

60 W 19 V SMPS demo board with ICE5GSAG and IPA80R650CE

DEMO_5GSAG_60W1

About this document

Scope and purpose

This document is an engineering report that describes a universal-input 60 W 19 V off-line flyback converter using the latest 5th generation Infineon Fixed Frequency Controller (FFC) [ICE5GSAG](#) and CoolMOS™ [IPA80R650CE](#). It offers high-efficiency, low-standby power with selectable entry and exit standby power options, a wide V_{CC} 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 ICE5GSAG and IPA80R650CE in terms of optimized efficiency, thermal and EMI performance.

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, 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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Abstract**1 Abstract**

This is an engineering report for a 60 W 19 V demo board designed in a fixed frequency flyback converter topology using the fifth-generation FFC, ICE5GSAG, and a CE series of HV CoolMOS™, IPA80R650CE. 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 from light loads up to 50% load. The selectable Active Burst Mode (ABM) power enables ultra-low power consumption. In addition, numerous adjustable protection functions have been implemented in ICE5GSAG to protect the system and customize the IC for the chosen application. In case of failure modes, like line over-voltage, V_{CC} over-/under-voltage, open control-loop or over-load, over-temperature, V_{CC} short-to-GND and CS short-to-GND, the device enters protection mode. By means of the cycle-by-cycle peak current Limitation (PCL), the dimensions of the transformer and the current rating of the secondary diode can both be optimized. Thus, a cost-effective solution can easily be achieved. The target applications of ICE5GSAG 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.

Demo board

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.

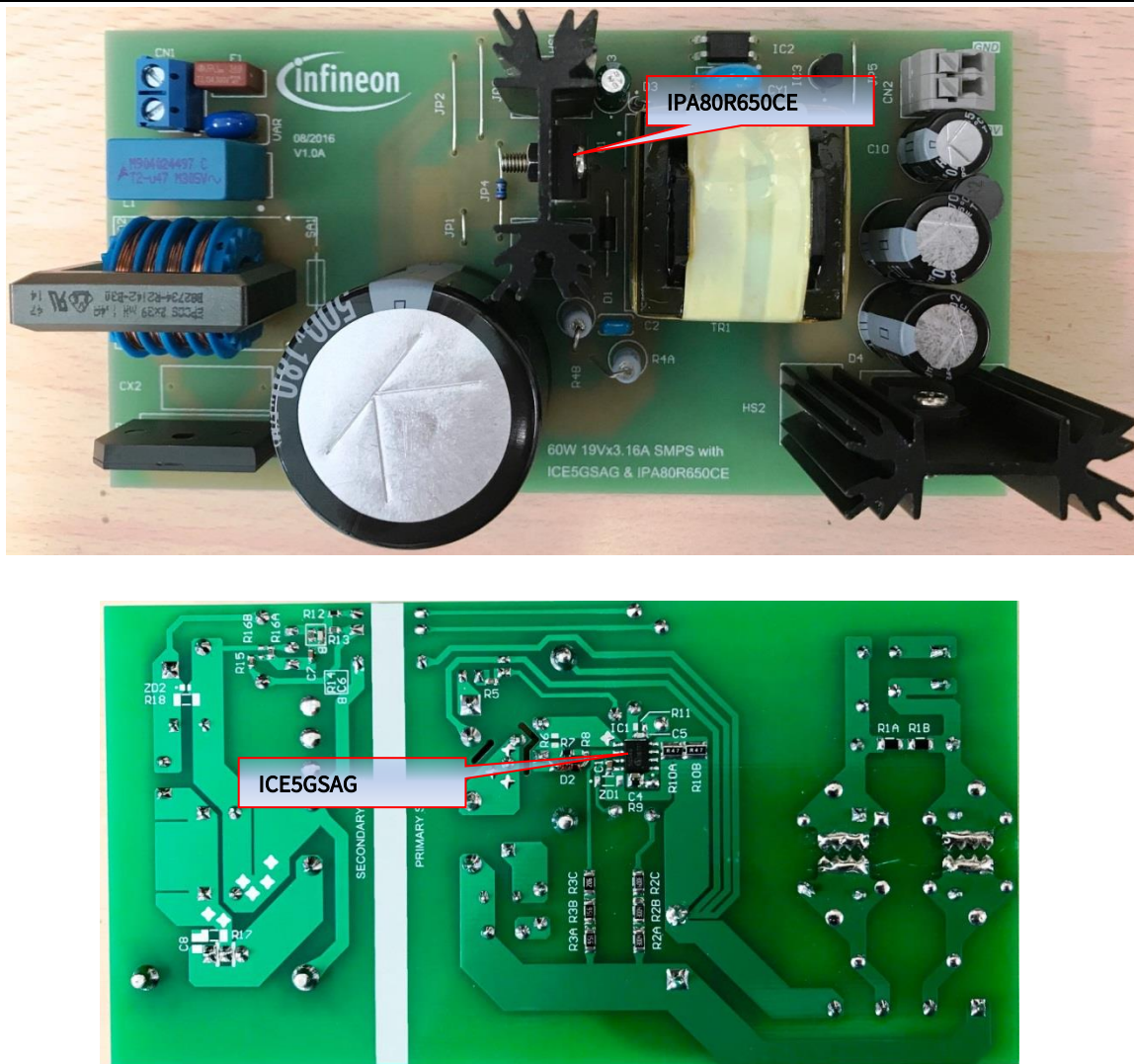


Figure 1 DEMO_5GSAG_60W1

Specifications of demo board

3 Specifications of demo board

Table 1 Specifications of DEMO_5GSAG_60W1

Input voltage and frequency	85 V AC (60 Hz)~300 V AC (50 Hz)
Output voltage, current and power	19 V x 3.16 A = 60 W
Dynamic load response (load change from 10% to 100%, slew rate at 1.5 A/ μ s, 100 Hz)	$\pm 5\%$ of nominal output voltage
Output ripple voltage (full-load, 85 V AC~300 V AC)	19 V _{ripple_p_p} < 200 mV
Active mode four-point average efficiency (25%, 50%, 75%, 100% load)	> 86% 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 7 dB margin for 115 V AC and 230 V AC
ESD immunity (EN 61000-4-2)	Special level (± 10 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)	(144 x 73 x 43) mm ³

Circuit description

4 Circuit description

4.1 Line input

The AC-line input side comprises the input fuse F1 as over-current protection. The choke L1, X-capacitor CX1 and Y-capacitor CY1 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 the bulk capacitor C3.

4.2 Start-up

To achieve fast and safe start-up, ICE5GSAG 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 ICE5GSAG 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 in increments from 0.3 V to 1 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 PWM control with frequency reduction and switching MOSFET

The PWM pulse is generated by the 5th generation FFC ICE5GSAG. The new controller can be operated in either DCM or Continuous Conduction Mode (CCM) with frequency reduction mode to achieve the overall average efficiency. This demo board is designed to operate in DCM.

When the system is operating at maximum power, the controller will switch at the fixed frequency of 125 kHz. In order to achieve a better efficiency between light and medium loads, 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).

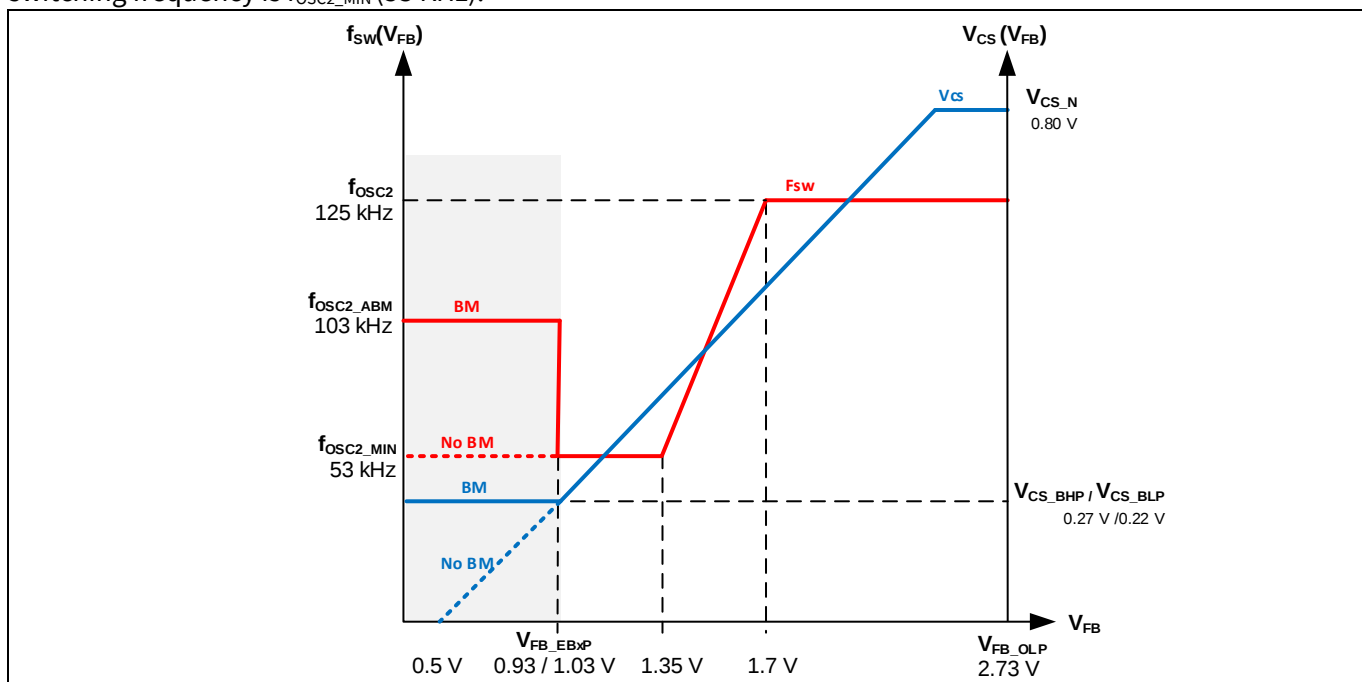


Figure 2 Frequency reduction curve

Circuit description

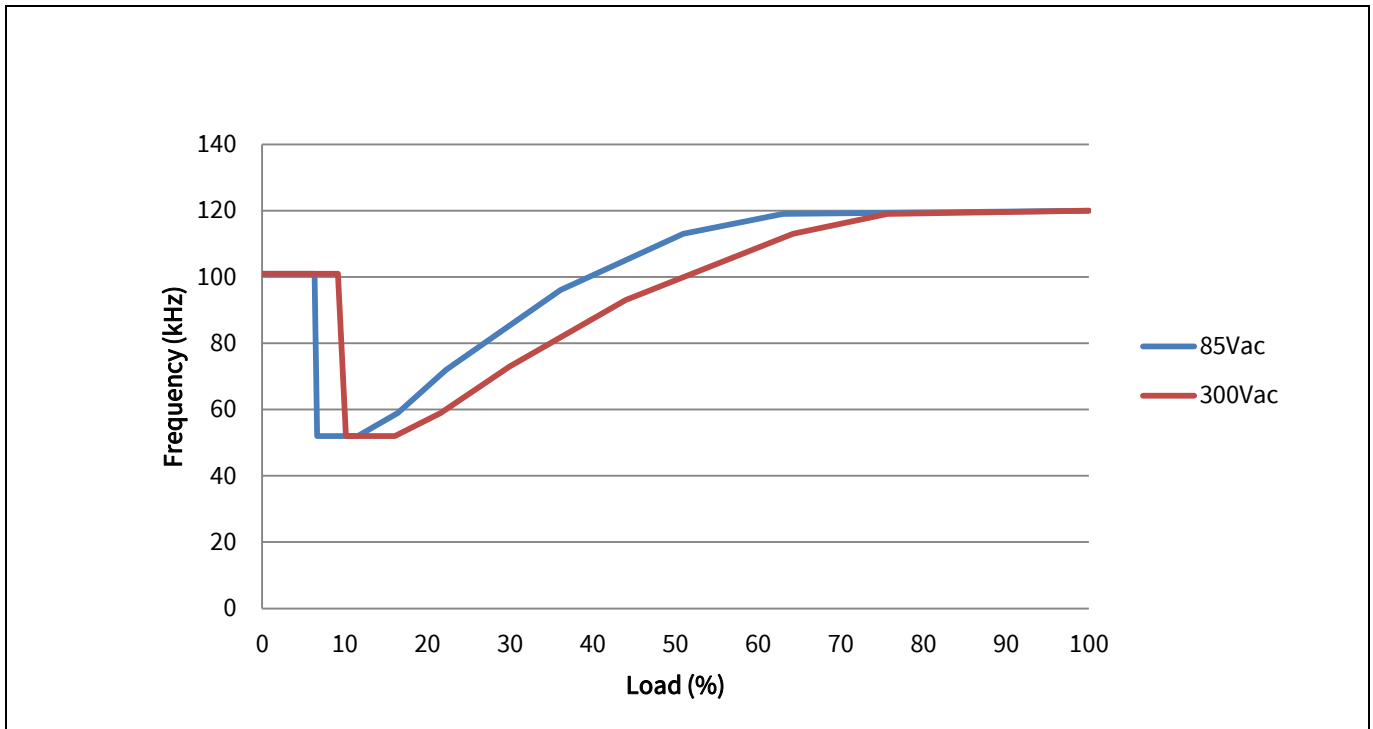


Figure 3 Frequency reduction curve of DEMO_5GSAG_60W1

The measured frequency reduction curve of DEMO_5GSAG60W1 is shown in Figure 3.

The PWM pulse drives the HV power MOSFET, IPA80R650CE. The CoolMOS™ provides all the benefits of a fast-switching superjunction (SJ) MOSFET while not sacrificing ease of use. It achieves extremely low conduction and switching losses, and can make switching applications more efficient, more compact, lighter and cooler. Details about the information mentioned above are illustrated in the product datasheet.

4.4 Frequency jittering

The ICE5GSAG 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 (R4A, R4B, C2 and D1) dissipates the energy of the leakage inductance and suppresses ringing on the SMPS transformer.

4.6 Output stage

On the secondary side the power is coupled out by Schottky diode D4. The capacitors C9A and C9B provide energy buffering, following with the LC filters L2 and C10 to reduce the output voltage ripple considerably. Storage capacitors C9A and C9B are selected to have a very small internal resistance (ESR) to minimize the output voltage ripple.

4.7 Feedback loop

For feedback (FB), the output is sensed by the voltage divider of R15, R16A and R16B and compared to the IC3 (TL431) internal reference voltage. C7, C6 and R14 comprise the compensation network. The output voltage of IC3 (TL431) is converted to the current signal via optocoupler IC2 and two resistors, R12 and R13, for regulation control.

Circuit description

4.8 Active Burst Mode (ABM)

ABM entry and exit power can be selected from three options, including no ABM. This demo board is set to level 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_{CC} 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.

For determination of entering ABM operation, two conditions apply:

1. The FB voltage is lower than the threshold of V_{FB_EBXP} , and
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 the efficiency during standby power measurement. 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 changes 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 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. ICE5GSAG provides comprehensive protection to ensure the system is operating safely. This includes line over-voltage, V_{CC} over-voltage and under-voltage, over-load, over-temperature (controller junction), CS short-to-GND and V_{CC} 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 are shown in the table below.

Table 2 Protection functions of ICE5GSAG

Protection function	Failure condition	Protection mode
Line over-voltage	$V_{VIN} > 2.9 \text{ V}$	Non-switch auto restart
V _{CC} over-voltage	$V_{VCC} > 25.5 \text{ V}$	Odd-skip auto restart
V _{CC} under-voltage	$V_{VCC} < 10 \text{ V}$	Auto restart
Over-load	$V_{FB} > 2.75 \text{ V}$ and lasts for 54 ms	Odd-skip auto restart
Over-temperature (junction temperature of controller chip only)	$T_J > 140^\circ\text{C}$	Non-switch auto restart
CS short-to-GND	$V_{CS} < 0.1 \text{ V}$ and lasts for 0.4 μs and 3 consecutive pulses	Odd-skip auto restart
V _{CC} short-to-GND ($V_{VCC} = 0 \text{ V}$, $R_{\text{Start-up}} = 50 \text{ M}\Omega$ and $V_{\text{DRAIN}} = 90 \text{ V}$)	$V_{VCC} < 1.2 \text{ V}$, $I_{VCC_Charge1} \approx -0.27 \text{ mA}$	Cannot start up

Circuit diagram

6 Circuit diagram

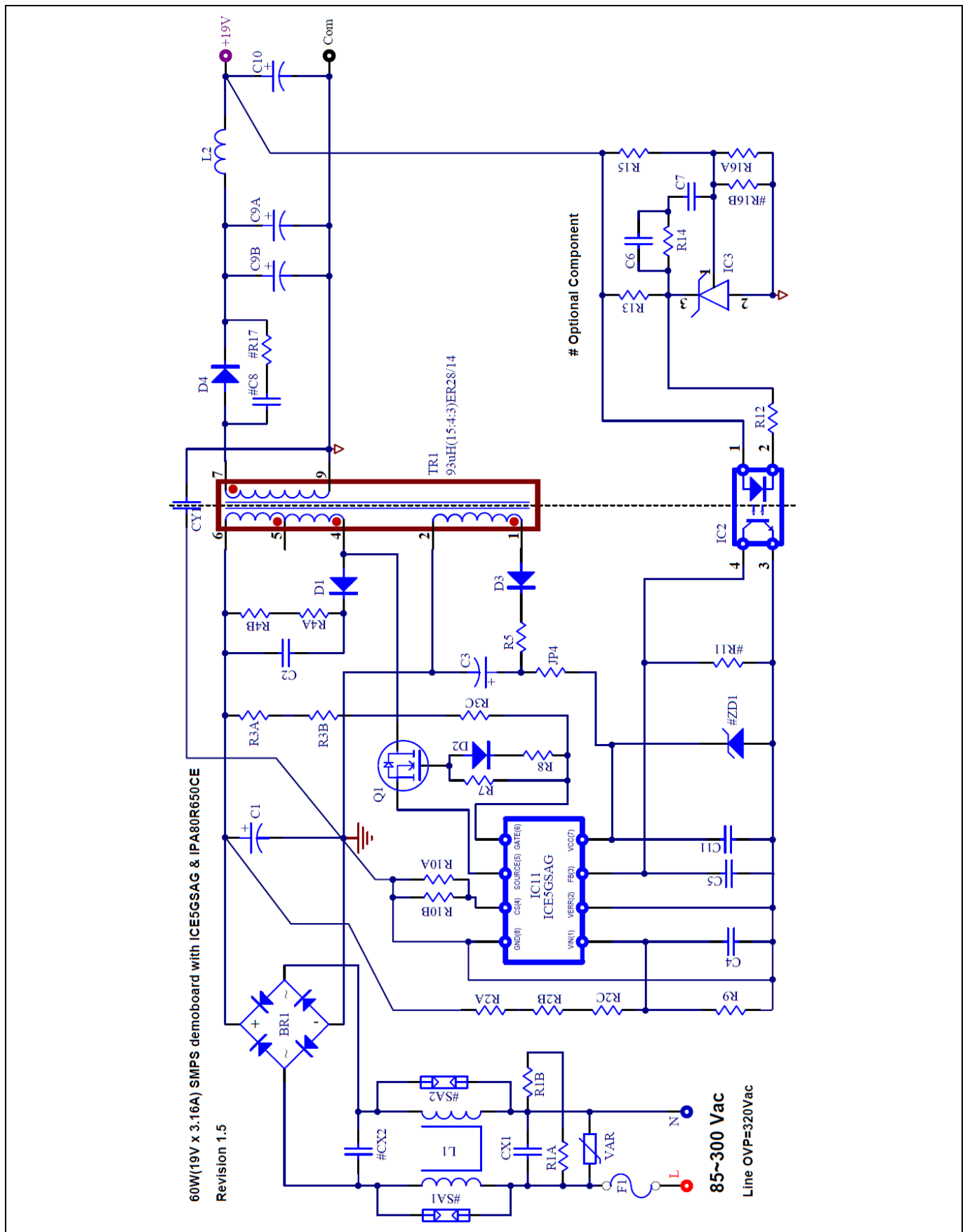


Figure 4 Schematic of DEMO_5GSAG_60W1

BOM

8 BOM

Table 3 BOM (R 1.5)

No.	Designator	Description	Part number	Manufacturer	Quantity
1	BR1	600 V/4 A	D4SB60L	Shindengen	1
2	CX1	0.47 μ F/305 V	B32922C3474	Epcos	1
3	CY1	2.2 nF/500 V	DE1E3RA222MA4BQ	Murata	1
4	C1	180 μ F/500 V	500VXG180MEFCSN35X30	Rubycon	1
5	C2	1 nF/1000 V	RDE7U3A102J2K1H03	Murata	1
6	C3	33 μ F/50 V	35PX33MEFC5X11	Rubycon	1
7	C11	100 nF/50 V	GRM188R71H104KA93D	Murata	1
8	C5, C6	1 nF/50 V	GRM1885C1H102GA01D	Murata	2
9	C4	22 nF/50 V	GCM188R71H223KA37D	Murata	1
10	C9A, C9B	1500 μ F/25 V	25ZLS1500MEFC12.5X20	Rubycon	2
11	C10	470 μ F/25 V	25ZLH470MEFC10X12.5	Rubycon	1
12	C7	220 nF/50 V	GRM188R71H224KAC4D	Murata	1
13	D1	1 A/800 V	UF4006		1
14	D2	0.2 A/150 V/50 ns	FDH400		1
15	D3	0.5 A/200 V	1N485B		1
16	D4	30 A/200 V	VF30200C		1
17	F1	3.15 A/300 V	36913150000		1
18	HS1, HS2	Heatsink	513102B02500G		2
19	IC1	ICE5GSAG	ICE5GSAG	Infineon	1
20	IC2	Optocoupler	SFH617A-3		1
21	IC3	Shunt regulator	TL431BVLPG		1
22	JP1, JP2, JP3, JP5	Jumper			4
23	L1	39 mH/1.4 A	B82734R2142B030	Epcos	1
24	L2	2.2 μ H/6 A	744772022	Würth Electronics	1
25	Q1	800 V/650 m Ω	IPA80R650CE	Infineon	1
26	R4A, R4B	15 k Ω /2 W/350 V	ERG-2SJ153		2
27	JP4	27 Ω			1
28	R5, R8	0 Ω (0603)			2
29	R10A, R10B	0.47 Ω /0.75 W/ $\pm$ 1%	ERJ-B2BFR47V		2
30	R3A, R3B	15 M Ω /0.25 W/5%	RC1206JR-0715ML		2
31	R3C	20 M Ω /0.25 W/5%	RC1206JR-0720ML		1
32	R2A, R2B, R2C	3 M Ω /0.25 W/1%	RC1206FR-073ML		3
33	R9	59 k Ω /0.1 W/0.5%	ERJ-3RBD5902V		1
34	R1A, R1B	1 M Ω /5%/200 V	RC1206JR-071ML		2
35	R7	15 Ω (0603)			1
36	R12	1.5 k Ω (0603)			1
37	R13	1.2 k Ω (0603)			1
38	R14	22 k Ω (0603)			1
39	R15	66 k Ω (0603)			1

BOM

40	R16A	10 k Ω (0603)			1
41	TR1	93 μ H (15:4:3) ER28/14	750343380 (Rev 0.4)	Würth Electronics	1
42	VAR	0.25 W/320 V	B72207S2321K101	Epcos	1
43	Con (L N)	Connector	691102710002	Würth Electronics	1
44	Con (+19 V com)	Connector	691 412 120 002B	Würth Electronics	1

Transformer construction

9 Transformer construction

Core and materials: ER28/14, TP4A (TDG)

Bobbin: 070-4869 (12-pin, THT, horizontal version)

Primary inductance: $L_p = 93 \mu\text{H}$ ($\pm 10\%$), measured between pin 4 and pin 6

Manufacturer and part number: Würth Electronics Midcom (750343080 R04)

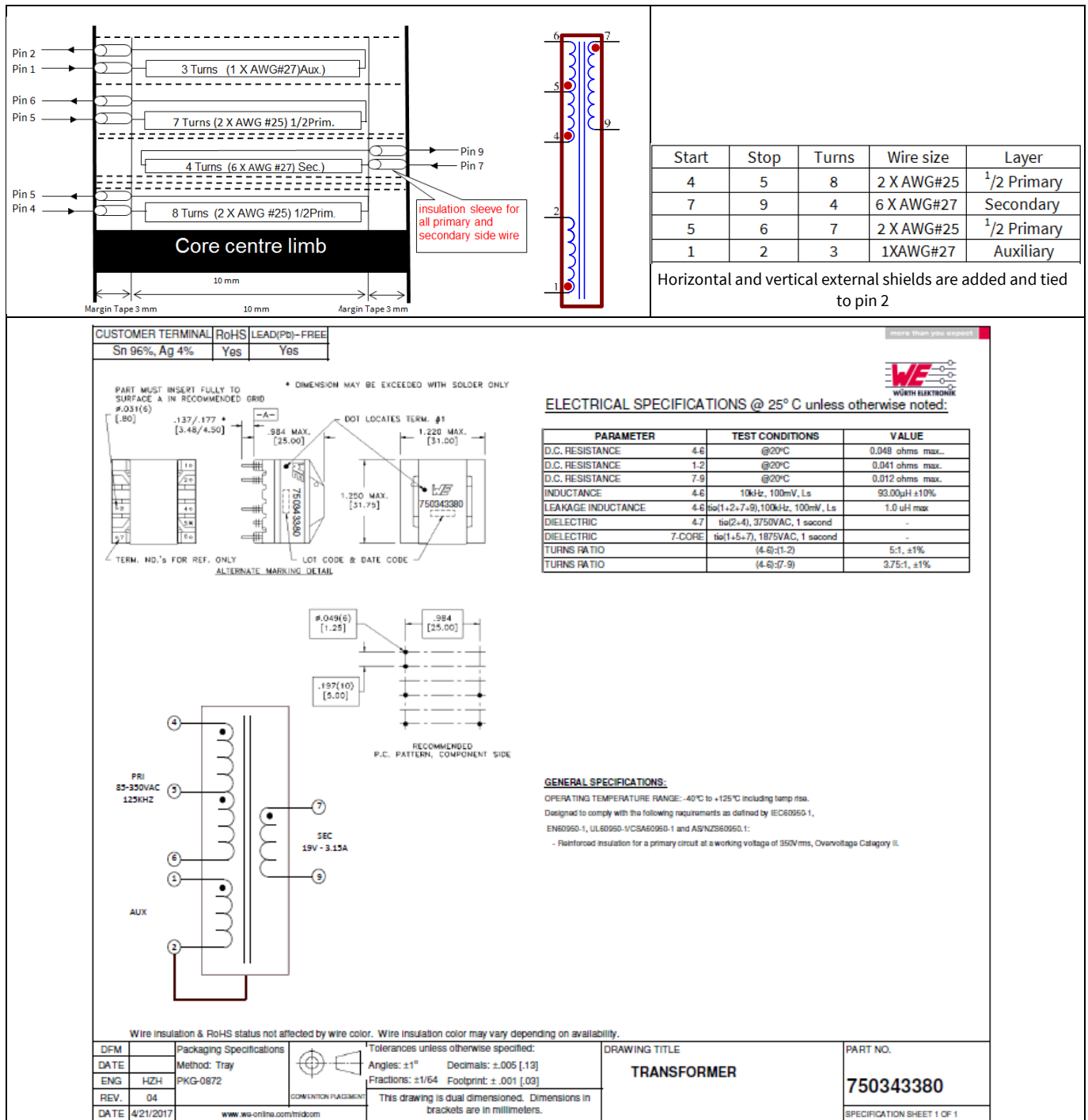


Figure 7 Transformer structure

Test results

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 _{out} (V DC)	I _{out} (A)	V _{RPP} (mV)	P _{out} (W)	Efficiency η (%)	Average η (%)	OLP P _{in} (W)	OLP I _{out} (A)
85 V AC/60 Hz	0.05670	19.05	0.000	115				81.00	3.51
	17.47	19.05	0.793	32	15.10	86.42	85.30		
	35.01	19.05	1.581	58	30.12	86.04			
	53.06	19.05	2.370	70	45.15	85.09			
	71.95	19.05	3.160	97	60.20	83.67			
115 V AC/60 Hz	0.06249	19.05	0.000	118				80.60	3.60
	17.32	19.05	0.793	44	15.10	87.17	86.85		
	34.49	19.05	1.581	58	30.12	87.34			
	51.90	19.05	2.370	76	45.15	86.99			
	70.06	19.05	3.160	90	60.20	85.92			
230 V AC/50 Hz	0.09808	19.05	0.000	113				82.00	3.79
	17.45	19.05	0.793	36	15.10	86.52	87.41		
	34.40	19.05	1.581	43	30.12	87.56			
	51.36	19.05	2.370	63	45.15	87.91			
	68.68	19.05	3.160	86	60.20	87.65			
265 V AC/50 Hz	0.11717	19.05	0.000	121				86.00	3.94
	17.59	19.05	0.793	33	15.10	85.83	87.02		
	34.59	19.05	1.581	40	30.12	87.08			
	51.50	19.05	2.370	55	45.15	87.67			
	68.80	19.05	3.160	78	60.20	87.50			
300 V AC/50 Hz	0.14020	19.05	0.000	123				89.00	4.00
	17.73	19.05	0.793	36	15.10	85.15	86.39		
	34.91	19.05	1.581	40	30.12	86.28			
	51.90	19.05	2.370	50	45.15	86.99			
	69.08	19.05	3.160	70	60.20	87.14			

Test results

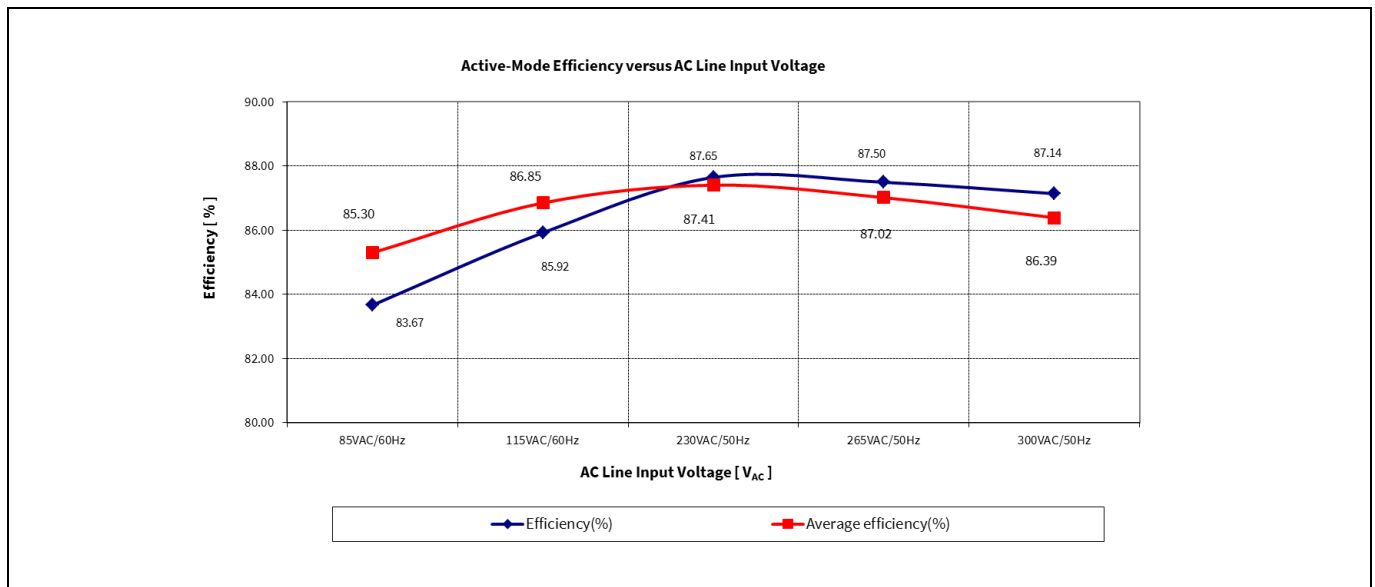


Figure 8 Efficiency vs AC-line input voltage

10.2 Standby power

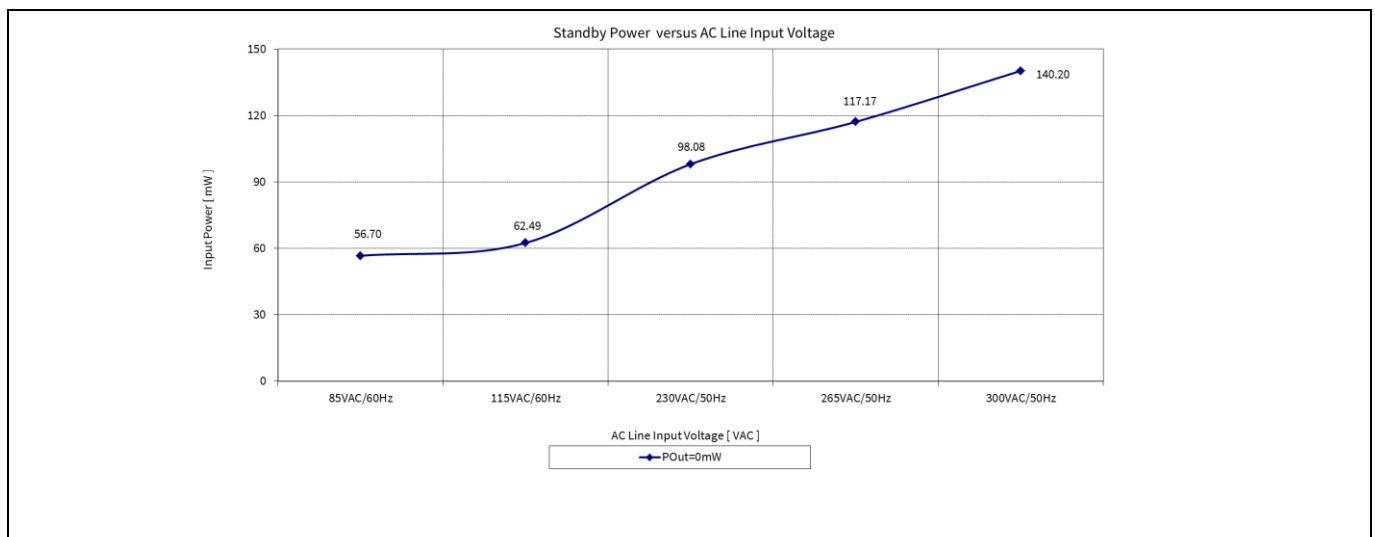


Figure 9 Standby power at no-load vs AC-line input voltage (measured by Yokogawa WT210 power meter – integration mode)

10.3 Line regulation



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

10.4 Load regulation

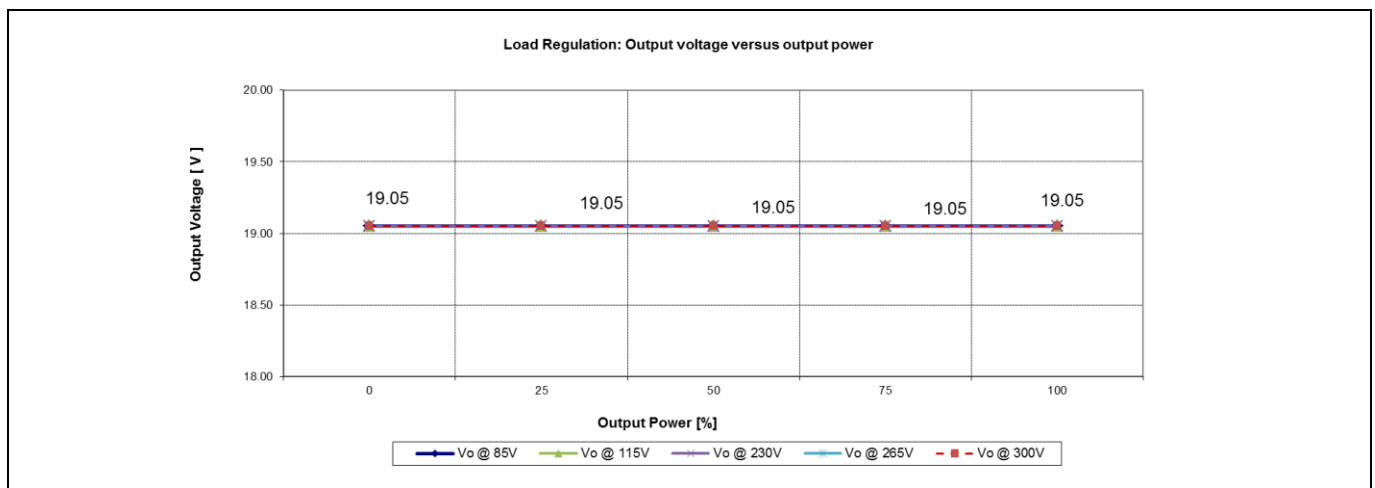


Figure 11 Load regulation V_{out} vs output power

10.5 Maximum input power

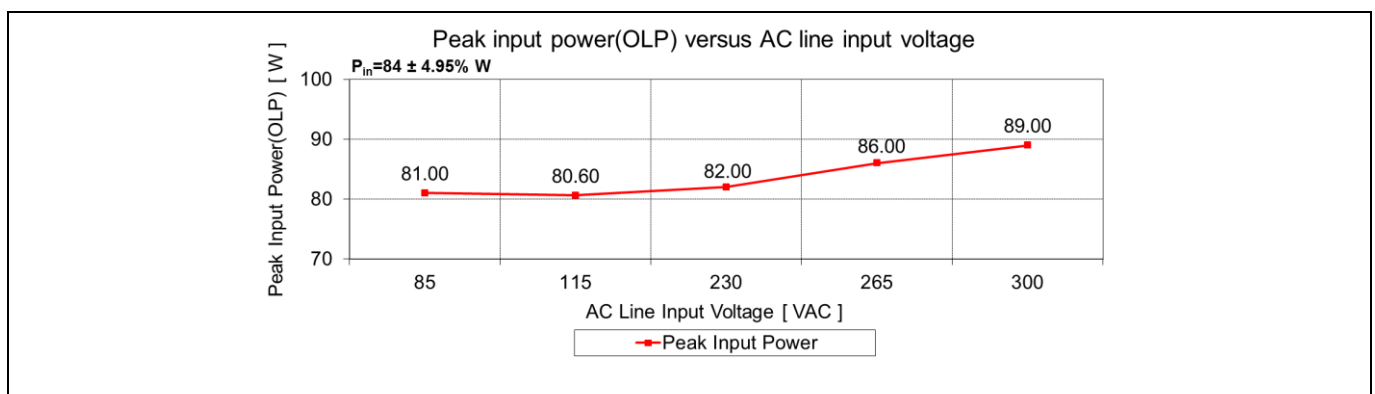


Figure 12 Maximum input power (before over-load protection) vs AC-line input voltage

Test results

10.6 ESD immunity (EN 61000-4-2)

Pass EN 61000-4-2 special level (± 10 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).¹

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 (60 W) with input voltage of 115 V AC and 230 V AC.

Pass conducted emissions EN 55022 (CISPR 22) class B with 7 dB margin for quasi peak measurement at low-line (115 V AC) and high-line (230 V AC).

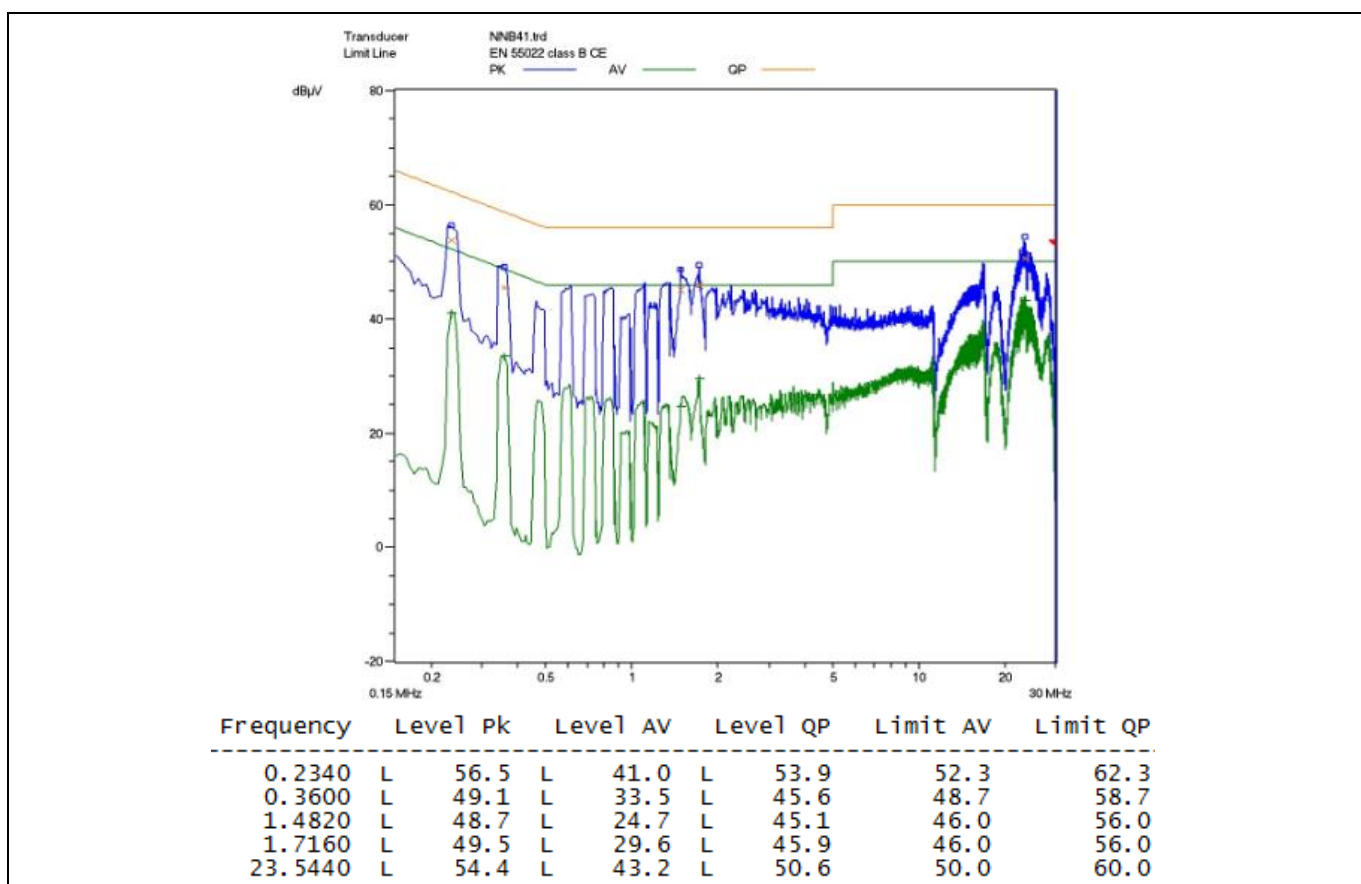


Figure 13 Conducted emissions (line) at 115 V AC and maximum load

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

Test results

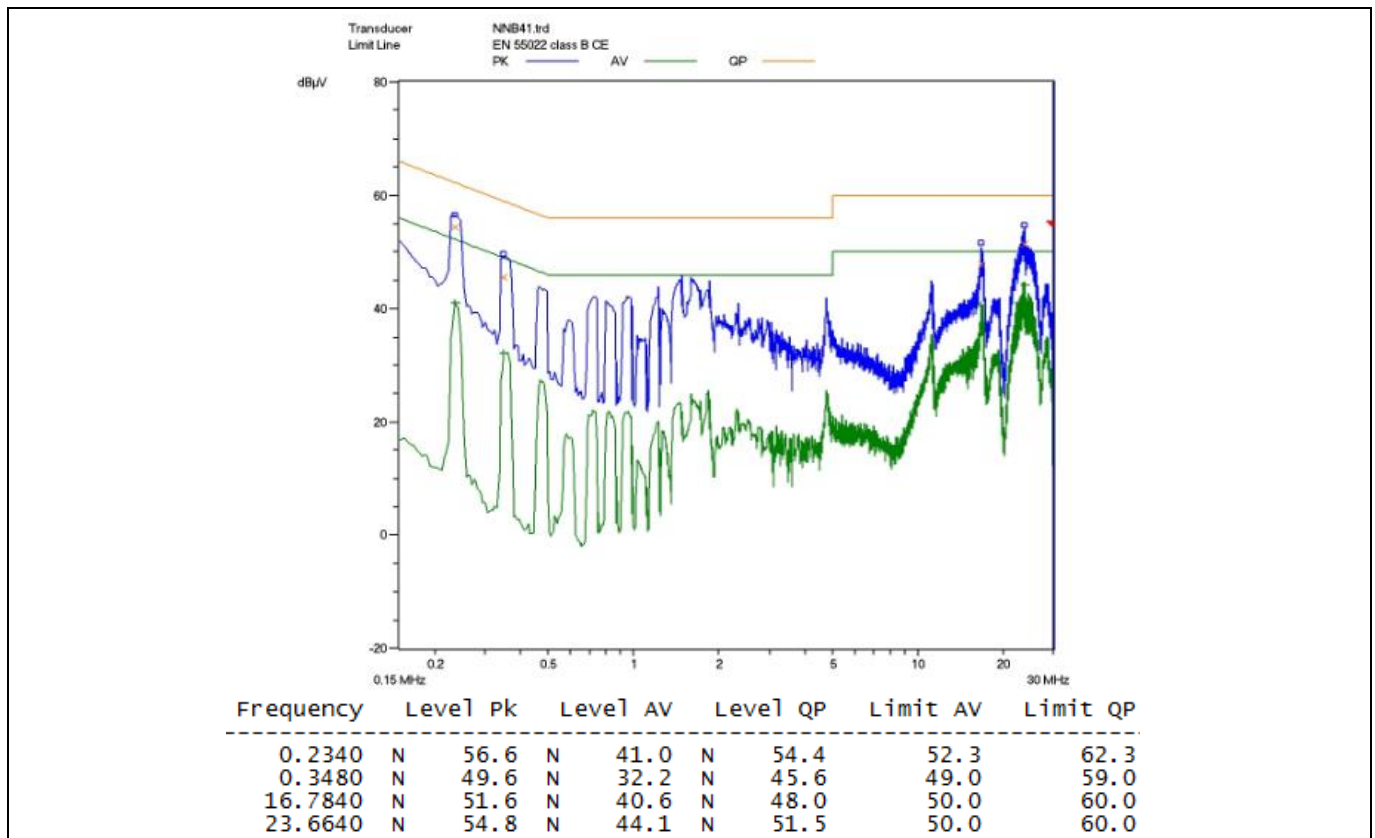


Figure 14 Conducted emissions (neutral) at 115 V AC and maximum load

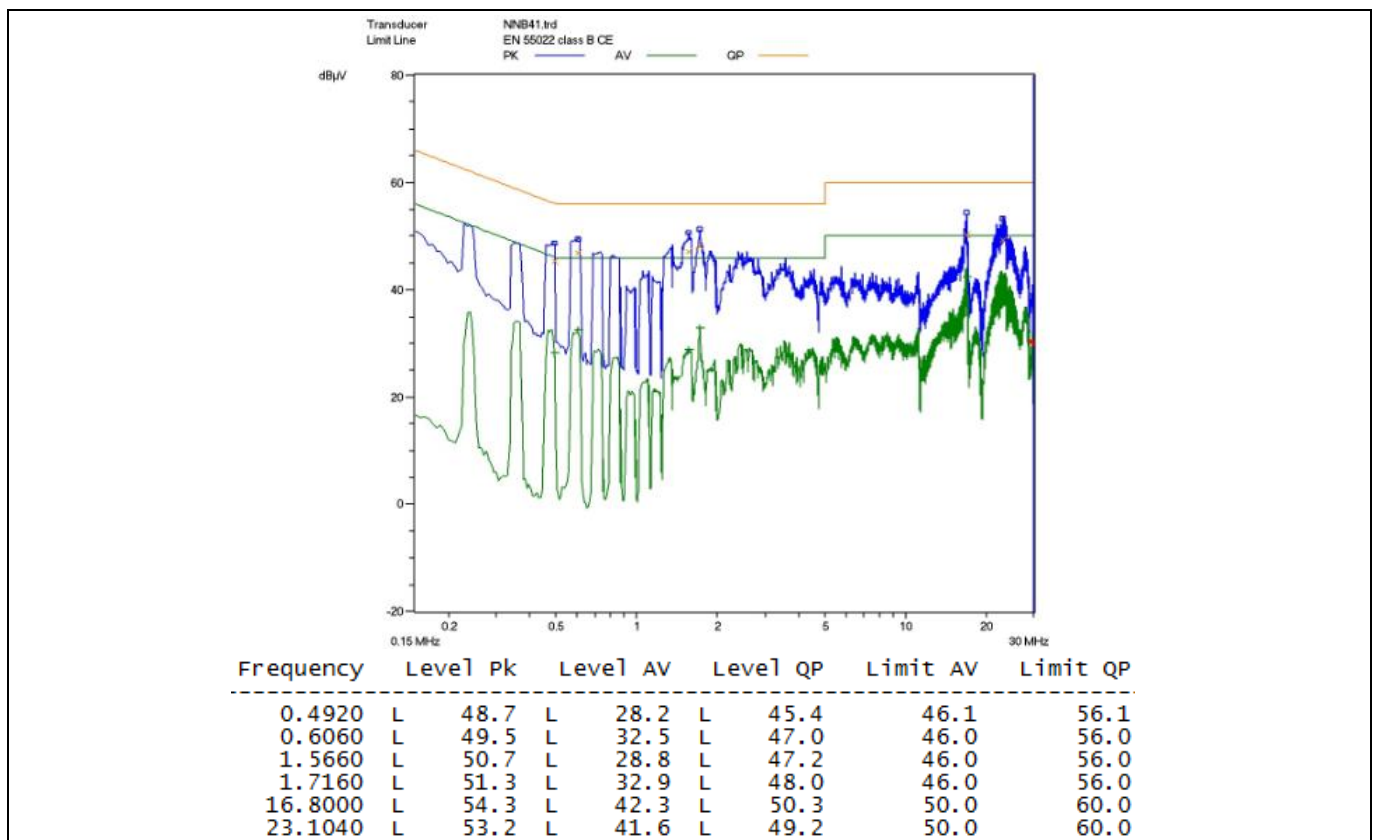


Figure 15 Conducted emissions (line) at 230 V AC and maximum load

Test results

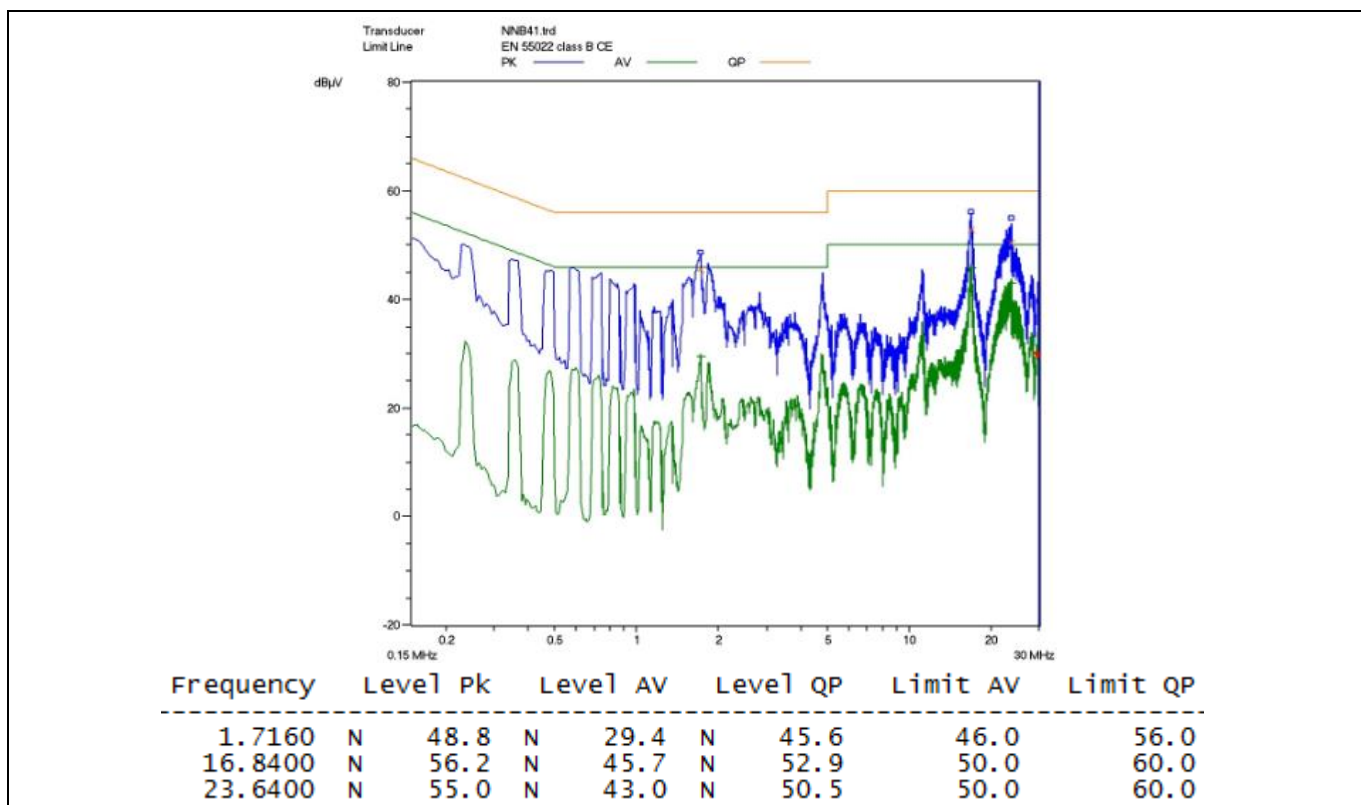


Figure 16 Conducted emissions (neutral) at 230 V AC and maximum load

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 (ICE5GSAG)	85.5	56.2
2	Q11 (IPA80R650CE)	58.9	60.5
3	R14A (CS resistor)	79.0	48.2
4	TR1 (transformer)	70.4	82.0
5	BR1 (bridge diode)	63.3	38.0
6	R11A (clammer resistor)	54.8	55.0
7	L11 (choke)	85.0	42.0
8	D21 (secondary diode)	61.8	60.6
9	Ambient	25.0	25.0

Test results

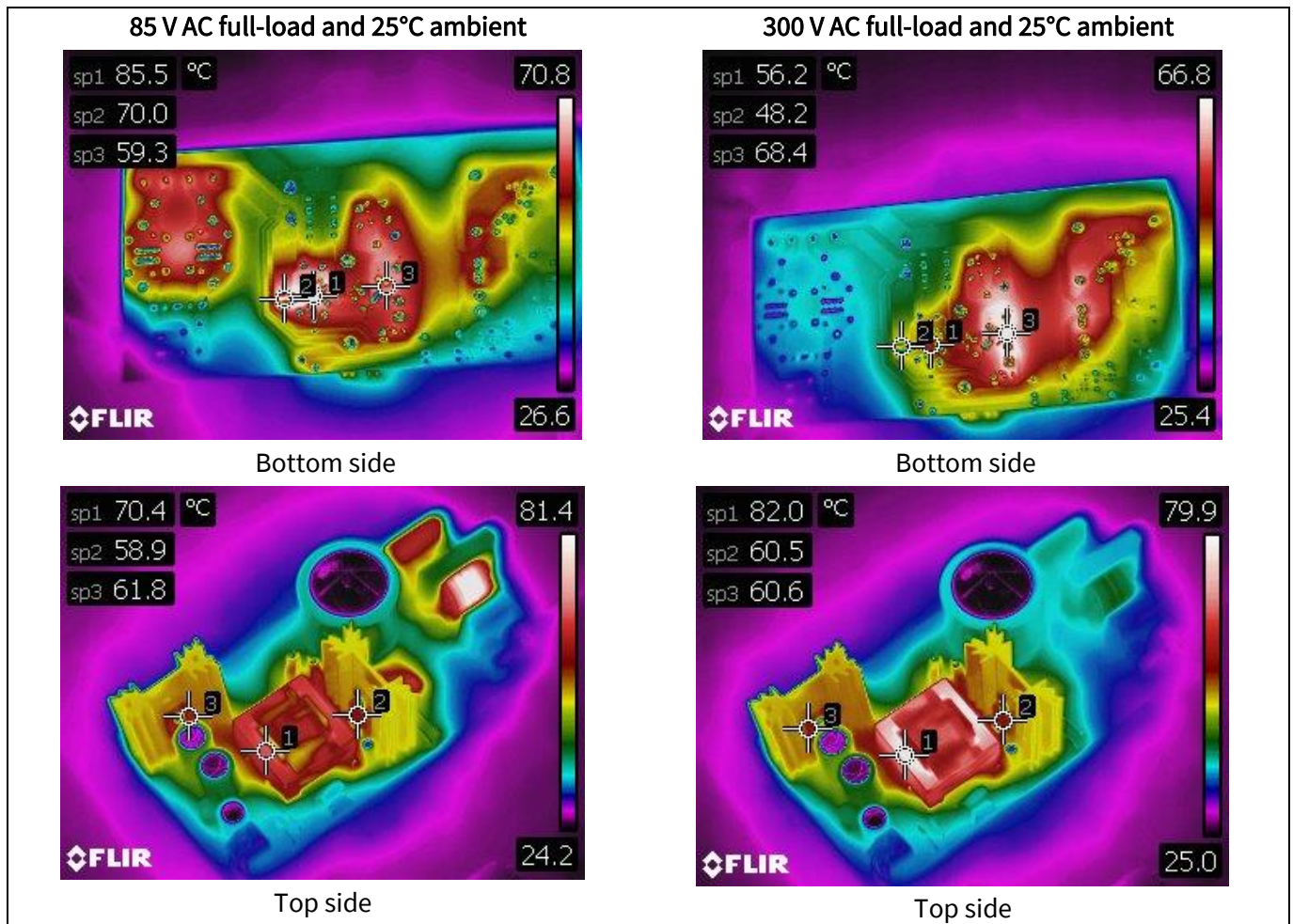


Figure 17 Infrared thermal image of DEMO_5GSAG_60W1

Waveforms and scope plots

11 Waveforms and scope plots

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

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

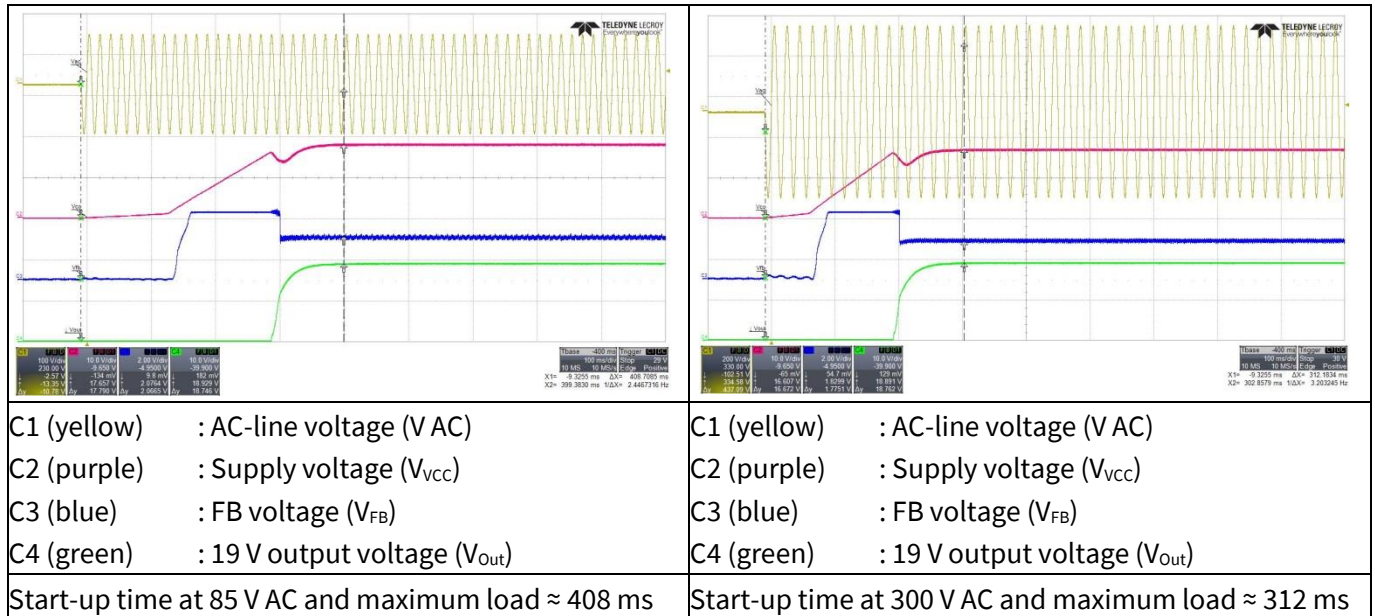


Figure 18 Start-up

11.2 Soft-start

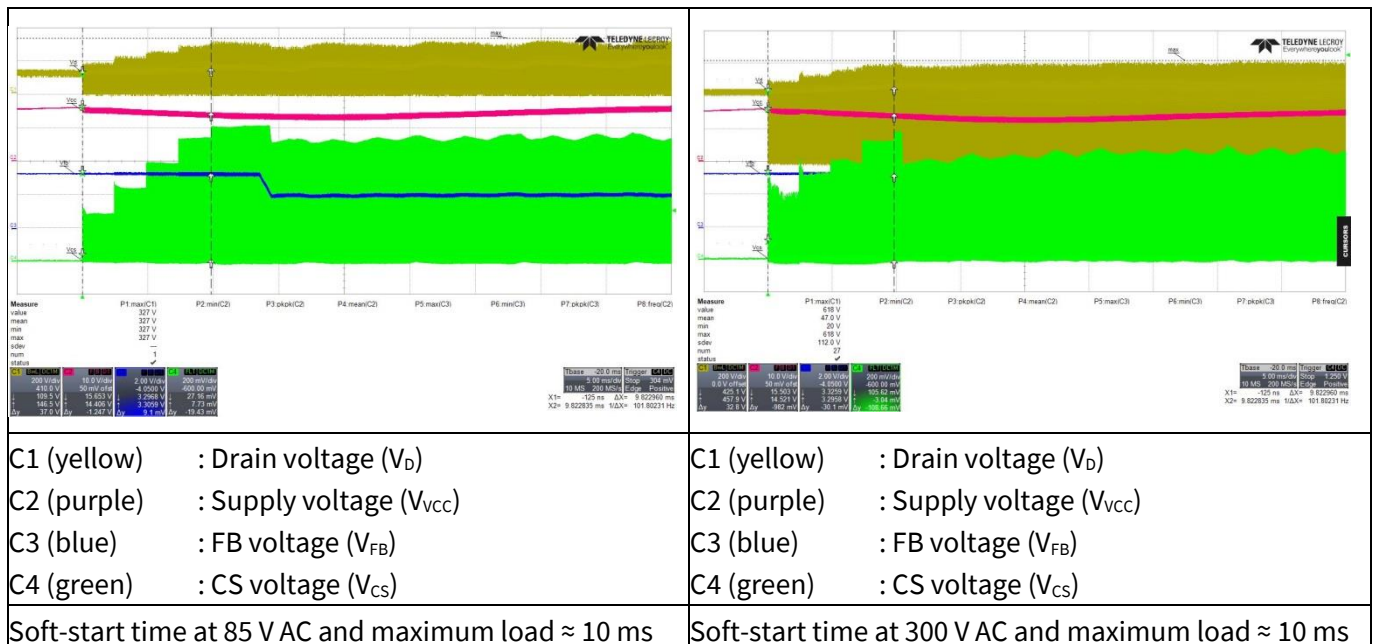


Figure 19 Soft-start

Waveforms and scope plots

11.3 Drain and CS voltage at maximum load

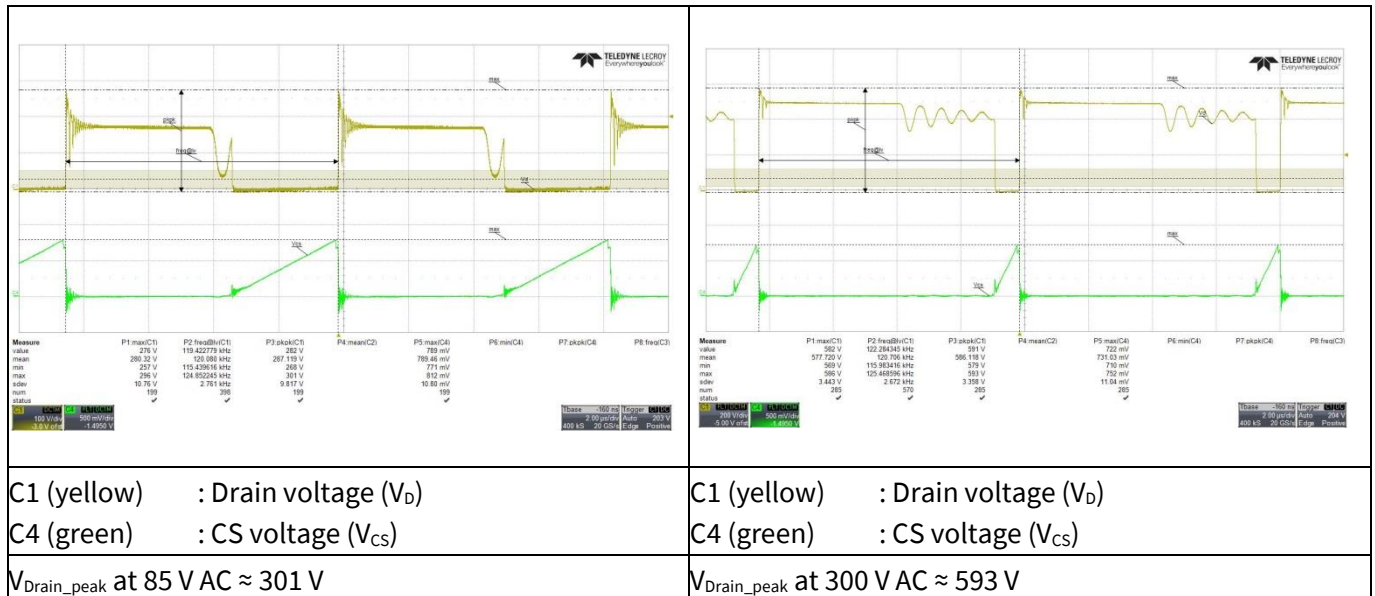


Figure 20 Drain and CS voltage at maximum load

11.4 Frequency jittering

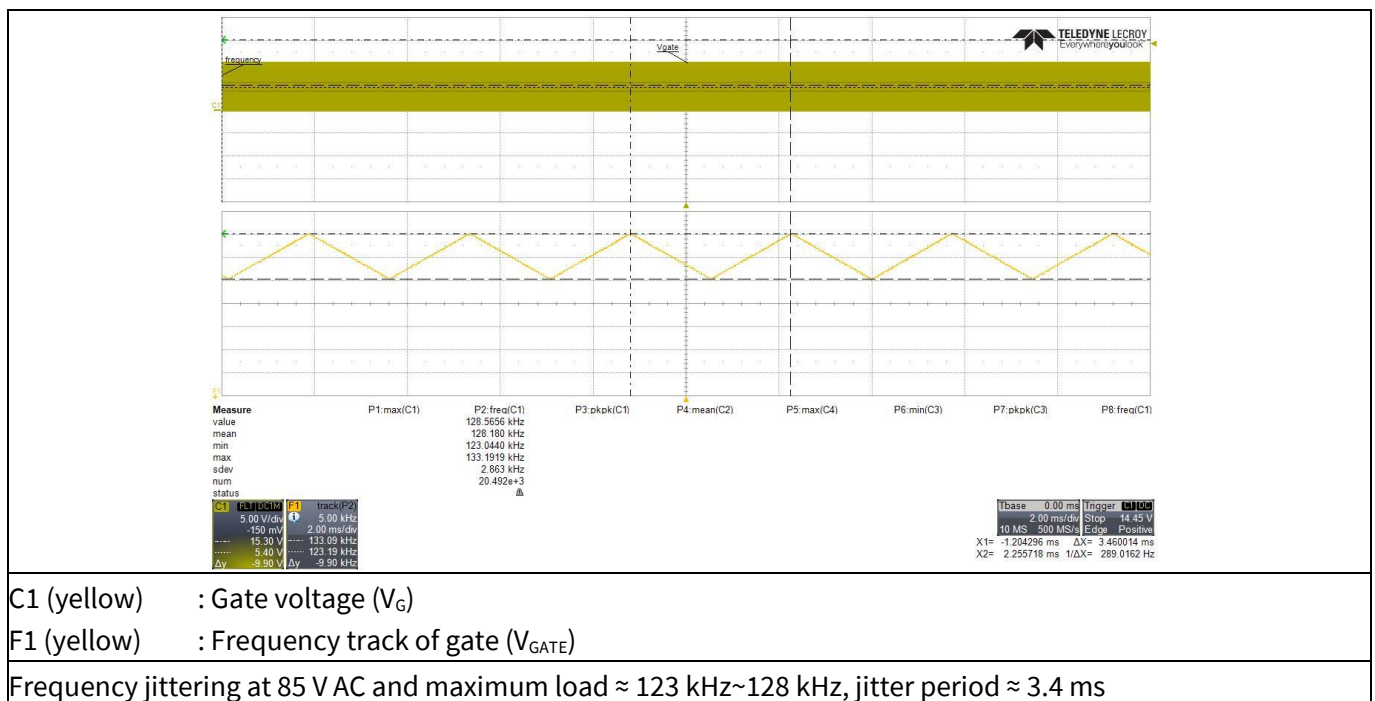


Figure 21 Frequency jittering

Waveforms and scope plots

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

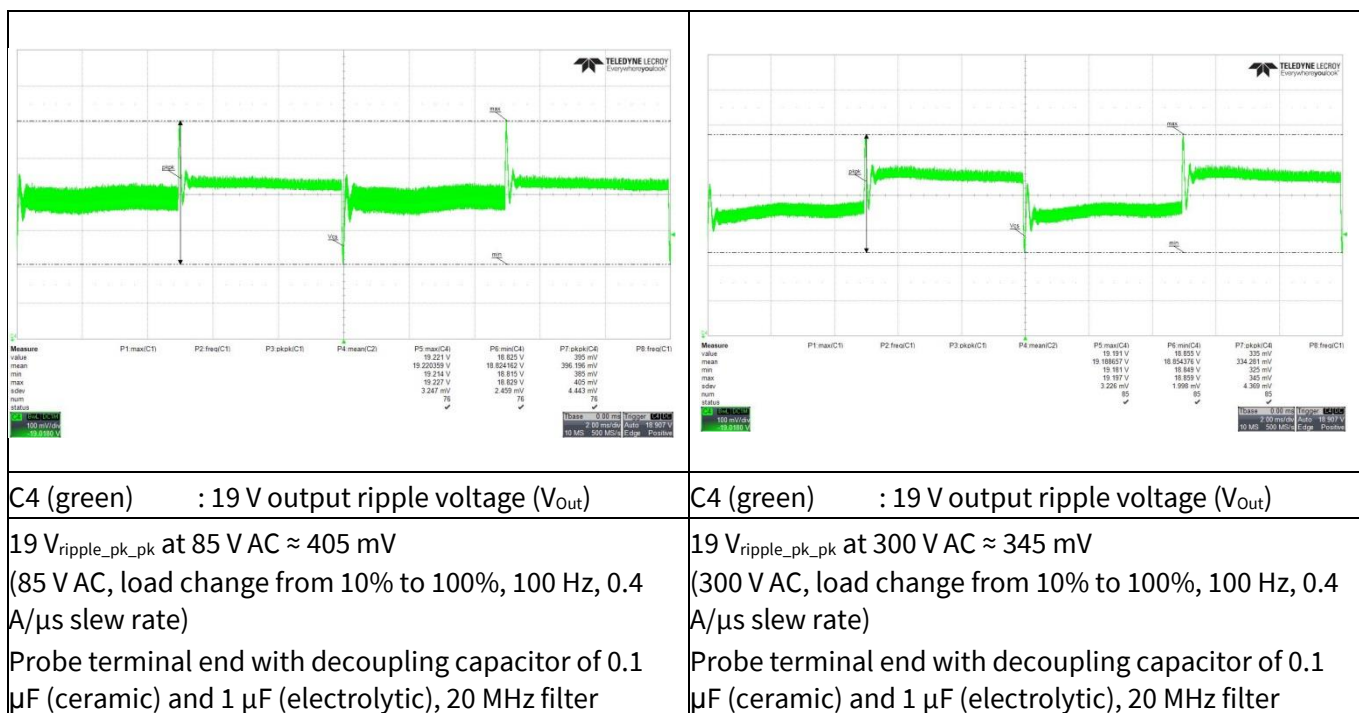


Figure 22 Load transient response

11.6 Output ripple voltage at maximum load

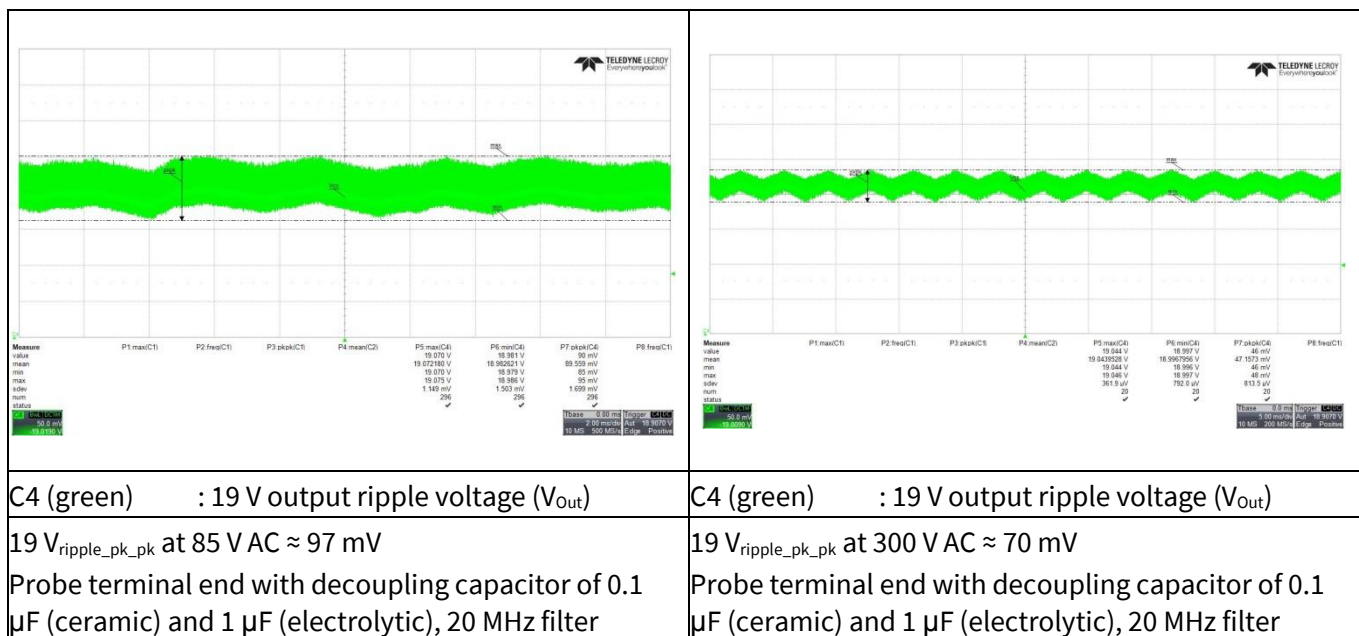


Figure 23 Output ripple voltage at maximum load

Waveforms and scope plots

11.7 Output ripple voltage at ABM 1 W load

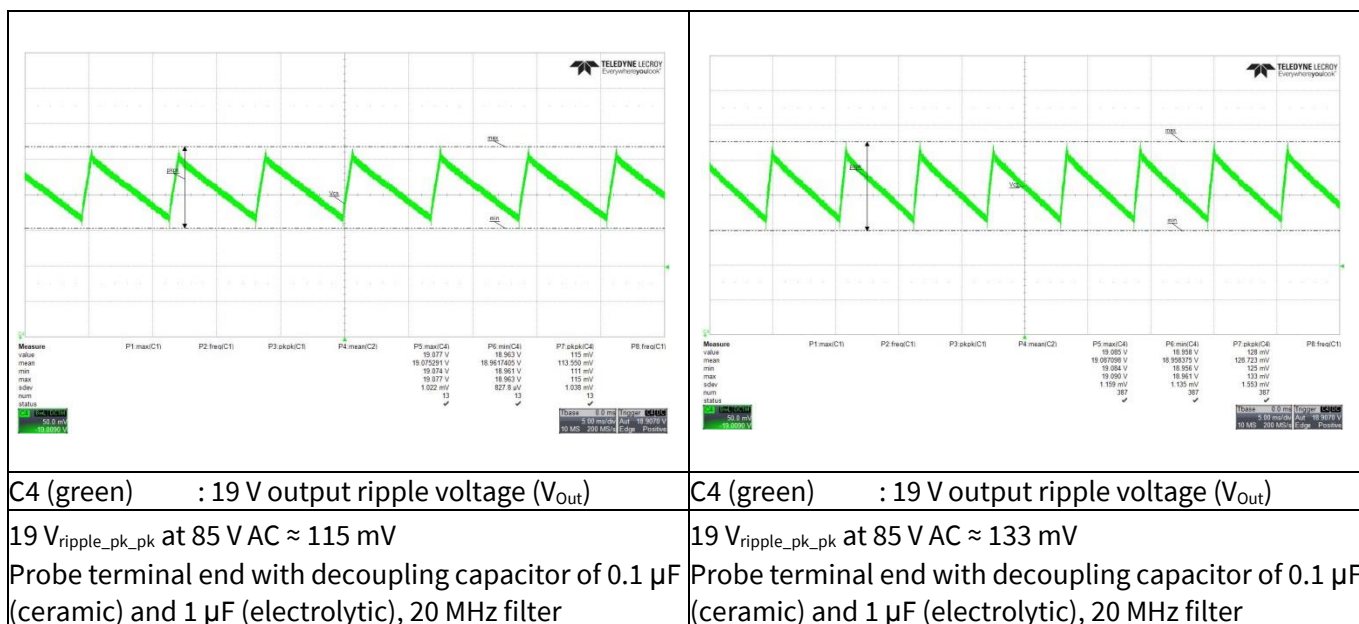


Figure 24 Output ripple voltage at burst mode 1 W load

11.8 Entering ABM

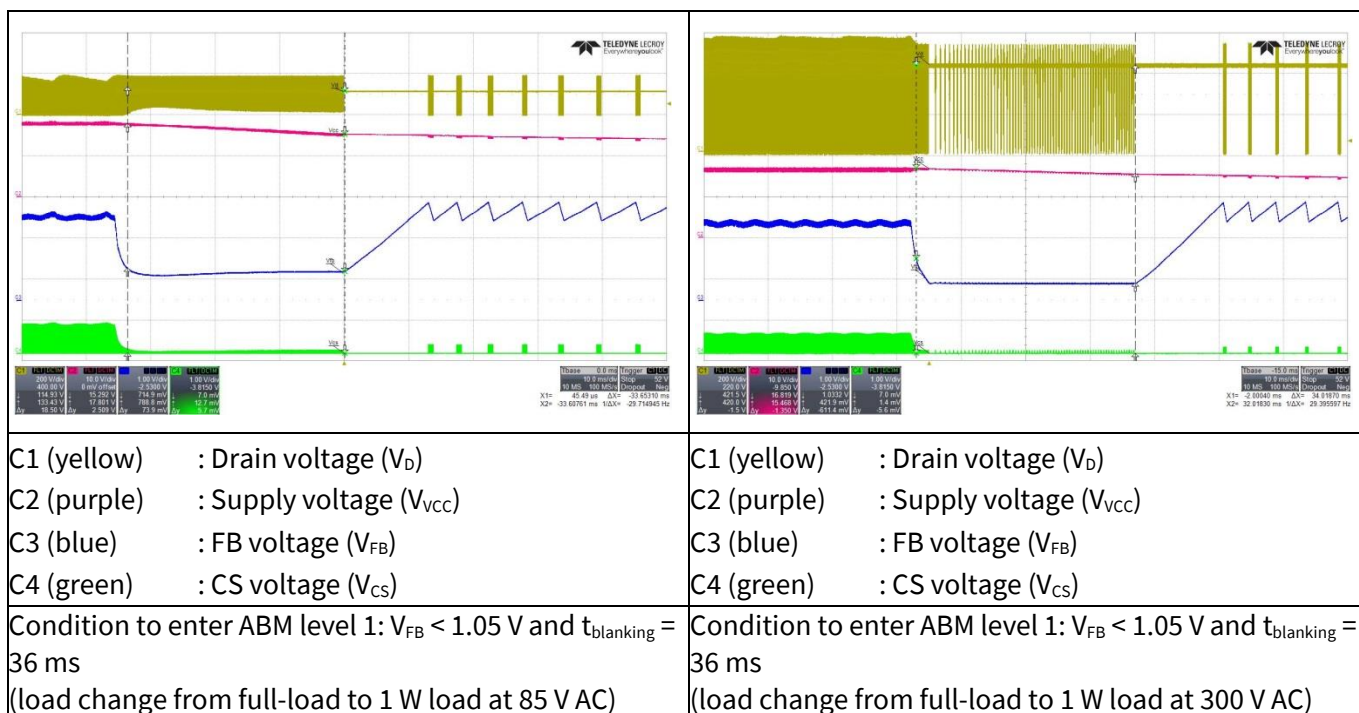


Figure 25 Entering ABM

Waveforms and scope plots

11.9 During ABM

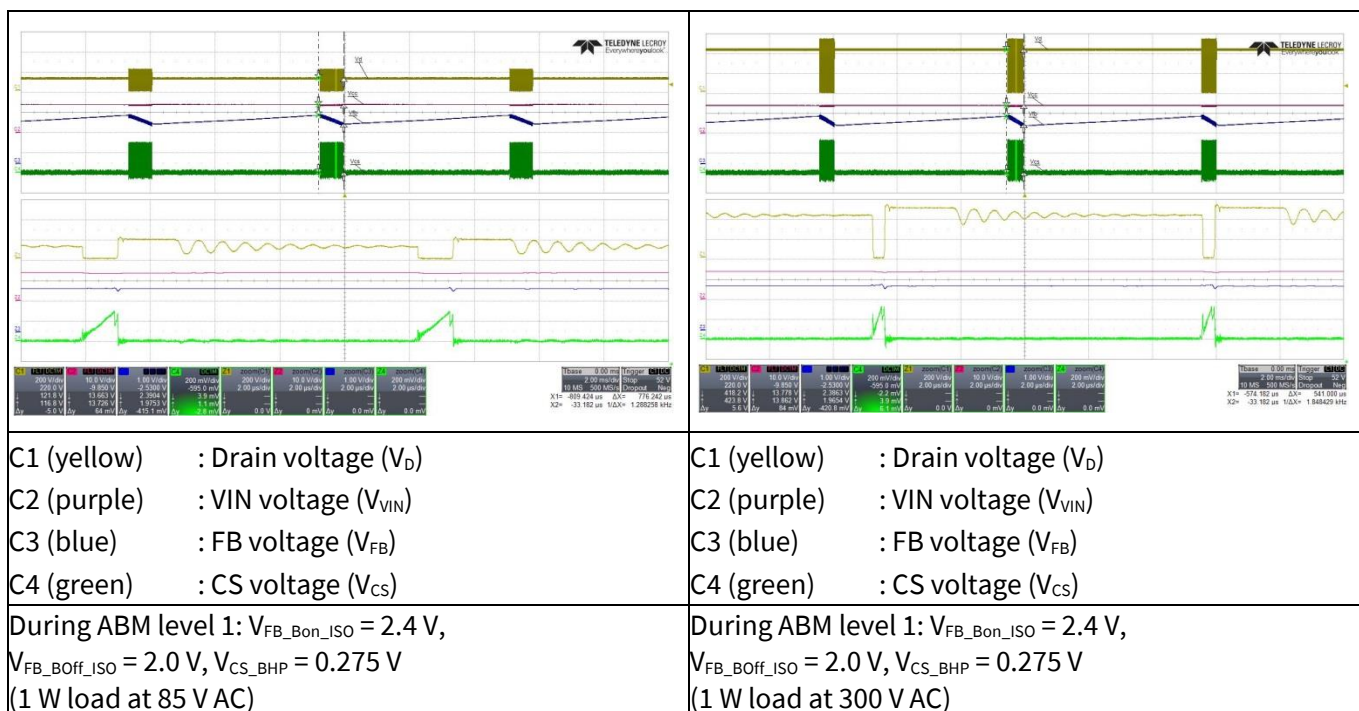


Figure 26 During ABM

11.10 Leaving ABM

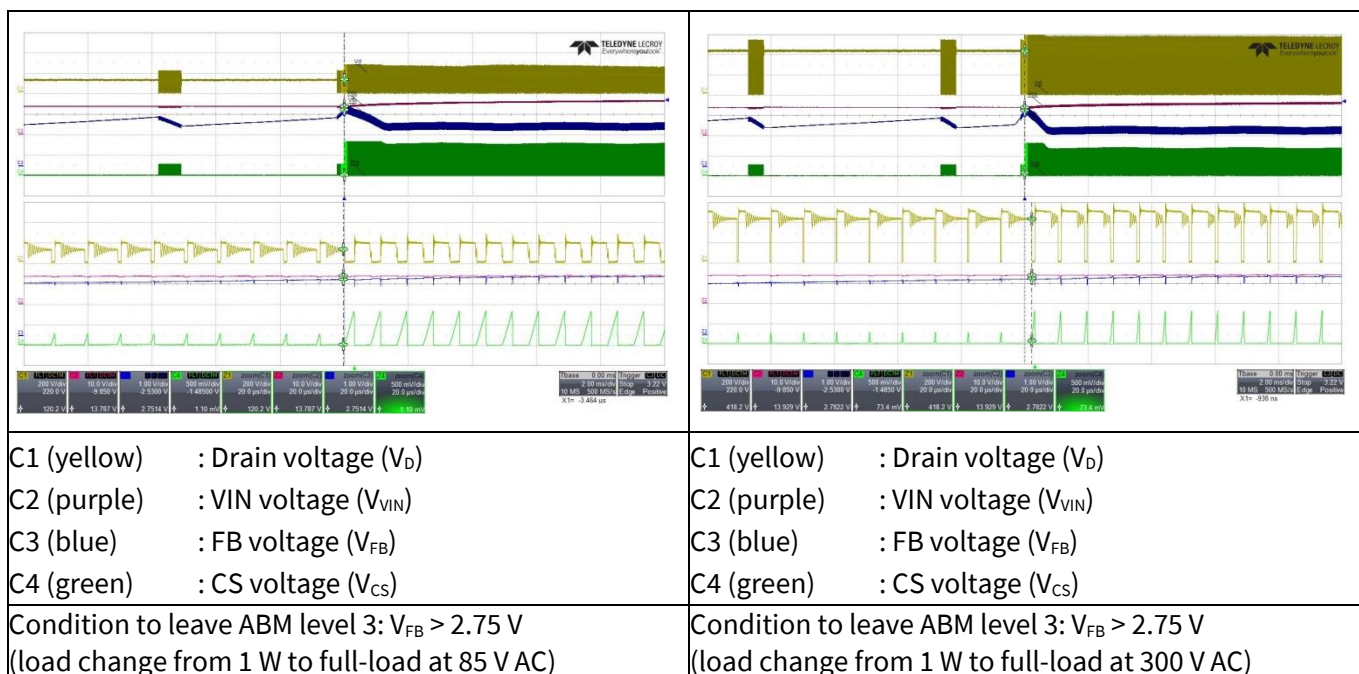


Figure 27 Leaving ABM

Waveforms and scope plots

11.11 Line OVP (non-switch auto restart)

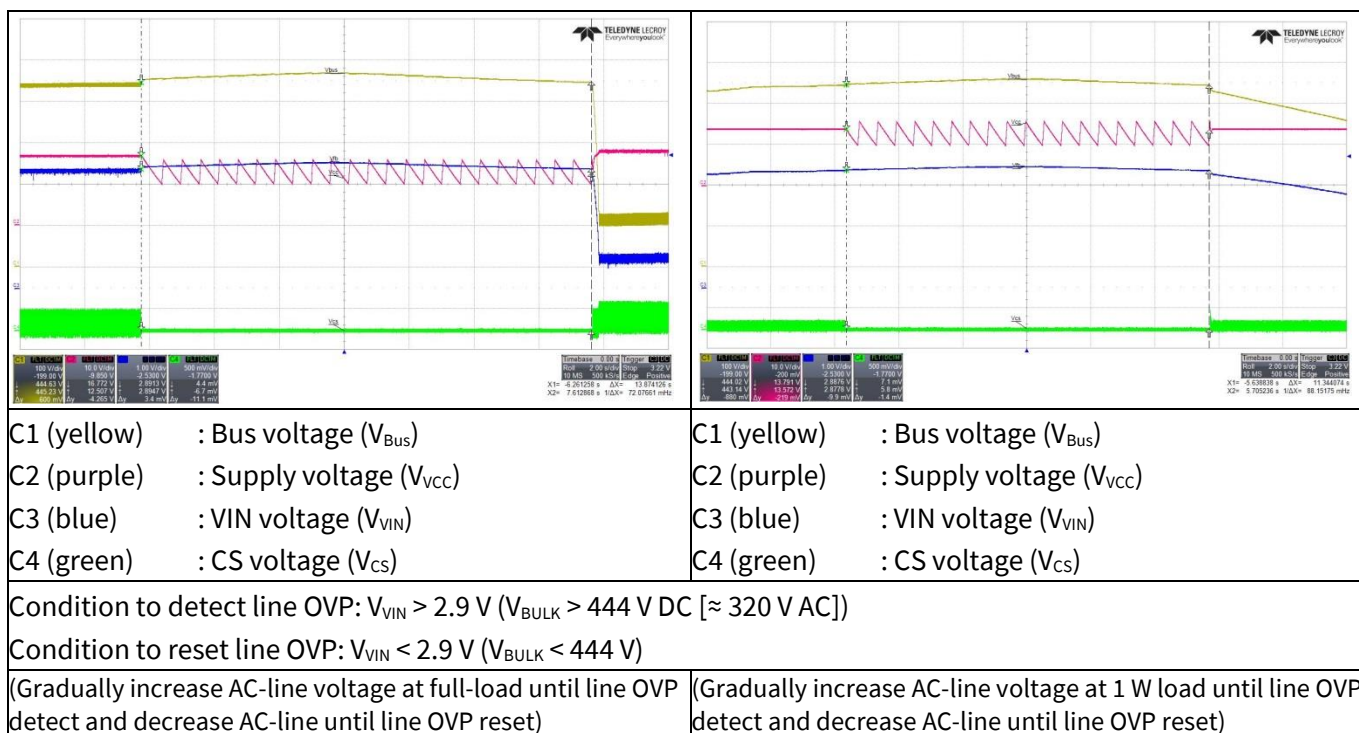
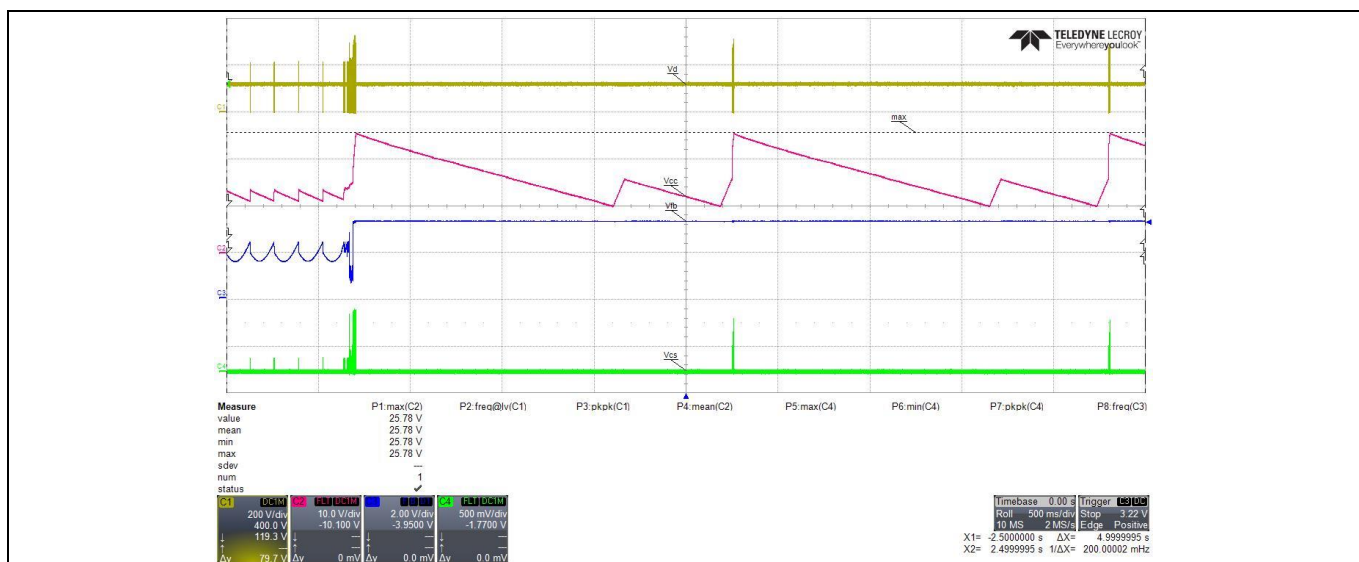


Figure 28 Line OVP

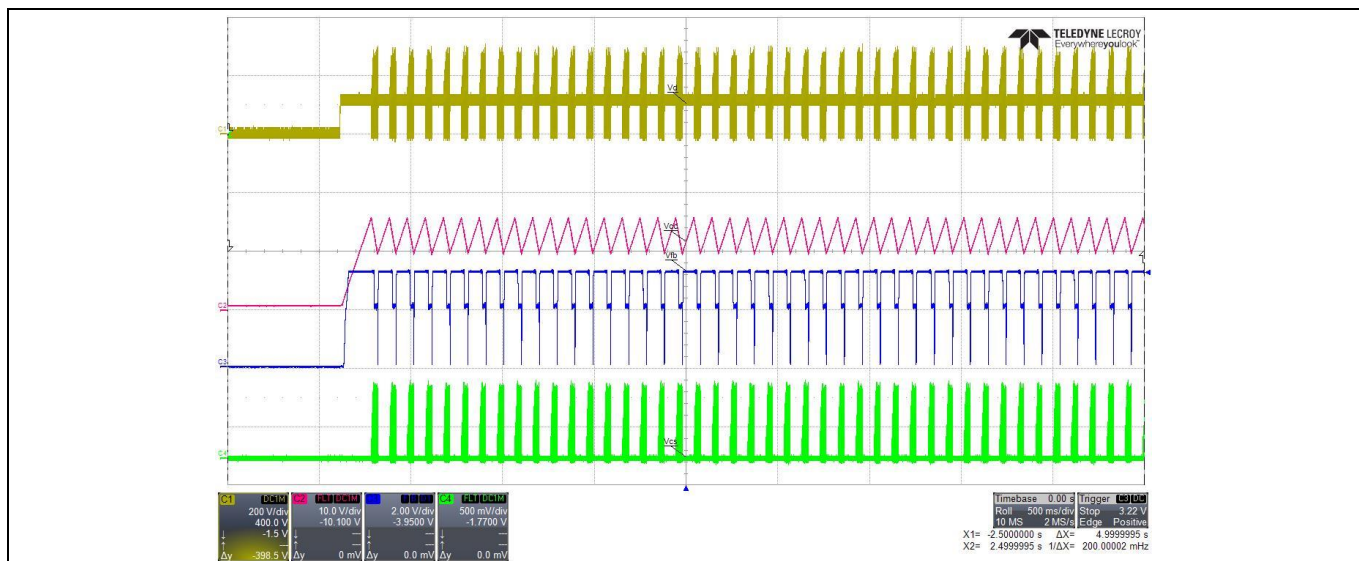
11.12 V_{CC} OVP (odd-skip auto restart)

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: $V_{VCC} > 25.5 \text{ V}$
 (short R16A while system operating at 85 V AC and no-load)

Figure 29 V_{CC} OVP

Waveforms and scope plots

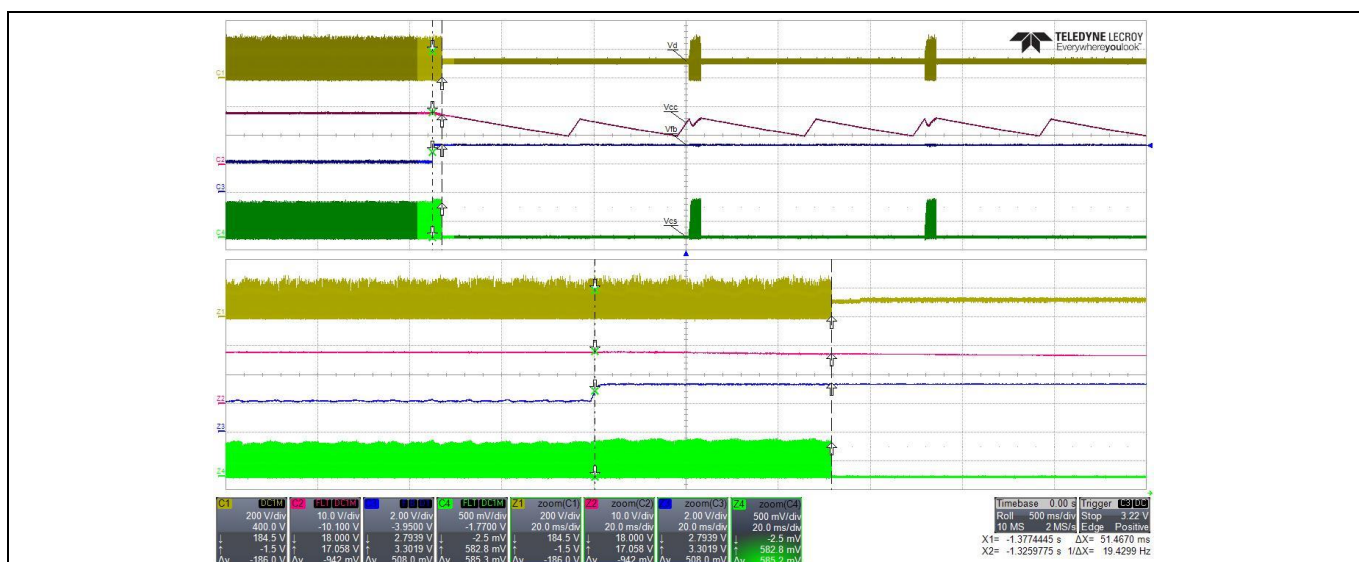
11.13 V_{CC} under-voltage protection (auto restart)

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

Condition to enter V_{CC} under-voltage protection: $V_{CC} < 10$ V
 (Remove R5 and power on the system with full-load at 85 V AC)

Figure 30 V_{CC} under voltage protection

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



- C1 (yellow) : Drain voltage (V_D)
 C2 (purple) : Supply voltage (V_{CC})
 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

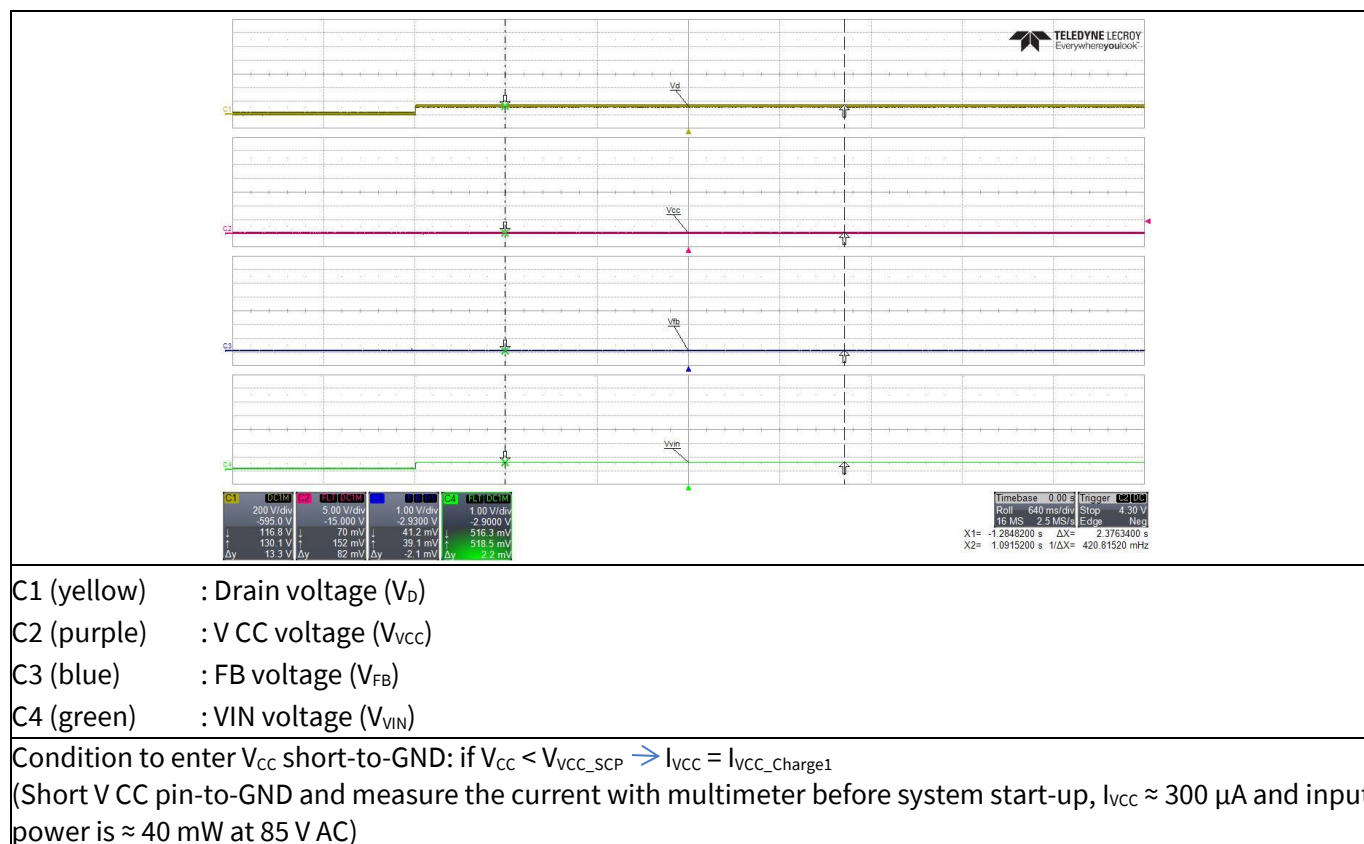


Figure 32 V_{CC} short-to-GND protection

References

12 References

- [1] ICE5GSAG datasheet, Infineon Technologies AG
- [2] 5th Generation fixed frequency design guide

Revision history

Major changes since the last revision

Page or reference	Description of change
--	First release.

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