22 W 12 V 5 V SMPS demo board with ICE5GR2280AG

DEMO_5GR2280AG_22W1

About this document

Scope and purpose

This document is an engineering report that describes a universal-input 22 W 12 V 5 V off-line isolated Flyback converter using the latest fifth-generation Infineon Fixed Frequency (FF) CoolSET™ ICE5GR2280AG, 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 ICE5GR2280AG 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 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 22 W 12 V 5 V demo board designed in an FF isolated Flyback converter topology using the fifth-generation FF CoolSET™ ICE5GR2280AG. The demo board is operated in Discontinuous Conduction Mode (DCM) and is running at 125 kHz fixed switching frequency. The frequency reduction with soft gate driving and frequency jittering offers lower EMI and better efficiency between medium 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 ICE5GR2280AG to protect the system and customize the IC for the chosen application. In case of failure modes, like line Over Voltage (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 dimension of the transformer and 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 ICE5GR2280AG 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 curves and scope waveforms are shown at the end of the report.

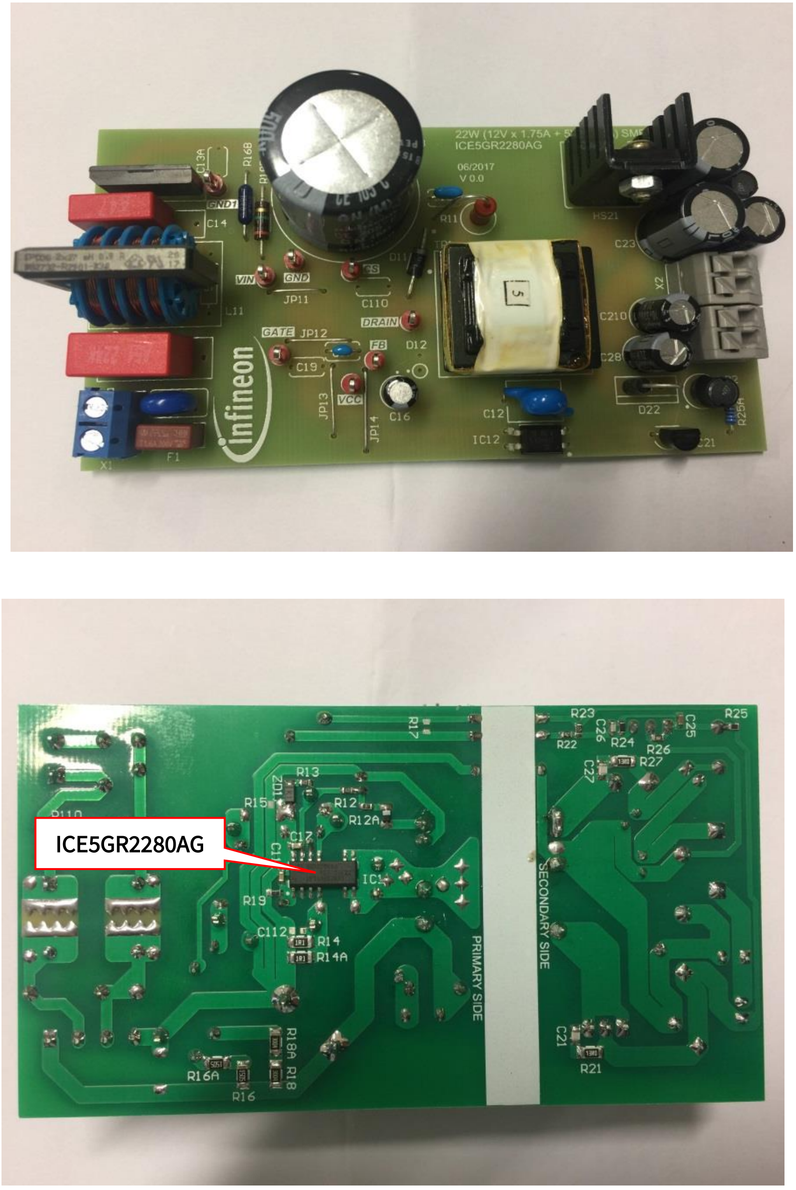


Figure 1 DEMO_5GR2280AG_22W1

3 Specifications of the demo board

Table 1 Specifications of DEMO_5GR2280AG_22W1

Input voltage and frequency	85 V AC (60 Hz) ~ 300 V AC (50 Hz)
Output voltage, current and power	(12 V × 1.75 A) + (5 V × 0.20 A) = 22 W
Regulation	+5 V: less than ±5% +12 V: less than ±5%
Output ripple voltage (full load, 85 V AC ~ 300 V AC)	5 $V_{ripple\_p\_p}$ < 100 mV 12 $V_{ripple\_p\_p}$ < 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} < 180 mW at 230 V AC
Conducted emissions (EN 55022 class B)	Pass with 10 dB margin for 115 V AC and 9.4 dB margin for 230 V AC
ESD immunity (EN 61000-4-2)	Level 4 for contact discharge and level 3 for air discharge (±8 kV for both contact and air discharge)
Surge immunity (EN 61000-4-5)	Installation class 4 (±2 kV for line-to-line and ±4 kV for line-to-earth)
Form factor case size (L × W × H)	(110 × 60 × 27) mm

Note: *"The demo board is designed for dual-output with cross-regulated loop feedback (FB). It may not regulate properly if loading is applied only to single-output. If the user wants to evaluate for single-output (12 V only) conditions, the following changes are necessary on the board.*

1. Remove D22, L22, C28, C210, R25A (to disable 5 V output)
2. Change R26 to 10 kΩ and R25 to 38 kΩ (to disable 5 V FB and enable 100% weighted factor on 12 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 L11, X-capacitor C11 and Y-capacitor C12 act as EMI suppressors. Optional spark-gap devices SA1, SA2 and varistor VAR 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 C13.

4.2 Start-up

To achieve fast and safe start-up, ICE5GR2280AG is implemented with 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 ICE5GR2280AG 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 controller

ICE5GR1680AG 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 CCM with frequency reduction mode. This demo board is designed to operate in DCM. When the system is operating at the maximum power, the controller will switch at the FF of 125 kHz. In order to achieve a 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_{OSC2_MIN} (53 kHz).

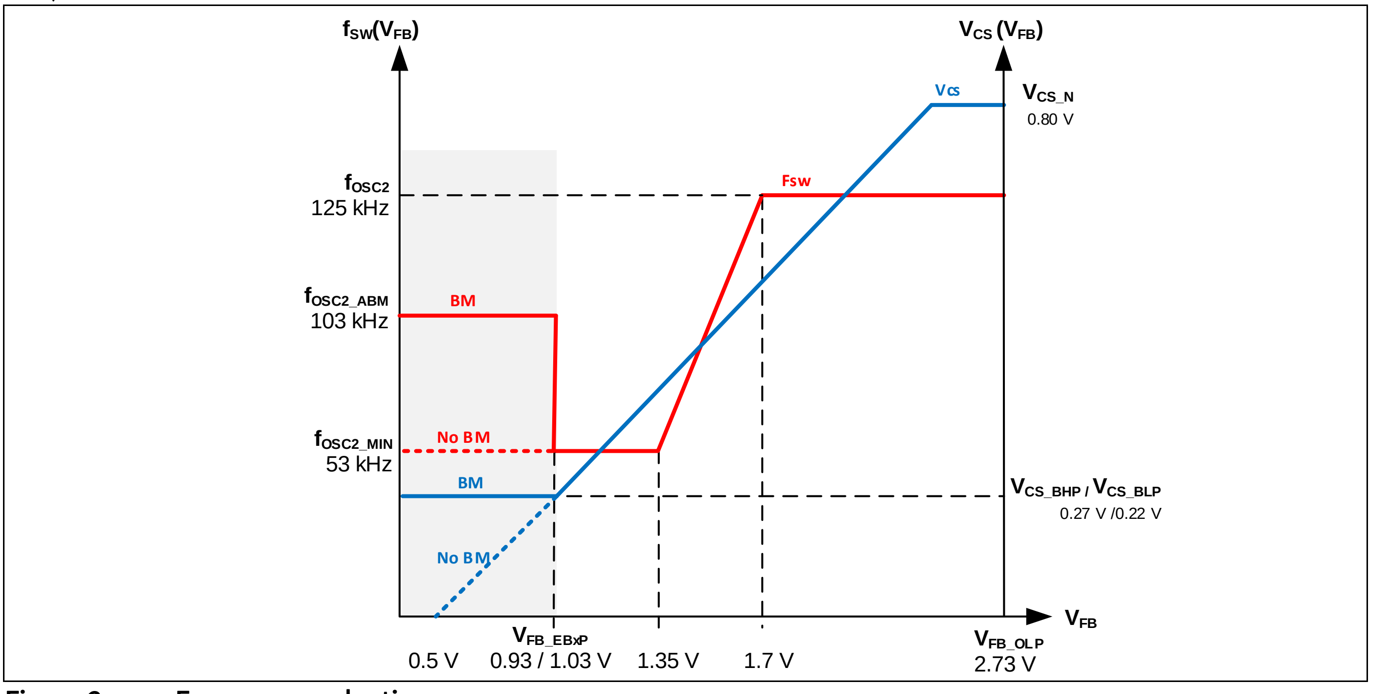


Figure 2 Frequency reduction curve

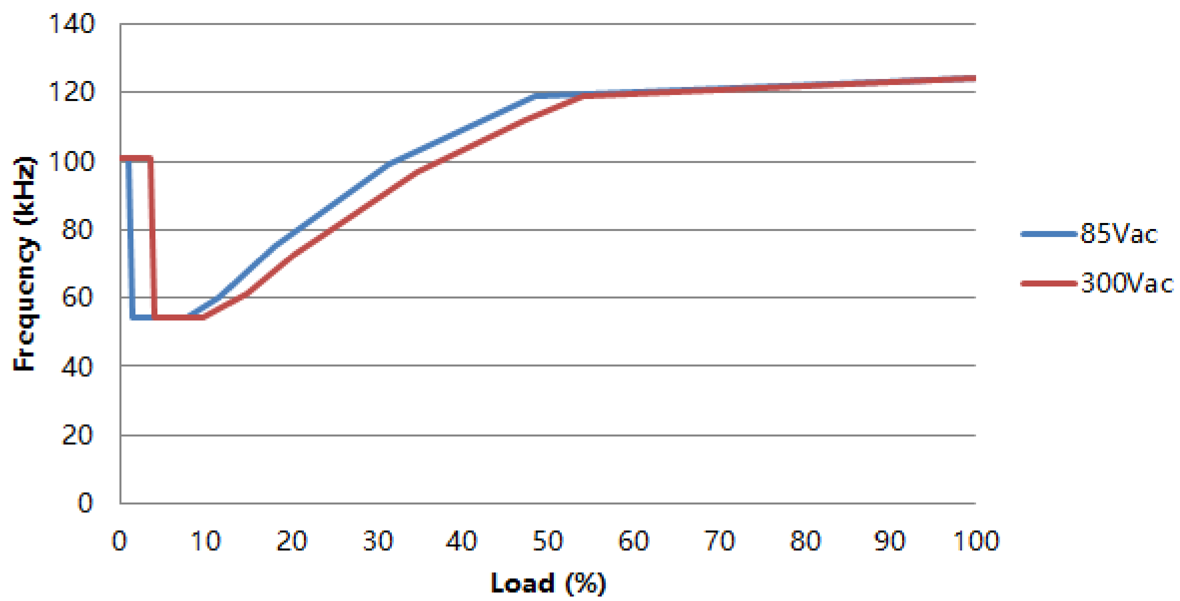


Figure 3 Frequency reduction curve of DEMO_5GR2280AG_22W1

The measured frequency reduction curve of DEMO_5GR2280AG_22W1 is shown in Figure 3.

4.4 Frequency jittering

The ICE5GR2280AG has a frequency jittering feature to reduce the EMI noise. The jitter frequency is internally set at 125 kHz (±5 kHz) and the jitter period is 4 ms.

4.5 RCD clamper circuit

A clamper network (R11, C15 and D11) dissipates the energy of the leakage inductance and suppresses ringing on the SMPS transformer.

4.6 Output stage

There are two outputs on the secondary side, 12 V and 5 V. The power is coupled out via Schottky diodes D21 and D22. The capacitors C22, C23 and C28 provide energy buffering followed by the L-C filters L21-C24 and L22-C210 to reduce the output ripple and prevent interference between SMPS switching frequency and line frequency. Storage capacitors C22, C23 and C28 are designed to have as small an internal resistance (ESR) as possible to minimize the output voltage ripple caused by the triangular current.

4.7 Feedback loop

For FB, the output is sensed by the voltage divider of R26, R25 and R25A and compared to the IC21 (TL431) internal reference voltage. C25, C26 and R24 comprise the compensation network. The output voltage of IC21 (TL431) is converted to the current signal via optocoupler IC12 and two resistors R22 and R23 for regulation control.

4.8 Active Burst Mode (ABM)

ABM entry and exit power (three levels) can be selected in ICE5GR2280AG. 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 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. ICE5GR2280AG provides comprehensive protection to ensure the system is operating safely. The 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 it resumes normal operation. A list of protection functions and the failure conditions are shown in the table below.

Table 2 Protection functions of ICE5GR2280AG

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, lasts for 0.4 µs and three consecutive pulses	Odd-skip auto restart
V_{CC} short-to-GND (V$_{VCC}$ = 0 V, $R_{Start\text{-}up}$ = 50 MΩ and V_{DRAIN} = 90 V)	V_{VCC} < 1.2 V, $I_{VCC\_Charge1}$ ≈ -0.27 mA	Cannot start up

6 Circuit diagram

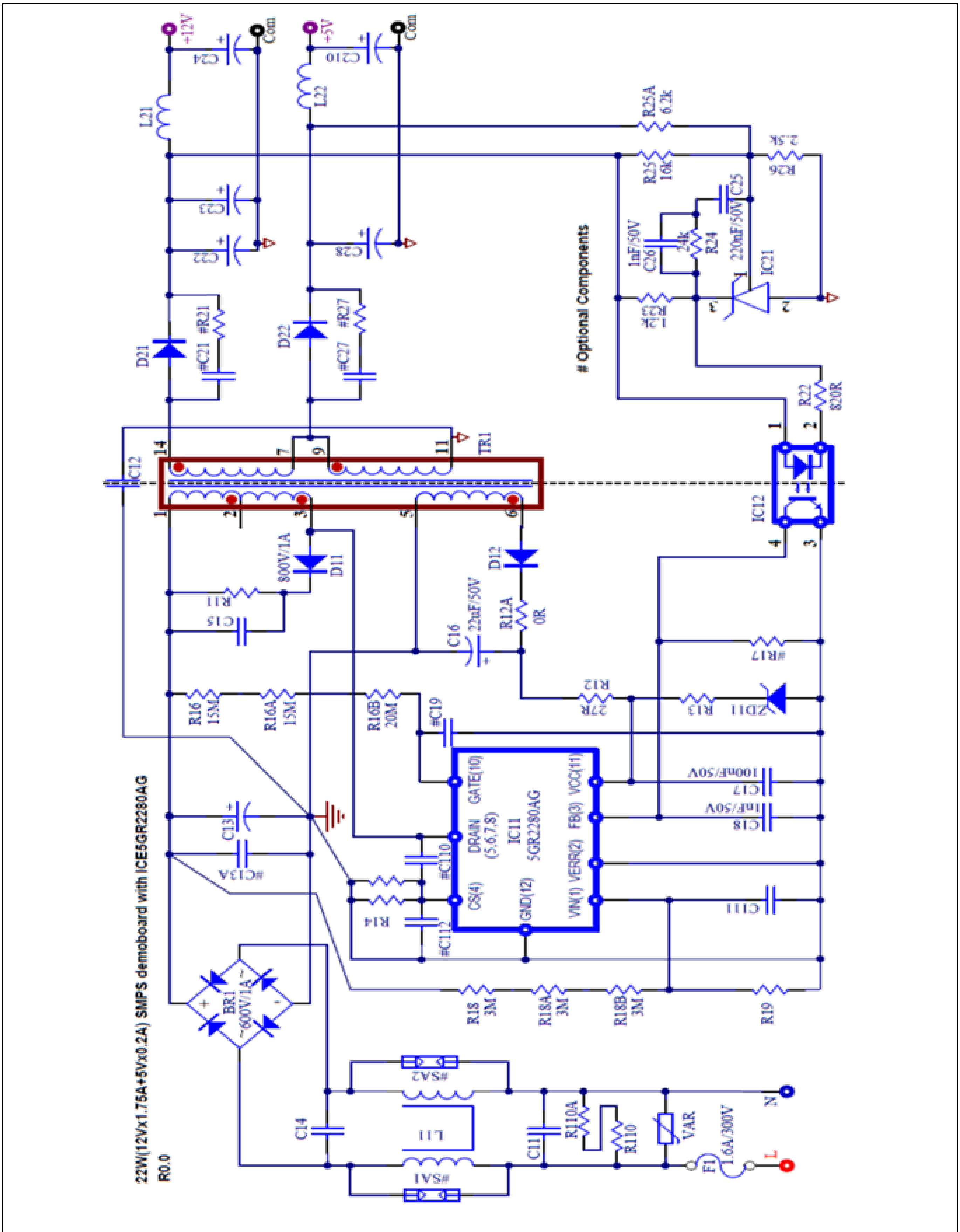


Figure 4 Schematic of DEMO_5GR2280AG_22W1

7 PCB layout

7.1 Top side

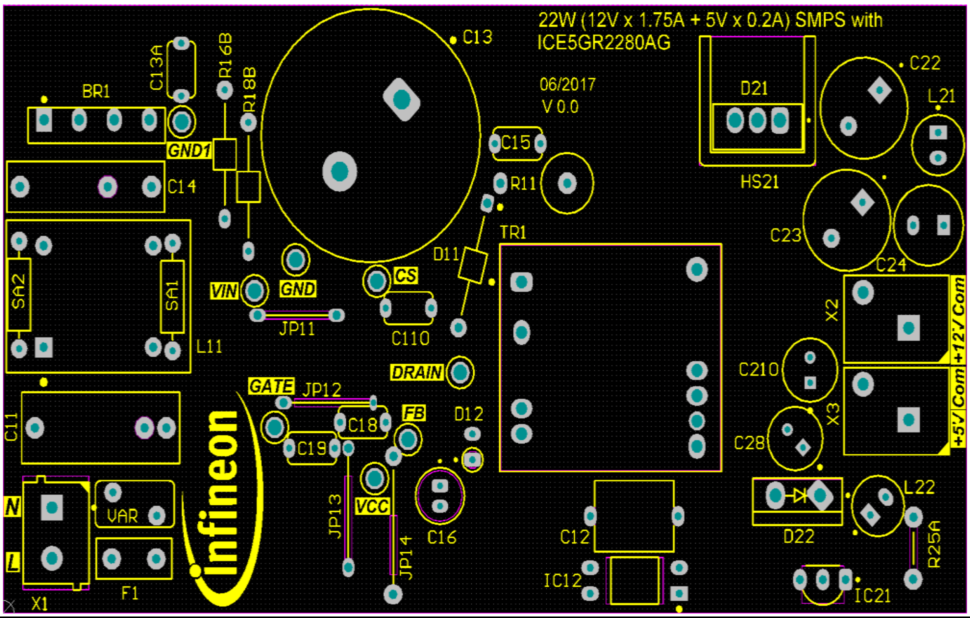


Figure 5 Top side component legend

7.2 Bottom side

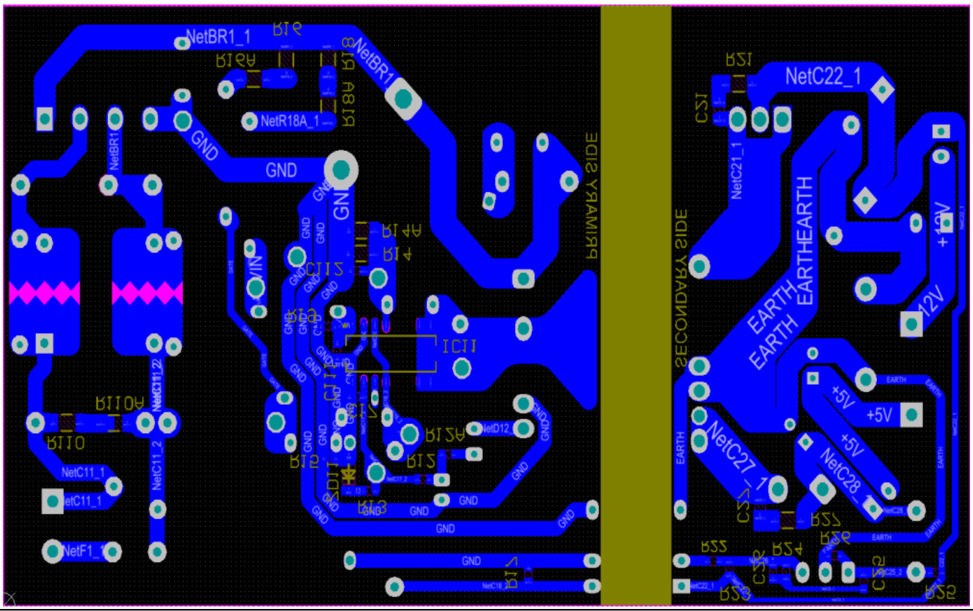


Figure 6 Bottom side copper and component legend

8 Bill of Materials (BOM)

Table 3 BOM (R 1.5)

No.	Designator	Description	Part number	Manufacturer	Quantity
1	BR1	600 V/1 A	S1VBA60	Shindengen	1
2	C11	0.15 µF, X-cap	B32932A3154K189	EPCOS/TDK	1
3	C12	1 nF/500 V	DE1E3RA102MA4BQ	Murata	1
4	C13	56 uF/500 V	LGN2H560MELZ25	Nichicon	1
5	C15	1 nF/1000 V	RDER73A102K2K1H03	Murata	1
6	C16	22 uF/50 V	50PX22MEFC5X11	Rubycon	1
7	C17	100 nF/50 V	GRM188R71H104KA93D	Murata	1
8	C18	1 nF/50 V	RCE5C1H102J0M1H03A	Murata	1
9	C22, C23	1000 uF/16 V	16ZLH1000MEFC10X16	Rubycon	2
10	C24	470 uF/16 V	16ZLH470MEFC8X11.5	Rubycon	1
11	C25	220 nF/50 V	GRM188R71H224KAC4D	Murata	1
12	C26	1 nF/50 V	GRM1885C1H102GA01D	Murata	1
13	C28	330 uF/10 V	10ZLH330MEFC6.3X11	Rubycon	1
14	C111	22 nF/50 V	GCM188R71H223KA37D	Murata	1
15	C210	330 uF/10 V	10ZLH330MEFC6.3X11	Rubycon	1
16	D11	800 V/1 A	UF4006-E3/54	Vishay	1
17	D12	0.2 A/200 V	1N485B	Fairchild	1
18	D21	100 V/10 A	MBRF10100CT	Vishay	1
19	D22	50 V/1 A	SB150	Vishay	1
20	F1	1.6 A/300 V	36911600000		1
21	IC11	ICE5GR2280AG	ICE5GR2280AG	Infineoon	1
22	IC12	Optocoupler	SFH617A-3		1
23	IC21	Shunt regulator	TL431BVLPG		1
24	JP11, JP12, JP13, JP14	Jumper			4
25	L11	39 mH/0.7 A	B82732R2901B030	Epcos	1
26	L21, L22	4.7 uH,4.2 A	7447462047	Wurth Electronics	2
27	R11	39 k/2 W/500 V	PR02000206802JR500		1
28	R12, R13	27 R (0603)	RESISTOR		2
29	R14	1.1 R/0.33 W	ERJ8BQF1R1V		1
30	R14A	1.2 R/0.33 W	ERJ8BQF1R2V		1
31	R16, R16A	15 MΩ/0.25 W/5%/1206	RC1206JR-0715ML	Yageo	2
32	R16B	20 M.0.125 W (axial leaded)			1
33	R18, R18A	3 MΩ/0.25 W/5%/1206	RESISTOR		2
34	R18B	3 M/0.125 W (axial leaded)	RESISTOR		1
35	R19	59 k (0603)	ERJ-3RBD5902V		1
36	R22	820 R (0603)			1
37	R23	1.2 k (0603)			1
38	R24	24 k (0603)			1
39	R25	16 k (0603)			1
40	R25A	6.2 k/0.1 W (axial leaded)			1
41	R26	2.5 k (0603)			1
42	R12A	0 R (0603)			1

43	R110, R110A	2 M/200 V (1206)			2
44	Test point of FB, VIN, CS, gate, drain, V_{cc}, GND, GND1	Test point	5010		8
45	TR1	EF20, 240 uH	750343685 (Rev 02)	Wurth Electronics	1
46	ZD11	22 V (SOD123)	MMSZ5251B-7-F		1
47	VAR	320 V/0.25 W	B72207S02321K101	Epcos	1
48	X1	Connector_ Con (L N)	691102710002	Wurth Electronics	1
49	X2, X3	Connector_Con (+12 V com), con(+5 V com)	691 412 120 002B	Wurth Electronics	2
50	HS21	Heatsink	577202B00000G	AAVID	1

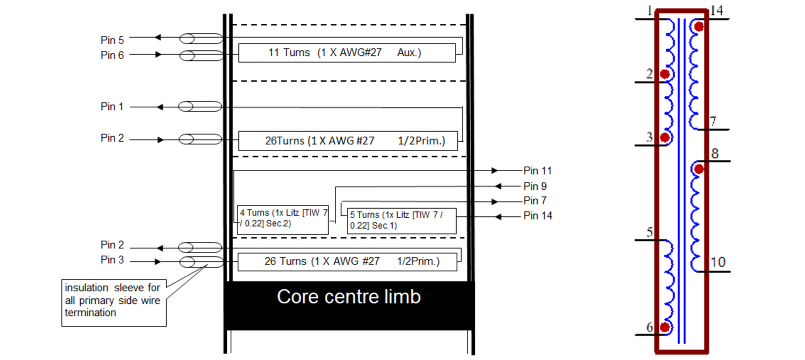
9 Transformer construction

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

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

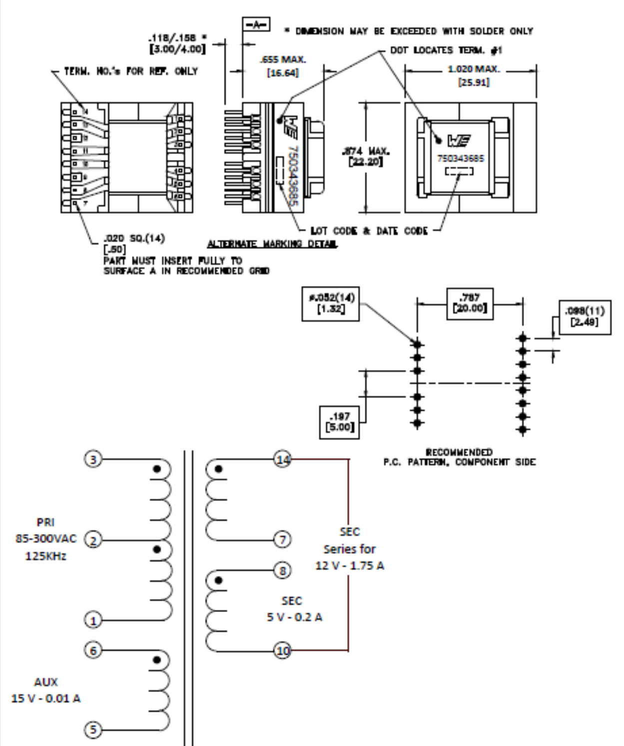
Primary inductance: Lp = 240 µH (±10%), measured between pin 1 and pin 3

Manufacturer and part number: Wurth Electronics Midcom (750343685 Rev02)



Start	Stop	No. of turns	Wire size	Layer
3	2	26	1XAWG#27	1/2 Primary
14	7	5	1 x Litz [TIW 7 / 0.22]	Secondary 1
8	10	4	1 x Litz [TIW 7 / 0.22]	Secondary 2
2	1	26	1XAWG#27	1/2 Primary
6	5	11	1XAWG#27	Auxiliary

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	3-1	@20°C	0.383 ohms max.
D.C. RESISTANCE	14-7	@20°C	0.020 ohms max.
D.C. RESISTANCE	8-10	@20°C	0.019 ohms max.
D.C. RESISTANCE	6-5	@20°C	0.110 ohms max.
INDUCTANCE	3-1	10kHz, 100mV, Ls	240.00µH ±10%
LEAKAGE INDUCTANCE	3-1	tie(5+6+7+8+10+14),100kHz, 100mV, Ls	10µH max.
DIELECTRIC	1-14	tie(3+5 , 7+8), 3750VAC, 1 second	3000VAC, 1 minute
DIELECTRIC	14-CORE	tie(7+8), 3750VAC, 1 second	3000VAC, 1 minute
TURNS RATIO		(3-1):(14-7)	10.4:1, ±1%
TURNS RATIO		(3-1):(8-10)	13:1, ±1%
TURNS RATIO		(3-1):(6-5)	4.73:1, ±1%

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:
- Reinforced insulation for a primary circuit at a working voltage of 265Vrms, 400Vpeak, Overvoltage Category II.

Application of the transformer allows for the leadwires between terminals 7 & 8 to solder bridge. Customer to tie terminals 7 + 8 on PC board.

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

DFM		Packaging Specifications Method: Tray PKG-0736	CONVENTION PLACEMENT	Tolerances unless otherwise specified: Angles: ±1° Decimals: ±.005 [.13] Fractions: ±1/64 Footprint: ± .001 [.03]	DRAWING TITLE TRANSFORMER	PART NO. 750343685
DATE						
ENG						
REV.	02			This drawing is dual dimensioned. Dimensions in brackets are in millimeters.		SPECIFICATION SHEET 1 OF 1
DATE	9/15/2017					

Figure 7 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)	12 V (V)	I_{out_12V} (mA)	5 V (V)	I_{out_5V} (mA)	12 V_{RPP} (mV)	5 V_{RPP} (mV)	P_{out} (W)	Efficiency (η) (%)	Average (%)	OLP pin (W)	OLP Iout12 V (Fixed 5 V at 0.2 A) (A)
85 V AC/60 Hz	0.0430	11.72	0	5.07	0	37	25				36.80	2.45
	0.118	12.23	2.5	4.87	6	33	48	0.06				
	6.440	11.68	437.5	5.08	50	37	25	5.36	83.29	82.42		
	12.92	11.68	875	5.07	100	43	25	10.73	83.03			
	19.58	11.69	1312.5	5.06	150	46	30	16.10	82.24			
	26.49	11.70	1750	5.05	200	60	35	21.49	81.11			
115 V AC/60 Hz	0.0480	11.71	0	5.07	0	43	28				37.00	2.55
	0.122	12.23	2.5	4.87	6	40	50	0.06				
	6.370	11.66	437.5	5.08	50	43	25	5.36	84.07	83.81		
	12.72	11.67	875	5.07	100	46	28	10.72	84.26			
	19.19	11.68	1312.5	5.07	150	53	30	16.09	83.85			
	25.83	11.68	1750	5.06	200	63	32	21.45	83.05			
230 V AC/50 Hz	0.072	11.69	0	5.08	0	66	30				38.00	2.70
	0.147	12.24	2.5	4.87	6	66	51	0.06				
	6.380	11.61	437.5	5.10	50	66	27	5.33	83.61	84.4		
	12.63	11.62	875	5.09	100	70	32	10.68	84.53			
	18.90	11.64	1312.5	5.08	150	73	32	16.04	84.87			
	25.30	11.65	1750	5.07	200	73	32	21.40	84.59			
265 V AC/50 Hz	0.086	11.70	0	5.08	0	70	30				39.00	2.76
	0.162	12.27	2.5	4.86	6	63	56	0.06				
	6.430	11.60	437.5	5.11	50	63	28	5.33	82.90	84.01		
	12.67	11.62	875	5.09	100	66	30	10.68	84.27			
	18.98	11.63	1312.5	5.08	150	66	32	16.03	84.44			
	25.32	11.64	1750	5.07	200	66	35	21.38	84.45			
300 V AC/50 Hz	0.112	11.70	0	5.08	0	60	30				39.50	2.83
	0.185	12.27	2.5	4.86	6	63	48	0.06				
	6.510	11.60	437.5	5.11	50	66	27	5.33	81.88	83.31		
	12.78	11.61	875	5.10	100	66	28	10.67	83.48			
	19.09	11.62	1312.5	5.07	150	63	30	16.01	83.88			
	25.45	11.64	1750	5.07	200	66	35	21.38	84.02			

60 mW load condition: 5 V @ 6 mA and 12 V @ 2.5 mA

Maximum load condition: 5 V @ 200 mA and 12 V @ 1750 mA

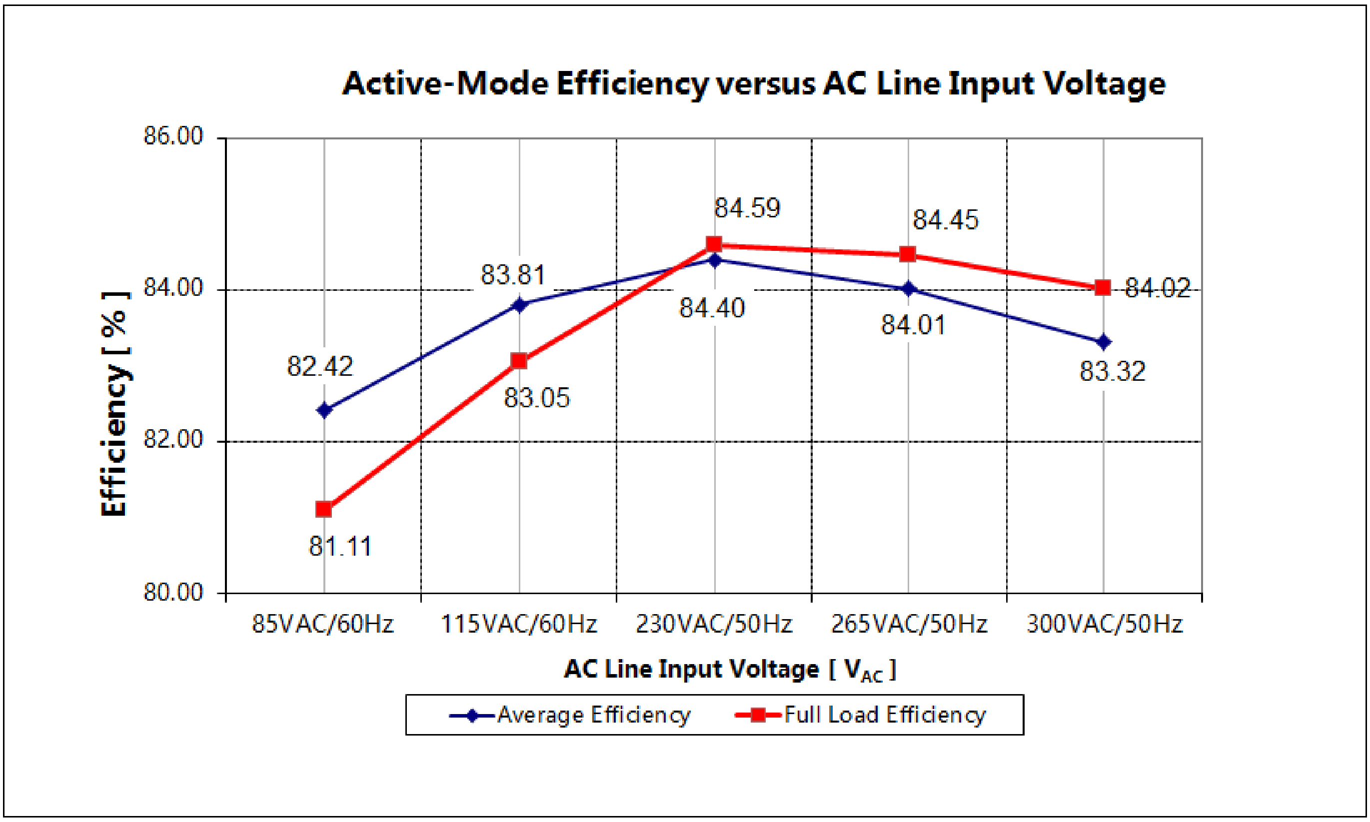


Figure 8 Efficiency vs AC-line input voltage

10.2 Standby power

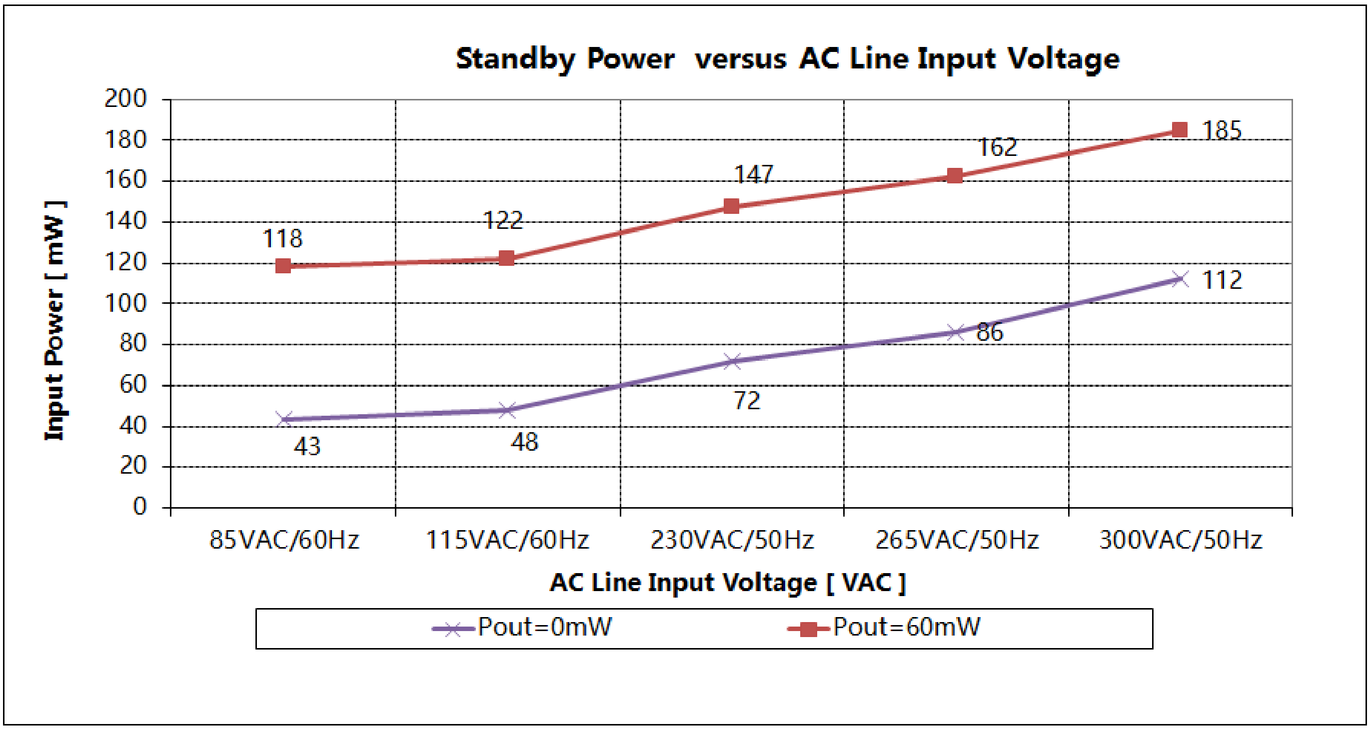


Figure 9 Standby power at no load and 60 mW load vs AC-line input voltage (measured by Yokogawa WT210 power meter – integration mode)

10.3 Line regulation

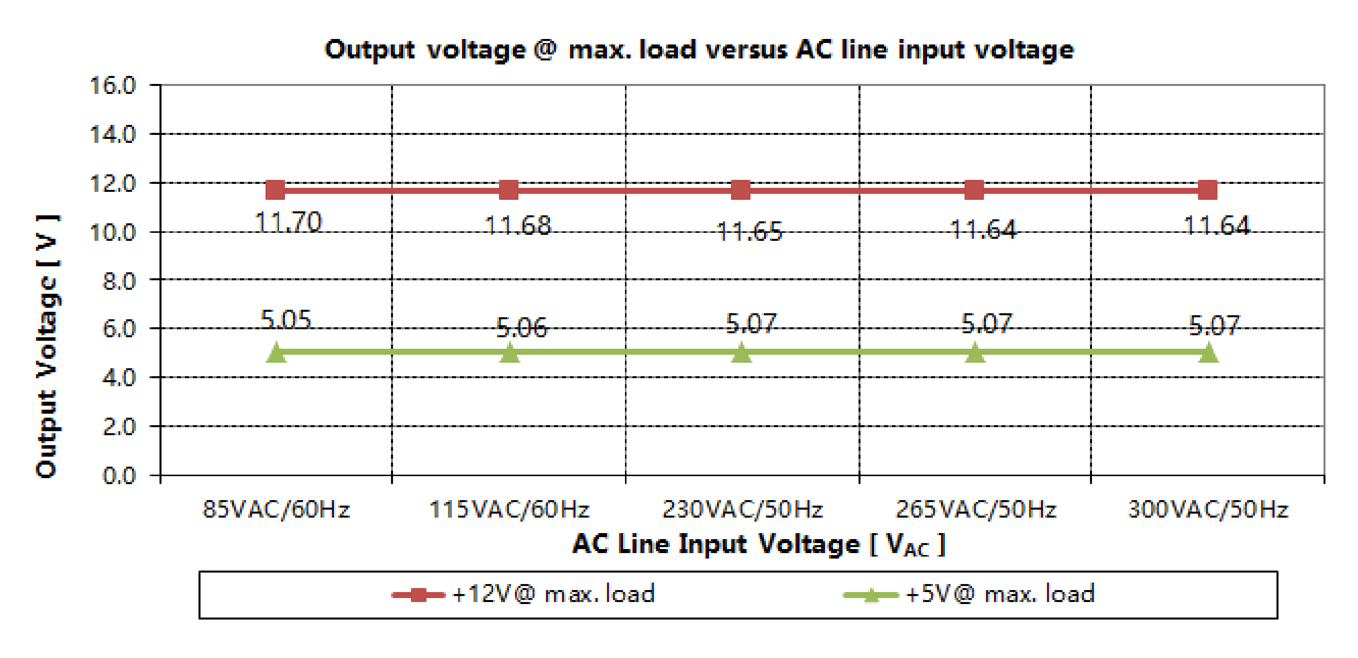


Figure 10 Line regulation V_{Out} at full load vs AC-line input voltage

10.4 Load regulation

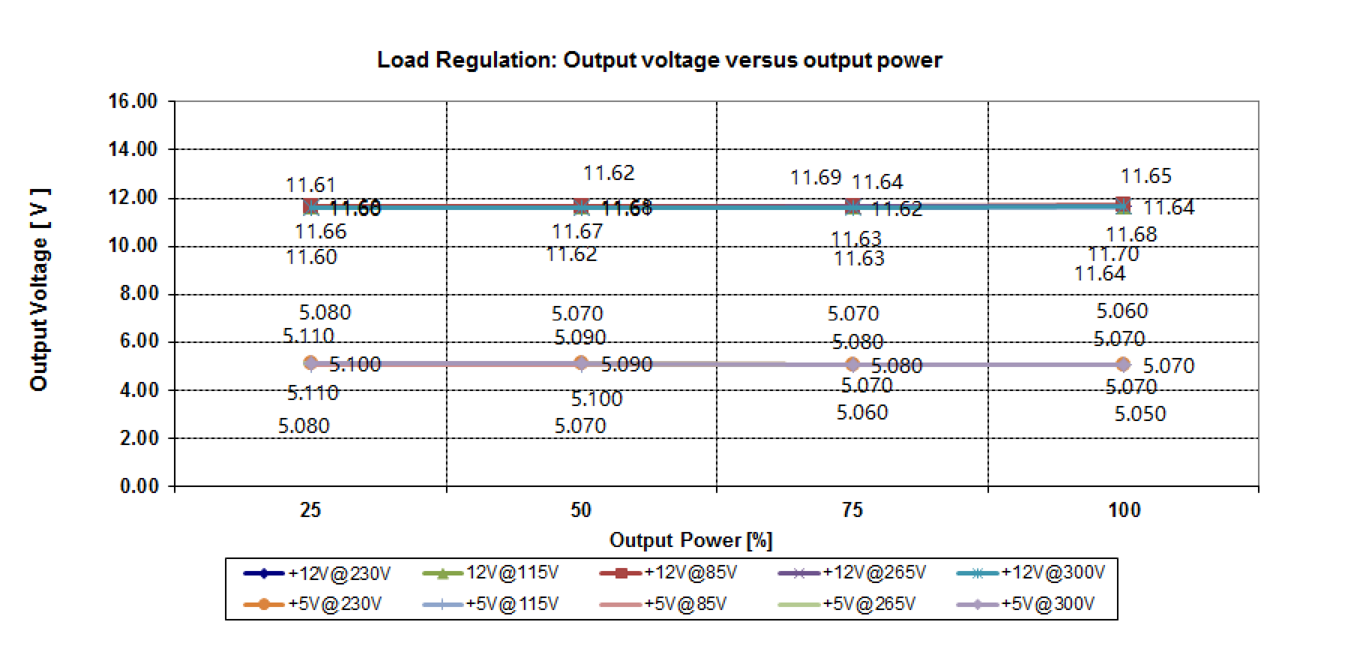


Figure 11 Load regulation V_{Out} vs output power

10.5 Maximum input power

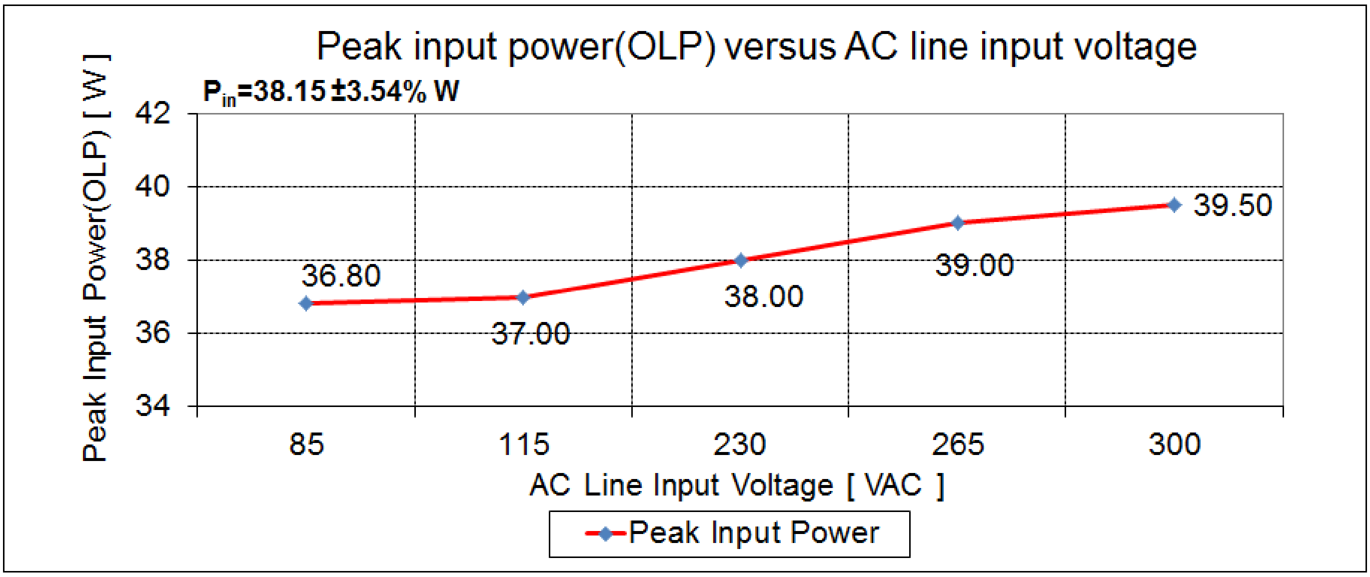


Figure 12 Maximum input power (before over-load protection) vs AC-line input voltage

10.6 ESD immunity (EN 61000-4-2)

Pass EN 61000-4-2 level 4 for contact discharge and level 3 for air discharge (±8 kV for both contact and air discharge).

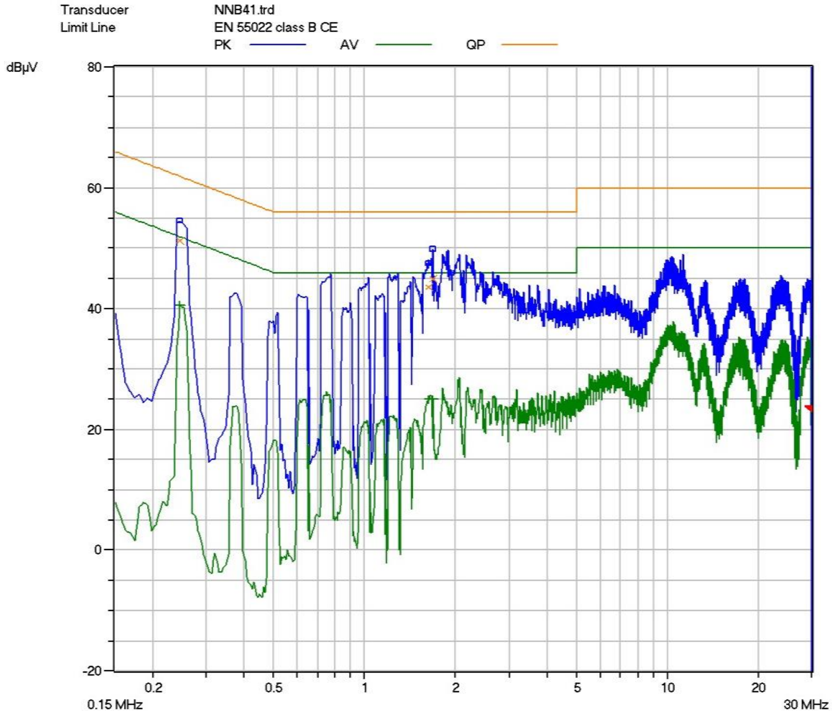
10.7 Surge immunity (EN 61000-4-5)

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

10.8 Conducted emissions (EN 55022 class B)

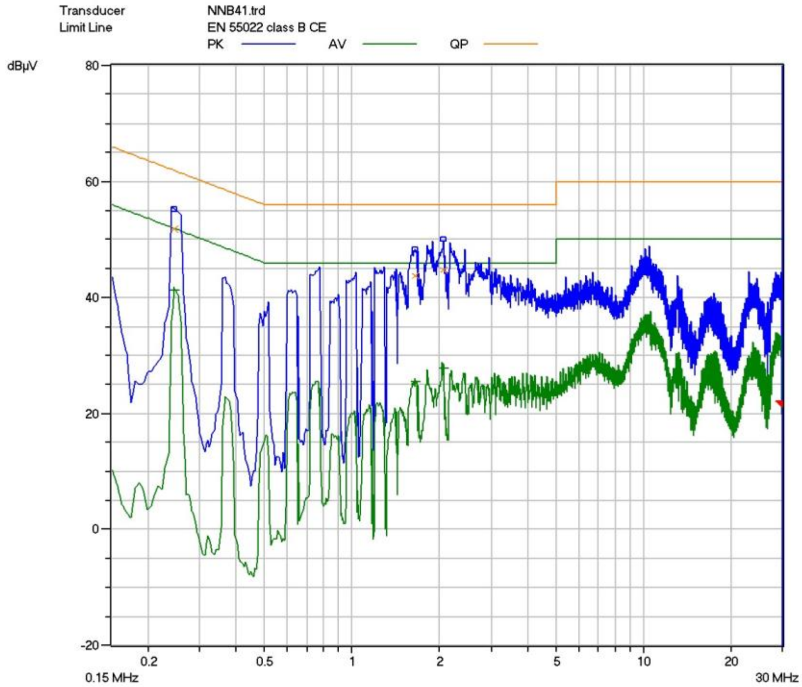
The conducted EMI was measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) class B. The demo board was set up at maximum load (22 W) with an input voltage of 115 V AC and 230 V AC.

Pass conducted emissions EN 55022 (CISPR 22) class B with 10 dB margin at low-line (115 V AC) and with 9.4 dB margin for high-line (230 V AC).



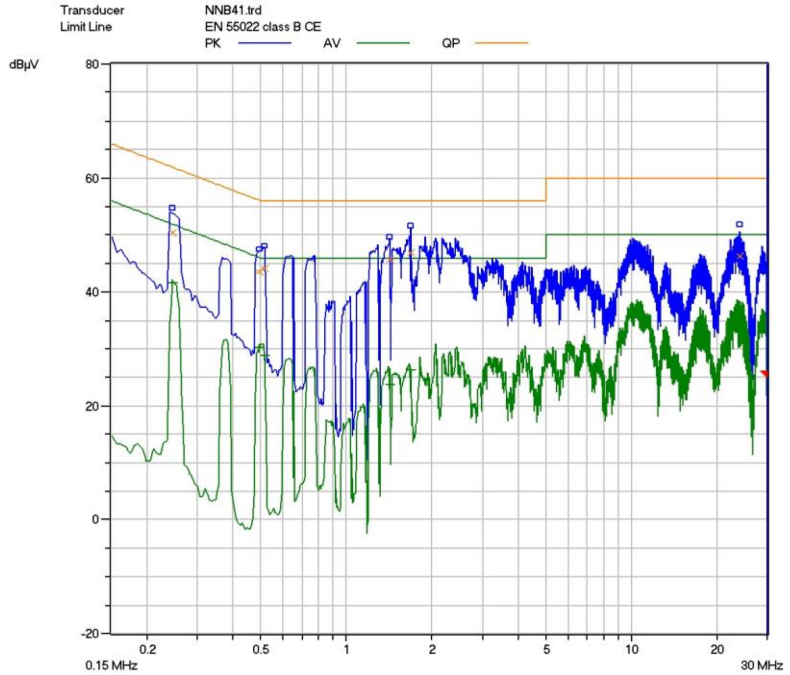
Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.2460	L	54.6	L	40.7	L	51.2	51.9	61.9	-10.7dB
1.6200	L	47.6	L	25.1	L	43.5	46.0	56.0	
1.6740	L	50.0	L	25.2	L	44.9	46.0	56.0	

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



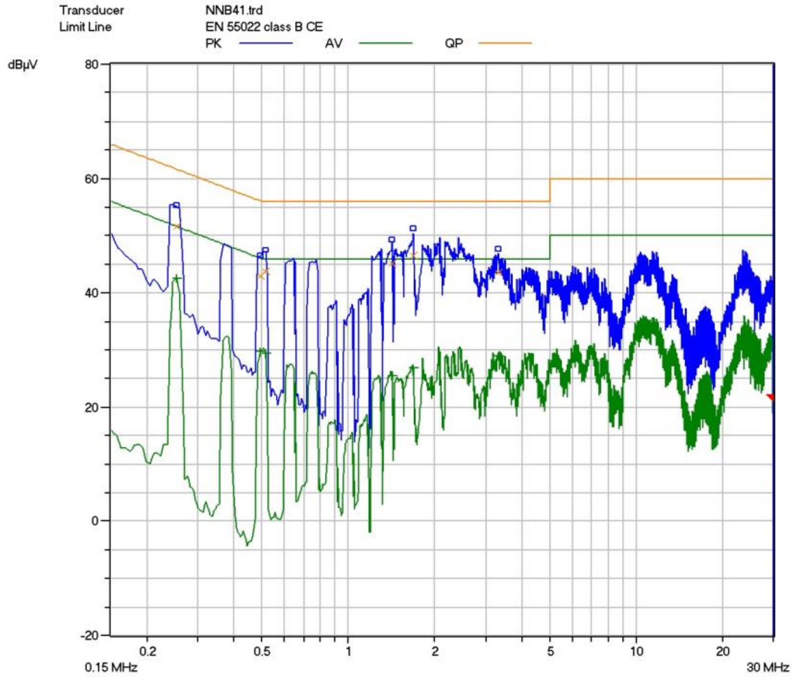
Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.2460	N	55.3	N	41.2	N	51.9	51.9	61.9	-10dB
1.6440	N	48.3	N	25.6	N	43.9	46.0	56.0	
2.0580	N	50.2	N	27.8	N	44.8	46.0	56.0	

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



Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.2460	L	54.8	L	41.5	L	50.5	51.9	61.9	
0.4920	L	47.5	L	30.3	L	43.5	46.1	56.1	
0.5160	L	48.1	L	28.8	L	44.1	46.0	56.0	
1.4220	L	49.6	L	23.8	L	45.7	46.0	56.0	-10.3dB
1.6800	L	51.6	L	26.3	L	46.9	46.0	56.0	
23.9520	L	51.9	L	36.8	L	46.3	50.0	60.0	

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



Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP	Margin
0.2520	L	55.4	L	42.6	L	51.6	51.7	61.7	-10.1dB
0.4920	L	46.5	L	29.7	L	43.0	46.1	56.1	
0.5160	L	47.5	L	29.4	L	43.7	46.0	56.0	
1.4220	L	49.2	L	25.5	L	45.2	46.0	56.0	
1.6800	L	51.3	L	26.8	L	46.6	46.0	56.0	-9.4dB
3.3120	L	47.8	L	28.9	L	43.5	46.0	56.0	

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

10.9 Thermal measurement

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 temperature of demo board

No.	Major component	85 V AC (°C)	300 V AC (°C)
1	IC1 (ICE5GR2280AG)	85.2	67.2
2	L1 (choke)	48.5	32.9
3	T1 (transformer)	68.2	71.9
4	D151 (12 V diode)	64.8	65.3

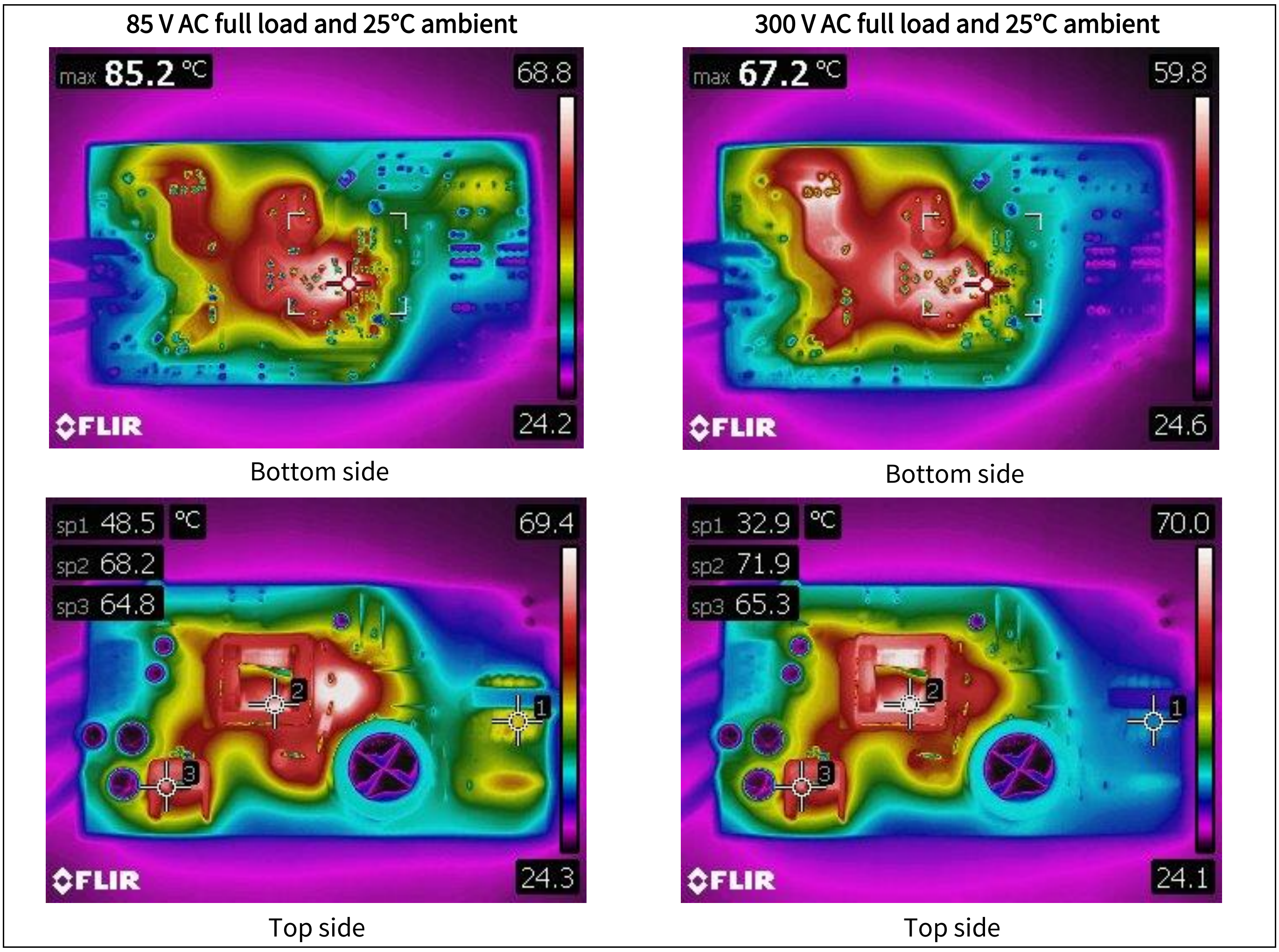


Figure 17 Infrared thermal image of DEMO_5GR2280AG_22W1

11 Waveforms and scope plots

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

11.1 Start-up at low/high AC-line input voltage with maximum load

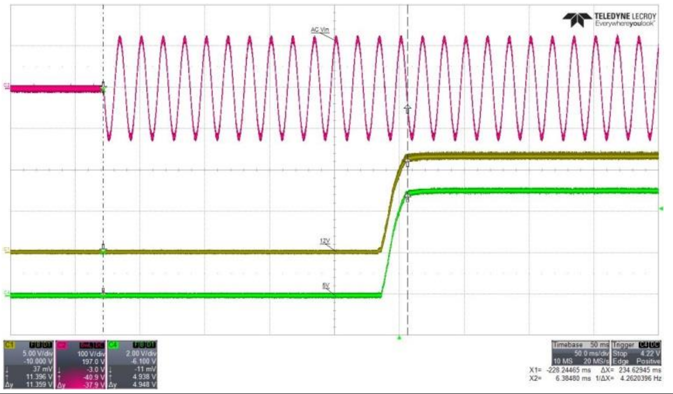
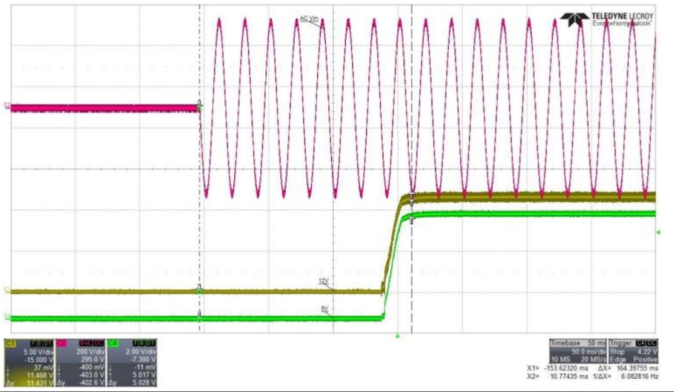
	
C1 (yellow) : 12 V output voltage (V_{Out12}) C2 (purple) : AC-line voltage (V AC) C4 (green) : 5 V output voltage (V_{Out5})	C1 (yellow) : 12 V output voltage (V_{Out12}) C2 (purple) : AC-line voltage (V AC) C4 (green) : 5 V output voltage (V_{Out5})
Start-up time at 85 V AC and maximum load ≈ 234 ms	Start-up time at 300 V AC and maximum load ≈ 164 ms

Figure 18 Start-up

11.2 Soft-start

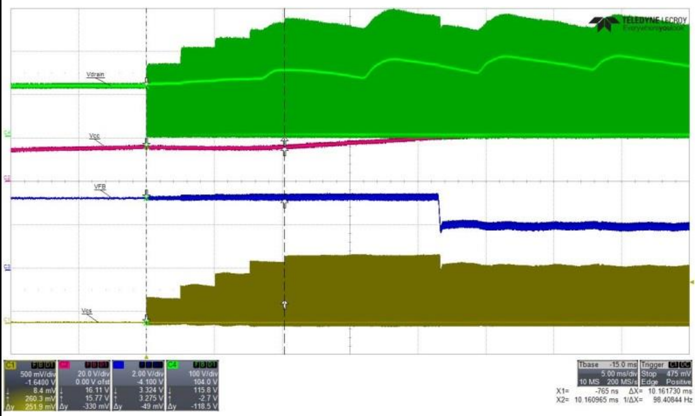
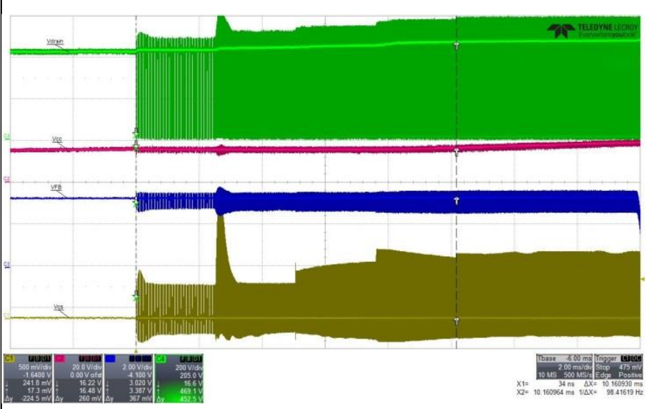
	
C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_D)	C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_D)
Soft-start time at 85 V AC and maximum load ≈ 10.1 ms	Soft-start time at 300 V AC and maximum load ≈ 10 ms

Figure 19 Soft-start

11.3 Drain and CS voltage at maximum load

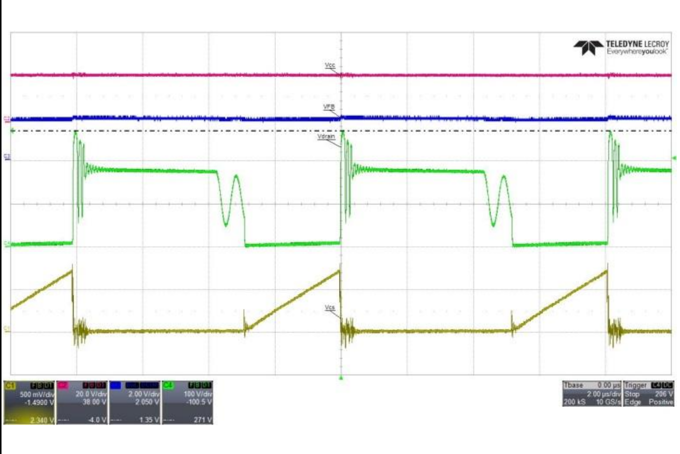
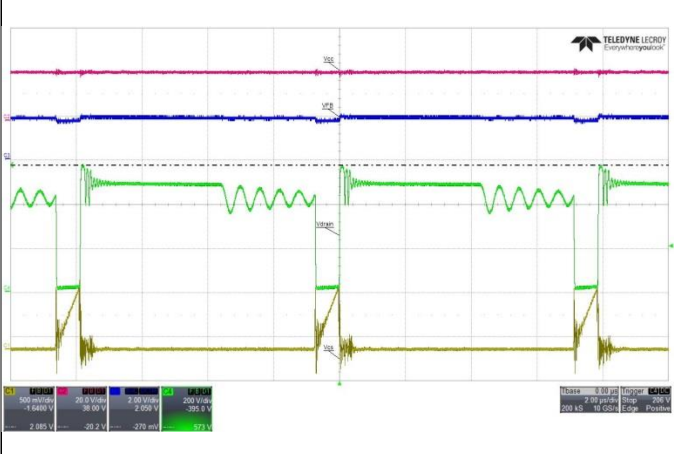
	
C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_{D})	C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_{D})
V_{Drain_peak} at 85 V AC ≈ 271 V	V_{Drain_peak} at 300 V AC ≈ 573 V

Figure 20 Drain and CS voltage at maximum load

11.4 Frequency jittering

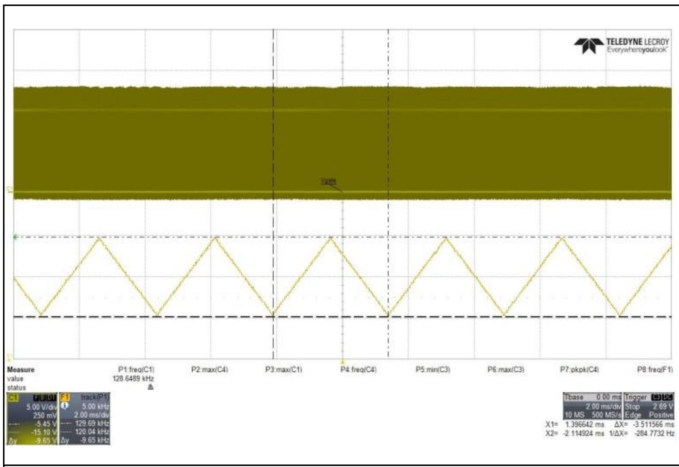
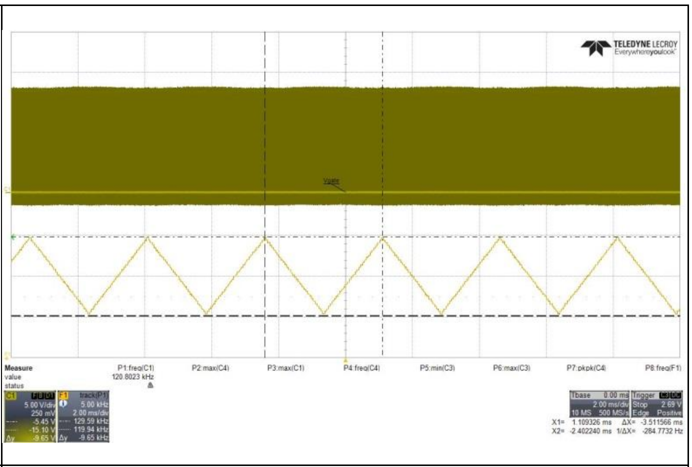
	
C1 (yellow) : Gate voltage (V_{G}) F1 (yellow) : Frequency track of gate (V_{GATE})	C1 (yellow) : Gate voltage (V_{G}) F1 (yellow) : Frequency track of gate (V_{GATE})
Frequency jittering at 85 V AC and maximum load ≈ 120 kHz ~ 129 kHz, jitter period is ≈ 3.5 ms	Frequency jittering at 300 V AC and maximum load ≈ 120 kHz ~ 129 kHz, jitter period is ≈ 3.5 ms

Figure 21 Frequency jittering

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

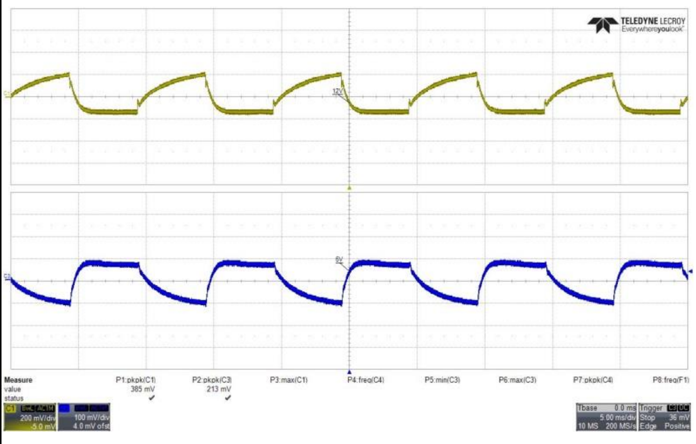
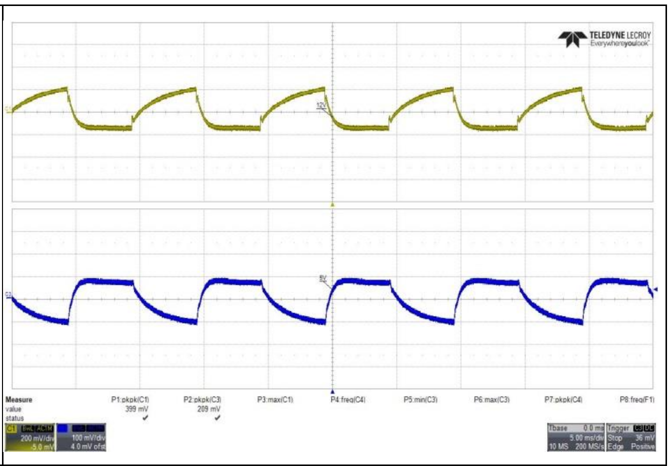
	
C1 (yellow) : 12 V output ripple voltage (V_{Out12}) C3 (blue) : 5 V output ripple voltage (V_{Out5})	C1 (yellow) : 15 V output ripple voltage (V_{Out12}) C3 (blue) : 5 V output ripple voltage (V_{Out5})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 399 mV 5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 209 mV (12 V load change from 10% to 100% and 5 V at 200 mA load at 85 V AC, 100 Hz, 0.4 A/µs slew rate) Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz filter	12 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 385 mV 5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 213 mV (12 V load change from 10% to 100% and 5 V at 200 mA load at 85 V AC, 100 Hz, 0.4 A/µs slew rate) Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz filter

Figure 22 Load transient response

11.6 Output ripple voltage at maximum load

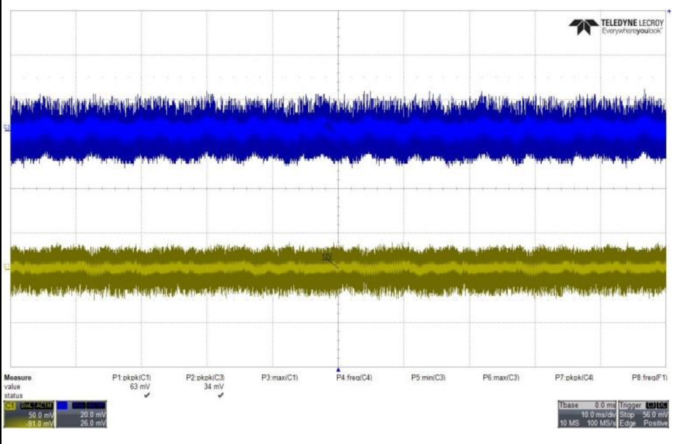
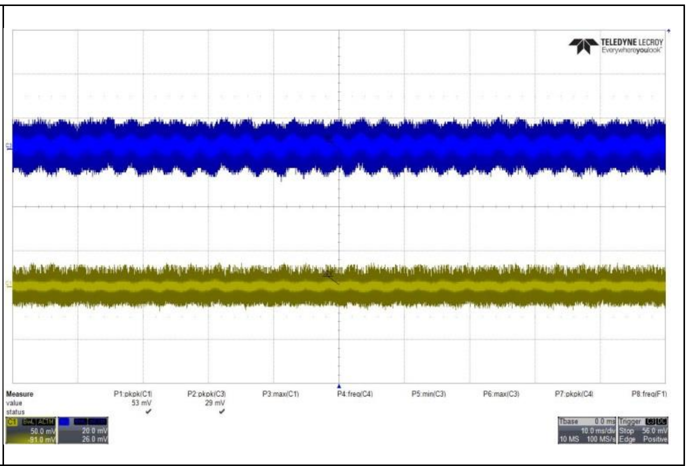
	
C1 (yellow) : 12 V output ripple voltage (V_{Out12}) C3 (blue) : 5 V output ripple voltage (V_{Out5})	C1 (yellow) : 12 V output ripple voltage (V_{Out12}) C3 (blue) : 5 V output ripple voltage (V_{Out5})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 63 mV 5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 34 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz filter	12 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 53 mV 5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 29 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz filter

Figure 23 Output ripple voltage at maximum load

11.7 Output ripple voltage at ABM 1 W load

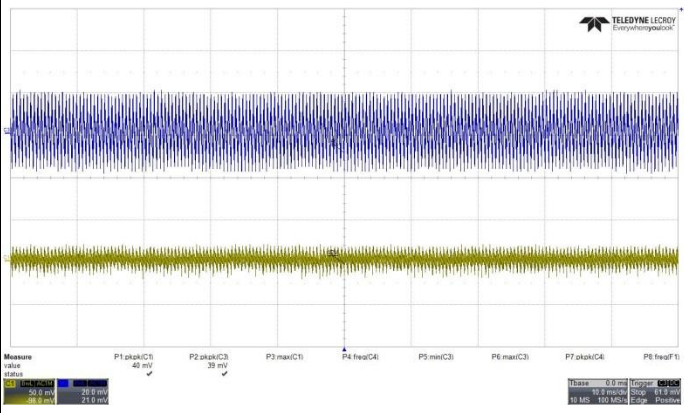
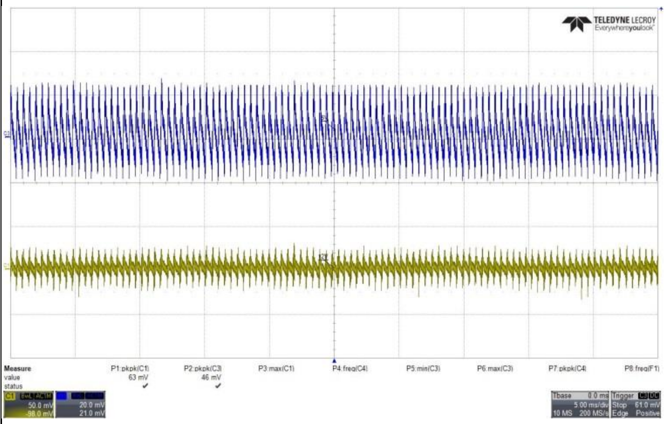
	
C1 (yellow) : 12 V output ripple voltage (V_{Out12}) C3 (blue) : 5 V output ripple voltage (V_{Out5})	C1 (yellow) : 12 V output ripple voltage (V_{Out12}) C3 (blue) : 5 V output ripple voltage (V_{Out5})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 40 mV 5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 39 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz filter	12 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 63 mV 5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 46 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz filter

Figure 24 Output ripple voltage at burst mode 1 W load

11.8 Entering ABM

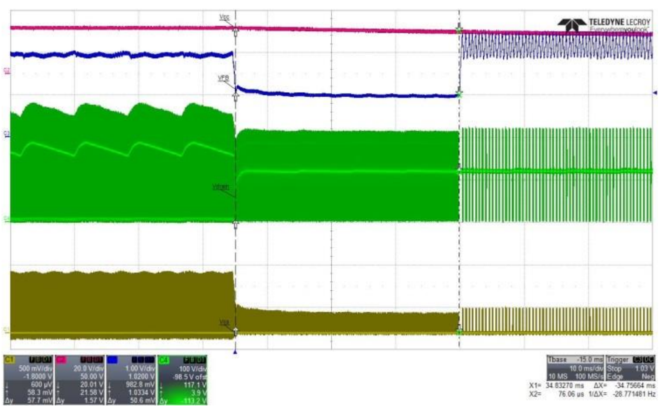
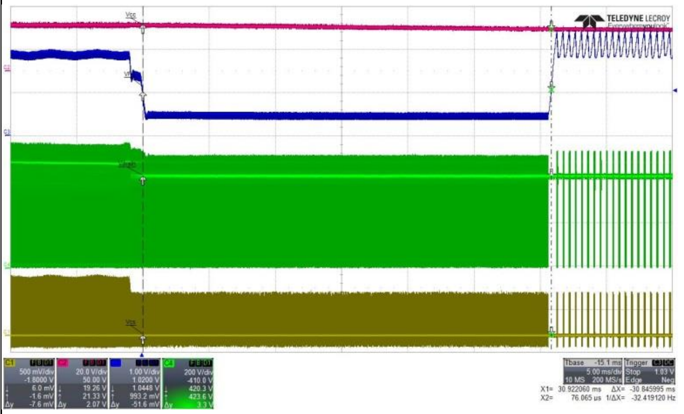
	
C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_D)	C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_D)
Condition to enter ABM level 3: V_{FB} < 1.03 V and $t_{blanking}$ = 36 ms (load change from full load to 1 W load at 85 V AC)	Condition to enter ABM level 3: V_{FB} < 1.03 V and $t_{blanking}$ = 36 ms (load change from full load to 1 W load at 300 V AC)

Figure 25 Entering ABM

11.9 During ABM

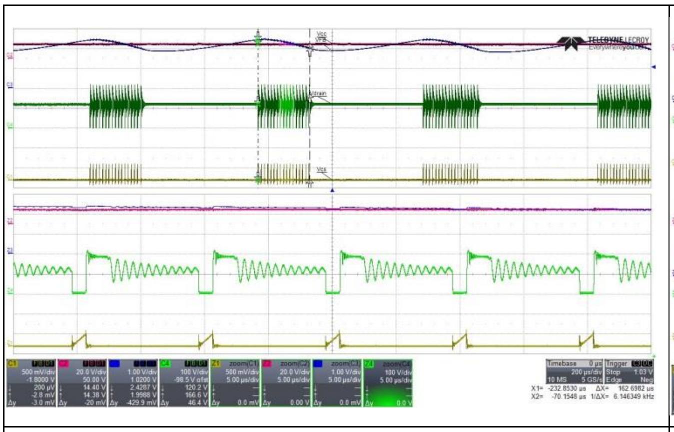
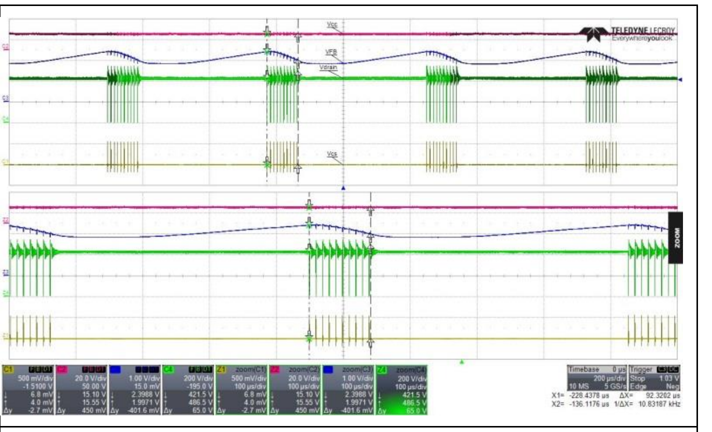
	
C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_D)	C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_D)
During ABM level 3: $V_{FB\_Bon\_ISO}$ = 2.4 V, $V_{FB\_Boff\_ISO}$ = 2.0 V, V_{CS_BHP} = 0.275 V (1 W load at 85 V AC)	During ABM level 3: $V_{FB\_Bon\_ISO}$ = 2.4 V, $V_{FB\_Boff\_ISO}$ = 2.0 V, V_{CS_BHP} = 0.275 V (1 W load at 300 V AC)

Figure 26 During ABM

11.10 Leaving ABM

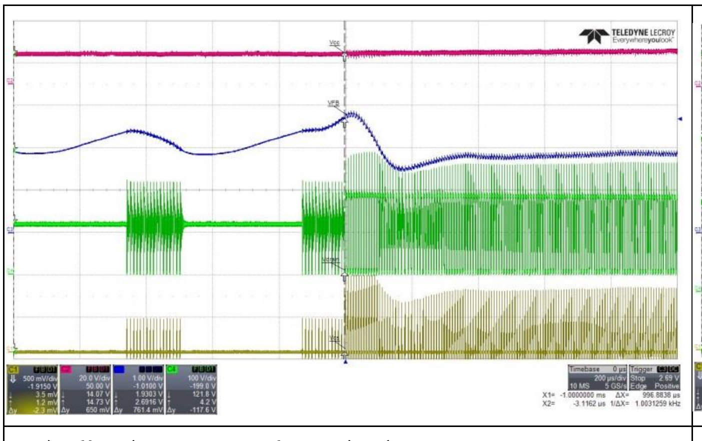
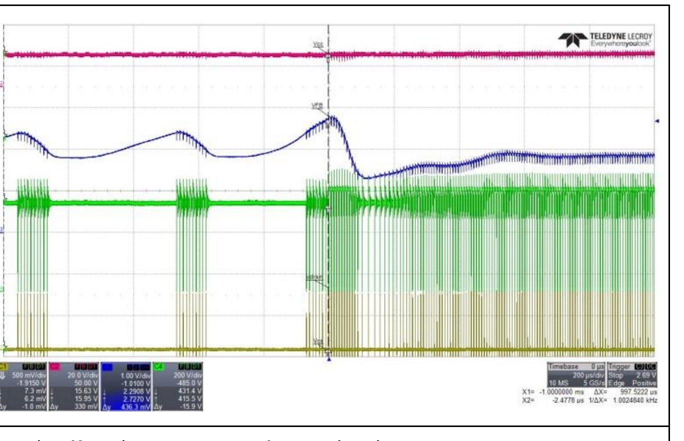
	
C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_D)	C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_D))
Condition to leave ABM level 3: V_{FB} > 2.73 V (load change from 1 W to full load at 85 V AC)	Condition to leave ABM level 3: V_{FB} > 2.75 V (load change from 1 W to full load at 300 V AC)

Figure 27 Leaving ABM

11.11 Line OVP (non-switch auto restart)

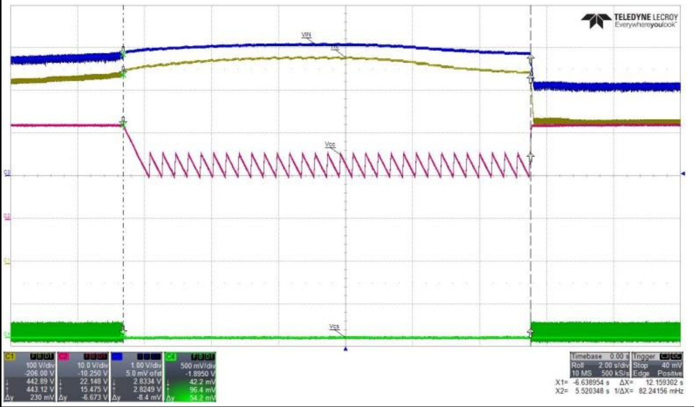
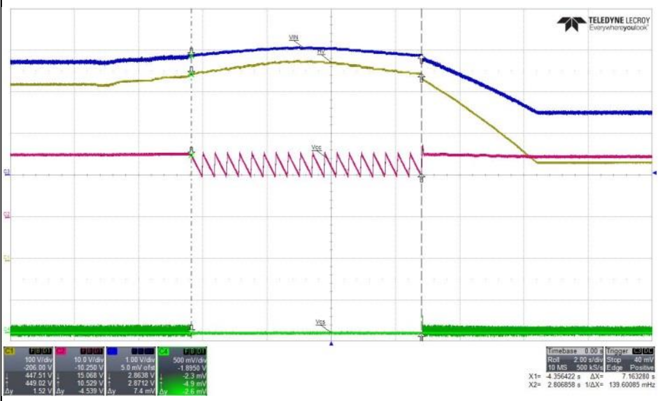
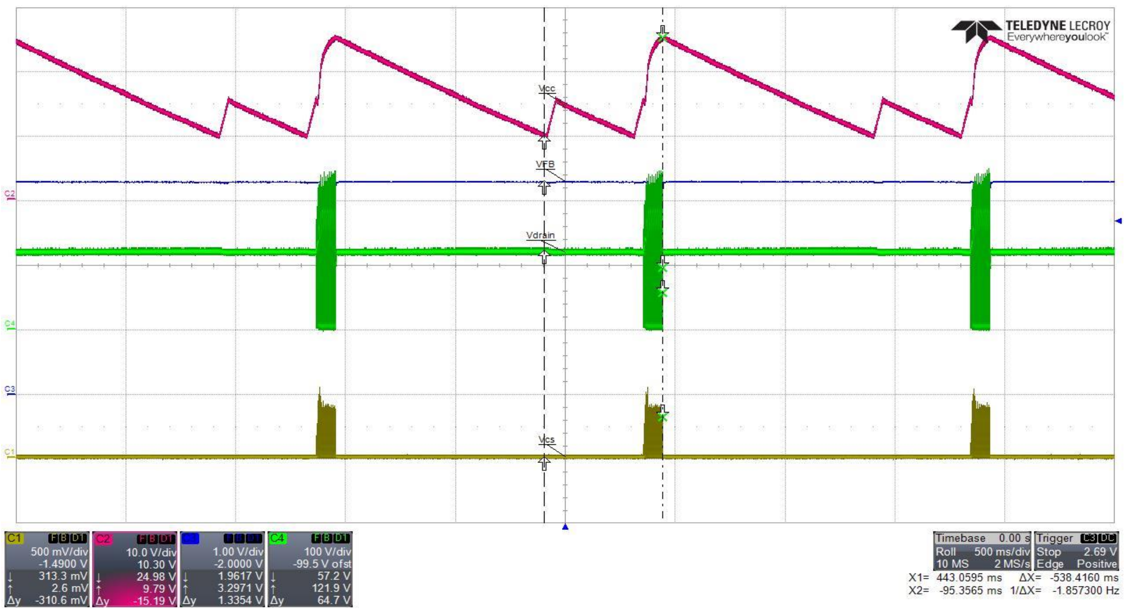
	
C1 (yellow) : Bus voltage (V_{Bus}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : V_{IN} voltage (V_{VIN}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Bus voltage (V_{Bus}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : V_{IN} voltage (V_{VIN}) C4 (green) : CS voltage (V_{CS})
Condition to detect line OVP: V_{VIN} > 2.85 V (V_{BULK} > 447 V DC [≈320 V AC]) Condition to reset line OVP: V_{VIN} < 2.85 V (V_{BULK} < 447 V)	
(Gradually increase AC-line voltage at full load until line OVP detect and decrease AC-line until line OVP reset)	(Gradually increase AC-line voltage at 1 W load until line OVP detect and decrease AC-line until line OVP reset)

Figure 28 Line OVP

11.12 V_{CC} OVP (odd-skip auto restart)

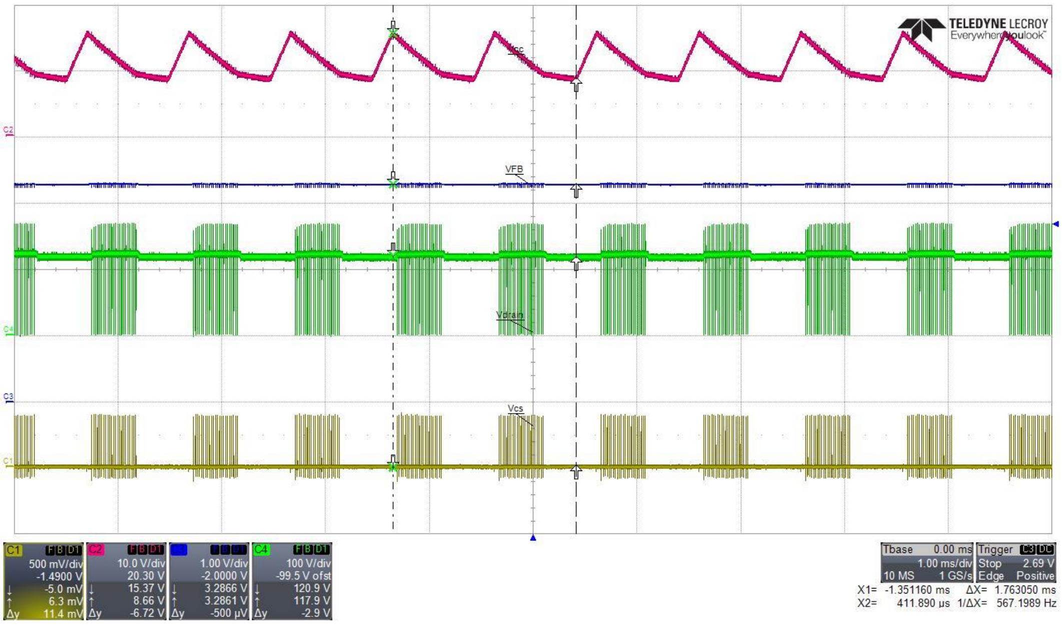


C1 (yellow) : CS voltage (V_{CS})
C2 (purple) : Supply voltage (V_{VCC})
C3 (blue) : FB voltage (V_{FB})
C4 (green) : Drain voltage (V_D)

Condition to enter V_{CC} OVP: V_{VCC} > 25.5 V
(remove ZD1 while system operating at 85 V AC and full load)

Figure 29 V_{CC} OVP

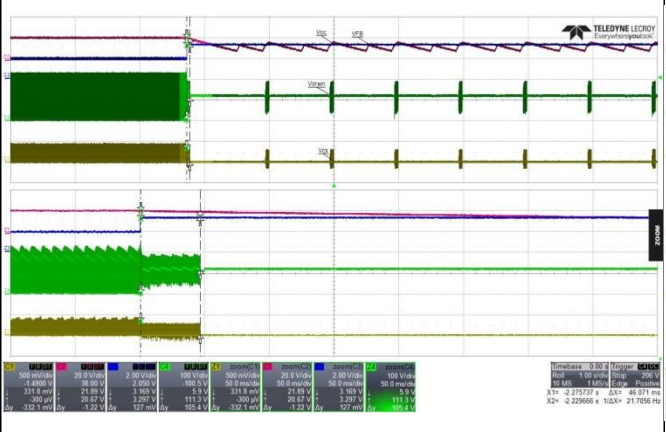
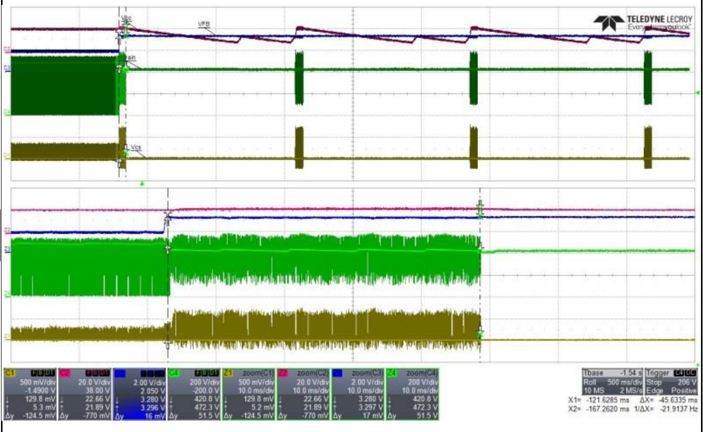
11.13 V_{CC} UVP (auto restart)



C1 (yellow)	: CS voltage (V_{CS})
C2 (purple)	: Supply voltage (V_{VCC})
C3 (blue)	: FB voltage (V_{FB})
C4 (green)	: Drain voltage (V_D)
Condition to enter V_{CC} UVP: V_{CC} < 10 V (remove R5 and power on the system with full load at 85 V AC)	

Figure 30 V_{CC} UVP

11.14 Over-load protection (odd-skip auto restart)

	
C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_D)	C1 (yellow) : CS voltage (V_{CS}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : Drain voltage (V_D)
Condition to enter over-load protection: V_{FB} > 2.73 V and lasts for 54 ms blanking time (12 V output load change from full to short at 85 V	Condition to enter over-load protection: V_{FB} > 2.73 V and lasts for 54 ms blanking time (12 V output load change from full to short at 300 V AC)

AC)	

Figure 31 Over-load protection

11.15 V_{CC} short-to-GND protection

C1 (yellow) : CS voltage (V_{CS})
C2 (purple) : V_{CC} voltage (V_{VCC})
C3 (blue) : V_{IN} voltage (V_{VIN})
C4 (green) : Drain voltage (V_D)

Condition to enter V_{CC} short-to-GND: if $V_{CC} < V_{VCC\_SCP} \rightarrow I_{VCC} = I_{VCC\_Charge1}$
(short V_{CC} pin-to-GND and measure the current with multimeter before system start-up, $I_{VCC} \approx 266$ µA at 85 V AC)

Figure 32 V_{CC} short-to-GND protection

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 change
–	First release

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Edition 2018-02-20

Published by

Infineon Technologies AG

81726 Munich, Germany

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Document reference
ER_201707_PL83_015