



# Gallium nitride technology in server and telecom applications

The promise of GaN in light of future requirements for power electronics

## **Abstract**

This paper will discuss the benefits of e-mode GaN HEMTs in high power applications such as server power supplies and telecom applications. In comparison to the next best silicon alternative, this paper will show quantitatively how much better systems based on GaN power devices will be. It will also provide further insight into corresponding topologies, choice of magnetics and switching frequencies to take the full benefit of the next generation of power devices.

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## 1 Introduction

The commercial availability of wide bandgap power semiconductors with their significantly better figures of merit raises some fundamental questions on the agenda of many customers: how much better will be system solutions based on these wide bandgap components in terms of density and efficiency? To what extent can silicon based solutions follow at the potential expense of more complex topologies and control schemes?

This paper tries to give answers to these questions for two application fields, server power supplies and telecom.

GaN HEMTs as lateral power devices have an order of magnitude lower gate charge and output charge compared to their silicon counterparts. Combined with virtually zero reverse recovery charge it enables hard commutation of reverse conducting devices. Thus, GaN supports simpler topologies and an optimization of control methods seamlessly changing between soft switching and (partial) hard switching. Even though hard commutation is acceptable for silicon based power devices in low and medium voltage classes, Superjunction devices as prominent technology in the 600V class prevent any such operation due to losses and voltage overshoots. The designer of AC-DC applications has fundamentally three choices as next best alternatives to the use of wide bandgap devices:

- the use of single ended topologies such as boost converter as a power factor correction stage,
- totem pole configuration with silicon based devices by strictly avoiding hard commutation through corresponding control methods such as triangular current mode (TCM) operation
- the use of cascaded converter architecture where the voltage stress is distributed to several series connected converter stages.

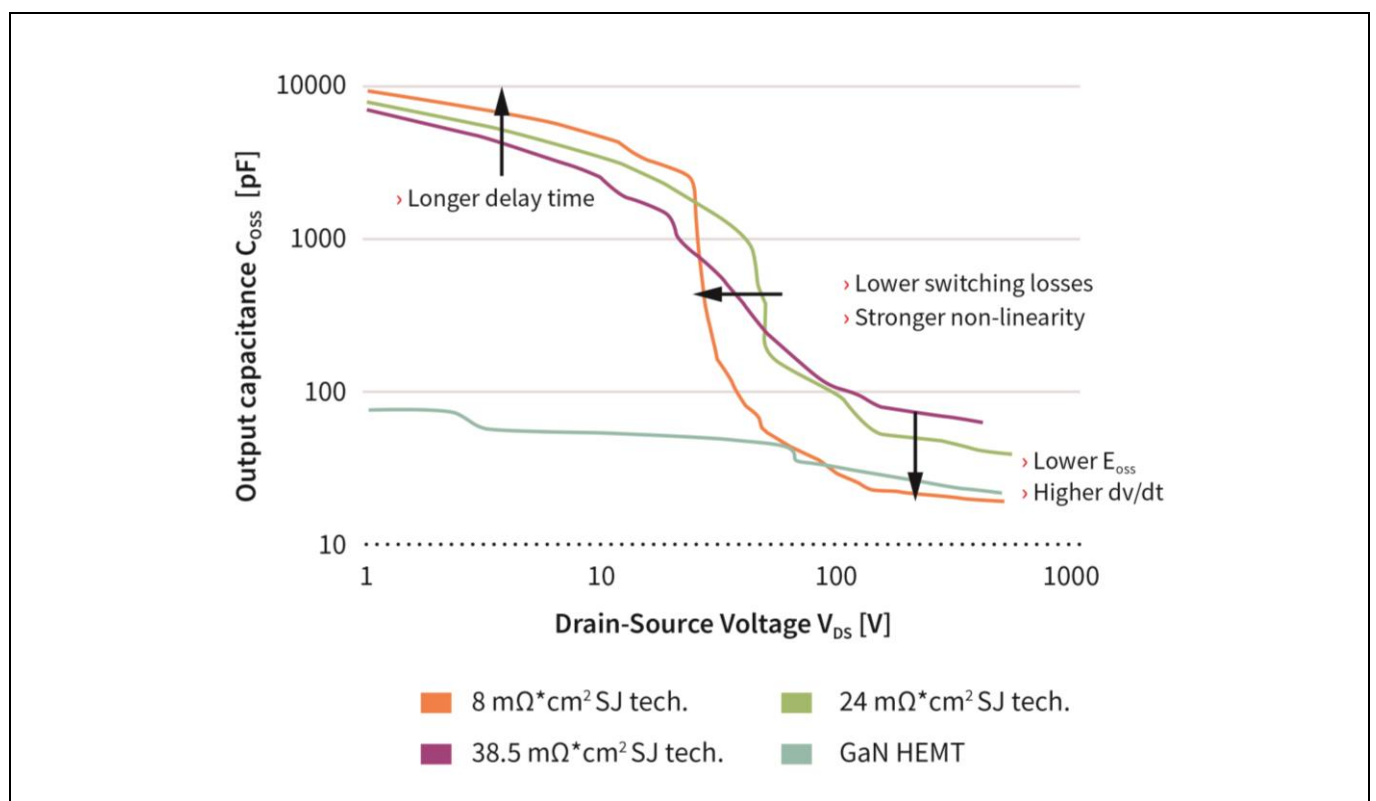
While single-ended topologies may not comply with efficiency targets, alternative solutions such as the dual boost may not reach density or cost targets. Even though cascaded solutions have demonstrated their ability to meet both efficiency and density targets [1], control efforts remain challenging and may limit the use of this concept to high power applications only. Hence, we see considerable value in using GaN HEMTs in relatively simple bridgeless topologies such as totem pole. This paper hence explores the value of GaN HEMTs in comparison to next best silicon alternatives.

## 2 Device concepts

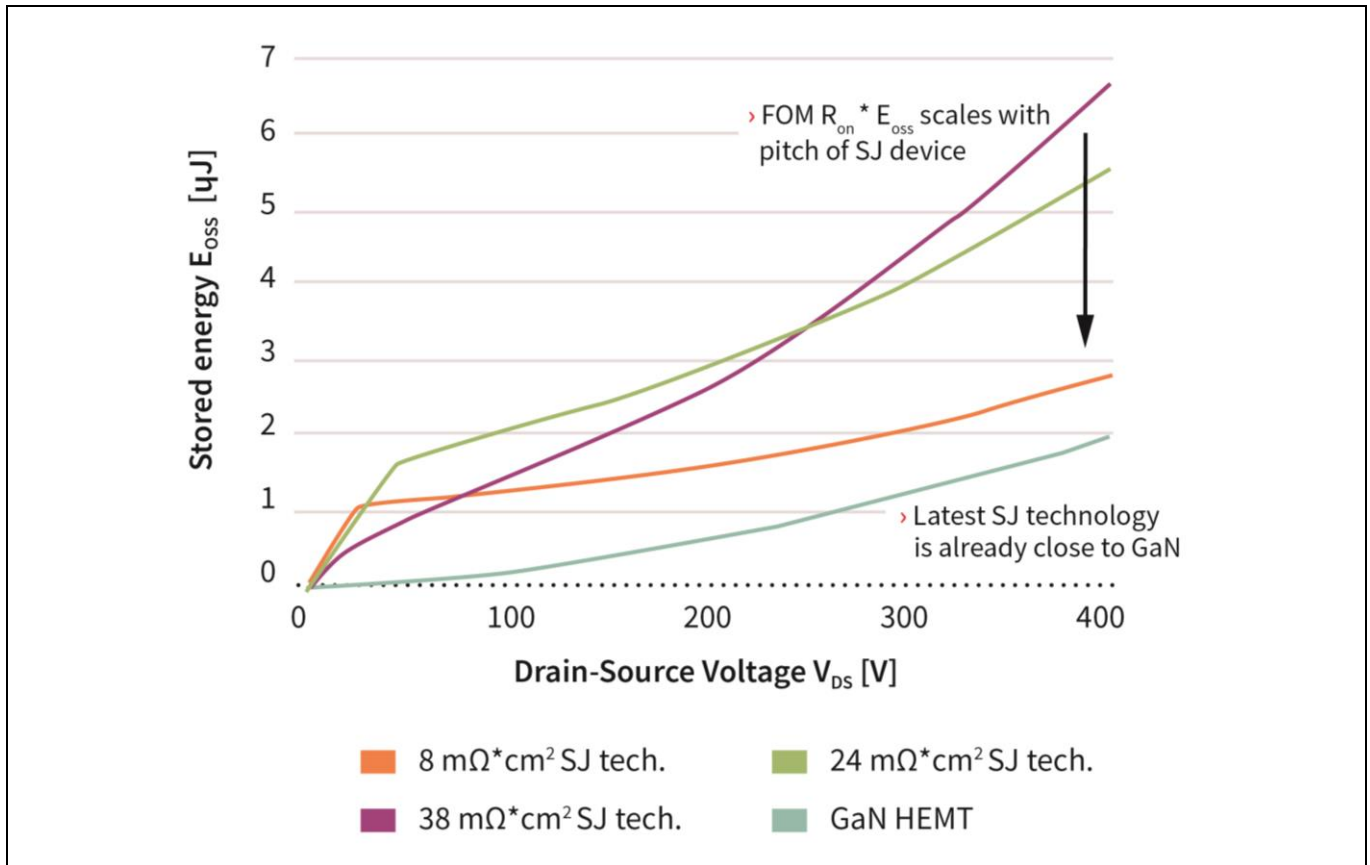
Server and telecom applications are using today dominantly silicon-based Superjunction devices. Before we discuss the advantages of GaN HEMTs we'll take a look into device characteristics of both concepts.

Superjunction devices have pushed for more than a decade towards ever lower on-state resistance [2], which in turn reduces the device capacitances and makes the devices inherently faster switching.

Figure 1 shows the output capacitance characteristics of three subsequent generations of Superjunction transistors versus an e-mode GaN HEMT. Figure 2 shows the energy stored in the output capacitance.



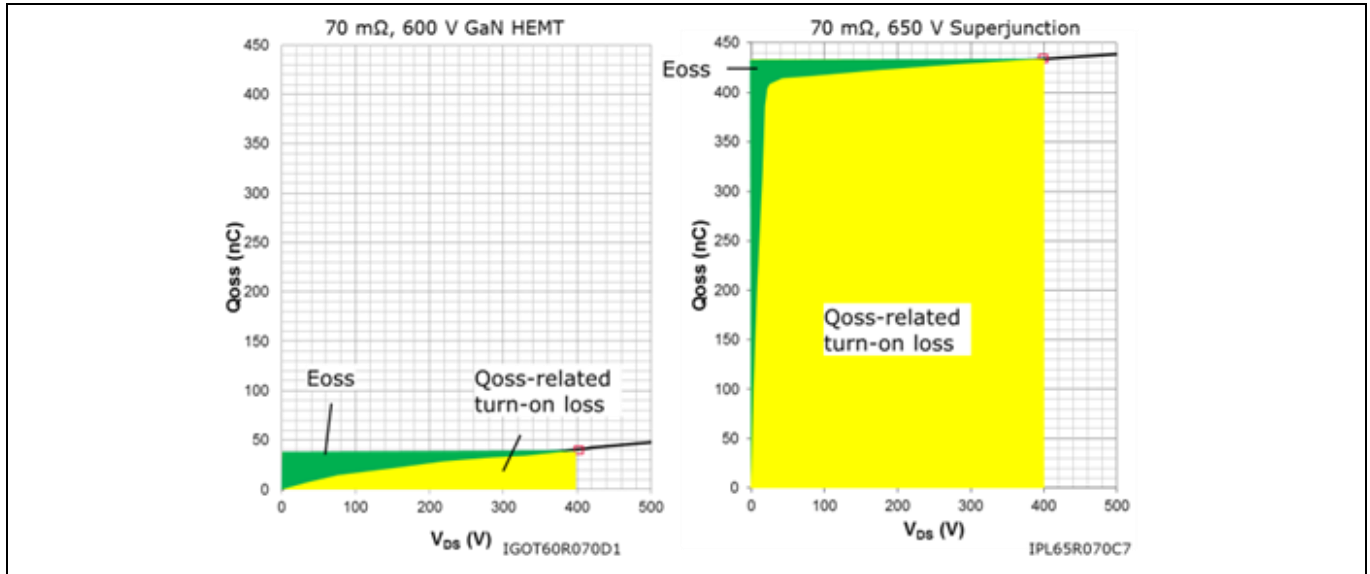
**Figure 1** Characteristic output capacitance curves of three consecutive technology nodes of Superjunction device in comparison to an e-mode GaN HEMT's



**Figure 2 Trend for the energy stored in the output capacitance across three consecutive generations of Superjunction devices in comparison to GaN HEMTs**

Even though the output capacitance of GaN is significantly lower in the low voltage range, the energy stored in the output capacitance is comparatively close to the values achieved by Superjunction devices. Since this energy is dissipated as heat in every switching cycle during hard switching transients, it is already obvious from this graph that the true value of GaN will be in half bridge based circuits and will be limited in single-ended topologies.

Figure 3 shows a comparison of the charge stored in the output capacitance as one of the key parameter for soft switching transitions.



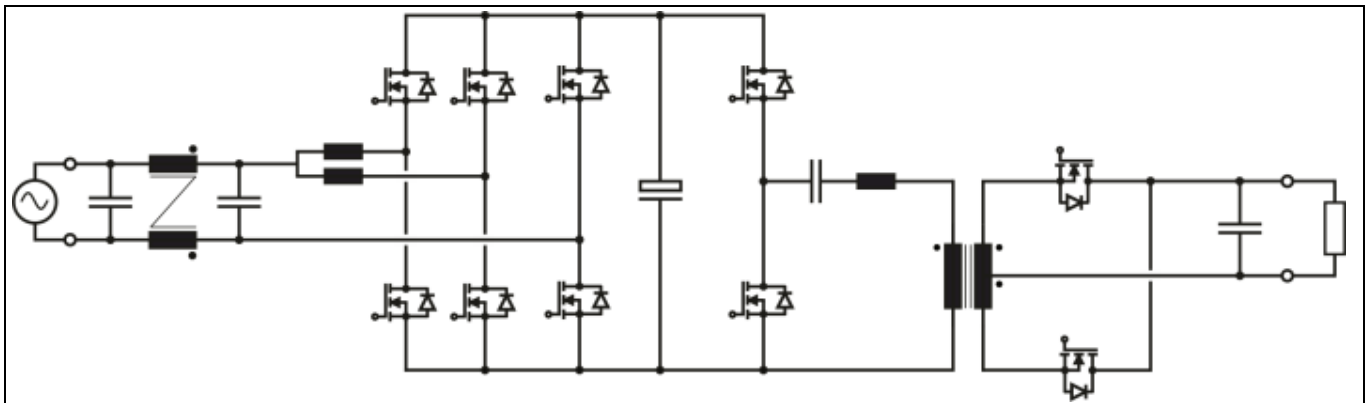
**Figure 3 Comparison of  $Q_{OSS}$  versus voltage for an e-mode GaN HEMT (left) to CoolMOS™ C7 (right)**

Whereas in single-ended topologies the  $E_{OSS}$  parameter is governing loss mechanisms, in half bridge based circuits the charge stored in the output capacitance [3] and the reverse recovery charge is determining the losses. While Superjunction devices are optimized for an extremely low  $E_{OSS}$  figure of merit (FOM), GaN HEMTs offer a much more favorable  $Q_{OSS}$  FOM, with the first generation being already one order of magnitude better than their silicon counterparts.

### 3 Application examples

#### 3.1 Server power supplies

The emergence of cloud based internet services, artificial intelligence, and cryptocurrency has initiated a strong growth of processing power in data centers around the world. Since the data centers are also facing rising electricity and real estate prices, there is a clear trend towards highly efficient and compact server supplies. These new power supplies do not only lead to a lower power consumption of the server, but also to a lower heat dissipation reducing secondary costs such as the cooling of the servers.



**Figure 4** Server supply comprising a totem pole AC-DC rectifier with two interleaved high frequency bridge legs and an LLC DC-DC converter with center-tapped transformer

Typically, state-of-the-art high efficiency power supplies are comprised of a bridgeless or semi-bridgeless PFC stage such as a totem-pole stage and a resonant DC-DC stage such as an LLC converter (see Figure 4). For an output voltage of 12 V typically a center tapped transformer is used, while for 48V systems a full bridge rectification shows better results. Table 1 shows the specification for a server power supply used as a basis for our optimization strategy.

**Table 1** Specification for server supplies

Parameter	Variable	Value
Input voltage	$V_{in}$	180 V – 277 V
Output voltage	$V_{out}$	12 V / 48 V
Rated power	$P_{out}$	3 kW
Hold-up time	$T_{hold}$	10 ms

### 3.1.1 12V server supplies

Currently, a majority of data center operators are running their mother boards on 12 V DC input. In the legacy architecture, uninterruptible power supplies (UPS) will provide back-up power to two independent AC distribution schemes throughout the datacenter. In a classic server board two AC-DC power supplies provide redundancy to each other, each power supply being sufficient to cover the full power demand of the attached load.

The need for lower operational cost (OPEX) and more payload per rack to save on capital expenditure (CAPEX) will drive two major transitions: first, local energy storage on rack level to cut out the UPS from the power flow, second, the transition from server based power supplies to rack based power supplies to reduce redundancy from 1+1 to n+1, thus saving cost. Both trends favor higher output power in a given form factor. Hence, the focus of this study is to analyze benefits of GaN HEMTs towards power density.

A bridgeless topology is used, in this case the totem pole configuration, both for silicon switches and GaN HEMTs. Using silicon devices mandates operation in triangular current mode (TCM) at all times, whereas, different modulation schemes can be selected for GaN HEMTs. The capability to operate the GaN switches in both hard and soft-switching enables the designer to run the totem pole in continuous conduction mode (CCM), triangular conduction mode (TCM), or optimal frequency modulation (OFM). The OFM is a seamless transition between hard and soft-switching over a grid period depending on the power level and/or grid voltage [4].

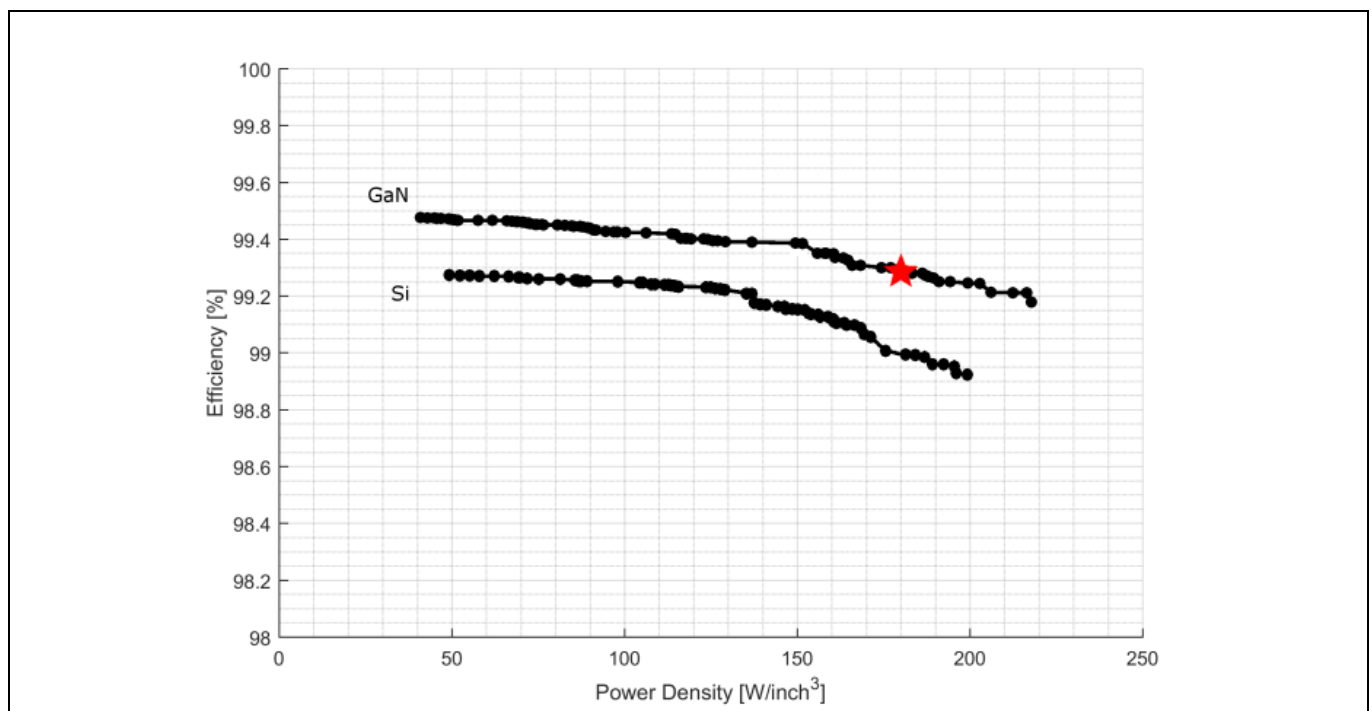
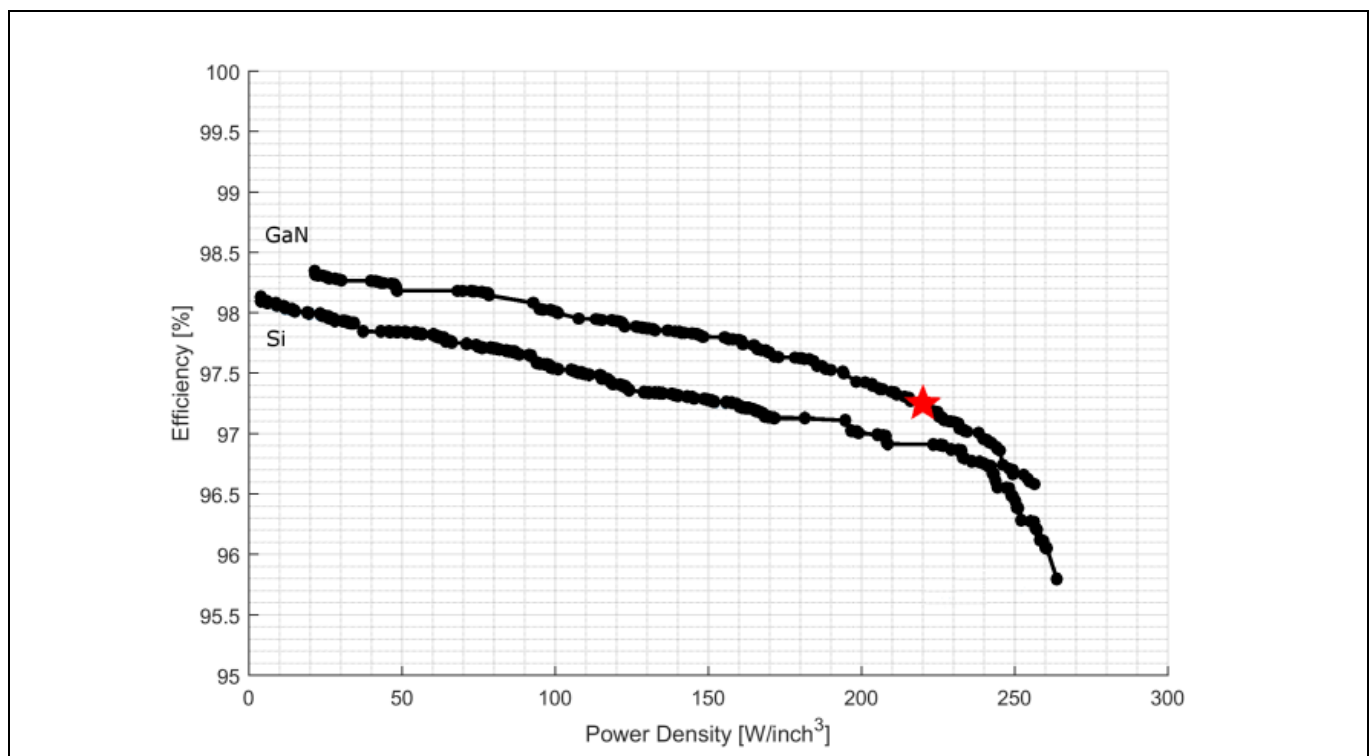


Figure 5 Optimization result for the totem pole PFC stage, including EMI filter, comparing system efficiency versus density for both GaN or Si-based power devices respectively



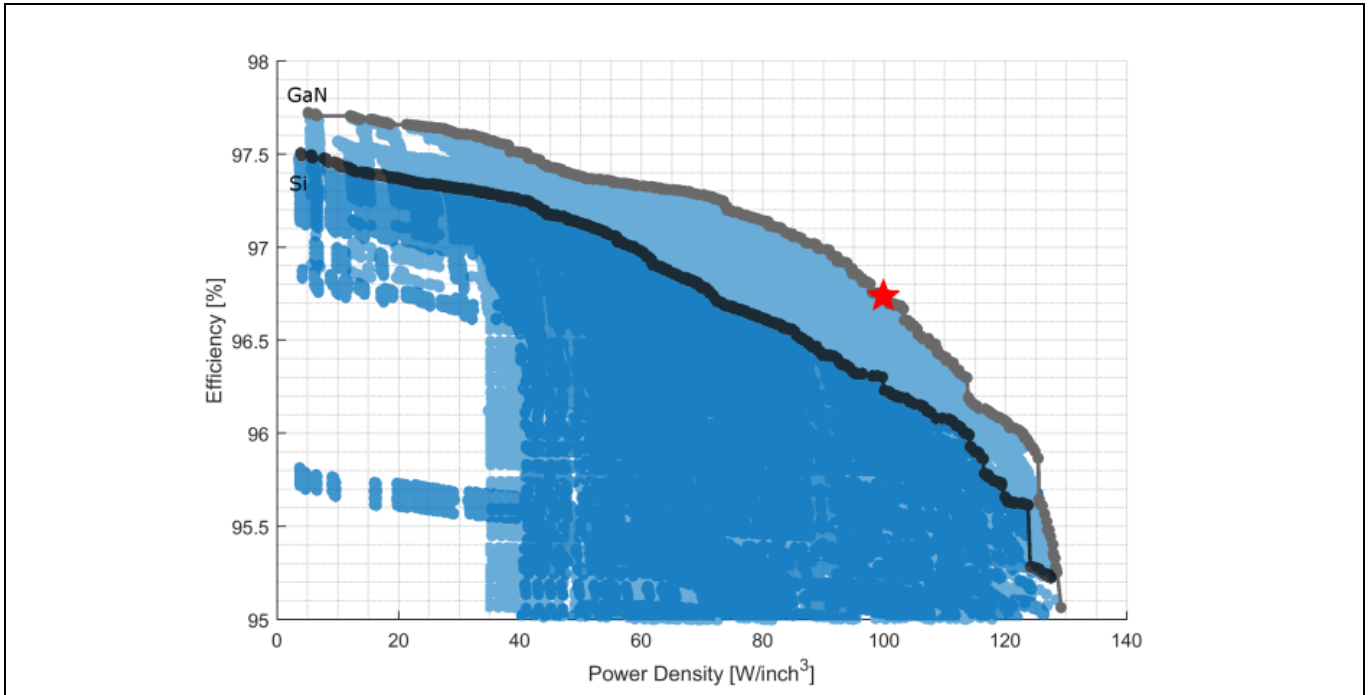
Figure 5 shows the optimization results for a Si totem pole rectifier stage (including the EMI filter) operating in TCM and a GaN totem pole stage using TCM or CCM. Both systems are optimized to deliver peak efficiency at 50% of the rated power and evaluated at nominal AC input voltages. The comparison includes the volume of the power electronics, the PCB and additional air between the components is considered. Excluded is the case and control/auxiliary electronics. The results clearly indicate the higher performance of the GaN designs, especially towards higher power density. An analysis of the designs using GaN transistors reveals that the TCM modulation offers a benefit compared to CCM specifically in the region of highest power density.

In a similar manner, the LLC stage has been optimized for Si and GaN semiconductors. The results are shown in Figure 6. As can be seen, GaN provides a simultaneous improvement of efficiency and power density.



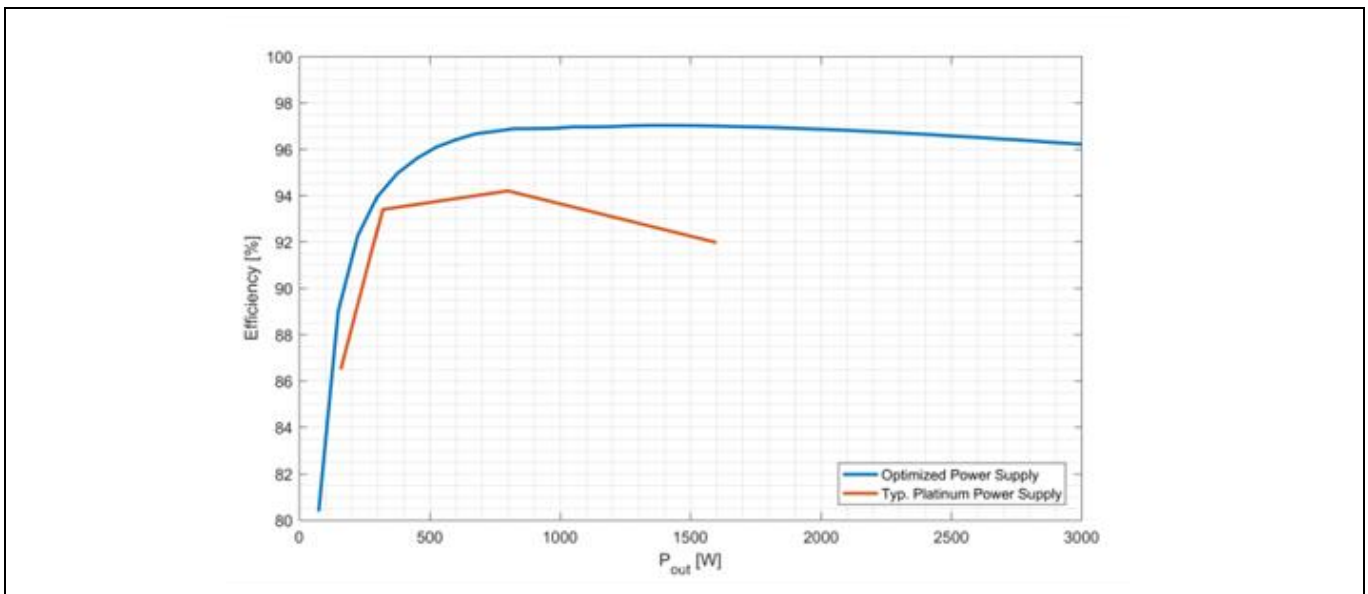
**Figure 6 Optimization results for the LLC stage showing efficiency versus power density both for Si and GaN based power devices**

Finally, the optimization results of the entire systems are shown in Figure 7. The results include all power electronic components, auxiliary electronics, PCB and 20% of additional volume being added to account for non-ideal placement of the components. The connectors and the casing with standoff are not included.



**Figure 7 Optimization results of the entire 12V server power supply showing efficiency versus density both for GaN or Si based power semiconductor devices**

The result clearly indicates a path to handle 3 kW in a given form factor such as the 68 mm × 41 mm × 184 mm flex slot size, thus nearly doubling the output power in this box size. Comparing to off the shelf solutions delivering 1600 W in this form factor, we not only nearly double the power but increase efficiency in average by 4% without increasing dissipated heat within the power supply (see Figure 8).



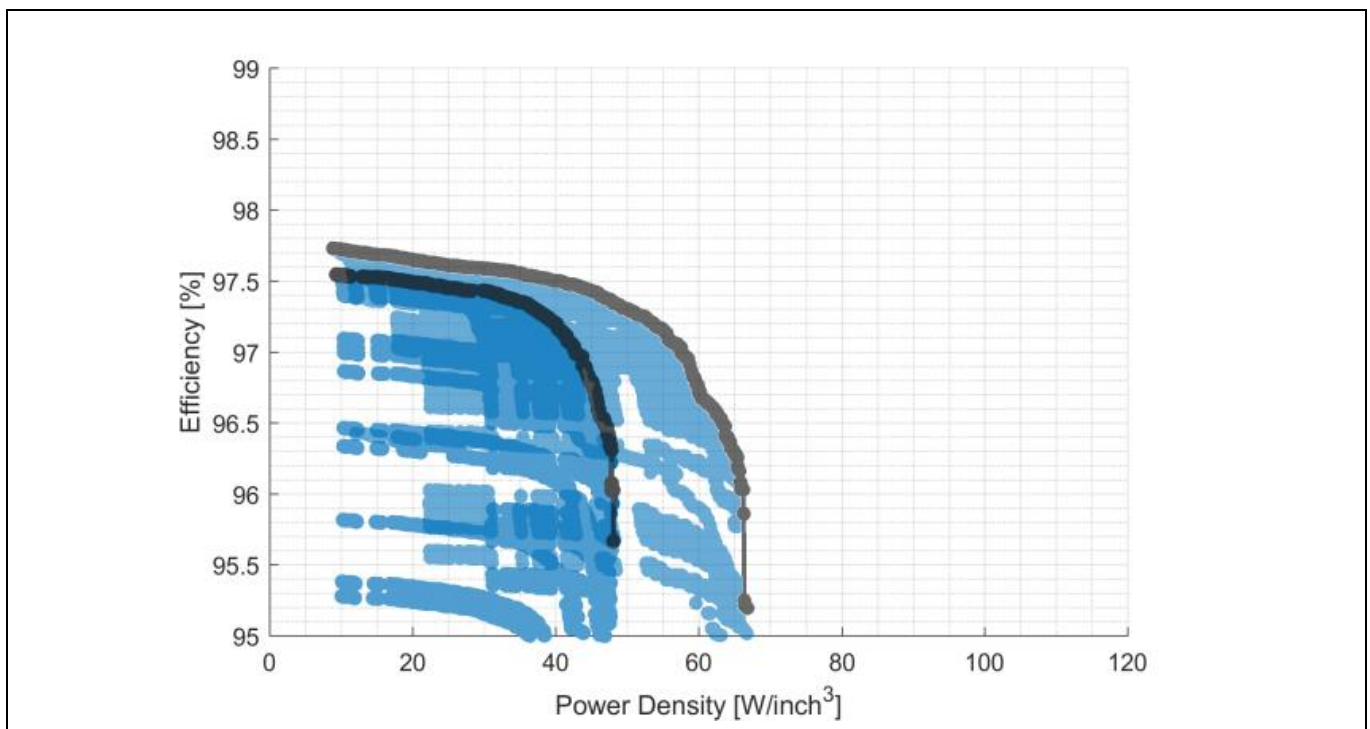
**Figure 8 Comparison of the efficiency curve of the high density GaN server design versus a state-of-the-art silicon based power supply**

### 3.1.2 48V server supplies

The emerging use of artificial intelligence in computer science and the training of the corresponding neural net-works has shifted the computational architectures from pure CPU-based servers to more specialized platforms with a very high degree of parallel data processing, e.g., employing GPUs. As a result of this trend, the power consumption per rack has roughly tripled now, pushing the power per rack to 20 kW and above. This power would lead to substantial losses within classic 12V distribution rails. As a solution, power distribution within the rack on 48 V level instead of 12 V will be more wide-spread in the future. Since the 48V server supplies are mainly targeting applications, being optimized for total cost of ownership (TCO), the performance of GaN in these systems is evaluated specifically from an efficiency perspective.

As a basis for the comparison an industrial 48V Si power supply with  $P_{\text{rat}} = 3 \text{ kW}$  is taken as reference. This power supply features a peak efficiency of 97.1% at half of the rated power and a power density of around  $33 \text{ W/in}^3$ . As a first step of improvement, the AC-DC stage can be changed into a totem pole rectifier with one high frequency bridge leg. This is enabled by the use of GaN switches ( $R_{\text{DS(on)25, max}} = 70 \text{ m}\Omega$ ) in the high frequency bridge leg, and Superjunction MOSFETs with very low on-state resistance in the low frequency bridge leg. As addressed before, GaN HEMTs offer a choice of different modulation schemes.

The Pareto-front for CCM operation at nominal operating voltages ( $V_{\text{in}} = 230 \text{ V}$ ,  $V_{\text{out}} = 48 \text{ V}$ ) and 50% power level is shown in Figure 9.



**Figure 9 Pareto-front of the state-of-art 48 V power supply at 50% load and nominal operating voltage. The performance improvement offered by interleaving two GaN high frequency bridge-legs is overlaid.**

As a second step of improving the efficiency of the AC-DC stage, several possibilities exist:

- Using two interleaved high frequency bridge-legs in the totem pole
- Increasing the chip area of the high frequency and low frequency switches
- Operating the totem pole in TCM

A cost analysis of the different options reveals that the most cost effective performance improvement can be achieved by interleaving two HF bridge legs using CCM control. This cuts the average current in each high frequency bridge leg by a factor of 2, which has two major benefits:

- The reduced RMS current significantly lowers the conduction losses in each high frequency branch (i.e., inductor and GaN switches).
- Natural ZVS can be achieved more easily when the high frequency current ripple (peak-peak) is larger than twice the average current, thereby reducing the switching losses.

The performance improvement is shown in Figure 9 by the overlaid opaque Pareto front. The introduction of TCM to achieve ZVS over the whole grid period, would allow larger chip area for a further reduction of conduction losses. This is a rather costly implementation, however, since the additional chip area and the optimization of the boost inductors for larger ripple currents with thin strands adds significant cost and control complexity with an improvement potential of only around 0.1% at the considered level of power density. Hence, CCM control is the option of choice for efficiency and cost driven converter designs.

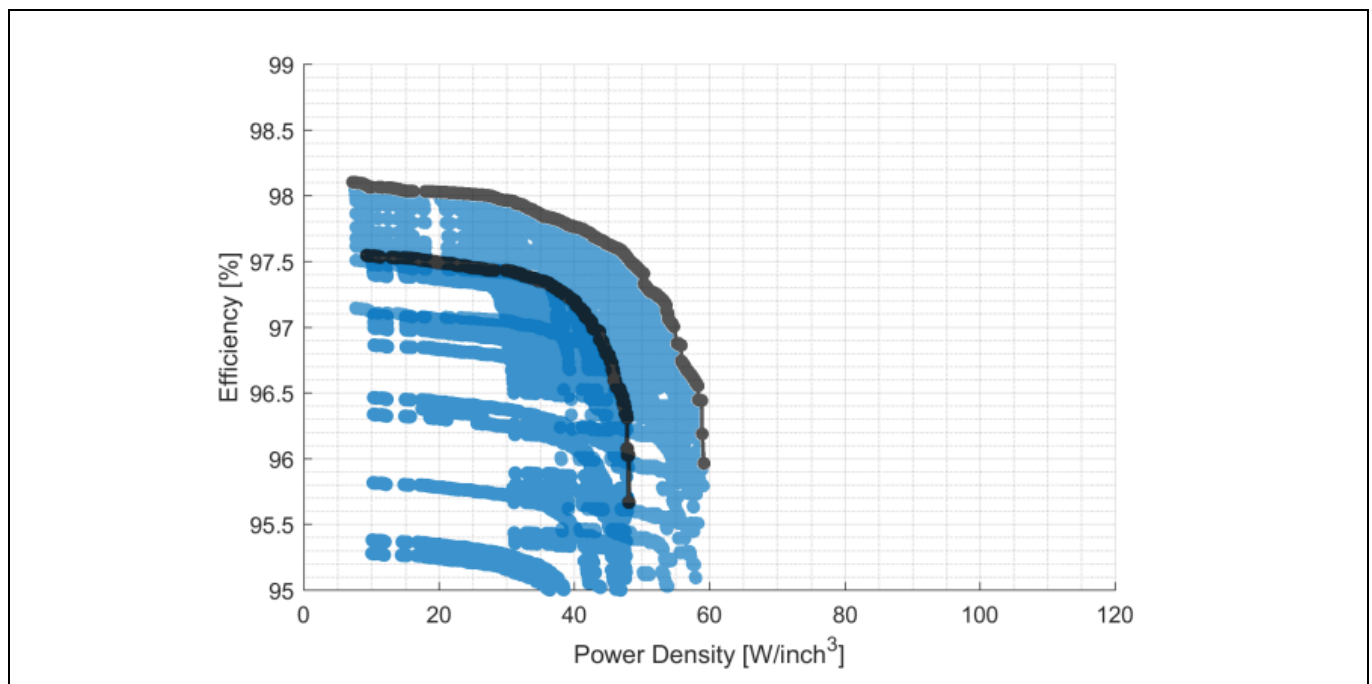
In the LLC stage, there are also several improvement options. Similarly, the optimization flow is based on an industrial design using 31m $\Omega$  fast body diode-type Superjunction devices at a relatively low switching frequency.

As a first measure, the primary side half-bridge is equipped with 35m $\Omega$  GaN switches. The system efficiency can be increased by around 0.3% by optimizing the resonant tank with one order of magnitude lower  $Q_{oss}$  charge on the switches, which includes adjustments of the resonant frequency and the magnetizing inductance.

On top of this, efficiency can be further improved by another 0.3% by changing the transformer setup to a matrix structure using two cores with series connected primary windings and parallel connected secondary side windings. This approach offers several advantages for the conversion efficiency:

- The high output current of the single transformer configuration is split among the two outputs. Under the assumption, that both configurations have comparable termination resistances, the total termination losses can be significantly lowered with the matrix transformer setup.
- Due to lower currents in each transformer, also the electrical fields that cause proximity effect losses are reduced in each transformer.
- The use of two synchronous rectification stages leads to a spatial distribution of the losses of the synchronous rectification MOSFETs which is beneficial especially from a thermal perspective.

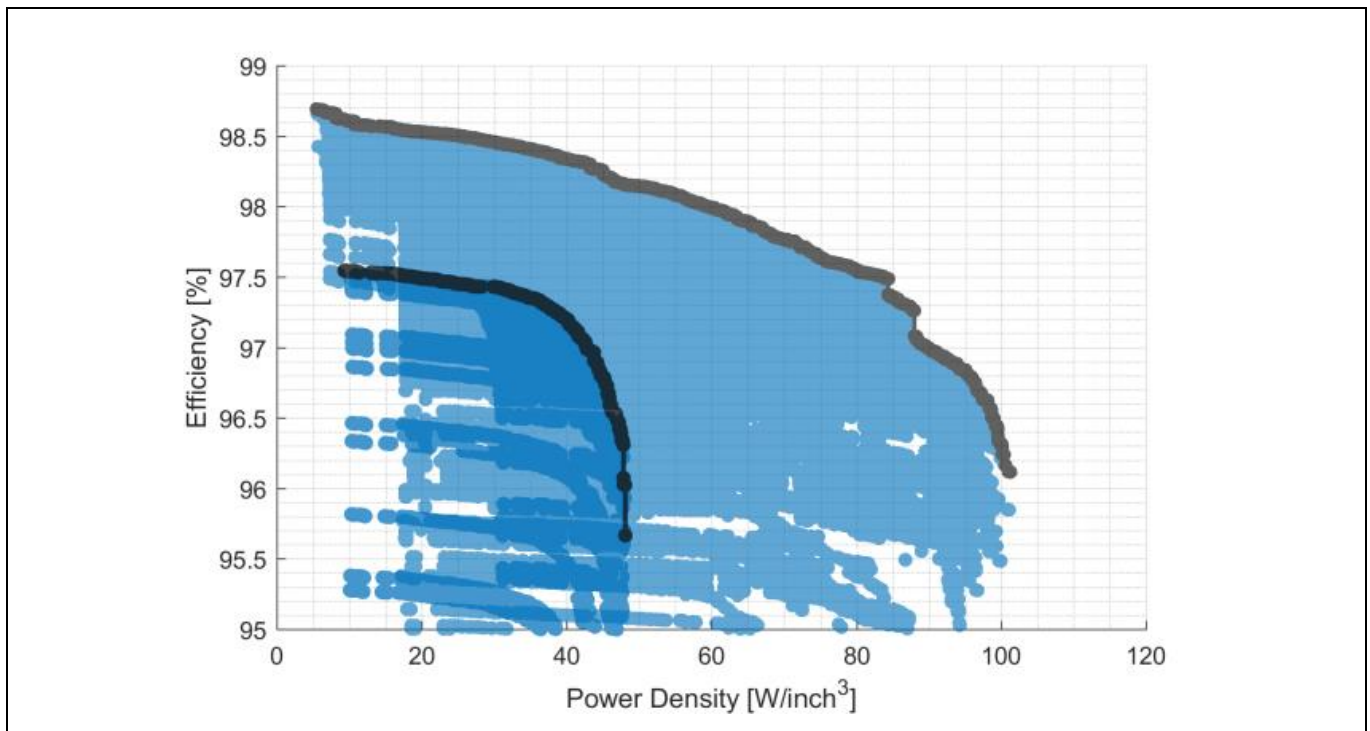
The input series-output parallel connection of the matrix transformer setup is inherently stable as it guarantees equal splitting of the primary voltage among the series connected primary terminals, and equal output current splitting among the secondary terminals of the transformers. Caution has to be taken to reduce the leakage inductance of each transformer such that it does not affect the resonance behavior of the LLC. The total systems cost will only marginally increase through this step.



**Figure 10 Performance improvements of the 48 V server supply provided by utilizing 35 mΩ GaN as primary switches in the LLC and a matrix transformer configuration.**

As a further measure for performance improvements, the secondary side of the transformers can be changed from center-tapped into full-bridge rectification circuits. On the one hand, this leads to a better copper utilization in the transformers, and on the other allows to use synchronous rectification MOSFETs with a lower voltage rating and thus with a better FOM. With this configuration, the transformer and synchronous rectification losses can be further reduced, but at the expense of increased system cost.

By combining the most cost effective performance improvement options of both PFC (i.e., two interleaved high frequency bridge legs with 70 mΩ GaN HEMTs in CCM operation) and LLC stage (i.e., 35 mΩ GaN HEMTs on the primary side and matrix transformer configuration), the total system peak efficiency can be increased by 0.8% to 0.9% to a level of around 98.2 - 98.3%. Using the full potential of all available performance improvement methods allows the efficiency of the entire system to increase up to 98.5%, giving a power density of around 30 to 35 W/in<sup>3</sup>.



**Figure 11 Achievable Pareto-front of the entire 48 V server power supply with all improvement options of the PFC and LLC incorporated.**

### 3.2 Telecom

The rapid growth of cloud based internet services does not only affect the development of data centers, but impacts similarly the telecom infrastructure. Due to increasing data traffic and the demand for higher bandwidth, telecom base stations as the ultimate link between the mobile world and hyper scale datacenters have gained significant importance. As existing telecom sites may serve multiple antennas within the roll-out of 5G, power distribution and overall power consumption move more and more into focus.

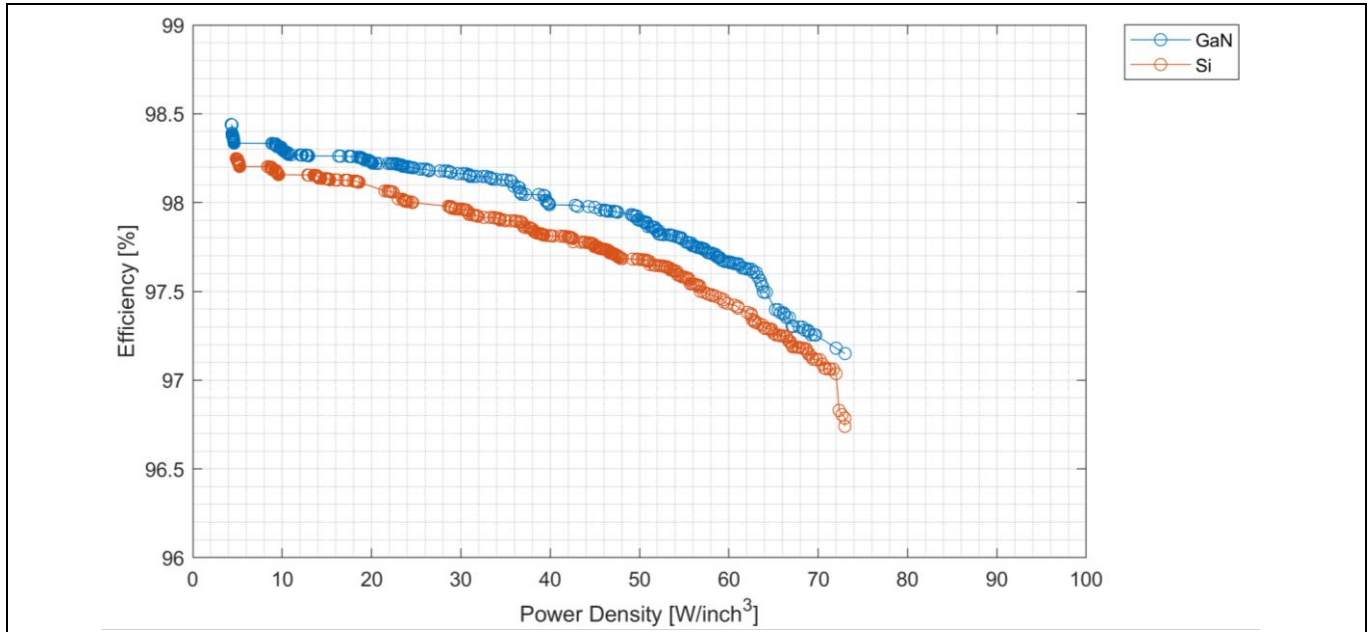
Even though in the recent years the 380 V DC distribution in telecom applications has gained popularity, the majority of telecom equipment is still powered by 48 V, in most cases referred to negative potential to inhibit corrosion. In contrast to the server power supplies addressed in the previous chapters with a fixed output voltage, the telecom power supplies typically have an output voltage range of 40 V to 60 V and



use typically no ORing MOSFETs for hot-plug capability. Another difference exists in the load profile, such that telecom supplies operate most of the time between 30% and 50% of the rated power, while hyperscale server supplies operate typically in the range of 50% to 70% of the rated power. This leads to different optimization targets with a greater emphasis on efficiency in the 30% to 50% load range.

In the following, the highest achievable performance with GaN HEMTs in a 3kW telecom power supply will be shown in comparison to the best Si solution. The selected topologies are the same as for the server supplies and consist of a totem pole PFC, which is either operated in CCM with GaN HEMTs or in TCM with Si MOSFETs, followed by an LLC DC-DC converter. For this comparison, both systems are optimized by means of a multi-objective optimization for 50% of the rated power and evaluated at an input voltage of 230 V and an output voltage of 48 V. In the GaN designs, all high voltage switches are GaN HEMTs, except for the low frequency totem pole return path switches, which are in both cases 17m $\Omega$  C7 MOSFETs (IPZ60R017C7). The low voltage switches for the secondary side of the LLC, which is a full bridge rectifier, are in both cases 80V OptiMOS 5 MOSFETs (BSC030N08NS5), with up to three devices in parallel. In order to have a fair system comparison between the two 600V device technologies without treating one technology preferentially due to a larger portfolio of  $R_{DS(on)}$  values, only 70m $\Omega$  devices are considered for the high voltage switches, i.e. CoolGaN™ (IGT60R070D1) and CoolMOS™ CFD7 (IPW60R070CFD7). As an optimization parameter, the devices can be paralleled up to three devices, thus creating effective  $R_{DS(on)}$  values of 70 m $\Omega$ , 35 m $\Omega$ , and 23 m $\Omega$ . Additional parameters that were varied during the optimization are similar to the ones described in the server section of this document, and include but are not limited to e.g., the number of HF legs in the PFC, the number of parallel PFC and LLC stages, the number of transformers connected in matrix configuration, and switching frequencies.

The results of the optimization are shown in Figure 12 and visualize the achievable performance gain of GaN HEMTs in a 3kW telecom power supply compared to the best Si solutions, which is consistently between 0.1% and 0.3%. Not reflected by the graphs, however, is the simplicity advantage of the GaN designs, given by the fact that the PFC stages in the GaN designs are operated with CCM modulation, which requires less control and measuring effort than the implementation of TCM modulation with its necessity to detect zero-current switching events.



**Figure 12 Pareto-front of the entire 48V, 3kW telecom power supply using either GaN or Si-based HV devices for 230 V AC<sub>in</sub> and 48V DC<sub>out</sub>, optimized for 50% of the rated power.**

The result shows a clear system benefit for GaN based solutions with an efficiency benefit in the range of 0.3% at significantly reduced complexity. Especially the PFC stage will run with GaN devices at fixed frequency using CCM modulation with typically relatively high AC ripple to facilitate natural ZVS switching at least partly across the sinusoidally varying input voltage and different load conditions.

One of the main differences of the Pareto optimal designs in the commercially interesting range of 30...40W/inch<sup>3</sup> between Si and GaN lies in the PFC stage. The TCM modulation of Si leads to high current ripples and RMS-values of the boost inductor currents. This mandates the interleaving of two HF totem-pole branches to reduce the input current ripple and to facilitate a reduced EMI filter size. In contrast, for the CCM controlled GaN PFC stages, designs with only one HF totem-pole leg are feasible and more cost effective on system level due to e.g. savings in magnetic components.

In the LLC stage, the GaN-HEMT based designs require a lower magnetizing current for soft switching and will need shorter delay times. Alternatively, for the same magnetizing current more parallel GaN switches can be employed in the system. Both alternatives allow to reduce the losses in the LLC stage with GaN. The optimization shows that both silicon-based as well as GaN based designs take benefit from a 2 stage matrix transformer configuration with primary windings being series connected and secondary windings being paralleled. Furthermore full bridge rectification yields better results than center tapped configurations. Switching frequencies are typically around 100 kHz for Si-based designs versus 150 kHz for GaN based designs.



## 4 Summary

The application studies performed show a clear value for e-mode GaN HEMTs in high power designs. GaN HEMTs allow us to push both efficiency and density frontiers.

This paper demonstrated a path towards 98.5% efficiency in 48 V servers and towards a density of up to 100 W/in<sup>3</sup> for 12 V servers thus offering large benefits in terms of OPEX and CAPEX savings. It also showed that GaN allows us to use easier control schemes such as CCM modulation in the PFC due to its hard switching capabilities, while at the same time offering performance benefits compared to the next best Si alternative.

For Infineon's CoolGaN™ portfolio of switches and dedicated GaN EiceDRIVER™, please visit [www.infineon.com/gan](http://www.infineon.com/gan) and [www.infineon.com/gan-eicedriver](http://www.infineon.com/gan-eicedriver).

## References

- [1] M. Kasper, D. Bortis, G. Deboy and J. W. Kolar, "Design of a Highly Efficient (97.7%) and Very Compact (2.2 kW/dm<sup>3</sup>) Isolated AC–DC Telecom Power Supply Module Based on the Multicell ISOP Converter Approach," in IEEE Transactions on Power Electronics, vol. 32, no. 10, pp. 7750-7769, Oct. 2017.
- [2] F. Udrea, G. Deboy and T. Fujihira, "Superjunction Power devices, History, Development and Future prospects", Transactions on Electron Devices, Vol. 64, No. 3, March 2017, pp. 713-727.
- [3] G. Deboy, O. Haerberlen and M. Treu, "Perspective of loss mechanisms for silicon and wide band-gap power devices", CPSS Transactions on Power electronics and applications, Vol. 2, No. 2, June 2017, pp. 89-100.
- [4] D. Neumayr, D. Bortis, E. Hatipoglu, J. W. Kolar and G. Deboy, "Novel efficiency-Optimal Frequency Modulation for high power density DC/AC converter systems," 2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia (IFEEC 2017 - ECCE Asia), Kaohsiung, 2017, pp. 834-839.

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