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Active Clamp Flyback And GaN Switches Shrink Auxiliary Power Supply Size

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The combination of smaller size and higher efficiency in electronic systems is forcing the adoption of soft-switching topologies and wide-bandgap technologies in modern switching power converters. In high-power systems, the design of the main power converters receives much attention, while the design of the auxiliary supply is sometimes an afterthought. So in this article, I'll focus on a server power-supply unit (PSU) auxiliary supply as defined by the modular common redundant power supply (M-CRPS) specification created by the Open Compute Project (OCP). However, you can easily apply the design procedure and decisions described here to other applications.

After reviewing the relevant details of the M-CRPS specification and the chosen board dimensions, power supply design choices are discussed, beginning with the selection of the active clamp flyback in combination with a GaN-based power stage. The design of a planar transformer and its performance is then explored in greater detail. Finally, test results for the final prototype are shared.

Auxiliary Power Supply Requirements

A next-generation server PSU is defined by the M-CRPS specification from the OCP. The OCP is a worldwide community of engineers focused on improving the efficiency of server, storage and data center hardware through consistent standards. Fig. 1 is a system-level block diagram of a typical server PSU, which requires a power factor correction (PFC) stage to achieve the harmonic distortion specifications of M-CRPS.

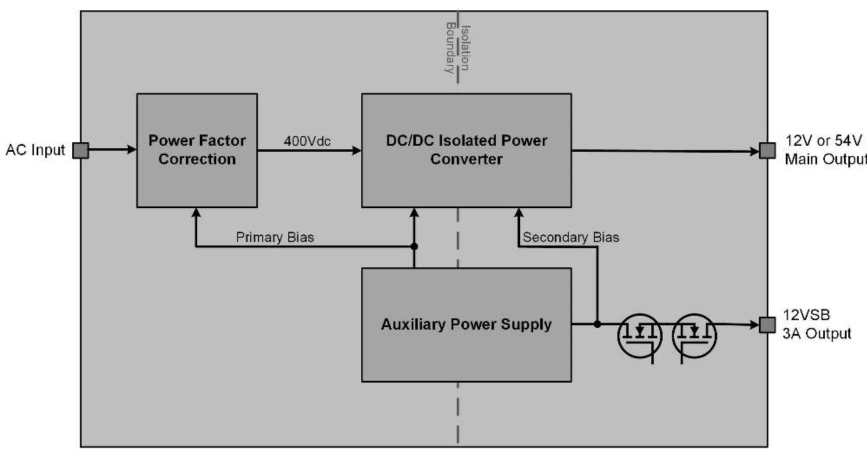

Fig. 1. System block diagram for a server PSU.

The output of the PFC stage is typically a 400-Vdc bus. An isolated dc-dc stage creates the main PSU output at either 12 V or 54 V to provide a few kilowatts of power. Resonant converters or phase-shifted full-bridge topologies often make up the main power stage in order to achieve high power density. The circuitry for the PFC and dc-dc stages typically requires an auxiliary supply to power the internal circuitry on both sides of the isolation boundary.

The design of the PSU determines the power requirements for the internal circuitry; they are not defined by the M-CRPS specification.[1] However, the M-CRPS specification does define an additional 12-V standby output, which is always on and provides up to 3 A of auxiliary power to the server rack. As shown in Fig. 1, a logical choice is to use one auxiliary supply to provide both the 12-V standby output and all internal bias power.

The table gives partial electrical specifications for an example auxiliary supply. This supply must provide 3 A for 12 V of standby power and 700 mA for internal bias power on the secondary side, for a total of 3.7 A at 12 V. The PSU circuitry on the primary side requires an 18-V rail capable of up to 400 mA.

The auxiliary supply only needs to provide full power when the PFC stage is operating, where the input to the auxiliary supply will be in the range of 250 Vdc to 410 Vdc. The auxiliary power supply must continue to operate over a 100-Vdc-to-410-Vdc input range with reduced loading, however. Because the loading is reduced at the minimum input condition, this wide input range does not impact the size or selection of the power stage components.

The M-CRPS specification defines additional requirements such as ripple, transients and droop compensation for the parallel operation of multiple units. Additionally, a fan may work when the 12 V of standby current is greater than 1.5 A and the ambient temperature is greater than 35°C.

Table. Power requirements for an example server auxiliary power supply.

Parameter	**Specifications**
Input voltage range (full rated power)	250 Vdc to 410 Vdc
Extended input voltage range (50% rated power)	100 Vdc to 410 Vdc
12-V standby and 12-V secondary-side maximum load current (combined)	3.7 A
18-V primary-side maximum load current	400 mA

The M-CRPS specification defines the dimensions for three different sizes of the server PSU. For example, Fig. 2 shows the 185-mm by 73.5-mm by 39-mm form factor. All three sizes share the same 39-mm height dimension.

Since the auxiliary supply is part of the internal design, M-CRPS does not directly specify the dimensions of the auxiliary supply. For our example, the auxiliary supply will be implemented as a daughtercard mounted perpendicular to the main printed circuit board (PCB) to minimize the footprint area on the main PCB. Based on the space available in the PSU, the intended dimensions for the example auxiliary supply are 30 mm by 35 mm by 12 mm. With 52 W of output power, these dimensions result in 4 W/cm^3 or 67 W/in^3.

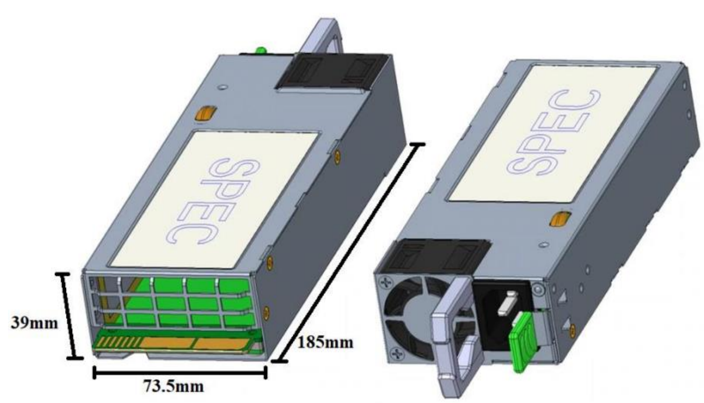

Fig. 2. A 185-mm by 73.5-mm by 39-mm server PSU defined by M-CRPS (Source: The Open Compute Project).

Picking A Topology

To achieve this power density, it is crucial to minimize the size of the power transformer by operating at a high switching frequency. A high-frequency power supply should employ zero voltage switching (ZVS) and power switches with low capacitance in order to minimize switching losses. For this power level, the active clamp flyback (ACF) is a good topology choice, as it provides ZVS and also recycles the transformer leakage energy.

For the power switches, gallium nitride (GaN) devices provide very low capacitance. Using highly integrated GaN devices that incorporate the half-bridge FETs and drivers will further reduce the solution size.

Fig. 3 is a block diagram of the example server auxiliary power supply. Using a planar transformer keeps the total height less than the intended 12-mm dimension. The planar transformer design integrates some electrical components to further reduce size and improve performance. For example, the synchronous rectifier FET, driver and high-frequency output capacitors are integrated into the planar transformer, which mounts to the auxiliary supply PCB as a subassembly.

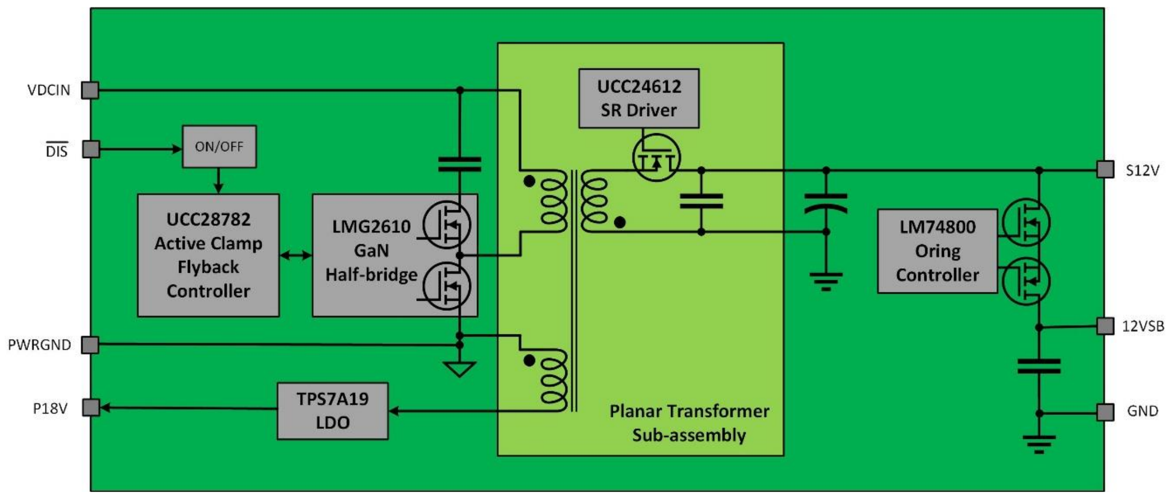

Fig. 3. Block diagram of a server auxiliary power supply.

Transformer Design Choices

Fig. 4 shows the final prototype design. An EQ20 + I core shape is the largest core that would fit and still allow enough board space for the other components with the proper primary-to-secondary creepage and clearance distances. By referencing the ferrite core to the secondary side of the isolation boundary, the creepage and clearance distances must be observed between any exposed conductor in the primary circuit and the ferrite core. This spacing results in longer traces on the primary side with higher resistance and leakage inductance.

Conversely, you can locate the secondary copper and circuitry near the core, which will keep the traces short on the secondary where the current is higher. However, higher resistance on the primary is less of a concern because the currents are lower. Additionally, leakage inductance on the secondary (associated with longer traces on the secondary) would cause ringing on the synchronous rectifier, whereas this is not so much an issue with longer traces on the primary side since the active clamp flyback recycles the primary leakage inductance energy and clamps the resulting voltage spike.

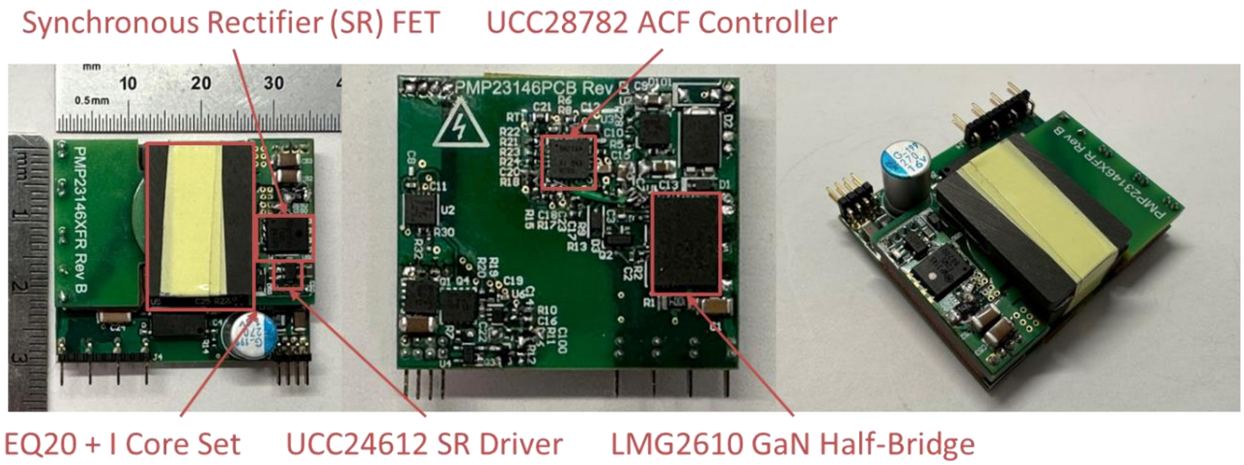

Fig. 4. The final prototype design.

Careful design of the planar transformer can help minimize power losses. Reducing the total number of turns reduces copper losses and parasitic capacitance, while for a flyback topology, reducing the number of secondary turns to two is great for interleaving.

To minimize the number of turns, look for a core with a large effective area. Next, use tools like Steinmetz equations or core-loss curves to estimate core losses and choose an operating frequency. In our example, the EQ20 + I core set with N49 material from TDK Electronics with two secondary turns is suitable for a target frequency range of 300 kHz to 500 kHz, as shown in Fig. 5.

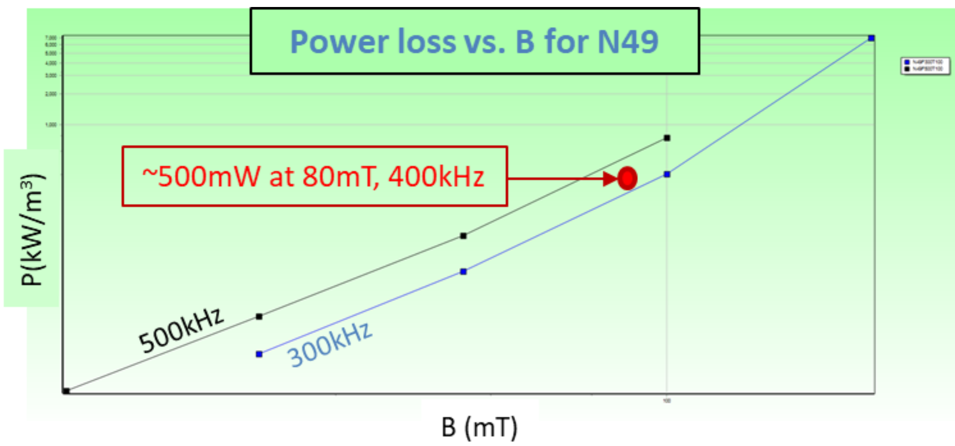

Fig. 5. Core-loss estimate for a two-turn secondary planar transformer.

Fig. 6 shows a cross-section diagram (not to scale) of the planar transformer, and illustrates the layer stackup and placement of the PCB windings. The labels for each turn show the winding name followed by the number of that turn from the beginning of the winding. For example, "Secondary-1" is the first turn of the secondary winding, and "Secondary-2" is the second turn of the secondary winding.

With the ferrite core secondary-referenced and a two-turn secondary winding, the high-current secondary turns are placed on the top and bottom layers for interleaving. The primary windings are located on the inner windings to minimize safety spacing requirements. The copper traces keep away from the air gap to reduce fringing losses.

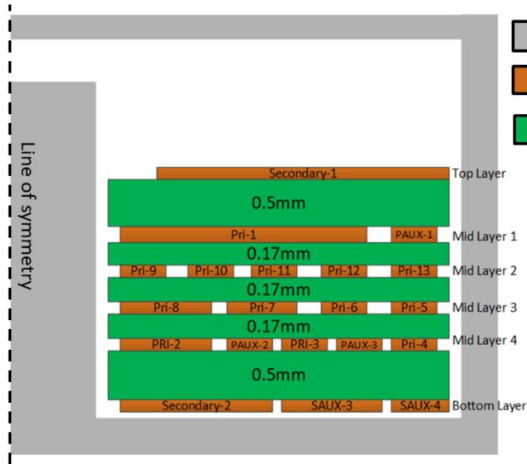

Fig. 6. Winding stackup for a planar transformer.

Notice the indent from the center leg on the Secondary-1 turn to avoid fringing losses. Similarly, minimizing the PCB dielectric thickness keeps the windings on the top layers away from the gap. Finally, notice that turns on adjacent sides of the isolation boundary have the same number of turns; for example, Secondary-1 is adjacent to "Pri-1" and "PAUX-1." This method minimizes common-mode noise by balancing the voltages on either side of the isolation boundary.

Tuning The Design And Test Results

During testing of the prototype, I adjusted the switching frequency to find the operating point with the best thermal performance, which is the main concern when designing for high power density. After optimization, the thermal performance was very good, with no components exceeding 60°C at maximum load. Fig. 7 shows thermal images of both sides of the board.

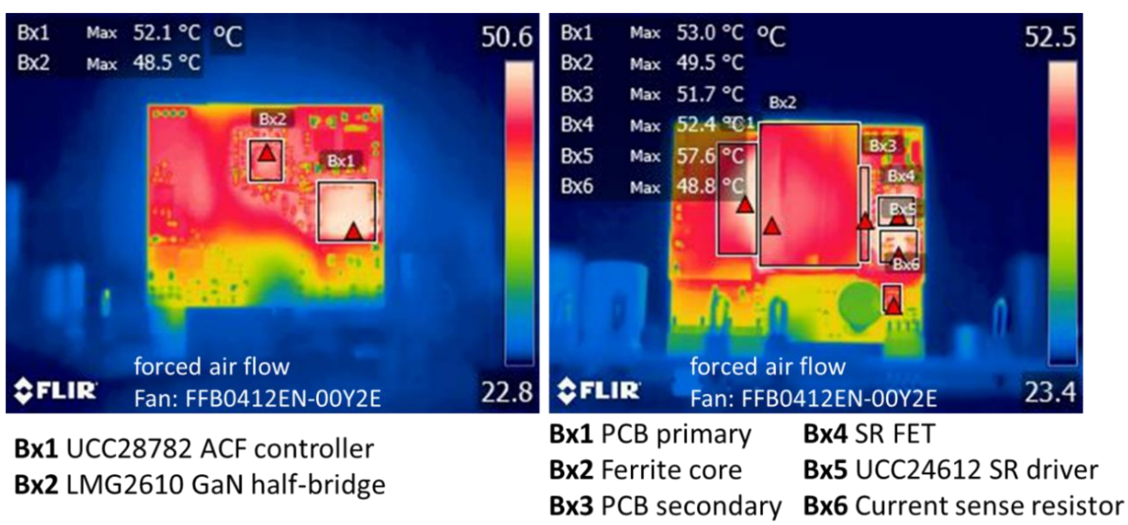

Fig. 7. Server auxiliary power supply thermal images at full load.

Efficiency at different operating conditions is shown in Fig. 8 which remains around 92% at maximum load. Even though this supply is not designed to operate for extended periods of time at full load with a 100 Vdc input, it is capable of supplying power under those conditions for shorter durations.

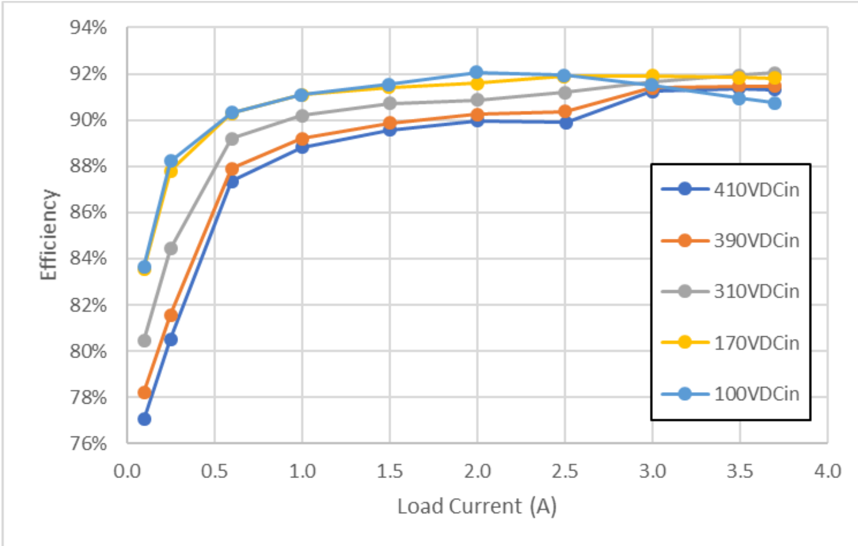

Fig. 8. Server auxiliary power supply efficiency.

The prototype also meets the additional requirements defined by the M-CRPS specification such as ripple and transients, with standby power losses below 85 mW over an input range of 100 Vdc to 410 Vdc. For more details about this design, check out the Texas Instruments reference design.[2]

Conclusion

High-power-density applications such as server PSUs require compact and efficient solutions for the auxiliary power supply. The active clamp flyback topology with GaN devices provides a great solution for this application and power range. Take extra care when designing the planar transformer for reduced size and the highest efficiency. For your next high-power-density design, consider using some of the design techniques highlighted here to reduce the size of your auxiliary supply, with minimal power losses.

References

1. Modular Hardware System-Common Redundant Power Supply (M-CRPS) Base Specification.
2. 45-W High-Power-Density Active Clamp Flyback with GaN Reference Design for Server Auxiliary Power.

About The Author

Brian King is a systems manager and senior member technical staff at Texas Instruments. He has over 26 years of experience in power supply design, specializing in isolated ac-dc and dc-dc applications. Brian has worked directly with customers to support over 1300 business opportunities and has designed over 750 unique power supplies using a broad range of TI power supply controllers with a focus on maximizing efficiency and minimizing solution size and cost.

He has published over 45 articles related to power supply design, and since 2016 is the lead organizer and content curator for the Texas Instruments Power Supply Design Seminar (PSDS) series, which provides training to thousands of power engineers worldwide on a regular basis. Brian received an MSEE and a BSEE from the University of Arkansas.

For more on designing active clamp flyback converters, see How2Power's Design Guide, and do a keyword search on "active clamp flyback".