal is to update the design with INA232. The best practice is to keep the firmware backward compatible so that the firmware works with hardware based on either INA219 or INA232.

3.2 Bench Setup and Hardware

Figure 3-2 shows the DUT boards used. The U1 footprint is populated with either INA232 (left) or INA219 (right). SW0 is a 4-position switch connected to the A0 pin in this experiment, and is used to select one of four device addressed. Address A1 (pin #8) of INA219 is connected to ground.

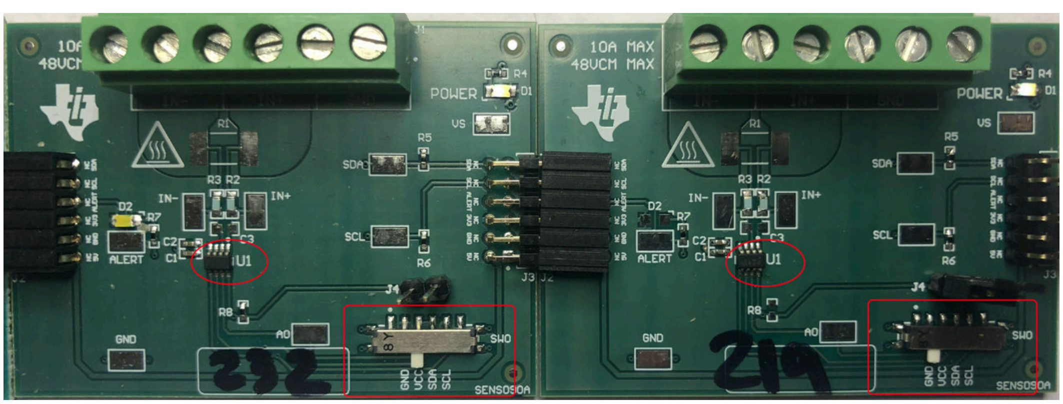

Figure 3-2. DUT Boards

Figure 3-3 shows the bench setup block diagram. Shunt and bus voltages are provided by voltage sources. Communication between the DUTs and the microcontroller is through the I^2C bus.

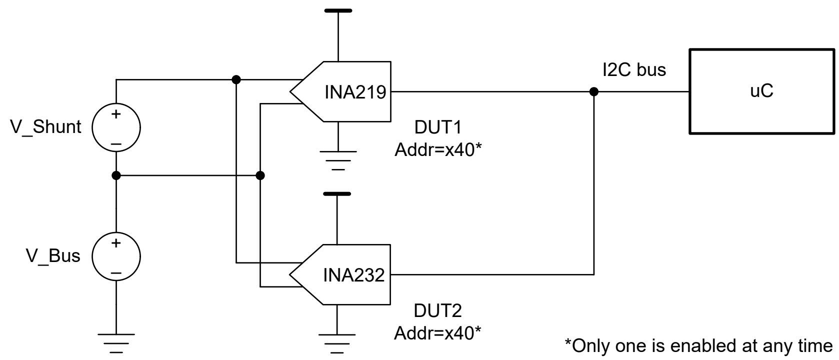

Figure 3-3. Bench Setup

Table 3-1 shows the bench setup parameters. Common design parameters are shared between the two devices. Columns *INA219* and *INA232* show device-specific settings, including Configuration and Calibration register values. These values are obtained based on the design parameters, as well as to keep the total ADC conversion cycle time closely matched.

Table 3-1. Bench and Device Settings

Setting	INA219	INA232
Power supply (V_S)	3.3 V	
Bus (V_{CM})	12 V	
PGA/ADC_range (Vsense_max)	80 mV	
R_{SHUNT}	2 mΩ	
Current LSB	1 mA	
Device address	40h	
Averaging	N/A	64
Bus conversion time	68.10 ms	1.1 ms
Shunt conversion time	68.10 ms	1.1 ms
ADC mode	Shunt and bus, continuous	
Configuration register value	2FFFh	4727h
Calibration register value	5000h	0A00h

3.3 Result Registers and Calculation

The controller reads results registers, including Shunt, Bus, Power, and Current continuously. Because of the differences in register effective bit-width and bit-weight, the math is slightly different in converting the register values into physical quantities. Table 3-2 shows the relevant information needed for results conversion. The differences between INA232 and INA219 are listed under each device column separately

Table 3-2. Result Calculation

Results and Calculation		INA219	INA232
Shunt voltage	Register	01h	
	LSB	10 µV	2.5 µV
	Data format	Two's compliment	
	Magnitude	Lower 13 bits	Lower 15 bits
	Sign	Any of upper 3 bits	MSB
Bus voltage	Register	02h	
	LSB	4 mV	1.6 mV
	Data format	Positive only	
	Magnitude	Upper 13 bits (<<3)	Lower 14 bits
	Sign	N/A	
Power	Register	03h	
	LSB	20 mW	32 mW
	Data format	Positive only	
	Magnitude	16 bits	
	Sign	N/A	
Current	Register	04h	
	LSB	1 mA	
	Data format	Two's compliment	
	Magnitude	Lower 14 bits	
	Sign	MSB	

3.4 Software Implementation

It is necessary to distinguish between INA232 and INA219 for the purpose of both programming and retrieving results. The default configuration register value is used to tell the two devices apart. Pseudocode of device detection is shown in Figure 3-4. The rest of the code deals with setup, read, and math calculation.

Configuration and Calibration registers are programmed depending on the device connected. Based on the settings determined by design parameters, if INA219 is connected, 2FFFh and 5000h are programed; if INA232, 4727h and 0A00h are programed. Similar to programming the device, retrieving and calculating measurement results are also slightly different depending on the device connected. Table 3-2 shows the details for calculation.

The program works with either INA219 or INA232 seamlessly, Figure 3-5 shows sample output logs.

```
 Start
//detect section
 Software reset (write '1' to MSB of Configuration register 01h)
 Read Configuration register
 if "399Fh" then INA219 is connected
 else
 if "4217h" then INA232 is connected
//setup section
 If (INA219 is connected) then { program INA219}
 If (INA232 is connected) then { program INA232}
//read section
 loop read result registers - Shunt, Bus, Power, Current
//math section - converting decimal to physical quantities
 If (INA219 is connected) then { INA219 math}
 If (INA232 is connected) then { INA232 math}
 Stop
```

Figure 3-4. Pseudocode

INA219 communication log

```
-> Detect and Setup CS device
-> Dev Addr:             40h
-> CONFIG_REG            399Fh
-> Device Connected      INA219
-> CAL REG:              5000h
-> CURRENT_LSB:          0.00100A
-> VOLTAGE_LSB:          0.00400V
-> POWER_LSB:            0.02000W
-> Bus: 12.348V          Shunt: 40.0200mV          Current: 20.010A          Power: 247.080W
-> Bus: 12.348V          Shunt: 40.0200mV          Current: 20.010A          Power: 247.080W
-> Bus: 12.348V          Shunt: 40.0100mV          Current: 20.005A          Power: 247.040W
-> Bus: 12.348V          Shunt: 40.0100mV          Current: 20.005A          Power: 247.040W
-> Bus: 12.348V          Shunt: 40.0100mV          Current: 20.005A          Power: 247.040W
-> Bus: 12.348V          Shunt: 40.0300mV          Current: 20.015A          Power: 247.080W
```

INA232 communication log

```
-> Detect and Setup CS device
-> Dev Addr:             40h
-> CONFIG_REG            4127h
-> MANUFACTURER_ID_REG   5449h
-> DIE_ID_REG            A080h
-> Device Connected      INA232
-> CAL REG:              A00h
-> CURRENT_LSB:          0.00100A
-> VOLTAGE_LSB:          0.00160V
-> POWER_LSB:            0.03200W
-> Bus: 12.354V          Shunt: 40.0250mV          Current: 20.014A          Power: 247.264W
-> Bus: 12.355V          Shunt: 40.0250mV          Current: 20.013A          Power: 247.264W
-> Bus: 12.355V          Shunt: 40.0300mV          Current: 20.015A          Power: 247.296W
-> Bus: 12.354V          Shunt: 40.0300mV          Current: 20.015A          Power: 247.264W
-> Bus: 12.354V          Shunt: 40.0375mV          Current: 20.019A          Power: 247.296W
-> Bus: 12.354V          Shunt: 40.0325mV          Current: 20.016A          Power: 247.296W
-> Bus: 12.354V          Shunt: 40.0350mV          Current: 20.018A          Power: 247.296W
```

Figure 3-5. Verification Datalogs