Novel GaN Design Reduces Volume of AC/DC Converters Substantially

Power Integrations recently released a GaN-based IC called MinE-CAP, intended for use in a new generation of mobile credit card-sized chargers or offline power supplies. By halving the size of the high-voltage bulk electrolytic capacitors required in offline power supplies, this IC enables a reduction in adapter size of up to 40 %. The device also reduces in-rush current making NTC thermistors unnecessary, increasing system efficiency and reducing heat dissipation. **Andy Smith, Product marketing manager at Power Integrations discusses this new GaN application in detail.**

The principle sounds easy – a smaller electrolytic capacitor can be used in parallel to the input bridge rectifier and the MinE-CAP adds a second capacitor during the rectified half waves in order to release energy for the flyback converter – preferably a GaN-based Innoswitch-3. MinE-CAP is connected in series with the second capacitor and switches is on when necessary in correspondence with the flyback IC. In other words, the MinE-CAP leverages the small size and low on-resistance of PowiGaN™ transistors to actively and automatically connect and disconnect segments of the bulk capacitor network depending on AC line voltage conditions. By using MinE-CAP the smallest high-line rated bulk capacitor required for high AC line voltages can be selected, and most of the energy storage can be allocated to lower voltage capacitors that are protected by the MinE-CAP until needed at low AC line. This approach drastically shrinks the size of input bulk capacitors without compromising output ripple, operating efficiency, or requiring redesign of the transformer.

Electrolytic capacitors are physically large, occupy a significant fraction of the internal volume and often constrain form factor options – particularly minimum thickness – of adapter designs. The MinE-CAP IC allows the designer to use predominantly lower voltage rated capacitors for a large portion of the energy storage, which shrinks the volume of those components linearly with voltage. USB PD has driven a major market push towards small 65 W chargers and many companies have concentrated on increasing switching frequency to reduce the size of the flyback transformer. MinE-CAP provides more volume saving than doubling the switching frequency, while actually increasing system efficiency.

Intelligent approach to reduce the size

The MinE-CAPTM IC dramatically shrinks the size of input bulk capacitors without compromising output ripple, operating efficiency or requiring redesign of the transformer. When compared to traditional techniques such as very high switching frequency operation, MinE-CAP achieves the same or greater overall power supply size reduction whilst avoiding the challenges of complex EMI filtering and the increased transformer/clamp dissipation associated with very high frequency

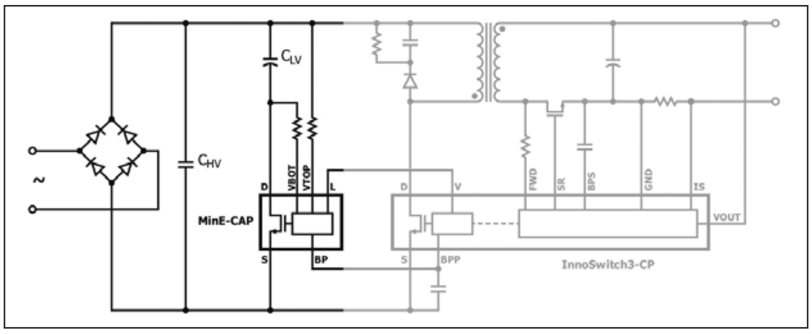

Figure 1: MinE-Cap typical application schematic

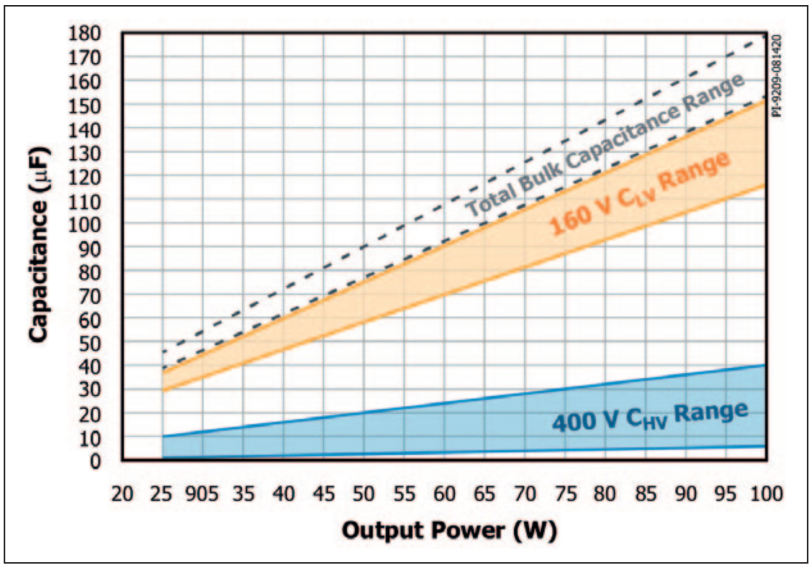

Figure 2: Typical component value ranges for optimal space saving and converter operation

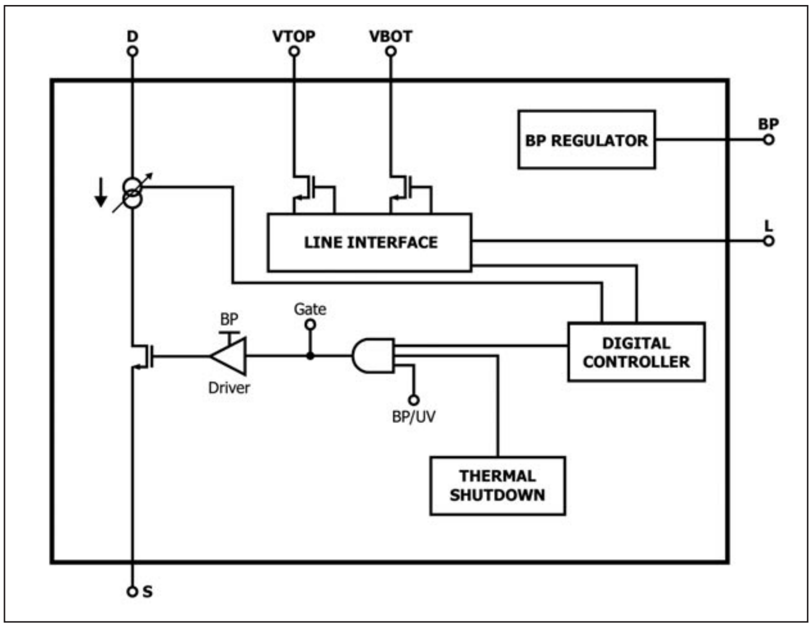

Figure 3: MinE-Cap IC block diagram

designs. MinE-CAP also precisely manages inrush current at AC turn-on, eliminating the need for dissipative NTCs or large slow-blow fuses.

Figure 1 illustrates a typical circuit configuration. The input E-CAPs are arranged with a small high-voltage capacitor (C_{HV} typically 400 V) in parallel with a low-voltage capacitor (C_{LV} typically 160 V) connected in series with the MinE-CAP IC. The physical size of the input capacitors is minimized because a high percentage of the input capacitance is 160 V rated rather than 400 V as would normally be used in conventional universal input converters.

During steady state-operation MinE-CAP introduces CLV into the circuit at low AC line voltage when maximum input capacitance is required. To achieve this, MinE-CAP monitors the input rail and voltage across C_{LV} to dynamically engage and disengage this capacitor during every AC line cycle as required to ensure that the power supply operates smoothly across the entire specified input voltage range.

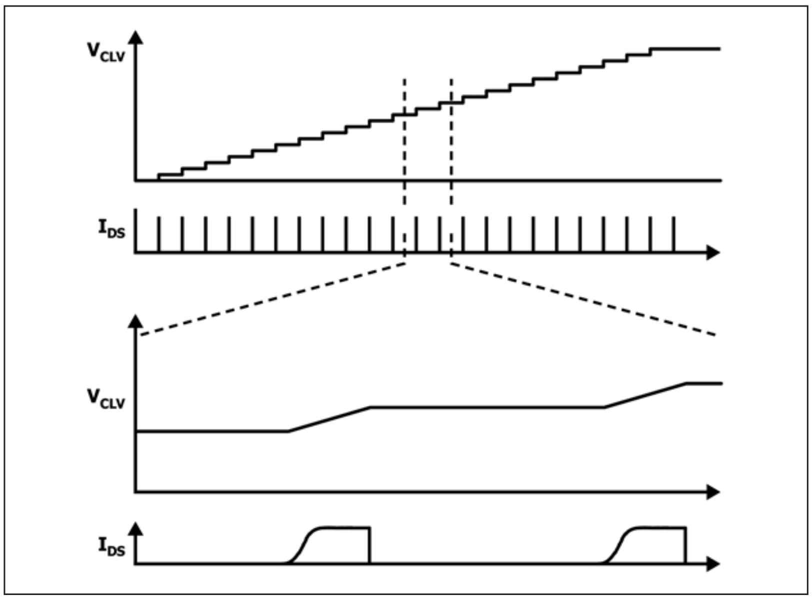

Figure 4: Charging algorithm for low-line start-up

Figure 2 illustrates the recommended range of C_{HV} and C_{LV} values to achieve the required total input capacitance for a given output power. C_{LV} is an electrolytic capacitor while C_{HV} can be selected as an electrolytic or ceramic. Ceramic capacitors in the range of 1 to 5 µF / 400 V (depending on power level) have very low series resistance (ESR) and typically offer the most space saving when the power supply is designed to accommodate ceramic capacitor characteristics. 400 V electrolytic capacitors are lower cost and when selected according to Figure 2 also provide up to 50 % size reduction compared to traditional designs. A variety of standard input EMI filter configurations can be adopted depending on the form factor of a particular application.

The MinE-CAP IC (Figure 3) is designed to partner directly with the InnoSwitch family of power supply ICs with a minimum of external components. The existing InnoSwitch V pin resistor is connected to the MinE-CAP VTOP pin while a resistor connected to the VBOT pin enables C_{LV} voltage monitoring. Input voltage and fault information is transmitted from the MinE-CAP LINE (L) pin to the InnoSwitch V pin with no additional components. The MinE-CAP IC also derives its bias supply directly from the InnoSwitch BPP pin (see application example left).

The MinE-CAP IC comprises a digital controller and high-voltage power switch which connected in series with the low-voltage bulk electrolytic capacitor in a power converter. The MinE-CAP IC connects this low-voltage capacitor into the power supply at low input line voltage conditions and disconnects it at high input line voltages. The high-voltage (400 V) capacitor is connected in parallel to support power delivery in high line conditions. The effective input capacitance is equivalent the sum of C_{LV} and C_{HV} at low input line to maintain the same minimum DC voltage to the DC/DC converter stage. At high input line condition the switch is disabled to ensure the voltage across C_{LV} does not exceeded the rated voltage of the capacitor. The MinE-CAP IC also includes a control signal transmitted from the MinE-CAP LINE pin to control the start-up and fault shutdown of an InnoSwitch IC via its V pin.

Upon application of AC input, the MinE-CAP controller is in the off-state and the power switch is open. The C_{LV} is not engaged in the circuit and only C_{HV} is charged by the AC input. The IC then performs controlled charging of C_{LV} allowing designs to eliminate the inrush NTC, improving the overall system design by removing a thermal hotspot and increases conversion efficiency (Figure 4).

Once the BYPASS (BP) pin reaches regulation the controller waits for the bulk voltage to be above the brown-in threshold (I UV+) measured on the VTOP pin. After brown-in, the controller enters a wait state for 20 ms to ensure power supply input voltage levels have stabilized. After that time, the IC samples the bulk DC voltage to determine which of two possible C_{LV}

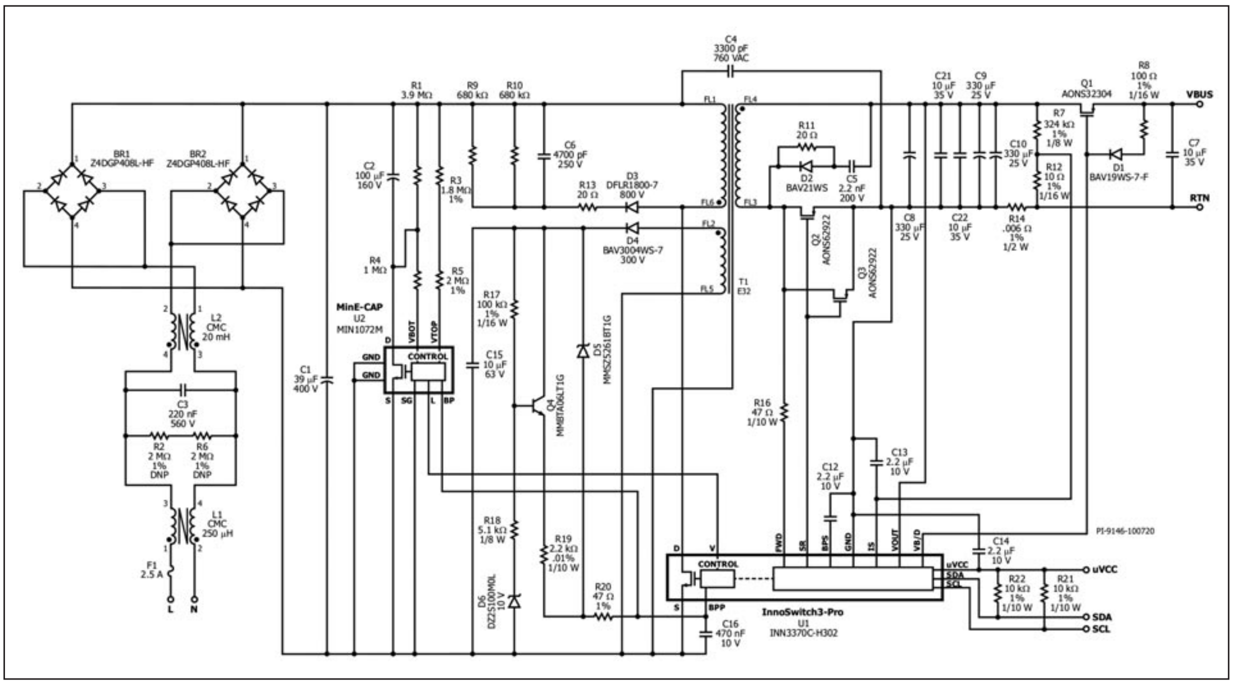

Figure 5: Application example of a 65 W power supply featuring GaN MinE-Cap IC and InnoSwitch3-Pro IC

charge up schemes to be adopted. In low-line start-up conditions (V_{IN} < 150 VAC), the MinE-CAP IC performs precisely controlled active charging of C_{LV}. At low-line start-up condition, it is important to pre-charge C_{LV} to support full power capability prior to enabling the InnoSwitch. The MinE-CAP IC controls the internal high-voltage switch as a current source and uses a precise constant current, pulse charging of C_{LV}, see Figure 4. This algorithm allows fast charging of C_{LV} and ensures PSU is able to deliver full power in less than 250 ms from initial AC line connection.

In high-line start-up condition (V_{IN} > 150 VAC), the active charging algorithm of C_{LV} is not employed. When selected according to Figure 2, CHV alone can deliver full power converter output power at line voltages above 150 VAC. The InnoSwitch power control IC is therefore enabled immediately using the V pin output signal while C_{LV} is trickle charged at a lower rate until the steady-state C_{LV} voltage is reached. The voltage across C_{LV} is subsequently precisely monitored and recharged as required depending on input line conditions.

Designing a 65 W adapter

The circuit in Figure 5 shows a 65 W (5 V / 3 A; 9 V / 3 A; 15 / 3 A; 20 V / 3.25 A) USB PD 3.0 compliant adapter using the MinE-CAP IC to maximize power density. The MinE-CAP IC allows for the significant reduction of the physical size of the input bulk capacitors by allowing the use of a smaller (both in size and capacitance) 400 V capacitor paired with a 160 V capacitor. The MinE-CAP IC also eliminated the need for an inrush current limiting thermistor, leading to more saved space and increased efficiency. Together with the InnoSwitch3-Pro IC and low-profile planar magnetics, a form factor of 82 mm x 51 mm x 12 mm was realized (Figure 6). This corresponds to a power density of 21.22 W/in^3 with a system efficiency exceeding 90 %. This design also meets DOE Level 6 and EC CoC 5 average efficiency standards.

Fuse F1 isolates the circuit and protects the AC line from excessive current due to component failure. Common mode chokes L1 and L2 along with capacitors C3 and C4 provide common mode and differential mode noise filtering to minimize conducted EMI emissions. The bridge rectifier formed by BR1 and BR2 rectifies the AC line voltage and provides a full-wave rectified DC voltage across the high voltage bulk capacitor, C1. Two bridge rectifiers are used to improve heat dissipation by doubling the rectifier surface area since power loss from two rectifiers is the same as that of a single device.

The MinE-CAP IC controls the rate of charge of the 160 V capacitor during start-up; thus, inrush current is mostly dependent on the value of the 400 V capacitor. Since the capacitance of the 400 V capacitor is significantly less when using a MinE-CAP IC, the use of a current limiting NTC thermistor is no longer necessary.

When a MinE-CAP IC is used in tandem with the InnoSwitch3, the V pin of the InnoSwitch3 IC is connected directly to the LINE pin of the MinE-CAP IC. Resistors R3 and R5 provide input voltage sensing for both the the MinE-CAP IC and InnoSwitch3 ICs. The MinE-CAP IC uses R3 and R5 primarily to monitor the line voltage and maintain the voltage across the low-voltage bulk capacitor, C2 below its voltage rating when the line voltage is above 100 VAC. In contrast, the InnoSwitch3 uses the current from the LINE pin to determine line under-voltage and over-voltage conditions. During regular operation, the current from the LINE pin follows the current flowing through R3 and R5, so the InnoSwitch3 IC operates as if said resistors are connected directly to the V pin. Resistor R1 is a bleed resistor used to regulate the voltage across C3, while resistor R4 is used by the MinE-CAP IC to sample the voltage at the negative terminal of C2.

For this specific design, bypass capacitor C16 is shared by both the BPP pin of the InnoSwitch3 IC and the BYPASS pin of the MinE-CAP IC. The value of C16 is chosen based on the desired current limit of the InnoSwitch3 IC. As with any flyback design using the InnoSwitch3 IC, one end of the transformer primary is connected to the rectified DC bus while the other end is connected to the InnoSwitch3 DRAIN pin.

A low-cost RCD snubber formed by diode D3, resistors R9, R10 and R13, and capacitor C6 limits the voltage across the InnoSwitch3's Drain-Source nodes during turn-off by dissipating the energy stored in the leakage inductance of the transformer.

The InnoSwitch3 IC has an internal current source that charges capacitor C16 when AC input is first applied. Once the InnoSwitch3 IC starts switching and during normal operation, bias current is drawn from the auxiliary winding of the

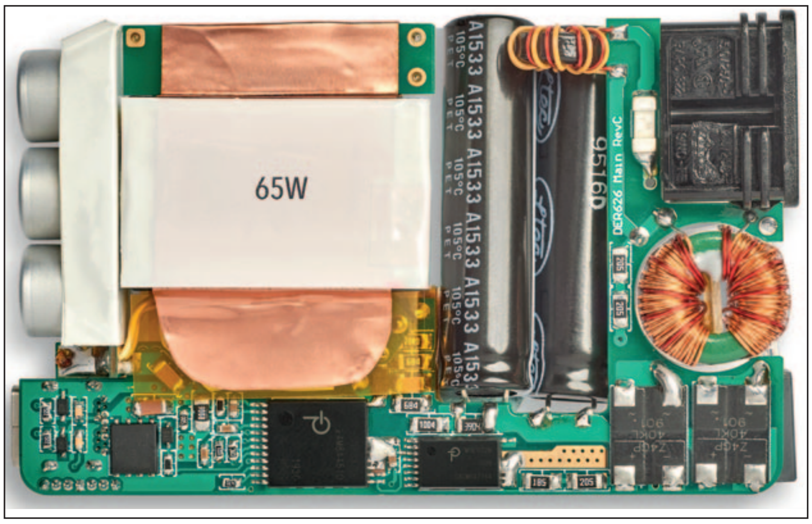

Figure 6: With MinE-Cap IC, InnoSwitch3-Pro IC and low-profile planar magnetics, a form factor of 82 mm x 51 mm x 12 mm for the 65 W design was realized

transformer. The output of the auxiliary winding is rectified using diode D4 and filtered by capacitor C15. An RC snubber can be placed across D4 to suppress voltage spikes, if necessary. Since the output voltage of the charger varies from 5 V to 20 V, the output of the auxiliary winding also varies and depending on the secondary to auxiliary turns ratio as well as the coupling coefficient between the primary and auxiliary. A linear regulator comprising resistors R17 and R18, Zener diode D6, and transistor Q4 provides a relatively stable DC voltage based on the breakdown voltage of D6 at the emitter terminal of Q4. Bias current can then be controlled using resistor R19.

Zener diode D5 offers primary sensed over-voltage protection. In case of over-voltage at the output of the converter, the auxiliary winding voltage also increases until D5 breaks down, causing excess current to flow into the BPP pin of the InnoSwitch3 IC. If the current flowing into the BPP pin exceeds the I SD threshold, the controller latches off to prevent any further increase in output voltage. Resistor R20 limits the current injected to the BPP pin during an over-voltage event.

MinE-CAP can also be used in applications requiring extended wide-range input (90 VAC to 350+VAC), again with a high percentage of the input capacitance 160 V rated along with either stacked 400 V or 500-600 V rated capacitors of much smaller value than would normally be required.

An other application for MinE-CAP are electrical distribution networks with unstable voltages. MinE-CAP reduces the number of high-voltage storage components, and shields lower voltage capacitors from the wild mains voltage swings, substantially enhancing robustness while reducing system maintenance and product returns.

Literature

"Power GaN Reduces Volume of AC/DC Converters Substantially", www.power-mag.com

MinE-Cap family datasheet