Comparing Quasi-Resonant and Active Clamp Flyback Topologies for 65W Wall Charger Applications Using GaN Technology

Wall chargers using power GaN devices offer many advantages such as high-power density, higher efficiency and low operating temperatures compared to silicon-based solutions. This article discusses comparative results of ACF and QRF topology-based, 65W wall chargers using a GaN-based solution.

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Introduction

With ever-increasing consumer demand for more compact, lightweight, low-cost power chargers for portable devices that can be quickly charged, efficient power conversion with higher switching frequencies are critical features for design engineers. Offering many advantages in terms of efficiency, power density and thermal performance compared to traditional silicon-based solutions, Gallium Nitride (GaN)-based devices are now being more widely adopted to solve the design challenges for applications such as cell phone wall chargers [1-6].

This article compares two 65 W, USB-PD wall charger prototypes based on two competing flyback topologies: quasi-resonant flyback (QRF) [1] and active clamp flyback (ACF) [2]. The QRF and ACF prototype chargers utilize a novel 650V, 360mΩ integrated GaN device, the TP44400NM that offers low output capacitance, low gate charge, and reduced parasitics. The wall chargers were tested to determine which approach presents the most elegant, energy efficient solution.

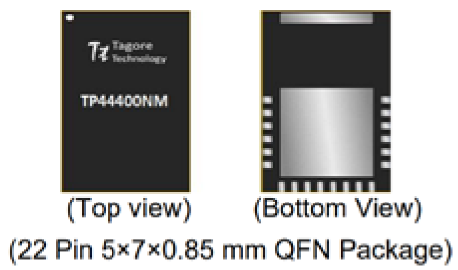


Figure 1: Tagore 360mΩ GaN Power IC, TP44400NM

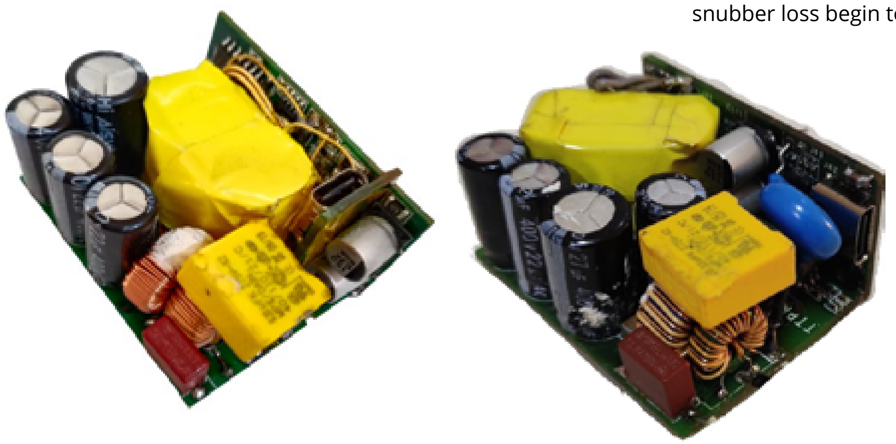


Figure 2: USB PD chargers with: ACF (left) and QRF (right) topologies.

GaN-based devices for USB-PD charger designs

Two 65W, USB-PD wall chargers based on QRF and ACF topologies **were designed using the TP44400NM 650V, 360mΩ integrated GaN** device (Figure 1). This GaN-based power IC with integrated driver, offered in a miniature QFN pack, offers extremely low conduction and switching losses to help meet stringent efficiency standards, delivers the required level of desired thermal performance for the application and enables a compact 30cc volume (corresponding to a power density of 35W/in3) design for both QRF and ACF- based charger solutions.

The two charger hardware prototypes based on the QRF and ACF topologies are shown in Figure 2. The ACF charger requires two GaN-based devices while the QRF charger requires only one GaN-based device.

The GaN-based ACF flyback converter [2] can clamp the primary switch voltage without any ringing and recycle the transformer leakage energy to the output without any snubber loss. This converter can be operated at a much higher switching frequency with the use of GaN devices while maintaining better efficiency and much higher power density than conventional Flyback chargers. One challenge in ACF design is the negative current needed for ZVS turn on of the main switch which increases the primary rms current leading to a higher conduction loss at the transformer and switches and core loss.

An alternative approach to increase conventional power charger efficiency is to adopt a GaN-based quasi-resonant flyback (QRF) topology [1] with a reduced valley switching loss at the primary side switch. Such designs are meant to be operated under 200kHz because at higher switching frequency the switching loss and the snubber loss begin to dominate.

Considering numerous design trade-offs in both chargers, such as switching frequency, system size versus frequency-related losses, the two chargers were designed to achieve the best possible performance.

Comparing ACF and QRF prototype chargers using an integrated GaN device

The ACF-based charger design utilizes two 360 mΩ GaN power ICs with integrated driver, the TP44400NM to keep the primary side conduction loss and core loss at a lower value by minimizing the -ve current requirement for ZVS. The QRF-based charger utilizes one GaN power IC with integrated driver.

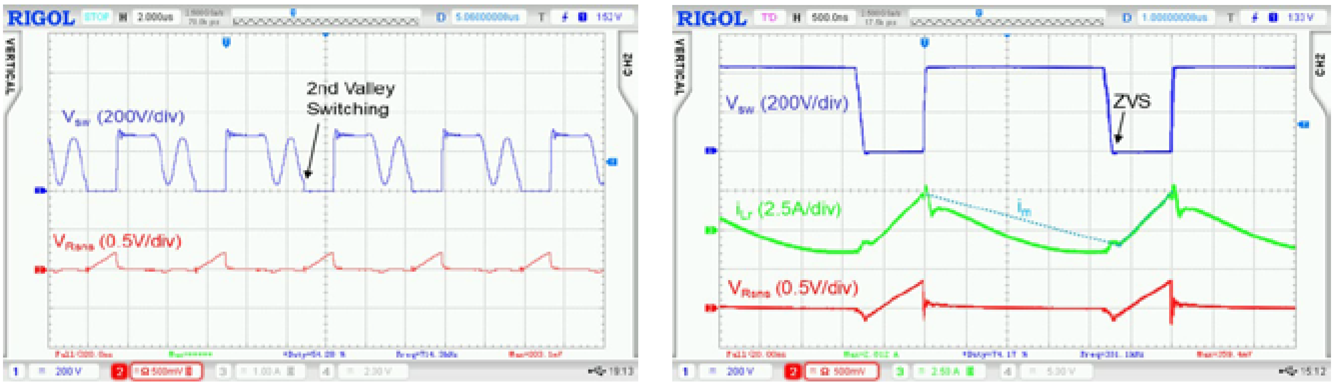


Figure 3: GaN drain switching waveforms of the QRF (left) and ACF (right) chargers.

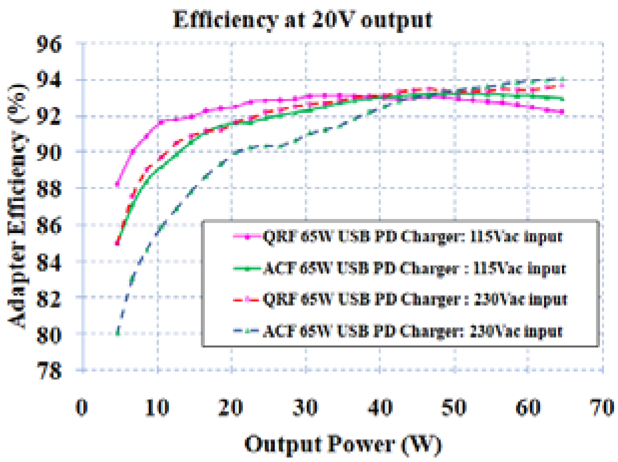


Figure 4: Comparative efficiencies of QRF and ACF chargers.

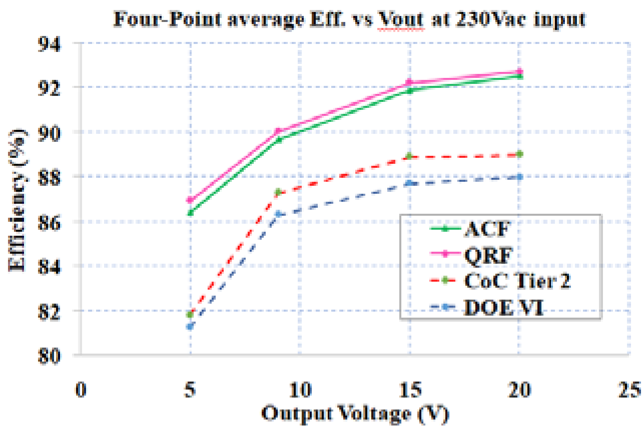


Figure 5: Comparative four-point efficiencies of QRF and ACF chargers.

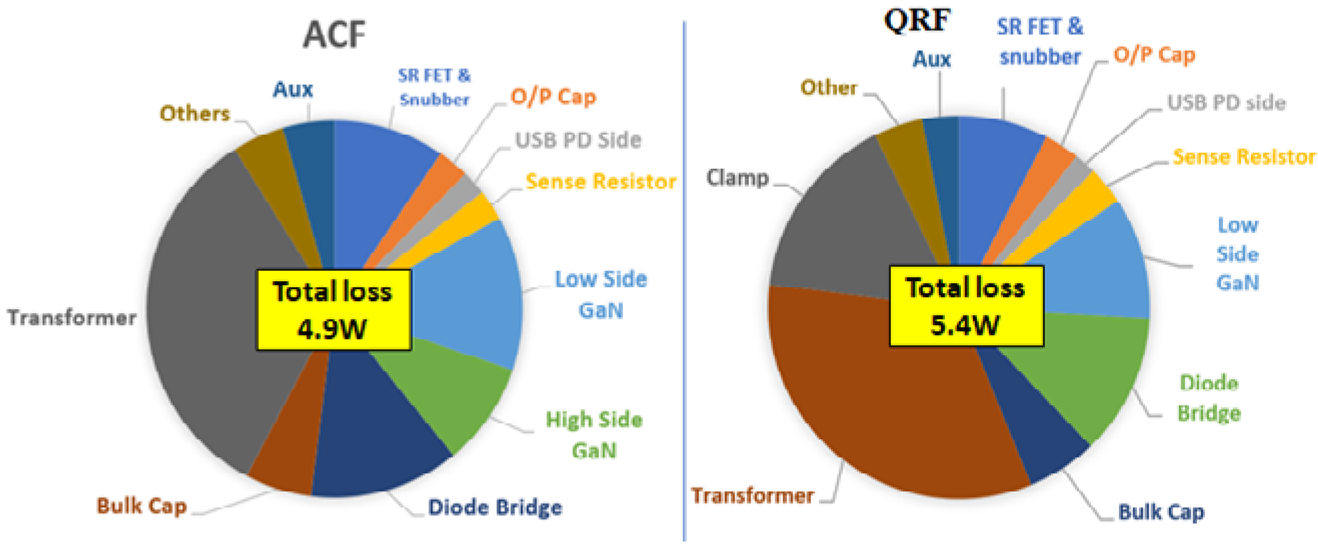
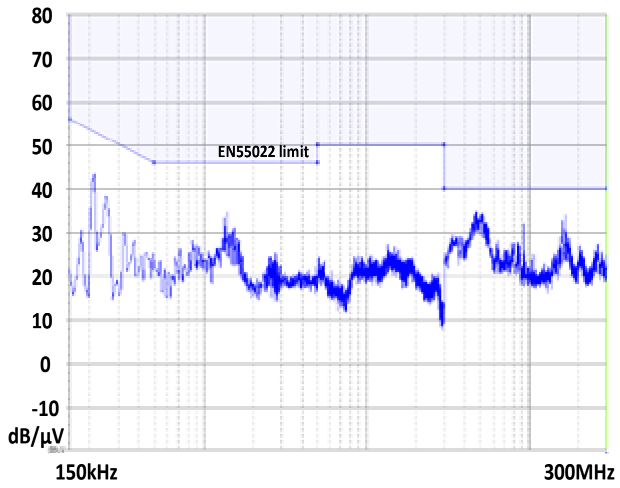


Figure 6: Full load loss distribution of ACF and QRF chargers.

Transformer design parameters such as Lm, n were selected so that the Fsw at 65 W load at 115Vac input line will be 100kHz and 300kHz for the QRF and ACF designs, respectively.

The GaN device drain switching waveforms of the two chargers at 115Vac input are shown in Figure 3. The QRF charger is shown to operate with valley switching turn on, while the ACF charger operates with ZVS switching turn. The comparative efficiencies, shown in Figure 4, indicate that the QRF is more efficient than the ACF prototype up to an output power of 45W, beyond which the efficiency of ACF charger dominates.



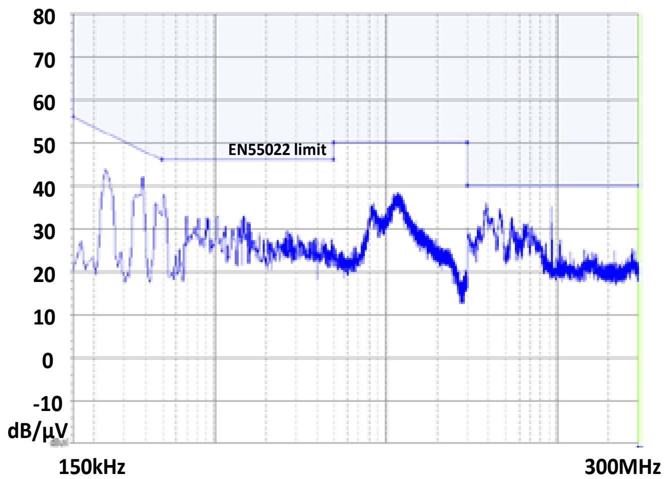


Figure 7: Conducted EMI test result of the ACF and QRF chargers.

USB-PD wall chargers need to meet stringent efficiency standards such as CoC Tie-2 and DoE Level VI. The four-point efficiencies of the two chargers, shown in Figure 5, closely follow each other, and both far exceed the limit lines specified by the above standards. The no load powers drawn by the QRF and ACF chargers are 45mW and 52mW, respectively. This helps comply with the no load power requirements specified in the previously referenced efficiency standards.

The distribution of power losses within various components of the chargers at full load is shown in Figure 6. It shows that the power loss in the GaN device is a small fraction of the total converter losses. Both the chargers have been tested thermally by putting them inside a closed box and running at full load for 30 minutes at room temperature. In both cases, the maximum GaN top plastic case temperatures were found to be less than 90°C.

The conducted EMI performances of the two chargers were tested for FCC Part 15 Class B EMI standard. Both chargers are seen to be passing the EMI at 220Vac input as shown in Figure 7.

Conclusion

Two USB-PD chargers using the TP44400NM 650V, 360mΩ integrated GaN device in a QFN package were analyzed.

While the ACF converter achieved ZVS at almost all load conditions at the cost of increased primary rms current, the core and winding loss at the coupled inductor also increased. This effect became prominent at light load where the efficiency drops as the switching frequency increased.

On the other hand, due to the valley switching and wastage of the leakage energy, the QRF converter had a 0.5-1% less full load efficiency than the ACF but a better light load efficiency profile for its moderate switching frequency and lower primary rms current leading to reduced transformer loss.

From the experimental efficiency data, it emerges that both topologies show similar average efficiency curves, resulting in both chargers meeting the CoC Tier-2 and DoE Level-VI energy standards, and the FCC Part 15 Class B EMI standard.

Consequently, it becomes the choice and requirements of the designer to choose between these two topologies for 65W adapter applications according to the sink load profile. On the other hand, the choice of the primary switching semiconductor device Rds(on) will depend on the maximum allowable temperature rise of the switching devices at full loading condition and at minimum rated input voltage in a closed case environment with the existing thermal design of the prototype.

The use of GaN-based technology for the main power switching device helps achieve higher power density and efficiency, and low operating temperature.

Based on this study, the QRF charger is found to be more efficient and has a simpler power train than the ACF charger up to 45W output power.

References

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