GaN Based High-Density Unregulated 48 V LLC Converters

Two-stage 48V voltage regulator module (VRM) with unregulated first stage DC/DC converter providing intermediate bus voltage followed by multi-phase buck converter has proven to be a scalable and efficient approach for 48V rack architecture in data centers. In this work an eGaN® based first stage unregulated LLC converters with integrated magnetics are proposed, the converters designed with fixed transformation ratios of 4:1 and 8:1 provide a continuous power of 900 W with maximum efficiencies of 98.4 % and 98.0 % in high-power-densities of 94 kW/liter and 75 kW/liter respectively. The bus voltage variation is evaluated to maximize the overall efficiency of 48 V VRM. **Mohamed H. Ahmed, CPES, Virginia Tech; Michael de Rooij, David Reusch, Efficient Power Conversion, El Segundo, USA**

Significant challenges arises with 48 V rack architecture for data centers, the 48 V voltage regulator module (VRM) in vicinity to CPU and GPU has to be designed with high-efficiency and power density.

Single or two-stages

48 V VRM solutions can be categorized as single-stage solutions, or two-stage solutions. The first commercial available 48 V VRM from VICOR uses two-stage configuration with regulator module followed by a DC/DC transformer achieving high-efficiency and power density. The two-stage approach shown in Figure 1 was proposed with unregulated transformer based first stage converter (DCX) followed by a multi-phase buck converter, the first stage can be designed in very high-efficiency and power density while the second stage is easily scalable and low cost solution.

The same approach was later adopted by Google replacing the first stage by an unregulated resonant switched capacitor achieving very-high efficiency and power density. However, the converter requires an extra buck converter for startup and protection with special controller for operating frequency adaptive tuning to compensate for all components tolerances.

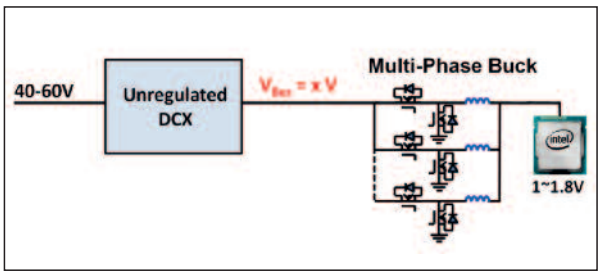
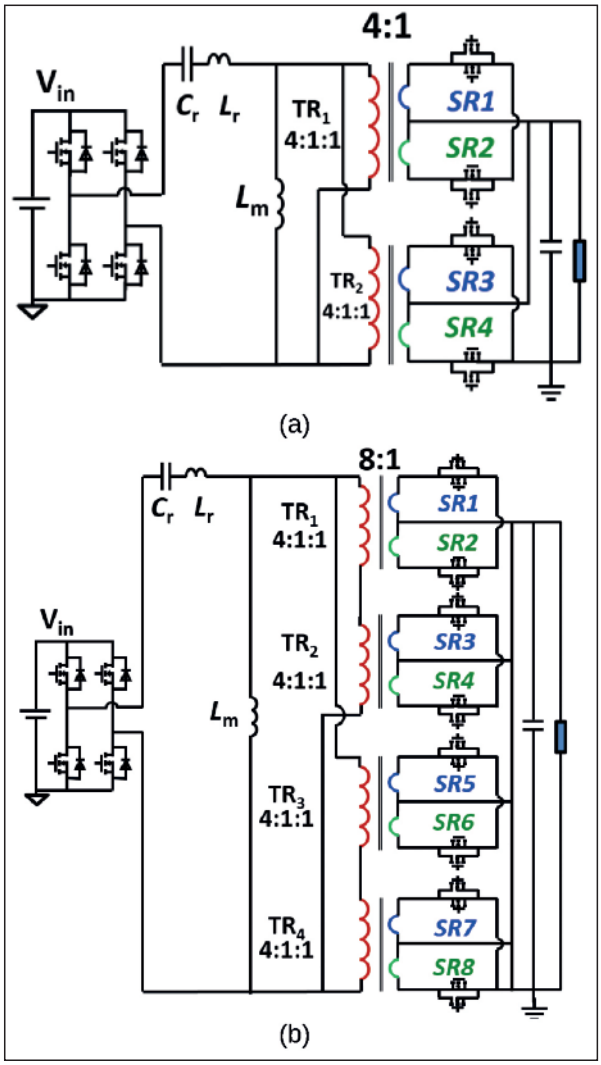
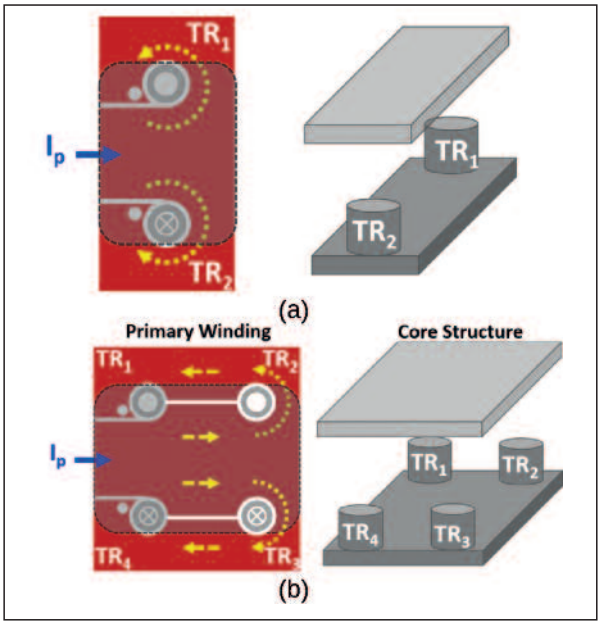


Figure 1: Two-stage 48 V VRM solution

In this work, the same approach is revisited. Unregulated LLC converter first stage will be used where all the startup,



RIGHT Figure 2: LLC-DCX with matrix transformer structure (a) 4:1 LLC-DCX (b) 8:1 LLC-DCX



LEFT Figure 3: **Symmetrical winding arrangement and magnetic core integration (a) 4:1 LLC-DCX (b) 8:1 LLC-DCX**

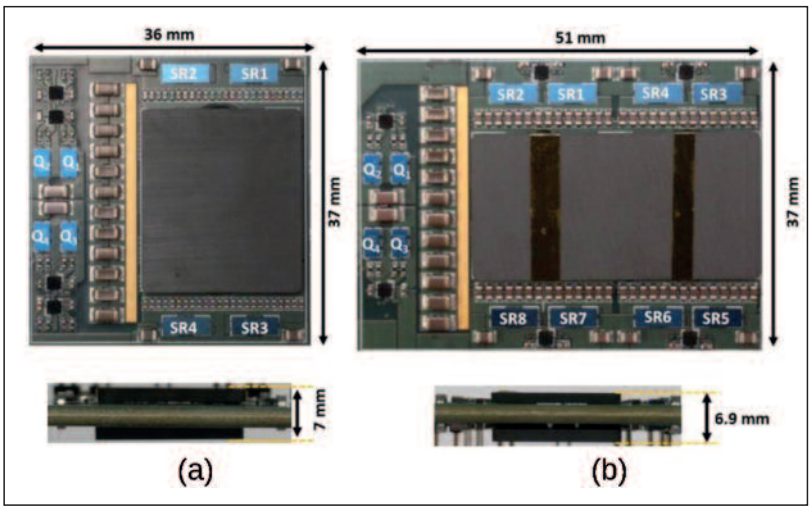


Figure 4: **48V LLC-DCX experimental prototypes (a) 4:1 LLC-DCX (b) 8:1 LLC-DCX**

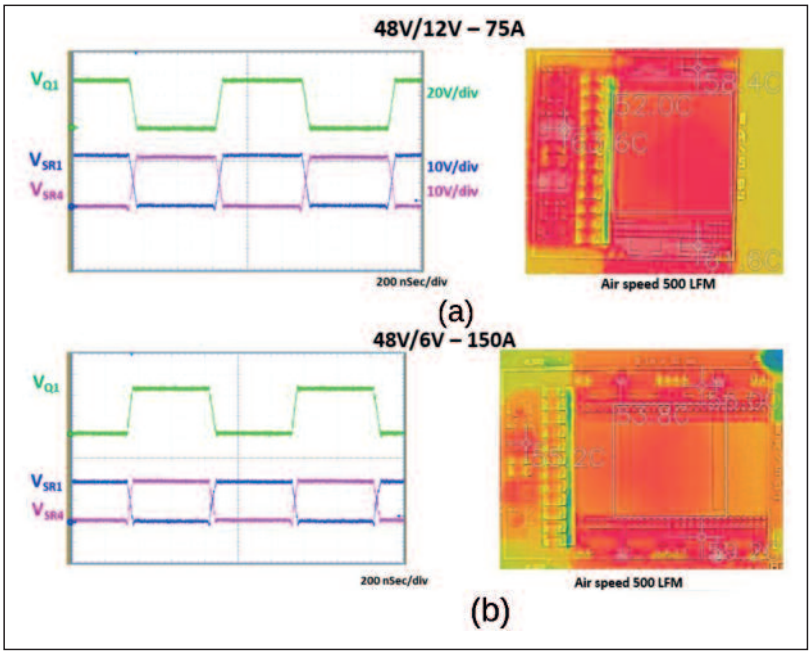


Figure 5: **Full load operating waveforms and thermal image (a) 4:1 LLC-DCX (b) 8:1 LLC-DCX**

short circuit control and synchronous rectifiers (SRs) adaptive driving can be easily implemented with a simple microcontroller. In addition, only one resonant capacitor is needed for operation no matter what is the transformation ratio of the converter. With soft switching operation for both primary and secondary devices, LLC converter designed with eGaN FETs can operate at high switching frequency (>1 MHZ) enabling high power-density with magnetic integration without scarifying efficiency.

Two GaN based LLC-DCX with integrated magnetics and fixed transformation ratio of 4:1 and 8:1 were designed for a two-stage 48 V VRM solution and the effect of the intermediate bus voltage on the two-stage efficiency will be evaluated.

Unregulated LLC-DCX with integrated magnetics

High operating frequency LLC-DCX will be subjected to high-frequency related losses in the transformer. Matrix transformers has proven to be the best candidate for LLC transformer to avoid high-frequency related conduction and termination losses. The designed LLC-DCX with matrix transformer structure and (4:1, 8:1) conversion ratios are shown in Figure 2. With multiple secondary side windings connected in parallel, the conduction loss reduces significantly, with primary side also connected in parallel, the primary side conduction loss is reduced, to ensure equal current sharing between the two primary parallel paths, a symmetrical PCB winding while integrating the multiple elemental transformers in one magnetic core is proposed. The symmetrical primary winding for both converters is shown in Figure 3 by which equal current sharing can be achieved.

The 4:1 LLC-DCX has two-elemental transformers integrated in one core structure. The 8:1 LLC-DCX, has 4-elemental transformers integrated in a single core to deliver double the output current at lower output voltage and keep the same output power. Integrating multiple-elemental transformers in one core will help to have similar magnetizing inductance for all elemental transformers to avoid any current sharing issues between these transformers.

Experimental results

The designed 4:1 and 8:1 LLC-DCX converter prototypes are shown in Figure 4. The primary side devices for both converters using the latest generation eGaN FET, the 100 V rated 4 mΩ EPC2053 and the secondary side devices are the 40 V rated 1.5 mΩ EPC2024 and

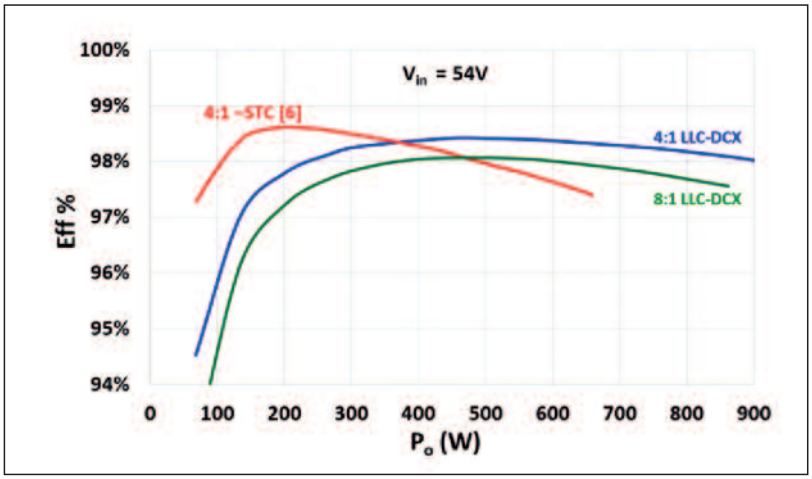


Figure 6: LLC-DCX measured efficiency at 54 V input and comparison with state-of-art

30 V rated 1.45 mΩ EPC2023 respectively.

The transformer magnetic core uses a custom designed ML91 from Hitachi. Both converters operate at 1 MHz and can provide a continuous power of 900 W with power density of (92 kW/liter) for the 4:1 converter and (73.5 kW/liter) for the 8:1 converter. The full load operating waveforms and thermal images are shown in Figure 5 where ZVS is achieved for both primary and secondary devices with a very good thermal performance.

The two converters demonstrated very high-efficiency operation ≥ 98 % that is a percent higher and with higher power-density than a comparable state-of-art solution using STC as shown in Figure 6.

Summary

In this paper an optimized integrated magnetic structure is proposed for a first-stage LLC converter in a two-stage 48 V VRM solution for data center applications. The designed converters with GaN devices and an optimized integrated magnetic structure can achieve very high efficiency of 98.4 % for (4:1) conversion and 98.0 % for (8:1) conversion with very high-power density of (98 kW/Liter) and (74 kW/Liter), respectively. The two-stage VRM efficiency was evaluated with different bus voltages, and 6 V was selected as an optimal intermediate bus voltage.

Literature

"GaN Based High-Density Unregulated 48 V to x V LLC Converters with ≥ 98% Efficiency for Future Data Centers", Mohamed H. Ahmed, Young Engineer Awardee PCIM Europe 2019, Center for Power Electronics Systems (CPES), The Bradley Department of Electrical and Computer Engineering, Virginia Tech, USA; PCIM Europe 2019 Proceedings, pages 69 - 76