Isolated sensing systems with low power consumption

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Current-shunt-monitor (CSM) ICs have been a mainstay in industrial applications for many years. Designed for either unidirectional or bidirectional current monitoring, CSMs offer excellent performance when used in either high-side or low-side current-shunt applications. However, many modern applications require some level of insulation to protect the end user from hazardous voltages.

The level of insulation that a particular circuit needs is driven mainly by the type of end equipment and where the end equipment will be deployed. For instance, is the end equipment a solar inverter to be mounted on a roof top or is it part of a servo motor drive used on an industrial robot? Global location of the end equipment plays a part as well. In the United States the Underwriters Laboratory (UL) maintains safety standards for various end-equipment. For Canada, it is the Canadian Standards Association (CSA). Europe has the International Electromechanical Commission (IEC) and the Association for Electrical, Electronic and Information Technologies (referred to as the VDE).

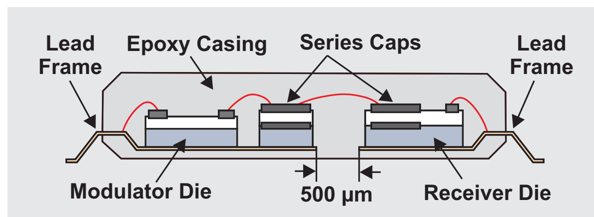
There are four main categories of insulation. The first is functional, which offers no protection against electric shock. As the name implies, functional insulation is provided to allow proper operation of a circuit or device. Think of this as the minimum trace spacing across a printed circuit board from a shunt resistor to the input terminals of the monitoring device.

The second level of insulation is basic. Basic insulation relates to the ability of an isolation device (an optocoupler or digital isolator, for example) to provide a level of protection against electric shock across an isolation barrier.

Next is supplemental or double insulation. This is an independent insulation layer that is applied in addition to basic insulation to ensure protection against electric shock in the event that the basic insulation fails. This is similar to adding a section of heat-shrink tubing over an input wiring harness. The fourth category is reinforced insulation. Reinforced insulation is a single insulation system that provides a level of protection against electric shock equal to double insulation.

For a typical insulation example, the AMC1305 is a precision, delta-sigma ($\Delta\Sigma$) modulator with the output separated from the input circuitry by a capacitive isolation barrier that is highly resistant to magnetic interference. This barrier is certified to provide reinforced isolation of up to 7000 V_{PK}, according to the VDE V 0884-10, UL1577, and CSA standards. As shown in Figure 1, the isolation barrier of this device is constructed with two series capacitors, each having an equivalent of basic insulation through a silicon dioxide (SiO_2) layer of 13.5 µm (27 µm total). The surge immunity is rated to ±10,000 V and the working voltage is 1500 VDC and 1000 V_{RMS}, respectively.

Figure 1. Example of the dual-capacitor isolation barrier



Unlike traditional CSM devices that provide an analog output, the AMC1305 provides a digital bit stream. The differential analog input is a switched-capacitor circuit feeding a second-order delta-sigma modulator stage that digitizes the input signal into a 1-bit output stream. The converter's isolated output (DOUT) provides a digital bit-stream of ones and zeroes that are synchronous to an externally provided clock source at the CLKIN pin. The output bit-stream can be fed directly to the SD-24B module of an MSP430™ microcontroller (MCU) or the sigma-delta filter module (SDFM) of a C2000™ Delfino™ TMS320F2837x MCU.

In addition to dictating the level of isolation required, the type of application determines how many currents and voltages need to be monitored. In many cases, the variables of a polyphase system are monitored. One of the most common types of polyphase system is the three-phase case. Typically, three currents and three voltages could be measured in three-phase systems, and sometimes a fourth voltage is measured, primarily in cases where a connection to neutral or ground is available.

Supplying power to the sensing circuitry is greatly simplified when the variables measured in a polyphase system have low common-mode voltages with respect to a common reference point. This could be the case when performing low-side current measurements and voltage measurements using resistive dividers. However, many systems require measuring currents and voltages that can have significantly different common-mode components. In such cases, isolated power supplies are required and the design becomes a bit more complex.

Consider the system depicted in Figure 2. There are seven circuit functions that could be monitored: Three line currents, three phase-to-phase voltages and one common-to-ground voltage. For simplicity, only three current shunts (R_S) are depicted and the divider circuits for voltage measurement are not shown.

Depending upon which power transistors (elements labeled 1 through 6) are conducting, the common-mode voltage of the shunt resistors can be either near the full DC-Link voltage or near ground potential.

In order to take advantage of a design using isolated delta-sigma modulators, each of the seven monitoring circuits require a separate isolated power supply for the high side of the delta-sigma modulators. The term "high side" is often used to refer to the analog input side of the galvanic isolation barrier.

For example, in a system with a 48-V DC-Link voltage, one approach to design the required power supply could start by producing 3.3 VDC from the 48-VDC source with a buck-bias, step-down switching regulator (Figure 3). Figure 4 shows how a second stage could generate an isolated 5-VDC supply from the 3.3-VDC supply with a small isolation transformer in conjunction with a transformer driver.

Figure 2. Example of a polyphase system with current shunts (R_S)

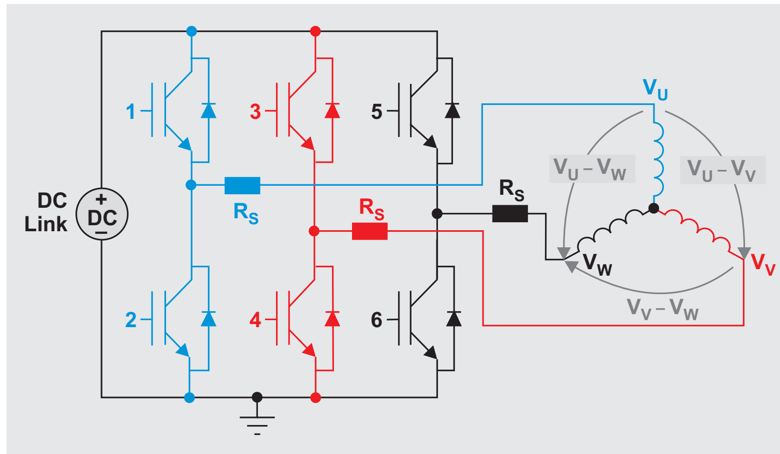


Figure 3. Step-down switching regulator design

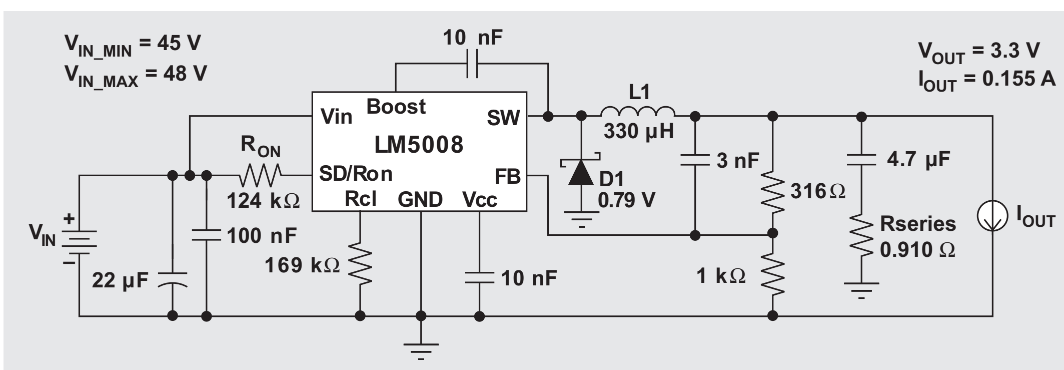


Figure 4. Isolated 5-VDC supply from 3.3 VDC

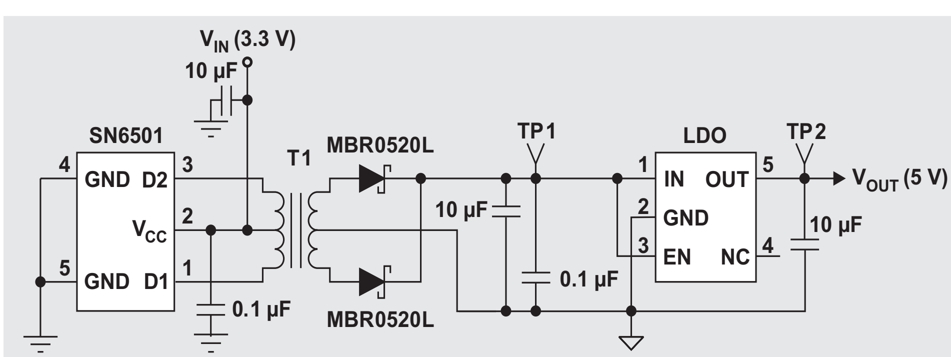


Table 1. A comparison between two acquisition systems based on isolated delta-sigma modulators

ISOLATED DELTA-SIGMA MODULATOR	IAVDD (max) (mA)	UNITS PER SYSTEM	SUM OF CURRENTS REQUIRED IN THE 5-VDC BUSES (mA)	EFFICIENCY OF THE 3.3-VDC TO 5-VDC STAGE (%)	POWER REQUIRED ON THE 3.3-V BUS (W)	CURRENT REQUIRED FROM THE 3.3-V BUS (A)*	POWER DRAWN FROM THE 48-VDC BUS (W)
AMC1305	7	7	49	54	0.45	0.155	0.69
Alternative Device	36	7	252	74	1.7	0.57	2.27

* An additional 10% to 12% margin has been added to the current requirement.

Table 1 compares two scenarios. In one scenario, seven AMC1305 units were used for monitoring. Figures 3 and 4 show the circuits that fulfilled the power requirements for the design with seven AMC1305 devices. The second scenario used an alternative device for the delta-sigma modulator and different components were used for the 48-V to 3.3-V power section.

The alternative-device scenario shows the implications of using seven units of a device that has higher power consumption on its analog input side (high side).

TI's family of isolated delta-sigma modulators includes some components with a specified input range of ±250 mV and others of ±50 mV. Compared to devices with a higher input range, devices with a lower input range allow system designers to reduce power dissipation in the sensing-current shunt by 80%.

Using a low-power, isolated-sensing solution brings about more efficient acquisition systems (from an energy point of view) as well as better performance. The greatest impact that higher power consumption can have in the acquisition system's performance is in gain-error drift and offset-error drift. An isolated delta-sigma modulator with higher power consumption is bound to experience a higher internal temperature rise during normal operation. Moreover, the ambient temperature of the isolated delta-sigma modulator is bound to be higher for systems with power-management circuitry that is tasked to deliver more than three times more power. The combination of higher internal and ambient temperatures in systems with higher power consumption yields solutions with more errors and poorer signal-to-noise ratio (SNR).

The best-in-class drift performance provided by the AMC1305 reduces temperature dependency and yields higher system performance over a wider temperature range. Also, gain-error drift is cut by as much as 58% and offset drift by 74% when compared to the closest competitor.

Conclusion

Many modern applications require isolation. The specific isolation level needed is driven by the type of end equipment in question and the regulatory body certifying the equipment.

Although power consumption is sometimes neglected as a key design criterion, the performance and efficiency of isolated sensing systems can be greatly improved by carefully selecting devices that have high-precision, isolated front-ends with optimized power-consumption specifications, such as the TI family of AMC1305 products.

Related Web sites

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