Isolation technology increases density and reliability

Switch mode power supplies (SMPS) are widely used for data centre networking because of their power density, efficiency, and reliability. Daniel A. Baker, Ph.D, NVE, reviews the evolution of SMPS technology, and examines recent improvements in isolation technology.

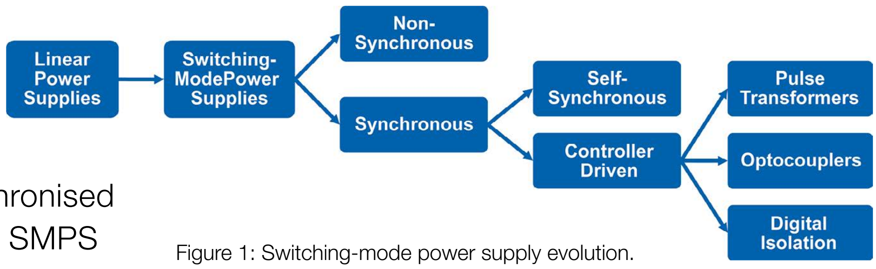

Figure 1: Switching-mode power supply evolution.

Switch mode power supplies have moved from non-synchronous buck converters to synchronous rectification. Synchronous rectification has evolved from self-synchronised to controller-driven (see Figure 1). Most SMPS designs are internally isolated. Synchronous gate drive isolation is the most challenging isolation element and has migrated from pulse transformers, to optocouplers, to several types of digital isolators.

Non-synchronous buck converters rely on diodes for rectification, usually Schottky diodes, because of their low voltage drop compared to silicon diodes. The diode's forward voltage drop reduces efficiency, but inherent limitations prevent diode forward voltages from being reduced below approximately 0.3V. Losses have become more significant as voltages decrease.

Synchronous rectification uses MOSFETs to rectify the waveform. Unlike diodes, MOSFET voltage drop is ohmic, with no inherent lower limit. Synchronous rectification can be either self-synchronised or controller synchronised.

Rectification choices

Self-driven synchronous rectification relies on the AC waveform to switch the MOSFETs. Bridges of four MOSFETs provide full-wave rectification and does not require any additional electronics. The voltage required to switch the MOSFETs, however, means the rectification is not perfectly synchronised with the AC waveform zero crossing, which results in inefficiencies. Furthermore, gate voltages are not always enough to drive MOSFETs to their minimum on resistance.

Controller-driven synchronous rectification uses signals from the pulse-width modulation (PWM) controller to drive the rectification MOSFETs. This maximises efficiency by allowing near-perfect synchronisation with the AC waveform. It also requires just two MOSFETs rather than four.

Demanding applications, such as data centre networking, use controller-driven rectification because it provides maximum efficiency, minimum size, and minimum heating. However, it presents an additional challenge of high-speed isolation of the MOSFET gate drivers from the controller.

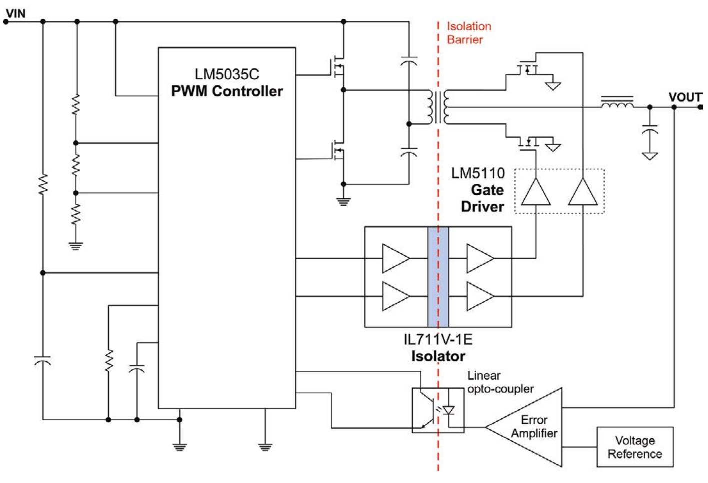

Figure 2: Typical SMPS circuit.

Electrical isolation

In most applications, power supply outputs must be electrically isolated from inputs and to prevent noise and ground loops. SMPS can use either external isolation transformers or internal isolation. External isolation is becoming less common because it requires a large transformer.

The key requirement for 220/240V SMPS internal isolation elements is 2.5kVRMS for one minute. This is more than an order of magnitude higher than mains voltage to ensure ample margin for surges and transients.

The typical SMPS circuit (Figure 2) shows the three signals that must typically cross the SMPS isolation barrier. A transformer isolates the pulse-width modulation controller from the output voltage, the output error amplifier provides isolated feedback, and two isolation channels drive the synchronous gate driver.

Each of the three isolation elements has different requirements. The transformer is inherently isolated, and its macroscopic dimensions make high isolation voltages straightforward. The isolated analogue error feedback system needs to be precise because it limits the output precision, but it does not need high linearity or accuracy, because it is part of a closed-loop system. This element does not require high speed because the error is DC, and feedback only needs to be fast enough to accommodate line and load changes, component drift, and environmental changes.

Isolation techniques

Isolating the controller from the MOSFET gate driver is perhaps the most challenging isolation element. Precise synchronisation with the AC waveform is critical to efficiency, so these isolators must be much faster than the switching frequency. Minimising pulse-width distortion minimises dead time and allows energy transfer for more of the switching period. Delays or distortion from the isolator also cause the FETs to switch after the AC waveform zero crossing. This results in transients that can cause spurious switching. Ironically, the isolators can be vulnerable to these common mode transients. Therefore, in addition to speed and distortion, transient immunity is an important figure of merit for gate-driver isolators.

Common gate-driver isolator options are pulse transformers, optocouplers, and digital isolators. Gate drive transformers can sometimes transfer enough power to drive the MOSFET directly and are generally rugged, with high isolation voltage, and good long-term reliability. Unfortunately they are larger than optocouplers or solid-state isolators. Also, because they are inductive, they can only transmit limited pulse widths that constrain control range.

Optocouplers do not have the pulse-width limitations of gate drive transformers and tend to be smaller. They also have the advantage of being ‘quiet’ for EMI. They are, however, relatively slow, causing drive waveform distortion and imprecise rectification. They also have relatively low transient immunity, making them susceptible to spurious switching. Finally, optical couplers tend to drift and eventually fail as the LEDs degrade over time. Despite their limitations, optocouplers remain popular for isolating analogue error feedback

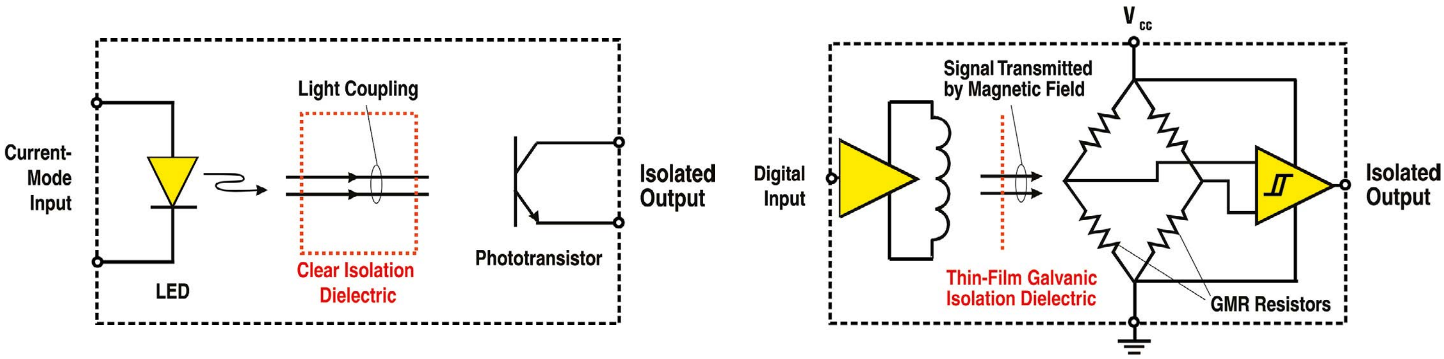

Figure 3: Optocoupler (left) compared to digital spintronic isolator (right).

because next-generation digital isolators are not well-suited for analogue signals.

Digital isolators

Non-optical digital isolators are generally faster than optocouplers, have higher transient immunity, and longer operating life. Three digital isolator types are used for gate isolation - inductive, capacitive, and spintronic.

Inductive isolators use radio-frequency carriers to transmit data through miniature antennae or transformers. Many are faster than optocouplers, but the carrier frequencies limit pulse position accuracy. They are also generally smaller than optocouplers and have higher transient immunity, and longer operating life. Operating life is limited by an isolation barrier in the devices, which are polymers or oxides less than one one-thousandth of an inch thick. The barriers must withstand high voltages, and the small dimensions make them susceptible to diffusion or partial-discharge failures. Operating lives of inductive digital isolators are 50 to 100 years, which is longer than optocouplers.

Capacitive isolators use a changing electric field to transmit data across the isolation barrier. Like inductive isolators, this requires high-frequency signalling, leading to imprecision and EMI. With life specifications of 13 years, they are less durable than other digital isolators.

Spintronic isolators transmit data using magnetics rather than light (see Figure 3). They do not have RF carriers or refresh clocks, so radiate very little EMI. This is important for meeting standards such as EN55022-B or FCC Part B. They use a ceramic / polymer composite barrier. Spintronic isolator life is 44,000 years.

Future trends

SMPS are expected to become smaller, more efficient, and more reliable. The PWM controller and gate driver in Figure 2, for example, are both available in small, leadless packages (the LM5035 in a WQFN-24 and the LM5110 in a WSON-10). MSOP-8 2.5kV isolators, introduced in late 2014, are half the footprint area of SOIC-8 isolators, which were previously the smallest. Faster electronics and higher frequencies allow smaller inductive components.

MOSFET manufacturers are reducing drain-source resistance to minimise losses, and reducing total gate charge for speed. Gate drivers and isolators are also becoming faster, and therefore, more efficient.

Error amplifier isolation is the weak link in SMPS reliability. Hybrid digital isolation amplifiers (i.e. analogue-to-digital modulators and demodulators separated by digital isolators), may become precise and inexpensive enough to replace analogue optocouplers. Isolator manufacturers are also developing non-optical analogue couplers.

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