Power and Energy Monitoring With Digital Current Sensors

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As the demand for power efficient systems continues to grow, accurately monitoring system power and energy consumption is increasingly important and is a problem more engineers must solve. One solution to this problem is to use an analog to digital converter (ADC) for both the current and voltage and then multiply the result in a processor to obtain power. However, the communications delay and overhead between getting the current and voltage information introduces time alignment errors in the power measurement since both the current and the voltage can be varying independently of each other. To minimize the delay between the voltage and current measurements, the processor would need to dedicate adequate processing power to ADC communications and power calculations. Even with the processor primarily dedicated to this function, any interactions with other devices in the system could delay the voltage and current measurements reducing power monitoring accuracy. Adding additional responsibilities like averaging the system voltage, current, and power, as well as energy monitoring would start to further burden the processor with additional functions.

A better way to monitor power is to use a digital current monitor to handle the mathematical processing, freeing up the processor to deal with other system tasks, and alerting the processor if higher level system actions need to occur. Texas Instruments provides a wide range of digital power and current monitors to address this problem. One such power, current and voltage monitor is the INA233. The INA233 enables the monitoring of voltage, current, power, and energy via an I^{2}C, SMBus, PMBus compatible interface. A typical application and block diagram of the INA233 is shown in Figure 1.

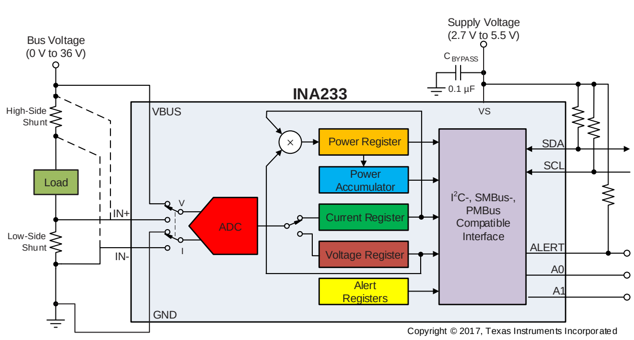

Figure 1. INA233 Typical Application Circuit

A simplified block diagram of the power conversion engine is shown in Figure 2. Power is internally calculated from the shunt and bus voltage measurements in an interleaved fashion to minimize time alignment errors in the power calculation.

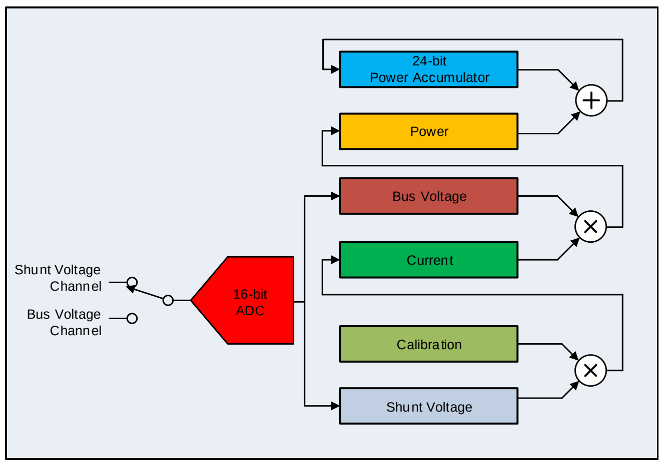

Figure 2. INA233 Power Conversion Engine

The internal calculations for power are done in the background independent of ADC conversion rates or digital bus communications. The device also features an ALERT pin that will notify the host processor if the current, power, or bus voltage is out of the expected range of operation. In the INA233, fault events are handled independently, such that multiple simultaneous fault conditions can be reported by reading internal status registers when the ALERT pin asserts. The internal processing and alert capabilities of the INA233 free the host processor to manage other tasks while the device takes care of continually monitoring the system. The host processor is notified via the ALERT pin only when additional attention is needed.

The INA233 also features a 24-bit power accumulator that continuously adds the current power reading to the sum of previous power readings. The power accumulator can be used to monitor system energy consumption to get an average measurement of the power consumption overtime. Since power levels can fluctuate during any given instant in time, monitoring the energy provides a better way to gauge the average system power usage over long time intervals. Knowing the system energy consumption provides a metric to gauge system runtime and power efficiency, as well as the effects of power optimizations involving adjustment of power supply voltages and processor clock rates.

The ADC conversion times for both shunt and bus voltage measurements are programmable from 140 µs to 8.244 ms. Longer conversion times are useful to decrease noise susceptibility and to achieve increased stability in device measurements. The effects of increased ADC conversion times measurements results is shown in Figure 3.

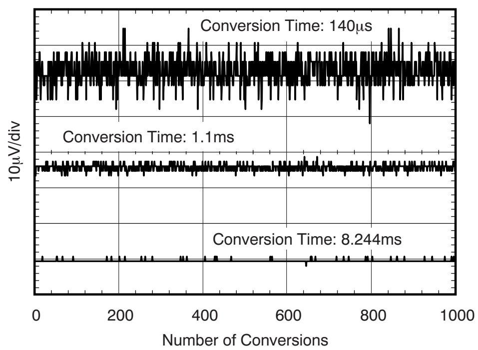

Figure 3. Noise vs. ADC Conversion Time

In addition to programmable ADC conversion times, the device can average up to 1024 conversion cycles and update the internal power, current, and voltage registers once the averaging is finished. Programmable conversion times along with averaging windows allow the device telemetry update rate to be adjusted to meet system timing needs.

Even though the INA233 has built in averaging and adjustable ADC conversion times, the user has to wait until the averaging is complete before getting the result. One benefit of the internal power accumulator is that it allows the host to calculate the average power on demand, eliminating the otherwise delay for the averaging interval to finish. Getting an average power reading on demand is achieved by taking the value of the total accumulated power and dividing by the total sample count for that accumulation period as shown in Equation 1.

$$\text{Average Power} = \frac{\sum_{i=1}^{n} \text{ADCPowerMeasurment}_i}{n} = \frac{\text{Total Accumulated Power over n samples}}{\text{Number of samples}} \quad (1)$$

Once the average power is calculated, the energy consumption is determined by multiplying the average power by the time interval of that average or by multiplying the total accumulated power by the ADC conversion time as shown in Equation 2.

$$\begin{aligned}\text{Energy} &= \text{Average Power} \times \text{time} \\ &= \left(\frac{\sum_{i=1}^{n} \text{ADCPowerMeasurment}_i}{n} \right) \times (n \times \text{ADC conversion time}) \\ &= \text{Total Accumulated Power} \times \text{ADC conversion time}\end{aligned} \quad (2)$$

Since the ADC conversion time can vary by as much as 10%, it is recommended to multiply the average power by the time measured by an external time base. The time interval for the energy calculation should be long enough so that the communications time due to the digital bus is insignificant to the total time used in the energy calculation.

The size of the power accumulator in the INA233 is limited to 24 bits. The value of the accumulator should be read periodically and cleared by the host to avoid overflow. The accumulator can be configured to be automatically cleared after each read. The time to overflow will be a function of the power, ADC conversion times and averaging times. Higher power levels will cause any overflow in the power accumulator to occur faster than lower power levels. Also, longer conversion times and higher number of averages will increase the time to overflow; in lower power cases, the time to overflow can be extended to be several hours up to days in length.

The INA233 is one of many digital current monitors offered by Texas Instruments. Table 1 shows some alternative devices that can be used to monitor a system and help free the host processor to handle higher level tasks.

Table 1. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
INA226	I2C/SMBus compatible with reduced register set	No Power Accumulator, no independent fault monitoring
INA231	WCSP package, reduced register set, lower cost	Less accuracy, no power accumulator, no independent fault monitoring.
INA219	Lowest Cost, reduced register set	Less accuracy and resolution, no ALERT, No power accumulator
INA3221	Monitors 3 channels	Less accuracy and resolution, monitors bus and shunt voltages

Table 2. Adjacent Tech Notes

SBOA179	Integrated, Current Sensing Analog-to-Digital Converter

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