

65W, 18.5W/in³, 58cc GaN-based QR Adaptor Reference Design

Abridged version

Technical Manual



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1. Introduction

The GS-EVB-ADP-65WQR-GS1 from GaN Systems Inc is a 65W USB-C AC-DC adapter using 650V 150m Ω Gallium Nitride (GaN) transistor with part number GS-065-011-1-L. This adapter shows the high power density and efficiency due to the high level performance of the GaN transistor. The peak efficiency is above 93.6% with 18.5W/in₃ cased power density. The EMI standard EN55023 class B has passed both conduction and radiation test levels. The average efficiency and standby power levels exceed the requirements of CoC Ver5 Tier 2 standards.

The objective of this document is to introduce this high power density 65W GaN-based adapter reference design and its performance test results.

2. Why a GaN-based QR adapter?

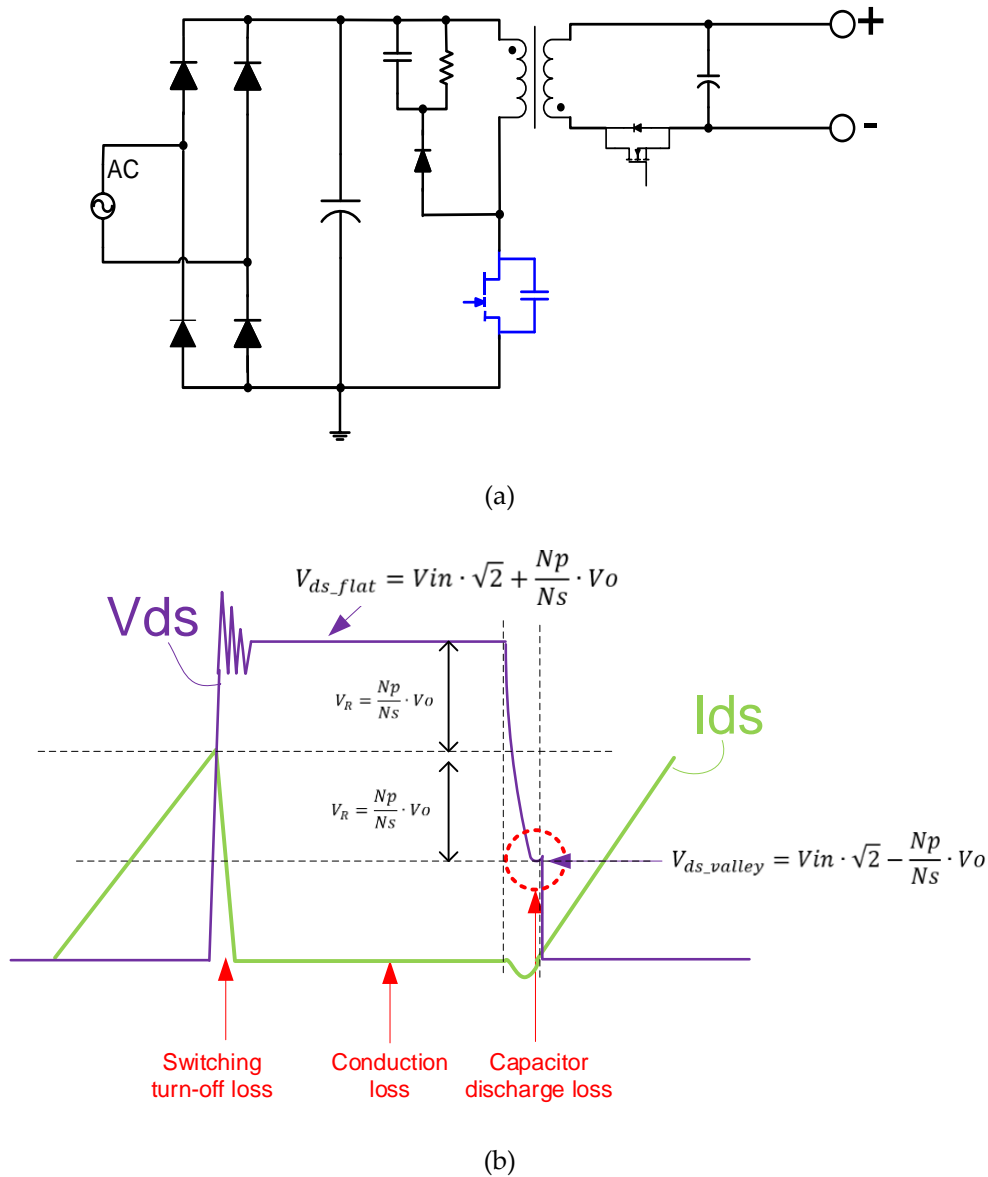


Figure 1. (a) GaN-based QR synchronous rectification Flyback and (b) V_{ds} and I_{ds} waveforms for QR Flyback

A Quasi-resonant (QR) Flyback with synchronous rectification as shown in Fig.1 is simply a Discontinuous Current Mode (DCM) Flyback having a valley switching turn-on to minimize the switching turn-on loss. It is also known as a variable frequency Flyback and is largely used in low

power SMPS applications such as charger, adapter and auxiliary supply. With the operation of Quasi-resonant, the topology has three main advantages:

- **Lower Turn-on Loss:** Since it turns on at the valley, the turn-on losses due to the discharging of parasitic capacitor are significantly reduced. This makes QR Flyback efficiency higher especially high line input compare to a conventional fixed frequency Flyback.
- **Less Conducted EMI:** Due to the ripple voltage appearing across the bulk capacitor, the switching frequency of QR Flyback is modulated at twice the mains frequency, e.g. 100Hz or 120Hz. This causes the spectrum to be spread over the wide frequency band rather than a single fixed frequency.
- **Lower System Cost:** The QR Flyback is a typical single end topology with only one high voltage transistor on the primary side which reduces drive and transistor compared to other topologies such as LLC or Active Clamp Forward (ACF).

Given the benefits, there are still some considerations when designing QR Flyback. Because it is still effectively a DCM Flyback, peak and RMS current remains higher compared to Continuous Current Mode (CCM) Flyback. When choosing the primary transistor, there are three losses that need to be evaluated for QR Flyback:

- **Switching turn-off loss.** During the turn-off period, the I_{ds} current reaches peak current, which is higher peak current for DCM Flyback, and the transistor is turn-off with hard-switching at this peak primary current, which will result in a switching crossover turn-off loss. The losses depend on the turn-off energy (E_{off}) of the transistor and can be evaluated by the parameters of gate charge, Q_g and Q_{gd} .
- **Conduction loss.** During on-state period, the transistor is turned on. There is a conduction loss which is relative to the on-state resistor of the transistor, R_{dson} .
- **Capacitor discharge loss.** During the turn-on period, due to zero drain current at turn-on, there is no switching crossover turn-on loss on the transistor. However, at high line input the turn-on valley voltage (V_{ds_valley}) is no zero, it exists a capacitor discharge loss due to the parasitic capacitor of transistor. For example, if the ac input voltage is 230V, the transform turns ratio is 7.5 and output voltage is 20V, the turn-on valley voltage V_{ds_valley} is around 175V to 200V. It has the capacitor discharge loss which can be evaluated by the transistor's stored energy E_{oss} at 200V voltage.

The GaN transistor is a low on-state resistor and low charge device. The combined advantages of gate charge, low parasitic capacitor and on-state resistor in the converter leads to a more efficient system. Meanwhile, with low gate charge and E_{oss} , the GaN transistor offers the fast switching speed for QR Flyback to achieve high power density without sacrificing the efficiency and thermal.

Table 1 compares two key Figure of Merits (FOM) for QR Flyback between GaN transistor and Si Super Junction MOSFET. The Input FOM indicates the voltage and current crossover loss during the switching turn-off of the device under the same on-state resistance. It is an important parameter for QR flyback's turn-off performance. The second FOM is QR Flyback FOM. It indicates the capacitor discharge loss caused by the parasitic capacitance of the transistor at 200V under the same on-state resistance in the QR Flyback. As can be seen in Table 1, the GaN device has much lower FOMs (both Input FOM and QR Flyback FOM) compared to Si MOSFET products. The Input FOM of the GaN transistor has only 10% of Si MOSFET's Input FOM. While QR Flyback FOM has more than 25% lower than the Si MOSFET's QR Flyback FOM.

Manufacturer	GaN Systems	Si MOSFET		
Part Number	GS-065-011-1-L	#1	#2	#3
Technology	GaN	Si Super Junction MOSFET		
Vdss(V)	650	600	600	700
Rdson (mohm) Typ. Tj=25C	150	159	300	300
Qg (nC)	2	24	13	16.4
Qgd (nC)	0.6	8	4	6
Qrr (nC)	0	2900	740	1000
Package type	PDFN5X6	PDFN8X8	DPAK	TO220-FP
Input FOM = Rdson Hot * Qg	660	7440	7800	9512
QR Flyback FOM = Rdson Hot * Eoss@200V	363	496	480	667

Table 1. GaN vs Si MOSFET Parameters for QR Flyback

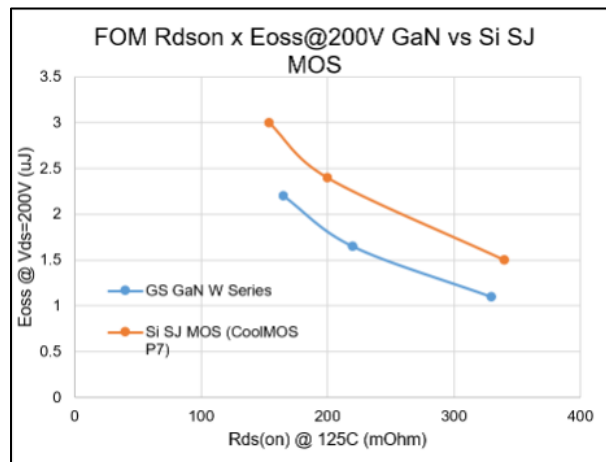


Figure 2. Output Energy Eoss at 200V (GaN vs Si SJ MOS)

As mentioned above, at high line AC input, QR Flyback will lose ZVS for turn-on with capacitor discharge loss; this will result in loss and limit maximum frequency with Si-based solution, around 100KHz. As shown Figure 2, GaN has 30% lower Eoss at Vds_valley=200V compared to the best

Si SJ MOSFET. This performance difference is an additional benefit for GaN-based QR Flyback for high switching operation increasing the power density.

3. Reference Design Board

In order to evaluate the high performance of GaN transistor for adapters, a 65W GaN-based QR adapter reference design is developed. The main components of the circuit are GaN Systems transistor GS-065-011-1-L and QR controller NCP1342 on the primary side and 100V SR Si MOSFET with SR controller NCP4306 on the secondary side for synchronous rectification. On the output side, a dedicated Power Delivery (PD) protocol controller is used to support the standard type C PD output.

Table 2 summarizes the key specification and performance for this 65W GaN-based QR adapter reference design.

Parameter	Value
Input Voltage (V_{in})	90-264 V_{rms}
Input Frequency Range	50/60 Hz
Max. Output Power	65W
Output Voltage and Current	5V3A,9V3A,12V3A,15V3A,20V3.25A
Max. Output Current	3.25A
PD Protocol	PD3.0, PPS, QC, QC4.0+, BC1.2
Performance	
Cased Power Density	18.5 W/in ³ (1.1W/cc)
Peak Efficiency	>93.6%
Average Efficiency	CoC V5 Tier 2
10% Efficiency	CoC V5 Tier 2
Standby Power	<40mW
Surface Temperature @20V/3.25A	<66°C
EMI standard	EN55032 Class B
Limited Power Source, LPS	<8A and <100W
Protections	OVP, OCP, SCP, Open Loop

Table 2. Key Parameters of 65W GaN-based QR adapter

4. Test Results

The section illustrates the performance test results of this 65W GaN-based QR adapter reference design.

4.1 Electromagnetic Interference (EMI)

The adapter reference design board is measured to meet EMI EN55032 class B requirement. The test results have 10dB margin for conduction EMI and 6dB margin for radiation EMI for both 230V and 110V ac input.

4.2 Thermal

The thermal performance results are reported after the adapter is operating at full load for more than 30 minutes steady state operation. The ambient temperature is approximately 25°C. The full load open frame maximum temperature on the PCBA is below 100°C. The full load maximum temperature on the surface of the cased adapter is below 66°C.

4.3 Performance Waveforms

Figure 3 shows the Vds waveform for both primary GaN transistor and secondary side SR MOSFET. Figure 3(a) is the steady state condition with 264V input and 20V/3.25A output. Figure 3(b) is the transient condition at short circuit protection with 264V input and 20V/3.25A output. It shows the voltage stress is under the breakdown voltage of the transistor for both primary side and secondary side transistors with sufficient margin.

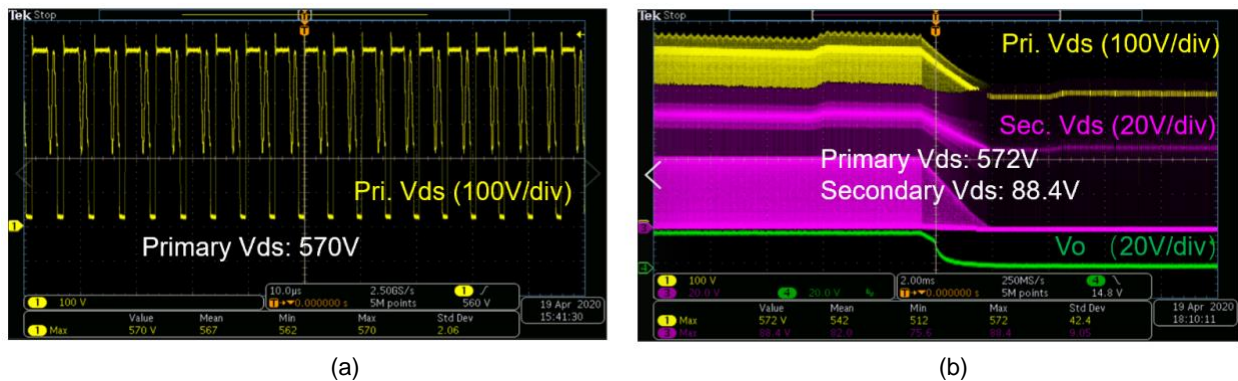


Figure 3. (a) Normal operation primary Vds waveform with 264V input 20V/3.25A output; (b) Output short protection Vds waveform with 264V input 20V/3.25A output

Figure 4 shows the Vds waveforms at steady state full load. The maximum frequency at full load is approximately 180KHz at 264V input. Output short circuit protection is shown in Figure 5, the adapter goes to hiccup-mode with auto-recovery time of 2.6 seconds when output is shorted. Figures 6 and Figure 7 show the transient waveform on the output voltage and SR MOSFET Vds. It proves the smooth transient response during the load change. Figure 8 gives the output ripple voltage waveform with different output PD voltage.

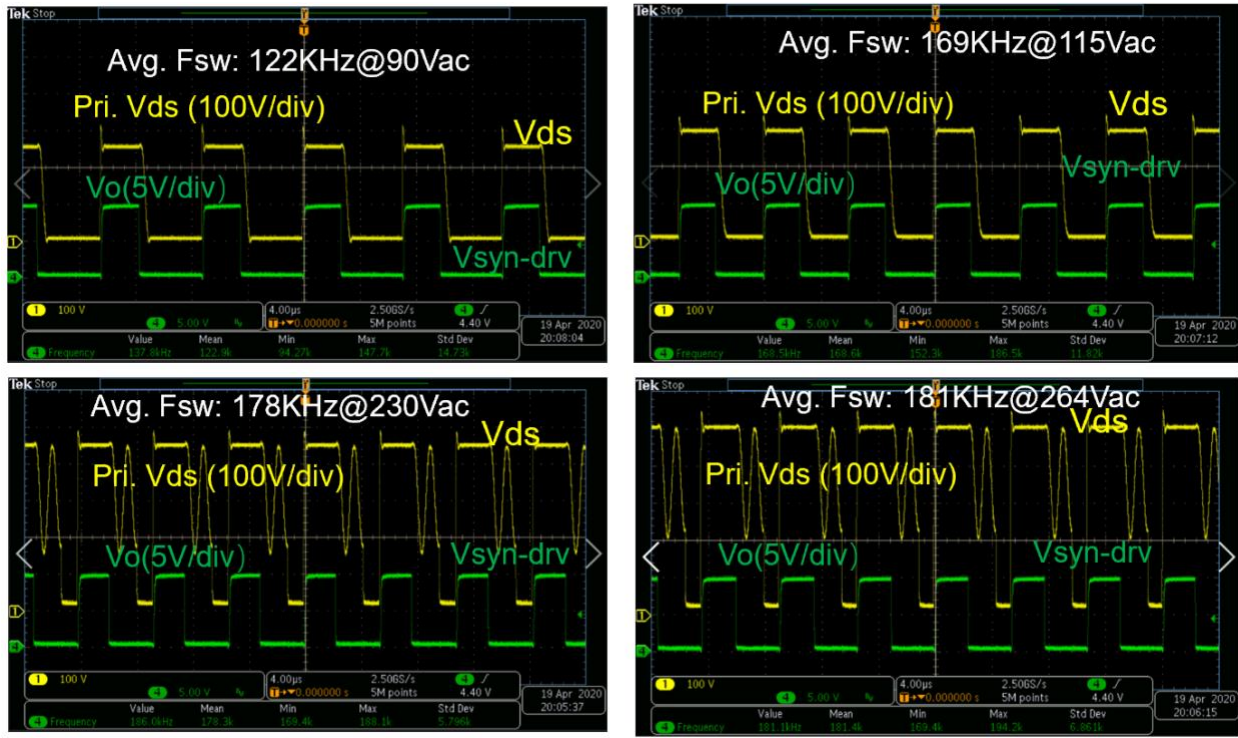


Figure 4. Primary Vds and SR MOSFET Vgs with 90V, 115V, 230V and 264V inputs and 20V/3.25A output

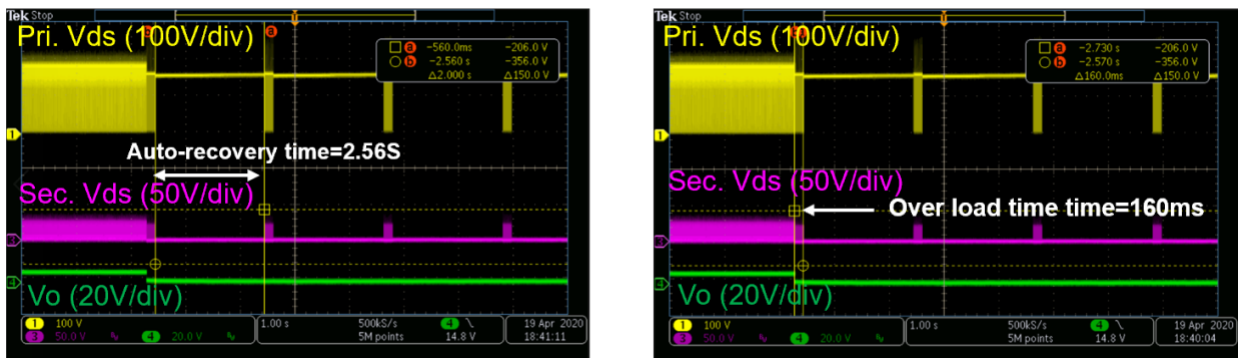


Figure 5. Output short circuit protection waveforms with 115V input and 5V output

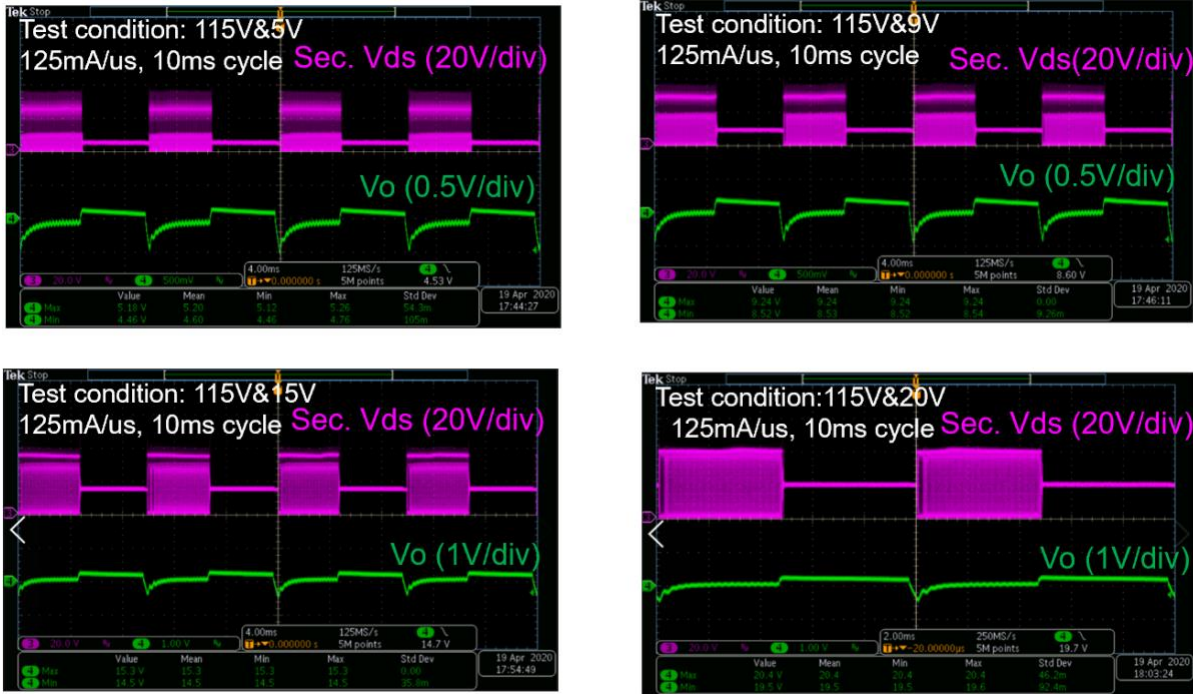


Figure 6. Transient response waveforms from no load to half load

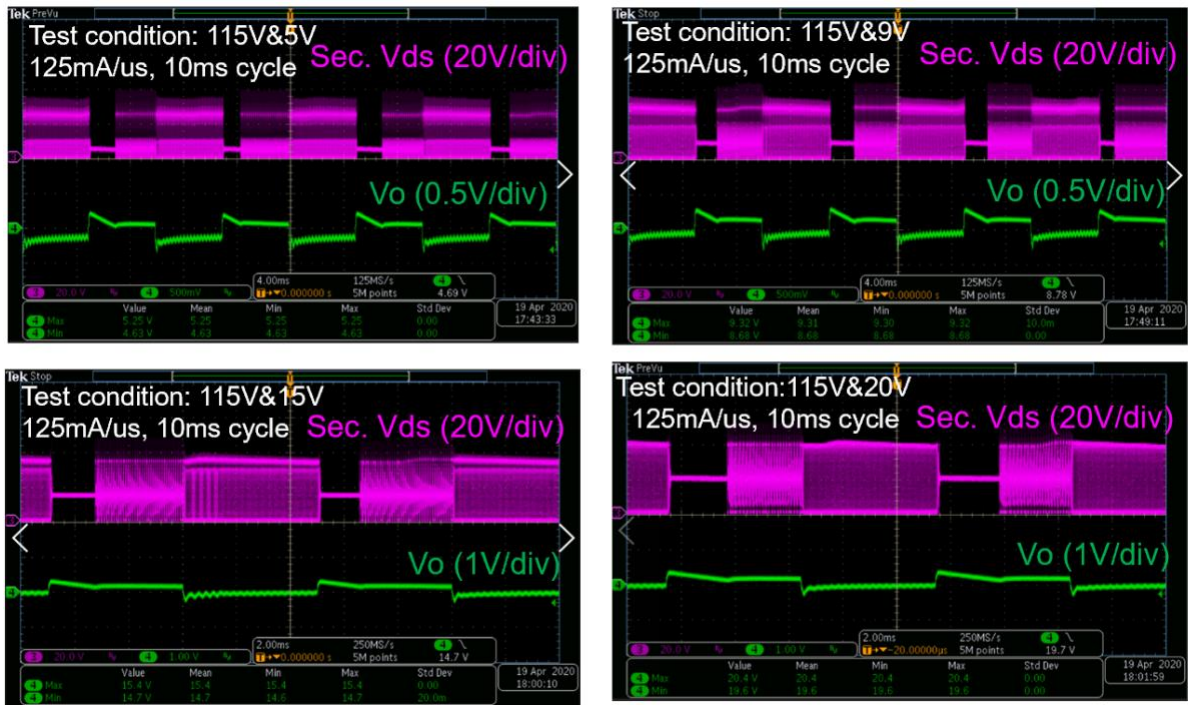


Figure 7. Transient response waveforms from no load to full load

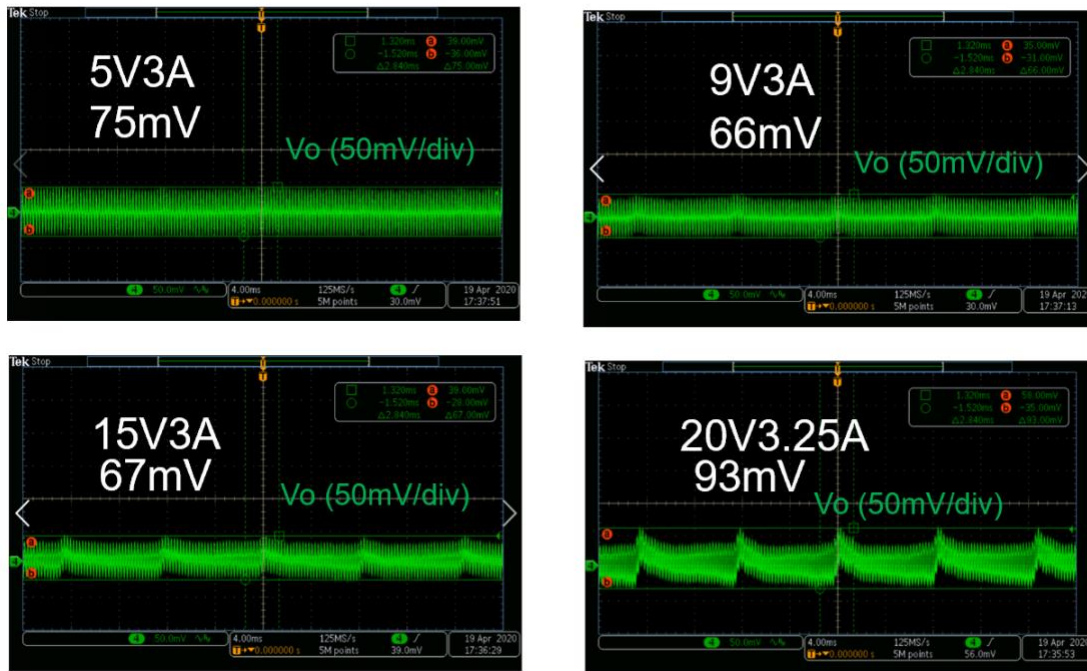


Figure 8. Output ripple voltage at different output voltage and full load

5. Conclusion

The 65W GaN Systems QR adapter reference design is reviewed in this technical manual. The reference design achieves the following world-class performance:

- Topology: Low cost QR Sync-Flyback
- Power density: Best-in-class 18.5W/in³ 65W QR
- Efficiency: >93.6%
- Standby power: Exceeds standards with <40mW
- Waveforms: Clean with full protections (SCP, OCP, OVP etc.)
- Thermal: ≤ 66°C adapter case temperature
- EMI: Meets EN55032 Class B with >6dB margin

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