GaN Power ICs Enable 300cc 700kHz 300W AC-DC Converter

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Abstract

A 300 W, AC-to-DC converter has been designed and demonstrated to achieve > 94% efficiency during 90 Vac and 100% load conditions, and an estimated cased size of 300 cc. The circuit topology includes a totem-pole PFC input stage, an LLC dc-dc stage, and a synchronous rectification output stage. The design includes GaNFast Power ICs and off-the-shelf controllers running at 700 kHz. This new design has resulted in a cased power density of 1 W/cc. The waveforms demonstrate zero-voltage switching in all stages and the performance results show very high efficiency and power density, and acceptable component temperatures.

1 Introduction

Existing 300 W designs are typically switching at frequencies of <100 kHz, use silicon FETs, and achieve overall power densities in the range of 0.5-0.6 W/cc. Designers are continuously looking for converter topologies that have higher efficiency, smaller size, and potentially lower cost. GaN technology has gained significant moment in recent years due to its high blocking voltage capability, low on resistance, and low capacitances. Increasing switching frequencies dramatically reduces the size of the magnetics but the circuit topology and switch technology must be suitable to work in these high frequency environments. The circuit topology selected for this 300 W design using GaNFast Power ICs includes (Figure 1) a totem-pole PFC front end (TTP), a half-bridge LLC dc-dc stage, and an SR output stage. A totem-pole PFC front end was selected to eliminate the input diode bridge and increase system efficiency.

The LLC dc-dc converter was selected due to high-efficiency and zero-voltage switching, also very suitable for operating at high frequencies (700 kHz).

The output rectification stage consists of two SR stages that are necessary to share the high output current (12.5 A) and to minimize conduction losses and thermals.

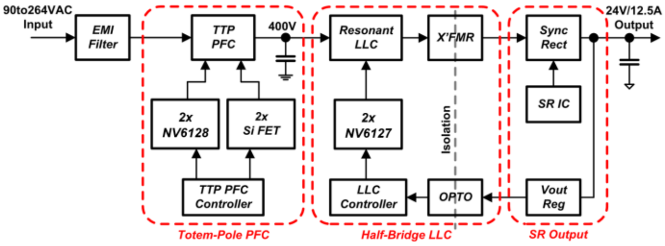


Fig. 1, Multi-stage 300 W TTP+LLC AC-DC power supply block diagram.

2 Traditional Input Diode Bridge

A standard PFC front end circuit consists of a traditional input diode bridge circuit (Figure 2). The input diode bridge circuit includes four diodes that perform a full-wave rectification of the AC mains input voltage and current. This full-wave rectification results in two of the four diodes conducting at all times and results in very high diode power losses. These losses limit overall system efficiency and result in very high diode component temperatures (Figure 3).

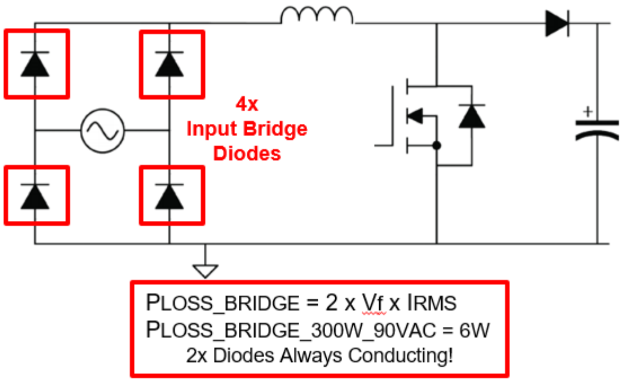


Fig. 2, Standard boost PFC circuit with traditional input diode bridge.

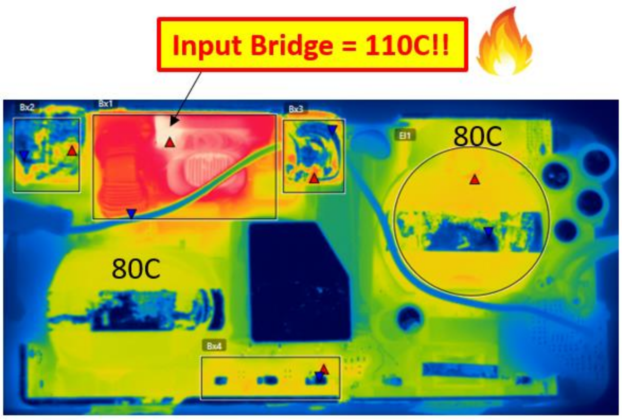


Fig. 3, Thermal image of Si-based 300W AC-DC power supply running in free-air with standard input diode bridge.

3 Bridgeless Totem-Pole PFC

The high losses of the traditional input diode bridge has given rise to many bridgeless PFC circuits over the years (Figure 4). Each version has advantages and disadvantages related to EMI, circuit complexity, and cost. The basic bridgeless PFC has high common mode noise due to one switch connected directly to the AC line. The semi-bridgeless and bi-directional bridgeless versions both have low common mode noise but require an additional inductor or lower RDSON FETs. The bridgeless totem-pole has low common mode noise and no extra inductor or lower RDSON needed, but still has some circuit complexities to be solved for voltage and current sensing.

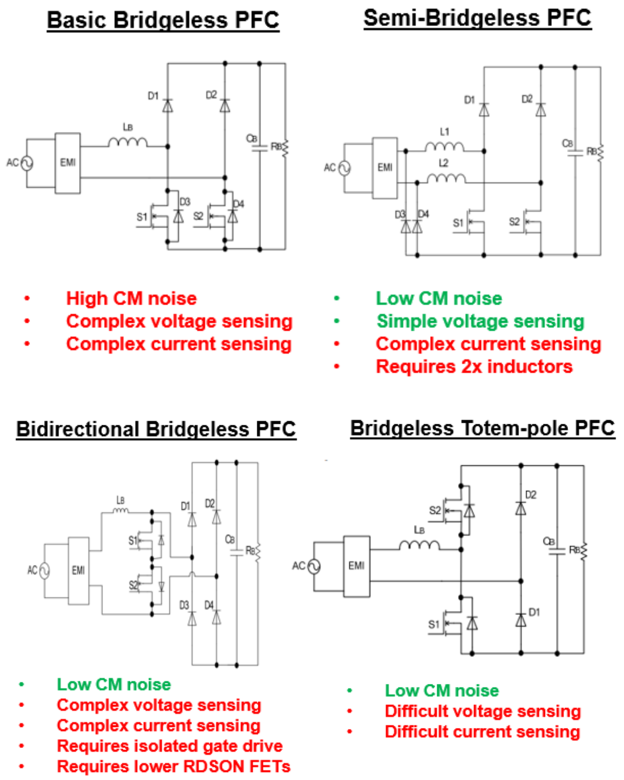


Fig. 4, Bridgeless PFC topologies and their comparisons.

The NCP1680 is an off-the-shelf controller option that simplifies the voltage and current sensing functions (Figure 5). The NV6128 GaNFast Power ICs have been selected for the fast-leg half-bridge of the totem-pole PFC circuit due to low output capacitance and low Qg for high-frequency operation, zero Qrr for zero reverse recovery losses, turn-on dV/dt control for low EMI, and integrated gate driver and regulator for robust and accurate gate voltage control.

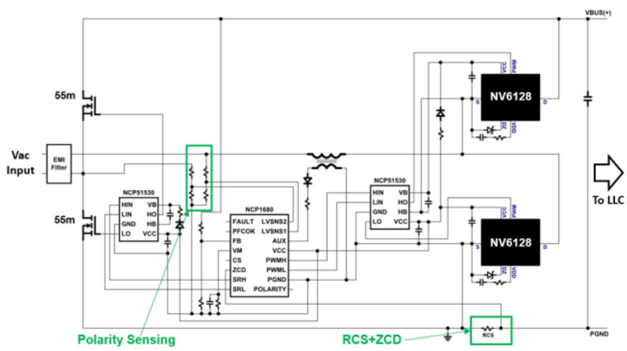


Fig. 5, Totem-pole PFC basic circuit schematic using NV6128 GaNFast Power ICs.

4 LLC DC-DC Stage

The LLC topology was selected for the dc-dc stage due to high frequency, high efficiency, and ZVS operating mode. The NCP13994 controller was selected due to off-the-shelf availability and 750 kHz steady-state operating frequency capability (Figure 6). The NV6127 GaNFast Power ICs have been selected for the LLC half-bridge due to low capacitance and low Qg for high-frequency operation, fast start-up during soft-start and burst modes, high dV/dt immunity, and integrated gate driver and regulator for robust and accurate gate voltage control.

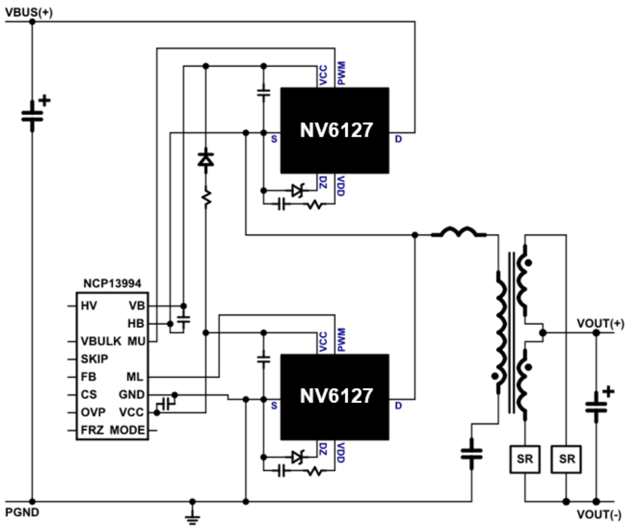


Fig. 6, LLC dc-dc stage basic circuit schematic using NV6127 GaNFast Power ICs.

5 AC-DC Converter Prototype

A modular, daughter card approach has been implemented during the design phase of the AC-DC converter prototype (Figure 7). The daughter card approach provides an ultra-compact design, easy thermal management, and is scalable for different power levels. The GaN power train for the totem-pole PFC circuit and the LLC half-bridge have been integrated onto separate daughter cards. The SR stage is also integrated onto another daughter card. This allows for independent heatsinking and thermal conduction to a metal shielding and/or plastic housing.

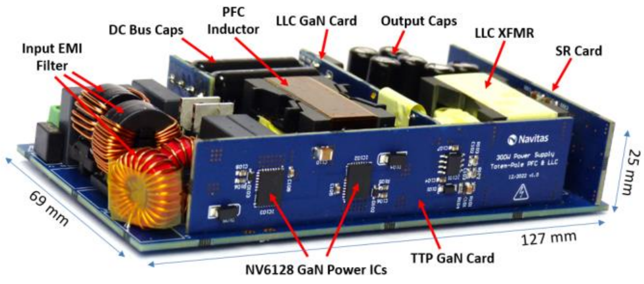


Fig. 7, 300 W AC-DC TTP+LLC converter prototype. Est. cased power density = 1 W/cc.

6 Circuit Waveforms

The complete power supply was built and tested for performance. The totem-pole PFC waveforms (Figure 8) are at 115 VAC, 100% load and at an operating frequency of 200 kHz at the peak of the AC line voltage.

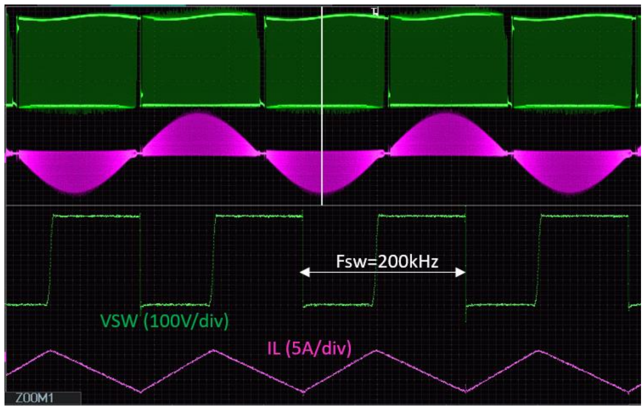


Fig. 8, Totem-pole PFC ZVS waveforms during 115 VAC input and full load conditions.

The LLC half-bridge voltage and current waveforms (Figure 9) show ZVS operation at an operating frequency of 670 kHz during steady-state and full load conditions. The operating frequency increases above 700 kHz at lighter load conditions.

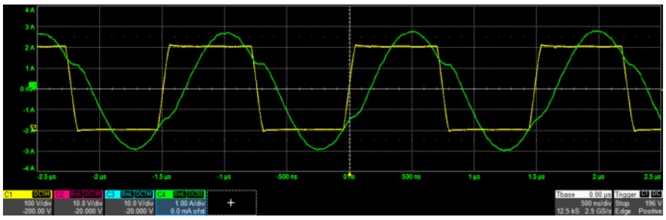


Fig. 9, LLC ZVS waveforms (670 kHz) during full load conditions (12.5 A). Yellow = half-bridge switched node (100V/div), Green = LLC tank current (1A/div).

7 Efficiency and Thermals

The power supply was tested for overall performance including efficiency and thermals. The efficiency curves show peak efficiencies of approximately 94.4% at 90 VAC, 94.8% at 110 VAC and 95.8% at 230 VAC (Figure 10). The thermal measurements (Figure 11) were taken during worst case conditions (90 VAC and full load) and show acceptable component temperatures necessary for manageable thermals during cased conditions.

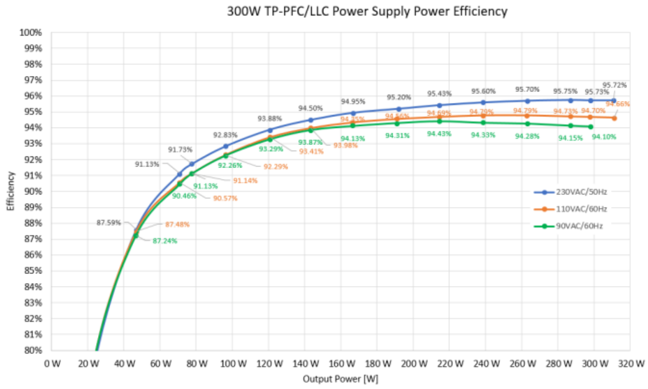
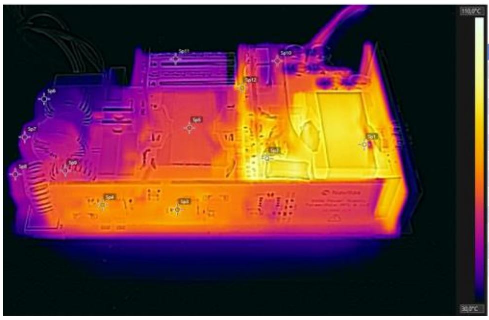


Fig. 10, Efficiency vs. load curves during different input voltage conditions.



Meas. point	Description	Temp
Sp1	LLC Transf.	92.4 °C
Sp2	LLC Lres	94.0 °C
Sp3	PFC GaN HS	77.1 °C
Sp4	PFC GaN LS	75.3 °C
Sp5	PFC L	63.6 °C
Sp6	CM choke 1	35.5 °C
Sp7	CM choke 2	47.3 °C
Sp8	Diff choke 1	50.2 °C
Sp9	Diff choke 2	58.9 °C
Sp10	Output cap	58.5 °C
Sp11	Bus cap	45.6 °C
Sp12	LLC GaN card	76.4 °C

Fig. 11, Thermal images during 90 VAC input and full load conditions.

8 Conclusions and Future Work

A 300 W, 300 cc, AC-DC converter operating at 700 kHz has been designed and demonstrated to show that a high density is achievable with readily available components and controllers. GaNFast Power ICs have enabled higher switching frequencies and high efficiency that has resulted in a dramatic size reduction of the magnetic components and overall converter size. The performance data shows high efficiency (95.8% peak efficiency at 230 VAC input) which is necessary to achieve acceptable thermals. Future work includes thermal management, EMI compliance (conducted and radiated), and voltage transient/surge testing.

9 References

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