Please note that GaN Systems is an Infineon Technologies Company

The document following this cover page is marked as “GaN Systems” document as this is the company that originally developed the product. Please note that Infineon will continue to offer the product to new and existing customers as part of the Infineon product portfolio.

Continuity of document content

The fact that Infineon offers the following product as part of the Infineon product portfolio does not lead to any changes to this document. Future revisions will occur when appropriate, and any changes will be set out on the document history page.

Continuity of ordering part numbers

Infineon continues to support existing part numbers. Please continue to use the ordering part numbers listed in the datasheet for ordering.

Infineon Technologies AG
81726 Munich, Germany
www.infineon.com

140W AC/DC Charger with USB PD3.1, Single Port Type-C Reference Design

Abridged Version

Technical Manual

Visit www.gansystems.com for the latest version of this document

Table of Contents

1. Scope and Purpose

This document provides a comprehensive functional description and guide to the 140W AC/DC Charger design with USB PD3.1, single port type-C output charger reference design (part number: GS-EVM-CHG-140WPFCQR-GS1) based on the 650V Gallium Nitride (GaN) enhancement-mode high electron mobility transistors (e-HEMTs) from GaN Systems. It describes the system operation and covers technical aspects essential to the design process, including calculation of key components as well as additional design documents (schematics, layout, and BOM). Test results and waveforms are also included in this document.

2. Introduction

The 140W USB PD3.1, single port type-C GaN-based charger reference design provides a cased turn-key solution with the following key features:

- High power density of 22.8W/in^3 (1.4W/cc) and high efficiency above 94.2%
- Single USB-C port
- Cost effective topologies with Totem Pole PFC+ Dual Switch QR Flyback
- Passes EN55032 Class B with >6dB margin for conduction and radiation EMI
- Meets IEC 62368-1 touch temperature requirement
- Meets IEC 61000-3-2 THD requirement with high power factor
- Output Voltage and Current: SPR: 5V3A / 9V3A / 12V3A / 15V3A / 20V5A EPR: 28V5A
- Supports most PD protocols including PD3.1, PPS, QC4.0+, BC1.2, etc.
- Comprehensive system protections such as OVP, OCP, SCP, and open loop
- Exceeds CoC Ver5 2019/1782 efficiency standard requirement
- Fixed AC Prong

2.1. System Block Diagram

As shown in Figure 1, the reference design includes two power conversion stages: Bridgeless Totem Pole Power Factor Correction (BTP-PFC) and Dual Switch Quasi-Resonant (DS-QR) Flyback. Bridgeless topologies eliminate the diode bridge that has been widely used in conventional PFC converters. BTP-PFC has superior performance compared to conventional

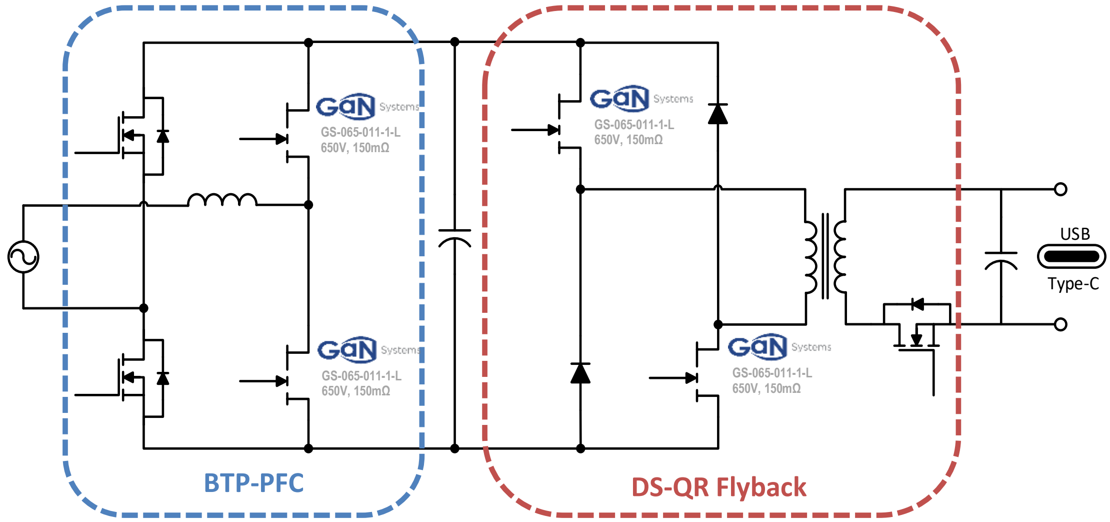


Figure 1. System block diagram for GS-EVM-CHG-140WPFCQR-GS1 reference design

PFC converters due to the high efficiency and the simple structure. The front-end BTP-PFC stage achieves high power factor and meets the IEC61000-3-2 THD standard. In addition, it maintains lower component counts, higher power density, and lower BOM cost. The second stage is the DS-QR Flyback, which provides galvanic isolation and steps down the dc bus voltage to meet the desired consumer electronics voltage. In the DS-QR Flyback converter, the overall voltage stress is divided between the two transistors, which makes it suitable for high voltage applications. In addition, the DS-QR flyback recycles the leakage energy back to the input rail. This results in removing the clamping losses. On the secondary side of the DS-QR Flyback stage, a synchronous rectifier (SR) and USB PD3.1 controller are used to achieve the various supported DC output voltages. Both PFC and DS-QR Flyback stages use two 650V, 150mΩ GaN transistor (part number: **GS-065-011-1-L**) for efficiency and power density improvements.

2.2. System Specifications

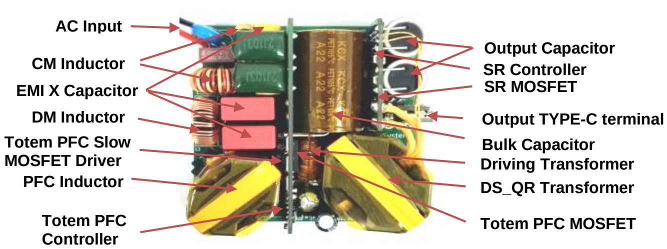
Table 1 summarizes the key specification and performance for this 140W GaN-based charger reference design.

Table 1. Key parameters and performance of GS-EVM-CHG-140WPFCQR-GS1 reference design

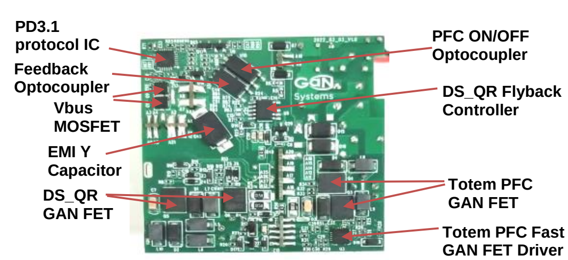
Parameter	Value
Input AC Voltage (V_{in})	90-264 V_{rms}
Input Frequency Range	50/60 Hz
Max. Output Power	140W
Output Voltage and Current	SPR: 5V3A / 9V3A / 12V3A / 15V3A / 20V5A EPR: 28V5A
Max. Output Current	5A
PD Protocols	PD3.1, PPS, QC4.0+, BC1.2 etc.
Performance	**Specification**
Cased Power Density	22.8 W/in^3 (1.4W/cc)
Board Dimension with Case	60mmX60mmX28mm (2.4inchX2.4inchX1.1inch)
Peak Efficiency	>94.2%
Average Efficiency	CoC V5 2019/1782
Standby Power	<120mW
Touch Temperature @ 28V/5A	IEC 62368-1
EMI Standard	EN55032 Class B
System Protections	OVP, OCP, SCP, Open Loop

2.3. Reference Design Board

Figure 2 shows the PCBA photo of this reference design which uses a 4-layer 2Oz FR4 PCB (1mm thickness) with common industrial components. This reference design has a mother board and two daughter boards. The daughter boards include the BTP-PFC controller and the SR controller. Figures 2a and 2b show the top-view and bottom-view of this reference design, respectively. The reference design board also includes a plastic case, copper shielding, and thermal interface material (TIM) for heat spread and EMI purposes.



(a)



(b)

Figure 2. PCBA photos for GS-EVM-CHG-140WPFCQR-GS1 reference design

3. GaN's Value Propositions

GaN Systems 140W reference design has several advantages, enabled by GaN e-HEMTs, over the other adapters in the market. According to Figure 10, these include:

- ¼ the size of Si-based 140W PD3.1 chargers in the market
- ½ the size of GaN-based PD3.1 chargers in the market
- ¾ the size of GaN-based 130W multi-output PD3.0 chargers in the market

In the following, GaN's value in the topologies used in the 140W reference design, which are BTP-PFC and DS-QR flyback, is explained.

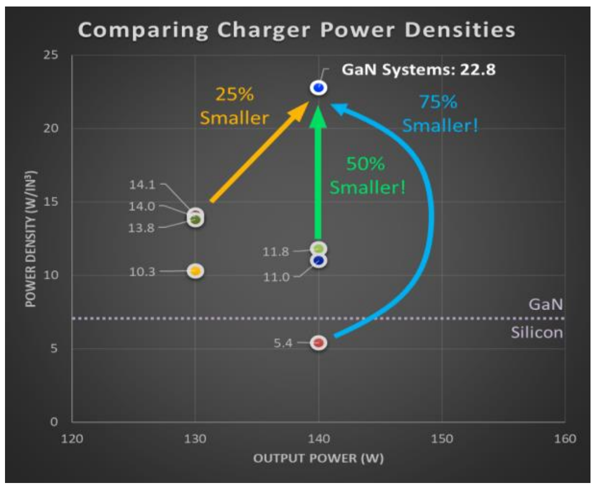


Figure 10. Comparison of state-of-the-art USB PD 3.x adapters in the market

3.1. GaN's Value in BTP-PFC

BTP-PFC has been proposed before, but its application has been minimal until recently. The major challenge is the poor reverse recovery performance of conventional Si MOSFETs in the half-bridge configuration. It makes CCM operation impractical due to the excess Q_{rr} loss at turn-on. To avoid body diode conduction, BTP-PFC with silicon MOSFETs must work in CrCM/DCM modes, which is only suitable for lower power and has more complicated control. Usually, a multi-phase interleaved configuration is used to achieve a higher power level and increases the current ripple, which again adds cost and complexity.

Moreover, GaN e-HEMTs is an ideal solution for CCM hard switching BTP-PFC, since the absence of a body diode (zero Qrr) and the fast-switching speed. Figure 8 shows the hard turn-on loss breakdown of Si MOSFET and GaN e-HEMTs . According to this figure, Q_{rr} measured using standard test methods include both Q_{rr} of the high side body diode and Q_{oss} of the MOSFET, though Q_{rr} usually dominates for Si MOSFETs. By contrast, GaN e-HEMTs exhibit significantly lower hard turn-on loss as there is only Q_{oss} loss - the loss induced at hard switching device during turn-on due to the output capacitance charging current of the free-wheeling switch. Compared to Si MOSFETs, SiC MOSFETs offer lower Q_{rr}. However, the Q_{rr} of SiC MOSFETs is highly temperature dependent. Thus, with the temperature rise, the body diode of the SiC MOSFET has increased losses.

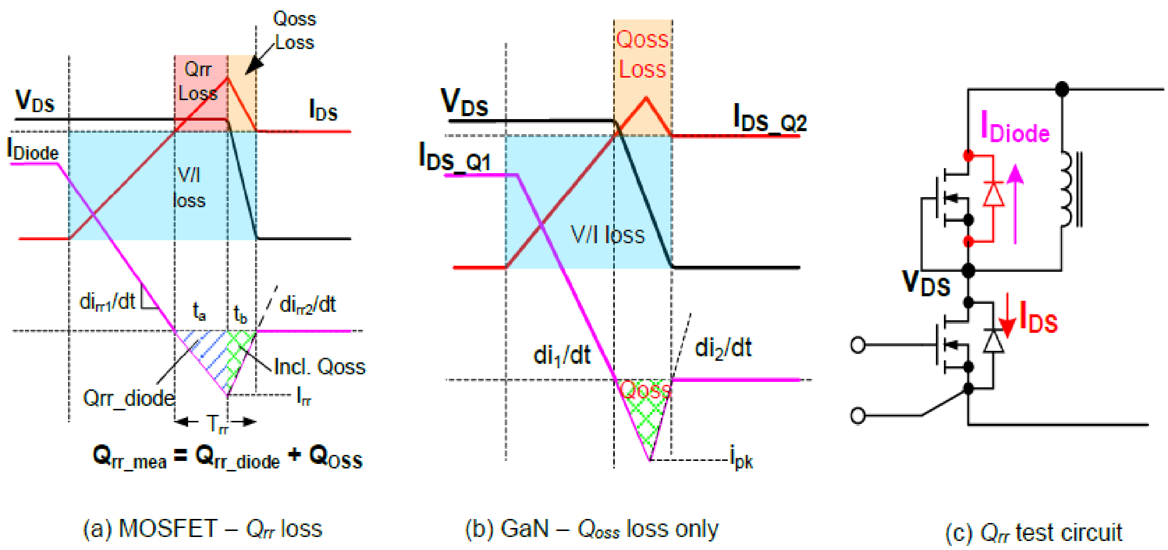


Figure 8. Hard turn-on loss breakdown in Si MOSFET and GaN e-HEMT

Table 4 summarizes key figures of merit (FOM) between the GaN transistor and Si Super Junction (SJ) MOSFET. As can be seen, a GaN transistor has much lower FOMs compared to Si SJ MOSFETs. The combined advantages of GaN transistors: low gate charge, low parasitic capacitor, and low on-state resistance in the converter lead to a more efficient system. Accordingly, GaN e-HEMTs is also a perfect solution for high frequency CrCM/ DCM BTP-PFC. To summarize GaN advantages in the BTP-PFC converter, the following benefits are highlighted:

- Highest efficiency (almost 99%)
- Highest system power density
- Highest switching frequency
- 40% fewer components
- 10-25% lower system cost
- zero Q_{rr} with small output charge Q_{oss} (independent of temperature)

Table 4. GaN vs Si MOSFET parameters for QR Flyback

Manufacturer	**GaN Systems**	**Si SJ MOSFET**			**GaN benefit**
Part Number	GS-065-011-1-L	#1	#2	#3	
Technology	GaN	Si Super Junction MOSFET			
V_{dss}(V)	650	600	600	700	Almost same
R_{dson} (mohm) Typ. Tj=25C	150	159	300	300	Almost same or 2x smaller typical R_{dsom}
Q_g (nC)	2	24	13	16.4	Lower gate driver loss
Q_{gd} (nC)	0.6	8	4	6	Lower switching loss
Q_{rr} (nC)	0	2900	740	1000	Lower switching turn-on loss for PFC stage;
Package type	PDFN5X6	PDFN8X8	DPAK	TO220-FP	Smaller size

3.2. GaN's Value in DS-QR Flyback

Even though the overall voltage stress is divided between the two transistors in DS-QR Flyback converter, it still has remarkable switching loss during high line applications. GaN e-HEMTs offer the lowest Rds,on and better FOM (mentioned in previous section), which results in better the efficiency and thermal performance for DS-QR flyback. Furthermore, the switching frequency can be increased (with much lower the switching loss), which leads to major magnetics size reduction and improved power density.

On the other hand, the zero-reverse recovery and optimized packaging of GaN power stage enable less EMI noise. In addition to significantly improved efficiencies, the lower switching energy of GaN transistors provides fewer thermal challenges, which is a critical advantage, especially for adapter applications.

4. Test Results

The section illustrates the performance test results of the charger reference design.

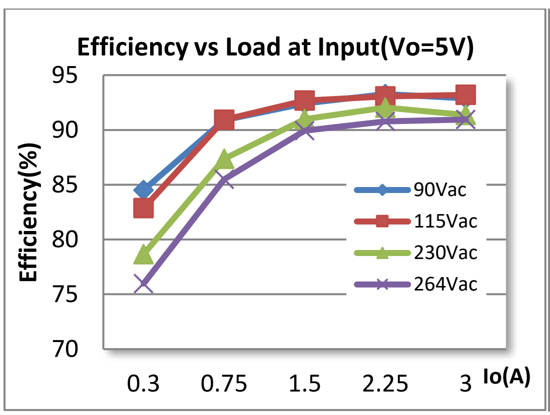
4.1. Test Equipment

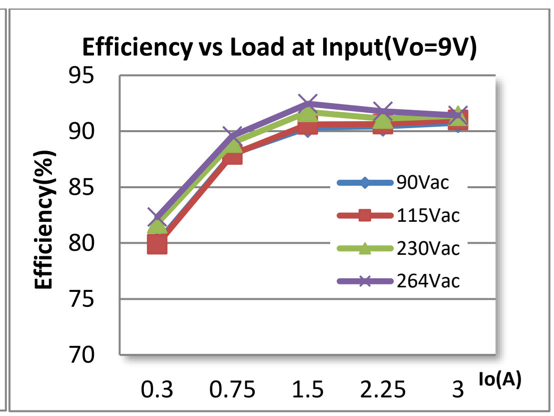
- Oscilloscope: Tektronix MDO3054
- AC power source: Chroma 6530
- Electronic load: Chroma 6312A
- Multi-meter: UNI-T UT61E+
- Digital power meter: Hioki PW3335

4.2. Efficiency

For the efficiency test, a PD emulator is used to simulate the Type C PD protocol. The Output voltage is directly measured by the multi-meter 34401A from USB-C port on the PCBA board and the output current is measured via the E-load 63115A. The input power is measured with the WT210.

Please note to have accurate input power, the input voltage is directly measured on the multi-meter 34401A from AC input on the PCBA when the output voltage is 15V and 20V from half load to full load.





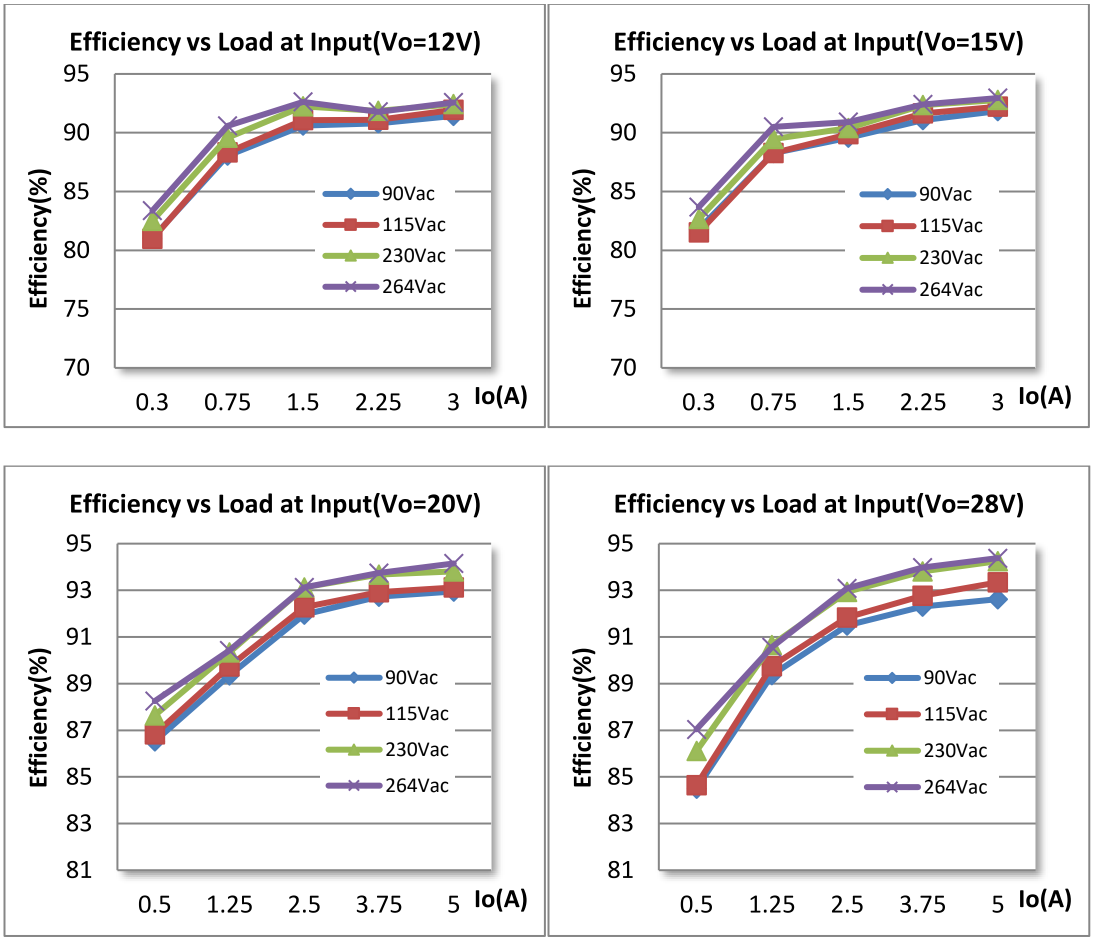
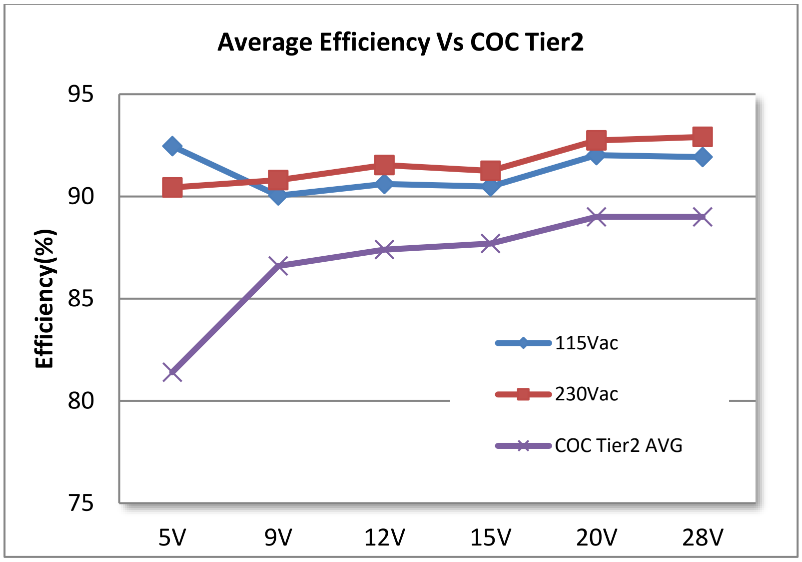


Figure 8. The USB-C port efficiency curve at 5V, 9V, 12V, 15V, 20V and 28V

The efficiency curve in Figure 8 shows the peak efficiency is above 94.2%. The average efficiency and 10% load efficiency curves in Figure 9 show the reference design exceeds the CoC V5 2019/1782 efficiency requirement with approximately 3% higher average efficiency over the universal input AC voltage.



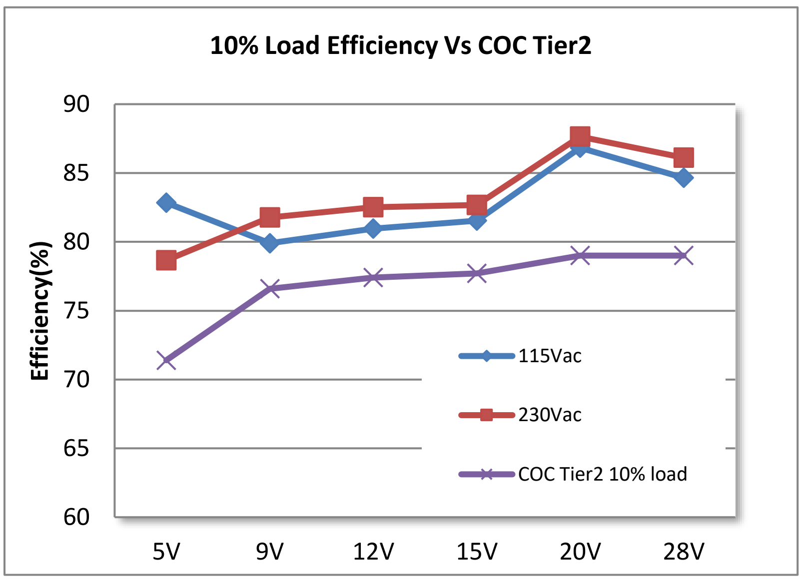


Figure 9. The average efficiency and 10% load efficiency curve at 115V and 230V.

4.3. Standby Power

In Figure 10, the no-load standby power is measured from 90V to 264V and the maximum standby power of 112mW occurs at the 264V input which meets the CoC V5 2019/1782 standard requirement with standby power less than 150mW.

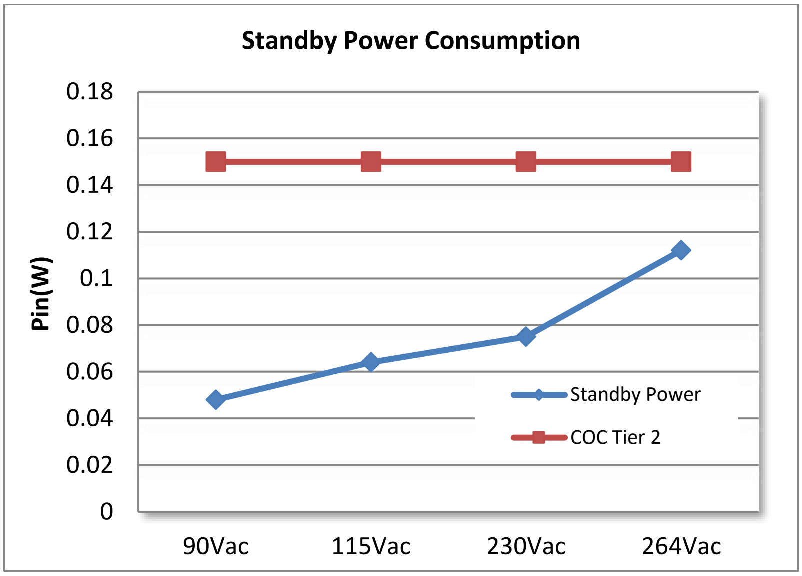
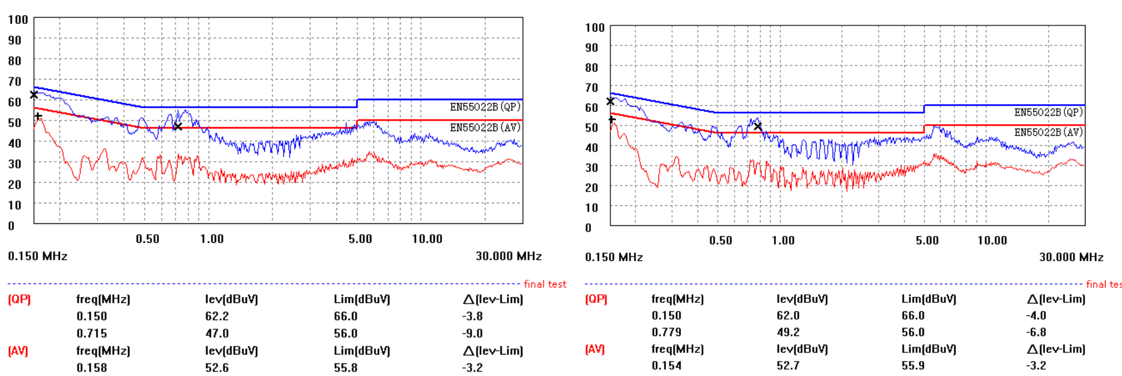


Figure 10. No load standby power from 90V to 264V

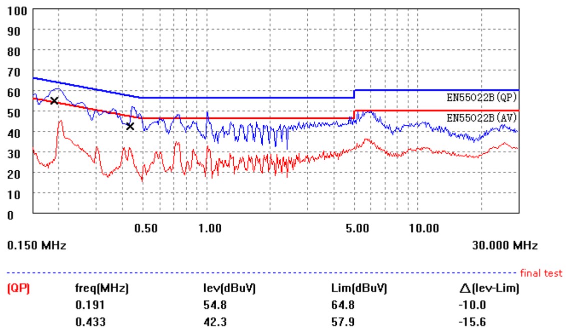
4.4. Electromagnetic Interference (EMI)

The charger reference design board is measured based on EN55032 CE Class B standard for EMI conduction and EN55032 RE Class B standard for EMI radiation. The test results show that this adapter passes the EMI conduction and EMI radiation tests with at least 10dB margin and 3dB margin, respectively. Figure 9 and Figure 10 show the conduction EMI results at 230V and 115V under full load conditions (28V/5A). Moreover, Figure 11 and Figure 12 demonstrate the radiation EMI results at 230V and 115 V under full load conditions (20V/5A).

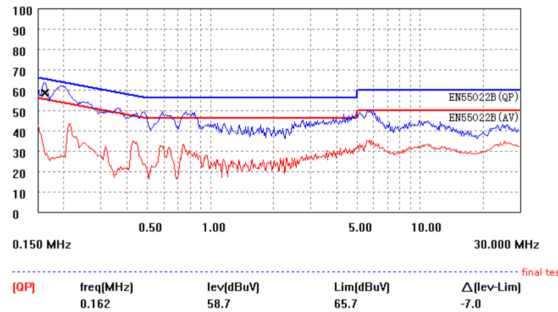


(a) (b)

Figure 9. Conduction EMI performance at (a) 230 Vac full load Line, and (b) 230 Vac full load neutral.

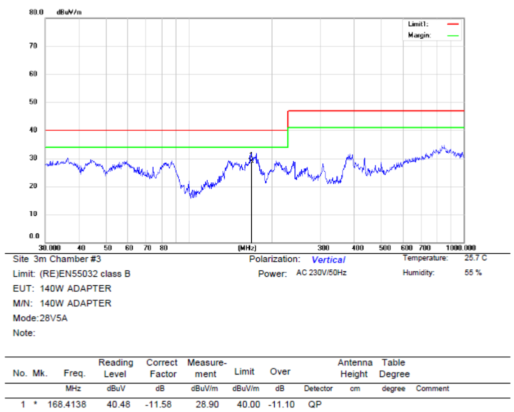


(a)

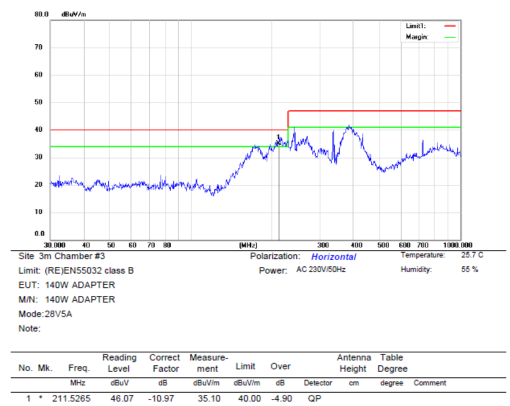


(b)

Figure 10. Conduction EMI performance at (a) 115 Vac full load Line, and (b) 115 Vac full load neutral.

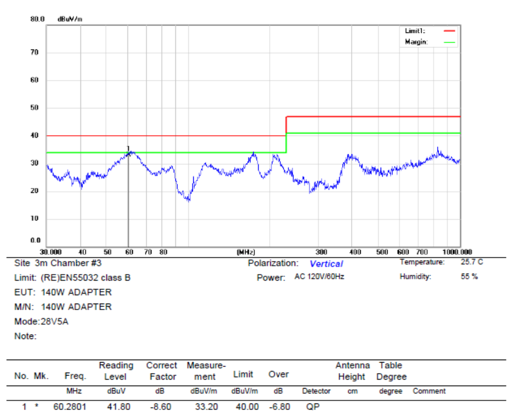


(a)

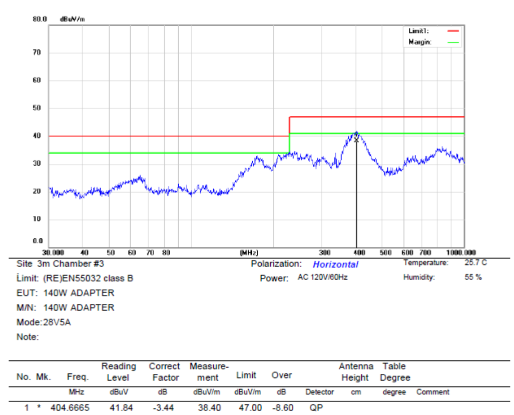


(b)

Figure 11. Radiation EMI performance at (a) 230 Vac full load vertical, and (b) 230 Vac Full load horizontal.



(a)



(b)

Figure 12. Radiation EMI performance at (a) 115 Vac full load vertical and (b) 115 Vac Full load horizontal.

4.5. Thermal

Figure 15 shows the construction of the internal thermal design. A plastic case with the electrical components potted in a highly conductive gel and "sandwiched" between layers of copper foil to spread the heat over the surface of the case. The surface temperature is measured at 140W output power as shown in Figure 16. The ambient temperature is approximately 25°C with the charger in operation for 20mins before the temperature is measured.

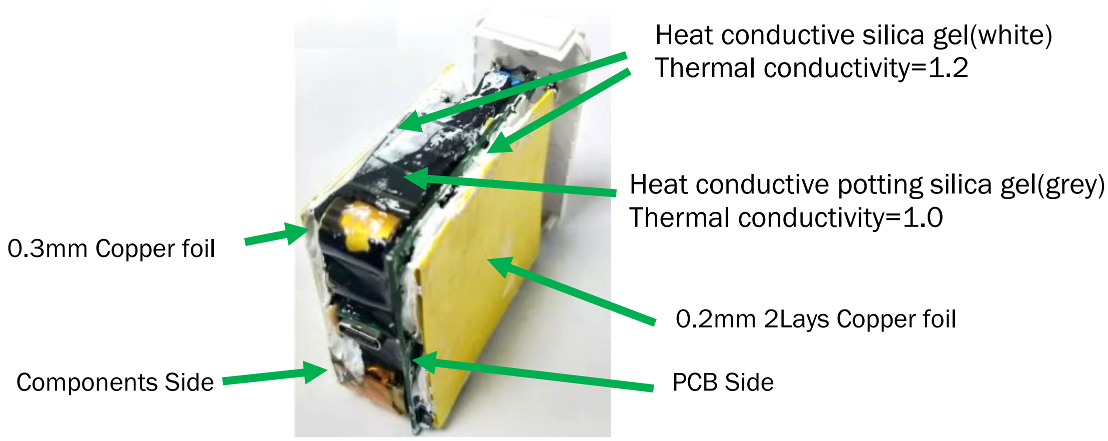


Figure 15. Internal Thermal Design

Result: 68 ℃ @ Ta = 25 ℃
Input: 90Vac
Load: 140W (Full Load)
Time: 20min

Result: 63 ℃ @ Ta= 25 ℃
Input: 115Vac,
Load: 140W (Full Load)
Time: 20min

Result: 58 ℃ @ Ta =25 ℃
Input: 230Vac
Load: 140W (Full Load)
Time: 20min

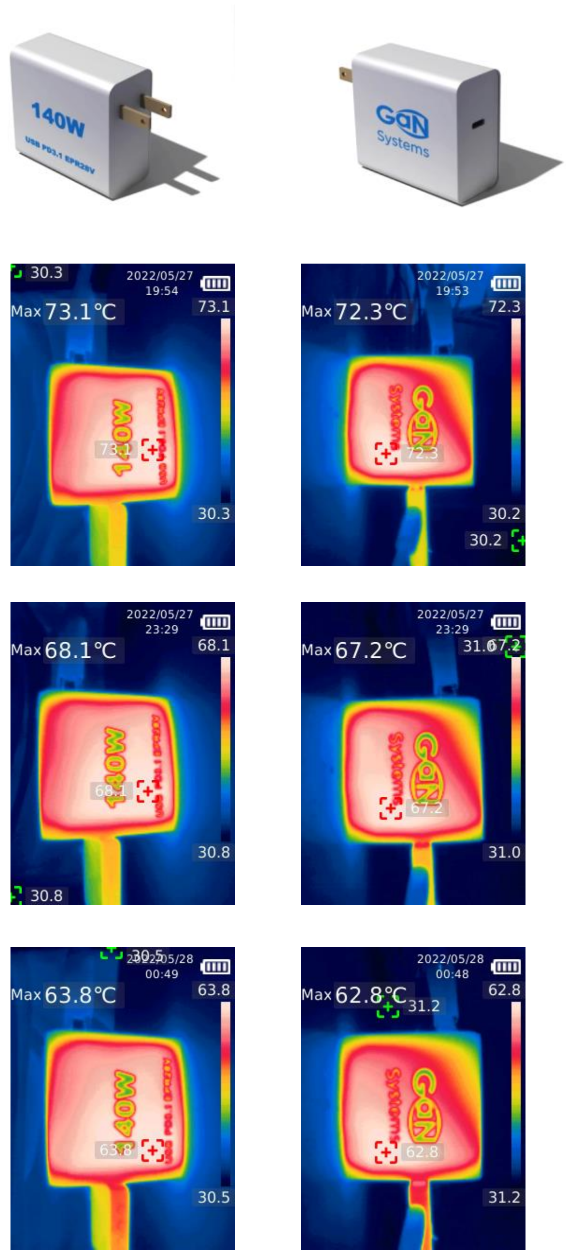
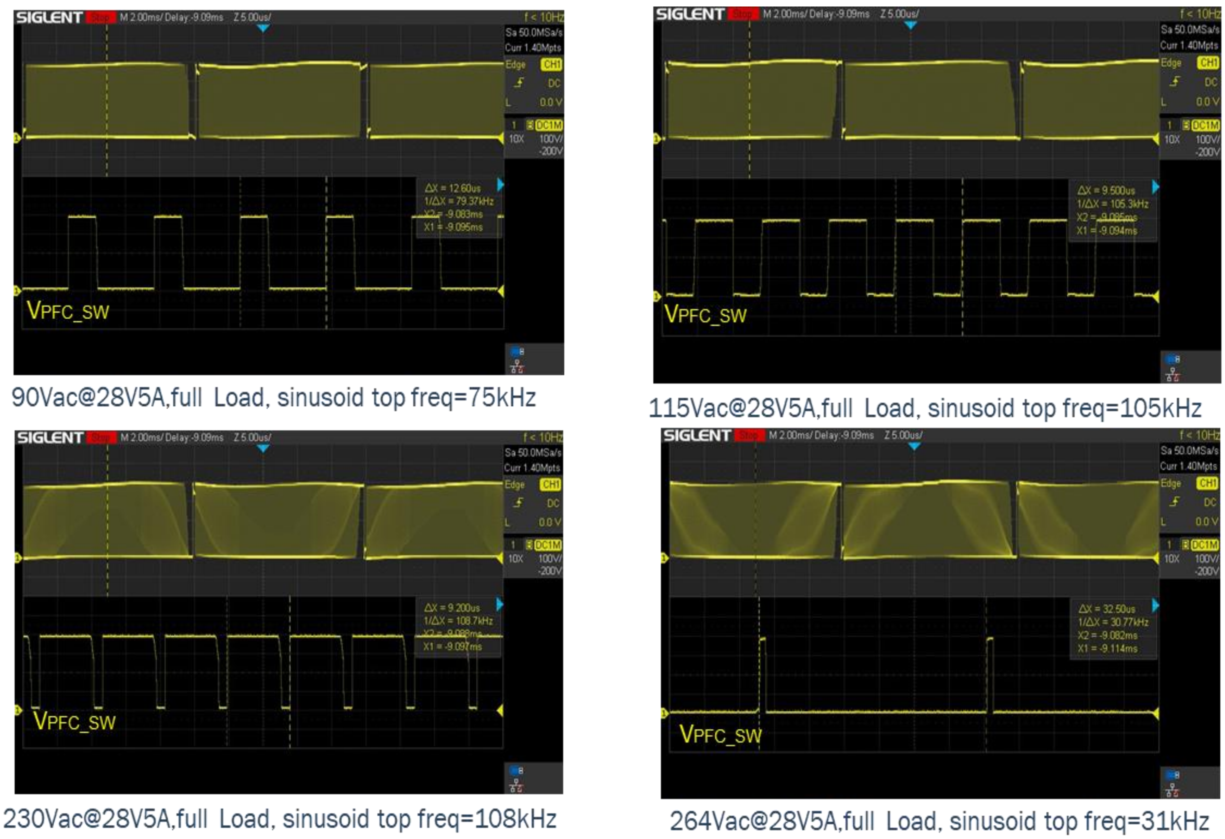


Figure 15. Surface temperature images after 1-hour continuous run at full load with 28V/5A (140W) output

The temperature results show 68°C maximum temperature for 140W at 25°C ambient temperature. The results meet the IEC 62368-1 requirement for touch temperature.

4.6. Electrical Waveforms

Figure 17 shows the PFC stage full load steady state waveforms at different input AC voltage.



90Vac@28V5A,full Load, sinusoid top freq=75kHz

115Vac@28V5A,full Load, sinusoid top freq=105kHz

230Vac@28V5A,full Load, sinusoid top freq=108kHz

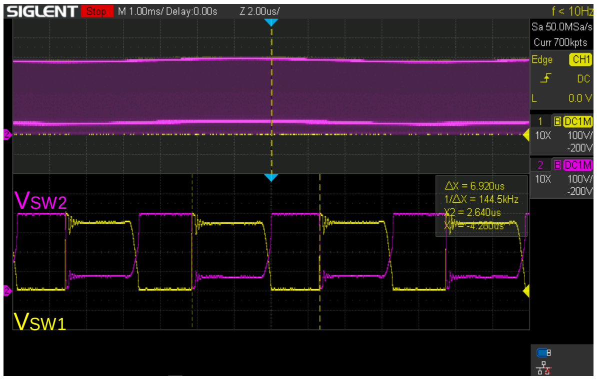
264Vac@28V5A,full Load, sinusoid top freq=31kHz

Figure 17. BTP-PFC stage switching waveforms at different input voltages and full load (***V_{PFC_sw}**: V_{ds} voltage of GaN*)

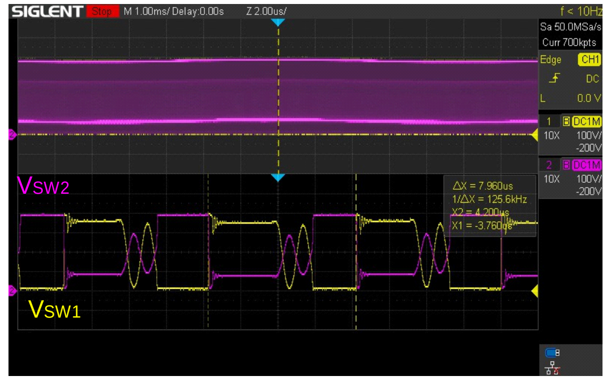
Figure 18 shows the DS-QR flyback dual switch steady state waveforms at different loads. The maximum frequency occurs at full load, which is approximately 150KHz at high line 264V input. Moreover, Figure 19 shows the synchronous rectification waveforms of the DS-QR flyback.

Figures 22 shows the output voltage is adjusted by the PD simulator; the Vds waveform is smooth when PD voltage is changed. When output PD voltage is changed from 5V to 9V at 3A, the PFC is turned on with the output power beyond 25W.

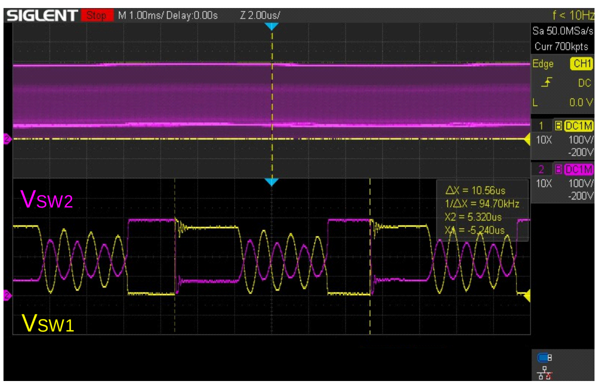
Figure 23 gives the output ripple voltage waveform with different output PD voltage. The output ripple voltage is below 430mV at different output PD voltages of 5V, 9V, 12V, 15V, 20V and 28V.



Full Load 28V 5A,Freq=144.5kHz

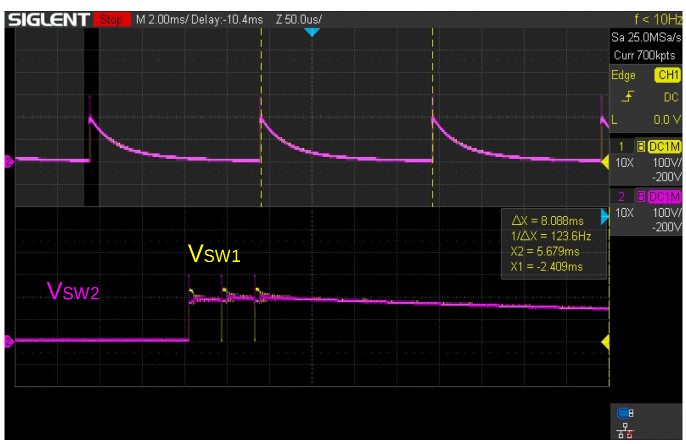


75% Load 28V 3.75A,Freq=125kHz



50% Load 28V 2.5A,Freq=94kHz

25% Load 28V 1.25A,Freq=82kHz



No Load in standby mode, skip freq= 123 Hz

Figure 18. DS-QR flyback primary steady state waveforms at different loads (*V_{SW1}: Vds voltage of high-side GaN;* *V_{SW2}: Vds voltage of low-side GaN*)

Figure 19. DS-QR flyback secondary side synchronous rectification waveforms under different loads (***V**DS_SR: Vds voltage on SR;* ***V**GS_SR: gate to source voltage of SR*)

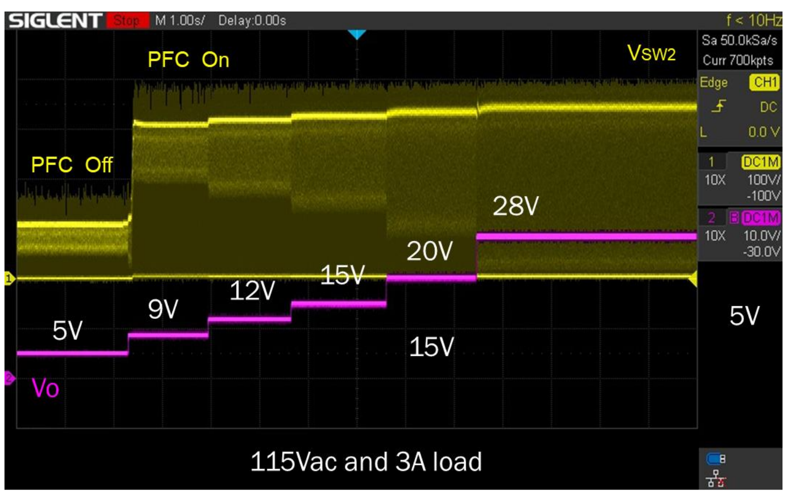


Figure 22. The output voltage is adjusted by the PD simulator with different PD output voltage (***V**SW2: Vds voltage for QR's GaN;* ***Vo**: USB-C output voltage)*

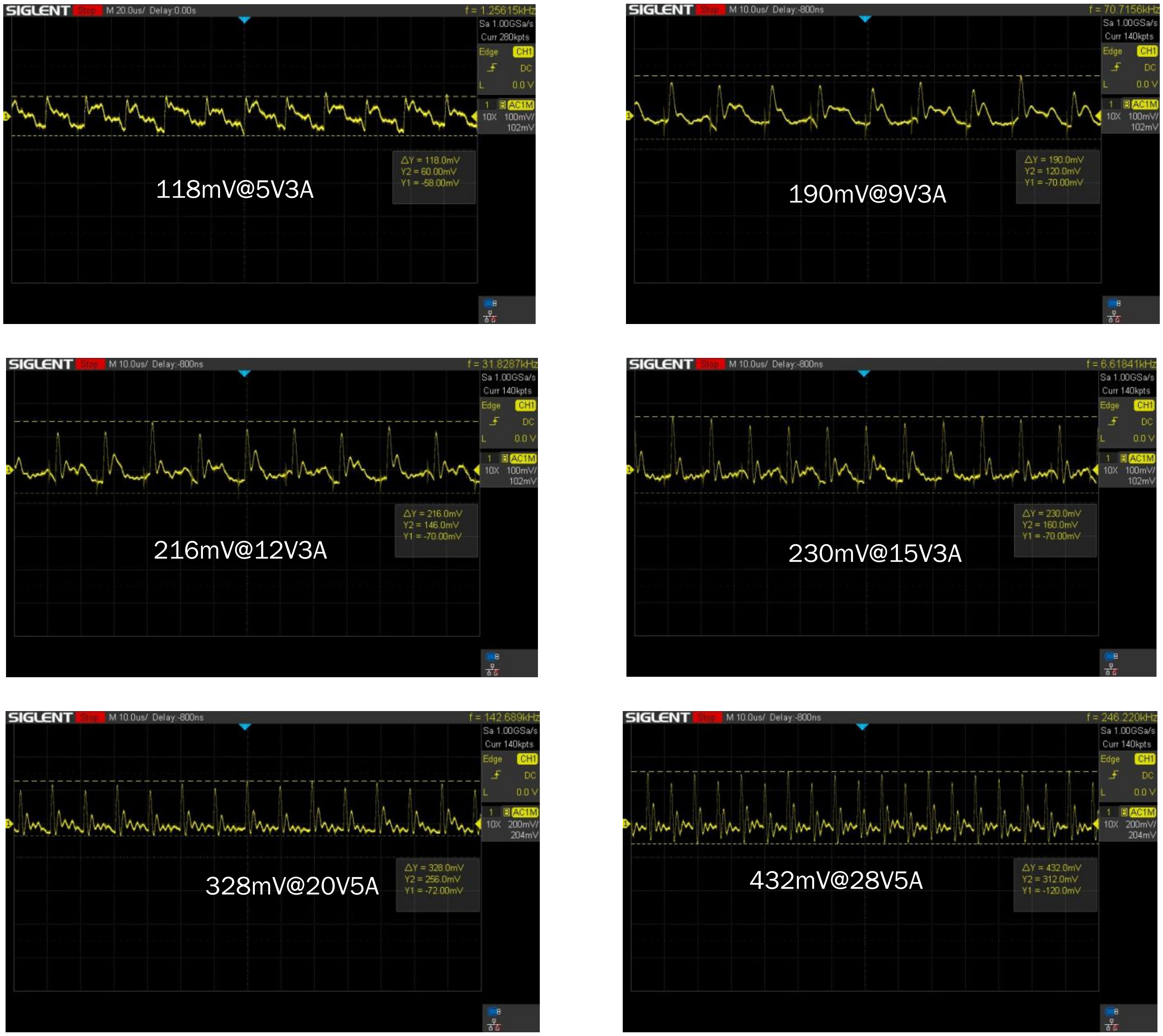


Figure 23. Output voltage ripple with different voltage and full load *(**Vo**: USB-C output voltage)*

5. Conclusion

The 140W USB PD3.1, single port type-C GaN-based charger reference design is introduced in this technical manual. The reference design achieves the following best-in-class features and performance:

- Topology: Cost Effective Totem Pole PFC+ DS-QR Flyback
- Cased Power density: 22.8W/in^3 (1.4W/cc)
- Efficiency: >94.2%
- Standby power: Exceeds standards with <150mW
- Waveforms: Clean with full protections (SCP, OCP, OVP etc.)
- Thermal: Case temperature ≤ 73.1°C (meet IEC 62368-1 touch temperature)
- EMI: Pass EN55032 Class B with >6dB margin

Please refer to the Reference Design Kit Important Notice on page 22

6. References

[1] GaN Systems Application Note GN010, EZDrive™ Solution for GaN Systems E-HEMTs, 2020, [Online]. Available: https://gansystems.com/wp-content/uploads/2020/07/GN010_EZDrive-Solution-for-GaN-Systems-GaN-Transistors-_20200715.pdf

[2] GaN Systems Reference Design, GS-EVM-CHG-65WQR-GS1, 65W Type-C PD QR Charger Reference Design [Online]. Available: https://gansystems.com/evaluation-boards/gs-evm-chg-65wqr-gs1/

[3] GaN Systems Reference Design, GS-EVM-CHG-100WQR-GS1, 100W PFC + QR Type-C USB PD 2C port Charger Reference Design [Online]. Available: https://gansystems.com/evaluation-boards/gs-evm-chg-100wpfcqr-gs1/

[4] GaN Systems Reference Design, GS-EVM-CHG-250WPFCLLC-GS1, 250W AC/DC Charger PFC & LLC reference design [Online]. Available: https://gansystems.com/evaluation-boards/GS-EVM-CHG-250WPFCLLC-GS1/

[5] GaN Systems Reference Design, GS-EVM-BTP-3kW-GS, 23kW High-Efficiency CCM Bridgeless Totem Pole PFC Reference Design using GaN E-HEMTs [Online]. Available: https://gansystems.com/evaluation-boards/gs-evb-btp-3kw-gs/

Reference Design Important Notice

GaN Systems Inc. (GaN Systems) provides the enclosed reference design under the following **AS IS** conditions:

This reference design is intended for use for **ENGINEERING DEVELOPMENT, DEMONSTRATION, and OR EVALUATION PURPOSES ONLY** and is not considered by GaN Systems to be the design of a finished end-product fit for general consumer use. As such, the reference design provided is not intended to be complete in terms of required design, marketing, and/or manufacturing-related protective considerations, including but not limited to product safety and environmental measures typically found in end products that incorporate such semiconductor components or circuit boards. This reference design does not fall within the scope of the European Union directives regarding electromagnetic compatibility, restricted substances (RoHS), recycling (WEEE), FCC, CE or UL, and therefore may not meet the technical requirements of these directives, or other related regulations.

No License is granted under any patent right or other intellectual property right of GaN Systems whatsoever. **GaN Systems assumes no liability for applications assistance, customer product design, software performance, or infringement of patents or any other intellectual property rights of any kind.**

In Canada:

GaN Systems Inc.
770 Palladium Drive, Suite 201
Ottawa, Ontario, Canada K2V 1C8
T +1 613-686-1996

In Europe:

GaN Systems Ltd., German Branch
Terminalstrasse Mitte 18,
85356 München, Germany
T +49 (0) 8165 9822 7260

In the United States:

GaN Systems Corp.
2723 South State Street, Suite 150, Ann Arbor, MI. USA 48104
T +1 248-609-7643

www.gansystems.com