Application note

15 W 5 V output USB adapter board with STCH03 CC-mode primary sensing switching controller

Introduction

The 15 W (5 V-3 A) wide range mains USB adapter evaluation board is based on the STCH03 current-mode quasi-resonant controller.

The STCH03 switching controller combines a high-performance low voltage PWM controller chip with a 650 V HV start-up cell in the same package. It provides constant output current (CC) regulation through primary-sensing feedback. This solution maintains accurate output current regulation, without the need for a dedicated current reference IC or a current sensor. Internally integrated hiccup protection protects the system in short-circuit events.

The power supply features high power density per watt, high efficiency, low standby power (less than 15 mW) and optimal EMI performance. The integrated protection features include OTP protection, which considerably increases end-product safety and reliability.

1 STEVAL-SMACH15V1 evaluation board overview

1.1 Electrical characteristics

Table 1. STEVAL-SMACH15V1 evaluation board electrical specifications

Parameter	Min.	Typ.	Max
AC Main Input voltage	90 V_{AC}		265 V_{AC}
Mains frequency	50 Hz		60 Hz
Output Voltage	4.75 V	5 V	5.25 V
Output Current		3.1 A	
Output voltage during transient load	4.3V		5.85V
Output overvoltage protection	5.98 V	6.3 V	6.62 V
Rated output power		15 W	
Input power in standby @230V_{AC}			15 mW
Active mode efficiency	81.84 %		
Active mode efficiency @10% nameplate O/P (*)	72.48 %		
Startup time			200ms
Rise time			40ms
Ambient operating temperature			50 °C
Board Dimensions	(35x44) mm – h15mm		

1. *Compliant with the European Code of Conduct rev.5 (Energy-Efficiency Criteria for Active Mode for Low Voltage external power supplies – Tier 2).*

1.2 Layout and schematics

Figure 1. STEVAL-SMACH15V1 evaluation board top

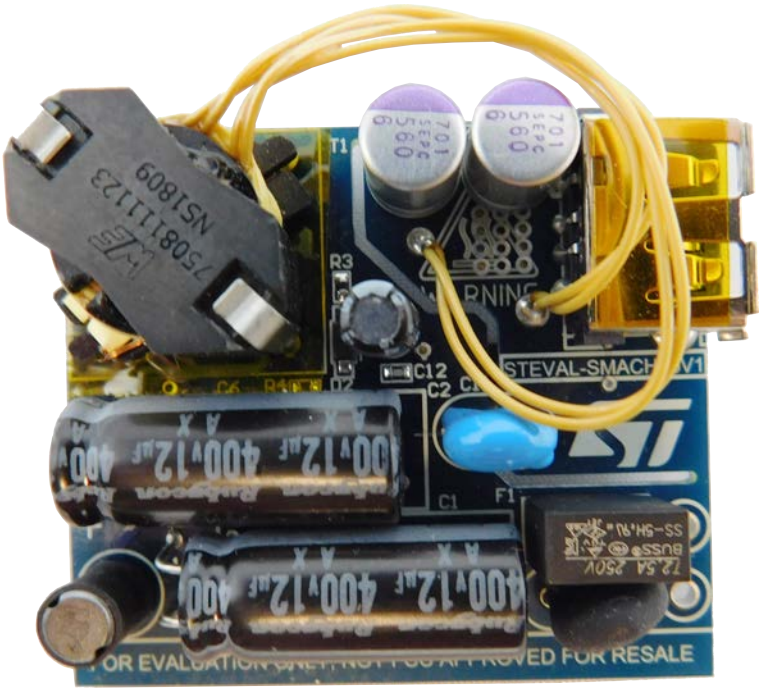


Figure 2. STEVAL-SMACH15V1 evaluation board bottom

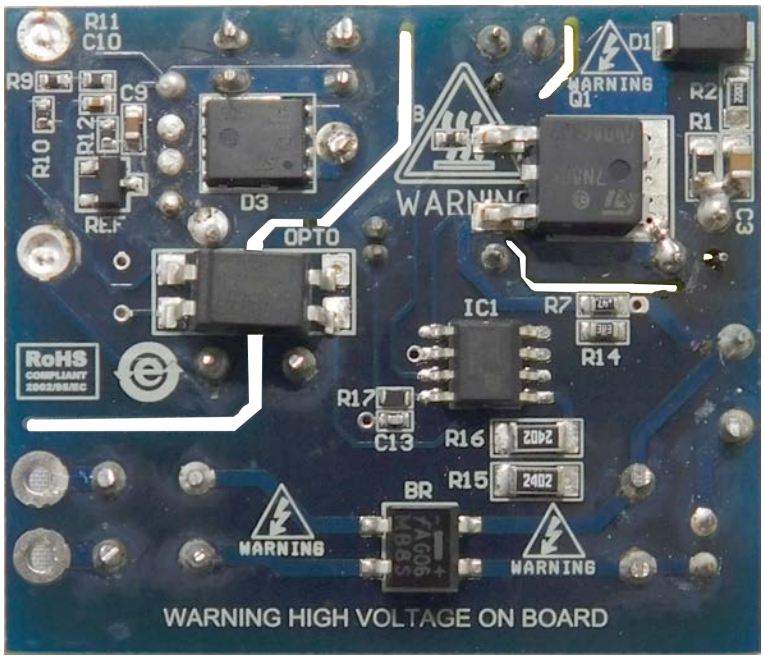


Figure 3. **PCB top layer layout**

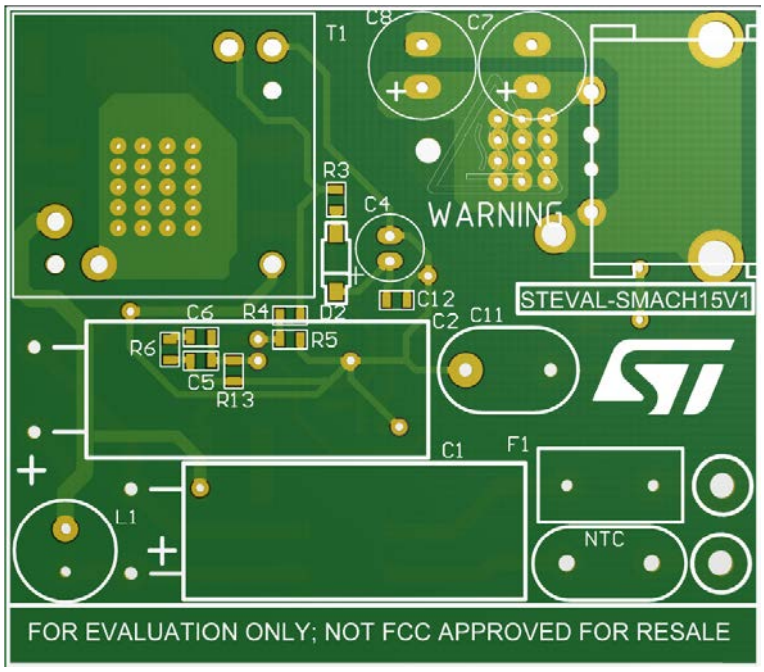
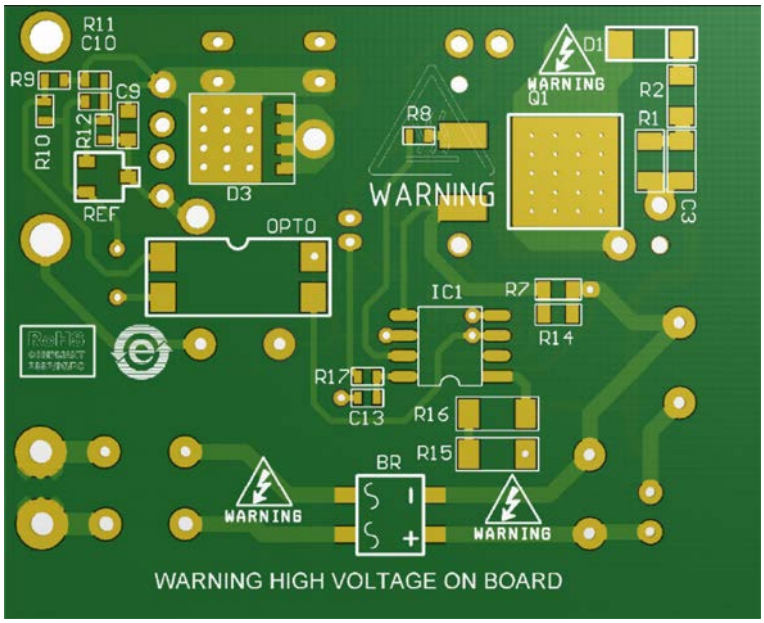
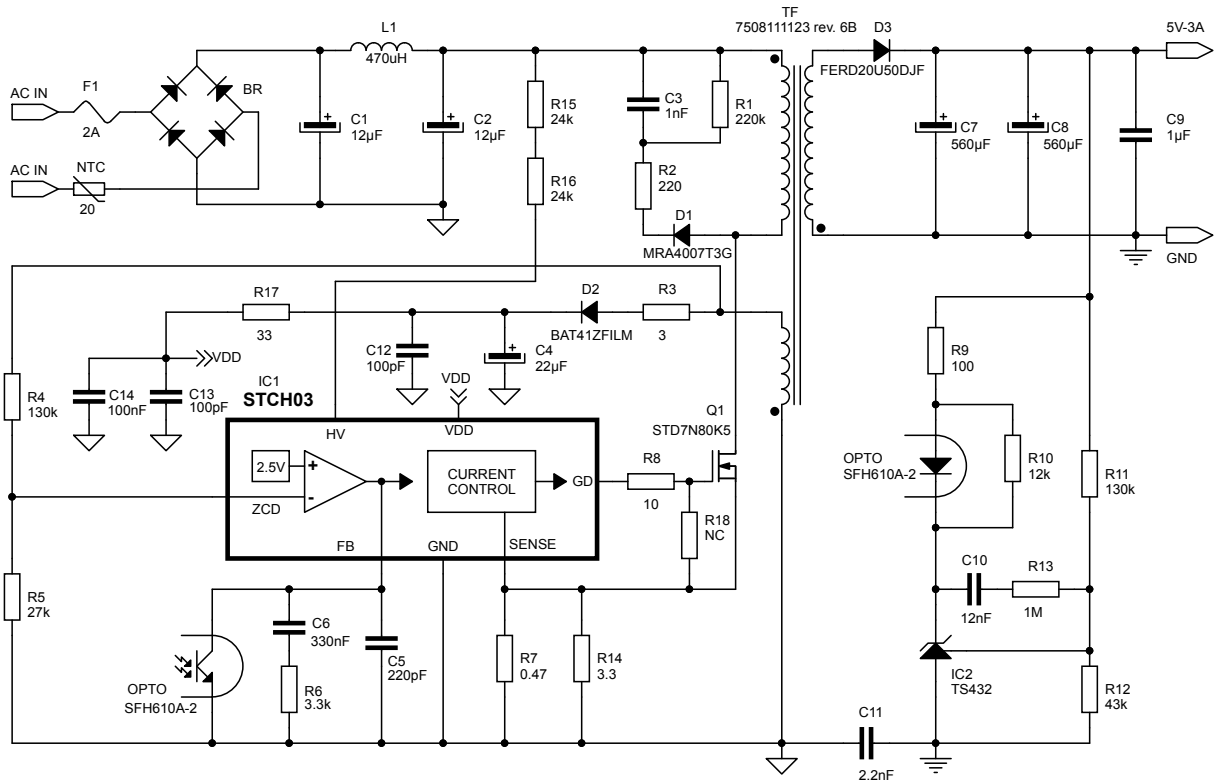


Figure 4. **PCB bottom layer layout**



1.2.1 Schematic diagram

Figure 5. **STEVAL-SMACH15V1 evaluation board schematic**



1.3 Bill of materials

Table 2. **STEVAL-SMACH15V1 evaluation board bill of material**

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
1	1	NTC	20Ω-2A	NTC	Ametherm	SL08 20002
2	1	F1	2.5A fuse	fuse	Cooper Bussmann	SS-5H-2-5A-BK
3	1	BR	-	Bridge rectifier	Taiwan Semiconductor	RMB6S
4	1	C1	12µF-400V	Elcap	Rubycon	400AX12M8X20
5	1	C2	12µF-400V	Elcap	Rubycon	400AX12M8X20
6	1	C3	1nF-1KV	MLCC capacitor	Kemet	C0805X102KDRACTU
7	1	C4	22µF-35V	Elcap	Nichicon	UVR1V220MDD6TP
8	1	C5	220pF-50V	MLCC capacitor	Murata	GRM1555C1H221JA01D
9	1	C6	330nF-25V	MLCC capacitor	TDK	C1005X5R1E334K050BB
10	1	C7	560µF-6.3V	OS-CON capacitor	Panasonic	6SEPC560MW
11	1	C8	560µF-6.3V	OS-CON capacitor	Panasonic	6SEPC560MW
12	1	C9	1µF-25V	MLCC capacitor	Murata	GRM188C81E105KAADD
13	1	C10	12nF-50V	MLCC capacitor	Murata	GRM155R71H123KA12D
14	1	C11	2.2nF 250Vac	Ceramic X1/Y1 capacitor	Murata	DE2E3KY222MA2BM01
15	1	C12	100pF-50V	MLCC capacitor	Murata	GRM1555C1H101JA01D

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
16	1	C13	100pF-50V	MLCC capacitor	Murata	GRM1555C1H101JA01D
17	1	C14	100nF-50V	MLCC capacitor	Murata	GRM188R11H104KA93D
18	1	D1	1A-1000V	Power rectifier diode	ON Semiconductor	MRA4007T3G
19	1	D2	0.15A-100V	Signal schottky	STMictroelectronics	BAT41ZFILM
20	1	D3	20A-50V	Field effect rectifier	STMictroelectronics	FERD20U50DJF
21	1	L1	470µH	radial inductor	Wurth Elektronik	7447462471
22	1	R1	220kΩ±1% - 0.5W - 400V	resistor	Panasonic	ERJP06F2203V
23	1	R2	220Ω±1% - 0.5W - 400V	resistor	Panasonic	ERJP06F2200V
24	1	R3	3Ω±5% - 0.1W	resistor	Panasonic	ERJ-2GEJ3R0X
25	1	R4	130kΩ±1% - 0.1W	resistor	Panasonic	ERJ-2RKF1303X
26	1	R5	27kΩ±1% - 0.1W	resistor	Panasonic	ERJ-2RKF2702X
27	1	R6	3.3kΩ±1% - 0.1W	resistor	Panasonic	ERJ-2RKF3301X
28	1	R7	0.47Ω±1% - 0.2W	resistor	Panasonic	ERJ3BQFR47V
29	1	R8	10Ω±1% - 0.125W	resistor	Vishay Dale	CRCW040210R0FKEDHP
30	1	R9	100Ω±1% - 0.1W	resistor	Panasonic	ERJ-2RKF1000X
31	1	R10	12kΩ±1% - 0.1W	resistor	Panasonic	ERJ-2RKF1202X
32	1	R11	130kΩ±1% - 0.1W	resistor	Panasonic	ERJ-2RKF1303X
33	1	R12	43kΩ±1% - 0.1W	resistor	Panasonic	ERJ2RKF4302X
34	1	R13	1MΩ±1% - 0.1W	resistor	Panasonic	ERJ-2RKF1004X
35	1	R14	3.3Ω±1% - 0.1W	resistor	Panasonic	ERJ-3RQF3R3V
36	1	R15	24kΩ±1% - 0.66W - 500V	resistor	Panasonic	ERJP08F2402V
37	1	R16	24kΩ±1% - 0.66W - 500V	resistor	Panasonic	ERJP08F2402V
38	1	R17	33Ω±1% - 0.25W	resistor	Panasonic	ERJPA3F33R0V
39	1	R18	Not mounted	resistor		
40	1	T1	-	Flyback transformer	Wurth Elektronik	7508111123 Rev. 6B
41	1	OPTO	-	Optocoupler	Vishay	SFH6106-2T
42	1	Q1	800V-1.2Ω	Power MOSFET	ST	STD7N80K5
43	1	REF	-	Reference	ST	TS432ILT
44	1	IC1	-	Switching controller	ST	STCH03
45	1	OUT	-	USB Typa A connector	Wurth Elektronik	614104150121

1.4 Transformer characteristics

Table 3. Transformer characteristics

Manufacturer	Wurth Elektronik
Part number	7508111123 rev. 6B
Core	RM6
Primary Inductance	900 µH ±10%
Saturation current	950 mA (20% roll-off from initial value)
Leakage inductance	40 µH max

Primary-to-auxiliary turns ratio	6.55 ±1%
Primary-to-secondary turns ratio	14.4 ±1%

Figure 6. Transformer schematic

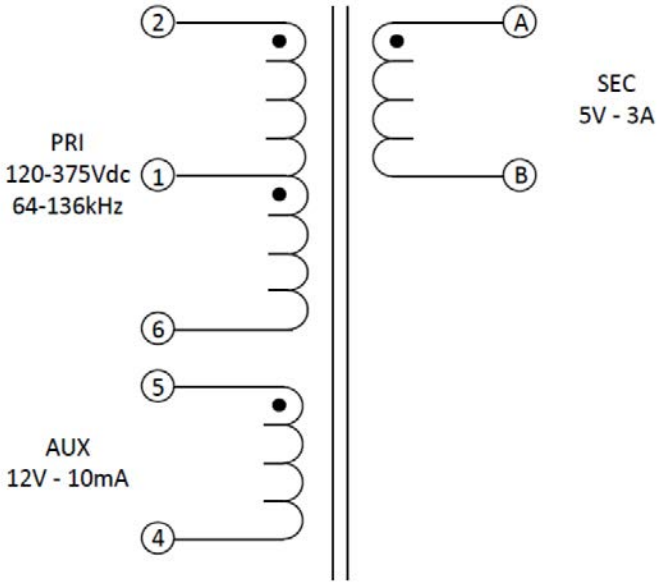


Figure 7. Transformer bottom

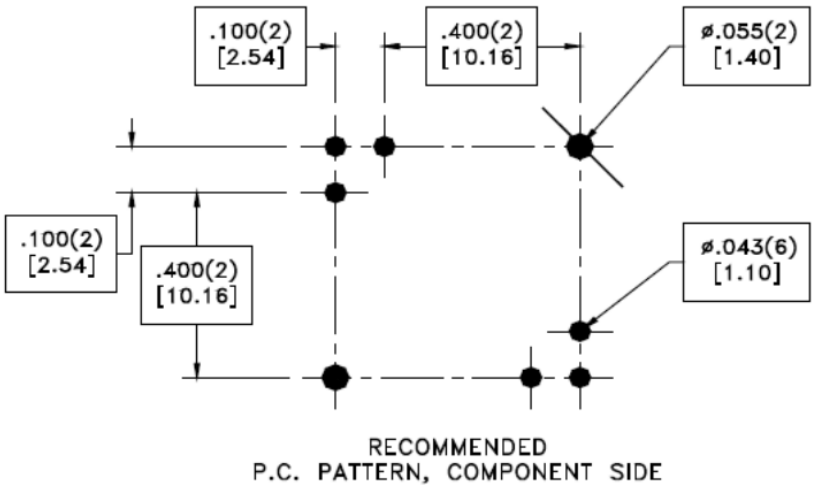
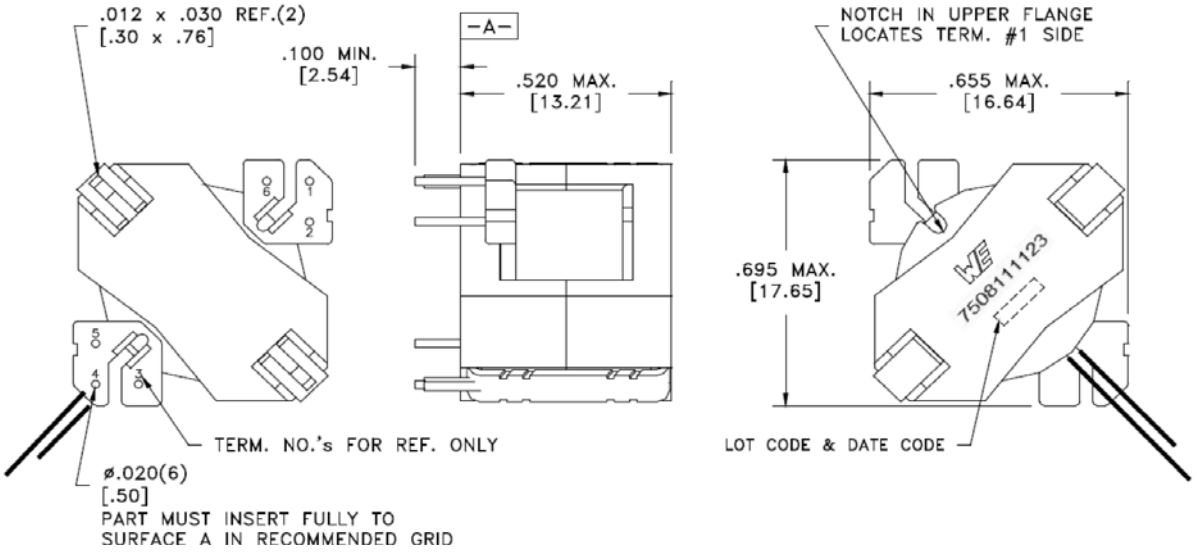


Figure 8. **Transformer mechanical drawing**



2 Circuit description

2.1 Input stage and filtering

The input stage comprises a fuse F1 to prevent catastrophic failure and an input NTC to limit the capacitor inrush current and protect the bridge rectifier (BR). A low cost π-filter (C1-L1-C2) is implemented to filter the differential mode conducted EM.

2.2 Snubber network

The clamping network (R1-C3-D1) limits the leakage inductance voltage spike peak by dissipating the corresponding energy at MOSFET turn-off. The R2 resistor also helps reduce transformer ringing by damping the resonance oscillations between leakage inductance and equivalent drain capacitance at turn-off.

2.3 PWM controller and Mosfet

The PWM controller is a current mode QR controller with embedded HV startup circuit featuring zero power consumption. This feature, together with low quiescent current, helps minimize the residual input consumption.

Resistors R15 and R16 increase the ruggedness of the HV chip during electrical fast transient events.

The R4 and R5 voltage dividers are used to sense both the zero-crossing signal for proper QR operations and the auxiliary voltage for OVP protection.

CV regulation is achieved by adjusting the voltage on the FB pin. This operation transfers the output voltage information via the optocoupler. The network connected on the FB pin is used for proper loop compensation.

The CC loop is fully integrated into the IC. No external components are required except for the resistors connected to the sense pins (R7 and R14), to adjust the CC set point.

During normal operation, the VDD pin is powered by the transformer auxiliary winding. The output is rectified by the D2 diode and the C4 capacitor.

Resistor R3 filters auxiliary spikes at turn-off to limit pin voltage fluctuation.

Capacitor C12 and the low-pass filter (C13 and R17) filter any narrow voltage spikes entering the VDD pin, improving the ruggedness of the IC during EFT tests. Capacitor C14 is used to provide the capacitive current to the gate of the MOSFET at power-on, avoiding negative spikes that could trigger the UVLO threshold.

The power MOSFET Q1 is an 800 V BVdss MDmesh K5, with an $R_{DS}(on) \leq 1.2\ \Omega$. This feature ensures a good compromise between low conduction losses and switching characteristics.

2.4 Output stage

The secondary transformer signal is rectified by the diode D3 and filter by output capacitors C7 and C8. These capicitors ensure an ESR that is as low as possible and sufficient AC ripple capability.

Capacitor C9 further reduces the output switching noise.

The output voltage is sensed by the R11 and R12 voltage divider and compared with the internal reference of the shunt voltage reference TS432 (1.24 V). Its output is then converted via the optocoupler into a current signal control for the primary PWM IC.

3 Performance data

3.1 CV/CC output voltage characteristics

The board V-I characteristic is measured at the PCB output connector, at both 115 and 230 V_{AC}, under different line and load conditions.

The figures below show the measurement results: the load regulation is very accurate and barely affected by the USB connector contact resistance (≈30 mΩ).

Figure 9. Output characteristic at 115 V_{AC}

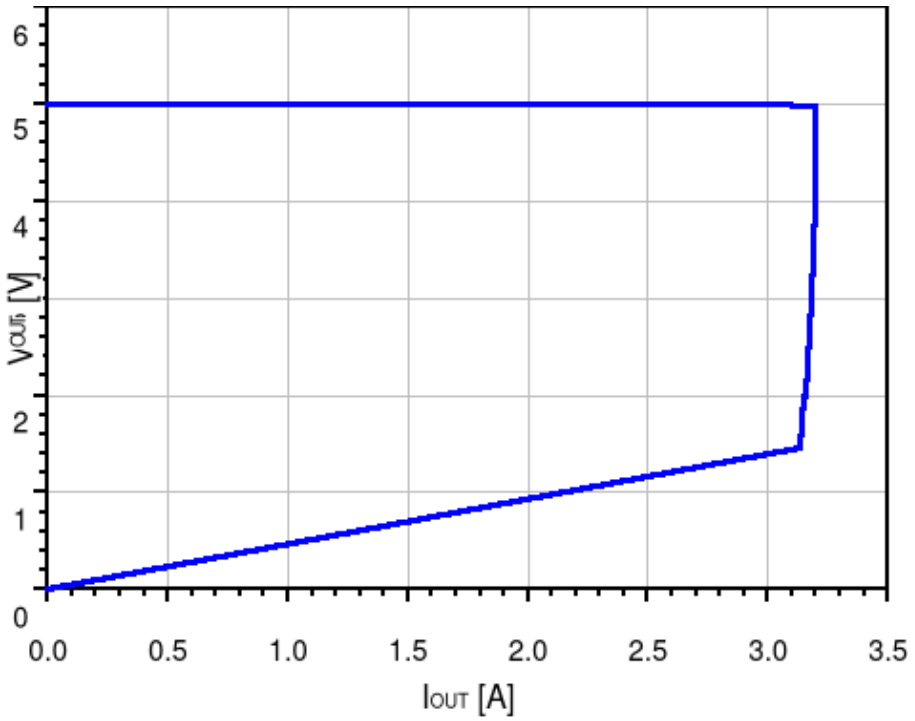
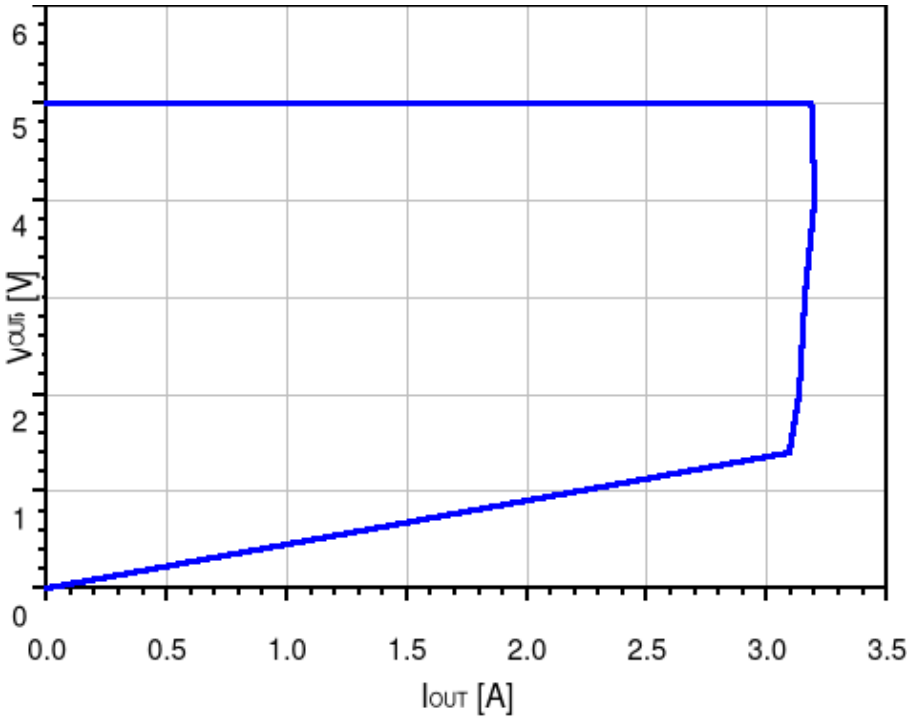


Figure 10. **Output characteristic at 230 V_{AC}**



3.2 Efficiency and light load measurements

Converter efficiency and no-load consumption are measured at nominal input voltages (115 V_{AC} and 230 V_{AC}): the rated average power is compared with the European Code of Conduct revision 5 - Tier 2 (EuCoC) requirements.

Figure 11. **Efficiency vs. output power**

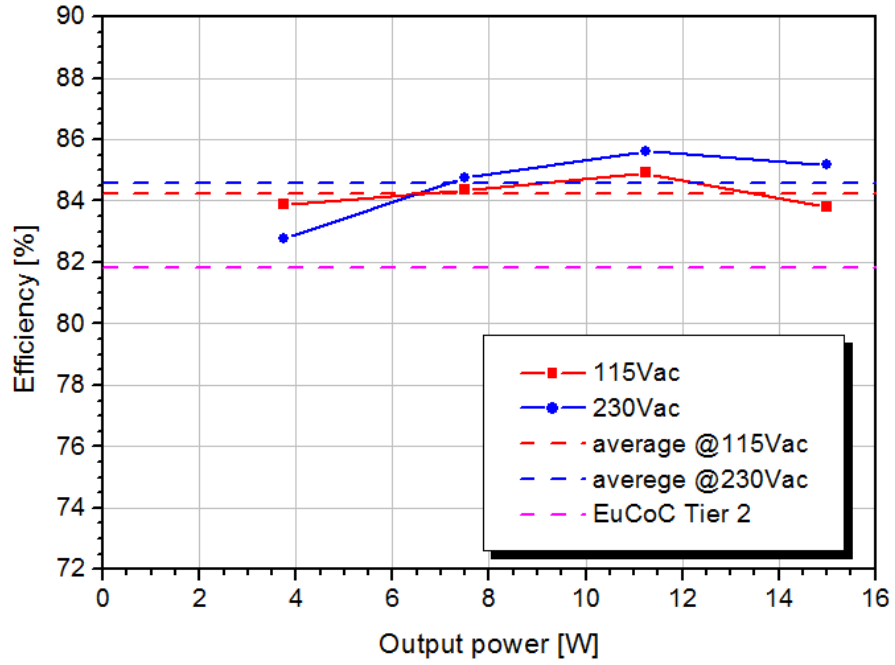


Table 4. Average efficiency of the rated output load

% of rated power	Efficiency	
	115 V_{AC}	230 V_{AC}
25%	83.89%	82.78%
50%	84.36%	84.75%
75%	84.91%	85.62%
100%	83.80%	85.18%
Average	84.24%	84.58%
EU Code of Conduct rev. 5 – Tier 2 limit : 81.84%		

Table 5. Efficiency at 10% of the rated output load

Input voltage	Efficiency
115 V_{AC}	81.36 %
230 V_{AC}	77.97 %
EU Code of Conduct rev. 5 – Tier 2 limit : 72.48%	

Table 6. No load consumption

Input voltage	Input power
115 V_{AC}	12.1 mW
230 V_{AC}	12.3 mW

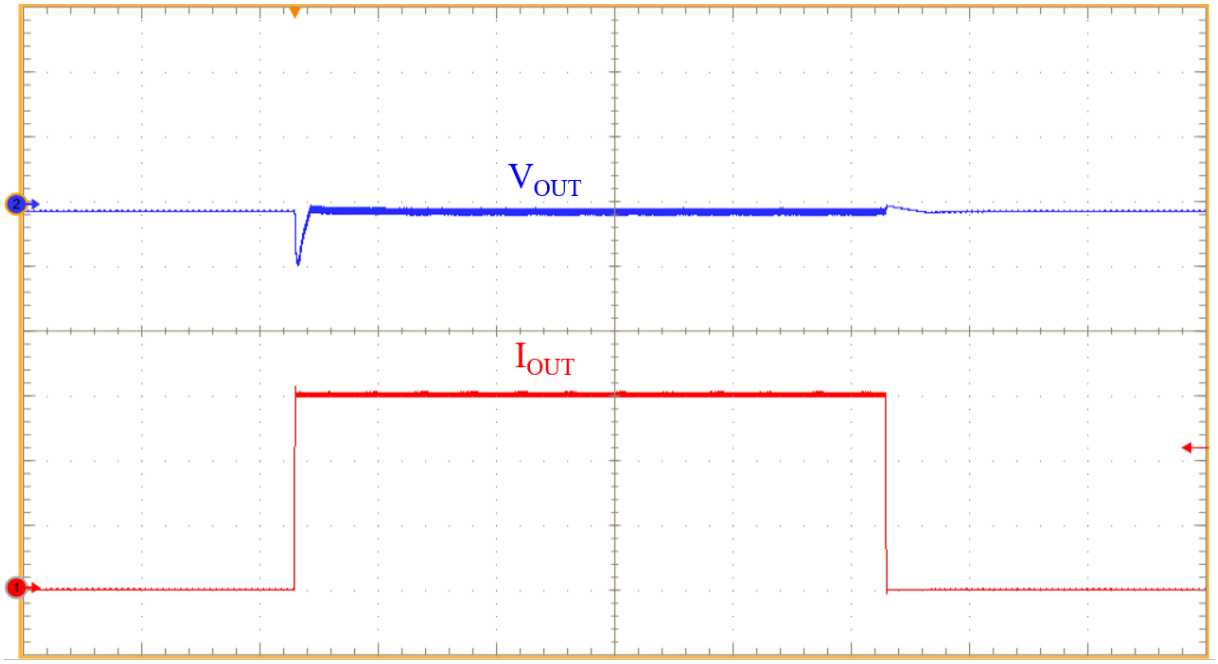
4 Typical waveforms

4.1 Dynamic load regulation response

The board V-I characteristic is measured at the PCB output connector at both 115 V_{AC} and 230 V_{AC} for different line and load conditions.

The board is subjected to dynamic load variations from 0% to 100% of the nominal load. The following figures show no abnormal oscillation in the output and the overshoot and undershoot values are acceptable.

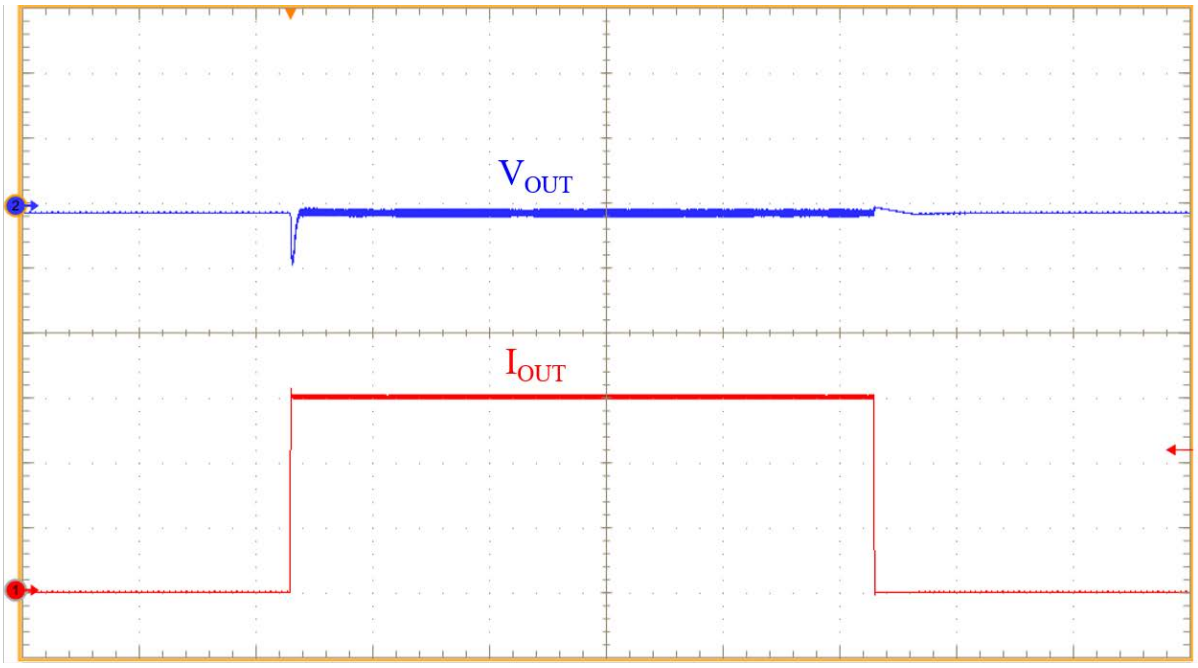
Figure 12. Dynamic load regulation from no load to full load at 115 V_{AC}



Ch1 1A/div
Ch2 500mV/div
Ch2 offset 5V
M 20.0ms/div

Ch1 (Max): 3.1A
Ch2 (Max): 5V
Ch2 (Max): 4.6V

Figure 13. **Dynamic load regulation from no load to full load at 230 V_{AC}**



4.2 Switching waveforms

The drain voltage and the drain current waveforms are given for the two nominal input voltages and for the minimum and the maximum voltage of the converter input operating range.

The following figures show the drain voltage and the drain current waveforms for the two nominal input voltages. They also show the minimum and maximum converter input operating voltage during converter constant voltage mode (CV).

Figure 14. **Normal operation in CC mode at full load and 90 V_{AC}**

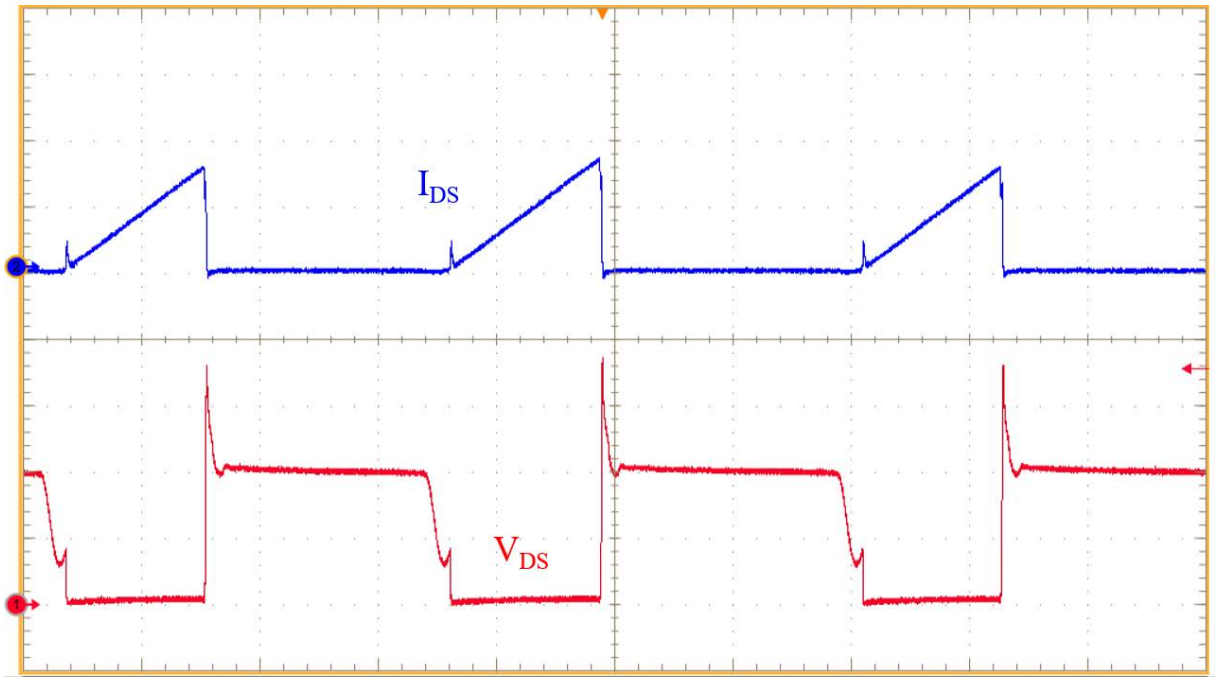


Figure 15. **Normal operation in CV mode at full load and 115 V_{AC}**

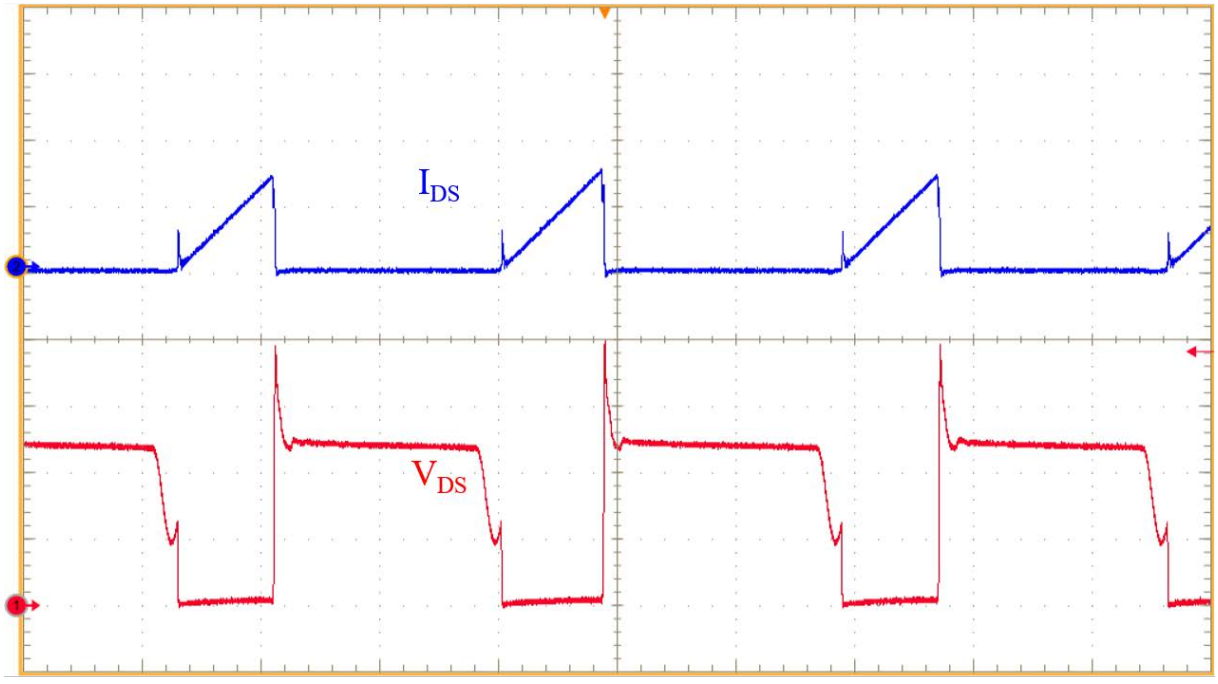
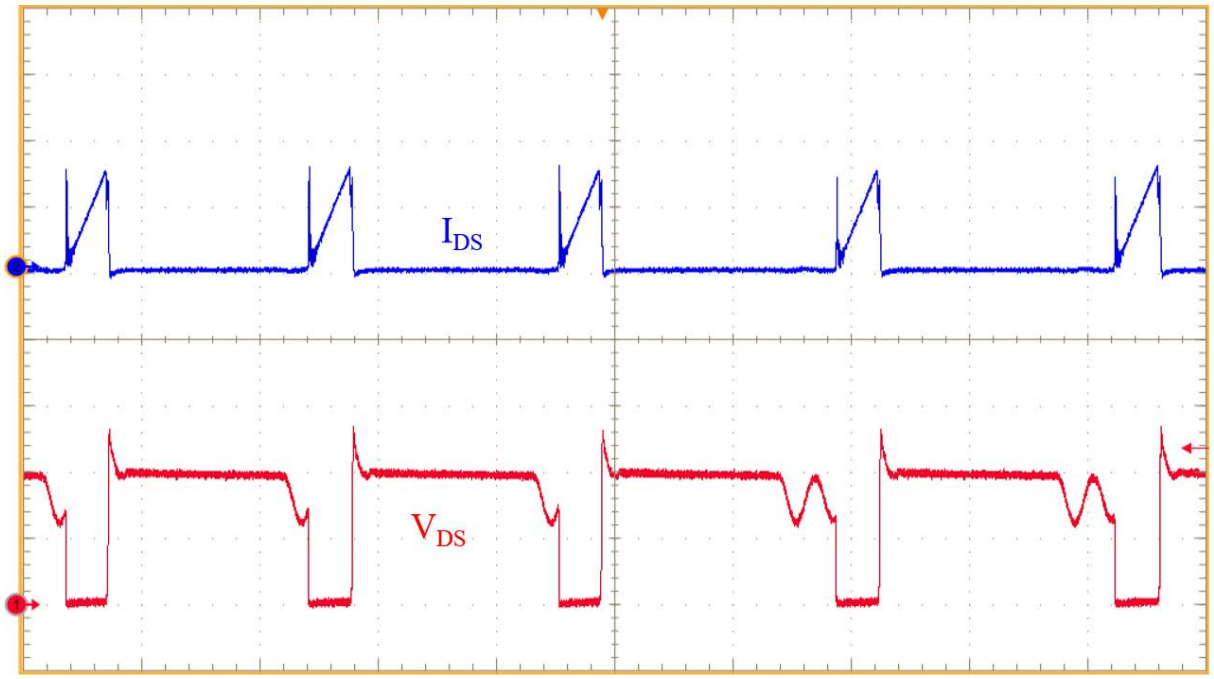


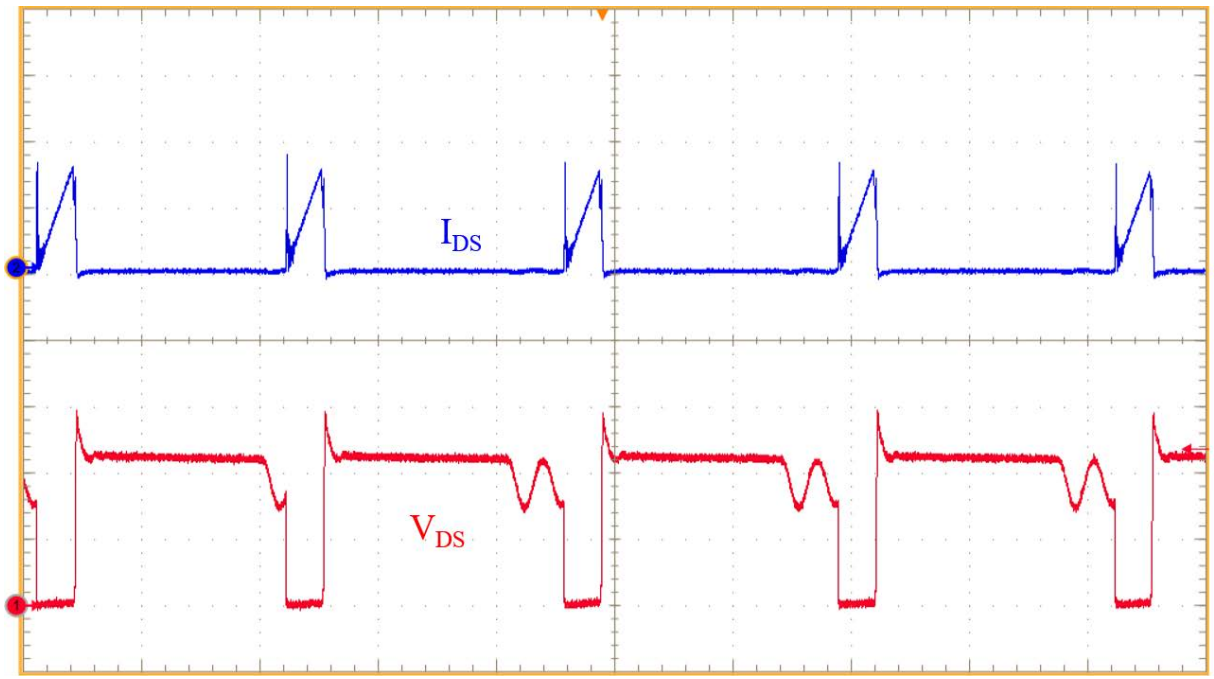
Figure 16. **Normal operation in CV mode at full load and 230 V_{AC}**



Ch1 200V/div
Ch2 400mA/div
M 5.0µs/div

Ch1 (Freq): 87.3kHz
Ch1 (Max): 563V
Ch2 (Max): 610.0mA

Figure 17. **Normal operation in CV mode at full load and 264 V_{AC}**



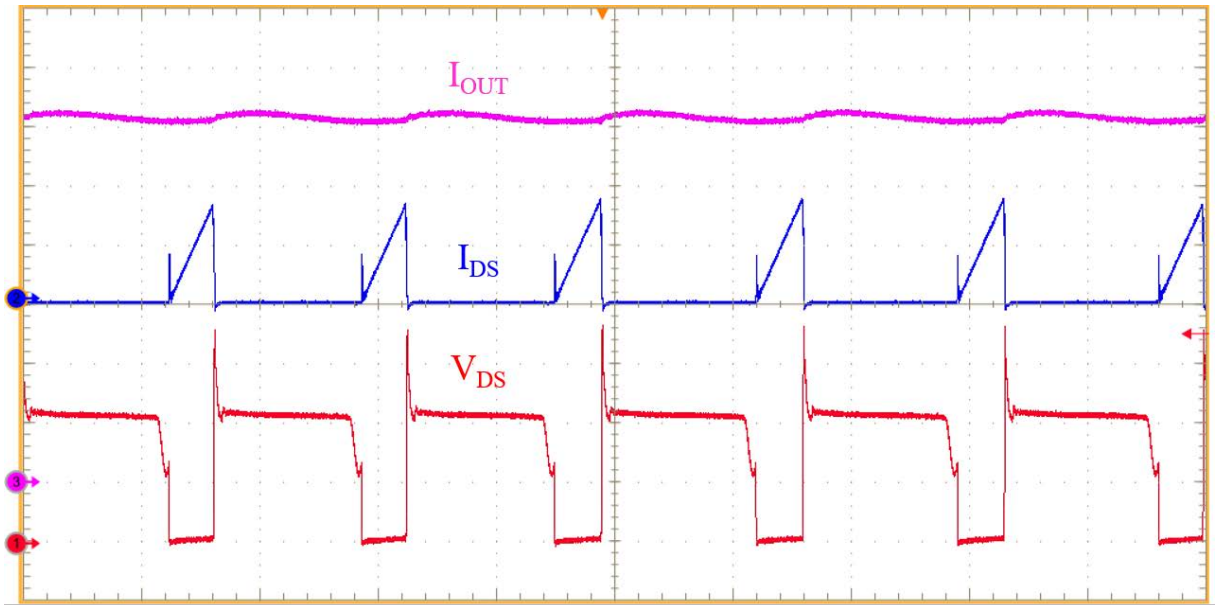
Ch1 200V/div
Ch2 400mA/div
M 5.0µs/div

Ch1 (Freq): 91.0kHz
Ch1 (Max): 590V
Ch2 (Max): 602.0mA

In order to simulate the operation constant current mode (CC mode), the electronic load has been set in constant voltage at 3V, so that this voltage is imposed on the charger output from the E-load: the charger is forced to enter CC mode, thus regulating the output current at its nominal value.

Figure 15 and Figure 16 show the CC mode typical waveforms.

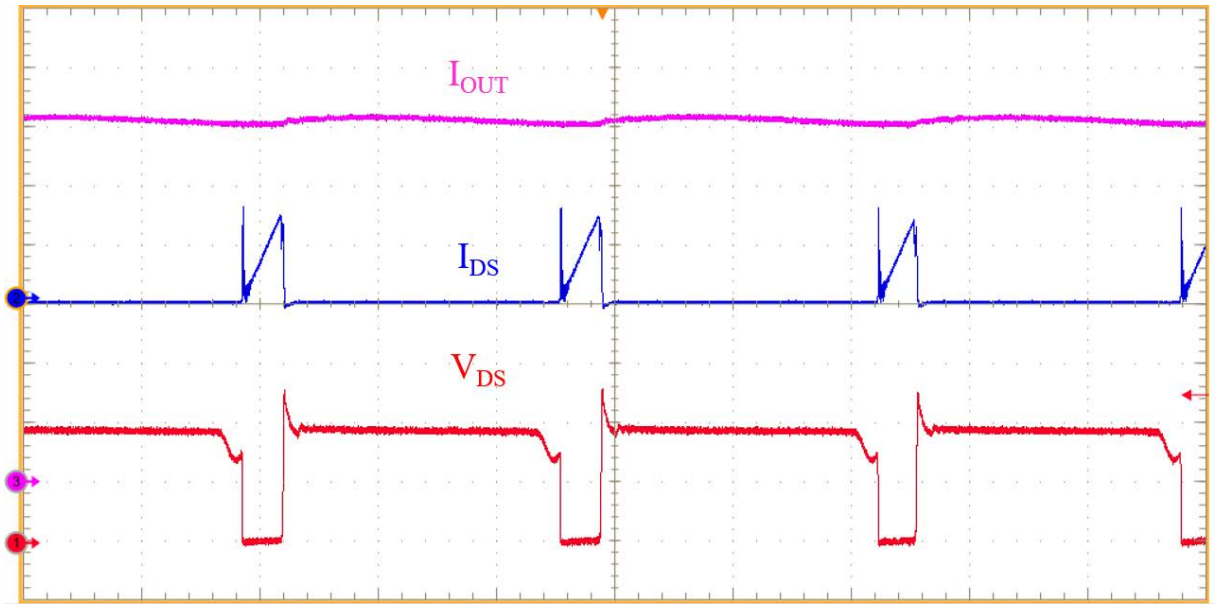
Figure 18. Normal operations in CC mode with V_{OUT} = 3 V and 115 V_{AC}



Ch1 100V/div
Ch2 400mA/div
Ch3 500mA/div
M 10.0µs/div

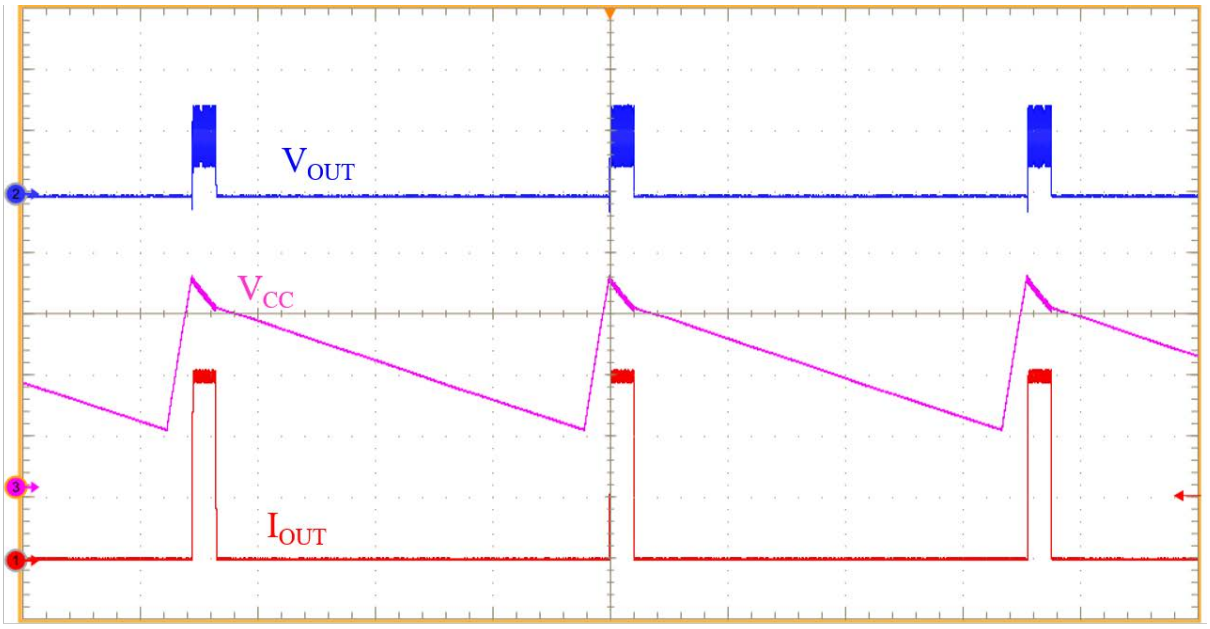
Ch1 (Freq): 61.4kHz
Ch1 (Max): 368.0V
Ch2 (Max): 673.3mA
Ch3 (Max): 3.08A

Figure 19. **Normal operations in CC mode with V_{OUT} = 3 V and 230 V_{AC}**



The converter is also tested in short-circuit to trigger the output UVP protection, which protect the converter in case of output short circuit: the typical waveforms are shown in Figure 17.

Figure 20. **Short-circuit protection**



Ch1 1A/div
Ch2 300mV/div
Ch3 5V/div
M 100ms/div

Ch1 (Max): 3.12A
Ch2 (Max): 17.3V
Ch3 (Min): 4.6V

4.3 Output overvoltage protection

The output overvoltage protection is tested by shorting the opto-diode. This causes the converter to operate in open loop and the excess power (with respect to the load) charges the output capacitance, increasing the output voltage as the OVP is tripped and the converter stops switching.

The figures below show how the converter stops switching and enters protection mode when the voltage reaches OVP threshold (set by the R4 and R5 voltage dividers).

Figure 21. **Output OVP protection: protection triggering**

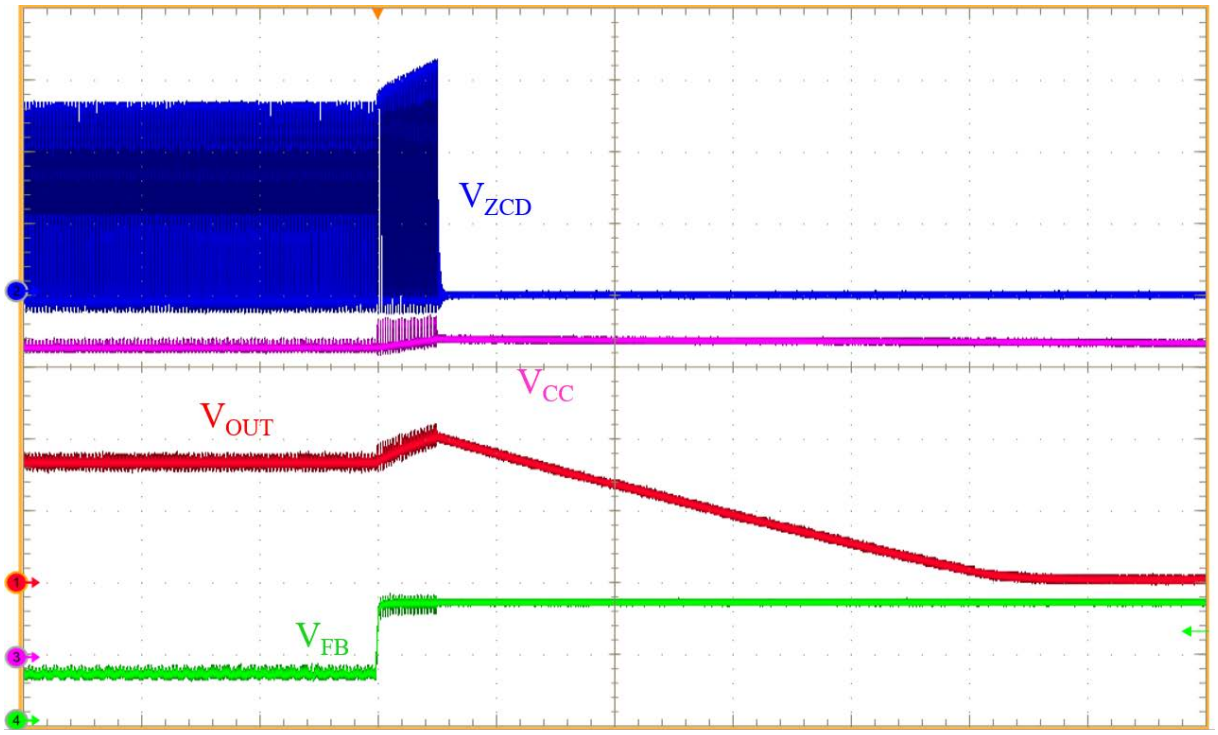


Figure 22. **Output OVP protection: zoom**

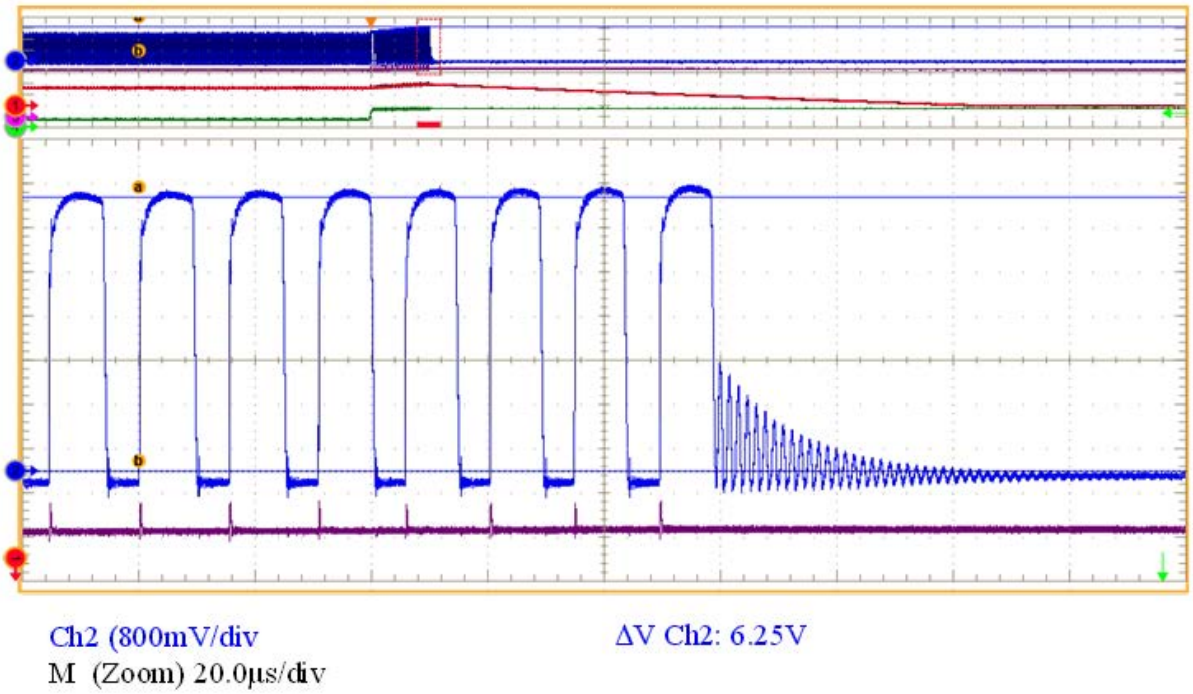
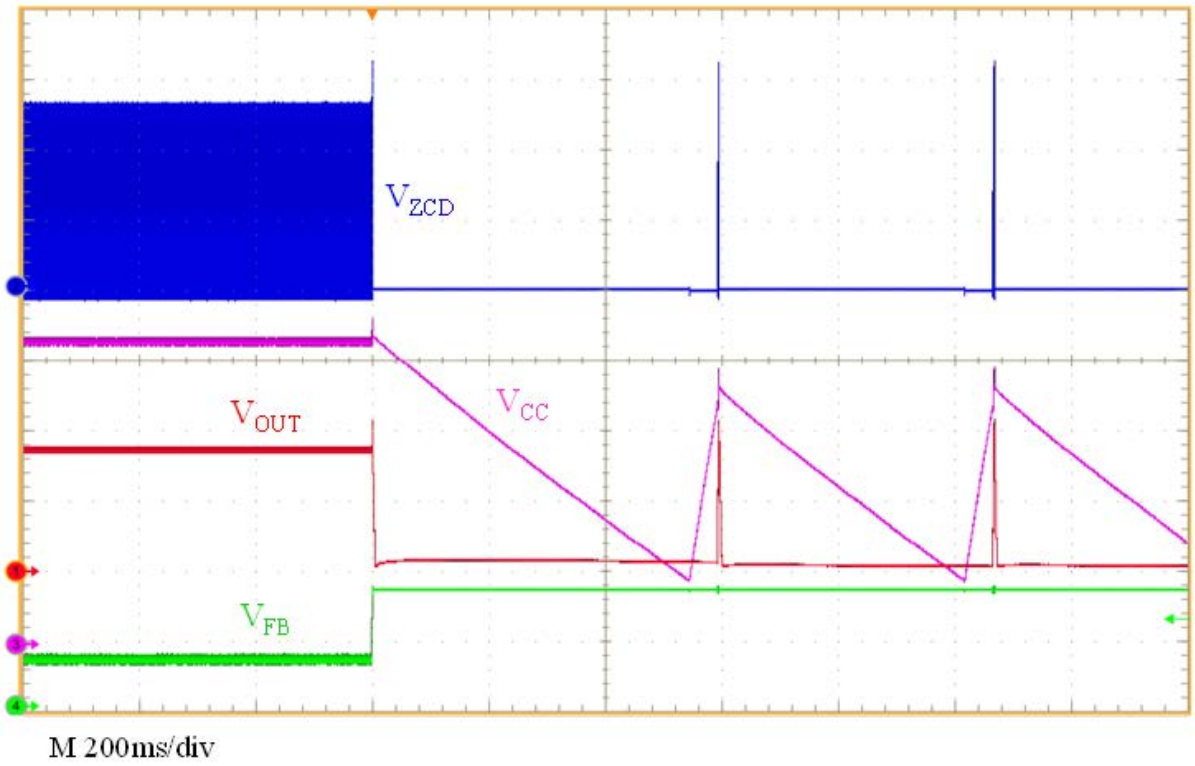


Figure 23. **Output OVP protection: zoom.**



5 Conducted noise measurements

A pre-compliance test for EN55022 (Class B) European normative was performed using an average measurement detector of the conducted noise emissions at full load and nominal mains voltages.

The results show a comfortable margin between the measurements and the respective limits

Figure 24. CE average measurement at 115 V_{AC} and full load

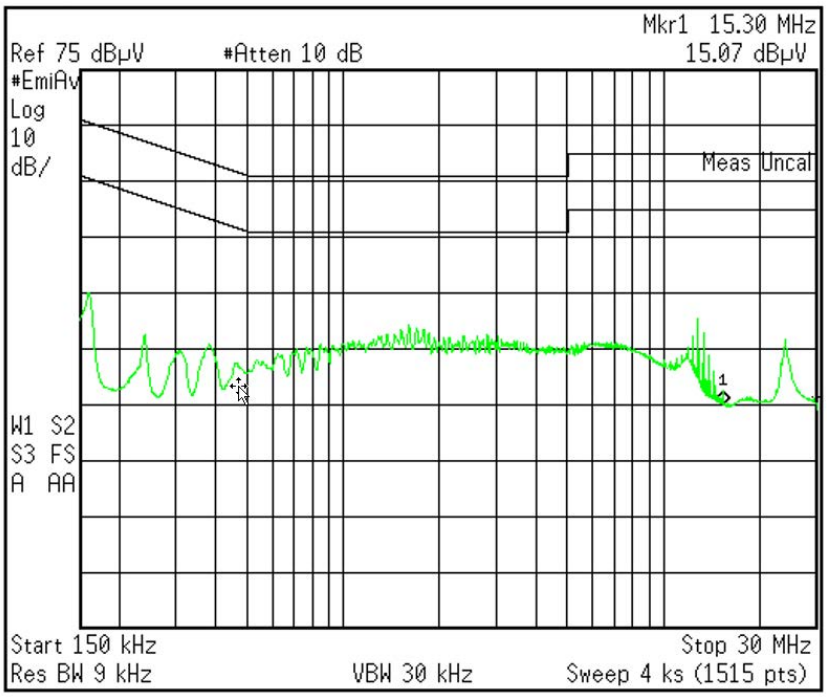
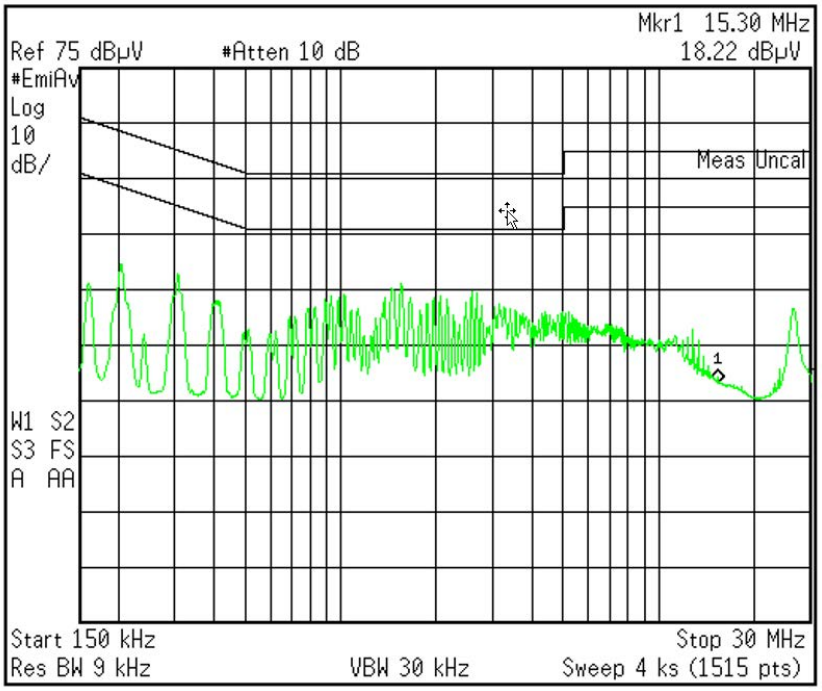


Figure 25. CE average measurement at 230 V_{AC} and full load.



6 Immunity tests

The board was subjected to immunity tests according to IEC61000. The results are classified according the criteria given by the standard:

1. Normal performance
2. Temporary degradation or loss of function or performance, with automatic return to normal operation
3. Temporary degradation or loss of function with external intervention to re-cover normal operation
4. Degradation or loss of function, need substitution of damaged components to recover normal operation

6.1 ESD Immunity test (IEC 61000-4-2)

The test was performed on a single test board. The input voltage was set to 230 V_{AC} and the output was loaded to full load and proper operation was verified through a current probe on the output.

The test conditions are listed below:

- Contact discharge and Air discharge methods
- Discharge circuit: 150pF/330Ω
- Polarity: positive / negative

Table 7. ESD contact discharge test results

Noise injection	ESD level	Polarity	Result	Criterion
L vs. PE	10 kV	Positive	PASS	A
L vs. PE	10 kV	Negative	PASS	A
N vs. PE	10 kV	Positive	PASS	A
N vs. PE	10 kV	Negative	PASS	A

Table 8. ESD contact discharge test results with PE connected on secondary GND

Noise injection	ESD level	Polarity	Result	Criterion
L vs. GND	8 kV	Positive	PASS	A
L vs. GND	8 kV	Negative	PASS	A
N vs. GND	8 kV	Positive	PASS	A
N vs. GND	8 kV	Negative	PASS	A

Table 9. ESD air discharge test results

Noise injection	ESD level	Polarity	Result	Criterion
Horizontal coupling plane	20 kV	Positive	PASS	A
Horizontal coupling plane	20 kV	Negative	PASS	A
Vertical coupling plane	20 kV	Positive	PASS	A
Vertical coupling plane	20 kV	Negative	PASS	A

6.2 Surge immunity test (IEC 61000-4-5)

The test was performed on a single test board. The input voltage was set to $230V_{AC}$ and the output was loaded with 10% of the nominal load and proper operation was verified connecting a current probe on the output.

The test conditions are listed below:

- Repetition rate: 1 minute
- Applied to: input lines vs. EARTH – Common Mode
- Applied to: both input line (L vs. N) – Differential Mode
- A network made up by a varistor and two Y1 capacitors is connected across the AC line connector according to the norm.

The test results are listed in the following tables.

Table 10. Common mode surge test results

Noise injection	Surge level	Polarity	Result	Criterion
L vs. PE	2 kV	Positive	PASS	A
N vs. PE	2 kV	Positive	PASS	A
L vs. PE	2 kV	Negative	PASS	A
N vs. PE	2 kV	Negative	PASS	A

Table 11. Differential mode surge test results

Noise injection	Surge level	Polarity	Result	Criterion
L vs. N	2 kV	Positive	PASS	A
L vs. N	2 kV	Negative	PASS	A

The tests performed show that the board is able to withstand lightning disturbances applied on the input line in Common Mode and Differential Mode for each severity level.

According to the standard, the application can be classified as level 3.

6.3 Burst immunity test (IEC 61000-4-4)

The test was performed on a single test board. The input voltage was set to $230V_{AC}$ and the output was loaded with 10% of the nominal load and proper operation was verified connecting a current probe on the output.

The test conditions are listed below:

- Polarity: positive/negative
- Burst duration: 15 ms ± 20 % at 5 kHz
- Burst period: 300 ms ± 20 %
- Duration time: 1 minute
- Applied to: AC lines through integrated capacitive coupling clamp.

Table 12. Burst test results

Noise injection	Burst level	Polarity	Result	Criterion
L / PE	4 kV	Positive	PASS	A
N / PE	4 kV	Positive	PASS	A
L / N	4 kV	Positive	PASS	A

Noise injection	Burst level	Polarity	Result	Criterion
L / PE	4 kV	Negative	PASS	A
N / PE	4 kV	Negative	PASS	A
L / N	4 kV	Negative	PASS	A

7 Thermal tests

A thermal analysis of the board was performed using an IR camera.

The board was submitted to full load at nominal input voltage and the thermal map was taken 30 minutes after the power on at ambient temperature (25 °C).

The following figures show the results.

Figure 26. Thermal map at 115 V_{AC} and full load (bottom side)

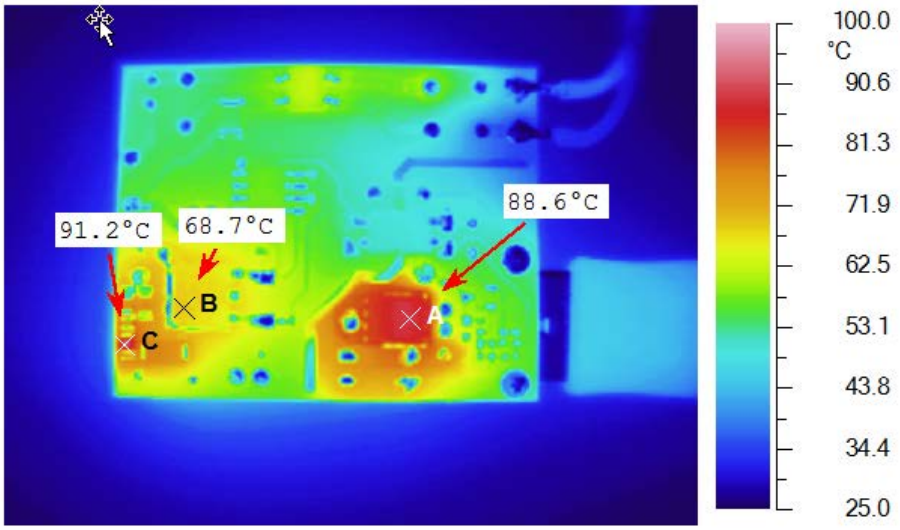


Figure 27. Thermal map at 115 V_{AC} and full load (top side)

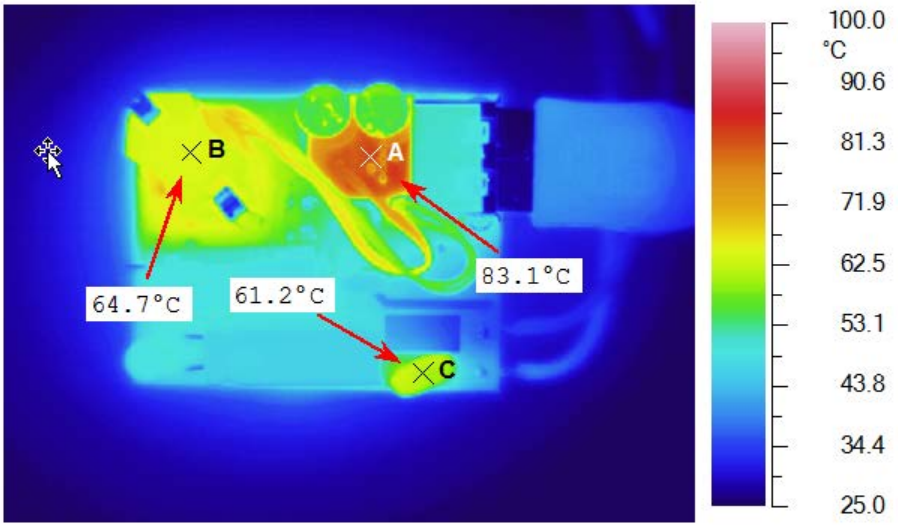


Figure 28. **Thermal map at 115 V_{AC} and full load (transformer)**

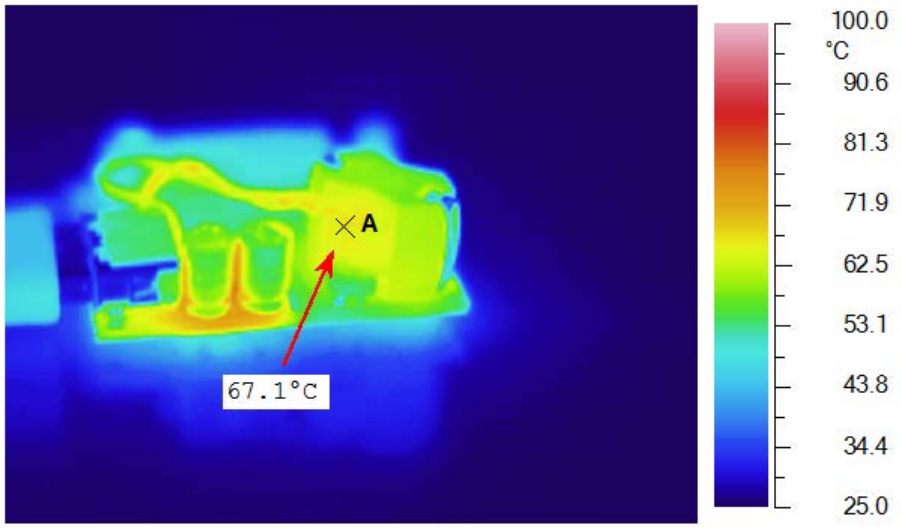


Figure 29. **Thermal map at 230 V_{AC} and full load (bottom side)**

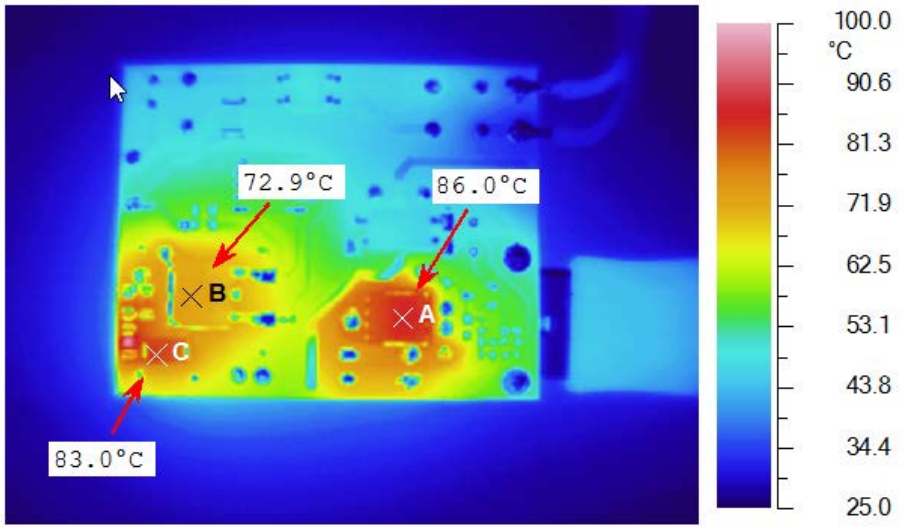


Figure 30. **Thermal map at 230 V_{AC} and full load (top side)**

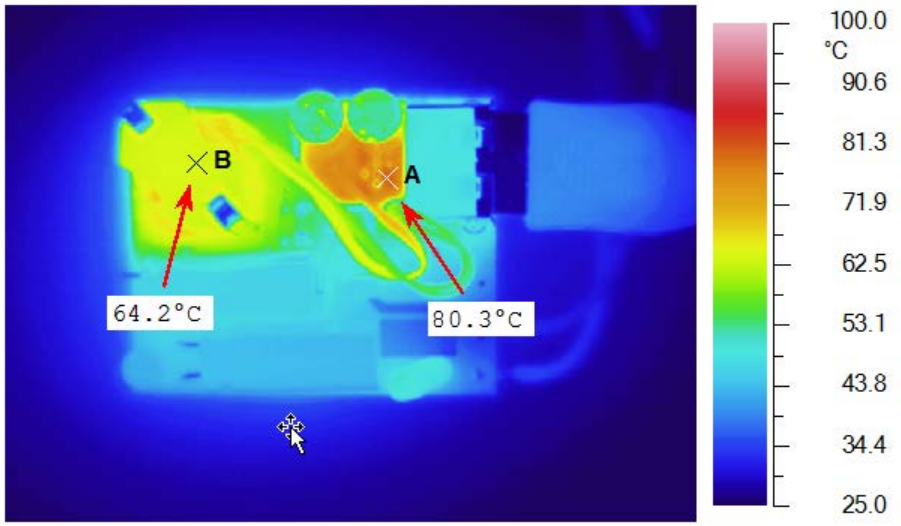
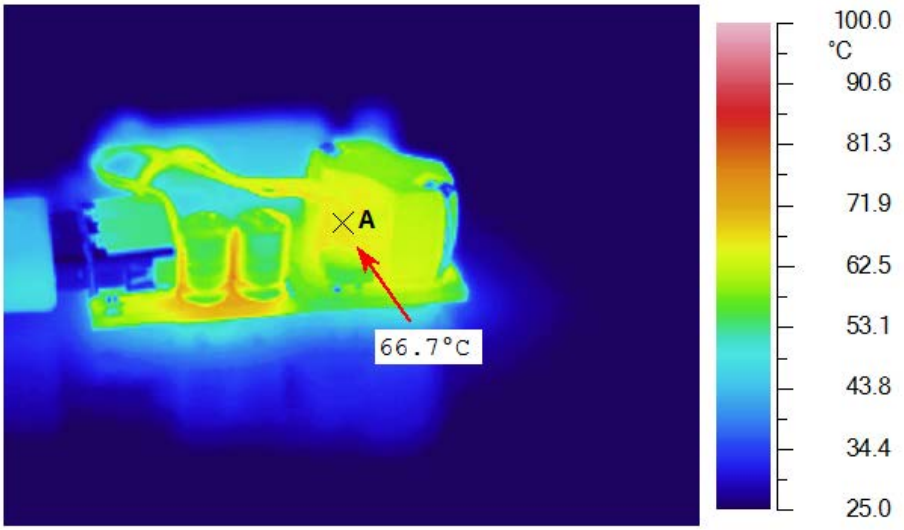


Figure 31. **Thermal map at 230 V_{AC} and full load (transformer)**



8 Conclusions

A 15 W wide range mains USB adapter using the new STCH03 was subjected to testing.

The results are very positive in terms of electrical performance.

The high efficiency and low standby consumption render the STCH03 a highly suitable IC for low or medium output power level USB adapters in a wide range of high performance, low cost chargers for mobile phones, tablets and hand-held equipment.

Revision history

Table 13. **Document revision history**

Date	Version	Changes
19-Jun-2018	1	Initial release.

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