# Programming Power Settings

TI Precision Labs – Current Sense Amplifiers

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Hello, and welcome to the TI precision labs series on current sense amplifiers. My name is Mubina Toa, and I'm a product marketing engineer in the Current & Position Sensing product line. In this video, I will go over how to program TI's digital power monitors for direct load current and power consumption readings.
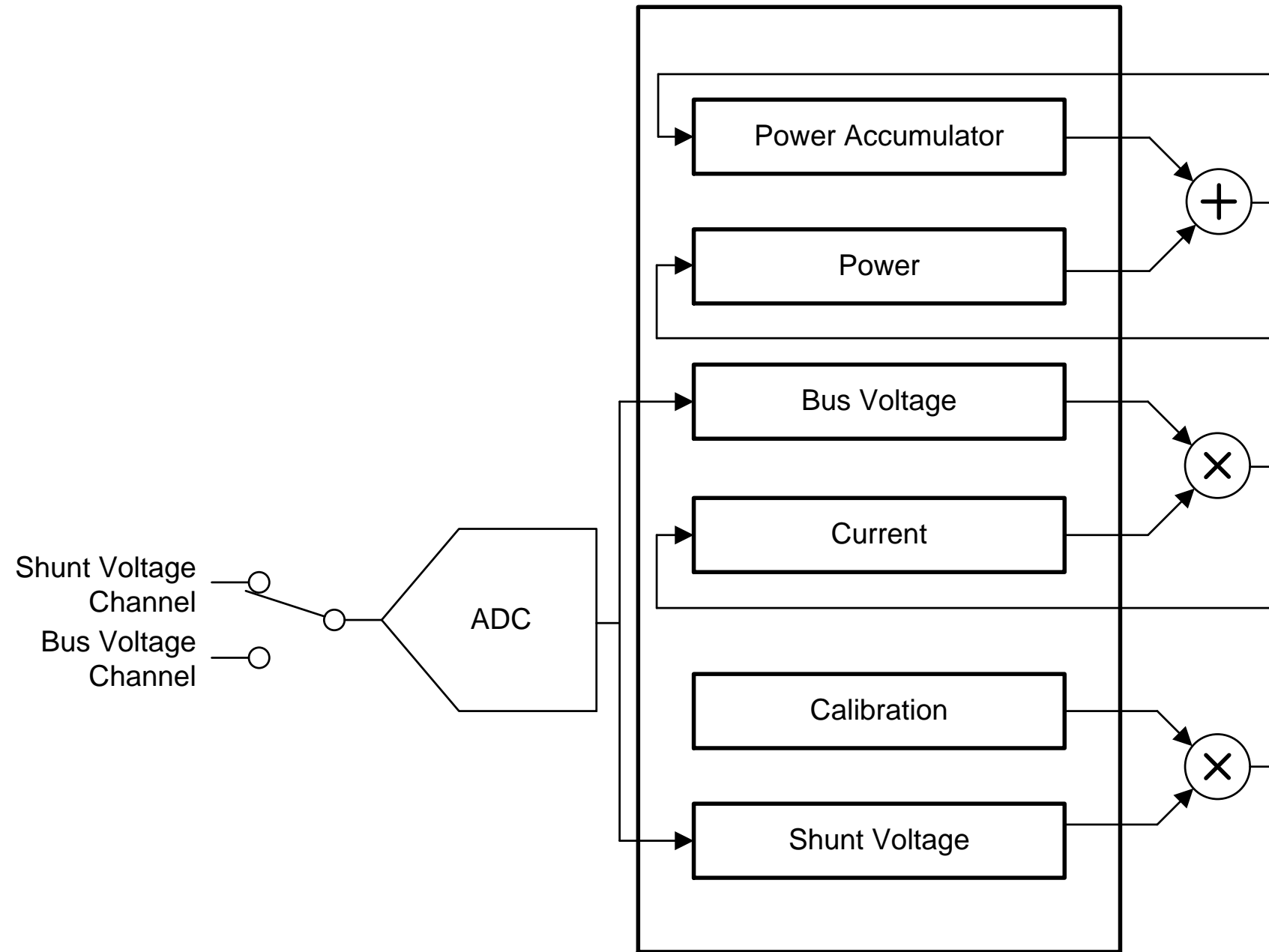
Digital power monitor block diagram
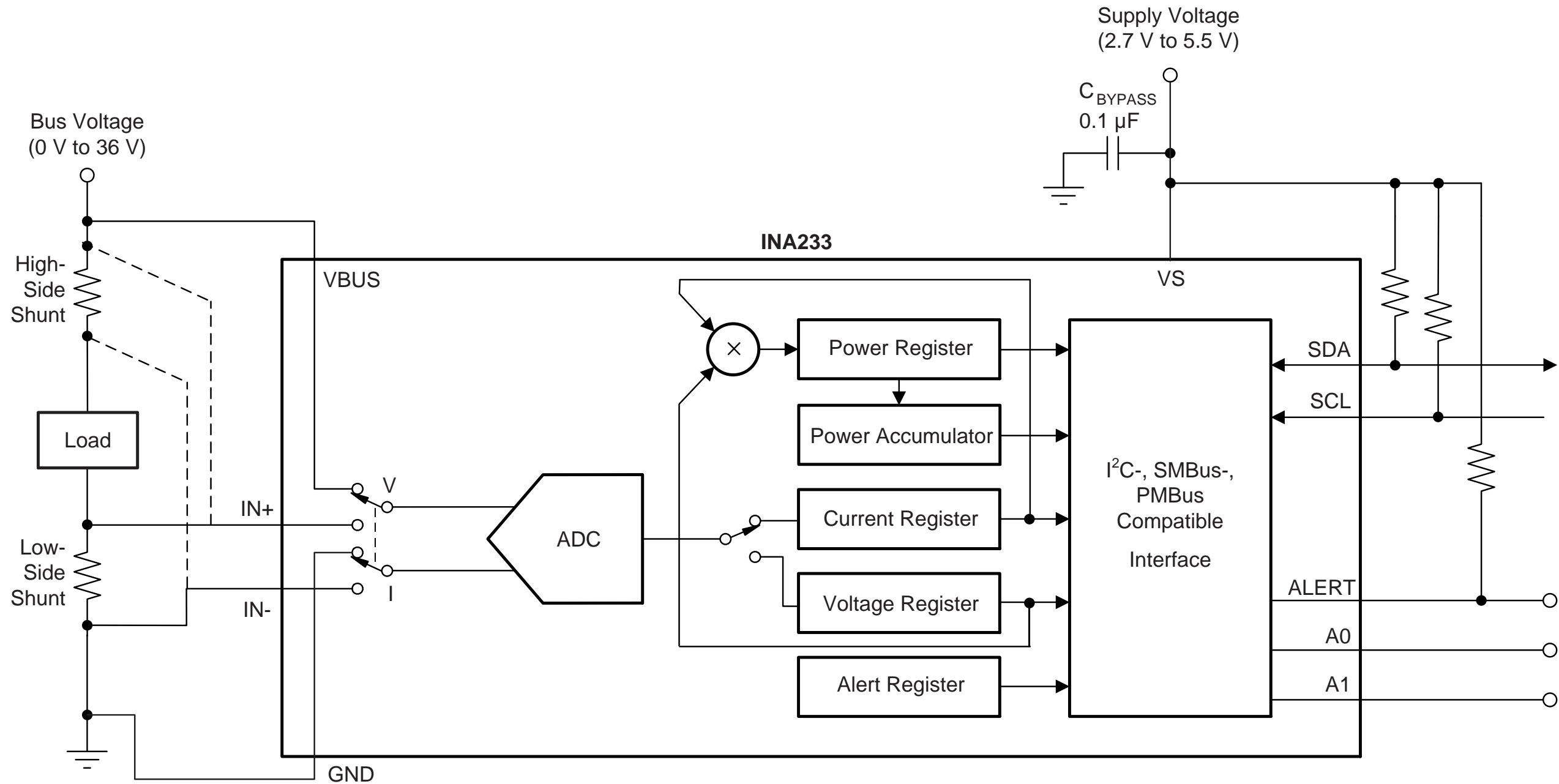
Digital power monitors are current sensing devices that measure both shunt voltage and bus voltage. A programmable calibration register, combined with an internal multiplier, also enables direct readouts of load current and power consumption.

The block diagram here shows the INA233 as an example. This device also comes with a power accumulator for energy and average power monitoring. Some power monitors may not have all the registers shown here, and some may not have a separate VBUS pin, but instead will monitor bus voltage at the IN- pin of the device. Please note these slight differences and refer to individual datasheets for device-specific information.

Register structure

Let's take a closer look at the register structure of the digital power monitors. The shunt voltage, bus voltage, current, and power registers are all read only registers, while calibration register is a read/write register. There is no programming needed if you only require shunt and bus voltage measurements, and do not need direct current and power readouts.

If direct current and power readings are required, then the calibration register must be programmed.

The current register is obtained by multiplying the contents of the shunt voltage register and the calibration register, then dividing by a constant for scaling purposes.

The power register is obtained by multiplying the contents of the current register and the bus voltage register content, then also scaling by a constant.

In some devices, the bus voltage register bits are not right-aligned. In order to compute the value of the bus voltage, the bus voltage register contents must be shifted right by a few bits. Please refer to the register information section of the datasheet for device specific information.

Parameters needed before programming

Required parameters:

1. Maximum expected current (I_{MAX})
2. Shunt resistor value (R_{SHUNT})

$$R_{SHUNT} \leq \frac{V_{SENSE\_MAX}}{I_{MAX}}$$
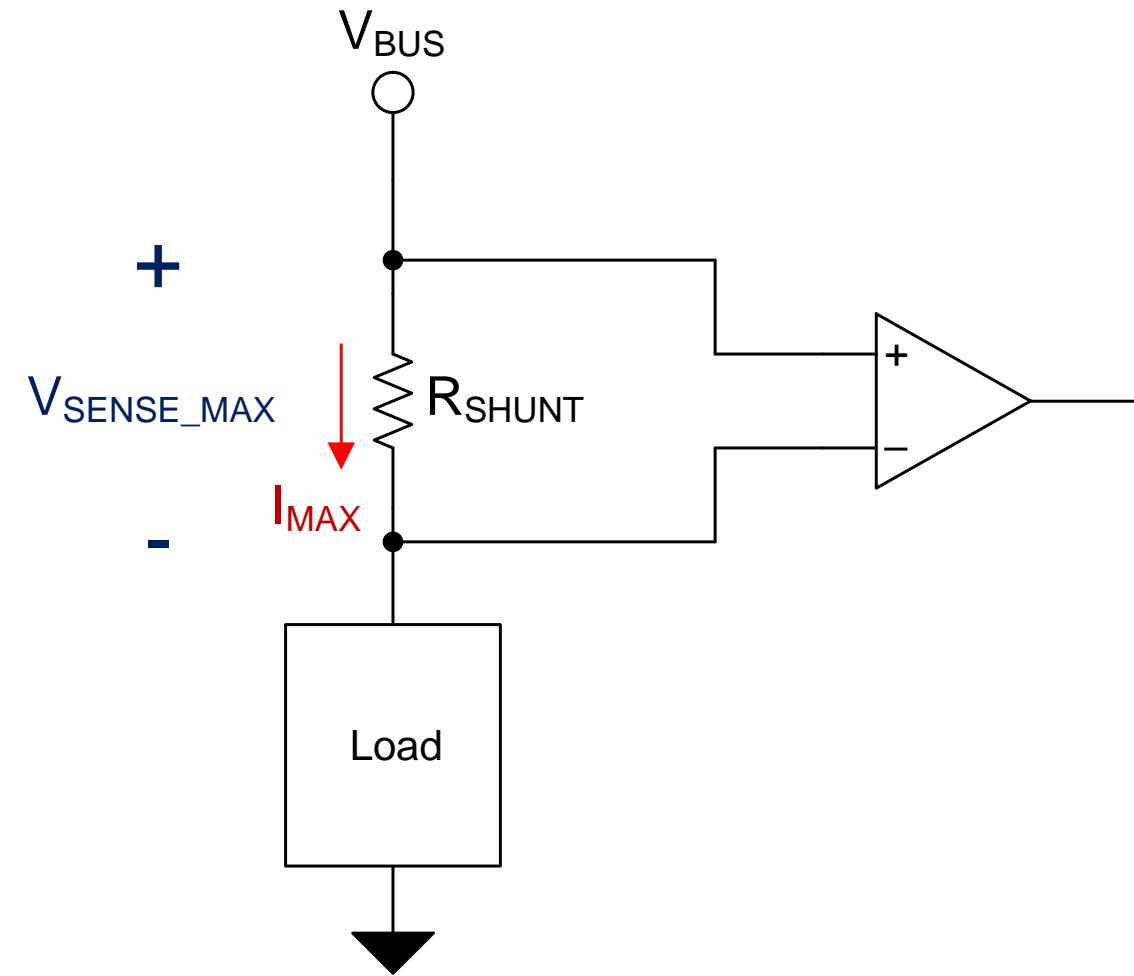
PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT					
Shunt voltage input range		−81.92		81.9175	mV

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Now let's get started on the steps to configure these devices for current and power readings. We need to know two parameters from the application: maximum expected current (IMAX) and shunt resistor value (RSHUNT). When selecting the shunt resistor value, we should keep in mind the maximum allowable input voltage range of the device. Here is a snapshot from the INA233 datasheet that shows the Vsense maximum and minimum limit. There are a few additional considerations in selecting an appropriate shunt resistor, which is covered in another video in this series.

How to program for direct current & power read out

Step 1:

- $Minimum\ Current\ LSB = \dfrac{I_{MAX}}{2^N}$

  – **N** is the shunt voltage register resolution, in number of bits

- $Current\ LSB = Round\ number \approx Minimum\ Current\ LSB$

- $Power\ LSB = A * Current\ LSB$

  – **A** is a constant specific to the device

Step 2:

- $CAL = \dfrac{B}{Current\ LSB * Rshunt}$

  – **B** is a constant specific to the device

Once we know the maximum expected current and shunt resistor value, programming the device is a simple two-step process.

Step 1 is to compute the Minimum Current Least-Significant-Bit (LSB) for the application, which is calculated as maximum expected current divided by 2 to the power of N, where N is the resolution of the current register in number of bits. It is common to select a Current LSB to be a round number larger than the Minimum Current LSB value, to simplify calculation.

Next, the Power LSB is calculated as the Current LSB times a scalar A, where A is a constant specific to the digital power monitor device.

Step 2 is to compute the Calibration Register value (CAL). It is equal to a constant B, divided by the product of the Current LSB and shunt resistor value as shown in this equation. Here B is an internal fixed value used to ensure correct scaling. Once this calculated calibration value is written to the calibration register, we are ready to start reading the registers for current and power.

Please refer to the datasheet for a particular digital power monitor to find out what constants N, A and B are for that device. For example, in the INA233, $N = 15$, $A = 25$, and $B = 0.00512$.

How to convert register values to physical results

From register values to physical results:

- Shunt voltage (V) = Shunt voltage register reading (dec) * Shunt voltage LSB

- Bus voltage (V) = Bus voltage register value (dec) * Bus voltage LSB

- Load current (A) = Current register value (dec) * Current LSB

- Load power (W) = Power register value (dec) * Power LSB

- Telemetry data conversion: $X = \frac{1}{m}(Y \times 10^{-R} - b)$

FYI only – how internal register values are calculated by power monitors:

- $Current\ Register = \dfrac{Shunt\ Voltage\ Register\ (dec) * Calibration\ Register\ (dec)}{C}$

- $Power\ Register = \dfrac{Current\ Register\ (dec) * Bus\ Voltage\ Register\ (dec)}{D}$

- $Y = (mX + b) \times 10^{R}$

Once the Calibration register is successfully written, the current and power registers can be read after conversion. Shunt and bus voltage registers have fixed LSB's. Once the registers are read, the adjusted decimal values of the readings multiplied by their LSBs will produce the real voltages measured.

When reading from the current and power registers, use the computed Current and Power LSBs per our discussion on the previous slide to get readings in Amperes and Watts respectively.

It should be noted that in some datasheets such as INA233, telemetry data conversion equations are provided alongside the coefficients m, b and R for current, voltage and power respectively. These two formats are equivalent. Either can be used and they produce identical results.

Expected current and power register readings can be computed using the equations shown here at the bottom of the screen. The current register value is obtained by multiplying the shunt voltage register value by the calibration register value and is divided by a constant C. For the power register, multiply the current register value by the bus voltage register value and divide by another constant D. Please refer to the datasheet to find out the values for C and D shown in these equations. Alternatively, the same results can be reached with the telemetry data formula found in some datasheets. Keep in mind that these calculations are not required, but they can be useful to help predict register values for a given application.

Programming example – INA233

Conditions

- $I_{MAX} = \pm 30$ A
- $V_{BUS} = 12$ V
- $R_{SHUNT} = 2.5$ mΩ
- $V_{SENSE\_MAX} = \pm 30$ A $* 2.5$ mΩ $= \pm 75$ mV
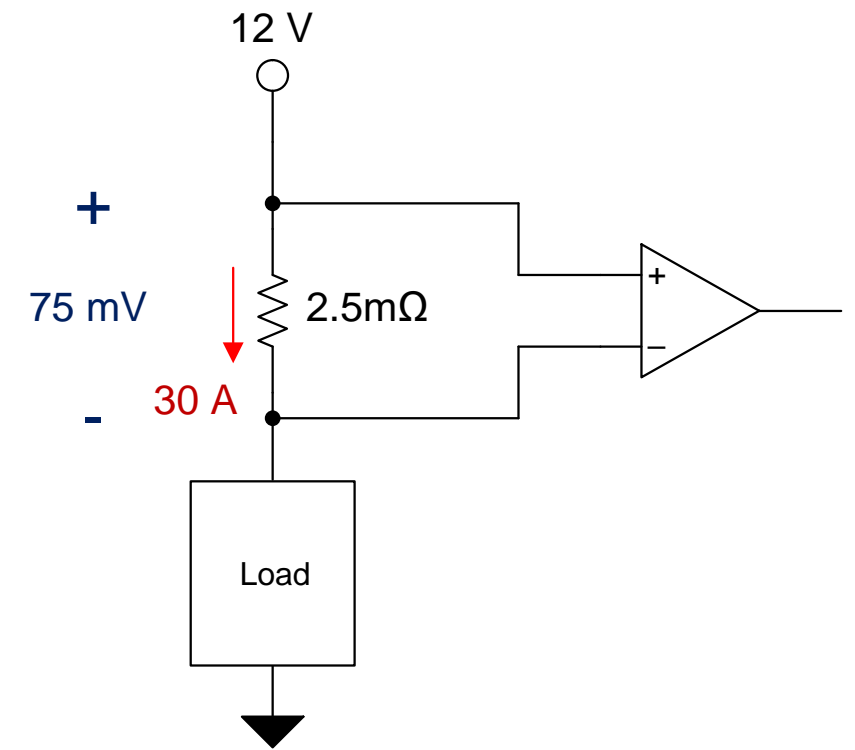
Step 1

$$Minimum\ Current\ LSB = \frac{I_{MAX}}{2^{15}}$$ $$\longrightarrow$$ $$Minimum\ Current\ LSB = \frac{30\ A}{32768} = 915.5\ \mu A$$

Round up to **1 mA**

Step 2

$$CAL = \frac{0.00512}{Current\ LSB\ * Rshunt}$$ $$\longrightarrow$$ $$CAL = \frac{0.00512}{1\ mA\ *2.5\ m\Omega} = \textbf{2048}\ (dec)$$

Let's work through an example to apply what we discussed so far, using the INA233 as the digital power monitor of choice. Let's say that the maximum expected current for this application is plus or minus 30 amps, the bus voltage is 12 volts, and the shunt resistor chosen is 2.5 milli-ohms to generate a maximum Vsense of plus or minus 75 mV.

Using the Max expected current of 30 amps, we arrive at the minimum current LSB value of 915 micro-amps. Let's round up and choose 1 milli-amp per bit as the current LSB.

The next step is to calculate the calibration register value. After we substitute in the current LSB of 1 milli-amp and the shunt resistor value of 2.5 milli-ohms, we get the calibration value of 2048 (in decimal).

INA233 example, continued

Register Address	Register Name	Internal Calculation	Register Value (decimal, adjusted)	LSB	Equation	Result
D4h	Calibration		**2048**			
D1h	Shunt Voltage		**20000**	2.5 µV	$Shunt\ Register\ Value\ (dec) * Shunt\ Voltage\ LSB$	**50 mV**
88h	Bus Voltage		**9600**	1.25 mV	$Bus\ RegisterValue\ (dec) * Bus\ Voltage\ LSB$	**12 V**
89h	Current	$\dfrac{Shunt\ Voltage\ Register\ *\ Calibration\ Register}{2048}$ $= \frac{20000 *2048}{2048} = 20000\ (dec)$	**20000**	1 mA	$Current\ Register * Current\ LSB$	**20 A**
97h	Power	$\dfrac{Current\ Register\ *\ Bus\ Voltage\ Register}{20000}$ $= \frac{20000 * 9600}{20000} = 9600(dec)$	**9600**	25 mW	$Power\ Register * Power\ LSB$	**240 W**

This table shows the register readings for INA233 when a nominal load of 20 amps is flowing through the shunt resistor. It should be noted that least significant byte is sent first and the most significant byte next.

Shown in this table, the column "Register Value" are after adjustment with this ordering taken into account. Not all power monitors follow this protocol. Please refer to the individual device datasheets for details.

The shunt voltage register reads 20000 in decimal, and when multiplied by the fixed shunt voltage LSB of 2.5 microvolts, yields 50 millivolts, which is what we expected for a 20 amp current through a 2.5 milli-ohm shunt.

The bus voltage register reads 9600 in decimal, and when multiplied by the fixed bus voltage LSB of 1.25 mV, yields 12 V.

The current register reads 20000 in decimal, and when multiplied by the 1 mA Current LSB we get 20 amps of current as expected.

The power register reads 9600 in decimal, and after multiplying by the 25 mW power LSB is equal to 240 W of power. This is equal to our expected value of 20 amps times 12 volts.

Since all values match our expectations, we conclude that we have successfully programmed INA233 using the simple two-step approach. Other TI digital power monitors can be programmed in a similar fashion.

In this example, we multiplied the adjusted register values with their corresponding LSB to get real world readings of shunt voltage, bus voltage, current and power. It would be equivalent when using the telemetry data conversion equation if provided in the datasheet.
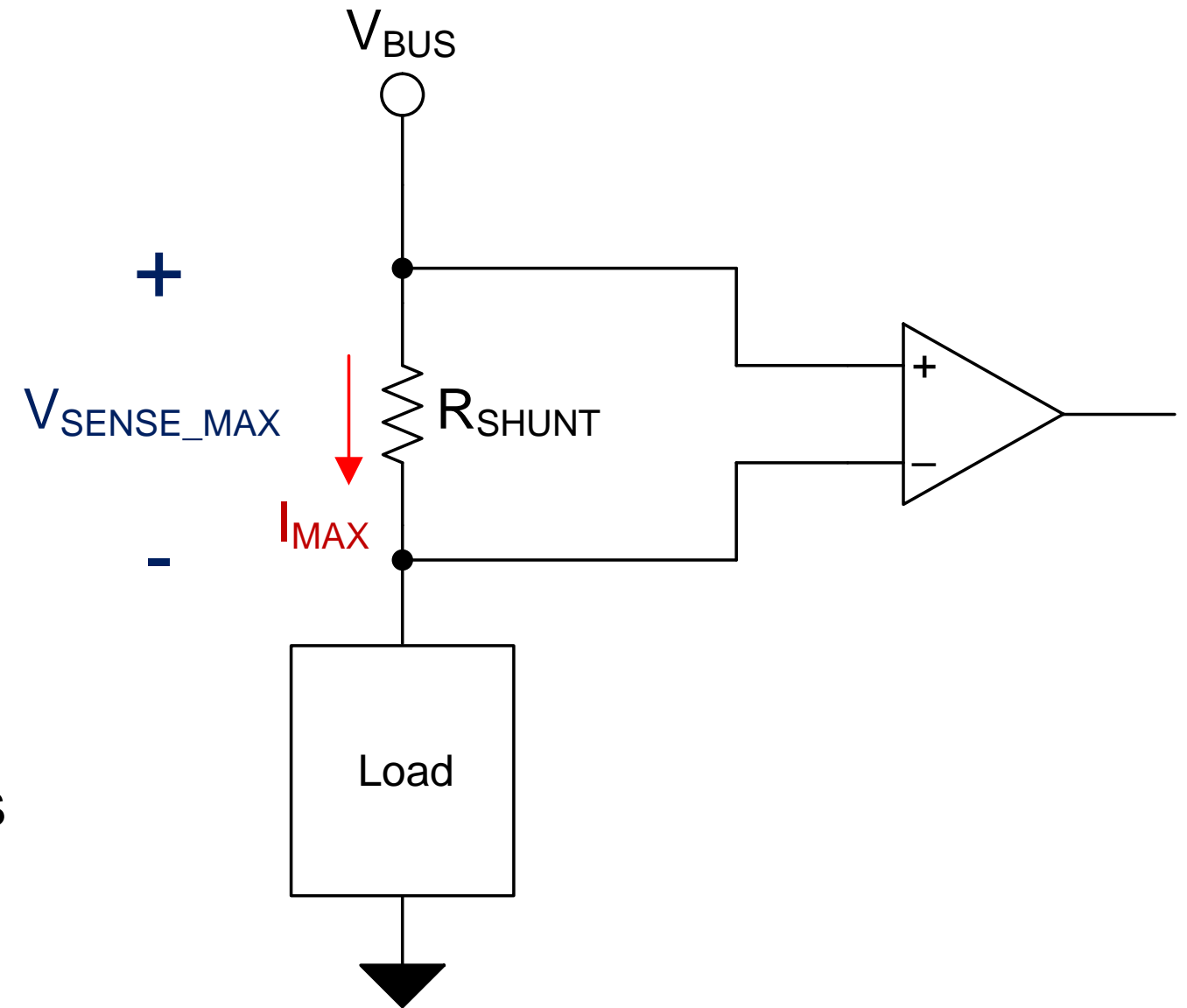
Programming power settings summary

1. **Determine:**
   – Maximum expected current (I_{MAX})
   – Shunt resistor value (R_{SHUNT})

2. **Program:**
   – Select a current LSB
   – Calculate calibration register value

3. **Read:**
   – Convert register values to physical values

Let's take a minute to summarize what we learned in this video.

Taking advantage of TI's digital power monitors is a simple three step process that can be called determine-program-read. Specifically, these three steps are:

1. Determine the system requirement. Find out what is the maximum expected current, and which shunt resistor to use.

2. Calculate the current LSB and select the smallest whole integer that is larger than the calculated value. This provides the best compromises among resolution, accuracy and ease of calculation.

3. Read the register values. Take into account bit shifting and byte order when applicable. Multiplying the register value with its LSB gives us the physical value we're looking for.

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That concludes this video - thank you for watching! Please try the quiz to check your understanding of the content.

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Quiz

Programming Power Settings – quiz

1. I'm going to use INA233 to measure a supply's current for diagnostics purposes. I don't need voltage and power information. I have no choice but to program the calibration register (address D4h).

   a) True
   b) False

2. All of TI's digital power monitors follow the same protocol when responding to a controller's request and sending telemetry data. All data is two-byte, with most significant byte sent first and least significant byte sent next. Therefore if I migrate from one device to another (eg, INA219 to INA233), all I need to do is to change addressing, and leave the data manipulation/calculation alone.

   a) True
   b) False

Programming Power Settings – quiz

3. Which of the following statement is correct regarding TI's digital power monitors? (select all that apply)
   a) They have specified and limited input voltage range.
   b) They measure current directly.
   c) Any value of shunt resistor can be used to measure a 10A (max) current.
   d) Some power monitors come with integrated shunt resistors, and I don't need to provide an external one.

4. When programming a power monitor for direct readout, what design information must the system designer provide? (select all that apply)
   a) The estimated PCB size.
   b) The maximum current the power monitor is expected to measure.
   c) The shunt resistor value.
   d) Official document of the power monitor's communication protocol.

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Answers

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   a) True

   b) **False**

2. All of TI's digital power monitors follow the same protocol when responding to a controller's request and sending telemetry data. All data is two-byte, with most significant byte sent first and least significant byte sent next. Therefore if I migrate from one device to another (eg, INA219 to INA233), all I need to do is to change addressing, and leave the data manipulation/calculation alone.

   a) True

   b) **False**

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