14 W 15 V 5 V SMPS demo board with ICE5AR4780BZS

ER_DEMO_5AR4780BZS_14W1

About this document

Scope and purpose

This document is an engineering report that describes universal-input 14 W 15 V and 5 V off-line non-isolated flyback converter using the latest fifth-generation Infineon fixed-frequency CoolSET™ ICE5AR4780BZS, which offers high-efficiency, low-standby power with selectable entry and exit standby power options, wide V_{CC} operating range with fast start-up, and various protection modes for a highly reliable system. This demo board is designed for users who wish to evaluate the performance of ICE5AR4780BZS 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 for off-line SMPS, either 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 and 5 V demo board designed in a fixed-frequency non-isolated flyback converter topology with primary-side feedback (FB) using the fifth-generation fixed-frequency CoolSET™ ICE5AR4780BZS. 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 percent load. The selectable Active Burst Mode (ABM) power enables ultra-low power consumption. In addition, numerous adjustable protection functions have been implemented in ICE5AR4780BZS to protect the system and customize the IC for the chosen application. In case of failure modes, like V_{CC} Over Voltage (OV)/Under Voltage (UV), open control-loop or over load, over-temperature, V_{CC} short-to-GND and Current Sense (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 ICE5AR4780BZS 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, power-supply specifications, circuit diagram, Bill of Materials (BOM) and transformer construction documentation of the DEMO_5AR4780BZS_14W1 demo board. Typical operating characteristics such as performance curve and oscilloscope waveforms are shown at the end of the report.

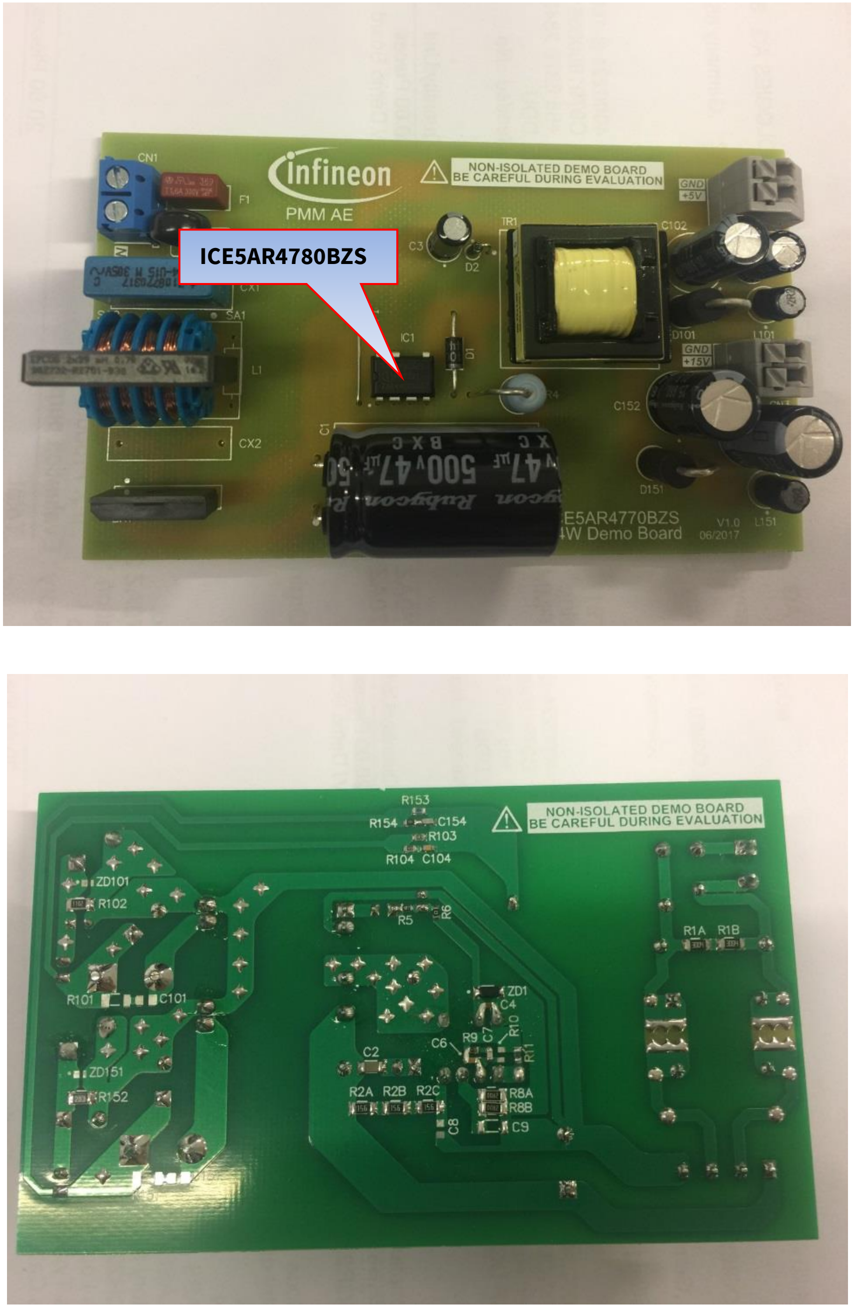


Figure 1 DEMO_5AR4780BZS_14W1

3 Specifications of 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 percent +15 V: less than ±15 percent
Output ripple voltage (full load, 85 V AC ~ 300 V AC)	5 $V_{ripple\_p\_p}$ less than 100 mV 15 $V_{ripple\_p\_p}$ less than 200 mV
Active-mode four-point average efficiency (25 percent, 50 percent, 75 percent, 100 percent load)	Greater than 83 percent at 115 V AC and 230 V AC
Standby power consumption	No load: P_{in} less than 100 mW at 230 V AC 60 mW load: P_{in} less than 180 mW at 230 V AC
Conducted emissions (EN 55022 class B)	Pass with 6.9 dB margin for 115 V AC and 7.8 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 (e.g. 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 condition."

4 Circuit description

4.1 Input filtering

The AC-line input side comprises the input fuse F1 as over-current protection. The Common Mode Choke (CMC) L1 and X-capacitor CX1 act as EMI suppressors. Optional spark-gap devices SA1, SA2 and varistor Z1 can absorb HV stress during lightning surge testing. 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, ICE5AR4780BZS is implemented with a high-resistance start-up resistor and V_{CC} short-to-GND protection. When V_{VCC} reaches the turn-on voltage threshold 16 V, the IC begins with a soft-start. The soft-start implemented in ICE5AR4780BZS 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

The integrated highly efficient CoolMOS™ and the frequency reduction control enable better efficiency from light load to 50 percent 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 load, the controller will switch at the fixed frequency 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).

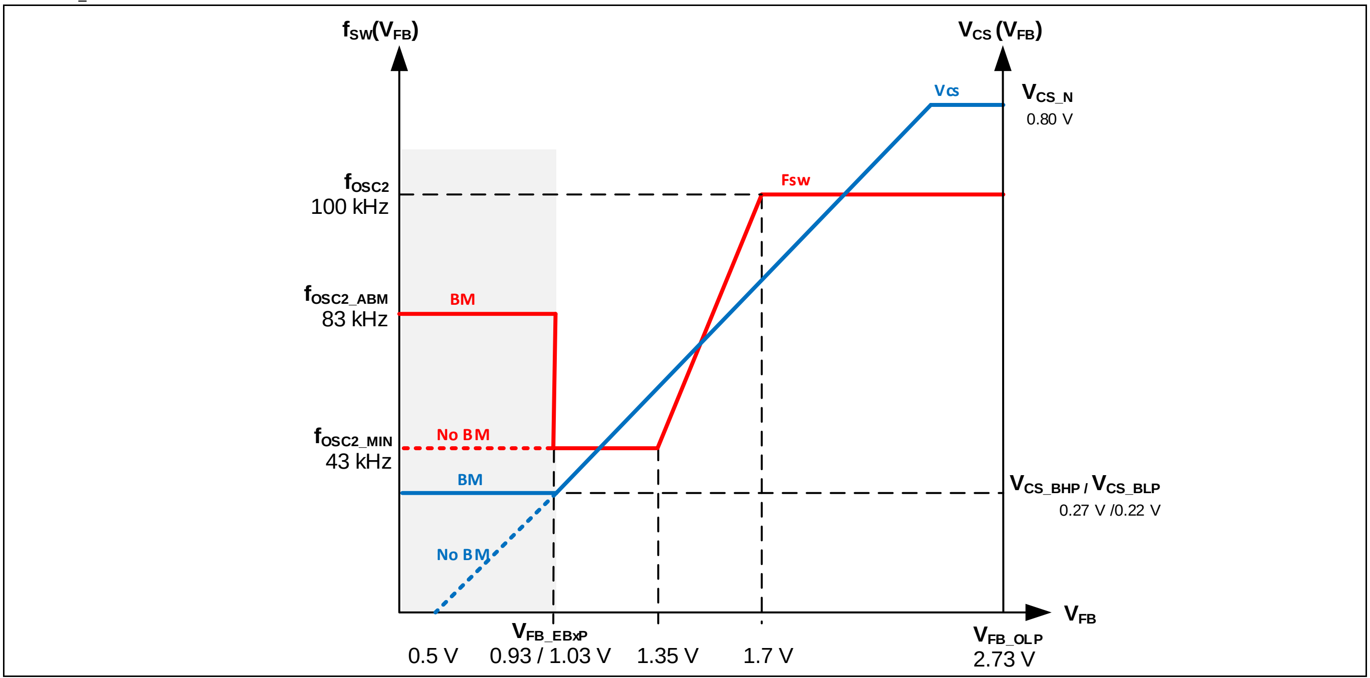


Figure 2 Frequency reduction curve (f_{OSC2})

4.4 Frequency jittering

The ICE5AR4780BZS 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 ESR to minimize the output voltage ripple.

4.7 FB loop

For FB, the output is sensed by the voltage divider of R11, R103 and R153 and compared to the internal reference voltage of ICE5AR4780BZS via the VERR pin, which is connected to the input of an integrated error amplifier internally. By connecting this pin, non-isolated application is achieved. Feed-forward circuit R154, C154, R104 and C104 comprises the compensation network. The comparison voltage is converted to the current signal via IC internal integrated error amplifier to the FB pin for regulation control.

4.8 ABM

ABM entry and exit power (three levels) can be selected in ICE5AR4780BZS. Details are illustrated in the product datasheet. At light-load condition, 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, two conditions must apply:

1. the FB voltage must be lower than the threshold of V_{FB_EBXP}
2. a certain blanking time must have elapsed (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 prevents mis-triggering, so that the controller enters ABM operation only when the output power is really low during the preset blanking time.

During ABM, the maximum CS voltage is reduced from V_{CS_N} to V_{CS_BXP} so as to reduce the conduction loss and the audible noise. In burst mode, 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 percent during ABM a certain load is needed so that FB voltage can exceed V_{FB_LB} (2.73 V). After leaving ABM, maximum current can 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. ICE5AR4780BZS provides comprehensive protection to ensure the system is operating safely. Protections include 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, and then resume normal operation. A list of protections and the failure conditions are shown in the below table.

Table 2 Protection features of ICE5AR4780BZS

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

6 Circuit diagram

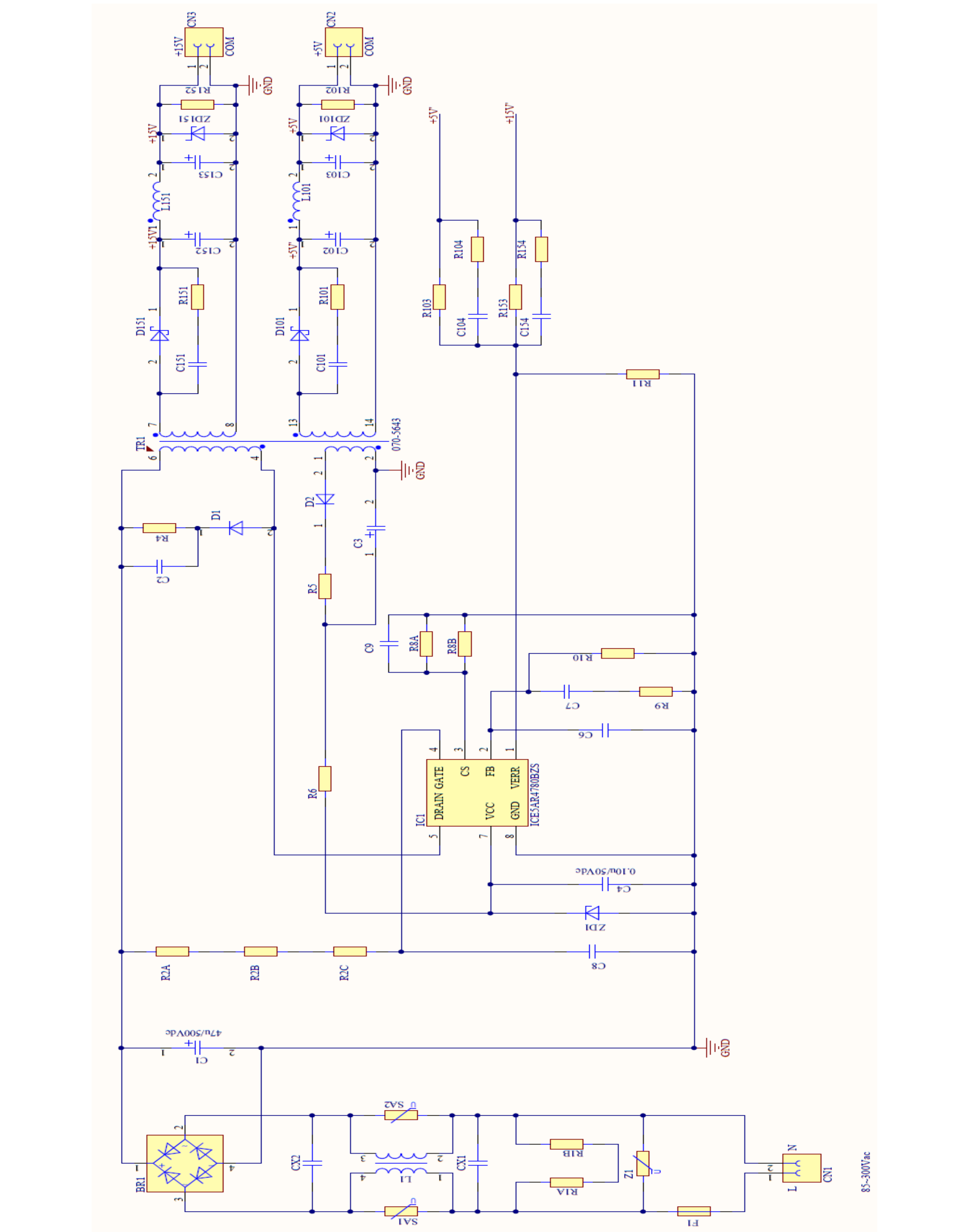


Figure 3 Schematic of DEMO_5AR4780BZS_14W1

7 PCB layout

7.1 Top side

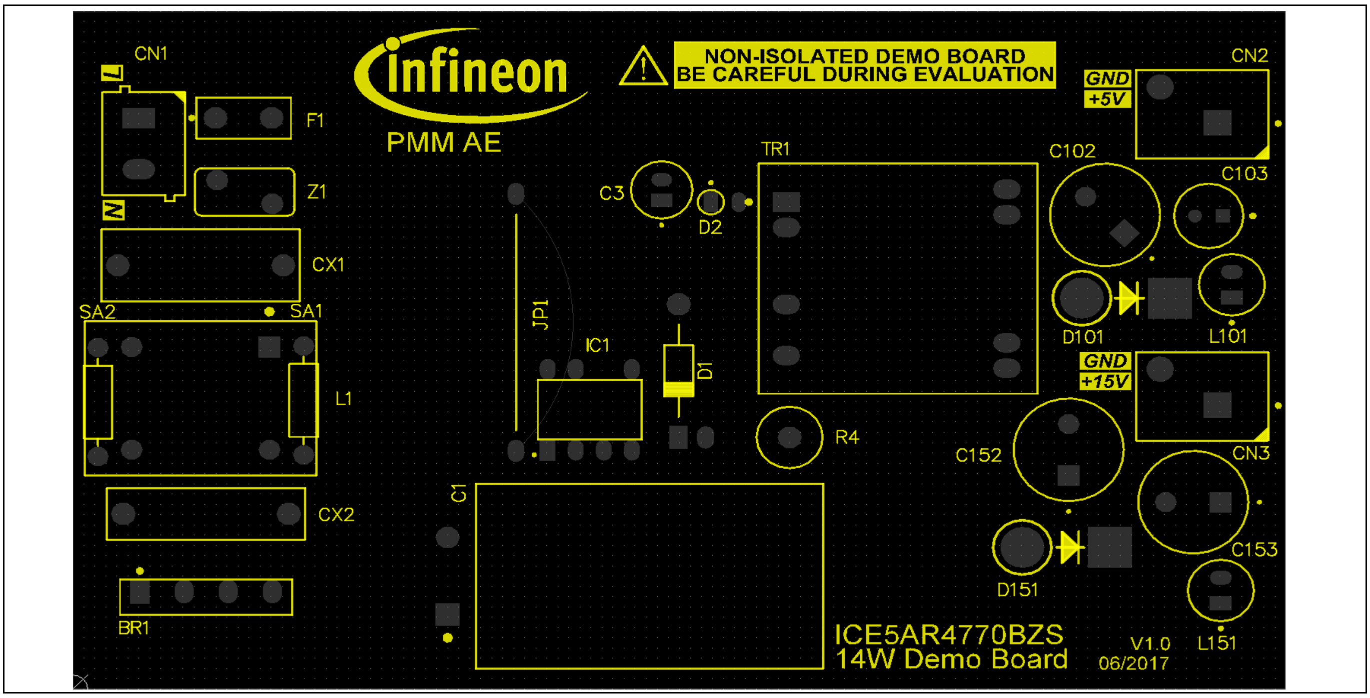


Figure 4 **Top-side component legend**

7.2 Bottom side

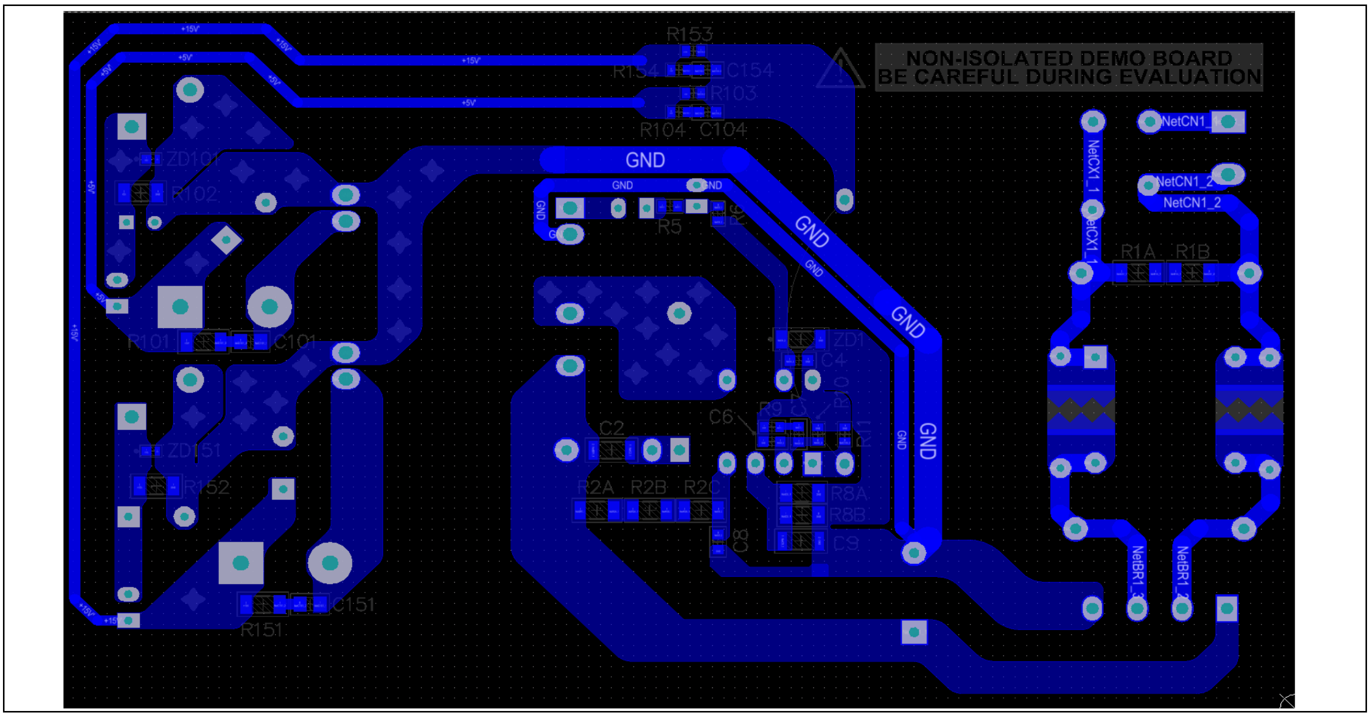


Figure 5 **Bottom-side copper and component legend**

8 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	B32932A3154K189	EPCOS/TDK	1
5	C1	47 µF/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 µF/50 V DC	GRM188R71H104KA93D	Murata	1
9	C154	1000 pF/50 V DC	GRM1885C1H102GA01D	Murata	1
10	C6, C104	4700 pF/50 V DC	GRM188R71H472KA01D	Murata	2
11	C7	15 pF/50 V DC	GRM1885C1H150JA01D	Murata	1
12	C102	680 µF/10 V DC	10ZL680MEFC8X16	Rubycon	1
13	C103	330 µF/10 V DC	10ZLH330MEFC6.3X11	Rubycon	1
14	C152, C153	680 µF/25 V DC	25ZLS680MEFC10X16	Rubycon	2
15	ZD1	22 V/500 mW	BZS55B22 RXG	Taiwan Semiconductor	1
16	D1	1 A/ 800 V	UF4006-E3/54	Vishay	1
17	D2	0.2 A/200 V	1N485B	Fairchild	1
18	D151	3 A/150 V	STPS3150	ST	1
19	D101	3 A/60 V	MBR360	Vishay	1
20	IC1	ICE5AR4780BZS	ICE5AR4780BZS	Infineon	1
21	L1	39 mH/0.7 A	B82732R2701B030	EPCOS/TDK	1
22	L101, L151	2.2 µH/4.3 A	744 746 202 2	Wurth Electronics	2
23	R1A, R1B	3 MΩ/0.25 W/5 percent/1206			2
24	R2A, R2B, R2C	15 MΩ/0.25 W/5 percent/1206	RC1206JR-0715ML	Yageo	3
25	R4	68 kΩ/2 W/500 V	MO2CT631R683J	KOA Speer	1
26	R5	4.7 Ω/0.1 W/5 percent/0603			1
27	R6	0 Ω/0603			1
28	R8A, R8B	2 Ω/0.25 W/ ±1 percent/1206	RC1206FR-072RL	Yageo	2
29	R9	260 kΩ/0.1 W/0603			1
30	R11	27 kΩ/0.1 W/1 percent/0603			1
31	R154	33 kΩ/0.1 W/1 percent/0603			1
32	R103	68 kΩ /0.1 W/1 percent/0603			1
33	R104	4.7 kΩ/0.1 W/1 percent/0603			1
34	R153	680 kΩ/0.1 W/1 percent/0603			1
35	R102	11 kΩ/0.25 W/5 percent/1206			1
36	R152	20 kΩ/0.25 W/5 percent/1206			1
37	T1	550 µH, EE20_H	750343698, rev 00	Wurth Electronics	1
38	CN1	Connector	691102710002	Wurth Electronics	1
39	CN2,CN3	Connector	691 412 120 002B	Wurth Electronics	2
40	JP1	Jumper			1
41	PCB	110 mm × 66 mm (L × W), single layer, 2 oz., FR-4			1

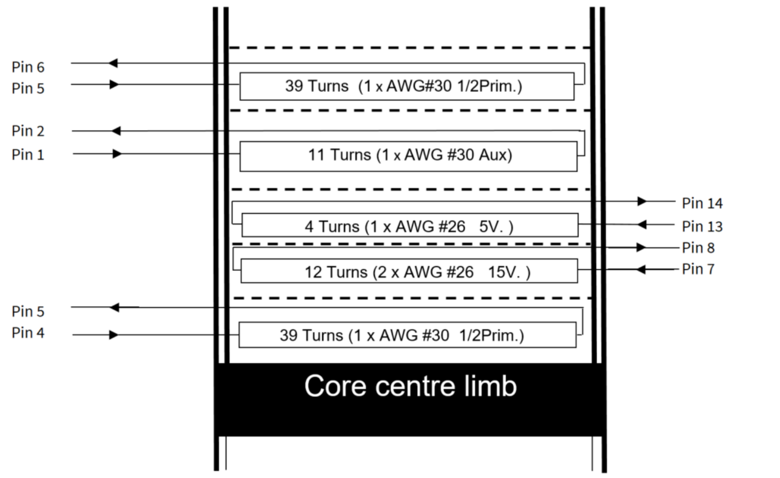
9 Transformer construction

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

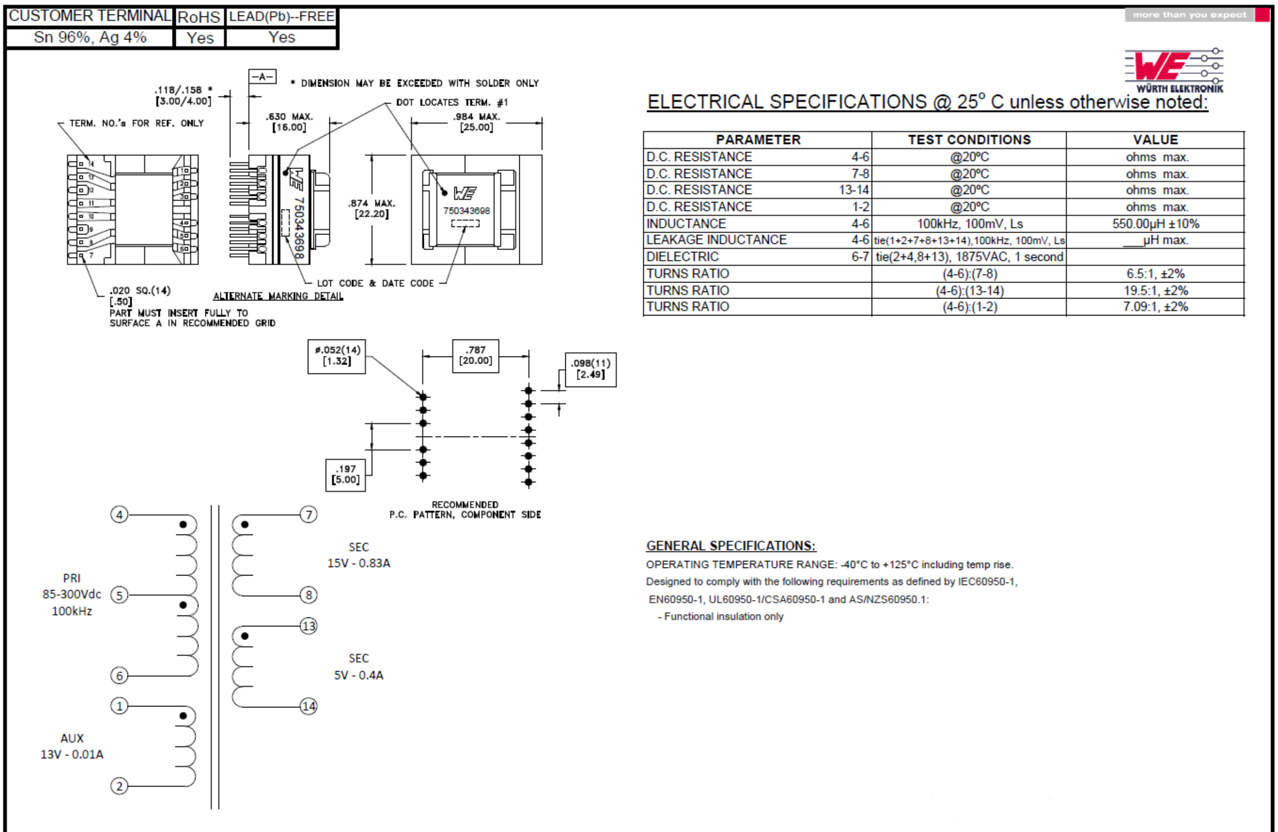
Bobbin: 070-5643 (14-pin, THT, horizontal version)

Primary inductance: Lp = 550 µH (±10 percent), measured between pin 4 and pin 6

Manufacturer and part number: Wurth Electronics Midcom (750343698)



Start	Stop	No. of turns	Wire size	Layer
4	5	39	1 x AWG#30	1/2 Primary
7	8	12	2 x AWG #26	15V
13	14	4	1 x AWG #26	5V
1	2	11	1 x AWG#30	Auxiliary
5	6	39	1 x AWG#30	1/2 Primary



ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	4-6	@20ºC	ohms max.
D.C. RESISTANCE	7-8	@20ºC	ohms max.
D.C. RESISTANCE	13-14	@20ºC	ohms max.
D.C. RESISTANCE	1-2	@20ºC	ohms max.
INDUCTANCE	4-6	100kHz, 100mV, Ls	550.00µH ±10%
LEAKAGE INDUCTANCE	4-6	tie(1+2+7+8+13+14),100kHz, 100mV, Ls	___µH max.
DIELECTRIC	6-7	tie(2+4,8+13), 1875VAC, 1 second	
TURNS RATIO		(4-6):(7-8)	6.5:1, ±2%
TURNS RATIO		(4-6):(13-14)	19.5:1, ±2%
TURNS RATIO		(4-6):(1-2)	7.09:1, ±2%

GENERAL SPECIFICATIONS:

OPERATING TEMPERATURE RANGE: -40°C to +125°C including temp rise.
Designed to comply with the following requirements as defined by IEC60950-1, EN60950-1, UL60950-1/CSA60950-1 and AS/NZS60950.1:
- 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. 750343698
DATE					
ENG	IYU		CONVENTION PLACEMENT		
REV.	00		This drawing is dual dimensioned. Dimensions in brackets are in millimeters.		SPECIFICATION SHEET 1 OF 1
DATE	8/8/2017				

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)	Pin (W)	15 V (V)	I_{out_15V} (mA)	5 V (V)	I_{out_5V} (mA)	15 V_{RPP} (mV)	5 V_{RPP} (mV)	P_{out} (W)	Efficiency (η) (%)	Average η (%)	OLP pin (W)	OLP I_{out15V} (fixed 5 V at 0.4 A) (A)
85 V AC/ 60 Hz	0.029	15.28	0	4.98	0	27	20				22.3	1.07
	0.115	17.27	0	4.78	12.2	20	33	0.06				
	4.335	15.25	207.45	4.99	100	25	19	3.66	84.49	82.49		
	8.867	15.27	414.9	4.98	200	30	20	7.33	82.68			
	13.483	15.28	622.7	4.98	300	37	23	11.01	81.65			
	18.100	15.29	830	4.98	400	40	25	14.68	81.13			
115 V AC/ 60 Hz	0.035	15.28	0	4.98	0	22	20				21.9	1.08
	0.120	17.47	0	4.77	12.2	18	32	0.06				
	4.316	15.24	207.45	4.99	100	25	20	3.66	84.80	83.44		
	8.850	15.26	414.9	4.99	200	32	22	7.33	82.82			
	13.240	15.28	622.7	4.98	300	35	22	11.01	83.15			
	17.700	15.30	830	4.98	400	40	24	14.69	83.00			
230 V AC/ 50 Hz	0.050	15.32	0	4.97	0	23	20				21.8	1.09
	0.143	17.54	0	4.75	12	20	33	0.06				
	4.434	15.24	207.45	4.99	100	25	20	3.66	82.56	83.44		
	8.830	15.27	414.88	4.99	200	30	22	7.33	83.05			
	13.130	15.27	622.7	4.99	300	37	24	11.01	83.82			
	17.420	15.30	830	4.99	400	43	26	14.69	84.35			
265 V AC/ 50 Hz	0.060	15.33	0	4.97	0	23	22				22.2	1.12
	0.153	17.57	0	4.75	12	18	33	0.06				
	4.570	15.24	207.45	4.98	100	25	20	3.66	80.08	82.56		
	8.900	15.27	414.88	4.99	200	30	23	7.33	82.40			
	13.170	15.29	622.7	4.99	300	40	25	11.02	83.66			
	17.460	15.29	830	4.99	400	43	27	14.69	84.12			
300 V AC/ 50 Hz	0.070	15.34	0	4.98	0	23	21				22.5	1.15
	0.170	17.62	0	4.75	12	20	34	0.06				
	4.570	15.28	207.45	4.99	100	25	20	3.67	80.28	82.23		
	8.970	15.27	414.88	4.99	200	30	31	7.33	81.75			
	13.230	15.29	622.7	4.99	300	27	24	11.02	83.28			
	17.580	15.30	830	4.99	400	45	27	14.70	83.59			

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

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

10.2 Efficiency

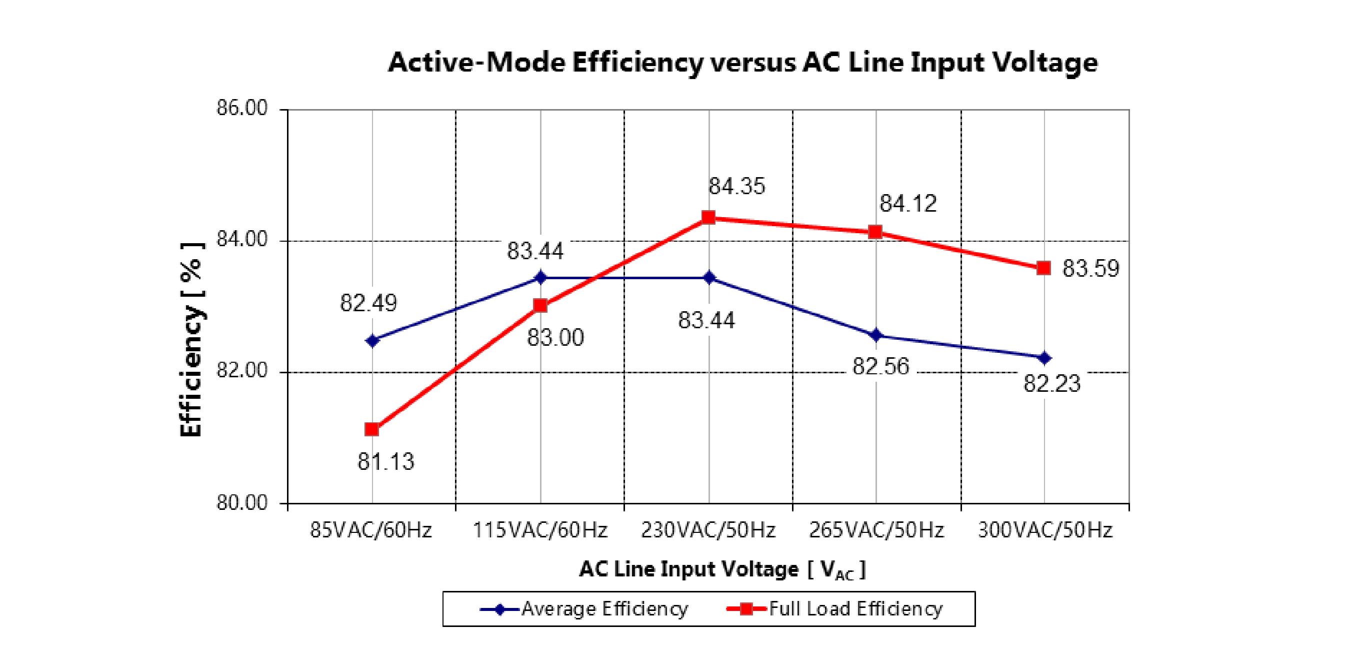


Figure 7 Efficiency vs AC-line input voltage

10.3 Standby power

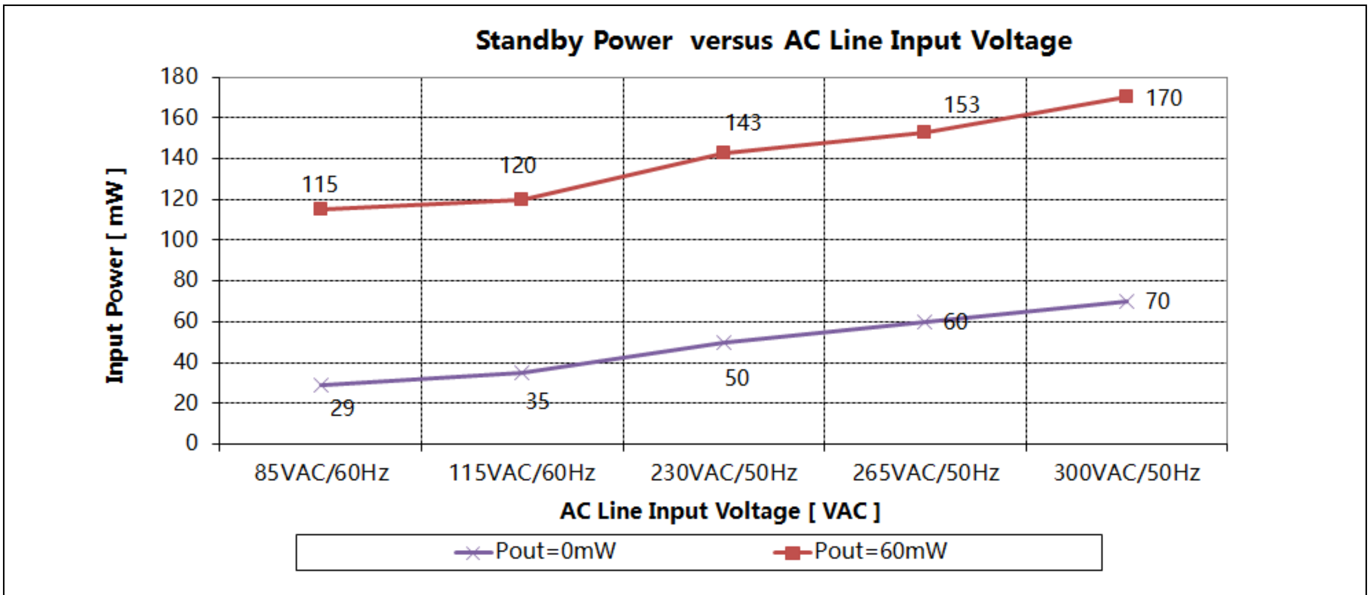


Figure 8 Standby power vs AC-line input voltage (measured by Yokogawa WT310 HC power meter – integration mode)

10.4 Line regulation

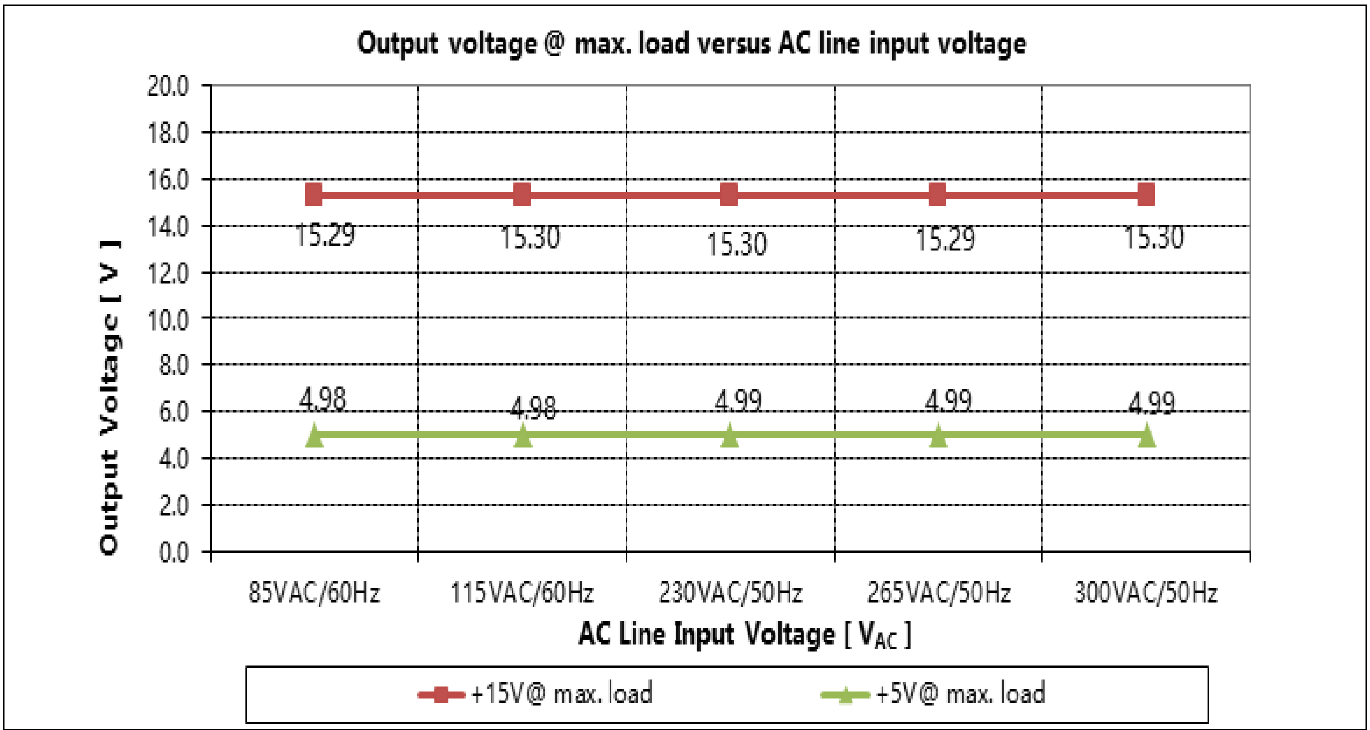


Figure 9 Output regulation at full load vs AC-line input voltage

10.5 Load regulation

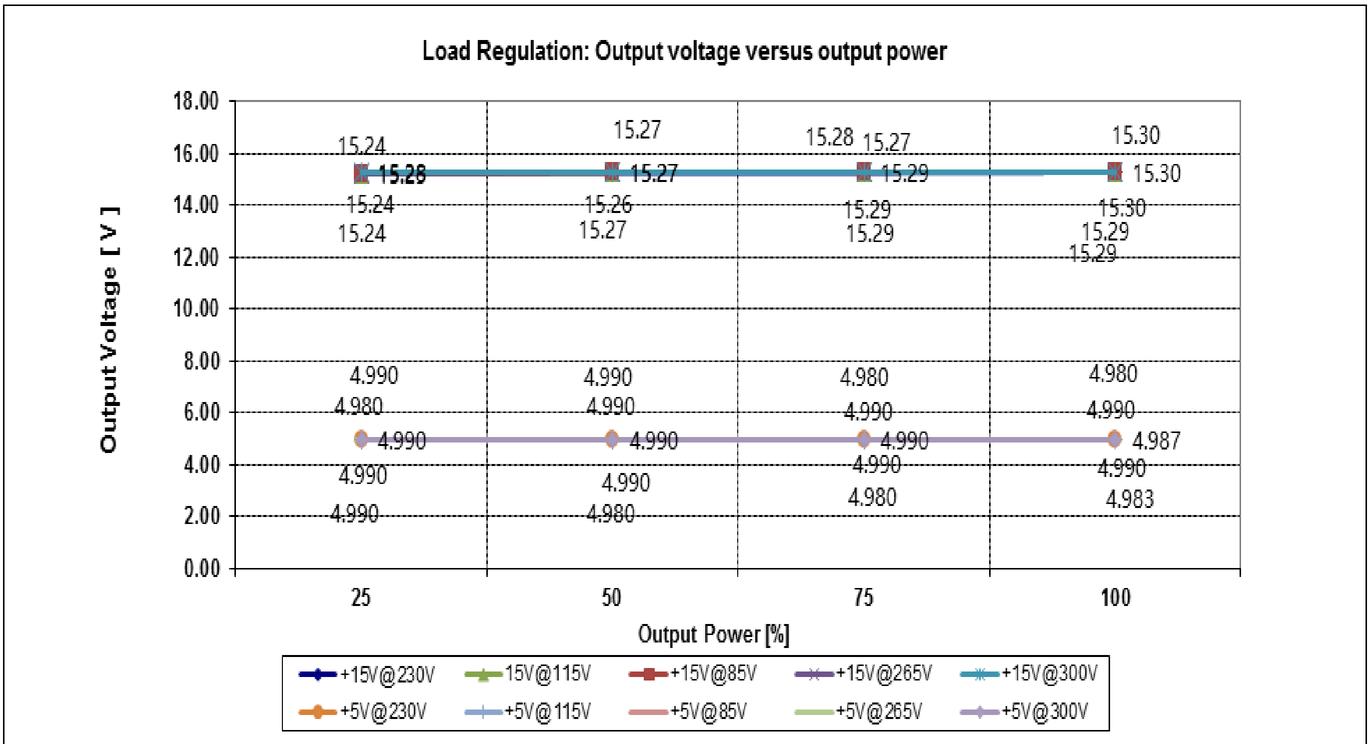


Figure 10 Output regulation vs output power

10.6 Maximum input power

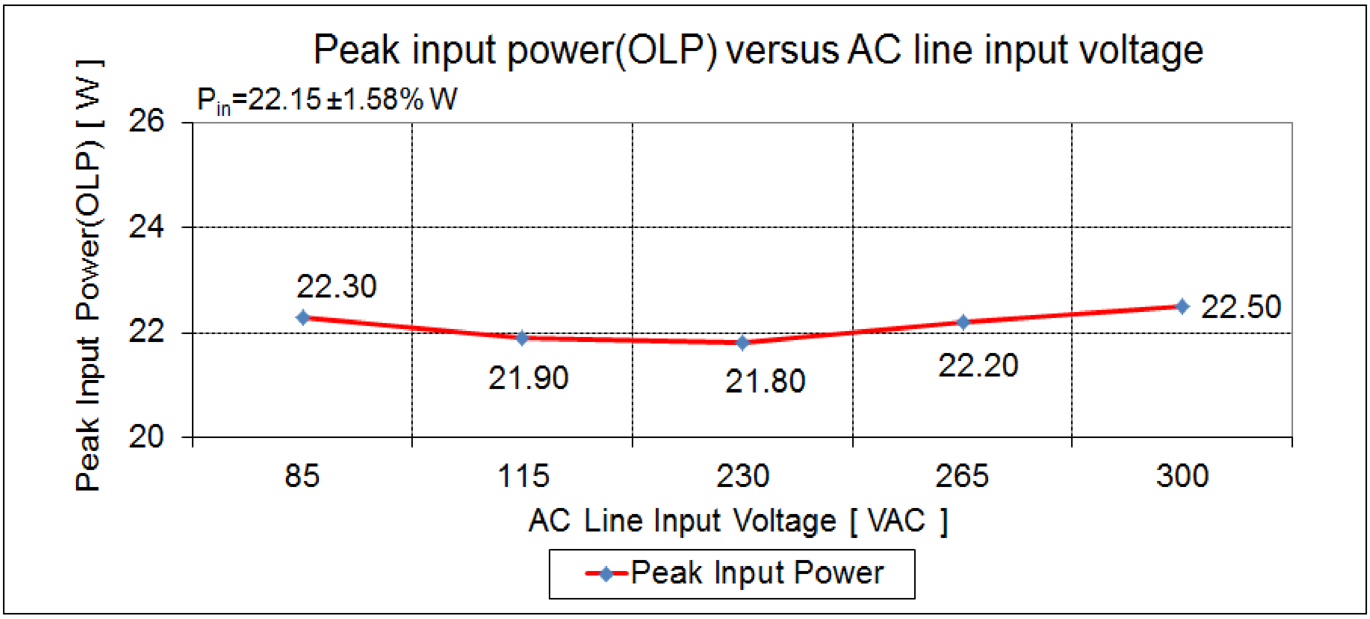


Figure 11 Maximum input power (before over-load protection) vs AC-line input voltage

10.7 Frequency reduction

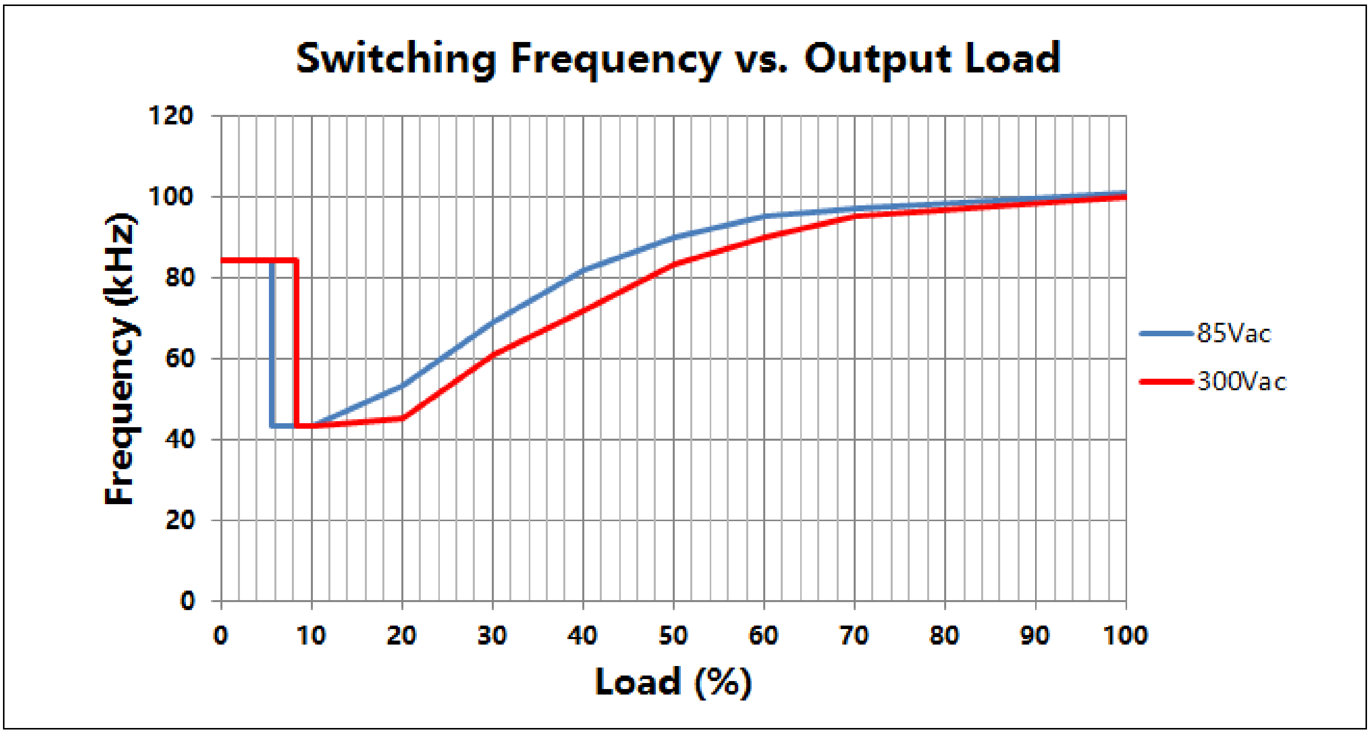


Figure 12 Switching frequency vs output load

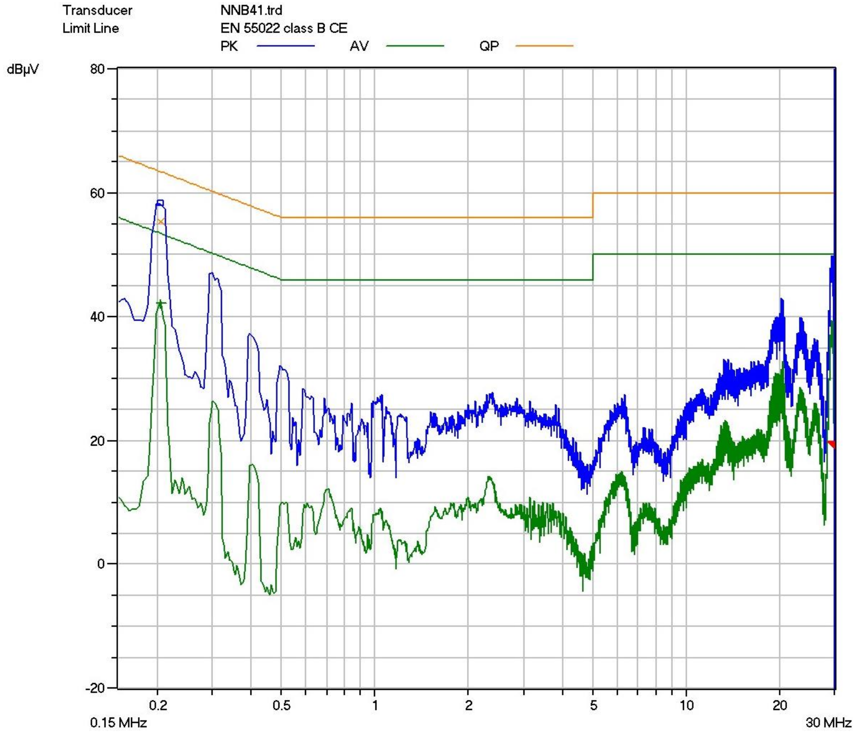
10.8 Surge immunity (EN 61000-4-5)

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

10.9 Conducted emissions (EN 55022 class B)

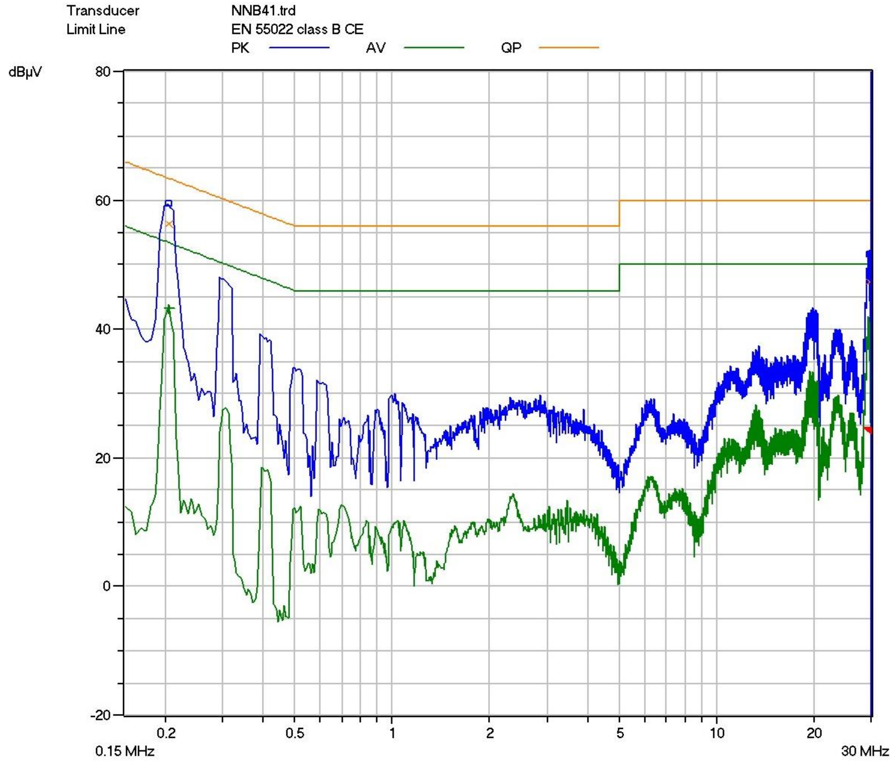
The conducted EMI was measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) class B. The demo board was tested at full load (14.45 W) using resistive load at input voltage of 115 V AC and 230 V AC.

Pass conducted emissions EN 55022 (CISPR 22) class B with 6.9 dB margin at low-line (115 V AC) and 7.8 dB margin at high-line (230 V AC).



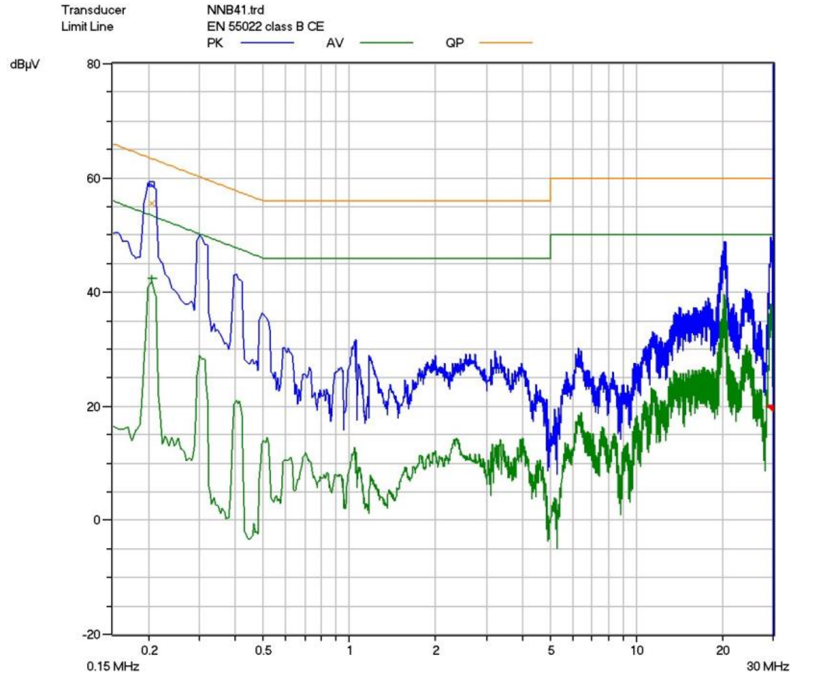
Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.2040	L	58.3	L	42.2	L	55.5	53.4	63.4	7.9dB(QP)

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



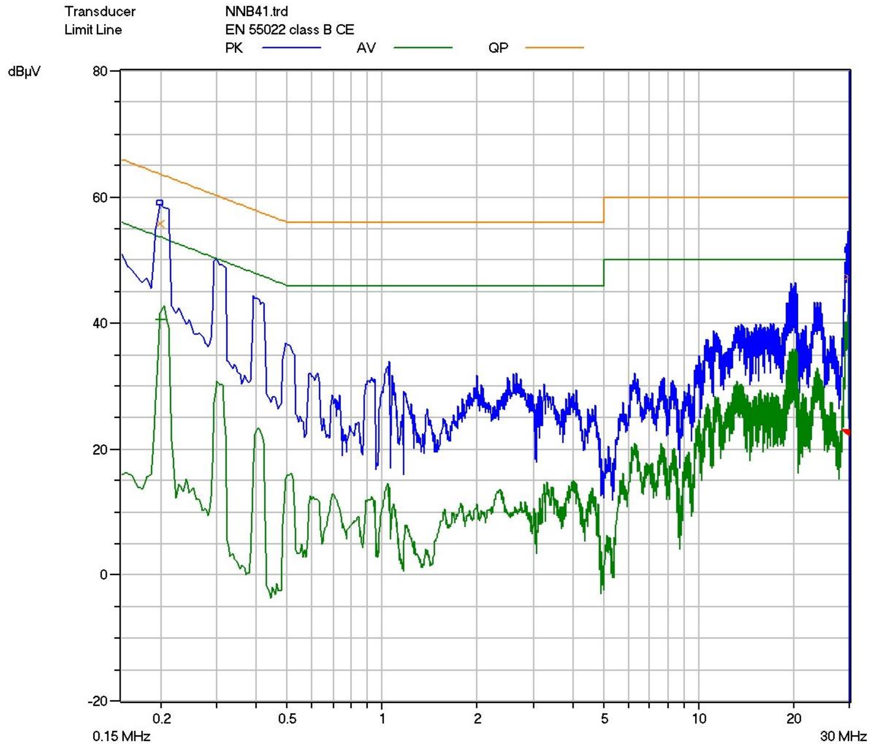
Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.2040	N	59.4	N	43.2	N	56.5	53.4	63.4	6.9dB(QP)
29.6000	N	51.7	N	38.7	N	47.3	50.0	60.0	

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



Frequency	Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.2040	L	59.0	L	42.3	L 55.6	53.4	63.4	7.8dB(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
0.1980	N	59.1	N	40.5	N 55.8	53.7	63.7	7.9dB(QP)
29.6960	N	51.7	N	37.8	N 47.3	50.0	60.0	

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

10.10 Thermal measurements

The thermal testing 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 at 85 V AC (°C)	Temperature at 300 V AC (°C)
1	IC1 (ICE5AR4780BZS)	75.6	66.3
2	TR1 (transformer)	54.4	62.5
3	D151 (15 V diode)	60.3	60.8

Top Side – 85 V AC | **Top Side – 300 V AC**

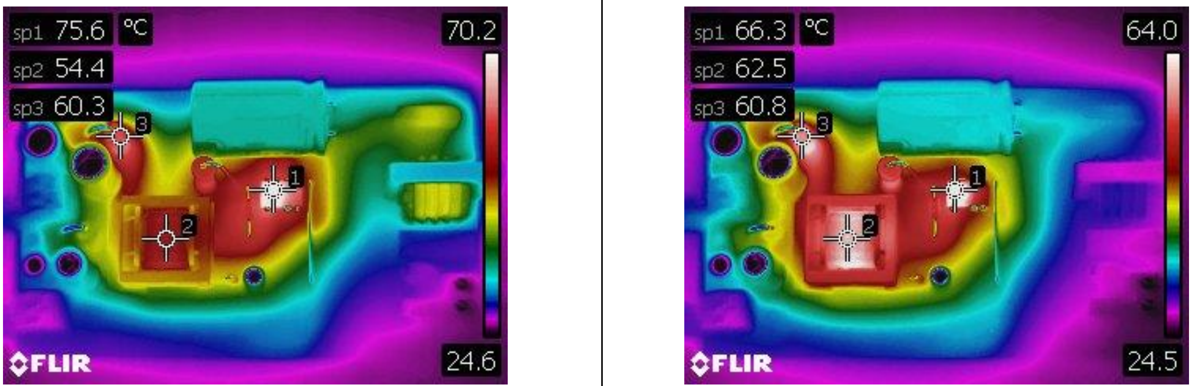


Figure 17 Infrared thermal image of DEMO_5AR4780BZS at full load

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

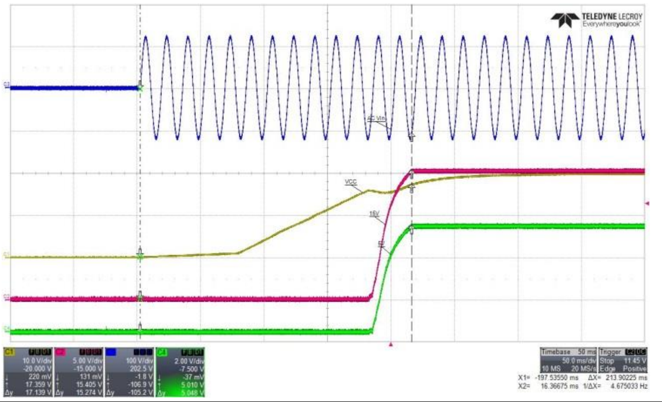
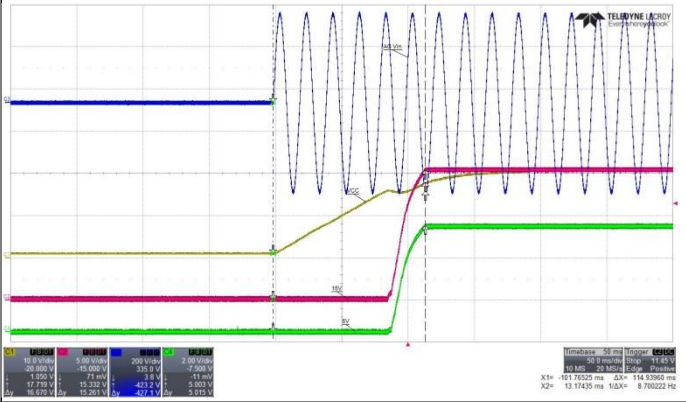
	
C1 (yellow) : V_{CC} voltage C2 (purple) : +15 V output voltage C3 (blue) : AC-line voltage C4 (green) : +5 V output voltage	C1 (yellow) : V_{CC} voltage C2 (purple) : +15 V output voltage C3 (blue) : AC-line voltage C4 (green) : +5 V output voltage
85 V AC start-up time at full load is less than 250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

Figure 18 Start-up

11.2 Soft-start at full load

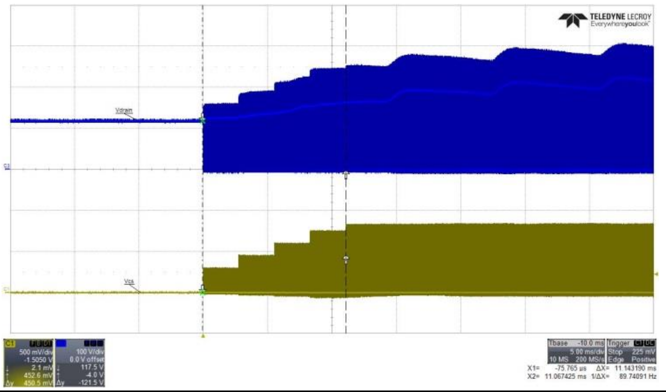
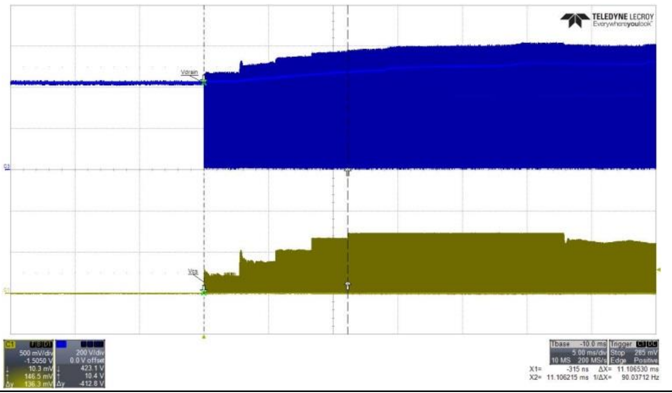
	
C1 (yellow) : CS voltage C3 (blue) : Drain voltage	C1 (yellow) : CS voltage C3 (blue) : Drain voltage
85 V AC soft-start time at full load is ~11.1 ms	300 V AC soft-start time at full load is ~11.1 ms

Figure 19 Soft-start

11.3 Drain and CS voltage at full load

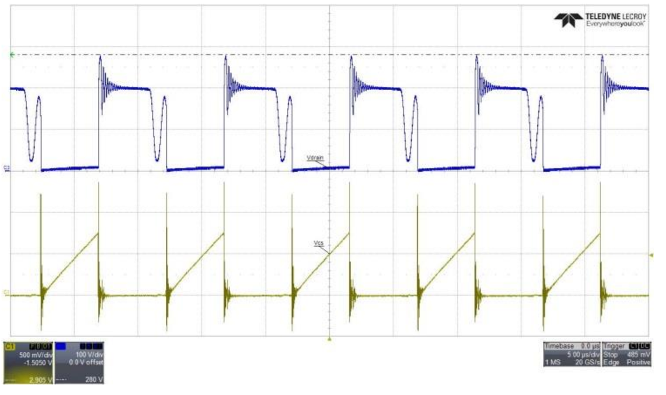
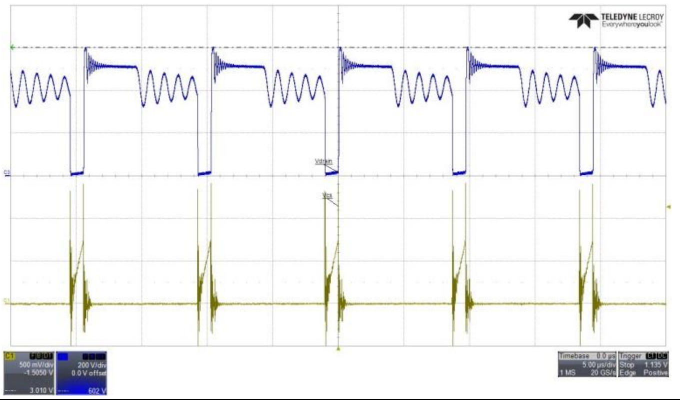
	
C1 (yellow) : CS voltage C3 (blue) : Drain voltage	C1 (yellow) : CS voltage C3 (blue) : Drain voltage
85 V AC maximum drain voltage at full load is ~280 V	300 V AC maximum drain voltage at full load is ~602 V

Figure 20 Drain and CS voltage

11.4 Frequency jittering at full load

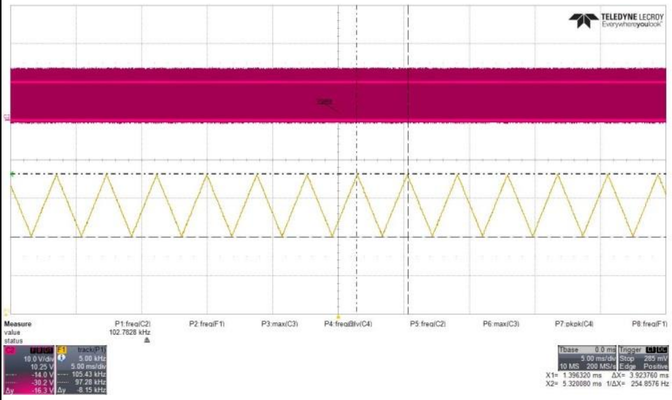
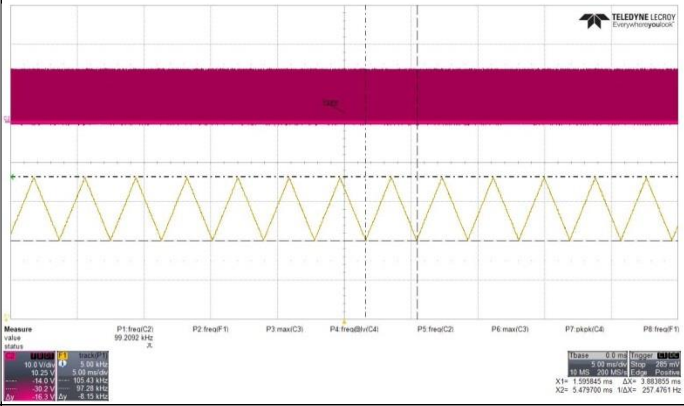
	
C2 (purple) : Gate voltage F1 (yellow) : Frequency track of gate voltage	C2 (purple) : Gate voltage F1 (yellow) : Frequency track of gate voltage
85 V AC frequency jittering at full load is ~97 kHz to ~105 kHz with a jitter period of 3.9 ms	300 V AC frequency jittering at full load is ~97 kHz to ~105 kHz with a jitter period of 3.9 ms

Figure 21 Frequency jittering

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

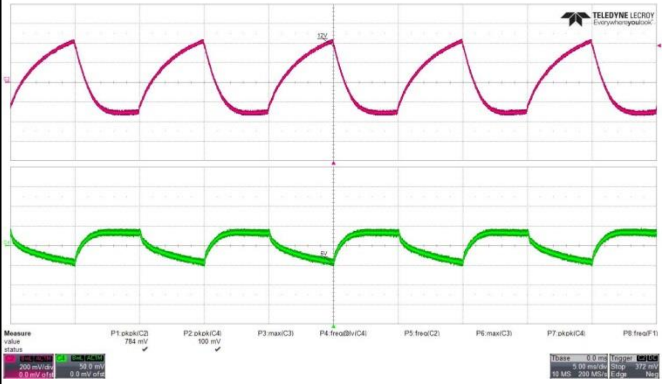
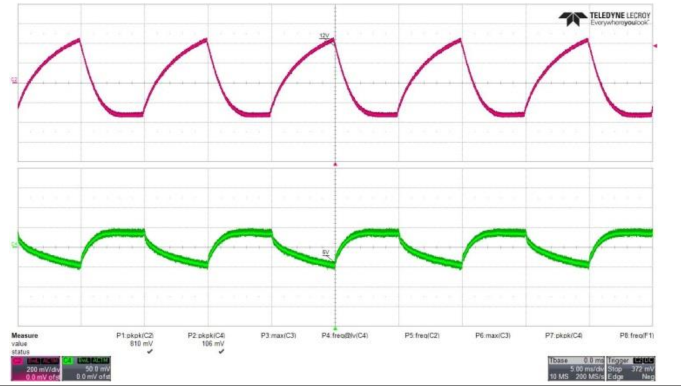
	
C2 (purple) : +15 V output voltage C4 (green) : +5 V output voltage	C2 (purple) : +15 V output voltage C4 (green) : +5 V output voltage
85 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~784 mV 85 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~100 mV	300 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~810 mV 300 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~106 mV

Figure 22 Load transient response with +15 V output load change from 10 percent to 100 percent at 0.4 A/µs slew rate, 100 Hz. +5 V output is fixed at 400 mA load. Probe terminals are decoupled with a 1 µF electrolytic and 0.1 µF ceramic capacitors. Oscilloscope is bandwidth filter limited to 20 MHz.

11.6 Output ripple voltage at full load

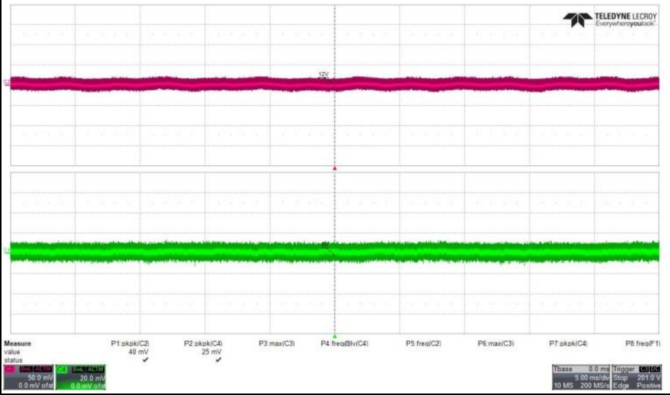
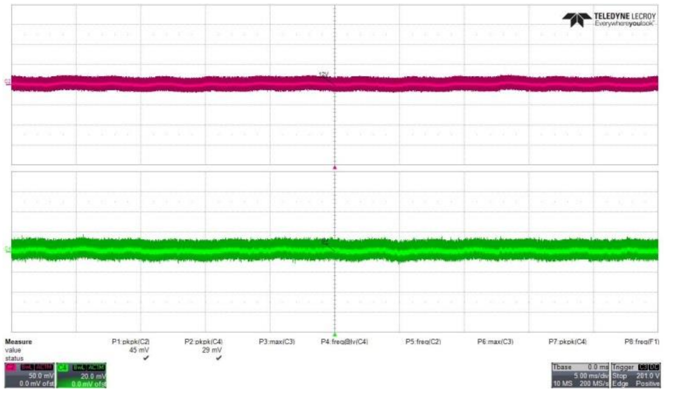
	
C2 (purple) : +15 V output voltage C4 (green) : +5 V output voltage	C2 (purple) : +15 V output voltage C4 (green) : +5 V output voltage
85 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~40 mV 85 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~25 mV	300 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~45 mV 300 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~29 mV

Figure 23 Output ripple voltage at full load. Probe terminals are decoupled with a 1 µF electrolytic capacitor and 0.1 µF ceramic capacitor. Oscilloscope is bandwidth filter limited to 20 MHz.

11.7 Output ripple voltage at ABM (0.5 W load)

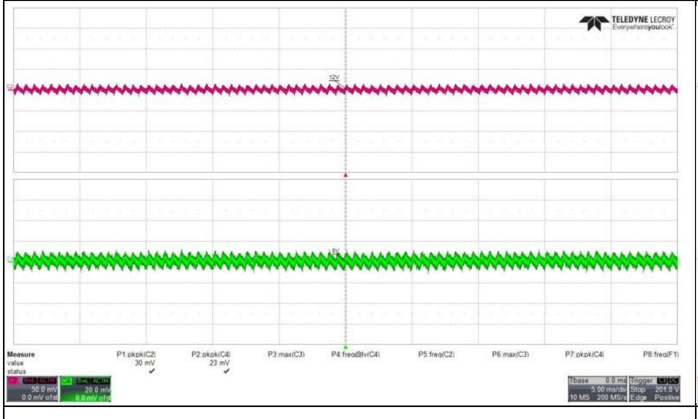
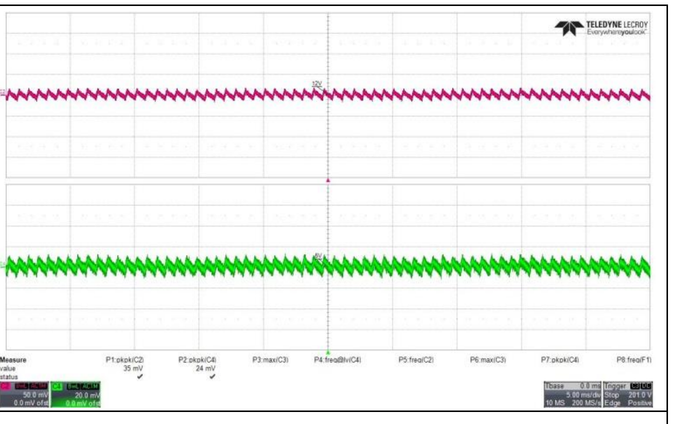
	
C2 (purple) : +15 V output voltage C4 (green) : +5 V output voltage	C2 (purple) : +15 V output voltage C4 (green) : +5 V output voltage
85 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~30 mV 85 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~23 mV	300 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is ~40 mV 300 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is ~25 mV

Figure 24 Output ripple voltage at 0.5 W load (+15 V/30 mA, +5 V/12 mA). Probe terminals are decoupled with a 1 µF electrolytic capacitor and a 0.1 µF ceramic capacitor. Oscilloscope is bandwidth filter limited to 20 MHz.

11.8 Entering ABM

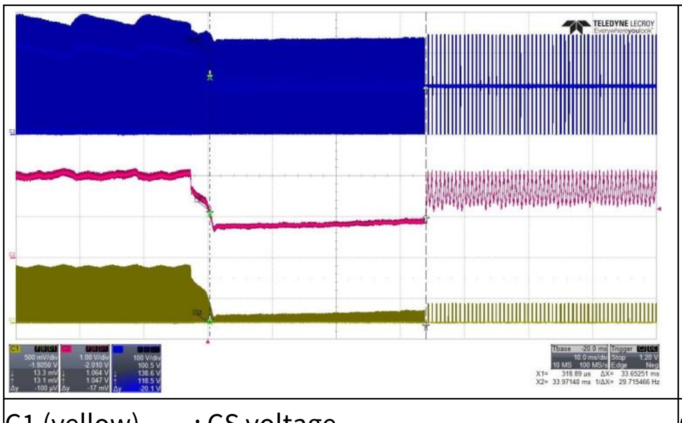
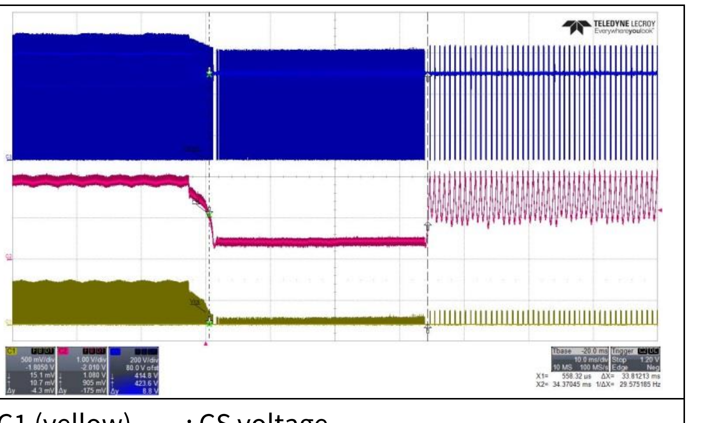
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : Drain voltage
85 V AC full load to 0.5 W load. Enter ABM at FB pin voltage less than 1.03 V (V_{FB_EBHP}) for more than 36 ms (t_{FB_BEB}).	300 V AC full load to 0.5 W load. Enter ABM at FB pin voltage less than 1.03 V (V_{FB_EBHP}) for more than 36 ms (t_{FB_BEB}).

Figure 25 Entering ABM. Output at full load to 0.5 W load (+15 V/30 mA, +5 V/12 mA).

11.9 During ABM

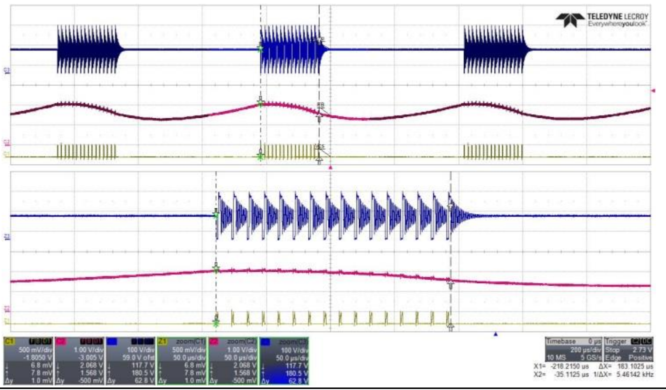
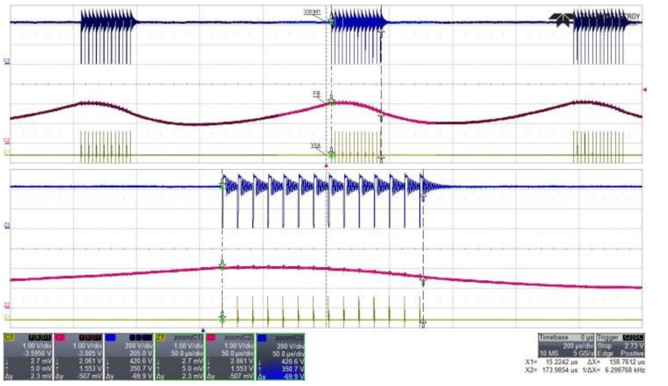
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : Drain voltage
85 V AC at 0.5 W load. Burst on at FB voltage 1.95 V ($V_{FB\_Bon\_NISO}$) and burst off at 1.55 V ($V_{FB\_BOff\_NISO}$). CS voltage at 0.27 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 26 During ABM. Output at 0.5 W load (+15 V/30 mA, +5 V/12 mA).

11.10 Leaving ABM

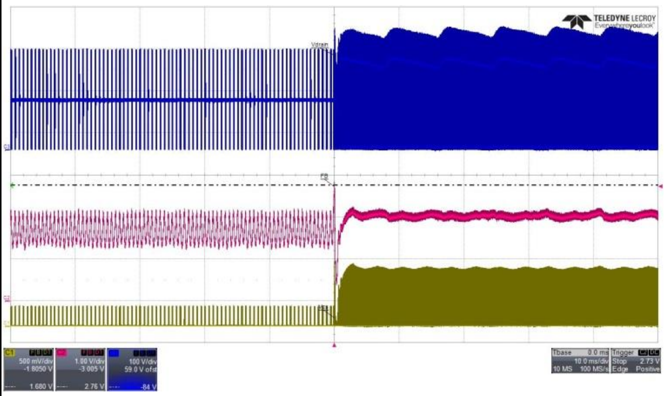
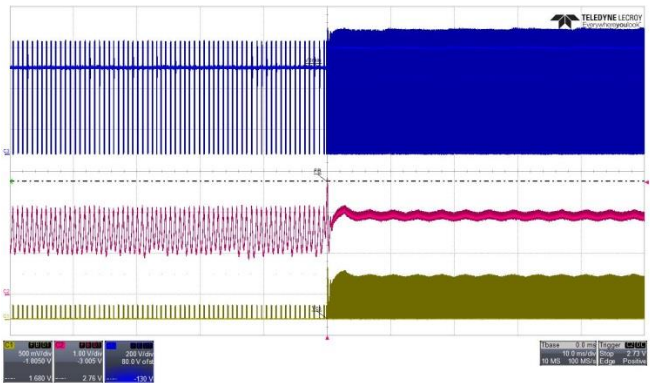
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : Drain voltage
85 V AC at 0.5 W load to full load. Leave ABM at FB voltage more than 2.73 V (V_{FB_LB}).	300 V AC at 0.5 W load to full load. Leave ABM at FB voltage more than 2.73 V (V_{FB_LB}).

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

11.11 V_{CC} OV/UV protection

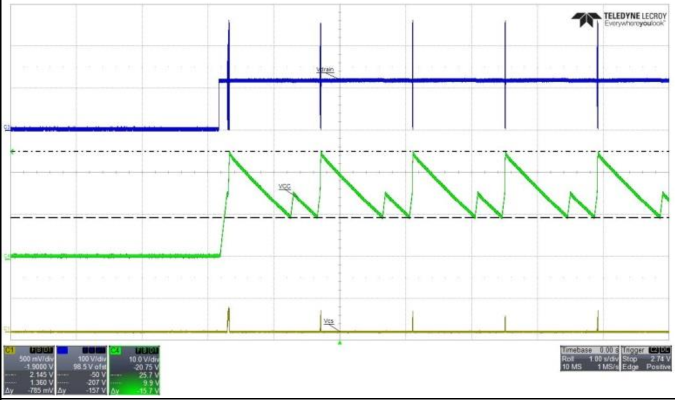
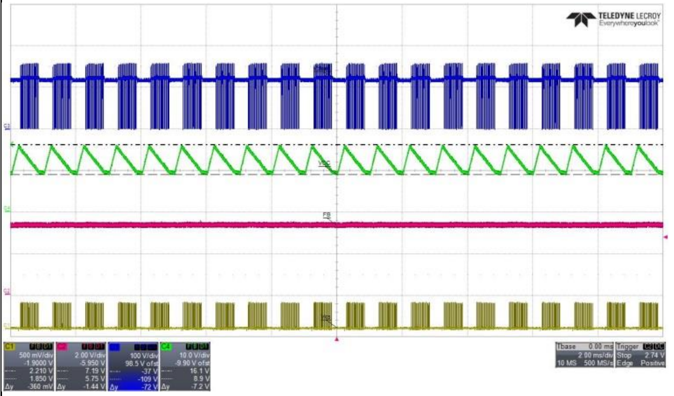
	
C1 (yellow) : CS voltage C3 (blue) : Drain voltage C4 (green) : V_{CC} voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : Drain voltage C4 (green) : V_{CC} voltage
85 V AC at no load. Removed ZD1, R103 and R153. Trigger V_{CC} OV protection at V_{CC} voltage more than 25.5 V (V_{VCC_OVP}). Odd-skip auto restart mode.	85 V AC at full load. Removed R6. Trigger V_{CC} UV protection at V_{CC} voltage less than 10 V (V_{VCC_OFF}). Auto restart mode.

Figure 28 V_{CC} OV/UV protection

11.12 Over-load protection

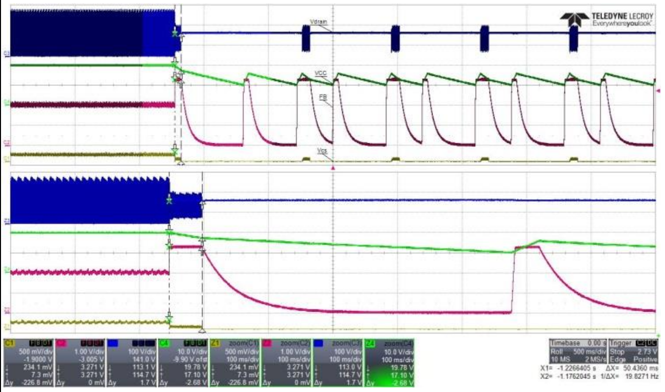
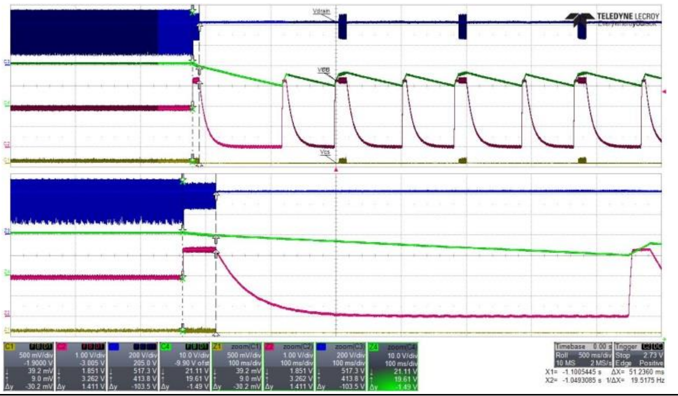
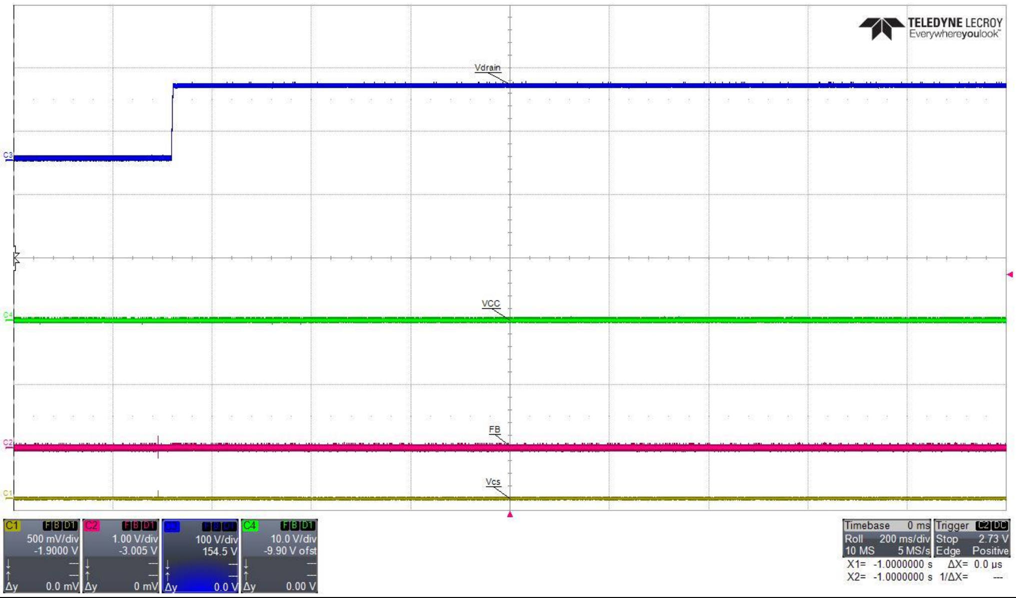
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : V_{CC} voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : V_{CC} voltage C4 (green) : Drain voltage
85 V AC at full load to over-load. Trigger protection at FB pin voltage more than 2.73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

Figure 29 Over-load protection. Short +15 V output to trigger protection.

11.13 V_{CC} short-to-GND



C1 (yellow)	: CS voltage
C2 (purple)	: FB pin voltage
C3 (blue)	: Drain voltage
C4 (green)	: V_{CC} voltage

85 V AC. V_{CC} charging current at ~283 µA ($I_{VCC\_Charge1}$).

Figure 30 **V_{CC} short-to-GND. V_{CC} charging current measured with a digital multimeter.**

12 References

[1] ICE5ARxxxxBZS datasheet

[2] Fifth-Generation Fixed-Frequency Design Guide

[3] Calculation tool for fifth-generation fixed-frequency CoolSET™

Revision history

Major changes since the last revision

Document version	Date of release	Description of changes
Revision 1.0	2018-02-20	First release.
Revision 1.1	2019-07-10	Correct transformer drawing in Figure 6

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Edition 2019-07-10

Published by

Infineon Technologies AG

81726 Munich, Germany

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Document reference
ER_201709_PL83_017