1. Introduction

Power delivery (PD) chargers are a much faster, smarter and safer way to charge devices such as laptops, phones, battery packs etc. This WAN012 Application Note describes a reference design for a 120W PD fast charger with PFC + LLC topology which uses a WeEn Semiconductors silicon carbide (SiC) rectifier diode in the PFC stage.

Silicon carbide (SiC) is a third-generation wide-bandgap semiconductor material which has greater dielectric breakdown strength, faster saturated electron drift speed and higher thermal conductivity compared to silicon material (Si). Consequently, a SiC power device can help reduce energy consumption and system size for power converter designs. Presently, SiC devices are widely used in electric vehicles, inverters, railway systems and solar and wind power generation systems. With the emerging technology of high-power PD fast chargers, SiC diodes have also begun to emerge in consumer PD chargers with peak charging power over 100W.

For the PFC stage a 6A, 650V, WeEn Semiconductors SiC diode is used as the rectifier diode. The SiC diode brings several advantages for the charger system which include reduced thermal stress, improved power efficiency and improved EMI performance. Figure 1 shows the PCB assembly of the PD fast charger.

Demo board	Description	SiC Diode
PDC120W	120W PFC+LLC Topology	WNSC2D06650D

Fig. 1. PD fast charger PCB

2. PD Charger using SiC diode

In order to increase the power factor of high-power power products and reduce the interference and pollution of harmonics to the grid, 3C certification (China National Compulsory Product Certification) requires active PFC circuits for a charging source above 75W.

A commonly used active PFC circuit is shown in Figure 2.

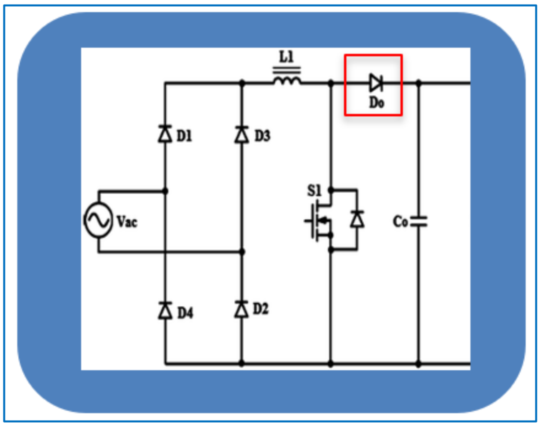

Fig. 2 Typical PFC boost circuit

The choice of the SiC diode as the rectification diode in the PFC compared with a traditional Si diode in this application has several advantages:-

- The SiC diode has nearly zero reverse recovery current compared to that of a Si diode and so power losses are reduced as well as heat generation. (See Figure. 3 and Figure. 4)

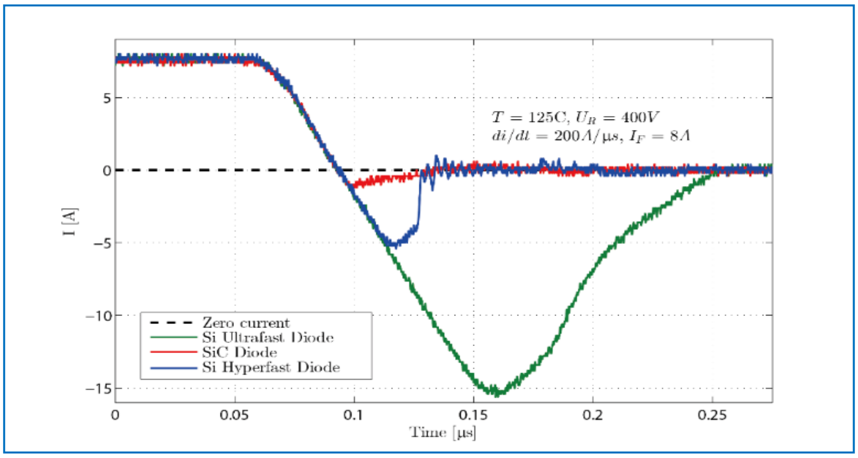

Fig. 3. Graphic showing the nearly zero reverse recovery current of SiC diode (red trace)

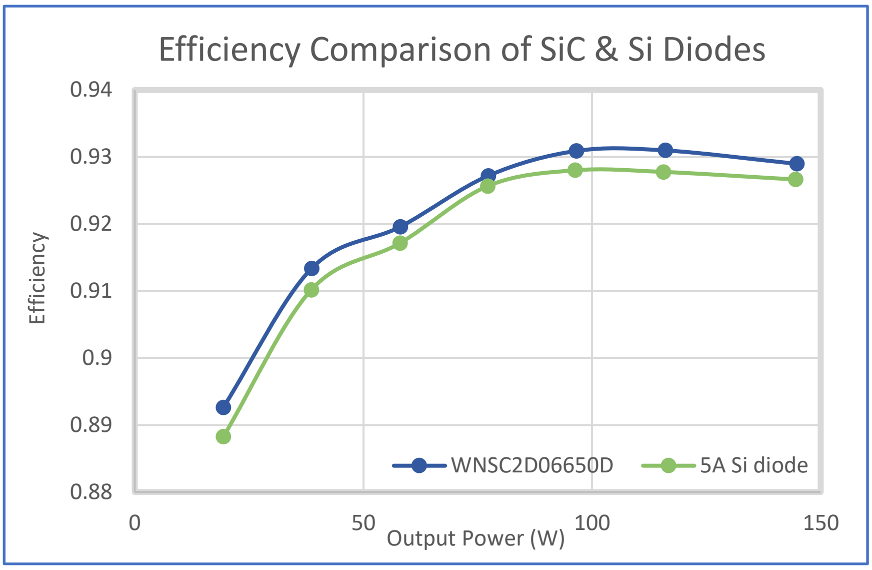

Fig. 4. Graphic showing improved power efficiency of converter using SiC diode

- SiC material has better thermal conductivity, which is beneficial for heat transfer and consequently a reduced junction temperature during operation. This also improves reliability. (See Figure. 5)

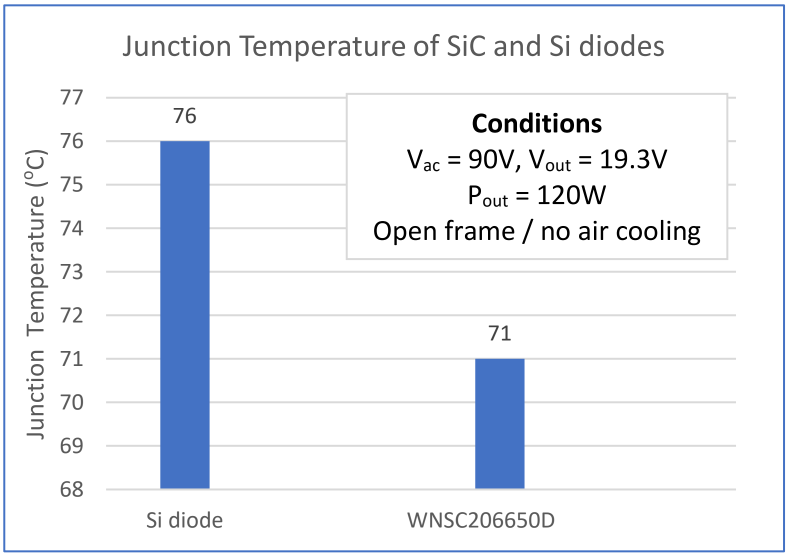

Fig. 5. Graphic showing reduced power efficiency of converter using SiC diode

- The switching or operating frequency can be increased to 300KHz from a usual frequency of less than 100KHz. This means the size of the boost inductor and consequently the size of the charger can be reduced to achieve a higher power density at reduced overall cost.
- A smaller reverse recovery current gives WNSC206650D better EMI performance and helps to achieve the Class B requirements in the GB/IEC Standard.

3. WeEn SMD SiC diodes

WeEn Semiconductor has surface mount packages (SMDs) dedicated for fast PD charger design. Currently available packages include DPAK and DFN. These packages have particular features which benefit users:-

- **Very low thermal impedance**. The WeEn SiC SMD diode uses a silver sintered chip soldering process. This yields a low thermal impedance which enhances heat dissipation and helps maintain a low junction temperature.
- **Leadless package - DFN 8x8**. The leadless package reduces parasitic inductance and resistance and therefore is suitable for higher frequency operation. It has a low package profile with a total thickness for the DFN package of less than 1mm. This facilitates compact PCB designs such as for a PD fast charger.

	DFN 8X8	DPAK
		
L x W x H (mm^3)	8 x 8 x 0.85	9 x 6.5 x 2.2
Footprint (mm^2)	64	58.5
Volume(mm^3)	54	128
Rth (K/W) (For 6A SiC diode)	1.2	1.35

Table 1. SMD package information

VR (V)	IF (A)	VF (V)	Qr (nC)	DPAK	DFN 8X8
					
650	4	1.5	7	WNSC2D04650D	WNSC2D04650T
	6	1.5	10	WNSC2D06650D	WNSC2D06650T
	8	1.5	13	WNSC2D08650D	WNSC2D08650T
	10	1.5	15	WNSC2D10650D	WNSC2D10650T

Table 2. WeEn SMD diode information

4. 120W PD charger design

4.1 Specification

This design uses a Critical Conduction Mode (CCM/DCM) PFC. It has AC mains input stage which converts AC mains to 400VDC (AC - 400 VDC), followed by an LLC DC-DC converter stage with input of 400V and output of 19.5VDC. For both stages, the switching frequency was increased to the maximum allowed by the control ICs that were readily available from “off-the-shelf”. The PCB is designed as a demonstration board and is not yet optimized as a production design. Even so, with this design, a power density of 1.56 W/cc or 25.5 W/in^3 was achieved, which is around 2x typical and 40% more than the best-in-class Si-based design available today. Customer designs are expected to achieve even higher power density.

The specification of the reference design is below:-

Term	Parameter	Value	Unit
V_{IN}	Input Voltage	90-264 47-63	V Hz
V_{OUT}	Output Voltage	19.5	V
I_{OUT}	Output Current	6.2	A
P_{OUT}	Output Power	120	W
F_{SW}	PFC (115V, 100%load, CRM) PFC (230V, 100%load, DCM) LLC	200 100 270	kHz
η	Efficiency (230V, 100% load)	94.5	%
PF	Power Factor	0.95	

Table 3. PD charger reference design - specification

4.2 Semiconductor components

Function	Part Number	Quantity
PFC Diode	WNSC2D06650D	1
PFC FET	NV6115	2
PFC Controller	NCP1615CDR2G	1
LLC FET	NV6117	2
LLC Controller	NCP13992ABDR2G	1
SR MOS	NTMFS5C645NL	2
SR Controller	NCP4306AAAZZZAMNTWG	2

Table 4. PD charger reference design- semiconductor parts list

4.3 Schematic

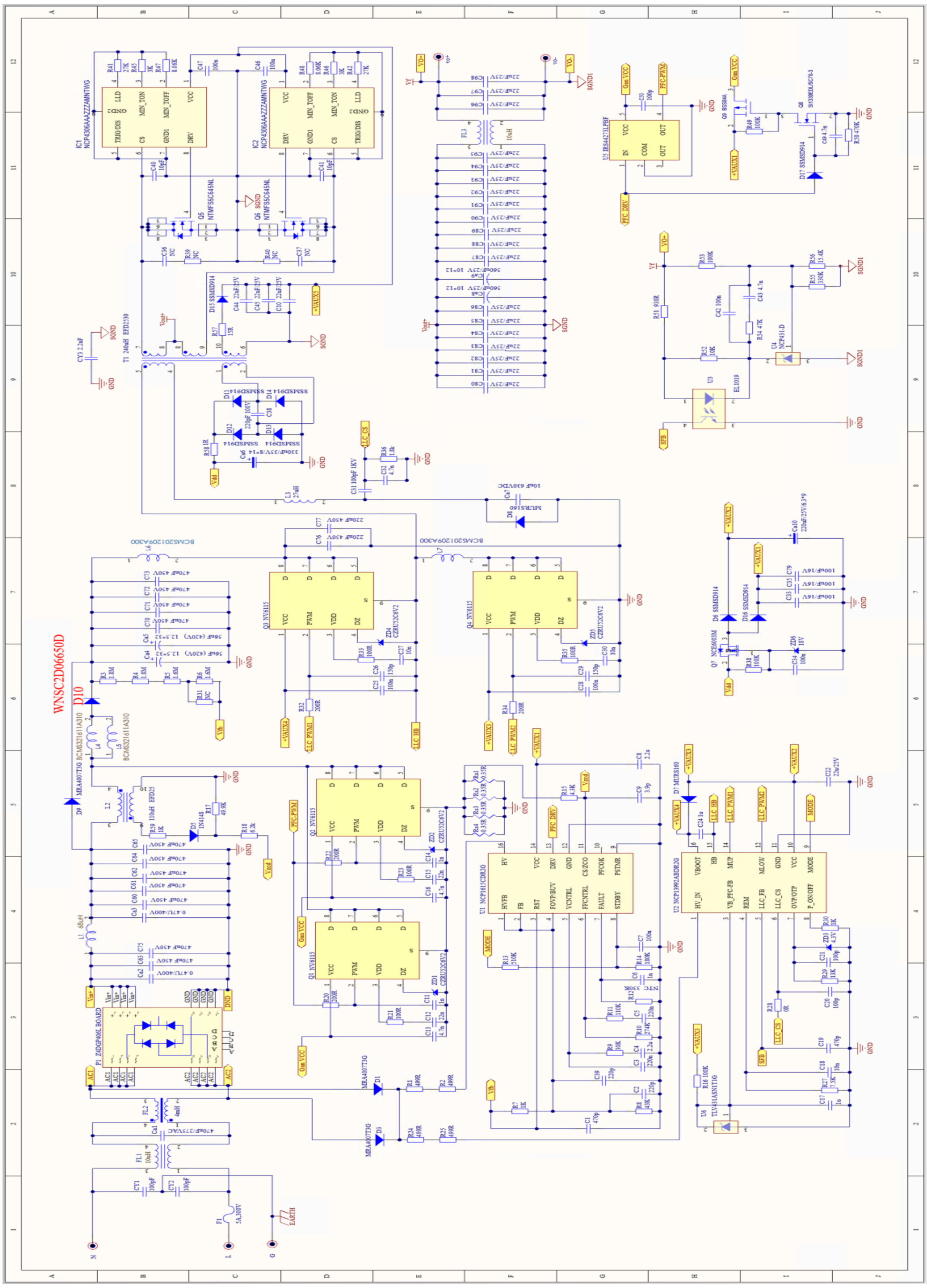

Fig. 6. PD charger reference design- schematic

4.4 PCB Board layout

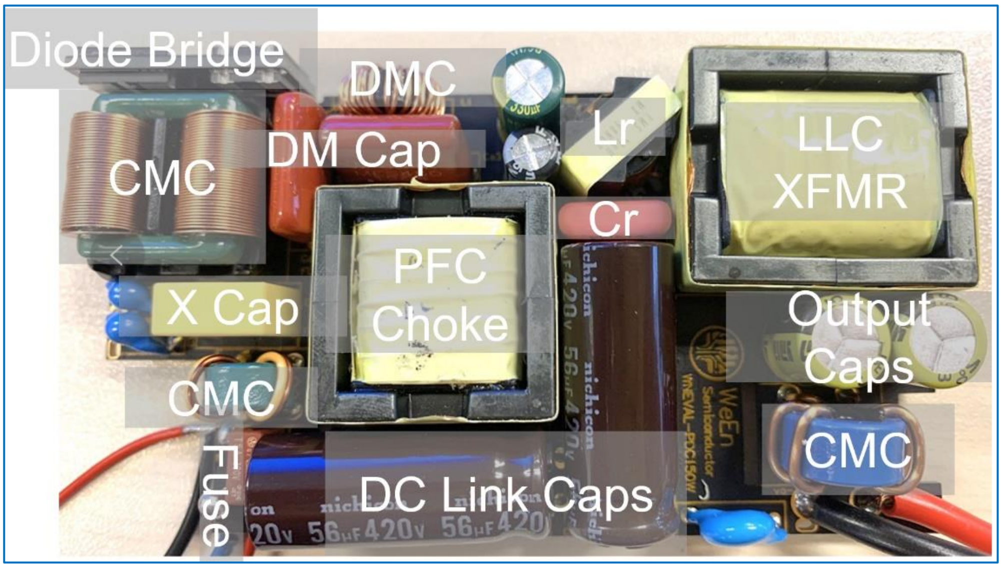

Fig. 7. PD charger reference design- PCB top view

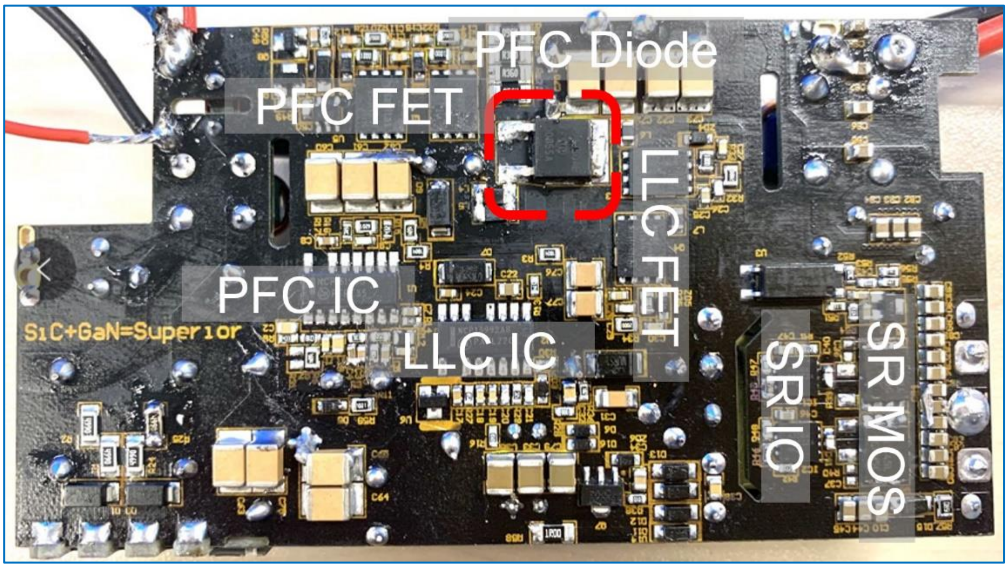

Fig. 8. PD charger reference design- PCB underside view

4.5 Connections and sequences

Start-up sequence:-

Set AC line to 0VAC

Set AC line to OFF

Connect AC line input

Connect DC load at the output

Set AC line input to 120VAC

Turn AC line input to ON

Measure DC output voltage (19.5V)

Increase output load current and monitor output voltage

Power-down sequence:

Turn-off AC power supply

Turn-off the load

4.6 Switching waveforms

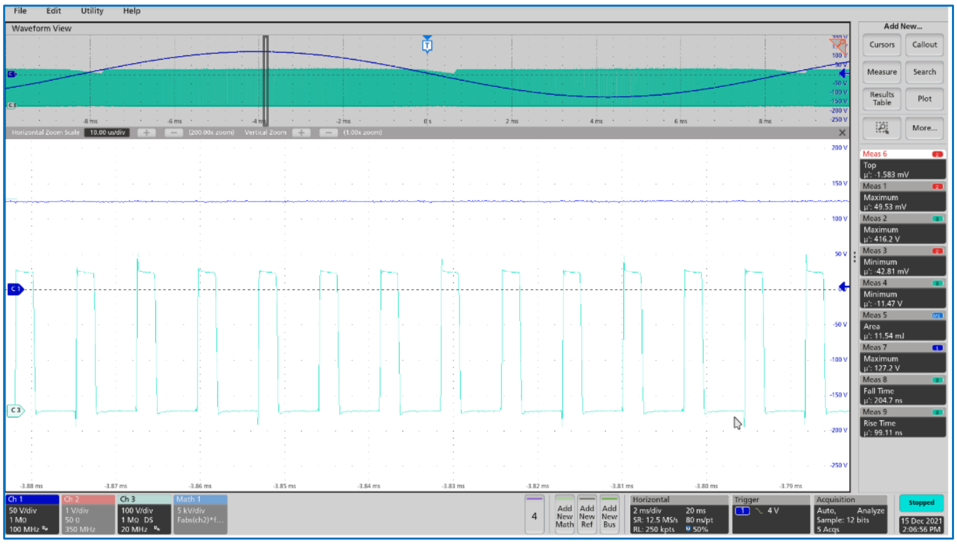

Fig. 9. CRM mode PFC Boost @ 90Vin, 400Vout, 120W, 140kHz

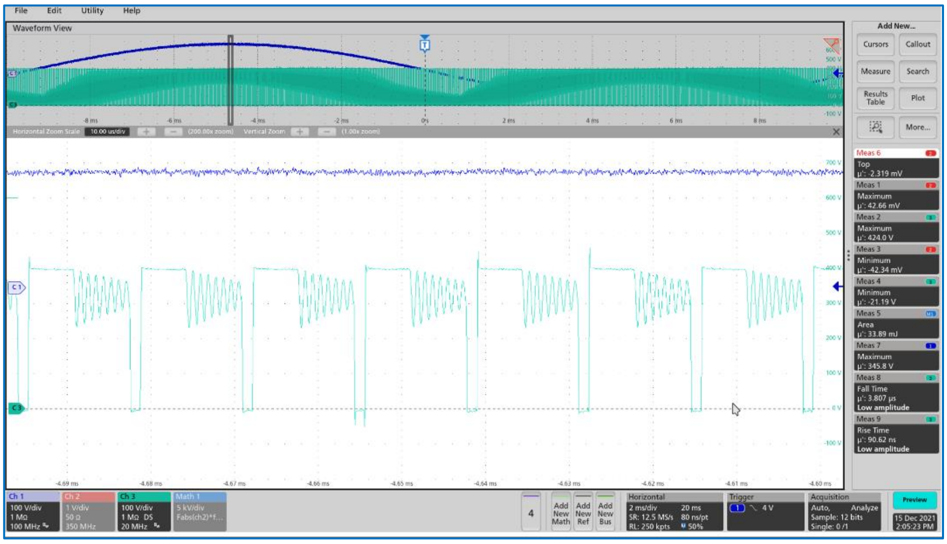

Fig. 10. DCM mode PFC Boost @ 230Vin, 400Vout, 120W, 110kHz

4.7 Efficiency curves and power factor curve

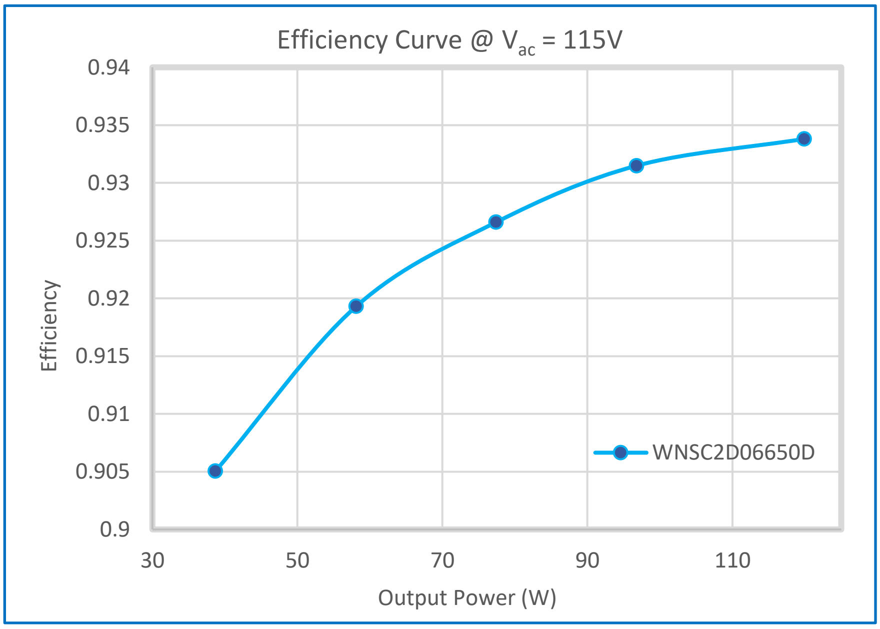

Fig. 11. Efficiency curve (115V)

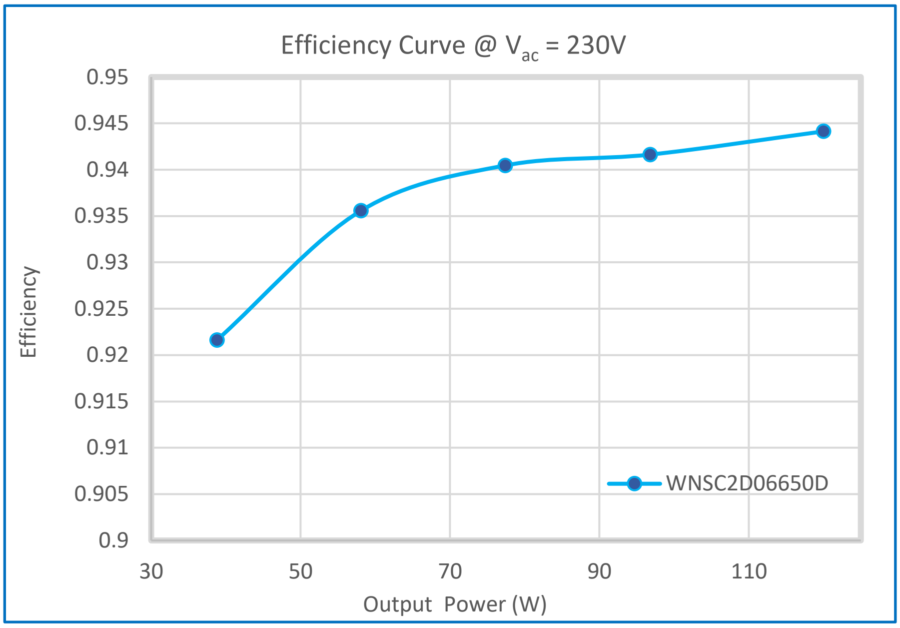

Fig. 12. Efficiency curve (230V)

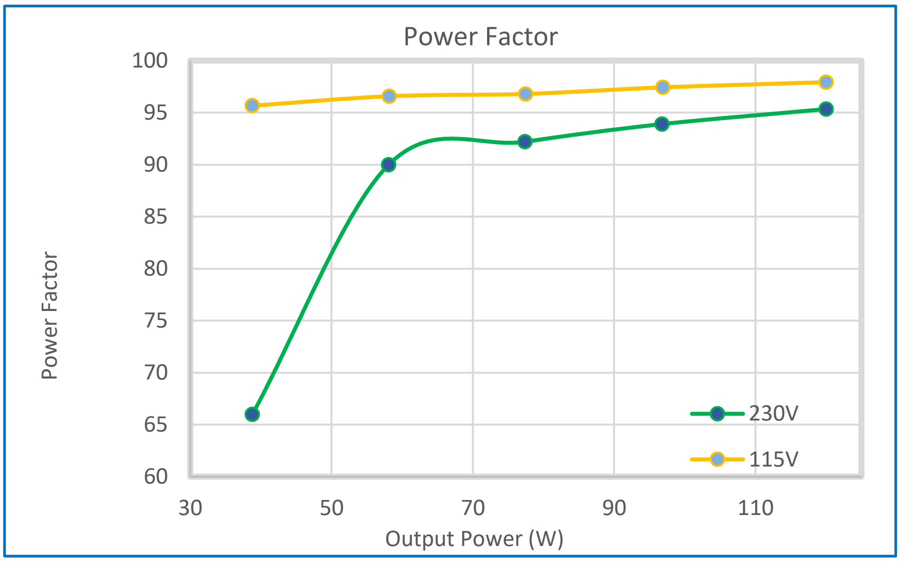

Fig. 13. Power factor curve

4.8 Thermal performance

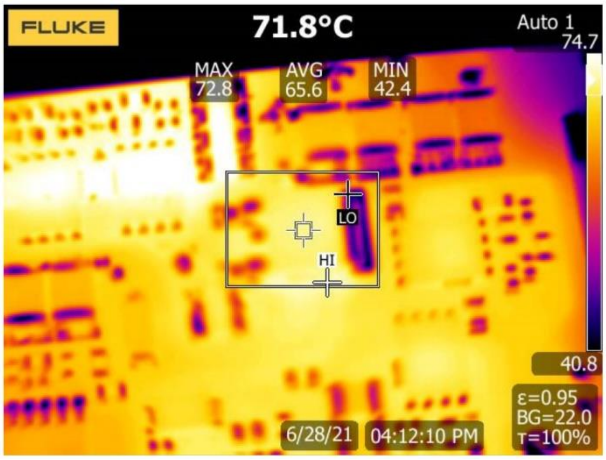

Fig. 14. WNSC2D06650D 71.8℃ @ 90Vin, 120W full load, open frame and no cooling

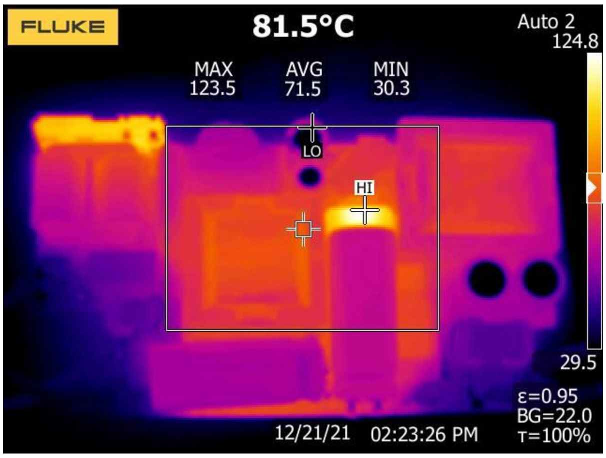

Fig. 15. PCB topside @ 90Vin, 120W full load, open frame and no cooling

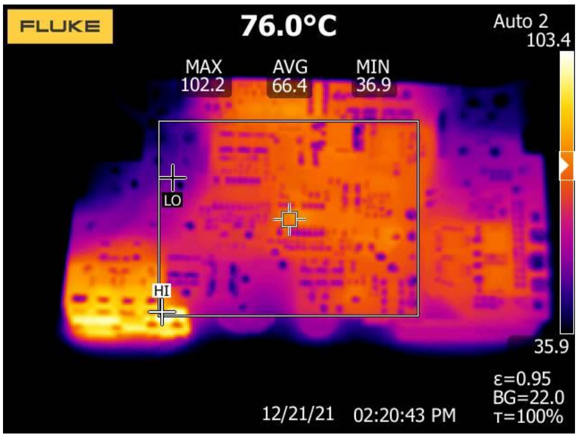

Fig. 16. PCB bottom @ 90Vin, 120W full load, open frame and no cooling

4.9 EMI measurement

Conducted EMI measurement results comply with EN55022 class B with 10dB margin. (See Figure 17)

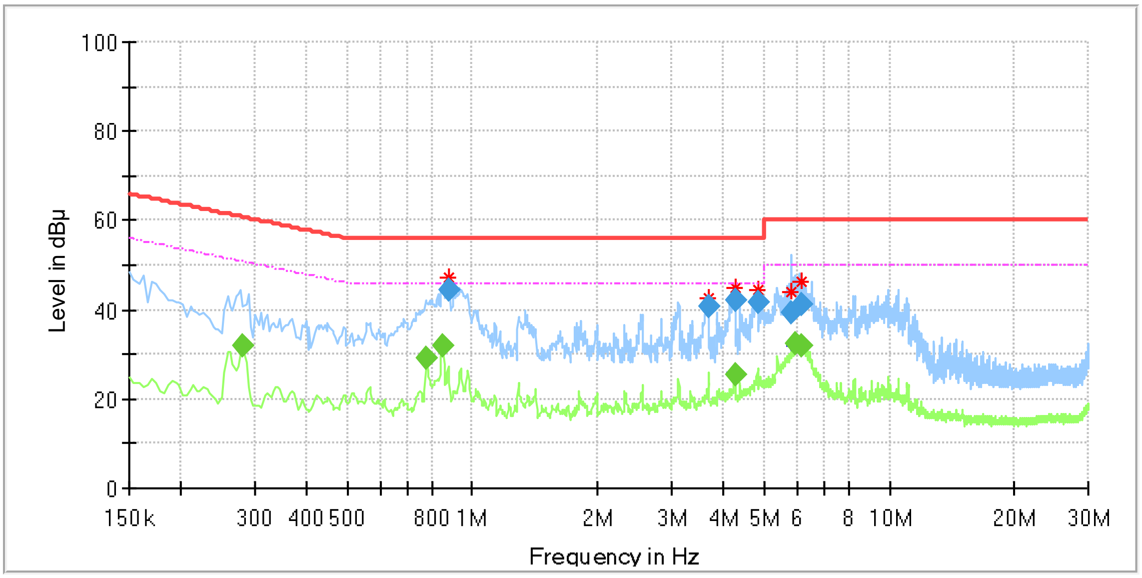

Fig. 17. Conducted EMI (Quasi-Peak blue, AVG green, V_{in} = 230V_{ac}, P_{out} = 120W)

Frequency (MHz)	QuasiPeak (dBµV)	Average (dBµV)	Limit (dBµV)	Margin (dB)
0.282000	---	31.87	50.76	18.89
0.774000	---	29.39	46.00	16.61
0.846000	---	32.03	46.00	13.97
0.878000	44.49	---	56.00	11.52
3.690000	40.63	---	56.00	15.37
4.254000	42.06	---	56.00	13.94
4.258000	---	25.66	46.00	20.34
4.826000	41.79	---	56.00	14.21
5.798000	39.27	---	60.00	20.73
5.942000	---	32.27	50.00	17.73
6.182000	41.38	---	60.00	18.62
6.186000	---	32.15	50.00	17.85

Revision history

Rev	Date	Description
v.01	20211223	New Application Note

Contact information

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