14 W 15 V 5 V SMPS demo board with ICE5AR4770AG

DEMO_5AR4770AG_14W1

About this document

Scope and purpose

This document is an engineering report that describes a universal-input 14 W 15 V 5 V off-line non-isolated Flyback converter using the latest fifth-generation Infineon Fixed Frequency (FF) CoolSET™ ICE5AR4770AG, which offers high-efficiency, low-standby power with selectable entry and exit standby power options, wide V_{CC} operating range with fast start-up, robust line protection with input Over Voltage Protection (OVP) and various protection modes for a highly reliable system. This demo board is designed for users who wish to evaluate ICE5AR4770AG in terms of optimized efficiency, thermal performance and EMI.

Intended audience

This document is intended for power supply design/application engineers, students, etc. who wish to design low-cost and highly reliable systems of off-line SMPS, either for auxiliary power supplies for white goods, PCs, servers and TVs, or enclosed adapters for Blu-ray players, set-top boxes, games consoles, etc.

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1 Abstract

This document is an engineering report for a 14 W 15 V 5 V demo board designed in an FF non-isolated Flyback converter topology with primary-side feedback (FB) using the fifth-generation FF CoolSET™ ICE5AR4770AG. The demo board is operated in Discontinuous Conduction Mode (DCM) and is running at 100 kHz fixed switching frequency. The frequency reduction with soft gate driving and frequency jittering offers lower EMI and better efficiency between light load and 50% load. The selectable Active Burst Mode (ABM) power enables ultra-low power consumption. In addition, numerous adjustable protection functions have been implemented in ICE5AR4770AG to protect the system and customize the IC for the chosen application. In case of failure modes such as line OV, V_{CC} OV/Under Voltage (UV), open control-loop or over-load, over-temperature, V_{CC} short-to-GND and CS short-to-GND, the device enters protection mode. By means of the cycle-by-cycle Peak Current Limitation (PCL), the dimensions of the transformer and the current rating of the secondary diode can both be optimized. In this way, a cost-effective solution can easily be achieved. The target applications of ICE5AR4770AG are either auxiliary power supplies for white goods, PCs, servers and TVs, or enclosed adapters for Blu-ray players, set-top boxes, games consoles, etc.

2 Demo board

This document contains the list of features, the power supply specifications, schematics, Bill of Materials (BOM) and the transformer construction documentation. Typical operating characteristics such as performance curve and scope waveforms are shown at the end of the report.

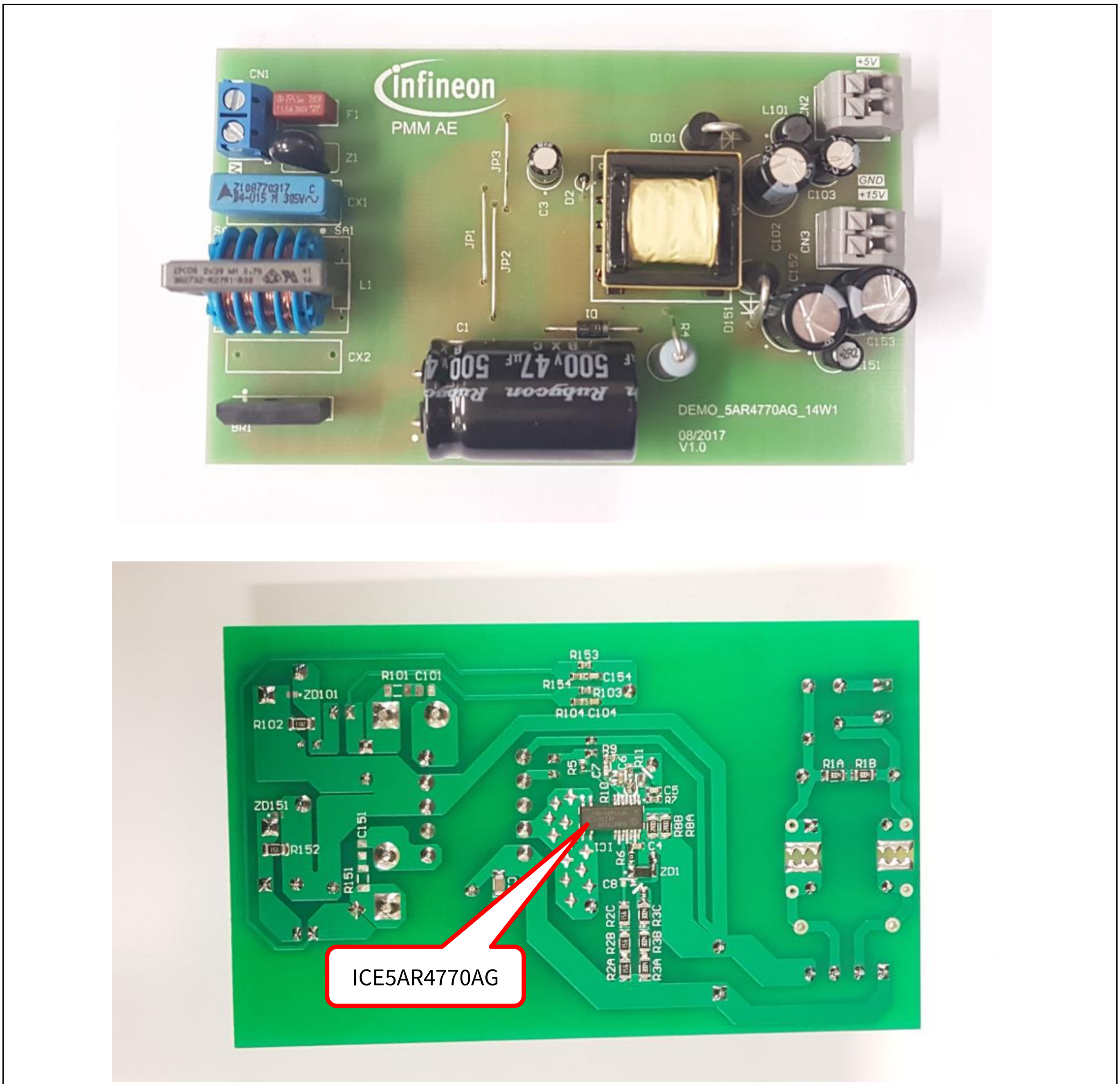


Figure 1 DEMO_5AR4770AG_14W1

3 Specification of the demo board

Table 1

Input voltage and frequency	85 V AC (60 Hz) ~ 300 V AC (50 Hz)
Output voltage, current and power	(15 V × 0.83 A) + (5 V × 0.40 A) = 14.45 W
Regulation	+5 V: less than ±5% +15 V: less than ±15%
Output ripple voltage (full load, 85 V AC ~ 300 V AC)	5 $V_{ripple\_p\_p}$ < 100 mV 15 $V_{ripple\_p\_p}$ < 200 mV
Active mode four-point average efficiency (25%, 50%, 75%, 100% load)	> 83% at 115 V AC and 230 V AC
Standby power consumption	No load: P_{IN} < 100 mW at 230 V AC 60 mW load: P_{IN} < 170 mW at 230 V AC
Conducted emissions (EN 55022 class B)	Pass with 6.3 dB margin for 115 V AC and 8.4 dB margin for 230 V AC
Surge immunity (EN 61000-4-5)	Installation class 4 (±2 kV for line-to-line)
Form factor case size (L × W × H)	(110 × 66 × 27) mm^3

Note: *"The demo board is designed for dual-output with cross-regulated loop FB. It may not regulate properly if loading is applied only to single-output. If the user wants to evaluate for single-output (15 V only) conditions, the following changes are necessary on the board.*

1. Remove D101, L101, C102, C103, R102, R103, R104 and C104 (to disable 5 V output).

2. Change R11 to 30 kΩ and R153 to 220 kΩ (full regulation FB at 15 V output).

Since the board (especially the transformer) is designed for dual-output with optimized cross-regulation, single-output efficiency might not be optimized. It is only for IC functional evaluation under single-output conditions."

4 Circuit description

4.1 Line input

The AC-line input side comprises the input fuse F1 as Over Current Protection (OCP). The choke L1 and X-capacitor CX1 act as EMI suppressors. Optional spark-gap devices SA1, SA2 and varistor Z1 can absorb HV stress during a lightning surge test. A rectified DC voltage (120 ~ 424 V DC) is obtained through the bridge rectifier BR1 together with bulk capacitor C1.

4.2 Start-up

To achieve fast and safe start-up, ICE5AR4770AG has been implemented with start-up resistor and V_{CC} short-to-GND protection. When V_{VCC} reaches the turn-on voltage threshold of 16 V, the IC begins with a soft-start. The soft-start implemented in ICE5AR4770AG is a digital time-based function. The preset soft-start time is 12 ms with four steps. If not limited by other functions, the peak voltage on the CS pin will increase incrementally from 0.3 V to 0.8 V. After IC turn-on, the V_{CC} voltage is supplied by auxiliary windings of the transformer. V_{CC} short-to-GND protection is implemented during the start-up time.

4.3 Integrated CoolMOS™ with frequency reduction control

ICE5AR4770AG is comprised of a CoolMOS™ and the frequency reduction controller, which enables better efficiency between light load and 50% load. This integrated solution greatly simplifies the circuit layout and reduces the cost of PCB manufacturing. The new CoolSET™ can be operated in either DCM or Continuous Conduction Mode (CCM) with frequency reduction mode. This demo board is designed to operate in DCM. When the system is operating at maximum power, the controller will switch at the FF of 100 kHz. In order to achieve better efficiency between light load and medium load, frequency reduction is implemented and the reduction curve is shown in Figure 2. The V_{CS} is clamped by the current limitation threshold or by the PWM op-amp while the switching frequency is reduced. After the maximum frequency reduction, the minimum switching frequency is f_{OSC4_MIN} (43 kHz).

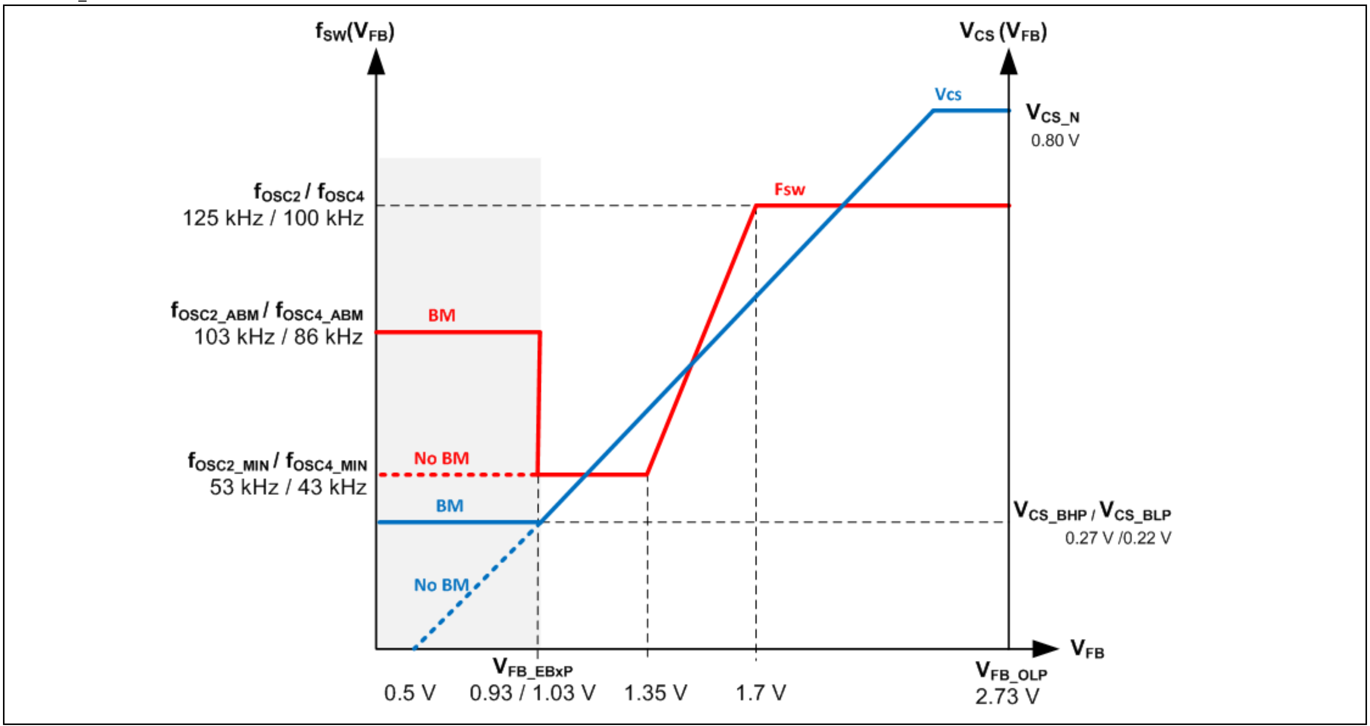


Figure 2 Frequency reduction curve

4.4 Frequency jittering

The ICE5AR4770AG has a frequency jittering feature to reduce the EMI noise. The jitter frequency is internally set at 100 kHz (±4 kHz), and the jitter period is 4 ms.

4.5 RCD clamper circuit

A clamper network (R4, C2 and D1) dissipates the energy of the leakage inductance and suppresses ringing on the SMPS transformer.

4.6 Output stage

There are two outputs in this converter, 15 V and 5 V. The power is coupled out via Schottky diodes D151 and D101. The capacitors C152 and C102 provide energy buffering, followed by the L-C filters L151-C153 and L101-C103 to reduce the output voltage ripple and prevent interference between SMPS switching frequency and line frequency. Storage capacitors C152 and C102 are selected to have a very small internal resistance (ESR) to minimize the output voltage ripple.

4.7 Feedback loop

For FB, the output is sensed by the voltage divider of R11, R103 and R153 compared to the internal reference voltage of ICE5AR4770AG via the V_{ERR} pin, which is connected to the input of an integrated error amplifier internally. Connecting this pin enables non-isolated application. Feed-forward circuit R154, C154, R104 and C104 comprises the compensation network. The comparison voltage is converted to the current signal via an IC internal error amplifier to the FB pin for regulation control.

4.8 Active Burst Mode (ABM)

ABM entry and exit power (three levels) can be selected in ICE5AR4770AG. Details are illustrated in the product datasheet. Under light-load conditions, the SMPS enters ABM. At this stage, the controller is always active but the V_{VCC} must be kept above the switch-off threshold. During ABM, the efficiency increases significantly and at the same time it supports low ripple on V_{out} and fast response on load-jump.

In order to enter ABM operation, two conditions must apply:

1. The FB voltage must be lower than the threshold of V_{FB_EBXP}.
2. There must be a certain blanking time (t_{FB_BEB} = 36 ms).

Once both of these conditions are fulfilled, the ABM flip-flop is set and the controller enters ABM operation. This dual-condition determination for entering ABM operation prevents mis-triggering of ABM, so that the controller enters ABM operation only when the output power is really low during the preset blanking time.

During ABM, the maximum Current Sense (CS) voltage is reduced from V_{CS_N} to V_{CS_BXP} to reduce the conduction loss and the audible noise. In ABM, the FB voltage is changing like a sawtooth between $V_{FB\_Bon\_NISO}$ and $V_{FB\_Boff\_NISO}$.

The FB voltage immediately increases if there is a high load-jump. This is observed by one comparator. As the current limit is 27/33% during ABM a certain load is needed so that the FB voltage can exceed V_{FB_LB} (2.73 V). After leaving ABM, maximum current can now be provided to stabilize V_{out}.

5 Protection features

Protection is one of the major factors in determining whether the system is safe and robust. Therefore sufficient protection is necessary. ICE5AR4770AG provides comprehensive protection to ensure the system is operating safely. These protections include line OV, V_{CC} OV and UV, over-load, over-temperature (controller junction), CS short-to-GND and V_{CC} short-to-GND. When those faults are found, the system will enter protection mode until the fault is removed, when the system resumes normal operation. A list of protections and the failure conditions are shown in the table below.

Table 2 Protection functions of ICE5AR4770AG

Protection function	Failure condition	Protection mode
Line OV	V_{VIN} > 2.85 V	Non-switch auto restart
V_{CC} OV	V_{VCC} > 25.5 V	Odd-skip auto restart
V_{CC} UV	V_{VCC} < 10 V	Auto restart
Over-load	V_{FB} > 2.73 V and lasts for 54 ms	Odd-skip auto restart
Over-temperature (junction temperature of controller chip only)	T_J > 140°C	Non-switch auto restart
CS short-to-GND	V_{CS} < 0.1 V, last for 0.4 µs and three consecutive pulses	Odd-skip auto restart
V_{CC} short-to-GND (V_{VCC} = 0 V, $R_{Start-up}$ = 50 MΩ and V_{DRAIN} = 90 V)	V_{VCC} < 1.2 V, $I_{VCC\_Charge1}$ ≈ -0.27 mA	Cannot start up

6 Circuit diagram

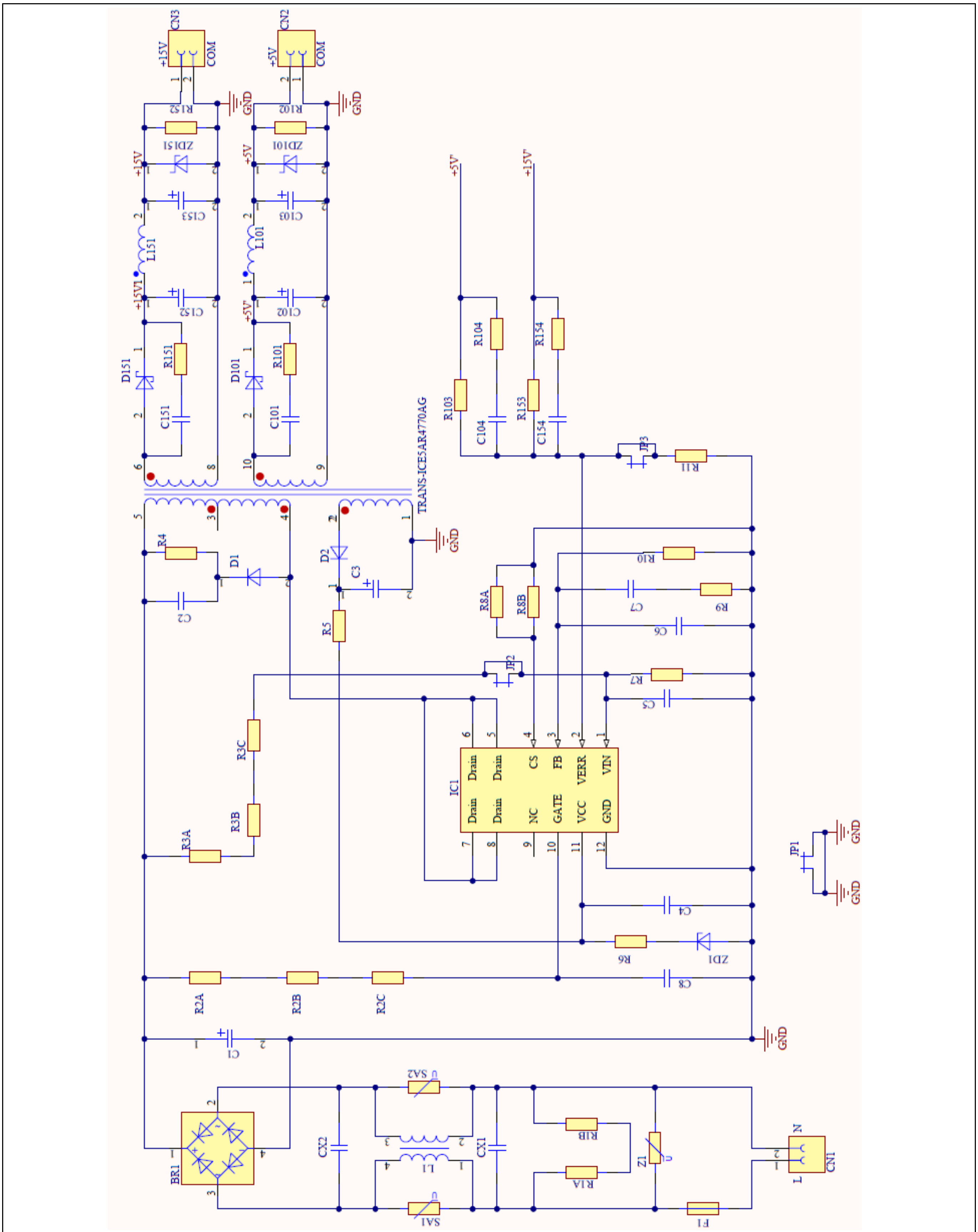


Figure 3 Schematic of DEMO_5AR4770AG_14W1

7 PCB layout

7.1 Top side

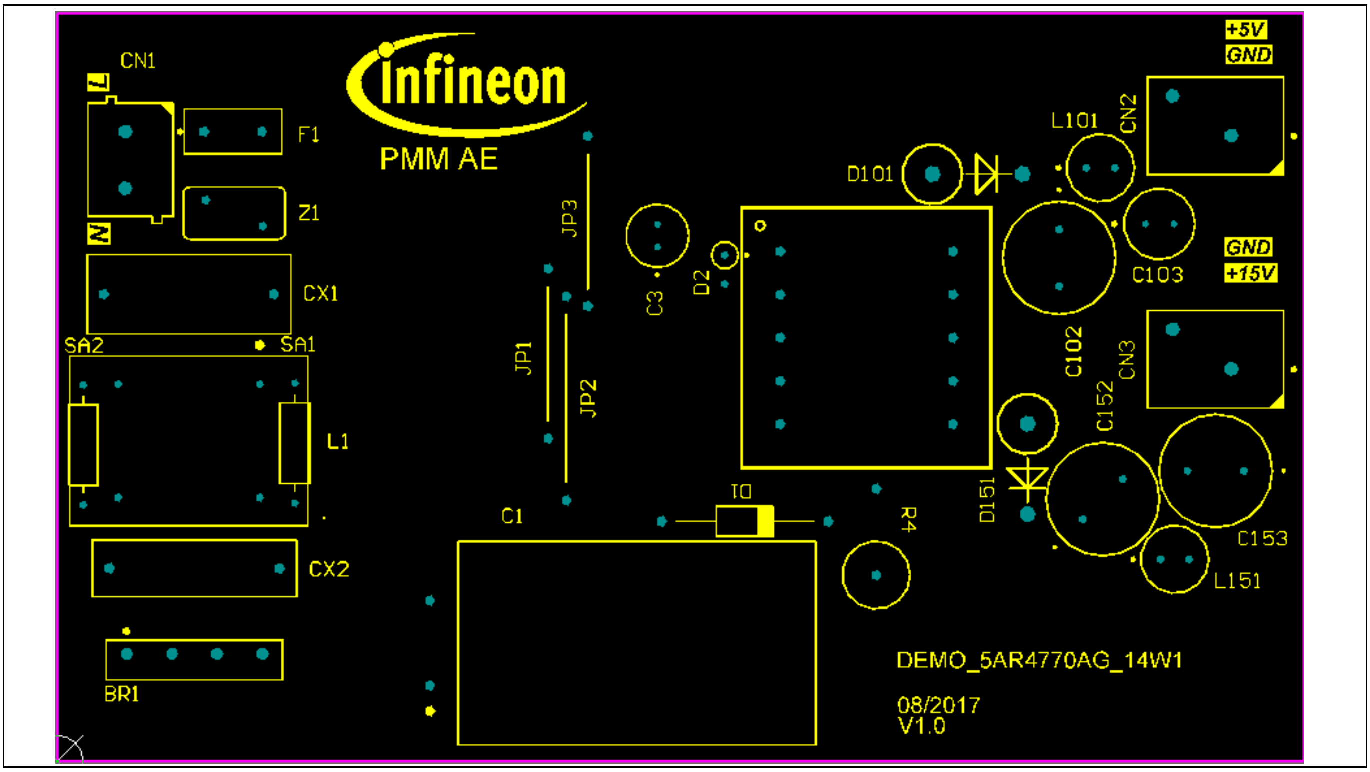


Figure 4 Top side component legend

7.2 Bottom side

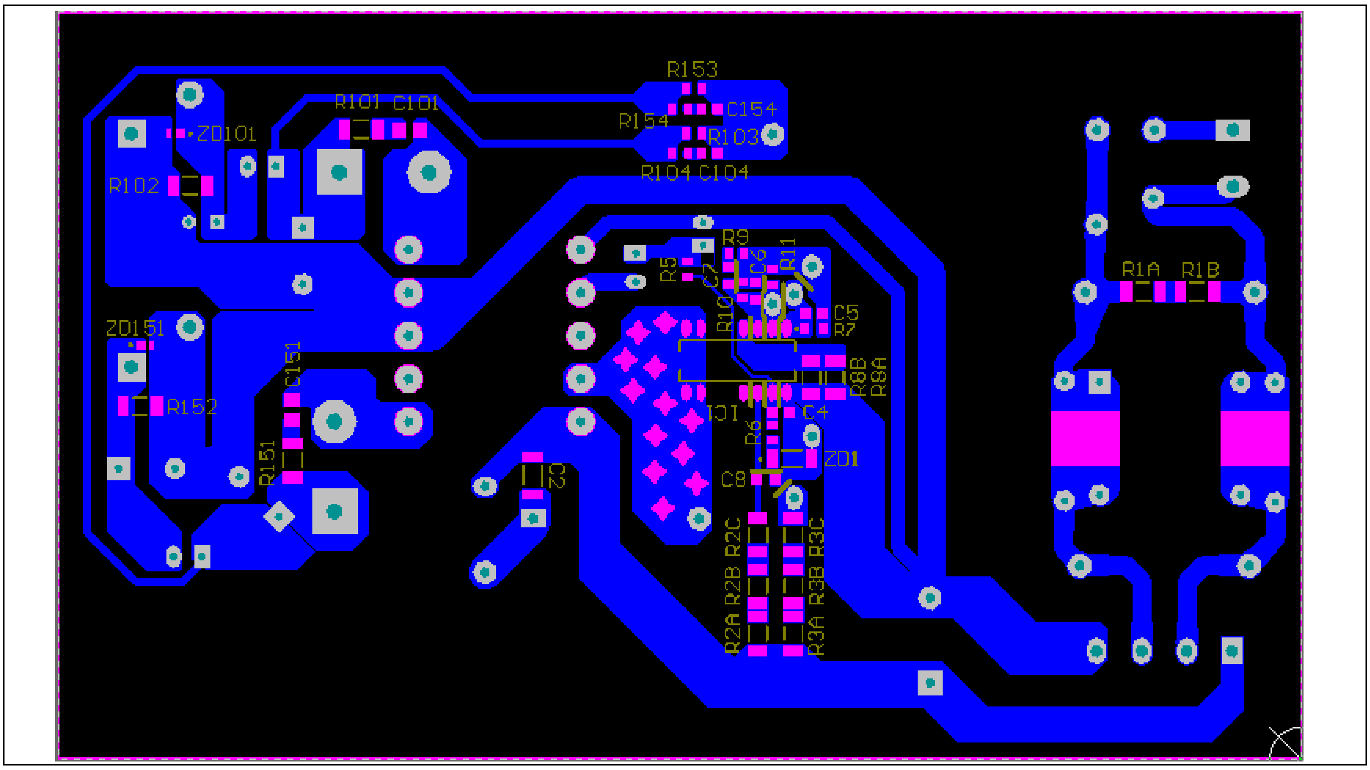


Figure 5 Bottom side copper and component legend

8 Bill of Materials (BOM)

Table 3 BOM

No.	Designator	Description	Part number	Manufacturer	Quantity
1	F1	1.6 A/300 V	36911600000	Littlefuse	1
2	Z1	Varistor, 0.3 W/320 V	ERZE07A511	Panasonic	1
3	BR1	600 V/1 A	S1VBA60	Shindengen	1
4	CX1	0.15 µF, X-cap	B32922C3154M000	EPCOS / TDK	1
5	C1	47 uF/500 V	500BXC47MEFC18X31.5	Rubycon	1
6	C2	1 nF/630 V (1206)	GRM31A7U2J102JW31D	Murata	1
7	C3	22 µF/50 V	50PX22MEFC5X11	Rubycon	1
8	C4	0.1 uF/50 V DC	GRM188R71H104KA93D	Murata	1
9	C5, C154	1000 pF/50 V DC	GRM1885C1H102GA01D	Murata	2
10	C6, C104	4700 pF/50 V DC	GRM188R71H472KA01D	Murata	2
11	C7	15 pF/50 V DC	GRM1885C1H150JA01D	Murata	1
12	C102	680 uF/10 V DC	10ZL680MEFC8X16	RUBYCON	1
13	C103	330 uF/10 V DC	10ZLH330MEFC6.3X11	RUBYCON	1
14	C152, C153	680 uF/25 V DC	25ZLS680MEFC10X16	RUBYCON	2
15	ZD1	22 V/500 mW	BZS55B22 RXG		1
16	D1	1 A/ 800 V	UF4006-E3/54		1
17	D2	0.2 A/200 V	1N485B		1
18	D151	3 A/150 V	STPS3150		1
19	D101	3 A/60 V	MBR360		1
20	IC1	ICE5AR4770AG	ICE5AR4770AG	Infineon	1
21	L1	39 mH/0.7 A	B82732R2701B030	EPCOS / TDK	1
22	L101, L151	2.2 uH/4.3 A	744 746 202 2	Wurth Electronics	2
23	R1A, R1B	3 MΩ/0.25 W/5%/1206			2
24	R2A, R2B, R2C	15 MΩ/0.25 W/5%/1206	RC1206JR-0715ML	Yageo	3
25	R3A, R3B, R3C	3 MΩ/0.25 W/1%/1206	RC1206FR-073ML	Yageo	3
26	R4	68 kΩ/2 W/500 V	MO2CT631R683J	KOA Speer	1
27	R5	4.7 Ω/0.1 W/5%/0603			1
28	R6	0 Ω/0603			1
29	R7	56 kΩ/0.1 W/±1%/0603			1
30	R8A, R8B	2 Ω/0.25 W/±1%/1206	RC1206FR-072RL	Yageo	2
31	R9	260 kΩ/0.1 W/0603			1
32	R11	27 kΩ/0.1 W/1%/0603			1
33	R154	33 kΩ/0.1 W/1%/0603			1
34	R103	68 kΩ /0.1 W/1%/0603			1
35	R104	4.7 kΩ/0.1 W/1%/0603			1
36	R153	680 kΩ/0.1 W/1%/0603			1
37	R102	11 kΩ/0.25 W/5%/1206			1
38	R152	15 kΩ/0.25 W/5%/1206			1
39	T1	550 uH, EE20_H	750343669	Wurth Electronics	1
40	CN1	Connector	691102710002	Wurth Electronics	1
41	CN2,CN3	Connector	691 412 120 002B	Wurth Electronics	2
42	JP1-JP3	Jumper			3
43	PCB	110 mm × 66 mm (LXW), single layer, 2 Oz., FR-4			1

9 Transformer construction

Core and materials: EE20/10/6, TP4A (TDG)

Bobbin: 070-4989 (10-pin, THT, horizontal version)

Primary inductance: Lp = 550 µH (±10%), measured between pin 4 and pin 5

Manufacturer and part number: Wurth Electronics Midcom (750343669)

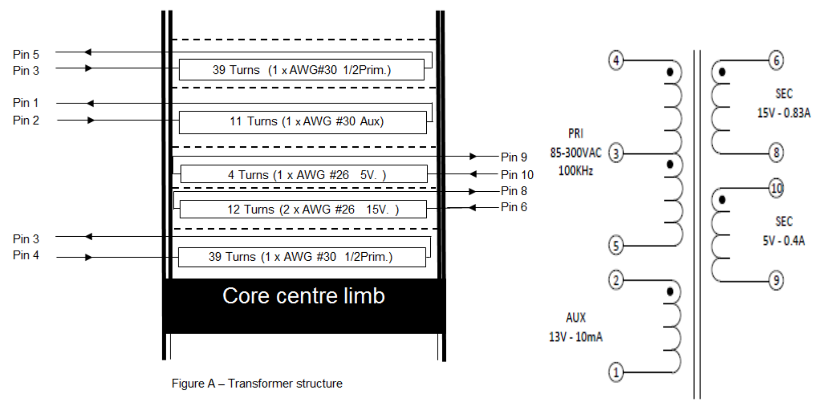
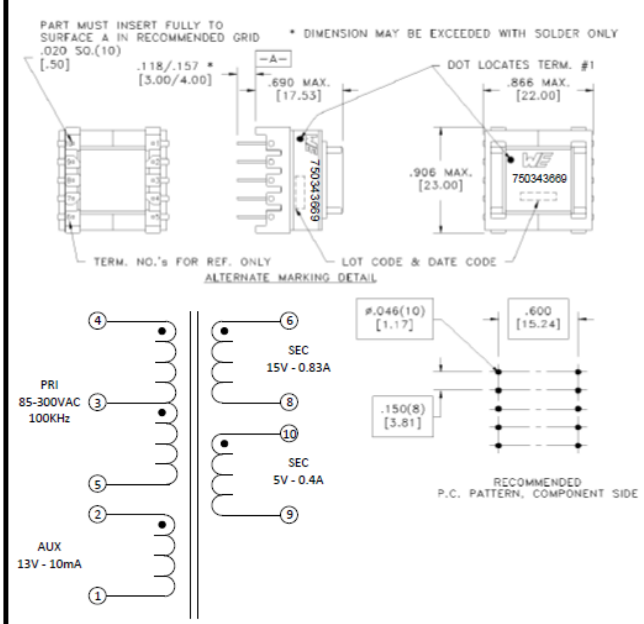


Figure A – Transformer structure

Start	Stop	No. of turns	Wire size	Layer
4	3	39	1 x AWG#30	1/2 Primary
6	8	12	2 x AWG #26	15V
10	9	4	1 x AWG #26	5V
2	1	11	1 x AWG#30	Auxiliary
3	5	39	1 x AWG#30	1/2 Primary

CUSTOMER TERMINAL	RoHS	LEAD(Pb)–FREE
Sn 96%, Ag 4%	Yes	Yes



ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	1-2	@20ºC	0.175 ohms max.
D.C. RESISTANCE	4-5	@20ºC	1.100 ohms max.
D.C. RESISTANCE	6-8	@20ºC	0.037 ohms max.
D.C. RESISTANCE	9-10	@20ºC	0.032 ohms max.
INDUCTANCE	4-5	10kHz, 100mV, Ls	550.00uH ±10%
LEAKAGE INDUCTANCE	4-5	tie(1+2+6+8+9+10),100kHz, 100mV, Ls	13µH max.
DIELECTRIC	5-6	tie(2+3, 8+9), 1875VAC, 1 second	
TURNS RATIO		(4-5):(2-1)	7.09:1, ±2%
TURNS RATIO		(4-5):(6-8)	6.50:1, ±2%
TURNS RATIO		(4-5):(10-9)	19.05:1, ±2%

GENERAL SPECIFICATIONS:

OPERATING TEMPERATURE RANGE: -40°C to +125°C including temp rise.

- Functional insulation only

Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability.

DFM		Packaging Specifications Method: Tray PKG-0736	Tolerances unless otherwise specified: Angles: ±1° Decimals: ±.005 [.13] Fractions: ±1/64 Footprint: ± .001 [.03]	DRAWING TITLE TRANSFORMER	PART NO. 750343669
DATE					
ENG	NWA	CONVENTION PLACEMENT			
REV.	00		This drawing is dual dimensioned. Dimensions in brackets are in millimeters.		SPECIFICATION SHEET 1 OF 1
DATE	2017-7-25				

Figure 6 Transformer structure

10 Test results

10.1 Efficiency, regulation and output ripple

Table 4 Efficiency, regulation and output ripple

Input (V AC/Hz)	P_{IN} (W)	15 V (V)	I_{out_15} V (mA)	5 V (V)	I_{out_5V} (mA)	15 V_{RPP} (mV)	5 V_{RPP} (mV)	P_{out} (W)	Efficiency (η) (%)	Average η (%)	OLP P_{IN} (W)	OLP $I_{out15\,V}$ (fixed 5 V at 0.4 A) (A)
85 V AC/ 60 Hz	0.039	15.18	0	5.00	0	27.1	12.5				22.70	1.07
	0.129	16.94	0	4.82	12	19.4	23	0.06				
	4.469	15.21	207.8	4.99	100.1	31.8	9.9	3.66	81.90	81.95		
	8.848	15.18	414.7	4.99	200.2	45	10.5	7.29	82.44			
	13.326	15.20	622.3	4.98	300.3	55.1	11.3	10.95	82.20			
	17.992	15.22	829.6	4.98	400.3	64.2	11.5	14.62	81.25			
115 V AC/ 60 Hz	0.043	15.19	0	5.00	0	26.5	13.1				22.03	1.07
	0.134	17.01	0	4.81	12	18.9	24.7	0.06				
	4.428	15.21	207.8	4.99	100.1	31.5	10	3.66	82.66	83.37		
	8.729	15.20	414.7	4.99	200.2	46.8	11.4	7.30	83.65			
	13.090	15.21	622.3	4.98	300.2	55.2	11.9	10.96	83.74			
	17.534	15.23	829.6	4.98	400.2	64.6	12.4	14.63	83.41			
230 V AC/ 50 Hz	0.069	15.24	0	4.99	0	30.7	13.9				21.96	1.10
	0.163	17.14	0	4.80	12	20.7	28.3	0.06				
	4.478	15.21	207.8	4.99	100.1	33.7	10.8	3.66	81.73	83.80		
	8.719	15.25	414.7	4.98	200.2	46.9	11.3	7.32	83.95			
	12.977	15.27	622.3	4.98	300.2	57.5	12.5	11.00	84.73			
	17.266	15.25	829.6	4.98	400.2	73	12.7	14.64	84.81			
265 V AC/ 50 Hz	0.080	15.24	0	4.99	0	30.5	13				22.41	1.13
	0.168	17.18	0	4.80	12	21.5	25.8	0.06				
	4.513	15.21	207.8	4.99	100.1	33.9	11.2	3.66	81.12	83.46		
	8.750	15.24	414.7	4.99	200.2	48.8	12.5	7.32	83.61			
	13.034	15.27	622.3	4.98	300.2	59	12.8	11.00	84.39			
	17.300	15.27	829.6	4.98	400.2	69.8	13.5	14.66	84.72			
300 V AC/ 50 Hz	0.093	15.25	0	4.99	0	34.2	13.7				22.95	1.15
	0.188	17.21	0	4.79	12	22.4	28.6	0.06				
	4.558	15.23	207.8	4.99	100.1	35.5	12.5	3.66	80.38	82.94		
	8.834	15.23	414.7	4.99	200.2	49.8	13.2	7.31	82.79			
	13.085	15.26	622.3	4.98	300.2	60.2	12.5	10.99	84.00			
	17.348	15.29	829.6	4.98	400.2	70.4	13.7	14.67	84.59			

60 mW load condition: 5 V @ 12 mA and 15 V @ 0 mA

Full-load condition: 5 V @ 400 mA and 15 V @ 830 mA

10.2 Efficiency

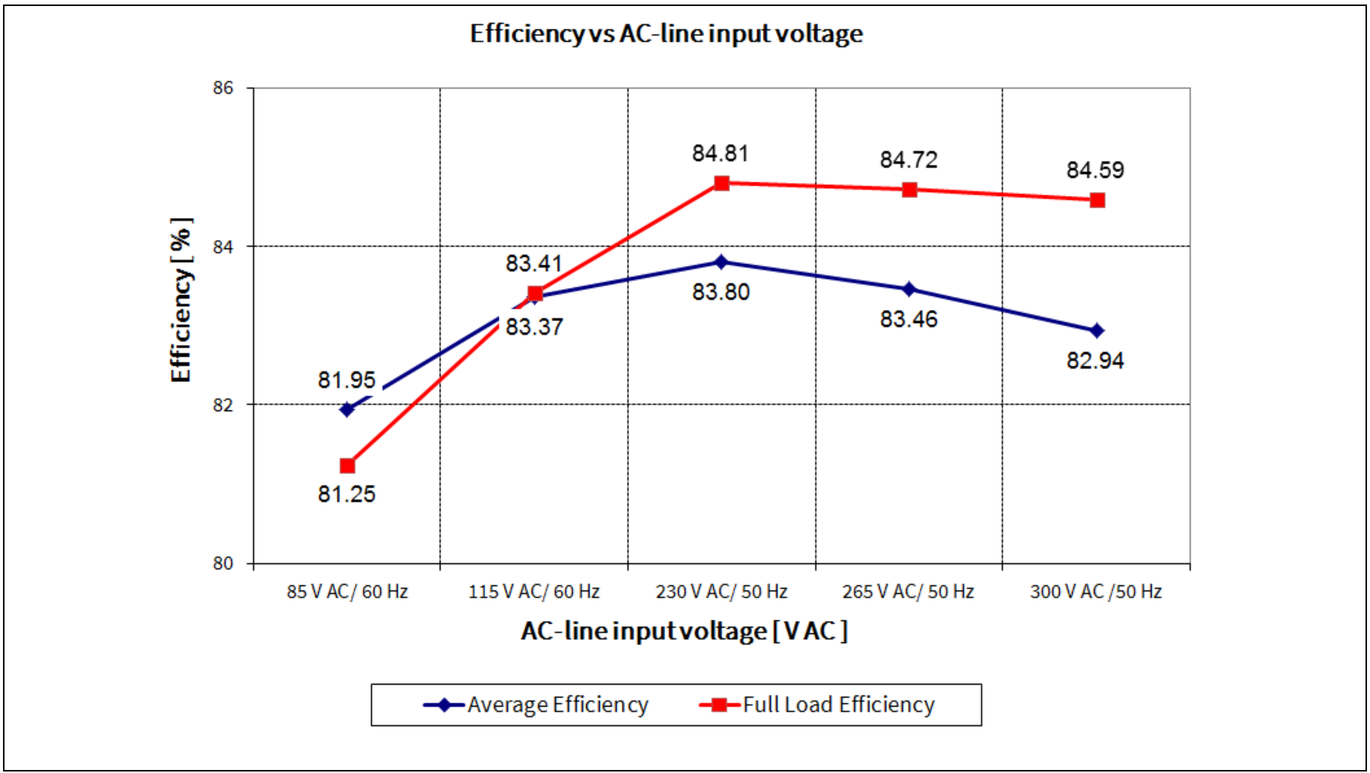


Figure 7 Efficiency vs AC-line input voltage

10.3 Standby power

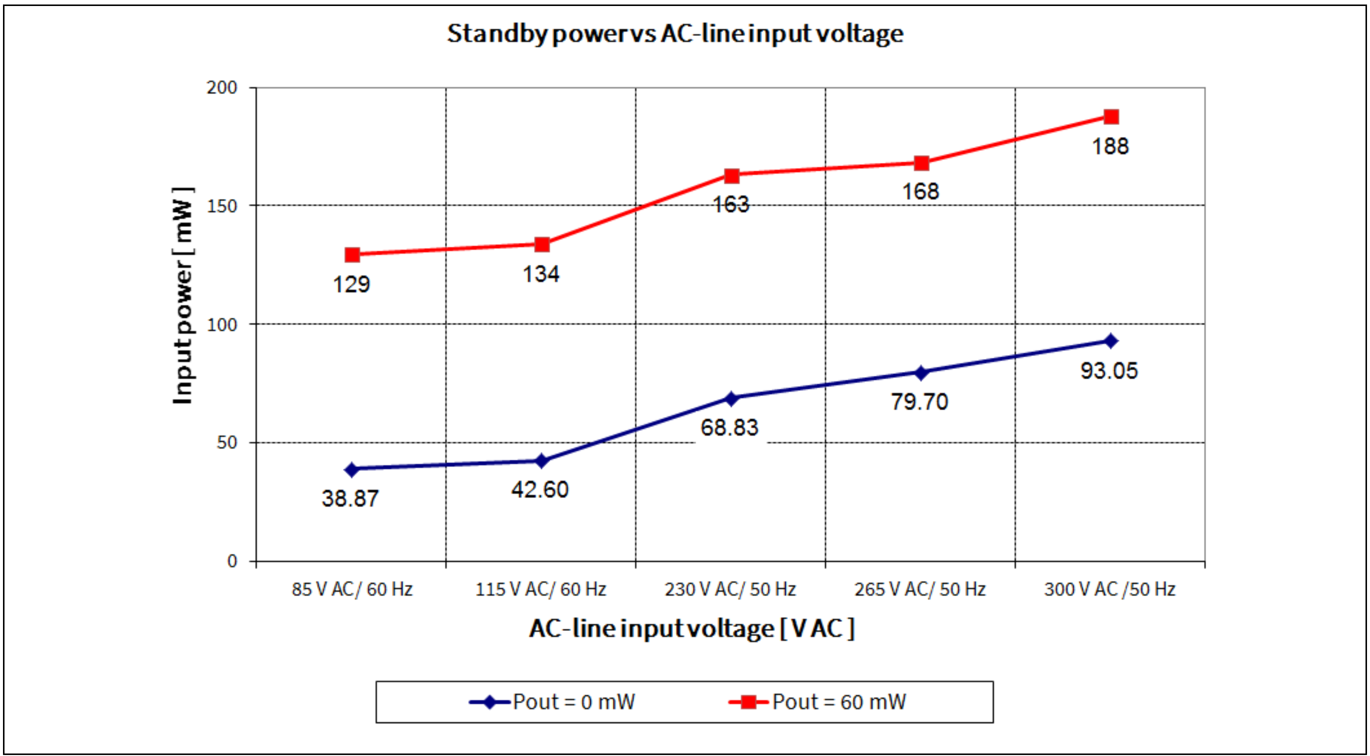


Figure 8 Standby power vs AC-line input voltage (measured by Yokogawa WT310HC power meter – integration mode)

10.4 Line regulation

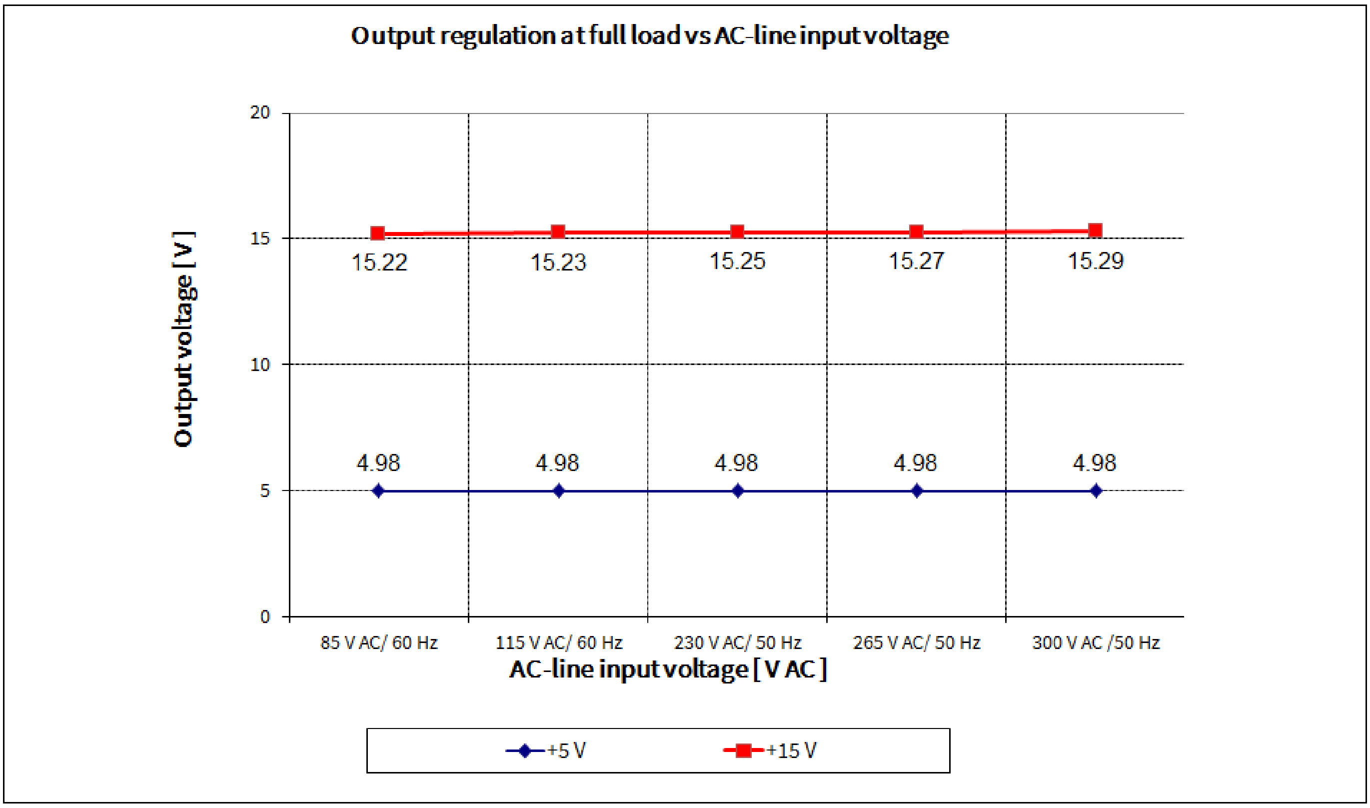


Figure 9 Output regulation at full load vs AC-line input voltage

10.5 Load regulation

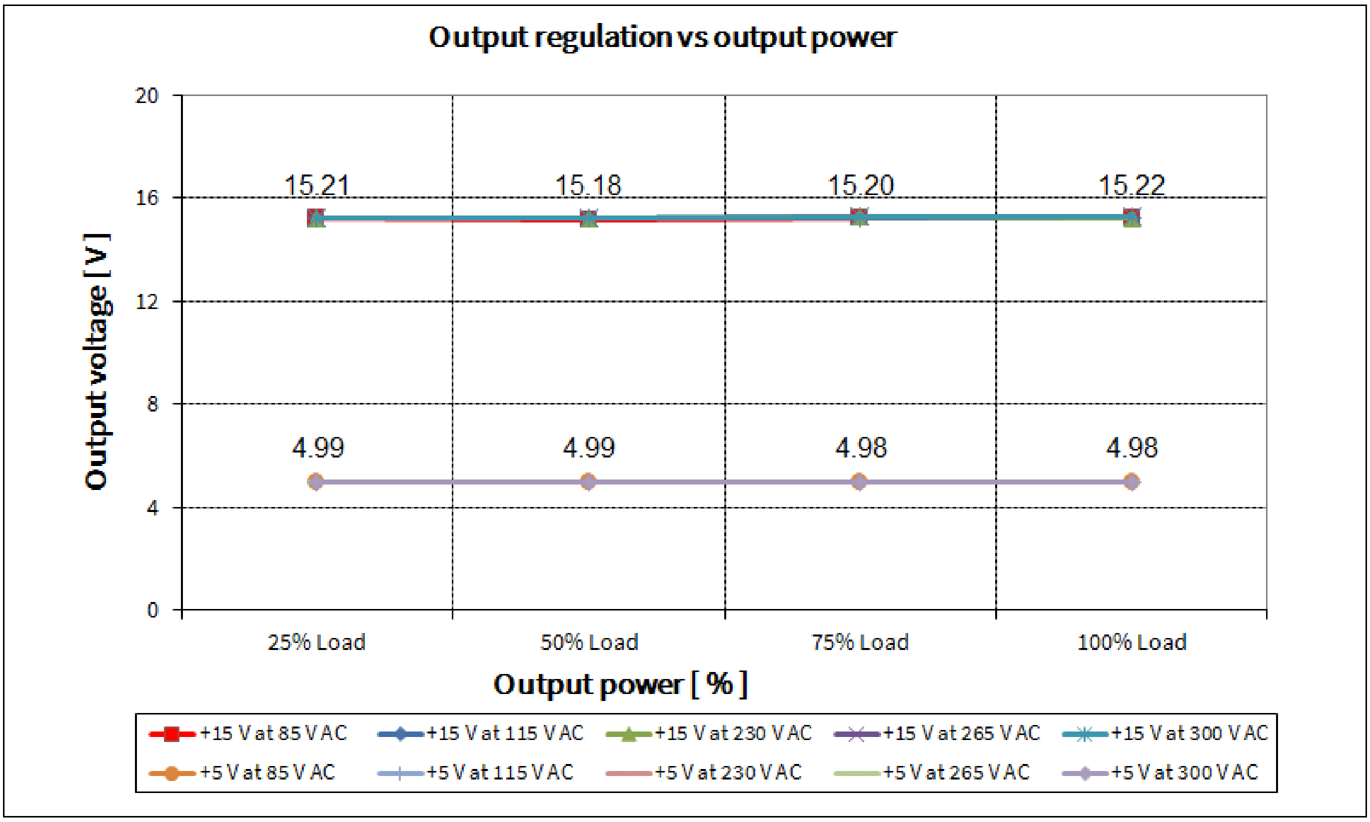


Figure 10 Output regulation vs output power

10.6 Maximum input power

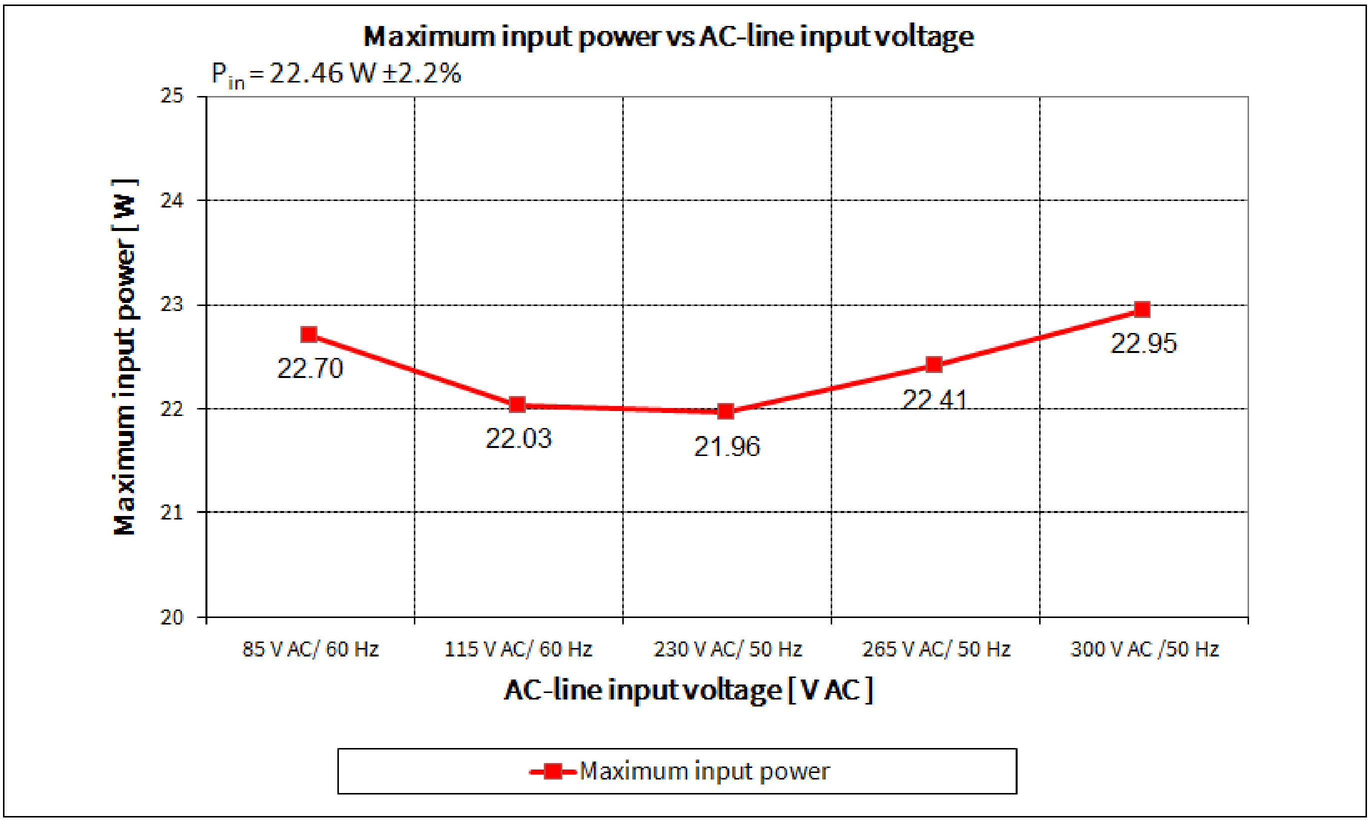


Figure 11 Maximum input power (before over-load protection) vs AC-line input voltage

10.7 Frequency reduction

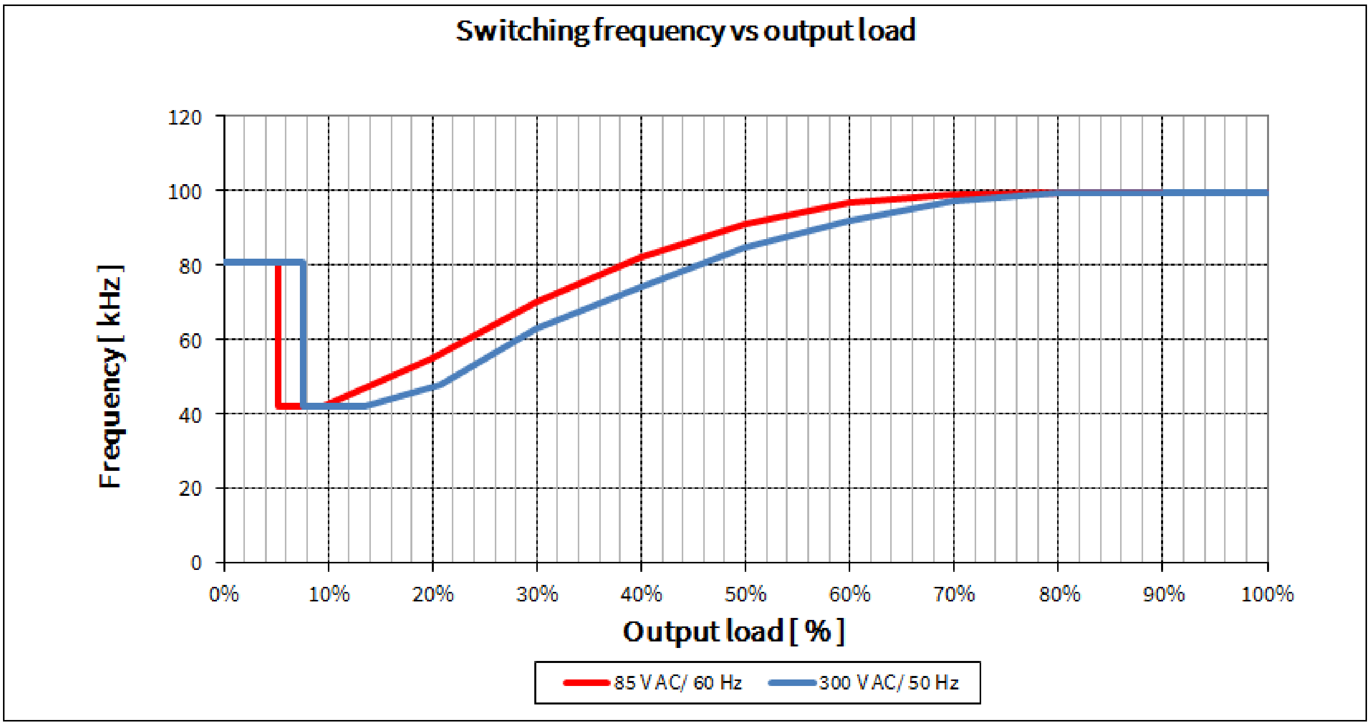


Figure 12 Frequency reduction curve vs output load

10.8 Surge immunity (EN 61000-4-5)

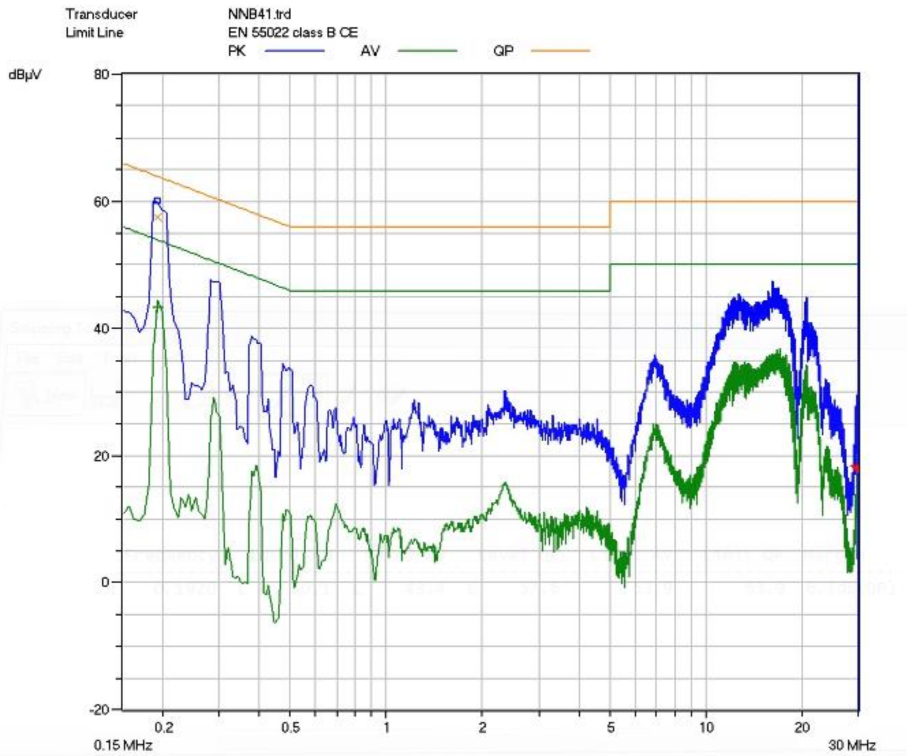
Pass EN 61000-4-5 installation class 4 (±2 kV for line-to-line).[1]

10.9 Conducted emissions (EN 55022 class B)

The conducted EMI was measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) class B. The demo board is tested at full load (14.45 W) using resistive load at an input voltage of 115 V AC and 230 V AC.

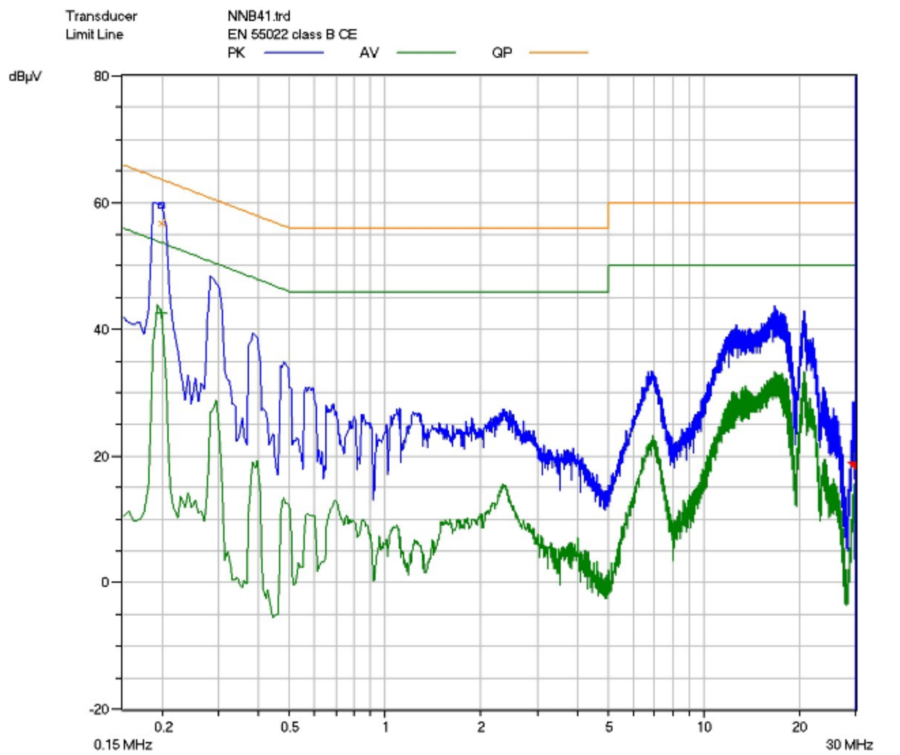
Pass conducted emissions EN 55022 (CISPR 22) class B with 6.3 dB margin at low-line (115 V AC) and 8.4 dB margin at high-line (230 V AC).

[1] PCB spark-gap distance needs to reduce to 0.5 mm.



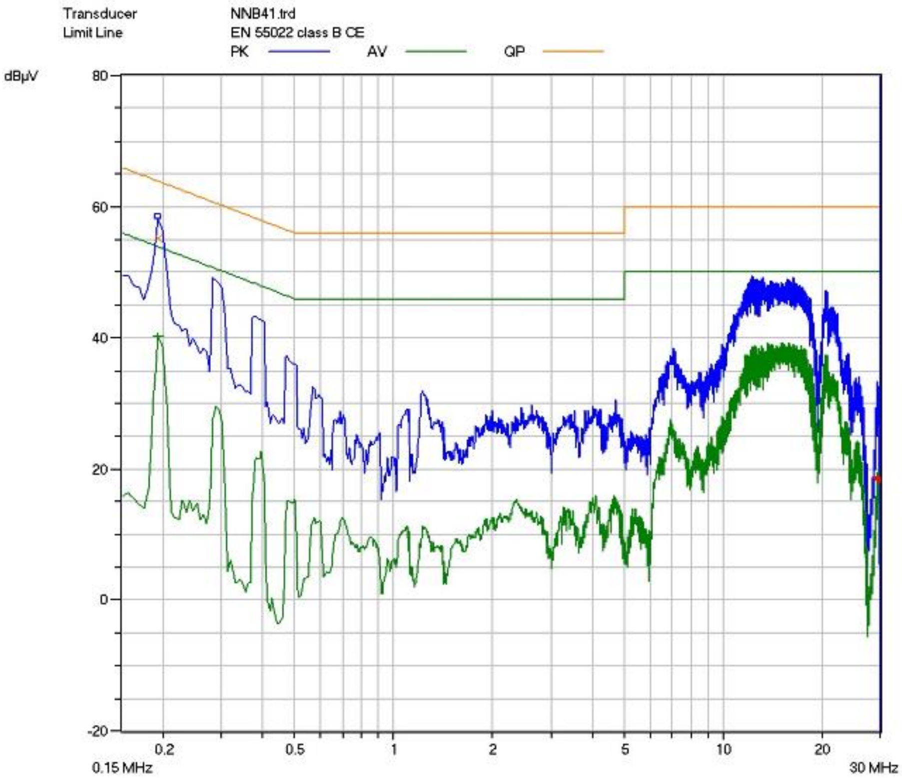
Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.1920	L	60.1	L	43.4	L	57.6	53.9	63.9	6.3dB(QP)

Figure 13 Conducted emissions (line) at 115 V AC and full load



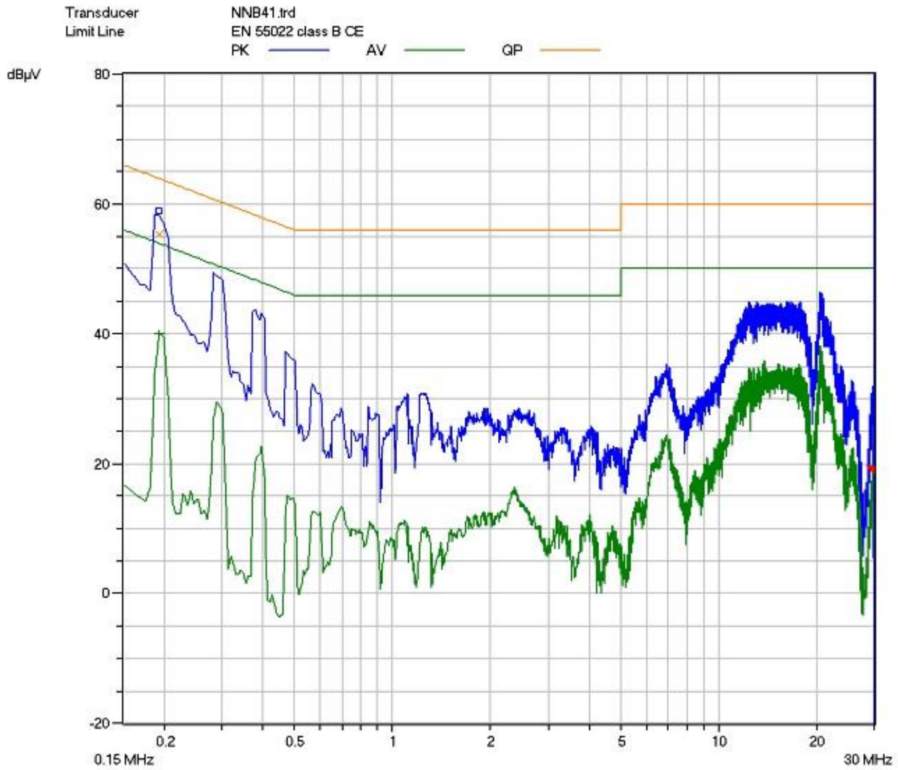
Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.1980	L	59.5	L	42.5	L	56.8	53.7	63.7	6.9dB(QP)

Figure 14 Conducted emissions (neutral) at 115 V AC and full load



Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.1920	L	58.5	L	40.3	L	55.3	53.9	63.9	8.6dB(QP)

Figure 15 Conducted emissions (line) at 230 V AC and full load



Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.1920	L	58.9	L	40.1	L	55.5	53.9	63.9	8.4dB(QP)

Figure 16 Conducted emissions (neutral) at 230 V AC and full load

10.10 Thermal measurements

The thermal test of the open-frame demo board was done using an infrared thermography camera (FLIR-T62101) at an ambient temperature of 25°C. The measurements were taken after one hour running at full load.

Table 5 Hottest components on the demo board

No.	Components	Temperature @ 85 V AC (°C)	Temperature @ 300 V AC (°C)
1	IC1 (ICE5AR4770AG)	81.2	63.3
2	L1 (CMC)	45.5	29.6
3	T1 (transformer)	55.7	60.4
4	D151 (15 V diode)	63	65.3

Top side Bottom side

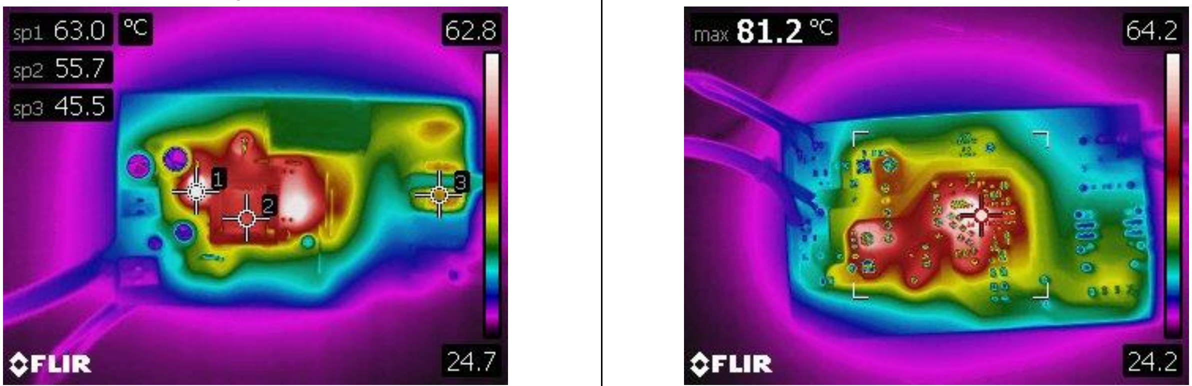


Figure 17 Infrared thermal image of DEMO_5AR4770AG at 85 V AC full load

Top side Bottom side

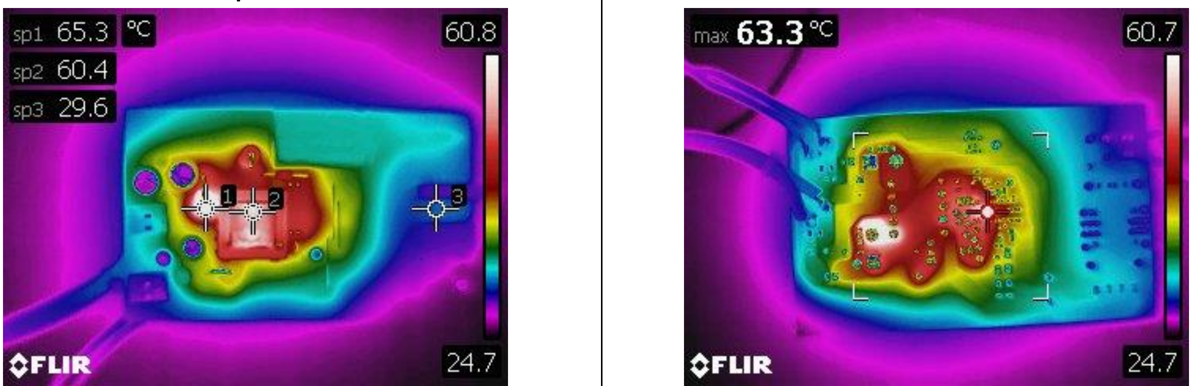


Figure 18 Infrared thermal image of DEMO_5AR4770AG at 300 V AC full load

11 Waveforms and oscilloscope plots

All waveforms and scope plots were recorded with a Teledyne LeCroy 606Zi oscilloscope.

11.1 Start-up at full load

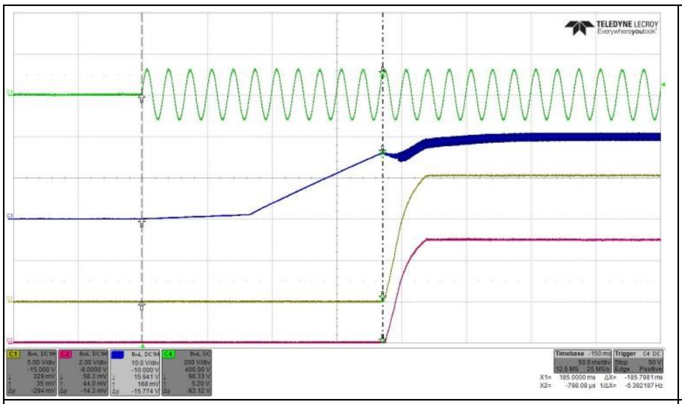
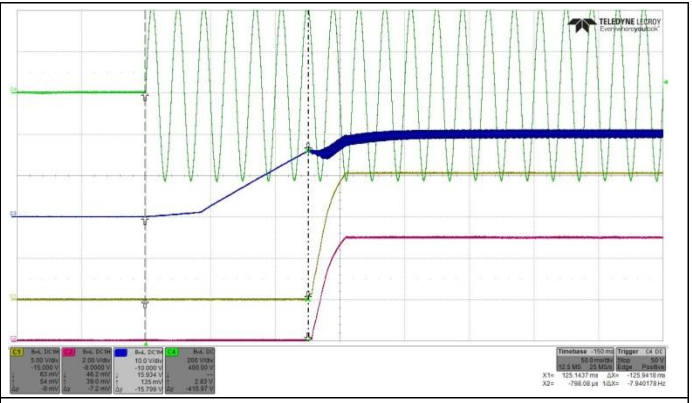
	
C1 (yellow) : +15 V output voltage C2 (purple) : +5 V output voltage C3 (blue) : V_{CC} voltage C4 (green) : AC-line voltage	C1 (yellow) : +15 V output voltage C2 (purple) : +5 V output voltage C3 (blue) : V_{CC} voltage C4 (green) : AC-line voltage
85 V AC start-up time at full load is < 250 ms	300 V AC start-up time at full load is < 200 ms

Figure 19 Start-up

11.2 Soft-start at full load

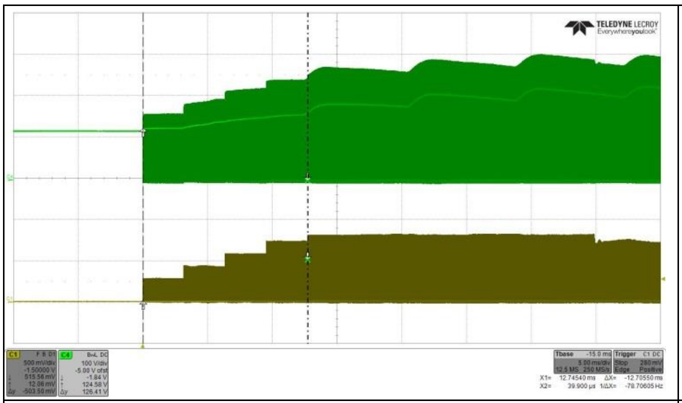
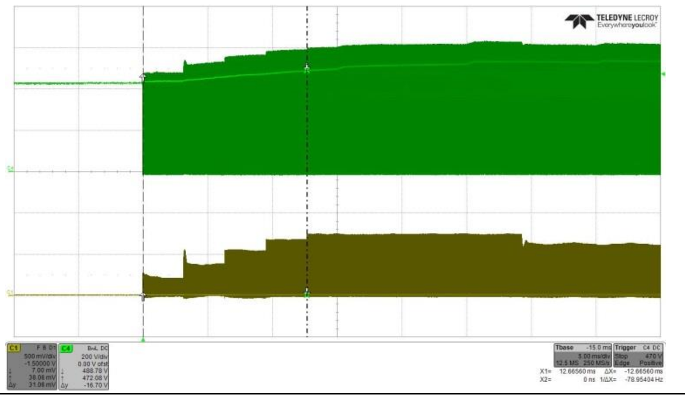
	
C1 (yellow) : CS voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C4 (green) : Drain voltage
85 V AC soft-start time at full load is ~12.7 ms	300 V AC soft-start time at full load is ~12.7 ms

Figure 20 Soft-start

11.3 Drain and CS voltage at full load

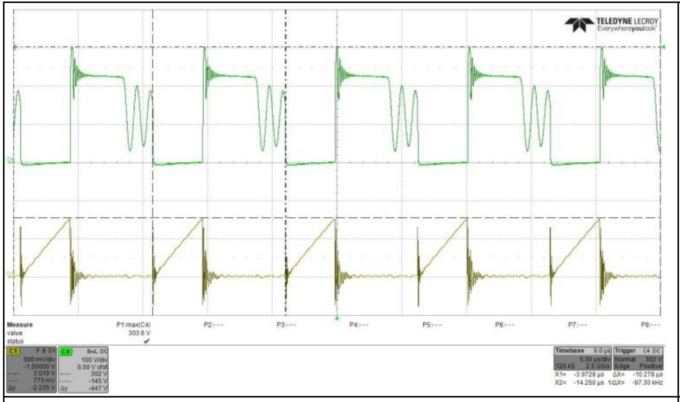
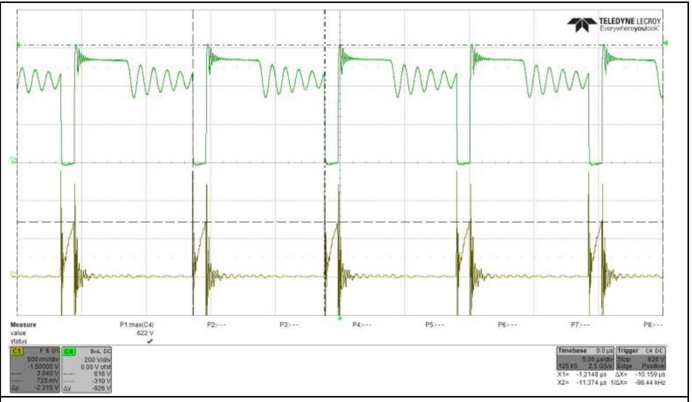
	
C1 (yellow) : CS voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C4 (green) : Drain voltage
85 V AC maximum drain voltage at full load is ~303 V	300 V AC maximum drain voltage at full load is ~622 V

Figure 21 Drain and CS voltage

11.4 Frequency jittering at full load

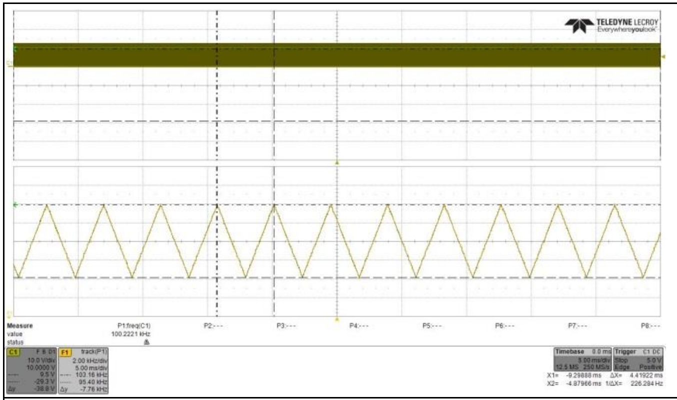
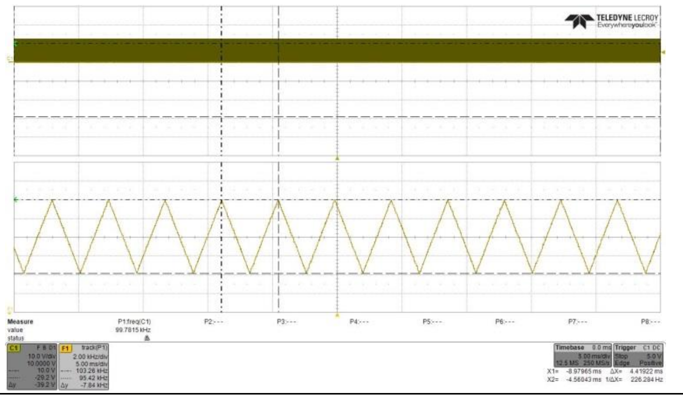
	
C1 (yellow) : Gate voltage F1 (yellow) : Frequency track of gate voltage	C1 (yellow) : Gate voltage F1 (yellow) : Frequency track of gate voltage
85 V AC frequency jittering at full load is ~95 kHz to ~103 kHz with a jitter period of 4.4 ms	300 V AC frequency jittering at full load is ~95 kHz to ~103 kHz with a jitter period of 4.4 ms

Figure 22 Frequency jittering

11.5 Load transient response (dynamic load from 10% to 100%)

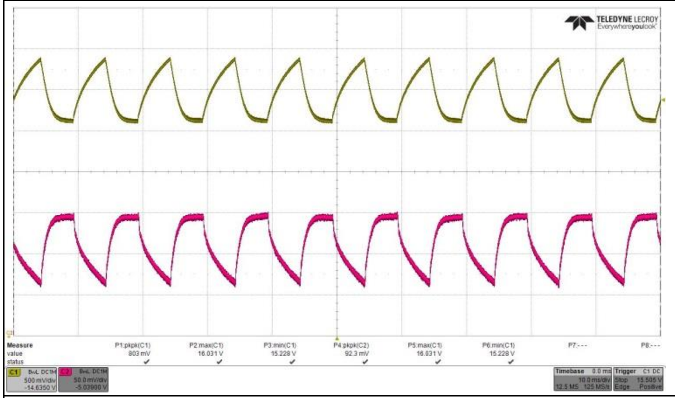
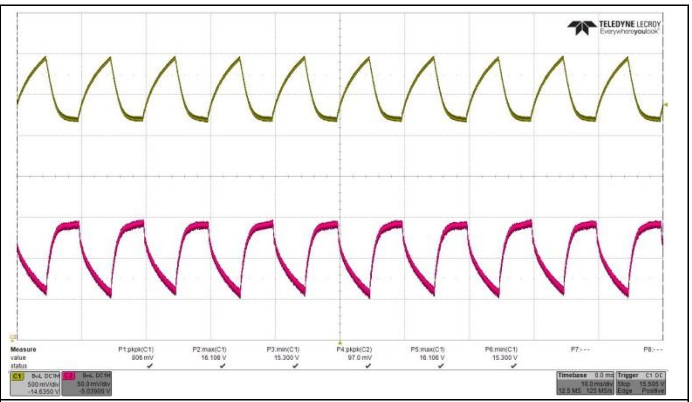
	
C1 (yellow) : +15 V output voltage C2 (purple) : +5 V output voltage	C1 (yellow) : +15 V output voltage C2 (purple) : +5 V output voltage
85 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~803 mV 85 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~92 mV	300 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~806 mV 300 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~97 mV

Figure 23 **Load transient response with +15 V output load change from 10% to 100% at 0.4 A/µs slew rate, 100 Hz. +5 V output is fixed at 400 mA load. Probe terminals are decoupled with 1 µF electrolytic and 0.1 µF ceramic capacitors. Oscilloscope is BW filter limited to 20 MHz.**

11.6 Output ripple voltage at full load

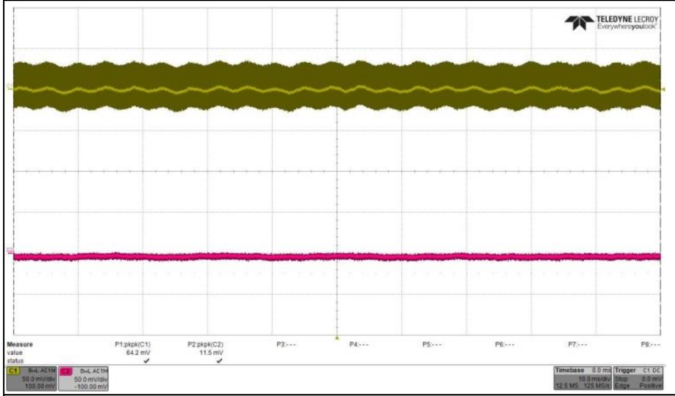
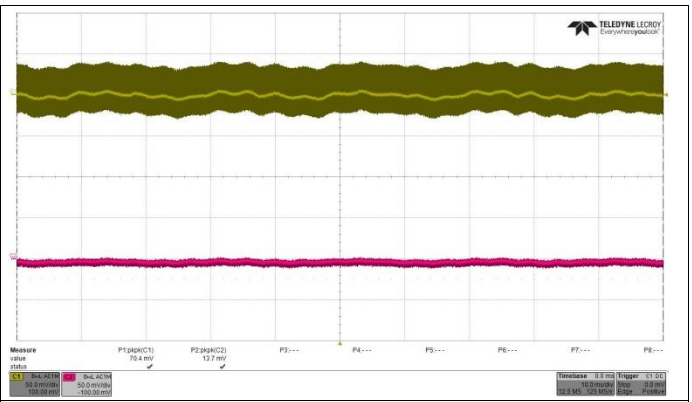
	
C1 (yellow) : +15 V output voltage C2 (purple) : +5 V output voltage	C1 (yellow) : +15 V output voltage C2 (purple) : +5 V output voltage
85 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~64 mV 85 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~11 mV	300 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~70 mV 300 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~14 mV

Figure 24 **Output ripple voltage at full load. Probe terminals are decoupled with 1 µF electrolytic and 0.1 µF ceramic capacitors. Oscilloscope is BW filter limited to 20 MHz.**

11.7 Output ripple voltage at ABM (0.5 W load)

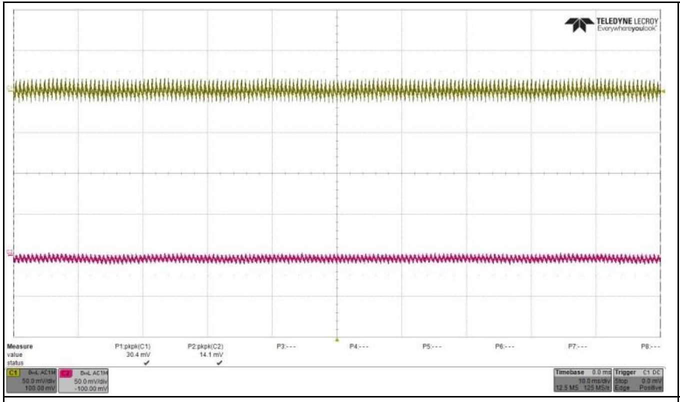
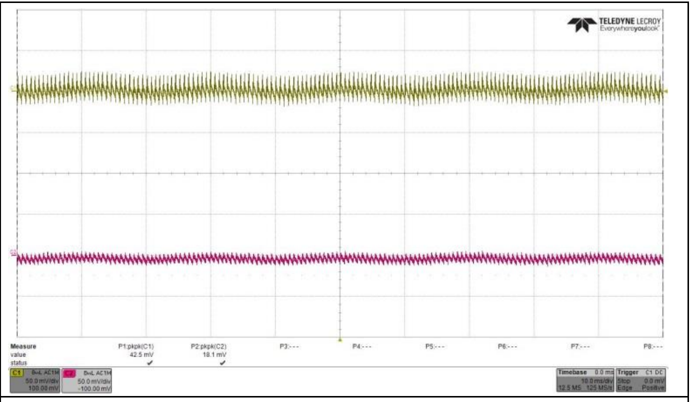
	
C1 (yellow) : +15 V output voltage C2 (purple) : +5 V output voltage	C1 (yellow) : +15 V output voltage C2 (purple) : +5 V output voltage
85 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~30 mV 85 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~14 mV	300 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~43 mV 300 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~18 mV

Figure 25 Output ripple voltage at 0.5 W load (+15 V/30 mA, +5 V/12 mA). Probe terminals are decoupled with 1 µF electrolytic and 0.1 µF ceramic capacitors. Oscilloscope is BW filter limited to 20 MHz.

11.8 Entering ABM

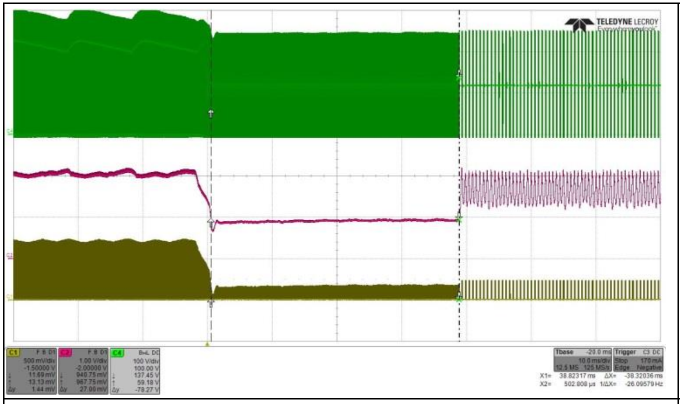
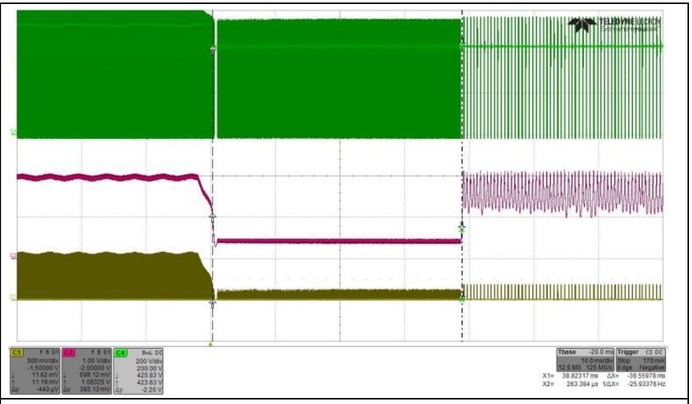
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage
85 V AC full load to 0.5 W load. Enter ABM at FB pin voltage < 1.03 V (V_{FB_EBHP}) for > 36 ms (t_{FB_BEB}).	300 V AC full load to 0.5 W load. Enter ABM at FB pin voltage < 1.03 V (V_{FB_EBHP}) for > 36 ms (t_{FB_BEB}).

Figure 26 Entering ABM. Output at full load to 0.5 W load (+15 V/30 mA, +5 V/12 mA).

11.9 During ABM

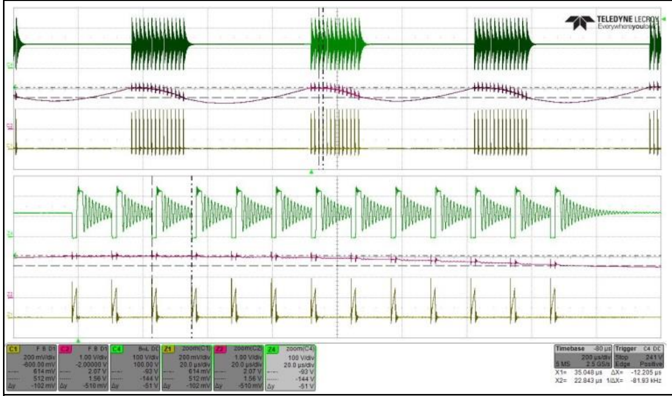
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage
85 V AC at 0.5 W load. Burst-on at FB voltage 1.95 V ($V_{FB\_Bon\_NISO}$) and burst-off at 1.55 V ($V_{FB\_BOff\_NISO}$). CS voltage at 0.27 V (V_{CS_BHP}). Switching frequency at 86 kHz (f_{OSC4_ABM}).	300 V AC at 0.5 W load. Burst-on at FB voltage 1.95 V ($V_{FB\_Bon\_NISO}$) and burst-off at 1.55 V ($V_{FB\_BOff\_NISO}$). CS voltage at 0.27 V (V_{CS_BHP}). Switching frequency at 86 kHz (f_{OSC4_ABM}).

Figure 27 During ABM. Output at 0.5 W load (+15 V/30 mA, +5 V/12 mA).

11.10 Leaving ABM

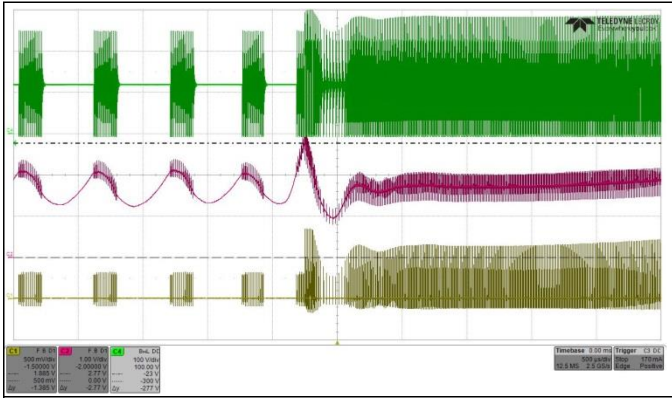
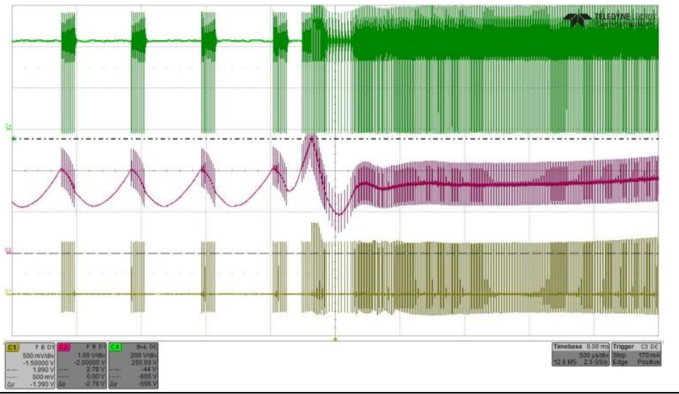
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage
85 V AC at 0.5 W load to full load. Leave ABM at FB voltage > 2.73 V (V_{FB_LB}).	300 V AC at 0.5 W load to full load. Leave ABM at FB voltage > 2.73 V (V_{FB_LB}).

Figure 28 Leaving ABM. Output at 0.5 W load (+15 V/30 mA, +5 V/12 mA) to full load.

11.11 Line OVP (non-switch auto restart)

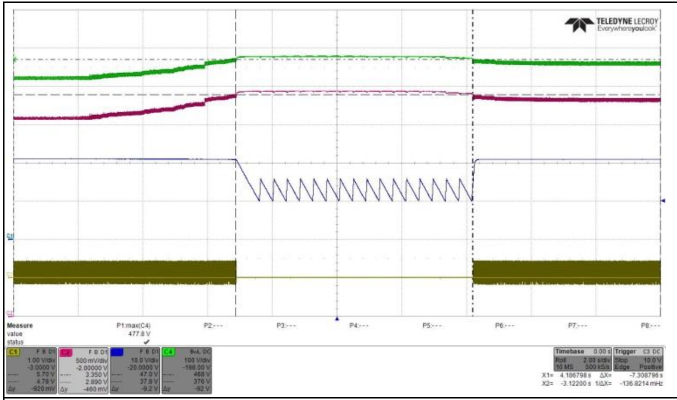
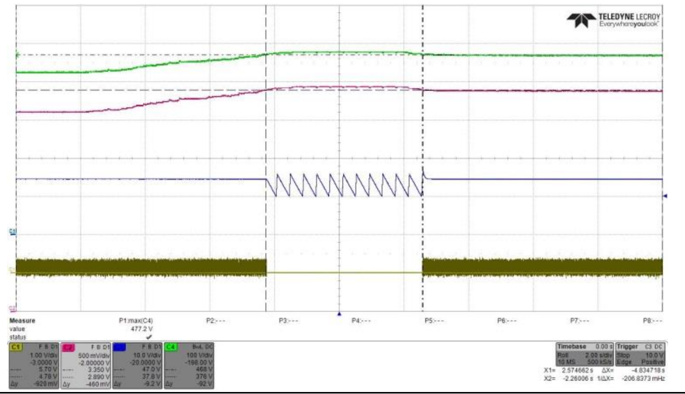
	
C1 (yellow) : CS voltage C2 (purple) : V_{IN} pin voltage C3 (blue) : V_{CC} voltage C4 (green) : Bus voltage	C1 (yellow) : CS voltage C2 (purple) : V_{IN} pin voltage C3 (blue) : V_{CC} voltage C4 (green) : Bus voltage
Output at full load. Trigger protection at V_{IN} voltage > 2.85 V (V_{VIN_LOVP}). Bus voltage at 468 V (~330 V AC).	Output at 0.5 W load. Trigger protection at V_{IN} voltage > 2.85 V (V_{VIN_LOVP}). Bus voltage at 468 V (~330 V AC).

Figure 29 Line OVP. Gradually increase input voltage to trigger protection and gradually reduce input voltage to reset.

11.12 V_{CC} OV/UV protection

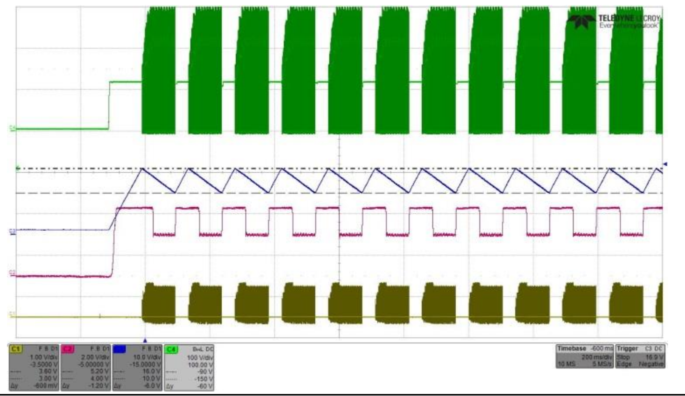
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : V_{CC} voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : V_{CC} voltage C4 (green) : Drain voltage
85 V AC at no load. Removed ZD1, R103 and R153. Trigger V_{CC} OV protection at V_{CC} voltage > 25.5 V (V_{VCC_OVP}). Odd-skip auto restart mode.	85 V AC at full load. Removed D2. Trigger V_{CC} UV protection at V_{CC} voltage < 10 V (V_{VCC_OFF}). Auto-restart mode.

Figure 30 V_{CC} OV/UV protection

11.13 Over-load protection

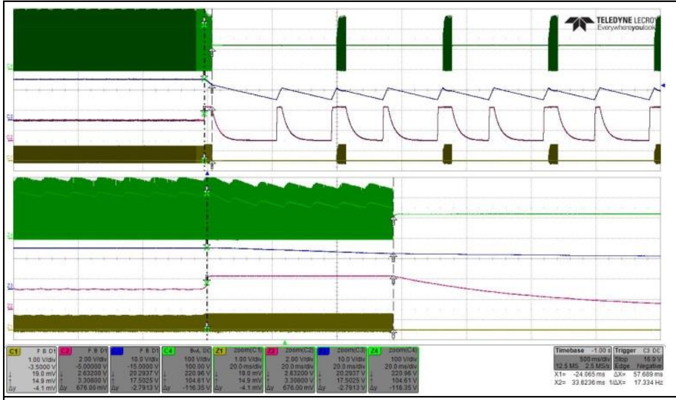
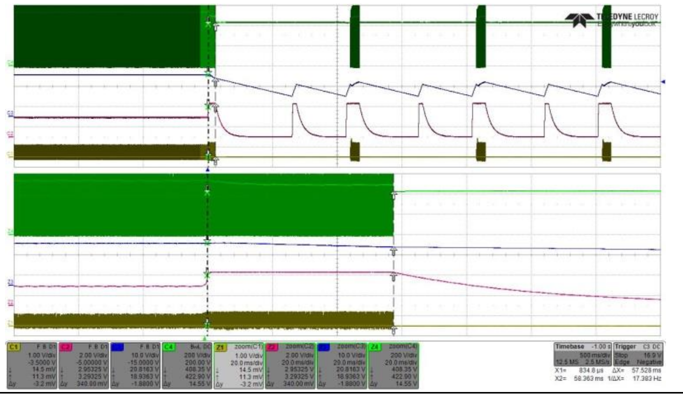
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : V_{CC} voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : V_{CC} voltage C4 (green) : Drain voltage
85 V AC at full load to over-load. Trigger protection at FB pin voltage > 2.73 V (V_{FB_OLP}) for > 54 ms ($t_{FB\_OLP\_B}$). Odd-skip auto restart mode.	300 V AC at full load to over-load. Trigger protection at FB pin voltage > 2.73 V (V_{FB_OLP}) for > 54 ms ($t_{FB\_OLP\_B}$). Odd-skip auto restart mode.

Figure 31 Over-load protection. Load increased at +15 V output to 2 A to trigger protection.

11.14 V_{CC} short-to-GND

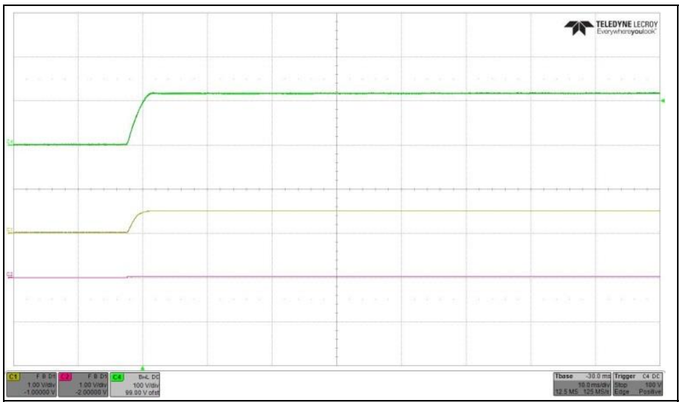
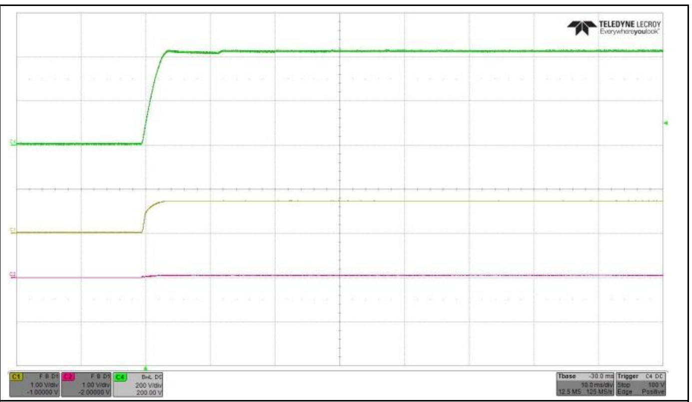
	
C1 (yellow) : V_{IN} pin voltage C2 (purple) : V_{CC} pin voltage C4 (green) : Bus voltage	C1 (yellow) : V_{IN} pin voltage C2 (purple) : V_{CC} pin voltage C4 (green) : Bus voltage
85 V AC. V_{CC} charging current at ~282 µA ($I_{VCC\_Charge1}$). IC power consumption is ~34 mW.	300 V AC. V_{CC} charging current at ~578 µA ($I_{VCC\_Charge1}$). IC power consumption is ~245 mW.

Figure 32 V_{CC} short-to-GND. V_{CC} charging current measured with a digital multimeter.

12 References

[1] ICE5xRxxxxAG datasheet, Infineon Technologies AG

[2] 5th Generation Fixed-Frequency Design Guide

[3] Calculation Tool Fixed Frequency CoolSET™ Generation 5

Revision history

Major changes since the last revision

Page or reference	Description of changes
--	First release

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