Capacitive Isolation: A Fundamental Building Block in Future AC/DC Power Conversion

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Capacitive isolation is a mature solution developed over the past decade to replace optocouplers in signal isolators, isolated gate drivers, isolated transceivers, and other applications [1]. However, the potential to use capacitive isolation to replace optocouplers in offline adaptors is often neglected. This articles explains why capacitive isolation can be a fundamental building block in future AC/DC power conversion, how it exceeds the performance of other isolation technologies, and the unique advantages it can bring to end applications.

Why Isolation and Types of Isolation

The “isolation” mentioned in this article also refers to galvanic isolation, which is used to isolate functional sections of electrical systems to prevent direct current from flowing between them. For power supplies where the input end may be a hazardous high voltage, the input must be galvanic isolated from the control end or output end (which may include a human-accessible terminal) with enough safety distance. If any failure occurs on the control end, the isolation barriers prevent the high voltage from reaching users and cause catastrophic results. A more detailed introduction to galvanic isolation can be found in Reference 1.

For example, as in electric vehicles, the high-voltage battery that powers the drivetrain is isolated from the low-voltage electronics by various isolated links across all sub-systems. As another example, AC/DC battery chargers are required by UL to offer isolation protection, as the output is typically user-accessible. However, IoT devices may not require isolation from AC, as the AC/DC portion of such device has no direct contact with the end users during normal operation.

A galvanic isolation barrier is based on either optical, magnetic, or capacitive isolation (see Figure 1) [2] [3]. Optical technology is light-emitting diode (LED)-based and is widely used in AC/DC conversion for output feedback. However, the reliability of optocouplers can degrade as these devices suffer from aging, temperature drift, and varying current gain issues. Sometimes, a second optocoupler is required for additional over-voltage protection (OVP) and takes up quite a bit of PCB space. It is easy to see how much space two big optocouplers take up on a small 5W Apple adaptor in Reference 4 [4].

Magnetic isolation can be achieved using coupled inductors. A popular physical form for magnetic isolation in AC/DC conversion is to use a special tooled lead frame to form a magnetic link between the primary and secondary side. According to Reference 1, magnetic isolation can be sensitive to electromagnetic interference, and high magnetic fields are strong and prevalent in some applications, such as HVAC systems and factory automation involving motors.

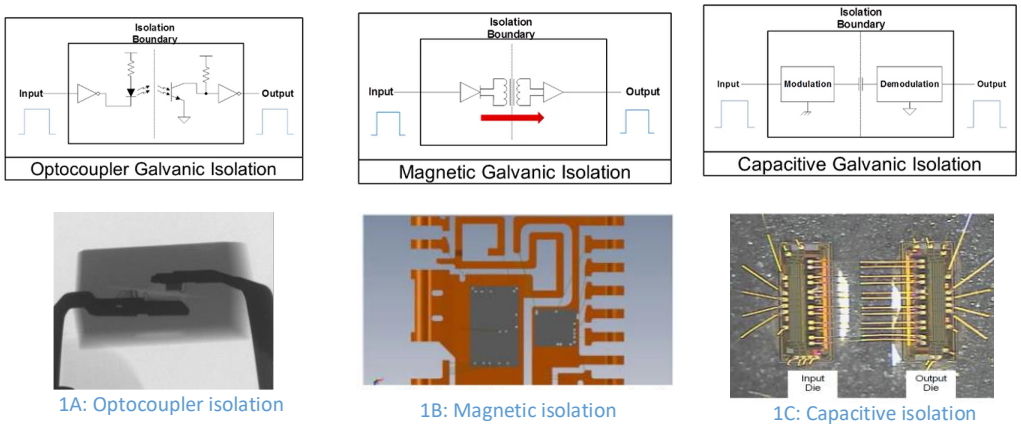

Figure 1: Various Galvanic Isolation Technologies

For capacitive isolation, which is made by adding capacitive isolation barrier on top of each die to connect in series, digital circuits are used for encoding and decoding various signals through the isolation barrier. A capacitive isolator's inability to pass DC signals makes it inherently the right choice for isolation, which is why it is widely used in sensitive and important applications, such as telecom and industrial power. Capacitive isolators are not susceptible to magnetic noise but can maintain high data rates and keep power consumption low. Capacitive isolation can also transfer signals bi-directionally, while optocouplers are unidirectional. Reference 3 raises some concerns about capacitive coupling, but with proprietary design methods, the capacitive current through the isolation barrier and high dV/dt common noise will not affect flyback controllers in normal operation.

The Key Benefits for Capacitive Isolation in Adaptors

The first benefit of capacitive isolation in adaptors is full secondary control of flyback converters.

For USB power delivery quick chargers, manufacturers are expected to add much higher power to their existing adaptor portfolio, but still within a reasonably small size. This requires high-frequency flyback controllers, secondary synchronous rectifiers, and high efficiency [5]. The challenge here is maintaining good communication from the primary side to the secondary side at a high frequency to prevent them from turning on at same time and causing severe problems. Capacitive isolation offers an easy solution to this. If the flyback control is generated at the secondary side, the controller can sense the turn-off of the synchronous rectifier (SR) and turn on the flyback quickly through the capacitive isolation link. Since the propagation delay from the secondary side to the primary side is very short, it offers safe operation and high-frequency operation potential. Therefore, users have a truly foolproof SR solution where a complete operation is integrated into a single IC compared to the difficult design of separate primary and secondary controllers normally required in optocoupler-based flyback power supplies.

The second benefit is that capacitive isolation offers higher reliability than optocouplers. According to Reference 6, capacitive isolation has several advantages over optocouplers, listed below [6]:

- Faster propagation time and better parametric stability over-voltage and over-temperature.
- A much lower failures-in-time (FIT) rate than optocouplers and an expanded operating temperature range of -40 to +125 °C. The isolation barrier lifetime is also a few times higher than that of optocouplers. Part-to-part matching is much tighter than the process used by optocouplers.
- The capacitive coupling output is either low or high, with none of the ambiguous output states found in optocouplers and excellent threshold stability over-voltage and over-temperature.
- Faster and more precise timing, lower-power operation, and reduced internal parasitic coupling for better CMTI.

The third benefit of capacitive isolation is the small bill of materials (BOM). Since capacitive coupling can be integrated inside the IC, adaptors can replace flyback controllers, SR controllers, optocouplers and the resistors/capacitors needed in a single IC solution (see Figure 2). This all-in-one capacitive coupled flyback IC may reduce the USB PD adaptor BOM by ~50%.

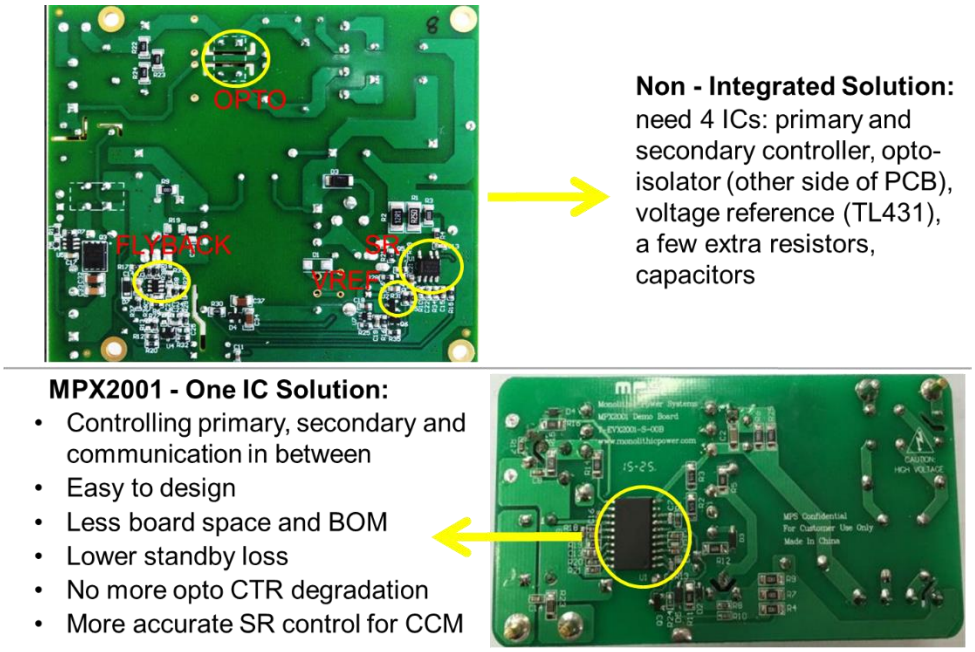

Figure 2: How Capacitive Coupling Saves BOM – TI[7] vs. MPS

The fourth benefit of capacitive isolation is its potential to support soft switching. In the past, soft switching, such as ZVS or active clamp, was very difficult to achieve without the communication from the secondary to primary side. However, with capacitive coupling, the parasitic capacitances of various switches can be discharged easily with perfect timing to achieve soft switching, offering much higher efficiency and reliability with accurate control.

The MPX2001

The MPX2001 from Monolithic Power Systems (MPS) is the first released IC that integrates capacitive coupling for flyback converter control. The MPX2001 integrates a primary driving circuit, capacitive isolation, and synchronous rectification driver all in one chip (see Figure 3).

Some key features of this IC include:

- 4.5kVrms isolation, 100% production HIPOT test, UL1577 and IEC 62368 safety approved
- Extremely low standby power consumption of <20mW
- 650V integrated HV current source for start-up
- 200V integrated SR controller, support both DCM and CCM operation
- 4-point average efficiency >91%
- Full protection features including OVP, POCP, OLP, brown-out, SCP, OTP, and UVLO
- Adjustable cable drop compensation

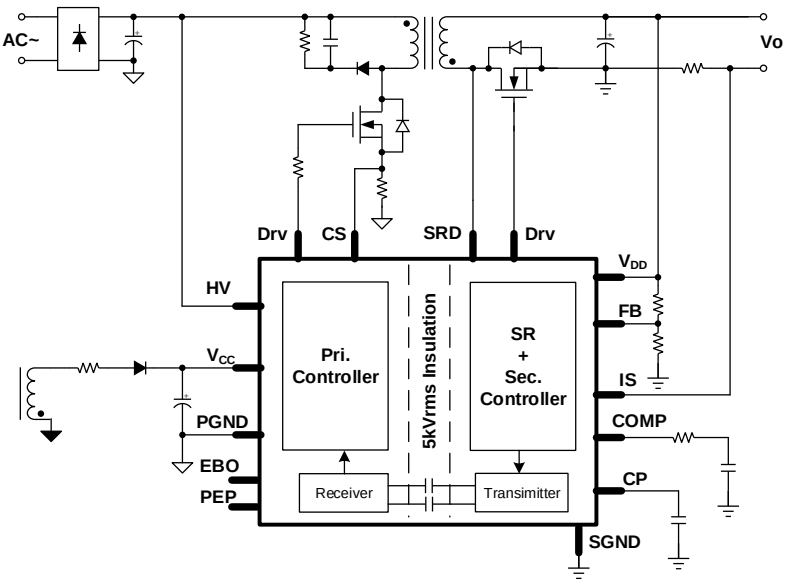

Figure 3: MPX2001 Basic Schematic

Figure 4 shows a certified 45W USB PD adaptor created based on the MPX2001 and Cypress CCG3PA USB PD protocol IC. The board shown has an obviously simpler BOM compared to past solutions.

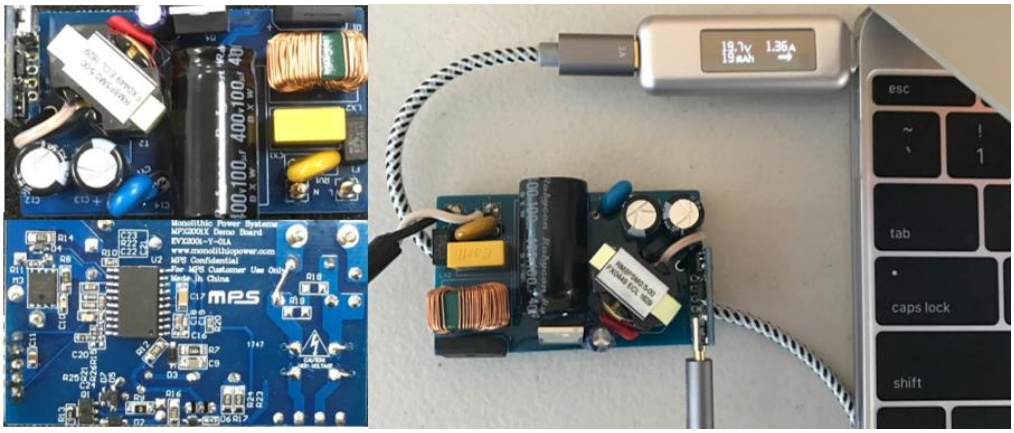

Figure 4: MPX2001-Based 45W USB PD Adaptor Charging a MACbook (Current Limited by Computer BMS not Power Supply)

Additionally, since capacitive coupling allows for secondary control of flyback controllers as an all-in-one solution, this opens a great deal of opportunities for future chipsets. For example, USB PD control is handled by a secondary-side PD protocol communication IC. This can be fully integrated with an all-in-one solution to achieve lower standby power, smaller board size, and an overall smaller BOM.

As another example, many commercial LED lighting fixtures are controlled by 0-10V analog dimmers or digital PWM dimmers [8]. Both dimmers control the LED power supply at the secondary side by means of a small isolation transformer and more than 10 external components. These also have the potential to be integrated onto the secondary control side and become an all-in-one solution for LED lighting.

Furthermore, digital power control prevails in high-end power supply designs, many for server power, where MCU/DSP are used on primary and secondary sides with capacitive isolated drivers and communication. Such solutions require high initial investment, high overall cost, and long development cycles. With capacitive isolation now available in analog chipsets, the advantage for digital control can be applied in the future across many more applications that are more cost-sensitive.

Summary

This article introduced why is capacitive isolation a better overall isolation technology, how capacitive isolation can be applied for AC/DC conversion, and how secondary control can offer many potential advantages in future AC/DC power conversion designs. The MPX2001 from MPS is an ideal all-in-one solution for integrating capacitive coupling for flyback converter control. For more detailed flyback controller, SR controller, and other AC/DC IC information from MPS, please visit https://www.monolithicpower.com or contact your local MPS sales office.

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[1] https://training.ti.com/zh-tw/introduction-isolation?cu=1135015

[2] https://www.silabs.com/documents/public/white-papers/CMOS-Digital-Isolators-WP.pdf

[3] http://www.powerguru.org/psu-ics-use-innovative-technology-to-reduce-25w-charger-cost-and-bom-count/

[4] http://www.righto.com/2012/05/apple-iphone-charger-teardown-quality.html

[5] Legislation in Power Supply Efficiencies Calls for Adopting Synchronous Rectifiers in Offline Power, https://www.allaboutcircuits.com/industry-articles/legislation-in-power-supply-efficiencies-calls-foradopting-synchronous-rec/

[6] https://www.silabs.com/documents/public/application-notes/AN731.pdf

[7] http://www.ti.com/tool/TIDA-00702#1

[8] https://www.dialog-semiconductor.com/sites/default/files/EBC980B_Reference_Design.pdf