Isolated Error Amplifier Replaces Optocoupler and Shunt Regulator for AC/DC and DC/DC Power

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Designers of isolated AC/DC, DC/DC or DOSA-compliant power modules face challenges when responding to market requirements for increased performance. This article introduces the digital isolator error amplifier, which improves transient response and the operating temperature range for primary side control architectures. The traditional application for a primary side controller is to use an optocoupler to provide feedback loop isolation and a shunt regulator as an error amplifier and reference. While often seen as an inexpensive isolator for use in a power supply, an optocoupler will limit the loop bandwidth to a maximum of 50 kHz, and in practice, it can be much lower. The use of fast and reliable digital isolator circuits, which integrate an isolated error amplifier and precision reference functions into a single package, will result in a precise isolated error amplifier with much lower temperature drift and much higher bandwidth. A loop bandwidth of over 250 kHz can be achieved by an isolated error amplifier, which makes it possible for isolated primary power supply designs to run at much faster switching speeds. With the right power supply topology, faster switching speeds enable the use of a smaller output filter inductor and capacitor for a more compact power supply.

The initial topology we will examine is a flyback converter, since this is the simplest circuit in terms of component count. The flyback circuit can have the fewest switches, in this case, just one on the primary side, and a rectifying diode on the secondary side. The simple flyback circuit is often used for relatively low output power, but it does have a high output ripple current and low crossover frequency due to the right half-plane (RHP) zero. As a result, flyback circuits require large values of output capacitance with a large output ripple current rating. The optocoupler approach is shown in Figure 1 and involves the use of a shunt regulator to act as the error amplifier of the feedback voltage of an isolated output voltage V_O. The shunt regulator provides the reference voltage with a typical 2% accuracy when used as

the accuracy standard. The divided down output voltage is compared to the shunt regulator's reference voltage by the internal error amplifier, and the output is fed to the optocoupler LED circuit. The optocoupler LED is biased by a current provided by the output voltage and a series resistor, and the amount of current needed is based on the optocoupler current transfer (CTR) characteristics as described in its data sheet.
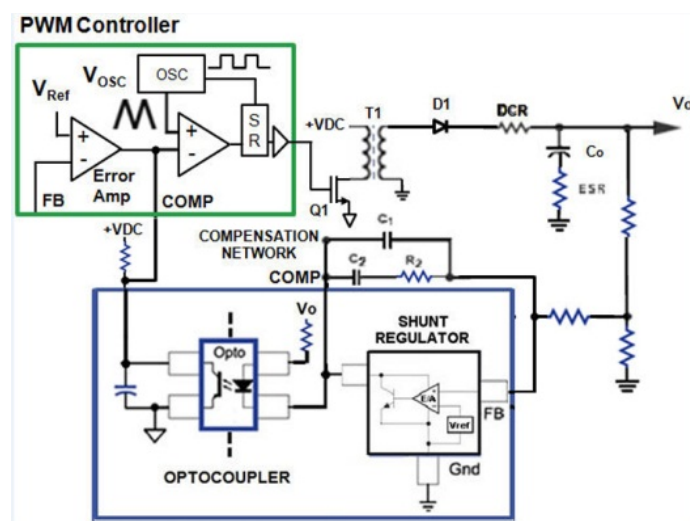

Figure 1. Block Diagram of a Flyback Regulator with Optocoupler and Shunt Regulator
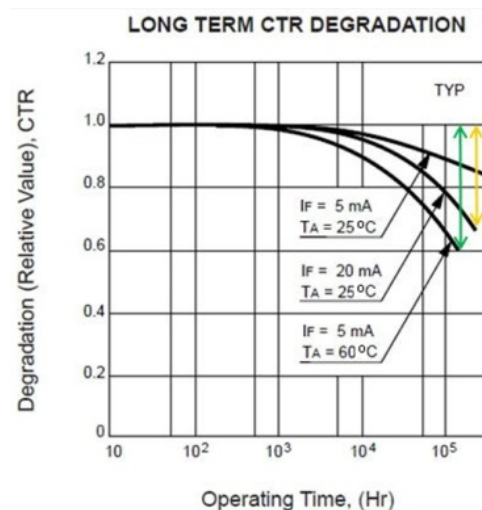

Figure 2. Optocoupler CTR Degradation

The CTR is the ratio of output transistor current to input LED current. The CTR characteristics are not linear and vary from optocoupler to optocoupler. As shown in Figure 2, optocoupler CTR will vary over operating lifetime, which makes designing for reliability very challenging. The optocoupler you design and test today will usually have a two to one uncertainty in initial CTR and will have 40% less CTR after years of use or service in high temperature environments found in high power and high density supplies. When an optocoupler is used as a linear device, it has a relatively slow transfer characteristic (the small signal bandwidth is about 50 kHz) which leads to slow loop response of the power supply. For the flyback topology, having slow transfer characteristics may not be a problem,

since this topology requires that the compensation of the error amplifier reduce the loop bandwidth to maintain a stable output. The concern with the optocoupler is that the variation of its output characteristics over time can force the designer to reduce the loop response even more to ensure the stability of the loop. The disadvantage of slower loop response is that this will degrade the transient response, and the output voltage will take a longer time to recover after a load transient. Adding a larger output capacitance can help reduce the output voltage drop but will increase the output response time. This leads to a larger and more costly power supply design, when a smaller and lower cost solution may be possible and more desirable.
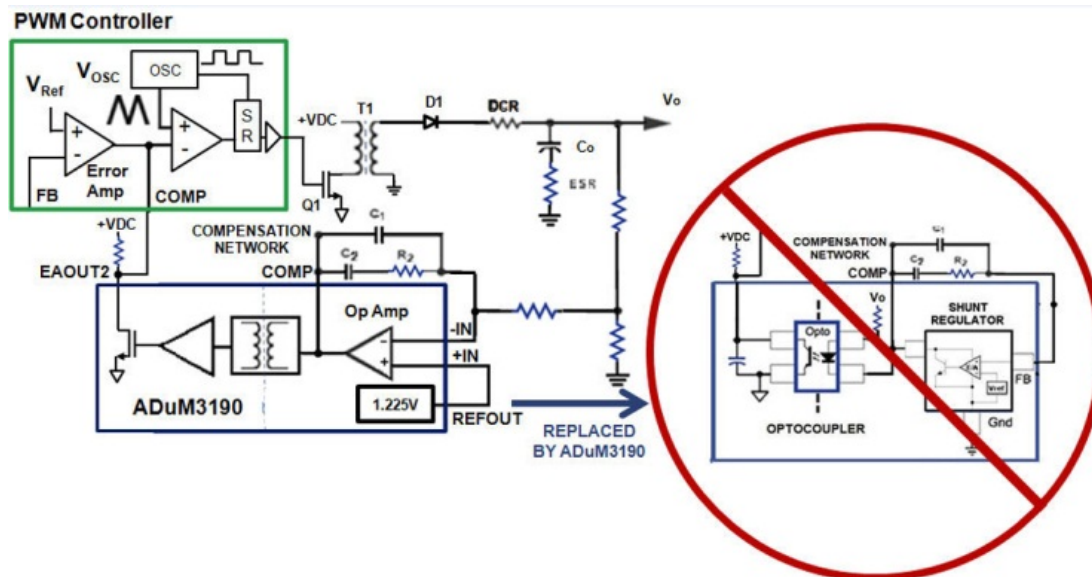

Figure 3. Isolated Error Amplifier Replaces Optocoupler and Shunt Regulator

Having illustrated the difficulties of obtaining stable operation of an optocoupler as a linear isolator, the ability of the isolated error amplifier to offer stable and reliable performance over time and temperature extremes can be examined. As shown in Figure 3, the shunt regulator and V_{REF} function are now replaced with the wideband operational amplifier and 1.225 V reference section, and the optocoupler is now replaced with the fast linear isolator based on digital isolator technology. The operational amplifier on the right side of the device has a noninverting +IN pin connected to the internal 1.225 V reference and an inverting −IN pin available for connecting a feedback voltage in an isolated dc-to-dc converter output, through a voltage divider. The COMP pin is the operational amplifier output, which can be used to attach resistor and capacitor components in a compensation network. The COMP pin internally drives the transmitter block, which converts the operational amplifier output voltage into a modulated pulse output that is used to drive the digital isolator transformer. On the left side of the isolated error amplifier, the transformer output signal is decoded and converted into a voltage that drives an amplifier block. The amplifier block produces the error amplifier output available at the EA_{OUT} pin, which is used to drive the input of a PWM controller in the dc-to-dc circuit.
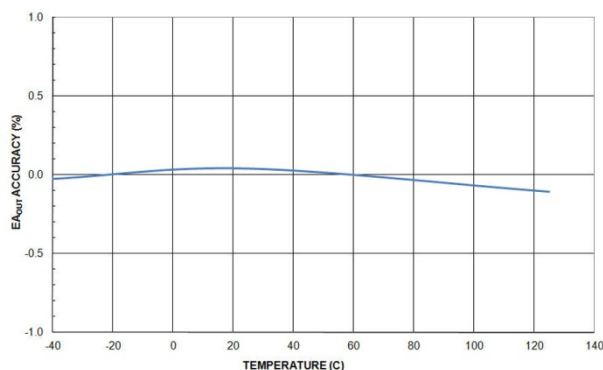

Figure 4. Isolated Error Amplifier Output Accuracy vs. Temperature

The advantages of this new isolated error amplifier include the reference and operational amplifier which have been designed to minimize offset and gain error drift over temperature. The 1.225 V reference circuit is trimmed for 1% stability over temperature, which is more accurate and has much less drift than a shunt regulator. As shown in Figure 4, the typical output characteristic of the isolated error amplifier changes only 0.2% over a −40°C to +125°C range, enabling a high accuracy DC/DC output. To maintain a stable output characteristic, the COMP output of the operational amplifier is pulse encoded to send digital pulses across the isolation barrier and then decoded back by the

digital isolator transformer block to an analog signal, completely eliminating the problems from CTR variations when using an optocoupler isolation.

For applications requiring faster transient response than possible with a flyback circuit, a push-pull topology can be implemented with the isolated error amplifier. The push-pull circuit is shown in Figure 5, with two MOSFETs alternately switching on and off, charging the two primary windings of a transformer, and then the two secondary windings with diodes to conduct and charge the output filter inductor and capacitor. When properly compensated, the push-pull topology will be very stable with much faster switching frequencies and faster loop response. The same isolated dc-to-dc design example used for the flyback circuit, 5 V in to 5 V out at 1.0 A output current, is now implemented for the push-pull circuit using the ADuM3190 isolated error amplifier. The push-pull design has a 1.0 MHz switching frequency versus the slower 200 kHz of a typical flyback design, so the ADuM3190, with its higher bandwidth, presents a better option than an optocoupler. The output filter capacitance has been reduced from 200 μF for a typical flyback down to only 27 μF for the push-pull, and a small 47 μH inductor is added. The waveforms shown in Figure 6 show that for the conditions of 100 mA to 900 mA load step, the push-pull circuit with the isolated error amplifier responds in only 100 μsec as compared to 400 μsec for a typical flyback, a four times improvement. Instead of a 400 mV change in output voltage seen by the flyback circuit, the push-pull circuit output voltage only changes by 200 mV, a two fold improvement. The use of the faster push-pull topology and the higher bandwidth of the isolated error amplifier, results in high performance with faster transient response and a smaller output filter.
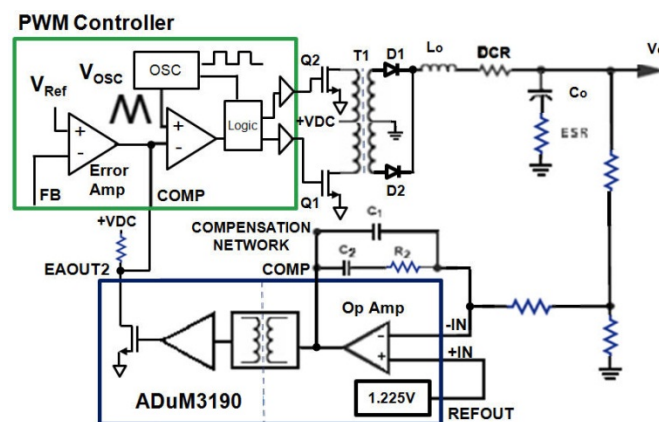

Figure 5. Block Diagram of a Push-Pull Converter with Digital Isolator Error Amplifier
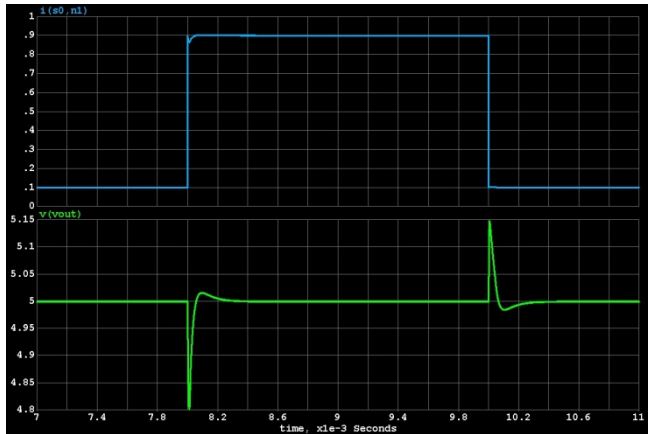
Figure 6. Push-Pull Converter with Digital Isolator Error Amplifier 100 mA to 900 mA Load Step

These improvements were made possible by the high bandwidth of the 400 kHz isolated error amplifier, which enables a faster loop response. The secondary side error amplifier, which has a high gain bandwidth product of 10 MHz, is about five times faster than a shunt regulator and enables the higher switching frequency to 1 MHz for an isolated dc-to-dc converter. Unlike optocoupler solutions, which have an uncertain current transfer ratio over lifetime and over temperature, the isolated error amplifier has a transfer function that does not change over its lifetime and is stable over a wide temperature range of −40°C to +125°C. With these performance improvements, the isolated error amplifier will become the solution of choice for power supply designers of isolated dc-to-dc converters who want to improve transient response and operating temperature range with primary side control architectures.

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