27 W 12 V 5 V SMPS demo board with ICE5GR1680AG

DEMO_5GR1680AG_27W1

About this document

Scope and purpose

This document is an engineering report that describes a universal-input 27 W 12 V and 5 V off-line flyback converter using the latest fifth-generation Infineon Fixed Frequency (FF) CoolSET™ ICE5GR1680AG, which offers high-efficiency, low-standby power with selectable entry and exit standby power option, wide VCC operating range with fast start-up, robust line protection with input Over Voltage Protection (OVP), and various modes of protection for a highly reliable system. This demo board is designed for users who wish to evaluate the performance of ICE5GR1680AG 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, highly reliable systems of off-line SMPS, such as 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 27 W 12 V and 5 V demo board designed in an FF flyback converter topology using the fifth-generation FF CoolSET™ ICE5GR1680AG. 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 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 ICE5GR1680AG to protect the system and customize the IC for the chosen application. In case of failure modes such as Line Over Voltage (LOV), VCC OV/UV, open control-loop or over-load, over-temperature, VCC short-to-ground and Current Sense (CS) short-to-ground, 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. Thus, a cost-effective solution can easily be achieved. The target applications of ICE5GR1680AG 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.

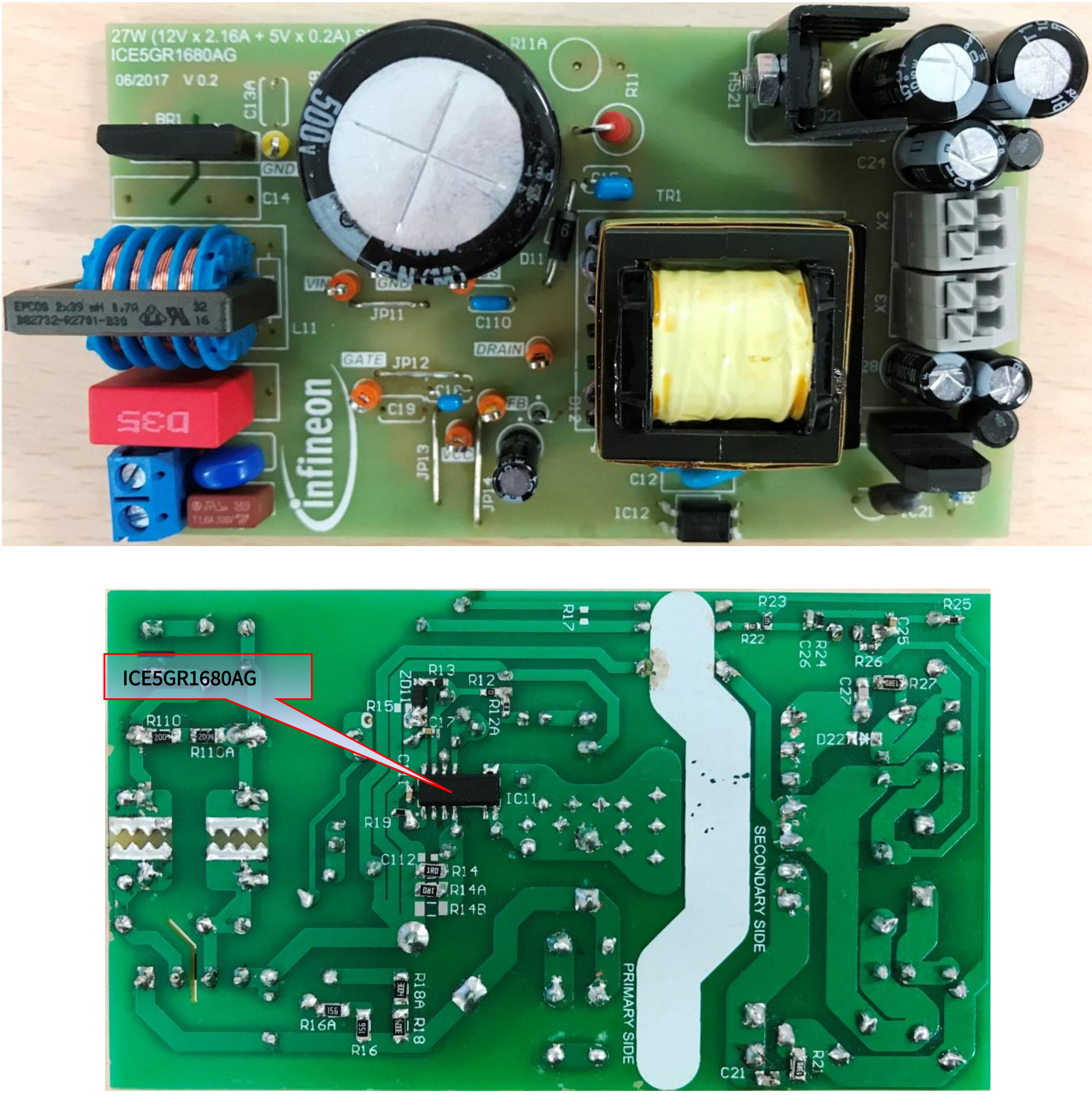


Figure 1 DEMO_5GR1680AG_27W1

3 Specifications of demo board

Table 1 Specifications of DEMO_5GR1680AG_27W1

Input voltage and frequency	85 V AC (60 Hz) ~ 300 V AC (50 Hz)
Output voltage, current and power	12 V x 2.16 A + 5 V x 0.2 A = 27 W
Dynamic load response (5 V at 0.2 A and 12 V load change from 10% to 100%, slew rate at 0.4 A/µs, 100 Hz)	±10% of nominal output voltage
Output ripple voltage (full load, 85 V AC ~ 300 V AC)	5 $V_{ripple\_p\_p}$ < 100 mV 12 $V_{ripple\_p\_p}$ < 100 mV
Active-mode four-point average efficiency (25%, 50%, 75%, 100% load)	> 84% at 115 V AC and 230 V AC
No-load power consumption	< 100 mW at 230 V AC
Conducted emissions (EN 55022 class B)	Pass with 6 dB margin for 115 V AC and 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 x W x H)	(112 x 63 x 27) mm^3

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, C21 and, 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. 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, ICE5QR0680AG is implemented with a start-up resistor and VCC 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 ICE5QR0680AG 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 step by step from 0.3 V to 0.8 V. After IC turn-on, the VCC voltage is supplied by auxiliary windings of the transformer. VCC short-to-GND protection is implemented during the start-up time.

4.3 Integrated CoolMOS™ with frequency-reduction controller

ICE5GR1680AG comprises 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 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).

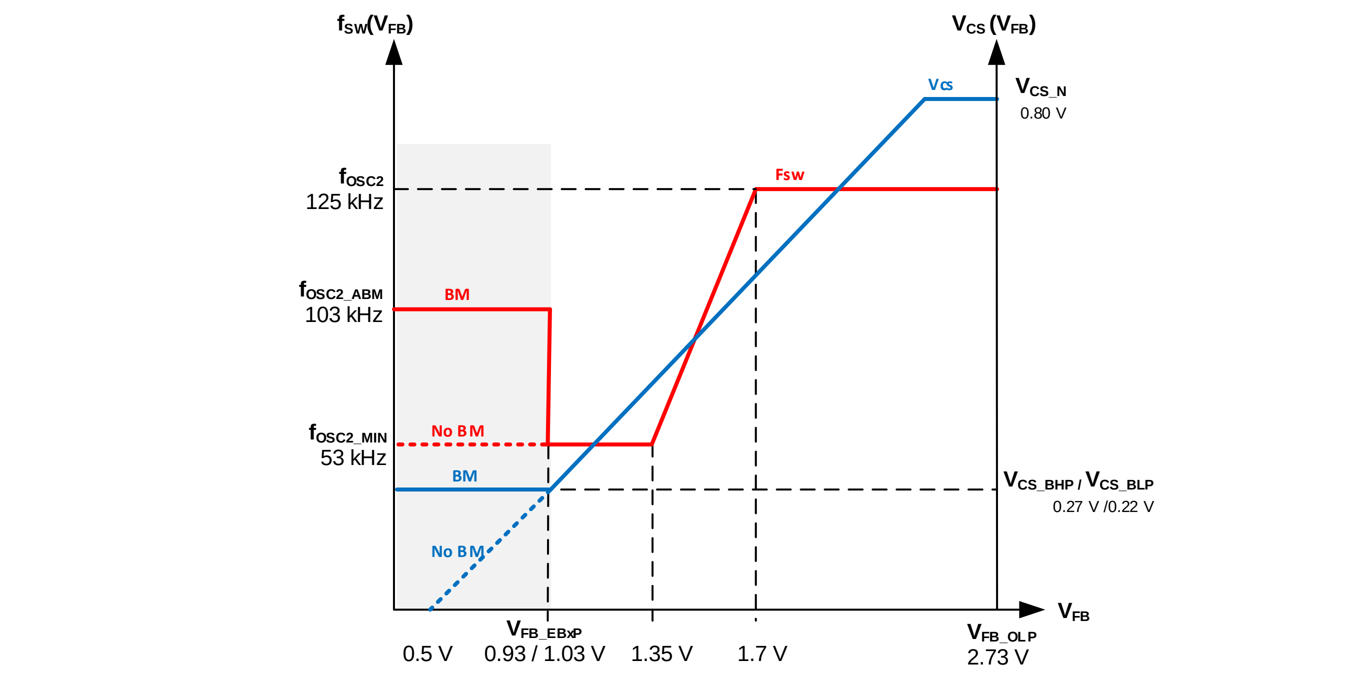


Figure 2 Frequency-reduction curve

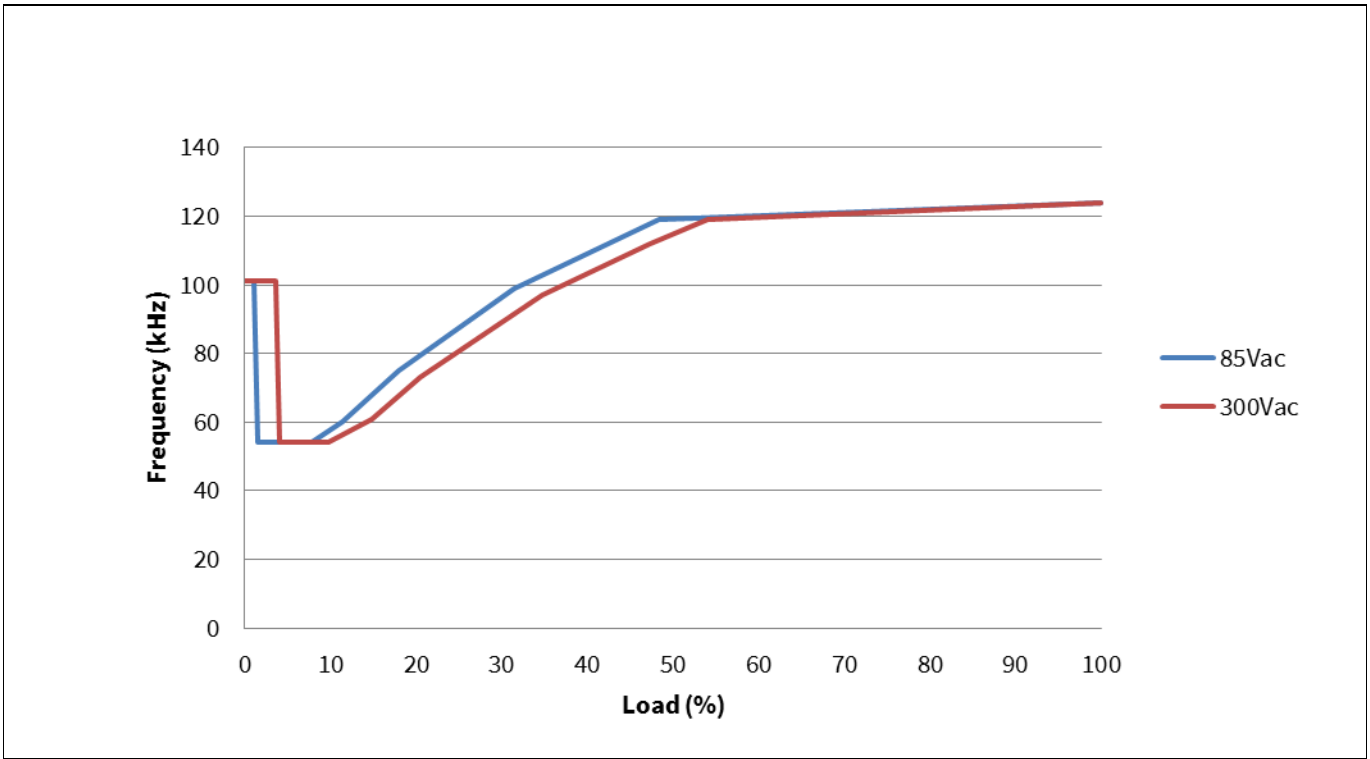


Figure 3 **Frequency-reduction curve of DEMO_5GR1680AG_27W1**

The measured frequency-reduction curve of DEMO_5GR1680AG_27W1 is shown in Figure 3.

4.4 Frequency jittering

The ICE5GR1680AG 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 an internal resistance (ESR) as small as possible to minimize the output voltage ripple caused by the triangular current.

4.7 Feedback loop

For feedback (FB), the output is sensed by the voltage dividers 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 ABM

ABM entry and exit power can be selected from three options, including no ABM. This demo board is set to option 3, and details are shown 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. A certain blanking time (t_{FB_BEB} = 36 ms) is required

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, switching frequency is reduced to 103 kHz for level 2 and 3 selections, and 53 kHz for level 1 (no ABM) to improve efficiency during standby power measurement. The maximum CS voltage is reduced from V_{CS_N} to V_{CS_BXP} to reduce the conduction loss and the audible noise. During ABM, the FB voltage is changing like a sawtooth between $V_{FB\_Bon\_ISO}$ and $V_{FB\_Boff\_ISO}$.

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} (2.75 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. ICE5GR1680AG provides comprehensive protection to ensure the system is operating safely. This includes LOV, VCC OV and UV, over-load, over-temperature (controller junction), CS short-to-GND and VCC short-to-GND. When those faults are found, the system will go into protection mode. Once the fault is removed, the system resumes normal operation. A list of protections and failure conditions is shown in the below table.

Table 2 Protection function of ICE5GR1680AG

Protection function	Failure condition	Protection mode
LOV	V_{VIN} > 2.9 V	Non-switch auto restart
VCC OV	V_{VCC} > 25.5 V	Odd-skip auto restart
VCC UV	V_{VCC} < 10 V	Auto restart
Over-load	V_{FB} > 2.75 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
VCC short-to-GND (V_{VCC} = 0 V, 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

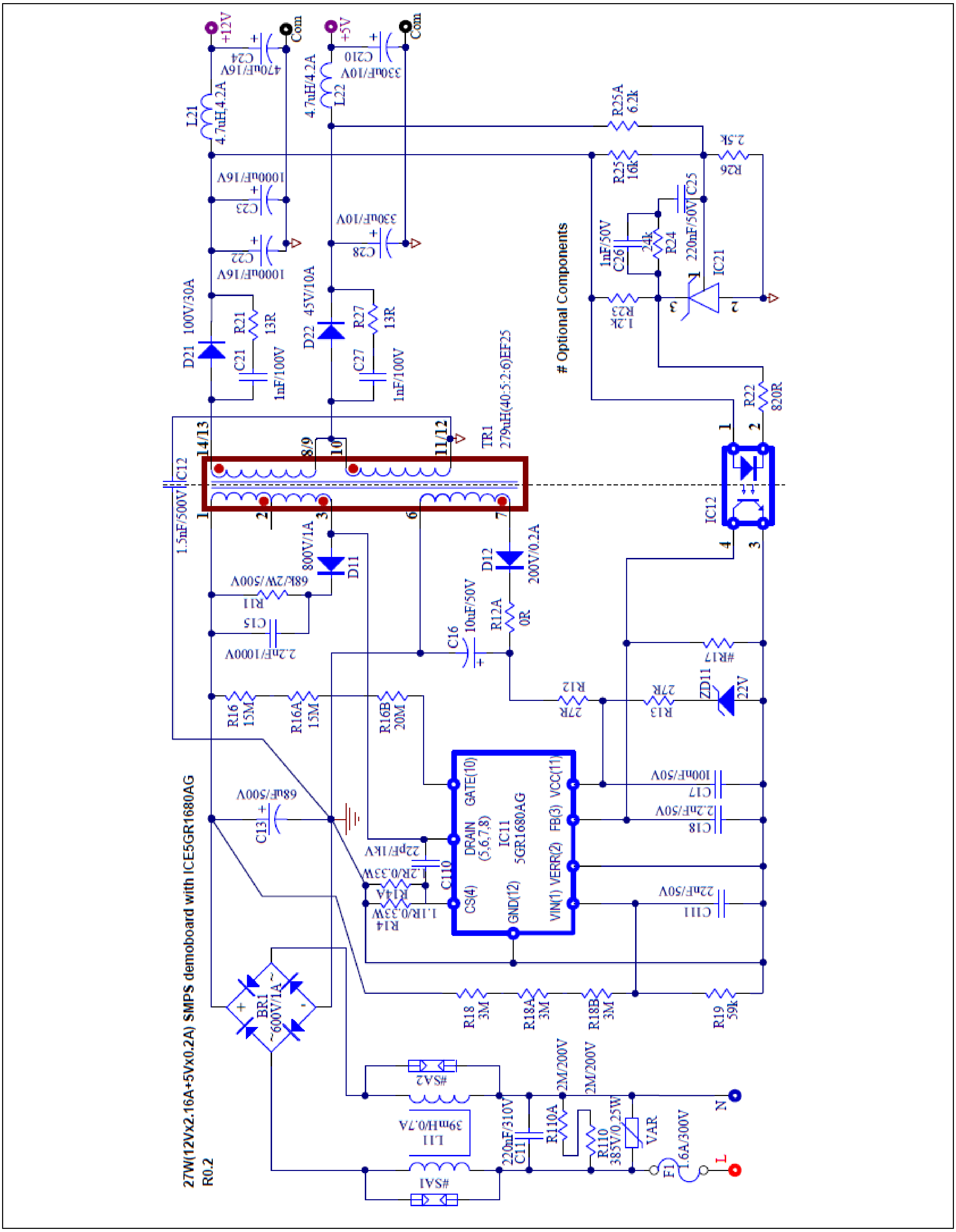


Figure 4 Schematic of DEMO_5GR1680AG_27W1

7 PCB layout

7.1 Top side

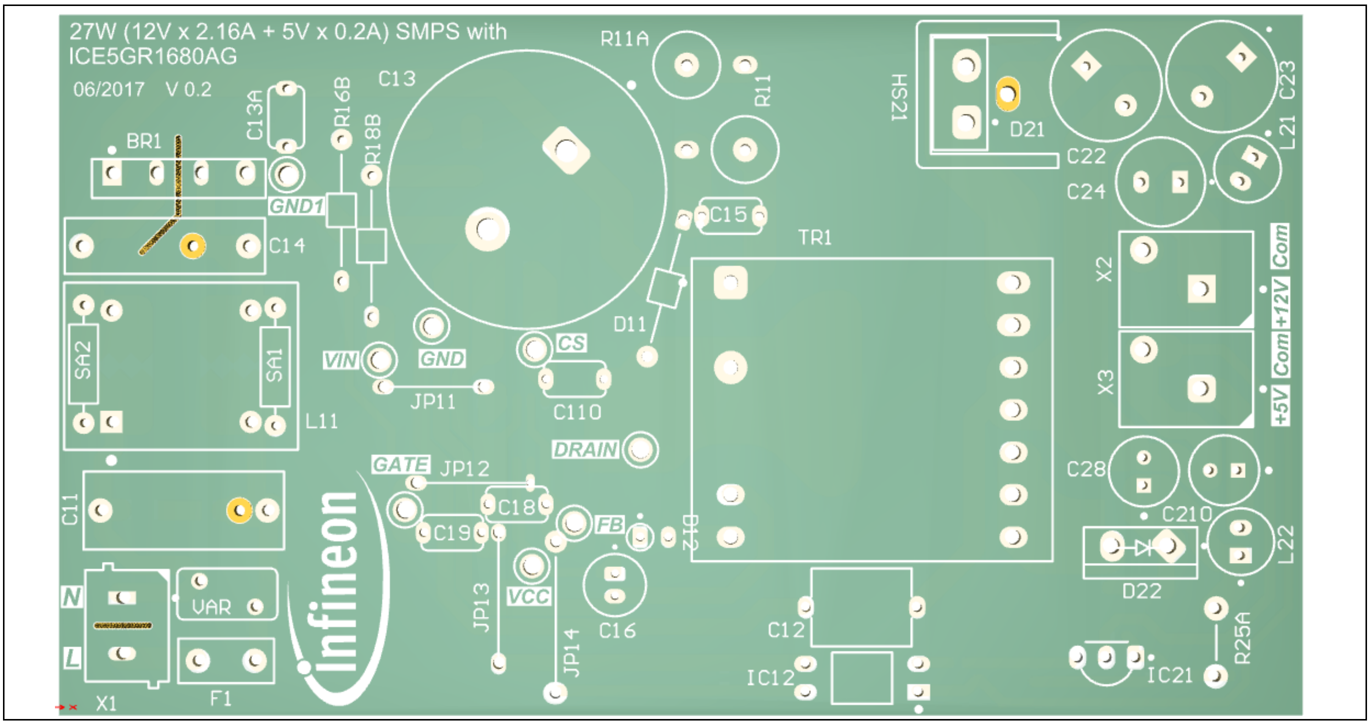


Figure 5 Top side component legend

7.2 Bottom side

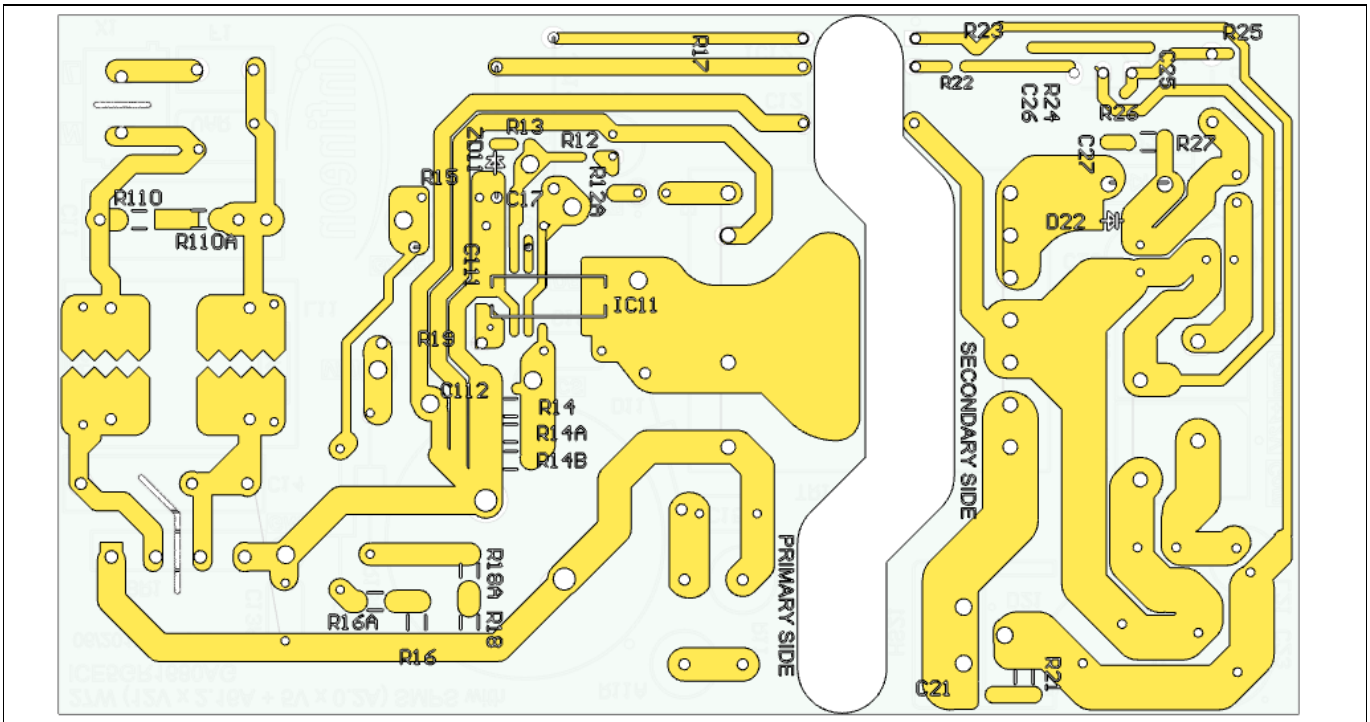


Figure 6 Bottom side copper and component legend

8 Bill of Materials

Table 3 BOM (R 0.2)

No.	Designator	Description	Part number	Manufacturer	Quantity
1	BR1	600 V/1 A	S1VBA60	Shindengen	1
2	C11	220 nF/310 V	890334024002	Wurth Electronics	1
3	C12	1.5 nF/250 V	DE1E3KL152MC4BNA1S	Murata	1
4	C13	68 uF/500 V	LGN2H680MELA25		1
5	C15	2.2 nF/1000 V	RDE7U3A222J3K1H03	Murata	1
6	C16	10 uF/50 V	50PX10MEFC5X11	Rubicon	1
7	C17	100 nF/50 V	GRM188R71H104KA93D	Murata	1
8	C18	2.2 nF/50 V	RDE5C1H222J0K1H03B	Murata	1
9	C21, C27	1 nF/100 V	GRM2162C2A102JA01	Murata	2
10	C22, C23	1000 uF/16 V	16ZLH1000MEFC10X16	Rubicon	2
11	C24	470 uF/16 V	16ZLH470MEFC8X11.5	Rubicon	1
12	C25	220 nF/50 V	GRM188R71H224KAC4D	Murata	1
13	C26	1 nF/50 V	GRM1885C1H102GA01D	Murata	1
14	C28	330 uF/10 V	10ZLH330MEFC6.3X11	Rubicon	1
15	C110	22 pF/1000 V	RDE7U3A220J2K1H03	Murata	1
16	C111	22 nF/50 V	GCM188R71H223KA37D	Murata	1
17	C210	330 uF/10 V	10ZLH330MEFC6.3X11	Rubicon	1
18	D11	800 V,1 A	UF4006		1
19	D12	200 V,0.2 A	1N485B		1
20	D21	100 V, 30 A	VF30100SG		1
21	D22	45 V,10 A	VFT1045BP		1
22	F1	1.6 A,300 V	36911600000		1
23	FB @ pin 1 & 3 of TR1 and D11 anode	Ferrite bead	B64290P0035X038	Epcos	3
24	IC11	ICE5GR1680AG	ICE5GR1680AG	Infineoon	1
25	IC12	Optocoupler	SFH617A-3		1
26	IC21	Shunt regulator	TL431BVLPG		1
27	JP11, JP12, JP13 and JP14	Jumper			4
28	L11	39 mH/0.7 A	B82732R2701B030	Epcos	1
29	L21, L22	4.7 uH,4.2 A	7447462047	Wurth Electronics	2
30	R11, R11A	33 k, 2 W, 500 V	PR02000206802JR500		2
31	R12,R13	27 R (0603)	Resistor		2
32	R12A	0 R (0603)	Resistor		1
33	R14	1.1 R/0.33 W/1%	ERJ8BQF1R1V		1
34	R14A	1.2 R/0.33 W/1%	ERJ8BQF1R2V		1
35	R16, R16A	15 M (1206)			2
36	R16B	20 M,0.125 W (axial leaded)	CF18JT20M0		1
37	R18, R18A	3 M (1206)	Resistor		2
38	R18B	3 M, 0.125 W (axial leaded)	CF18JT3M00		1
39	R19	59 k (0603)	ERJ-3RBD5902V		1
40	R21, R27	13 R (1206)	ERJ8ENF13R0V		2
41	R22	820 R (0603)			1

42	R23	1.2 k (0603)			1
43	R24	24 k (0603)			1
44	R25	16 k (0603)			1
45	R25A	6.2 k, 0.125 W (axial leaded)	CF18JT6K20		1
46	R26	2.49 k (0603)			1
47	R110, R110A	2 M, 200 V (1206)			2
48	Test point of FB, VIN, CS, GATE, Drain, V_{CC}, GND, GND1	Test point	5010		8
49	TR1	279 uH (40:5:2:6)	750343599(R01)	Wurth Electronics	1
50	VAR	385 V/0.25 W	B72207S381K101	Epcos	1
51	ZD11	22 V (SOD123)	MMSZ5251B-7-F		1
52	Con (L N)	Connector	691102710002	Wurth Electronics	1
53	Con (+12 V com), Con (+5 V com)	Connector	691 412 120 002B	Wurth Electronics	2

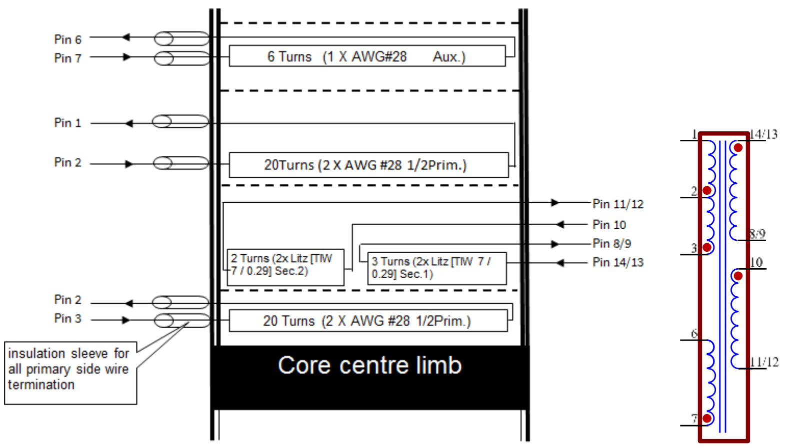
9 Transformer construction

Core and materials: EE25/13/7(EF25), TP4A (TDG)

Bobbin: 070-5644 (14-pin, THT, horizontal version)

Primary inductance: Lp = 279 µH (±10%), measured between pin 1 and pin 3

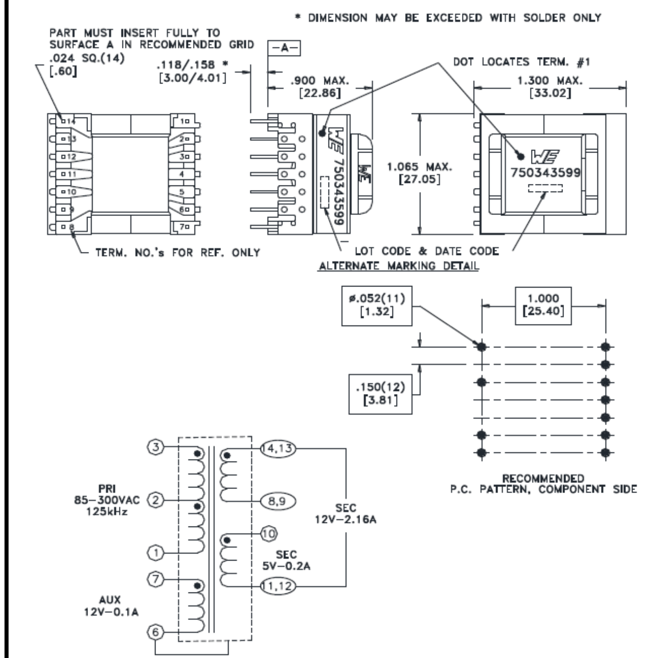
Manufacturer and part number: Wurth Electronics Midcom (750343599 R01)



Start	Stop	No. of turns	Wire size	Layer
3	2	20	2XAWG#28	1/2 Primary
14/13	8/9	3	2 x Litz [TIW 7 / 0.29]	Secondary 1
10	11/12	2	2 x Litz [TIW 7 / 0.29]	Secondary 2
2	1	20	2XAWG#28	1/2 Primary
7	6	6	1XAWG#28	Auxiliary

Horizontal external shield is added and tied to pin 6

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	1-3	@20ºC	0.220 ohms max.
D.C. RESISTANCE	8-13	tie(8+9,13+14) @20ºC	0.008 ohms max.
D.C. RESISTANCE	10-11	tie(11+12) @20ºC	0.008 ohms max.
D.C. RESISTANCE	6-7	@20ºC	0.09 ohms max.
INDUCTANCE	3-1	50kHz, 100mV, Ls	279.00µH ±10%
LEAKAGE INDUCTANCE	3-1	tie(6+7+8+9+10+11+12+13+14),100kHz, 100mV, Ls	7 µH max.
DIELECTRIC	1-14	tie(3+6,8+9+10),5000VDC, 1 second	5000VDC, 1 minute
DIELECTRIC	3-6	625VAC, 1 second	
TURNS RATIO		(3-1):(14-8), tie(8+9,13+14)	13.33:1, ±2%
TURNS RATIO		(3-1):(10-11), tie(11+12)	20:1, ±2%
TURNS RATIO		(3-1):(7-6)	6.67:1, ±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:

- Reinforced insulation for a primary circuit at a working voltage of 300Vrms, 430Vpeak, Overvoltage Category II.

Application of the transformer allows for the leadwires between terminals 8&9, 11&12, 13&14 to solder bridge.

Customer to tie terminals 8+9, 11+12 and 13+14 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-0737	Tolerances unless otherwise specified: Angles: ±1° Decimals: ±.005 [.13] Fractions: ±1/64 Footprint: ± .001 [.03]	DRAWING TITLE TRANSFORMER
DATE				
ENG	IYU	CONVENTION PLACEMENT	This drawing is dual dimensioned. Dimensions in brackets are in millimeters.	PART NO. 750343599
REV.	01	www.we-online.com/midcom		SPECIFICATION SHEET 1 OF 1
DATE	6/26/2017			

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)	V_5 (V DC)	I_5 (A)	V_{5RPP} (mV)	V_{12} (V DC)	I_{12} (A)	V_{12RPP} (mV)	P_{out} (W)	Efficiency η (%)	Average η (%)	OLP P_{in} (W)	OLP I_{out12V} (fixed 5 V at 0.2 A) (A)
85 V AC/60 Hz	0.05	4.78	0.000	23	12.46	0.000	41				39.40	2.49
	8.27	4.81	0.050	16	12.36	0.540	29	6.91	83.61	82.86		
	16.54	4.81	0.100	18	12.35	1.080	39	13.82	83.55			
	24.98	4.81	0.150	20	12.34	1.620	48	20.71	82.92			
	33.89	4.81	0.200	22	12.32	2.160	58	27.57	81.36			
115 V AC/60 Hz	0.05	4.78	0.000	23	12.46	0.000	41				38.90	2.53
	8.20	4.82	0.050	17	12.36	0.540	30	6.92	84.33	84.48		
	16.30	4.81	0.100	18	12.35	1.080	38	13.82	84.78			
	24.40	4.81	0.150	19	12.34	1.620	48	20.71	84.89			
	32.86	4.81	0.200	21	12.32	2.160	54	27.57	83.91			
230 V AC/50 Hz	0.08	4.78	0.000	25	12.48	0.000	45				40.12	2.70
	8.33	4.81	0.050	16	12.37	0.540	33	6.92	83.08	84.51		
	16.38	4.81	0.100	17	12.35	1.080	40	13.82	84.37			
	24.28	4.81	0.150	19	12.34	1.620	46	20.71	85.31			
	32.33	4.81	0.200	21	12.32	2.160	51	27.57	85.29			
265 V AC/50 Hz	0.09	4.78	0.000	27	12.48	0.000	47	0.00	0.00		41.01	2.76
	8.43	4.81	0.050	15	12.37	0.540	34	6.92	82.09	83.99		
	16.46	4.81	0.100	17	12.36	1.080	42	13.83	84.02			
	24.46	4.81	0.150	18	12.34	1.620	46	20.71	84.68			
	32.37	4.81	0.200	21	12.32	2.160	51	27.57	85.18			
300 V AC/50 Hz	0.10	4.78	0.000	27	12.48	0.000	47				42.10	2.84
	8.54	4.81	0.050	16	12.37	0.540	35	6.92	81.03	83.39		
	16.58	4.81	0.100	16	12.36	1.080	41	13.83	83.41			
	24.61	4.81	0.150	18	12.34	1.620	46	20.71	84.16			
	32.45	4.81	0.200	20	12.32	2.160	52	27.57	84.97			

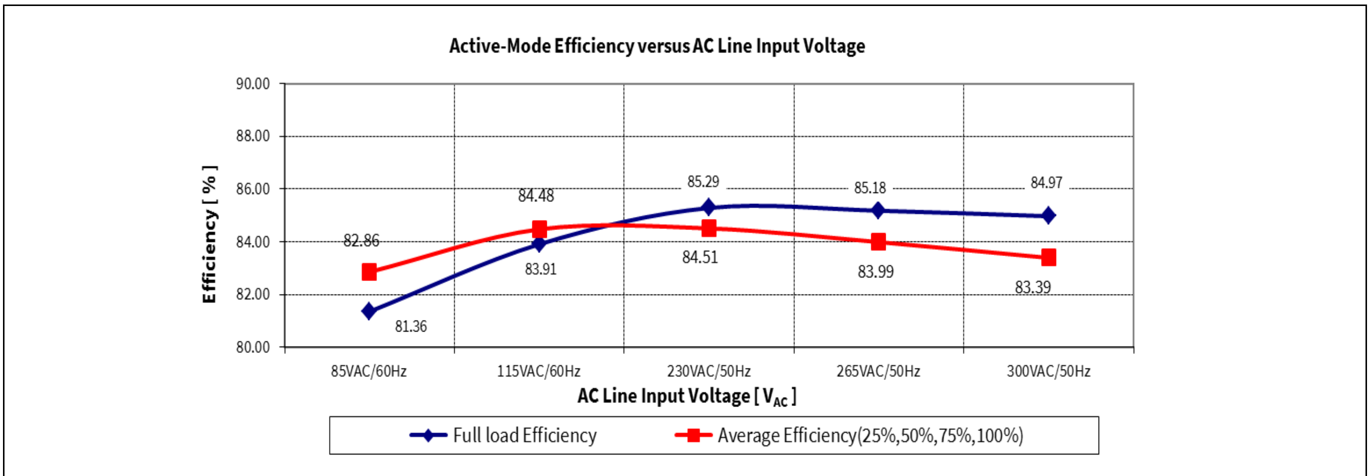


Figure 8 Efficiency vs AC-line input voltage

10.2 Standby power

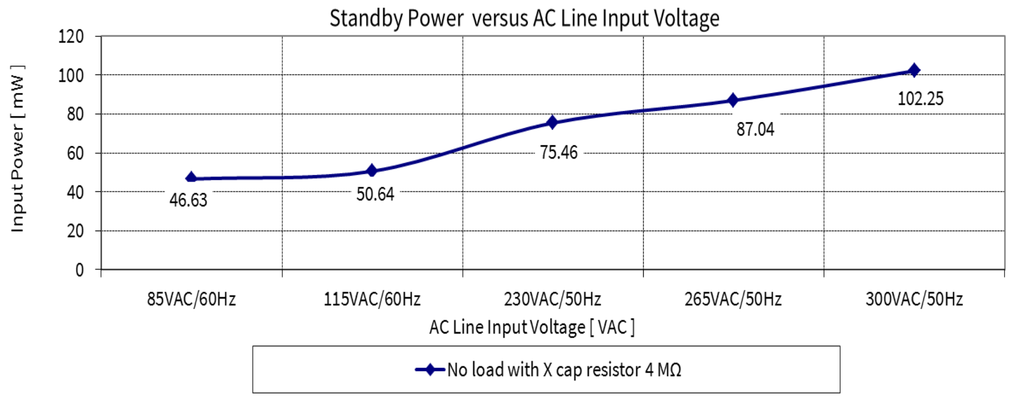


Figure 9 Standby power at no load vs AC-line input voltage (measured by Yokogawa WT210 power meter – integration mode)

10.3 Line regulation

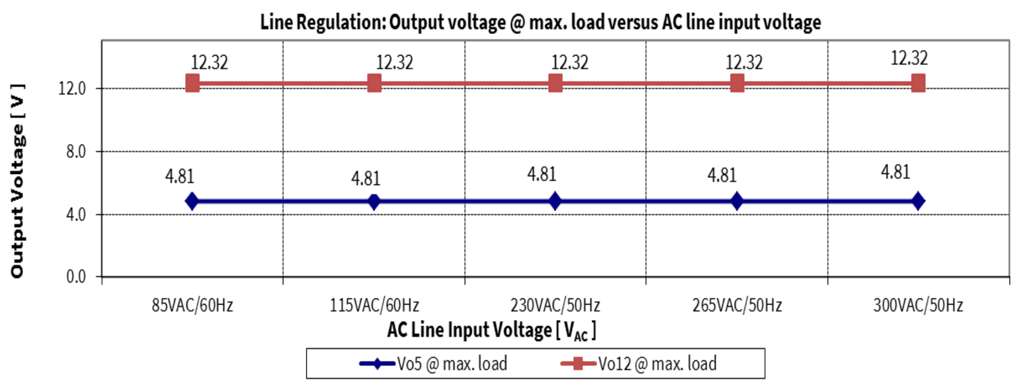
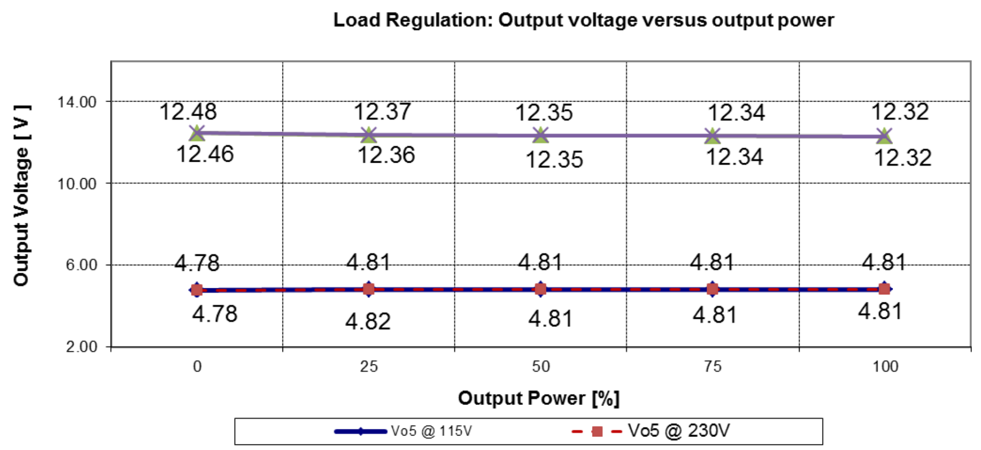


Figure 10 Line regulation V_{Out} at full load vs AC-line input voltage

10.4 Load regulation



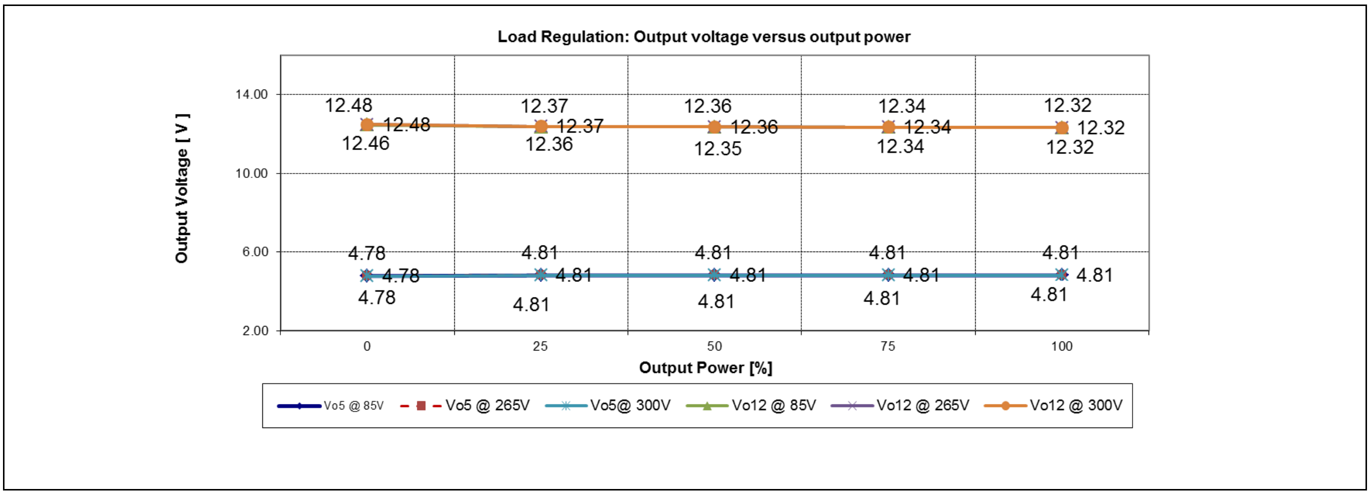


Figure 11 Load regulation V_{Out} vs output power

10.5 Maximum input power

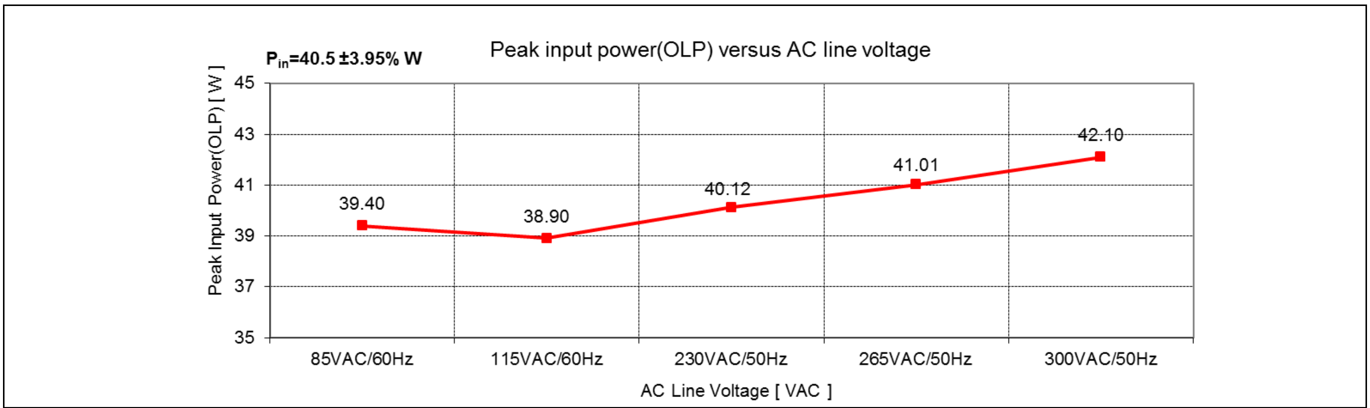


Figure 12 Maximum input power (before OVP) vs AC-line input voltage

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).[1]

10.7 Surge immunity (EN61000-4-5)

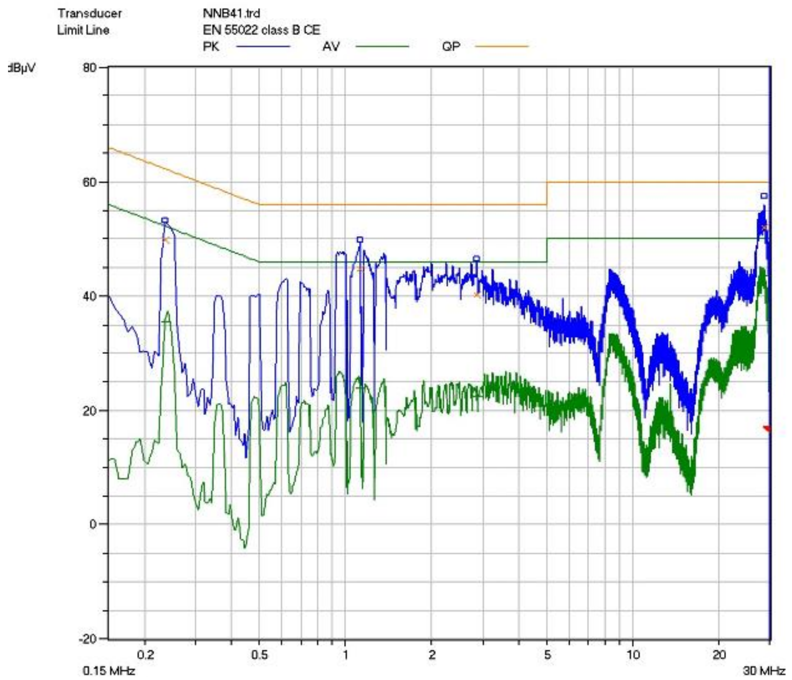
Pass EN 61000-4-5 installation class 4 (±2 kV for line-to-line and ±4 kV for line-to-earth).[2]

10.8 Conducted emissions (EN55022 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 (27 W) with input voltage of 115 V AC and 230 V AC.

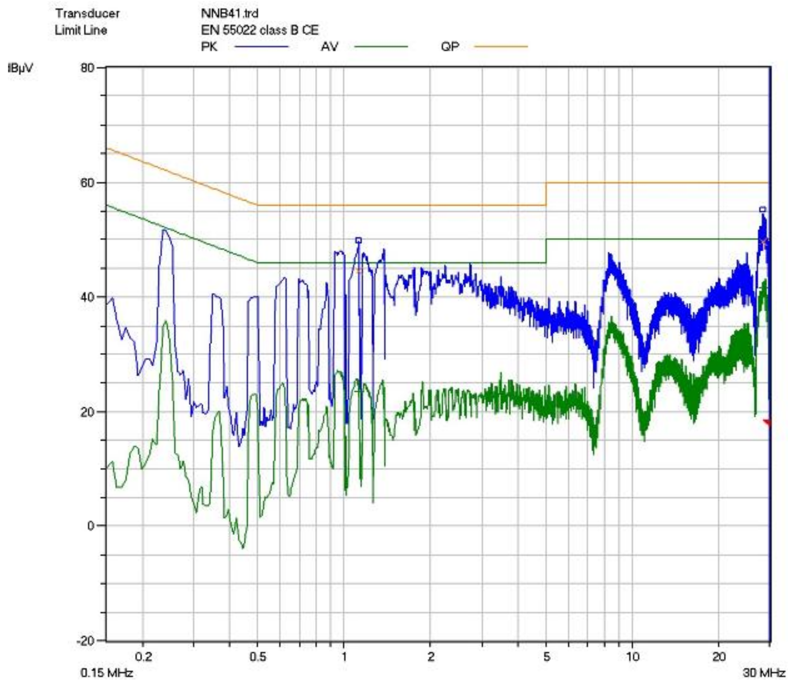
Pass conducted emissions EN 55022 (CISPR 22) class B with 6 dB margin for both low-line (115 V AC) and high-line (230 V AC).

[1] Add ferrite bead at transformer pin 6 and 7.
[2] C13 change to 120 µF/500 V.



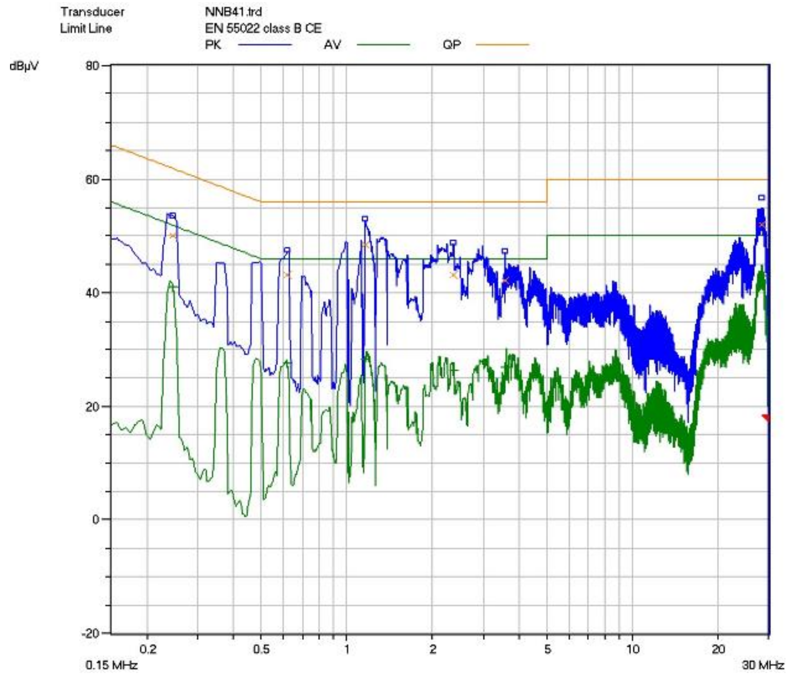
Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP
0.2340	L	53.2	L	35.5	L	49.9	52.3	62.3
1.1220	L	49.9	L	23.9	L	44.7	46.0	56.0
2.8680	L	46.5	L	22.4	L	40.2	46.0	56.0
28.6320	L	57.6	L	43.6	L	52.0	50.0	60.0

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



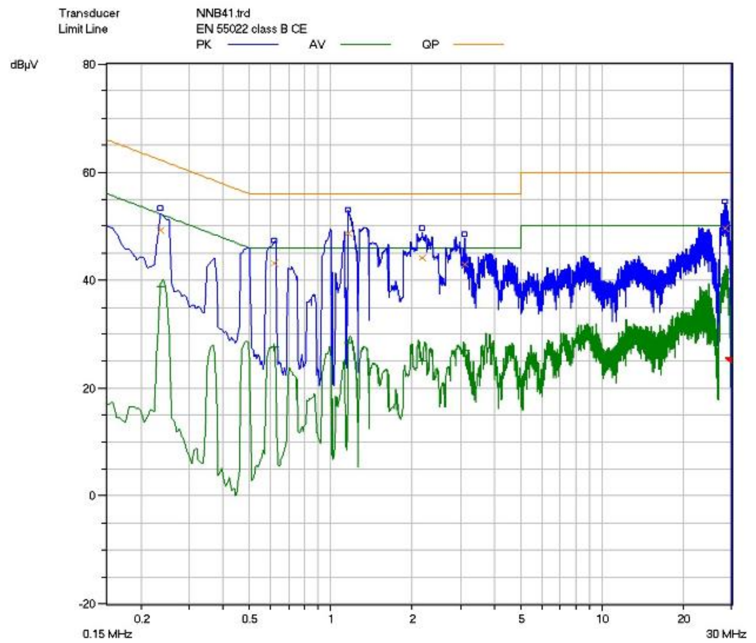
Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP
1.1220	N	49.8	N	23.6	N	44.6	46.0	56.0
28.5040	N	55.1	N	41.6	N	49.8	50.0	60.0

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



Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP
0.2460	L	53.7	L	41.0	L	50.1	51.9	61.9
0.6180	L	47.4	L	27.6	L	43.2	46.0	56.0
1.1580	L	52.9	L	28.2	L	48.4	46.0	56.0
2.3700	L	48.8	L	26.3	L	43.2	46.0	56.0
3.5840	L	47.4	L	26.8	L	42.3	46.0	56.0
28.5680	L	56.8	L	43.1	L	52.1	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
0.2340	N	53.5	N	38.9	N	49.4	52.3	62.3
0.6180	N	47.3	N	27.6	N	43.2	46.0	56.0
1.1580	N	53.1	N	28.5	N	48.7	46.0	56.0
2.1660	N	49.7	N	25.0	N	44.1	46.0	56.0
3.1120	N	48.4	N	27.1	N	43.0	46.0	56.0
28.4880	N	54.5	N	40.3	N	49.7	50.0	60.0

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	IC11 (ICE5GR1680AG)	85.3	83.8
3	R14 (CS resistor)	53.6	46.7
4	TR1 (transformer)	57.5	59.9
5	BR1 (bridge diode)	64.2	37.9
6	R11 (clamper resistor)	74.0	68.2
7	L11 (choke)	88.9	37.2
8	D11 (secondary diode)	66.7	68.7
8	D21 (secondary diode)	42.2	43.2
9	Ambient	25.0	25.0

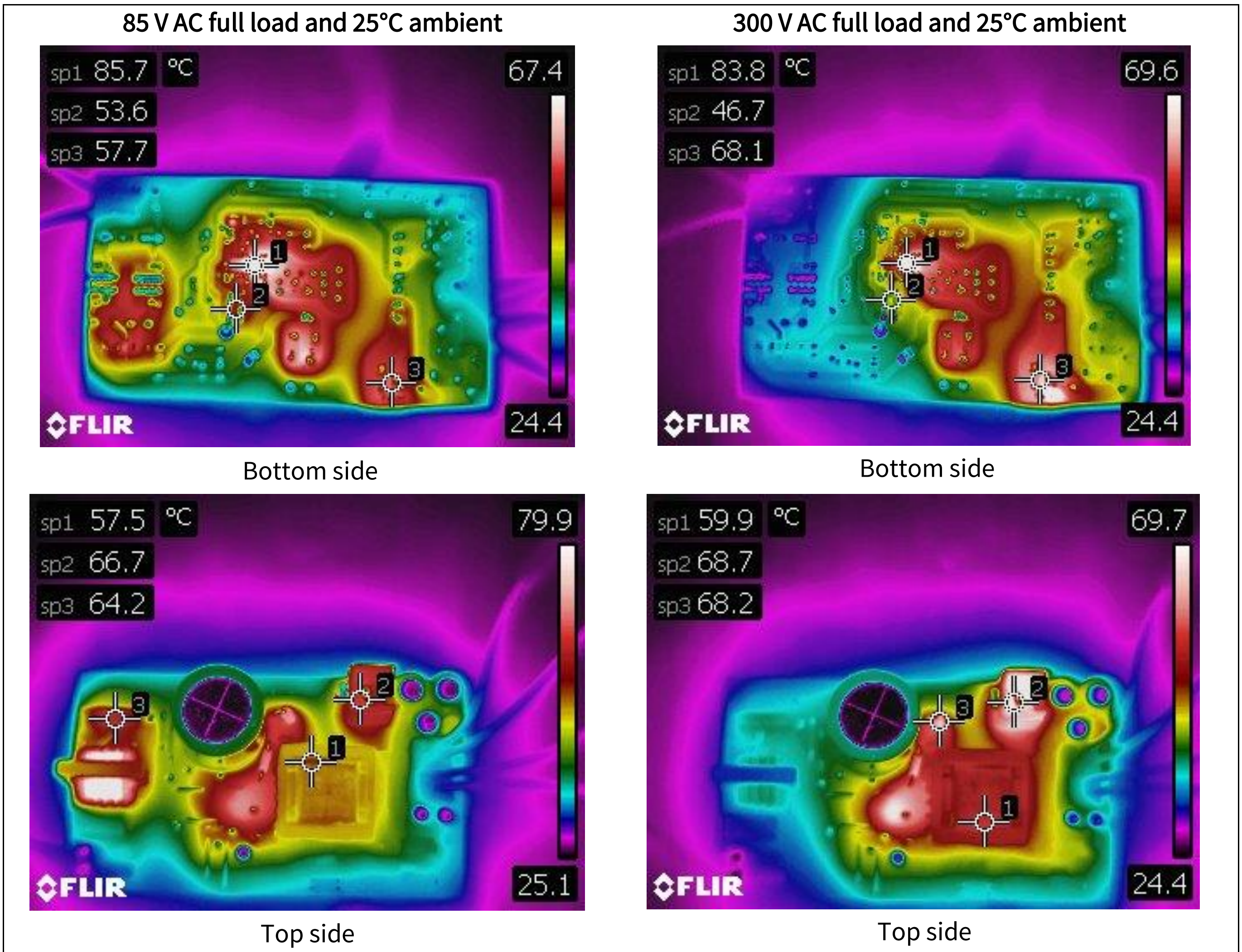


Figure 17 Infrared thermal image of DEMO_5GR1680AG_27W1

11 Waveforms and scope plots

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

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

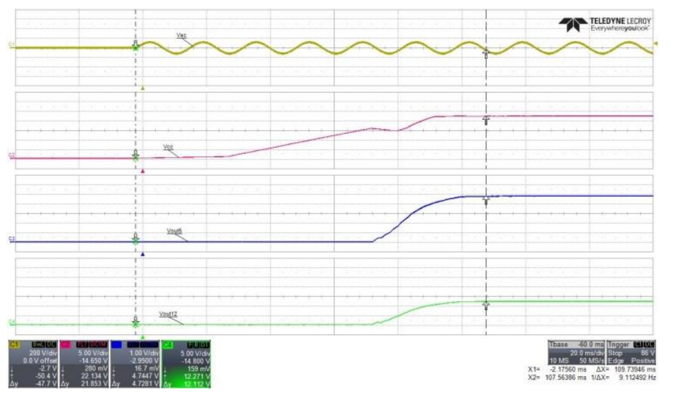
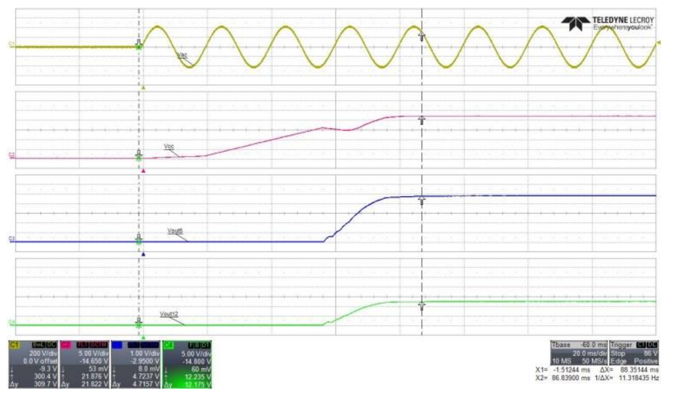
	
C1 (yellow) : AC-line voltage (V AC) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : 5 V output voltage (V_{Out5}) C4 (green) : 12 V output voltage (V_{Out12})	C1 (yellow) : AC-line voltage (V AC) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : 5 V output voltage (V_{Out5}) C4 (green) : 12 V output voltage (V_{Out12})
Start-up time at 85 V AC and maximum load ≈ 110 ms	Start-up time at 300 V AC and maximum load ≈ 90 ms

Figure 18 Start-up

11.2 Soft-start

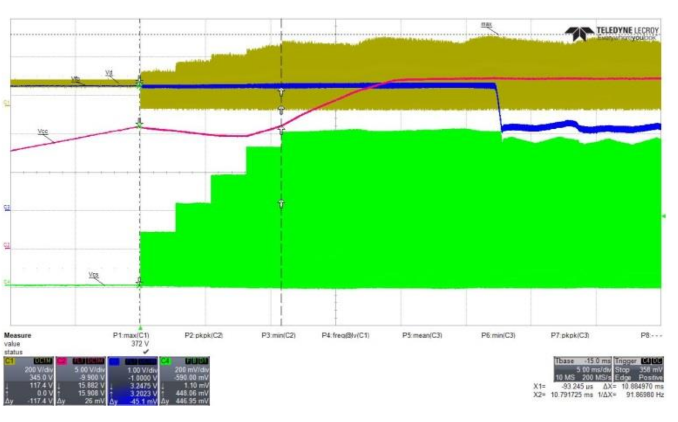
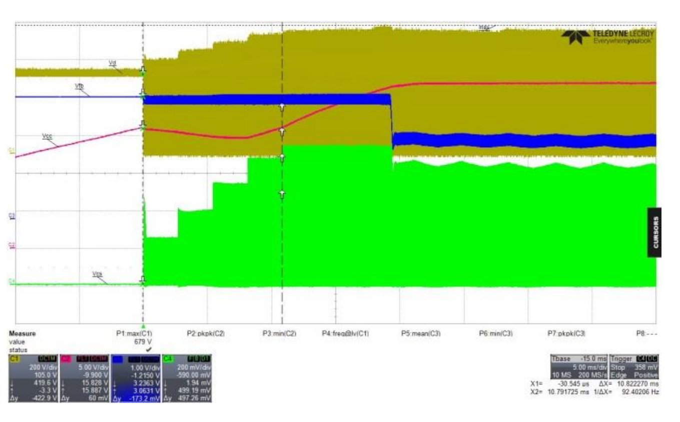
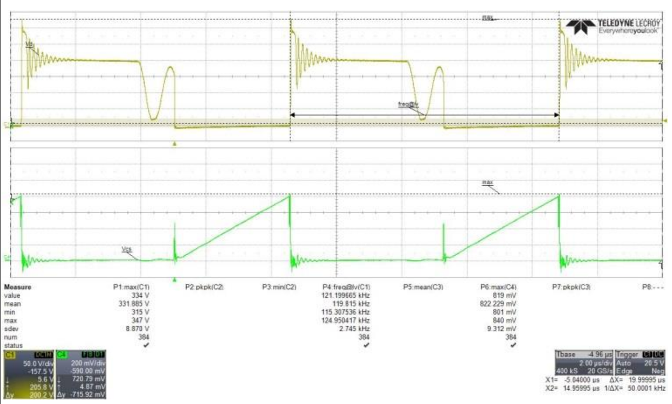
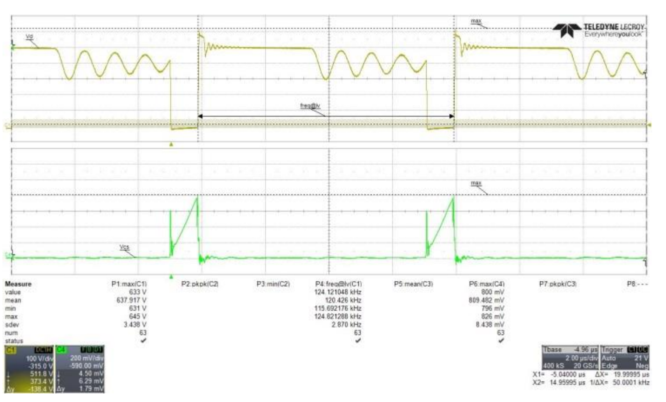
	
C1 (yellow) : Drain voltage (V_D) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})
Soft-start time at 85 V AC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

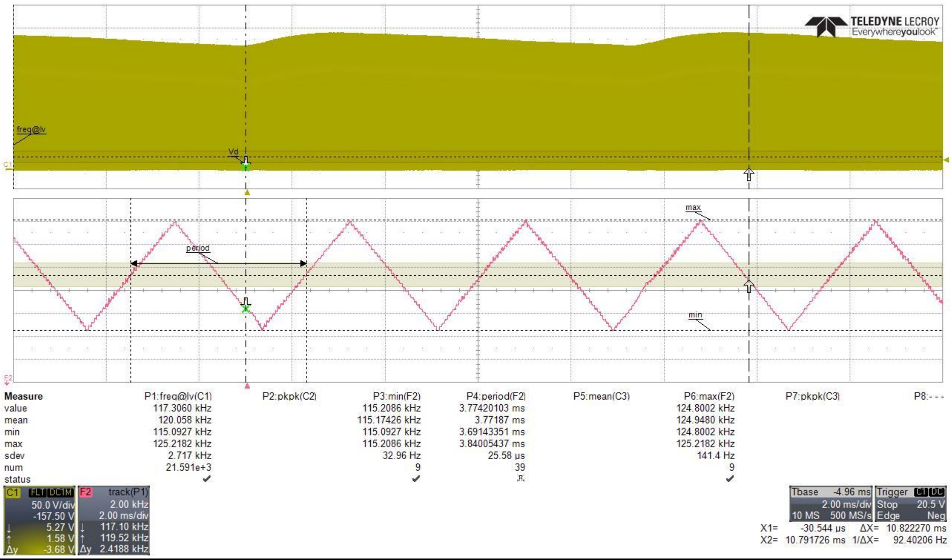




C1 (yellow) : Drain voltage (V_D) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C4 (green) : CS voltage (V_{CS})
V_{Drain_peak} at 85 V AC ≈ 301 V	V_{Drain_peak} at 300 V AC ≈ 645 V

Figure 20 Drain and CS voltage at maximum load

11.4 Frequency jittering



C1 (yellow) : Drain voltage (V_D)
F1 (yellow) : Frequency track of drain

Frequency jittering at 85 V AC and maximum load ≈ 115 kHz ~ 125kHz, jitter period is ≈ 3.7 ms

Figure 21 Frequency jittering

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

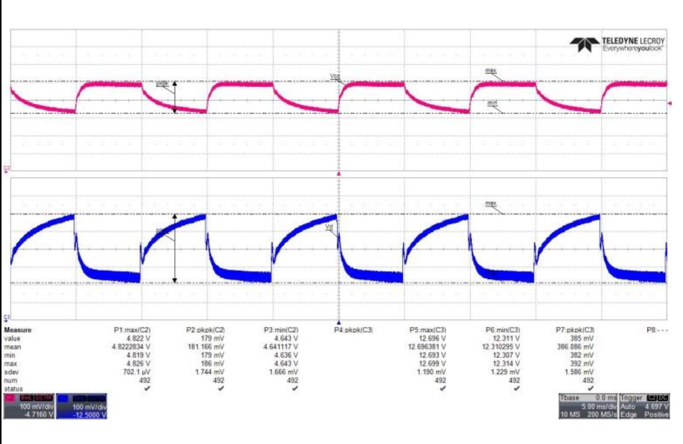
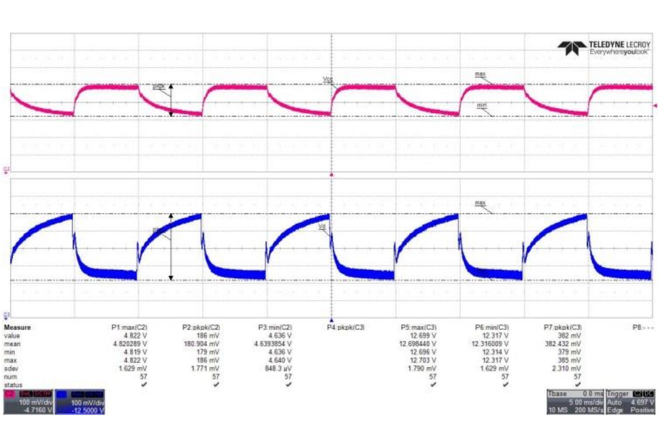
	
C2 (purple) : 5 V output ripple voltage (V_{Out}) C3 (blue) : 12 V output ripple voltage (V_{Out})	C2 (purple) : 5 V output ripple voltage (V_{Out}) C3 (blue) : 12 V output ripple voltage (V_{Out})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 186 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 392 mV (85 V AC, 12 V load change from 10% to 100% and 5 V at 0.2 A load, 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	5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 186 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 389 mV (300 V AC, 12 V load change from 10% to 100% and 5 V at 0.2 A load, 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

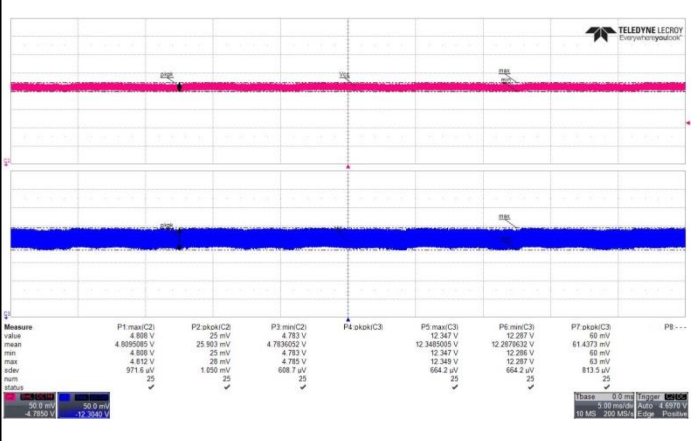
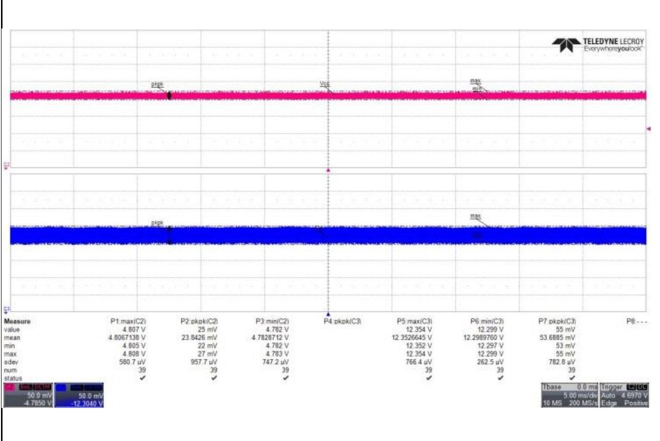
	
C2 (purple) : 5 V output ripple voltage (V_{Out}) C3 (blue) : 12 V output ripple voltage (V_{Out})	C2 (purple) : 5 V output ripple voltage (V_{Out}) C3 (blue) : 12 V output ripple voltage (V_{Out})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 28 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 60 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz filter	5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 27 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 55 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

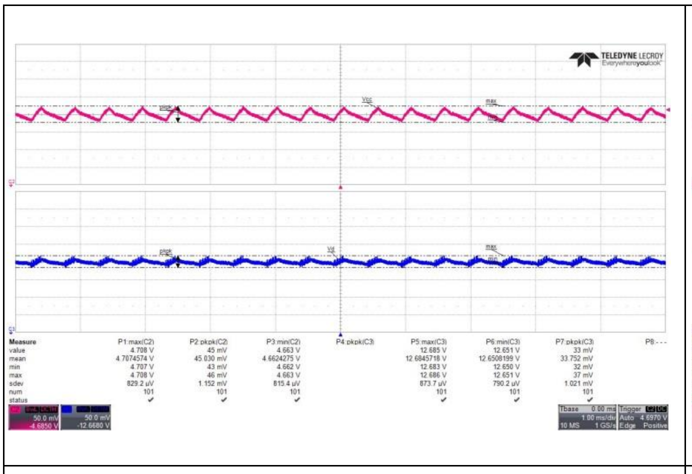
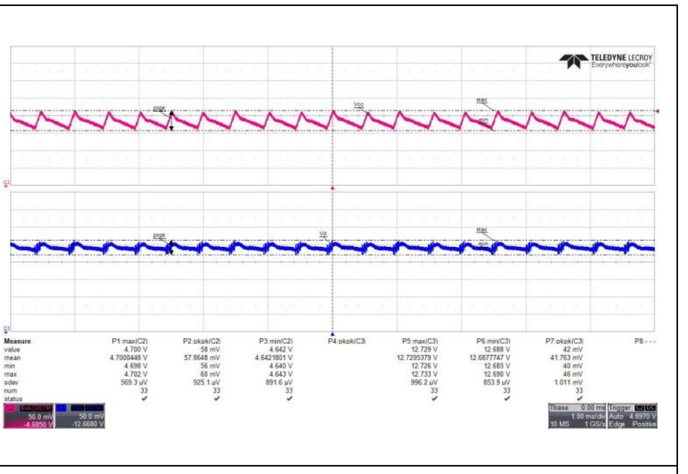
	
C2 (purple) : 5 V output ripple voltage (V_{Out}) C3 (blue) : 12 V output ripple voltage (V_{Out})	C2 (purple) : 5 V output ripple voltage (V_{Out}) C3 (blue) : 12 V output ripple voltage (V_{Out})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 46 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 37 mV Load: 5 V at 50 mA and 12 V at 62 mA Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz filter	5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 60 mV 12 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 46 mV Load: 5 V at 50 mA and 12 V at 62 mA 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

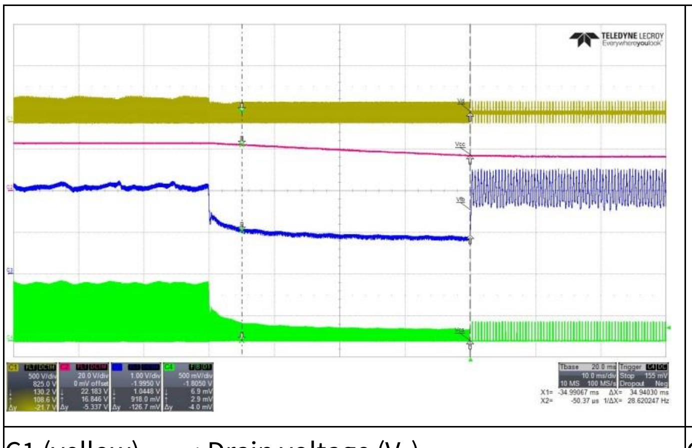
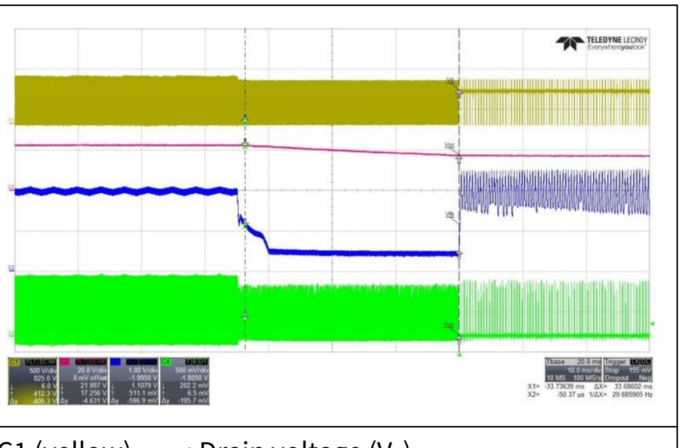
	
C1 (yellow) : Drain voltage (V_D) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})
Condition to enter burst mode level 1: V_{FB} < 1.05 V and $t_{blanking}$ = 36 ms (load change from full load to 0.5 W load at 85 V AC)	Condition to enter burst mode level 1: V_{FB} < 1.05 V and $t_{blanking}$ = 36 ms (load change from full load to 0.5 W load at 300 V AC)

Figure 25 Entering ABM

11.9 During ABM

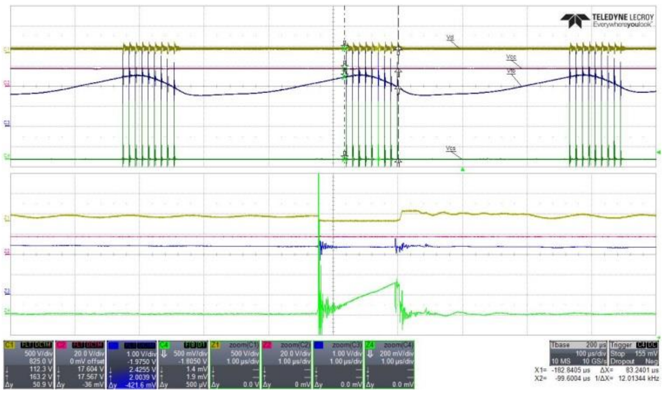
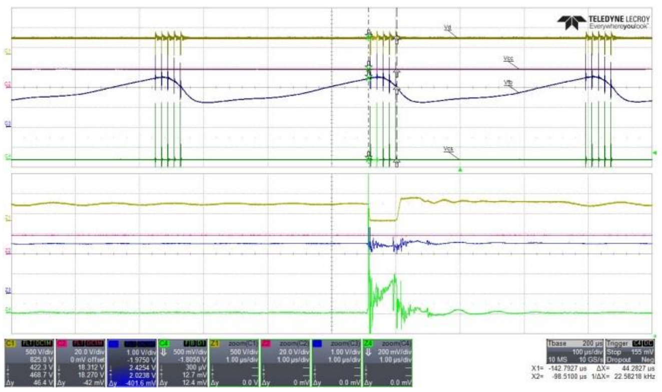
	
C1 (yellow) : Drain voltage (V_D) C2 (purple) : VIN voltage (V_{VIN}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C2 (purple) : VIN voltage (V_{VIN}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})
During ABM level 1: $V_{FB\_Bon\_ISO}$ = 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 1: $V_{FB\_Bon\_ISO}$ = 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

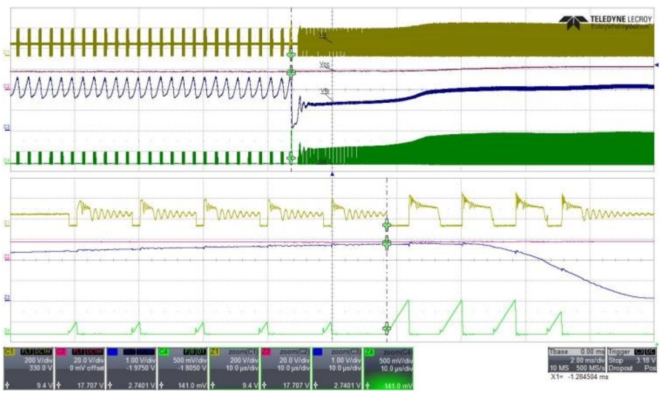
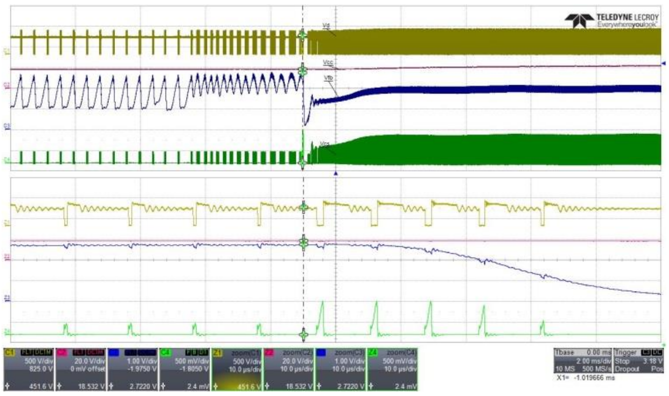
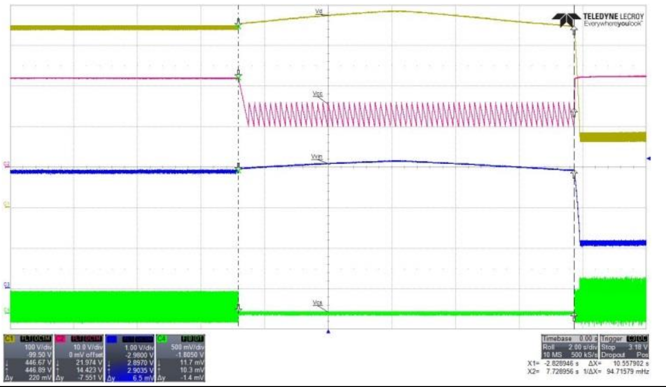
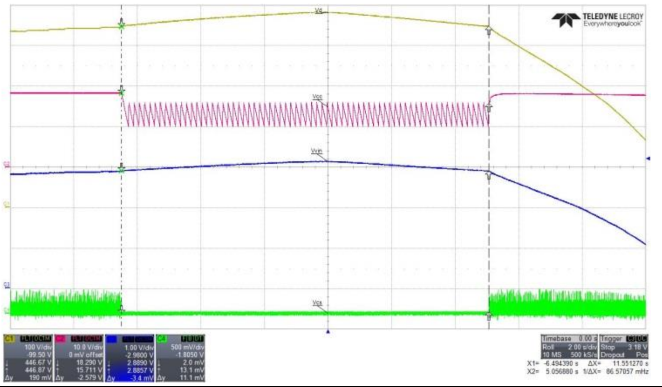
	
C1 (yellow) : Drain voltage (V_D) C2 (purple) : VIN voltage (V_{VIN}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C2 (purple) : VIN voltage (V_{VIN}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})
Condition to leave burst mode level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



C1 (yellow) : Bus voltage (V_{Bus})
C2 (purple) : Supply voltage (V_{VCC})
C3 (blue) : VIN voltage (V_{VIN})
C4 (green) : CS voltage (V_{CS})

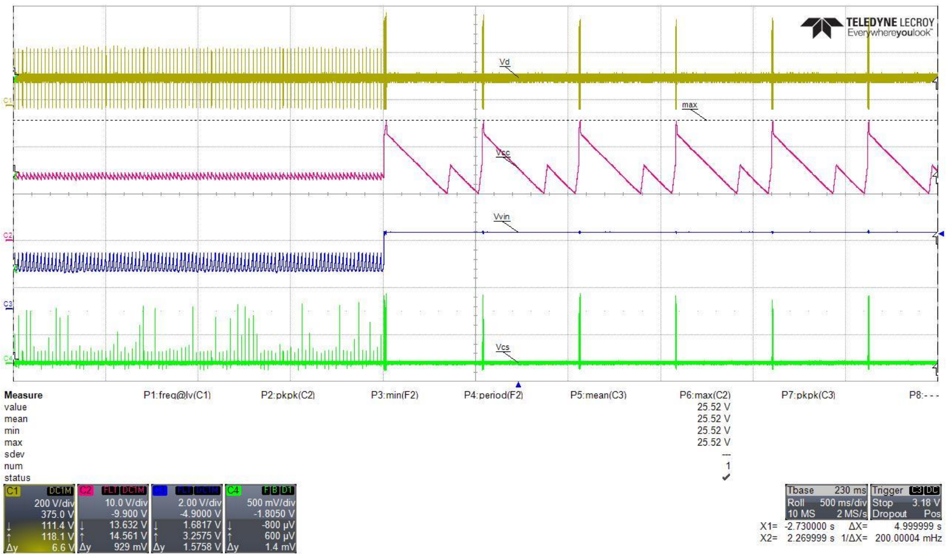
Condition to detect line OVP: V_{VIN} > 2.9 V (V_{BULK} > 446 V DC [≈ 320 V AC])
Condition to reset line OVP: V_{VIN} < 2.9 V (V_{BULK} > 446 V DC [≈ 320 V AC])

(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)

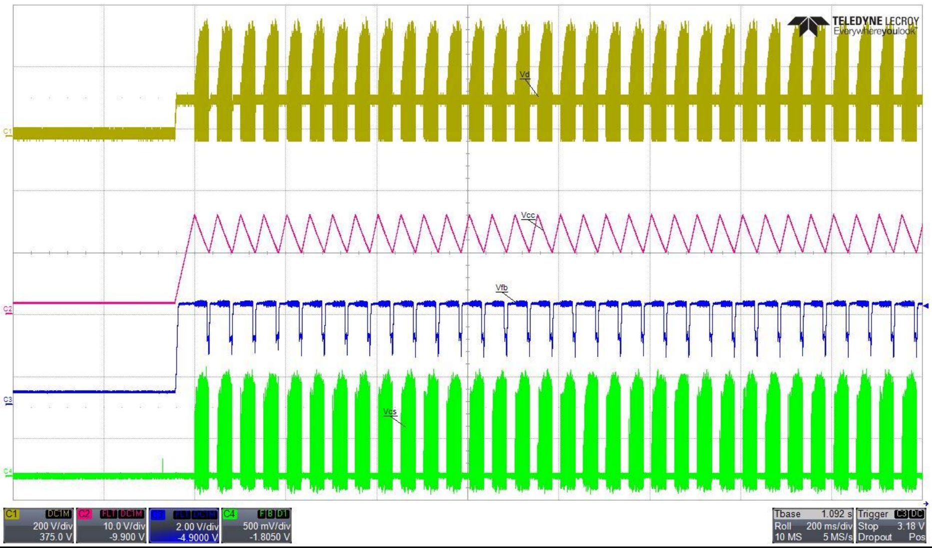


C1 (yellow) : Drain voltage (V_D)
C2 (purple) : Supply voltage (V_{VCC})
C3 (blue) : FB voltage (V_{FB})
C4 (green) : CS voltage (V_{CS})

Condition to enter V_{CC} OVP: V_{VCC} > 25.5 V
(short R26 while system operating at 85 V AC and no load)

Figure 29 V_{CC} OVP

11.13 V_{CC} UVP (auto restart)

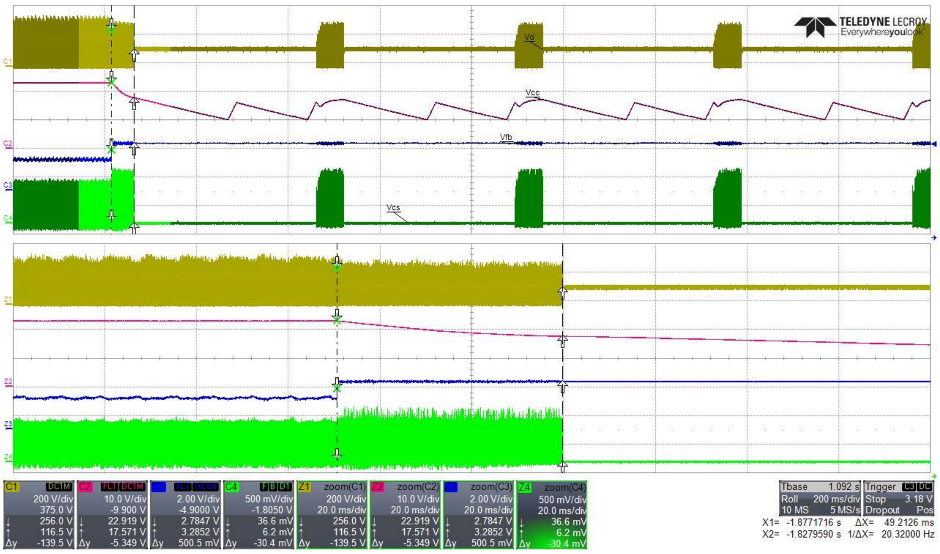


C1 (yellow) : Drain voltage (V_D)
C2 (purple) : Supply voltage (V_{VCC})
C3 (blue) : FB voltage (V_{FB})
C4 (green) : CS voltage (V_{CS})

Condition to enter VCC UVP: V_{CC} < 10 V
(Remove R12A 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) : Drain voltage (V_D)
C2 (purple) : Supply voltage (V_{VCC})
C3 (blue) : FB voltage (V_{FB})
C4 (green) : CS voltage (V_{CS})

Condition to enter over-load protection: V_{FB} > 2.75 V and lasts for 54 ms blanking time
(load change from full to short load at 85 V AC)

Figure 31 Over-load protection

11.15 V_{CC} short-to-GND protection

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

Condition to enter V_{CC} short-to-GND: if $V_{CC} < V_{VCC\_SCP} \rightarrow I_{VCC} = I_{VCC\_Charge1}$
(Short VCC pin-to-GND and measure the current with multimeter before system start-up, $I_{VCC} \approx 300$ µA and input power is ≈ 40 mW 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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«JONHON» (основан в 1970 г.)

Разъемы специального, военного и аэрокосмического назначения:

(Применяются в военной, авиационной, аэрокосмической, морской, железнодорожной, горно- и нефтедобывающей отраслях промышленности)

«FORSTAR» (основан в 1998 г.)

ВЧ соединители, коаксиальные кабели, кабельные сборки и микроволновые компоненты:

(Применяются в телекоммуникациях гражданского и специального назначения, в средствах связи, РЛС, а так же военной, авиационной и аэрокосмической отраслях промышленности).

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