

Optimizing Power Conversion for Isolated Sensor Interfaces

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IDEA IN BRIEF

In the world of industrial controls, only a few things are certain; the next product will have a smaller form factor, more channels, and have a lower target cost per channel. The expectation is that technology has improved since the last design and all of these things are possible. To a large extent, that is the way things have worked out in the past, and your luck may be holding. The data interfaces have been improving steadily from the era of optocouplers to the latest high speed low power highly compact digital isolators. In this article, we will examine one aspect of isolated sensor interfaces that gets less attention than it deserves. How do we get isolated power to the ADC and conditioning circuits while shrinking the size of the interface and improving performance? In the past, the analog interface boards did not have high channel counts, so there was enough room on the board for a modest dc-to-dc converter to be designed to provide power to the sensor interface. Power dissipation was not a great concern since there were only one or two interfaces to a module. Currently, analog PLC modules, as illustrated in Figure 1, can have four, eight, or even 16 independent isolated channels. Multiple copies of a modest dc-to-dc converter take up a lot of space and create a lot of heat.



Figure 1. Typical Multichannel Sensor Interface

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A good place to start a discussion of power is with a generic analog interface as shown in Figure 1. The active circuits consist of a signal conditioning element like an op amp or instrumentation amp and an ADC with a serial interface which can be interfaced with the FPGA through digital isolator channels. This circuitry typically needs significantly less than 150 mW.

The basic challenge of providing power to the sensor interface is optimizing the supply to work well within the required power range. Operation at 0 mW to 150 mW means that the fixed quiescent power of the controller and feedback elements that make up the power supply will be a large portion of the total power used so the efficiency will be lower. This can be seen in the quiescent current values in Table 1 for various supply configurations. Alternately, many simple power supply designs require a minimum load to operate properly, so power must be wasted in resistive dead loads to ensure that the supply functions properly. While it is very simple to drop a 555 timer and transistor on the board and get some power, it is difficult to make an efficient and reliable supply that works at low power levels.

There are three basic categories of dc-to-dc converters used for this power range:

- 1. Unregulated switching supplies or modules
- 2. Regulated switching supplies or modules
- 3. Chip-scale power converters

Each of these supply architectures needs increasing complexity of control circuitry and, in the case of the first two options, increasing component count and solution size.

UNREGULATED SUPPLIES

The simplest solution is the unregulated dc-to-dc converter as shown in Figure 2.





This design uses fixed frequency fixed duty cycle input switching to create a secondary side power that is rectified and filtered. The transformer chosen will need to be rated for the isolation voltage required by the application. The higher the isolation requirement, the larger the transformer will be, in both PCB footprint and height. The cost of this solution is dominated by the transformer so in reasonable volume, a discrete solution cost is less than \$1.00.

The price you pay for attaining the low cost is that there can be significant variability in the output voltage over load and temperature, making the selection of the analog components of the analog interface more difficult. All analog components in the analog interface must have excellent power supply rejection, and the load must not vary quickly, or significant supply variation can be induced. This results in higher component costs or, at a minimum, much more engineering time to evaluate the solution under extreme conditions. The unregulated supply can have fairly high efficiency, but the quality of the power is low.

REGULATED SUPPLIES AND MODULES

Regulated supplies offer much better output characteristics. Figure 3 shows a typical dc-to-dc module in the 1 W power range.



Figure 3. Regulated DC-to-DC Module

The controller switches power into the transformer similar to the unregulated example above. The power level and turns ratio of the transformer are chosen to give sufficient voltage at the maximum load to allow an LDO to regulate the output voltage to a stable level. This scheme gives good power efficiency at high loads but rolls off to poor efficiency at low loads. This is exactly where our analog interface application runs.

There are many active regulation schemes that could allow better efficiency over the full load range, but they require much more complex control circuitry, and most require a feedback channel across the isolation barrier. This adds significant cost and size to the design and is typically not done for modules in this power range.

Integration of these power supplies has not progressed past the potted module or PCB daughter card because of difficulty incorporating the transformer into the assembly. Manufacturers have had limited success reducing the size of these devices.

CHIP-SCALE CONVERTERS

The development of chip-scale transformer technology by Analog Devices for the *i*Coupler[®] digital isolator products has created a new class of dc-to-dc converters. The technology lends itself well to low power high functionality power supply designs. The transformers are "air core" meaning that there are no magnetic materials present in the transformer. This means that these tiny transformers have their highest Q at about 125 MHz. The switching frequency is so high it is not practical to alter the duty factor of the switch signal to control power. Instead, the control circuitry gates the entire oscillator of and on to regulate voltage at the secondary.

The transformers are small enough to be integrated into a standard IC package with an internal split lead frame. All of the components from both sides of the isolation barrier required for forward power and output feedback can be integrated into a pair of silicon die eliminating the need for discrete external components and allowing advanced features to be implemented. The chip-scale power converter can contain all of the functionality of a fully regulated dc-to-dc power supply providing tight regulation and good efficiency at low load conditions.





COMPARISONS

Let's look at some practical examples to illustrate the differences between the designs we have discussed. Table 1 shows a comparison of the properties of two power modules and a chip-scale converter. The TI modules chosen were the closest commonly available module in power to the 0 mW to 150 mW range identified in the sensor interface requirement.

Most designers need to make a power efficient design. What jumps out of Table 1 is the efficiency of the unregulated solution, but there are drawbacks to choosing that solution. This module is rated at 1 W, and its data sheet does not even rate its performance below 100 mW. It is likely that the output voltage is significantly higher than rated and the efficiency falls off rapidly.

3%

10%

Size

 $7.4 \times 7.4 \times 2$

 $18 \times 10 \times 2.5$

 $20 \times 8 \times 10$

Cost

\$1.50

\$5.95

\$4.25

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Гуре	P/N	Peak Efficiency	10 mA Efficiency	Quiescent Current	Max Power	Load Regulator
Chip-Scale Converter	ADuM5010	30%	27%	6.8 mA	150 mW	1.3%

21%

N/A

Table 1. Technology Comparison

Regulated Module

Unregulated Module

DCR010505

DCH010505

50%

72%

18 mA

60 mA

1 W

1 W

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The next highest efficiency is with the regulated module. It is rated for use at light loads and is well behaved. However, if we actually look at the efficiency of the regulated module compared to the chip-scale converter, Figure 5 shows that since the chip-scale converter has active feedback regulation, its efficiency rises much faster to its final value, so between 0 mA and 15 mA of load the chip-scale solution is actually more efficient. This is most of the target range identified in the original analog interface definition. So, the chip-scale solution is a better choice even though it has the lowest maximum efficiency.



Figure 5. Efficiency of DC-to-DC Regulated Module Compared to Chip-Scale Converter

The solution size is the next point of comparison. The modular solutions are both 180 mm² on the PCB, and the unregulated module is actually 10 mm tall, making it not only take up board space, but it is likely the tallest item on the board, determining the case size for our theoretical module. The clear choice again is the chip-scale module in a low profile SSOP20 JEDEC standard package, at 55 mm², plus some bypass capacitors and two resistors.

The advantage of choosing a regulated versus an unregulated solution is related to the power supply rejection of the ADC and amplifier in the analog front end. Better regulation allows much more flexibility in choosing components that do the measurement job required rather than limiting the choices to the parts with the best power supply rejection numbers.

The final differentiating factor between modular and discrete solutions and chip-scale solutions is the operating frequency. The switching currents create noise and ripple on the power supply. In many cases, the modules operate in the 200 kHz to 1 Mhz frequency range, which corresponds to the frequency sample rates for many sensor applications. Care must be taken to properly filter or antialias the data from the power supply noise. The chip-scale solution runs its primary power oscillator at 125 MHz well above the sampling frequency of most industrial sensor ADCs. There is still ripple due to the PWM control of the power oscillator, but the biggest noise source is above the bandwidth of the ADC and easily filtered.

ADDITIONAL BENEFITS OF CHIP-SCALE CONVERTERS

Just on the basis of the size efficiency, the chip-scale converter is a good choice for this application. However, there are many other advantages to the technology. Let's look at the new ADuM5010 isolated power converter in detail. This device can give the performance of a telecom dc-to-dc converter at the low power range required for analog interfaces.

- Infinitely adjustable output voltage. The ADuM5010 sets its output voltage via a voltage divider on the secondary side. It can range from 3.15 Vto 5.5 V. Many analog ADCs and op amps operate with nonstandard supply rails, so the voltage can be adjusted to take advantage of optimum supply conditions.
- 2. Thermal shutdown protects the supply during short circuit overload conditions, especially at high ambient temperatures where the maximum die temperature could be exceeded. The thermal shutdown trips at 154°C, and the die must cool by 10°C before the part will automatically restart. No external processor intervention is required to restart the supply.
- 3. Softstart is implemented through primary side control of the PWM as power is applied. This allows the part to start with negligible inrush current. When multiple parts are starting simultaneously, inrush current can overwhelm a weak dc input supply rail and cause unpredictable operation.
- 4. Primary side power disable allows the converter to be shut down to a very low standby state. This feature combined with softstart can allow power saving schemes which turn power off to a sensor between measurements.
- 5. Under voltage lockout (UVLO) on the primary side input supply. This feature prevents the converter from starting at low input supply rails. This allows the input supplies to charge significantly before the downstream ADuM5010 tries to draw power.
- 6. Fully certified isolation. This can allow reduced type testing of modules and elimination of in-line test during production.

CONCLUSION

The analog sensor interface application, as designed for most PLC applications, requires isolation of both digital communications and power. The power levels are very low, lower than most dc-to-dc converters can function efficiently and predictably. However, the interface benefits greatly from having a well regulated and well behaved power supply. The ADuM5010 isolated chip-scale converter fits the requirements of the isolated analog input very well, with 150 mW of power and a set of features normally only available in high power dc-to-dc converters. This part is the power-only version of a family of devices that combine power with isolated data channels. The ADuM521x dual data channel devices will allow the data interface to be combined saving even more space. Higher channel count devices will fill out the line as it develops. This allows power to be applied safely and simply with a minimum of design effort.

ABOUT THE AUTHOR

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