Analog Isolation in the 21st Century

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Editor's note: Here is an article regarding a new approach to analog isolation. Each application example makes use of a high-current PVI as an isolated power source, a micropower digital isolator, and a micropower data converter. All of the examples are "building block" type of circuits put together by Arlie Stonestreet whom I met at an Analog Aficionados dinner a few years ago. He designed these circuits out of need for a new system design on which he was working and thought that EDN readers might be interested in the various solutions here. We have here a great example of how designers think and use their resources to solve problems. (Note the hand-drawn schematics in Figures 4 through 8—that's the way we roll as designers.)

Analog isolation is becoming increasingly important in a multitude of applications including industrial inverter designs, medical applications, metering, isolated sensor applications, and battery management to name just a few. While dedicated isolation amplifiers have been around for some time, often these amplifiers are application specific. Many are targeted for use in isolated current sensing applications and consequently have a limited input range, undesirably low input impedance, and poor gain accuracy.

An additional key challenge has also been in providing isolated power to these devices. While a typical miniature 1W DC/DC converter may sport a 1kV or higher isolation voltage, this is usually only a 1 second rating and the fine print often reveals that the true working voltage is but a paltry 42.4V peak – rendering such devices wholly unsuitable for use in numerous isolation applications. However, even with a DC/DC converter having a suitably high continuous working isolation voltage, the coupling capacitance between the isolated windings must also be kept low if one is to preserve high common mode transient immunity.

Today, a new class of high-current photovoltaic isolators, low-power high speed isolators, and micropower data converters are available. This is the trifecta needed to enable an endless number of isolated designs that no longer require the compromises mentioned above.

High Current PVI Milliwatt Power Source

The 8A100-1 and 8A100-2 family of devices from Dionics-USA are dual high-current PVI milliwatt power sources. Since these are dual devices, the independent outputs may be wired in parallel for increased output current, in series for higher output voltage, or as a split supply if needed. For example, in the application shown in Figure 1 below the outputs are paralleled and a micropower shunt reference provides a stable 3.00V regulated output.

For a 20mA input LED bias the shunt regulated output can source 200uA for the 8A100-1 and nearly 300uA for the 8A100-2 all while maintaining a stiff output voltage of 3.00V. Considerably higher output power in excess of 3mW can be achieved on a duty-cycle limited basis. Additionally, the true galvanic isolation provides high continuous working isolation voltage and vanishingly low coupling capacitance.

Another benefit of the PVI approach is no minimum loading requirement; the clean power produced on the output eliminates the need for EMI output filtering, and the LED input produces no inherent reflected ripple current. The 8-pin surface mount gull-wing or through-hole package is also smaller and less costly than any other isolated power source that could be envisioned in such an application. The relatively high output power of this device, in comparison with other PVI devices, is achieved using an optimized detector structure and customized for voltage levels used by most modern data converters and logic devices.

To achieve even higher output current and efficiency, the 8A100-2 uses a dual LED emitter in each channel thus yielding a 1.5X increase in output current at the expense of the increased forward voltage drop on the input. As we will soon see this flexible mW isolated power source hits the “sweet spot” for many potential isolation applications.

Figure 1: Dionics 8A100 High Current PVI Output Current vs. Input LED Drive

Micropower Digital Isolators

Micropower Digital Isolators

The NVE IL500, IL700 series isolator and the equivalent Avago HCPL-9000/-0900 series, use giant magnetoresistive (GMR) technology for high-speed digital isolation (Figure 2). The advantage these devices have over other isolators is that for the transmitting channels the quiescent power is less than 30uA per channel and the additional dynamic power consumption is around 14uA/100kbps per channel. If the data rate is equivalent to 100kbps the total isolator supply current is only 44uA, which can be easily supplied by the 8A100 Dionics-USA high-current PVI mW power source while still leaving plenty of current in reserve for powering the associated data converter.

Figure 2: IL711 Two-Channel Digital Isolator - Input channels are micropower

For applications requiring bi-directional digital isolation such as SPI interfaces, Analog Devices recently released the micropower ADuM144x series quad-channel digital isolators based on their iCoupler® technology (Figure 3). For these devices, the quiescent supply current is under 10uA/channel and the dynamic current is under 10uA/100kbps and again are easily powered by the 8A100 devices.

Figure 3: ADuM144x Micropower Digital Isolator

Isolated Analog Voltage-to-PWM

The Linear Technology LTC6992 micropower PWM TimerBlox® accepts a 0 to 1V analog input and produces an output duty cycle proportional to the input voltage. The PWM output is isolated via the IL510 and demodulated with a simple RC filter (Figure 4). Alternatively, the PWM output may be read directly in digital form by the input capture port of a microcontroller to determine duty cycle and hence voltage.

Even when configured for a PWM frequency of 100kHz the device current for the TimerBlox was around 112uA and the device current for the IL510 isolator was 64uA for a total supply current of 176uA. This supply is easily furnished by the Dionics 8A100 high-current PVI and proper voltage regulation on the isolated side is set using the 3.0V shunt reference. A TimerBloxDesigner Excel Spreadsheet is available from the Linear Technology website to ease component selection for frequency, duty cycle, and control voltage range.

Figure 4: Isolated PWM

Isolated Analog-to-Digital Converters

There are a number of micropower data converters available in both delta-sigma (Table 1) and SAR flavors (Table 2) that can be used to create a custom isolated ADC signal path typical of Figure 5. In this example the micropower ADuM1441 provides isolation of the SPI interface between the ADC and the microcontroller and the Dionics 8A100 high current PVI again provides a clean source of isolated power to the ADC and the digital isolator. For most ADC’s the highest power draw is often consumed only during conversion mode, or when operating at the highest sampling rates.

Even though many ADC’s are not advertised explicitly as micropower, often times they can achieve micropower operation by scaling back the conversion rate duty cycle or operating at lower sample rates. Alternatively, the PVI power source can be set to run at a relatively lean bias current during converter sleep mode and then during periods of high conversion current the PVI can be biased at considerably higher currents on a duty-cycle limited basis. For example, the 8A100-2 PVI could deliver in excess of a full 1mA (i.e. 1000uA) supply current at 3.3V under a 75mA LED input bias having a 25% duty cycle.

Figure 5: Isolated ADC

Table 1: Micropower Delta-Sigma ADCs

Table 2: Micropower SAR ADCs

Isolated Active Current Load

Isolated Active Current Load

The previous examples have focused on isolating analog inputs. A similar approach can be taken with isolated analog output such as the Active Current Load shown in Figure 6. An AD5290 digital pot provides a convenient means for setting the current to a defined level via an isolated SPI interface. Most digital pots are inherently micropower and this one is no exception with a 15uA (typ) current consumption. The micropower op-amp is used to sense current from across the 1.0 ohm sense resistor and servo the gate drive to the FET so that the current matches the setpoint provided from the wiper of the digital pot.

With a 1.0 ohm sense resistor and 3.0V across the digital potentiometer provided by the precision shunt reference, the full scale range can adjust between 0 to 3.0 Amps with 8-bits of resolution. Since the output is fully floating, there need be no concern about circulating ground loops with the attached circuit under load, and the maximum voltage that can be applied is limited only by the voltage rating of the FET. As with any implementation of an active current load, the FET gate can present an awkward capacitive load to the op-amp output that can compromise phase margin; if the capacitive loading is too high, additional compensation is necessary to maintain stability.

Figure 6: Isolated Active Load

Self-Powered Analog Isolation Amplifier

The Dionics 8A100-1 PVI can also be used to create a self-powered isolation channel. Since the input is self-powered, no special isolated supply is required on the input side when measuring voltages higher than the forward voltage drop of the LED. The circuit leverages the highly linear relationship between input LED current and output PVI short-circuit current. In addition, the channel-to-channel match and tight thermal coupling of the Dionics 8A100-1 dual channel PVI ensure stability over time and temperature.

In this circuit the current through the input LED is made to be proportional to the input voltage via selection of the input resistor. A full scale current of roughly 1mA was chosen for the circuit in this example. The PVI associated with the input channel is tied to the inverting input of the op-amp, which is at virtual ground, so the available short circuit current of the PVI will flow in proportion to the input current or changes in the input current.

Negative feedback from the op-amp will servo current through the high-side LED to generate a balancing bias in the high-side PVI to maintain the inverting input at the same level as the non-inverting input – thus continuously forcing current equality between the top and bottom PVI's in the process. With the matched characteristics of the optocoupler pairs afforded by the Dionics 8A100 multichannel isolator, and an output resistor scaled to match the input resistance, the resulting current required to maintain this balance will closely track the input current and hence the output voltage of the op-amp will be a reflection of the input voltage. The coupled gain tracking requires the following conditions be met:

- The PVI’s must operate in “short circuit” current mode
- A multi-channel PVI isolator must be used to ensure matching and thermal coupling

This example shows unity gain isolation. The output resistor can easily be adjusted to establish the desired transfer function gain and, if necessary, trimmed to compensate for any residual gain mismatch between the optocoupler pairs. The servo nature of the design ensures there is no additional offset term (apart from the guaranteed input offset of the op-amp) for input voltages above the LED forward voltage drop so the design need not provision for any offset adjustment. Feedforward compensation is provided to ensure stability. The compensation values are best determined empirically in the final circuit by applying a full-scale square wave input and ensuring a suitably damped response. The tested design has excellent large-signal waveform conformity for frequencies up to 20kHz and a usable frequency range on out to 55kHz.

While similar isolation techniques can be attempted with classical phototransistors, the CTR of phototransistor couplers follows a roughly square–law relationship as a function of LED bias current. As a consequence, the GBW product of such implementations varies as a function of input level, as these elements are a part of the feedback loop, and this results in quite apparent distortions, non-linearity, and severely limits bandwidth for large signal variations.

Figure 7: Self-Powered Analog Isolation Amplifier

Multiple Isolated General Purpose I/O

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There are a number of microcontrollers which offer micropower operation such as the Atmel ARM Cortex SAM4L series (100uA/MHz), the Renesas RL78 series (66uA/MHz), and the Silicon Labs Geko series just to name a few. Such devices enable a number of complete isolated function blocks channels to be networked together as shown in Figure 8. In this example, two PVI devices are used to produce four independent fully floating sources with each floating source capable of powering a dedicated microcontroller and digital isolator pair. The output of the independent microcontrollers is networked on a single SPI bus to a microcontroller serving as a Master. While the example shows four isolated channels the concept can be extended to any number of channels with little effort.

Figure 8: Multiple Isolated General Purpose I/O

Conclusion

With the recent availability of a high current isolated power source – the Dionics 8A100, micropower digital isolators, and a full complement of high performance support components, analog isolation is as easy as 1-2-3. It is now convenient and cost effective to have multiple channels while maintaining not only input-to-output isolation but channel-to-channel isolation as well. Of course, these techniques need not be limited to just analog isolation but can be equally be applied to discrete digital isolation applications and data bus isolation in general.

References

[1] For information on the Dionics 8A100-2 High Current PVI refer to www.Dionics-USA.com

[2] For information on NVE Digital isolators refer to www.NVE.com

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[5] For information on Analog Devices micropower Digital Isolators, Digital pots, and Data Converters refer to www.analog.com

[6] For information on TI Data Converters refer to www.ti.com

About the author

Arlie Stonestreet II obtained a BSEE from Kansas State University in 1995 and is Chief Design Engineer at Ultra Electronics - ICE Corporation, an AS9100 registered company specializing in custom design, manufacture, and test of complex electronic controllers for aircraft and aerospace applications. He holds multiple US and international patents and enjoys analog and mixed signal design challenges.