85 W power supply using CoolSET™ SiP ICE189LM

EVAL_85W1_ZVS_189LM

About this document

Scope and purpose

This engineering report describes the EVAL_85W1_ZVS_189LM Evaluation Board for a flyback converter with an isolated 12 V, 7.08 A output using the latest Infineon CoolSET™ ICE189LM System in Package (SiP) zero-voltage switching (ZVS) flyback integrated solution with CoolSiC™ MOSFET. This 85 W evaluation board serves the purpose of understanding the technical features and capability of the CoolSET™ ICE189LM. For detailed features and power delivering capability, see the device datasheet [1].

Highlights of this power supply:

- Overall high efficiency to meet energy efficiency requirement
- Simplified circuitry with high-level integration of power control and protection features
- Auto-restart protection scheme to minimize interruption and enhance the user experience
- Zero-voltage switching (ZVS) technology to boost efficiency
- CoolSiC™ MOSFET to enable higher output power

Intended audience

This document is intended for power supply design, application engineers, or others who want to design efficient and reliable auxiliary power supplies.

CoolSET™

Infineon's CoolSET™ AC-DC integrated power stages in fixed frequency and quasi-resonant switching schemes offer increased robustness and outstanding performance. This family offers superior energy efficiency, comprehensive protective features, and reduced system costs and is ideally suited for auxiliary power supply applications in a wide variety of potential applications such as:

- SMPS
- Home appliances
- Server power supply units (PSU)
- Telecom

Table of contents

About this document **1**
Table of contents **2**
1 Introduction **3**
2 EVAL_85W1_ZVS_189LM Evaluation Board **4**
3 Power supply specifications **5**
4 Schematic **6**
5 Circuit description **7**
6 PCB layout **10**
6.1.1 Top-side layout 10
6.1.2 Bottom-side layout 10
7 Bill of materials **11**
8 Transformer specification **14**
8.1 Electrical diagram and coil structure 14
9 Test results **15**
9.1 Efficiency 15
9.2 Standby power 16
9.3 Line and load regulation 17
9.4 ESD immunity (EN 61000-4-2) 17
9.5 Surge immunity (EN 61000-4-5) 17
9.6 Conducted electromagnetic interference (EN 55022 Class B) 18
9.7 Thermal measurement 19
10 Waveforms and scope plots **20**
10.1 Startup with maximum load 20
10.2 Soft-start 20
10.3 Primary SiC MOSFET drain voltage and current at maximum load 21
10.4 SR MOSFET drain voltage at maximum load 21
10.5 Output ripple voltage at maximum load 22
10.6 Hysteretic mode operation 22
10.7 Overload protection (auto-restart) 23
10.8 Line OVP 23
10.9 Brown-in and brown-out 24
Design support **25**
References **26**
Revision history **27**
Disclaimer **28**

1 Introduction

This engineering report describes the EVAL_85W1_ZVS_189LM Evaluation Board designed in a zero-voltage switching (ZVS) quasi-resonant (QR) flyback converter using CoolSET™ ICE189LM System in Package (SiP) from Infineon's first fully integrated controller. The evaluation board provides 85 W output at 12 V and 7.08 A, with an input range of 90 VAC to 264 VAC. The evaluation board can achieve 94.1% peak efficiency.

The CoolSET™ SiP ICE189LM is ideally targeted for auxiliary power supplies for SMPS, home appliances, servers, and telecom applications. The SiP integration includes an 800 V CoolSiC™ MOSFET, primary and a secondary controller, and isolated communication. An advanced PWM switching pattern forces a zero-voltage switching (ZVS) quasi-resonant (QR) operation, reducing the turn-on switching losses and optimizing the EMI signature. A comprehensive set of protection features supports system reliability against fault conditions.

Table 1 lists the general system requirements for a power supply and the corresponding Infineon solution using ICE189LM.

Table 1 General system requirement and proposed design solution

	General system requirement	Proposed design solution – ICE189LM
1	High efficiency to meet energy-efficiency requirements	Primary zero-voltage switching and secondary optimal synchronous rectifier (SR) control
2	Simplified circuitry with high-level integration	Primary 800 V CoolSiC™ MOSFET, primary and secondary controller, and communication integrated in a DSO-27 package
3	Minimize interruption to enhance user experience	All protections are defined to enter auto-restart mode

2 EVAL_85W1_ZVS_189LM Evaluation Board

This document provides the complete design details including power supply specification, schematics, bill of materials (BOM), PCB layout, transformer specification, and performance data.

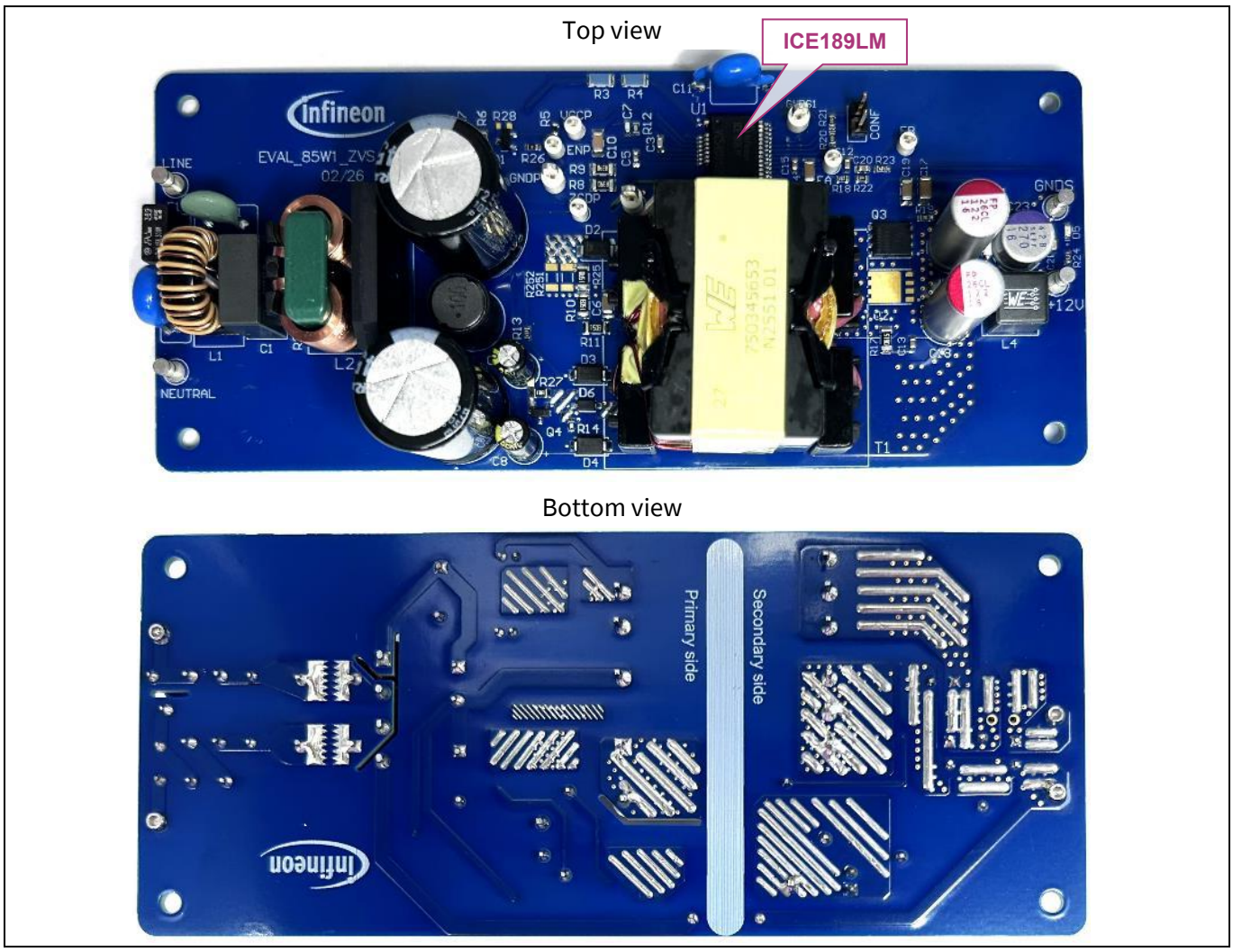


Figure 1 EVAL_85W1_ZVS_189LM Evaluation Board

3 Power supply specifications

The following table represents the minimum acceptance performance of the design. The actual performance is listed in the measurement data and graphs section.

Table 2 Specifications of EVAL_85W1_ZVS_189LM

Parameter	Symbol	Min.	Typ.	Max.	Unit	Conditions/notes
Input						
Voltage	V_{IN}	90	–	264	VAC	2-wire (no P.E.)
Frequency	f_{LINE}	47	50/60	64	Hz	–
Line overvoltage	V_{IN_OVP}	–	298	–	VAC	–
Output						
Voltage	V_{OUT}	–	12	–	V	–
Output current	I_{OUT}	–	7.08	–	A	–
Output voltage ripple	V_{ripple}	–	–	240	mV	–
Overcurrent protection	I_{OCP}	–	–	8.6	A	–
Total output power	P_{OUT}	–	85	–	W	–
Efficiency						
Maximum load efficiency	η	–	93.8	–	%	Measured at 230 VAC
EMC						
Conducted EMI	–	6	–	–	dB	EN55022 Class B
ESD – contact discharge	–	±8	–	–	kV	EN 61000-4-2
ESD – air discharge	–	±15	–	–	kV	
Surge immunity – differential mode	–	±2	–	–	kV	EN61000-4-5
Surge immunity – common mode	–	±4	–	–	kV	
PCB size	–	–	140 × 60	–	mm	L × W
Ambient temperature	T_a	–20	–	50	°C	Convection cooling

Note: The table above represents the minimum acceptable performance of the design. Actual measurement results are listed in the Test results section.

4 Schematic

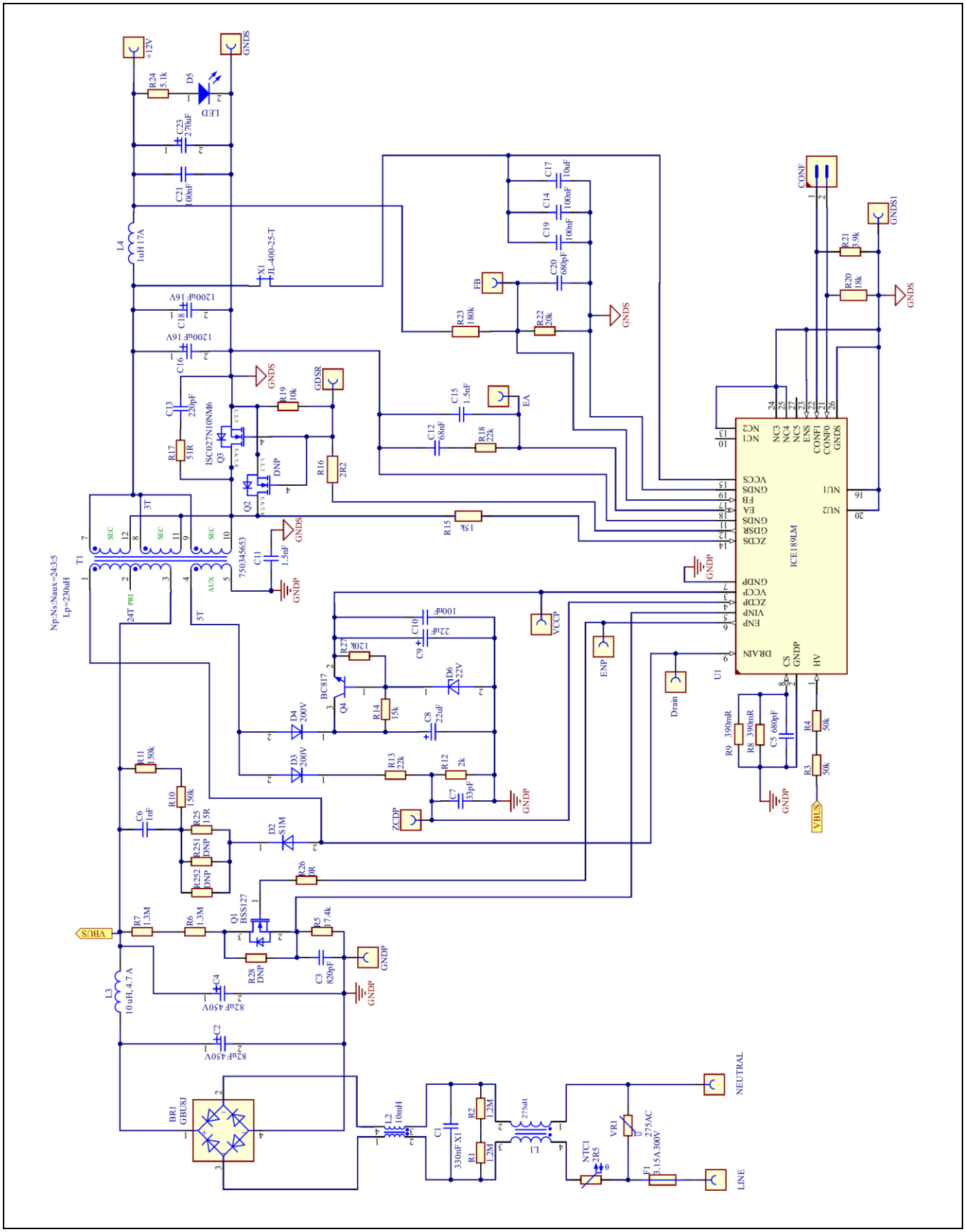


Figure 2 Schematic of EVAL_85W1_ZVS_189LM

5 Circuit description

This section briefly describes the reference design circuit by different functional blocks. For details of the design procedure and component selection for the flyback circuitry, see the IC datasheet [1] and design guide [2].

5.1 EMI filtering and line rectification

The input of the power supply is taken from the AC power grid, which is in the 90 VAC ~ 264 VAC range. The fuse (F1) is right at the entrance to protect the system in case of excess current entering the system circuit due to a fault. Following is the varistor (VR1), which is connected across L and N to absorb the line surge transient.

Common mode choke L1, L2, and the X-capacitor C1 form a basic filter to reduce the EMI noise. The bridge rectifier (BR1) rectifies the AC input into DC voltage, filtered by the π filter (C2, C4, and L3). R1 and R2 resistors discharge C1 when the power supply is disconnected from the AC mains. NTC1 is used to suppress the inrush current when the AC is connected to the board.

5.2 CoolSET™ SiP power stage

The flyback converter power stage consists of a power transformer, primary SiC power MOSFET, secondary synchronous rectifier (SR) MOSFET, secondary output capacitors, and so on.

Primary and secondary sides, power management are separated for isolated power supply domains (VCCP, GNDP, and VCCS, GNDS). ICE189LM provides reinforced isolation and safe communication between primary and secondary sides.

5.2.1 CoolSET™ SiP primary side

The CoolSET™ ICE189LM SiP integrates a 950 V startup cell at the primary side. The IC self-starts through the startup resistors (R3 and R4) in series with this startup cell to charge the VCCP pin capacitors (C9, C10) when DC supply is applied. These startup resistors, together with ZCDP pin external configuration resistor R_{ZCDPL} (R12), determine the brown-in and brown-out protection, as shown in Table 3.

Table 3 Primary-side configuration options

Option	$R_{ZCDPL(min)}$; $R_{ZCDPL(max)}$	Brown-in current threshold I_{HV_BI}	Brown-out current threshold I_{HV_BO}	Internal shunt resistor $R_{HVshunt}$
1	[1.00 kΩ; 1.05 kΩ]	2.00 mA	1.40 mA	0.5 kΩ
2	[1.87 kΩ; 2.70 kΩ]	1.00 mA	0.70 mA	1.0 kΩ
3	[4.30 kΩ; 5.00 kΩ]	0.67 mA	0.47 mA	1.5 kΩ
4	[9.20 kΩ; 9.50 kΩ]	0.50 mA	0.35 mA	2.0 kΩ

Option 2 is selected with R_{ZCDPL} (R12) = 2 kΩ, the brown-in voltage can be estimated as:

$$V_{BI} = (R_{HV} + R_{HVshunt}) \times I_{HV_BI} = (100\ \text{k}\Omega + 1\ \text{k}\Omega) \times 1\ mA = 101\ V$$

Equation 1

And the brown-out voltage can be estimated as:

$$V_{BO} = (R_{HV} + R_{HVshunt}) \times I_{HV_BO} = (100\ \text{k}\Omega + 1\ \text{k}\Omega) \times 0.7\ mA = 70.7\ V$$

Equation 2

Moreover, R12 and R13 resistors offer zero-crossing detection during the soft-start period and primary-sensed output overvoltage protection.

$$V_{OUT_OVP} = \left(\frac{(R_{ZCDPH}+R_{ZCDPL})\times V_{ZCDP_OVP_min}}{R_{ZCDPL}} + V_{Daux)}\right) \times \frac{N_{SEC}}{N_{AUX}} - V_{Dsec}$$
$$= \left(\frac{(22\ k\Omega + 2\ k\Omega) \times 2.05\ V}{2\ k\Omega} + 0.3V\right) \times \frac{3}{5} - 0.1V \approx 14.84\ V$$

Equation 3

Where,

N_{SEC}: Number of secondary turns

N_{AUX}: Number of auxiliary turns

V_{Daux}: Diode forward voltage drop at auxiliary winding

V_{Dsec}: Voltage drop across SR MOSFET

$V_{ZCDP_OVP_min}$: Minimum voltage of the output overvoltage threshold

V_{OUT_OVP}: User-defined output overvoltage level

C7 is chosen to adjust the delay time, which starts when the drain-source voltage falls below the bus voltage until the ZCDP voltage falls to $V_{ZCDPthr}$ (100 mV, Typ.). Therefore, the power switch can be turned on at the valley point of the drain-source voltage.

A total 44 µF capacitor for C8, C9 are applied to ensure stable system operation and enough break time for auto-restart protection. The VCCP linear regulator (R14, R27, D6, and Q4) is placed to avoid the VCCP voltage exceeding the pin voltage rating (32 V) in case of severe voltage spike coupling from the transformer during the surge test.

DC line overvoltage protection is detected by sensing the bus capacitor voltage through the VINP pin via the divider resistor R5. Once the VINP pin voltage is higher than the line overvoltage threshold V_{VINP_LOVP}, the controller enters the line overvoltage protection and releases the protection mode when the VINP pin voltage falls below V_{VINP_LOVP}.

A typical LOVP voltage is calculated as follows:

$$V_{BUS_OVP} = V_{VINP_LOVP} \times \frac{R5+R6+R7}{R5} = 2.80\ V \times \frac{1.3\text{M}\Omega+1.3\text{M}\Omega+17.4\ \text{k}\Omega}{17.4k\Omega} = 421\ V$$

Equation 4

The primary overcurrent protection is sensed by the R8 and R9 resistor through the CS pin. The V_{CSOCP1} is 0.76 V and V_{CSOCP2} is 1.1 V. The R8 and R9 are selected to ensure the system during normal operation will not enter the premature overcurrent protection.

A low-cost RCD clamp consisting of the D2 diode, R25, R251, R252 resistor, and the C6 capacitor is implemented to suppress the peak drain voltage when turning off the power switch inside ICE189LM. This passive snubber helps dissipate the energy stored in the transformer leakage inductance.

5.2.2 CoolSET™ SiP secondary side

The secondary side of CoolSET™ ICE189LM SiP starts to take over the PWM control when the output voltage reaches 95% of its regulation target. The ICE189LM PWM control is based on sensing the reflected voltage from the primary side via the ZCDS pin and the error amplifier (EA) output voltage. ICE189LM integrated PWM and SR control ensures that the timing of the SR power switch (Q2 and Q3) and the primary-side power switch is well synchronized, which avoids the cross conduction of the two switches and provides reliable synchronous rectification. In addition, the current injection function via the SR power switch (Q2 and Q3) enables zero-voltage switching operation on the primary side.

R20 is connected to CONF0 and serves as R_{SET0}. The value of R20 is determined by the transformer turns ratio, which is a critical parameter in the design. According to Table 4, the transformer turns ratio is specified as 8. Based on this value, R20 is set as 18 kΩ.

Table 4 Resistance for R_{SET0}

Turns ratio N_{MAIN}/N_{SEC}	R_{SET0}
5	3.9 kΩ
6	6.8 kΩ
7	12.0 kΩ
8	18.0 kΩ
9	27.0 kΩ
10	39.0 kΩ

R21 is connected to CONF1 and acts as R_{SET1}, defining the parameters for Hysteretic-mode operation. Choose options between 1 to 3 to finetune the amount of loading for which system stays in Hysteretic mode. For this board, 3.9 kΩ (option 1 in Table 5) is chosen to keep the smallest power range operating in Hysteretic mode. For details, see the design guide [2].

Table 5 Resistance for R_{SET1}

Symbol / Parameter	Option	1	2	3	4	5	6
	R_{SET1}	3.9 kΩ	6.8 kΩ	12.0 kΩ	18.0 kΩ	27.0 kΩ	39.0 kΩ
EA voltage for wakeup in Hysteretic mode	V_{EA_HMOn}	1.25 V	1.20 V	1.10 V	1.25 V	1.20 V	1.10 V
EA voltage for off-phase in Hysteretic mode	V_{EA_HMOff}	0.95 V	0.9 V	0.8 V	0.95 V	0.9 V	0.8 V
EA voltage Hysteretic mode exit threshold	V_{EA_LHM}	1.4 V	1.4 V	1.4 V	1.6 V	1.6 V	1.6 V

The output voltage feedback is through the sense resistors R22 and R23 to the FB pin. The FB reference voltage is 1.2 V. A compensation network consisting of C12, C15, and R18 is implemented to stabilize the output voltage regulation. This network is carefully designed to ensure that the power supply's output voltage remains stable and within the desired range. For a detailed understanding of the compensation network's calculation, see the design guide [2].

To minimize output voltage ripple, the choice of output capacitors is crucial. The output capacitors C16, C18 are recommended to have low equivalent series resistance (ESR) type capacitor. A low pass filter L4 and C23 are added to further filter the output ripple. And a ceramic capacitor C21 is added to suppress the high frequency noise.

6 PCB layout

This section provides 85 W PCB layout.

6.1.1 Top-side layout

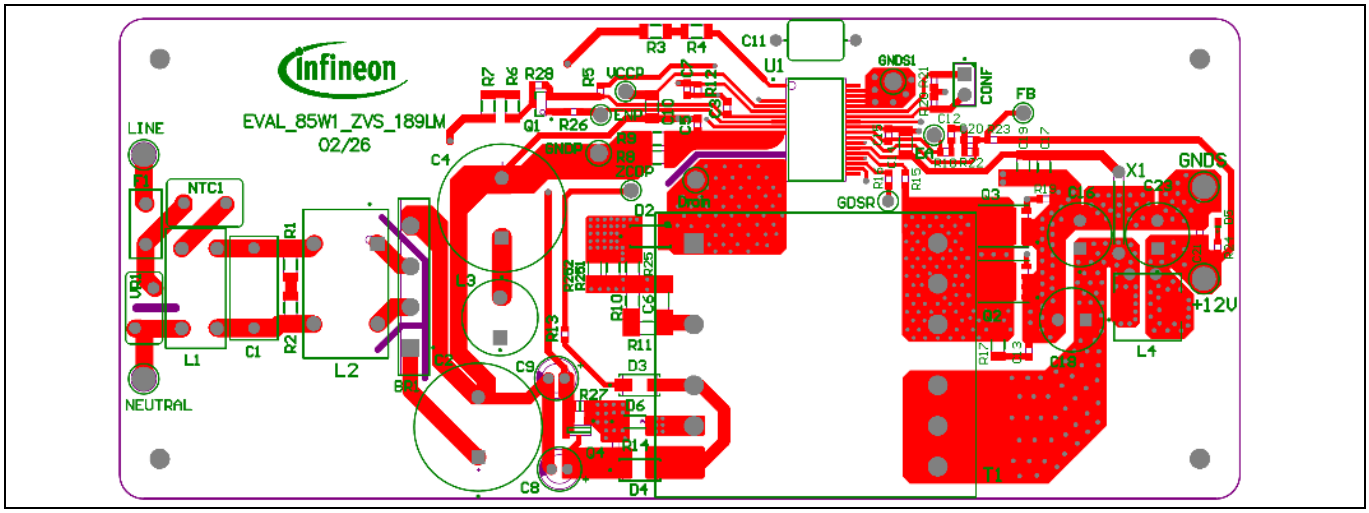


Figure 3 Top-side layout (view from top side)

6.1.2 Bottom-side layout

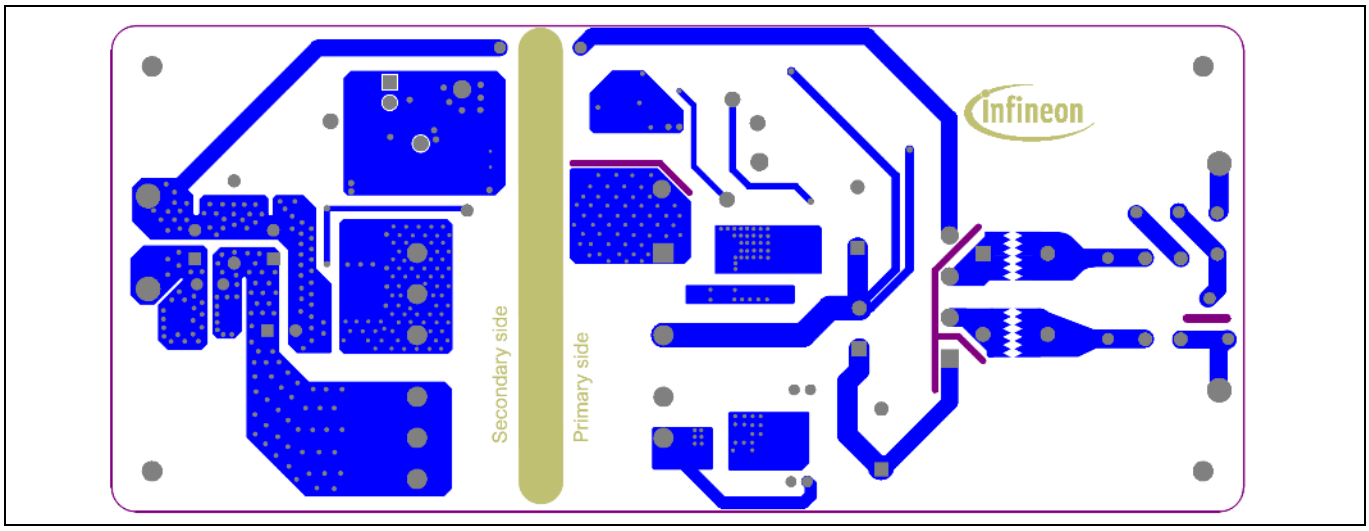


Figure 4 Bottom-side layout (view from bottom side)

7 Bill of materials

Table 6 Bill of materials

No.	Symbol	Description	Manufacturer	Part number	Qty
1	BR1	BRIDGE RECT 1PHASE 600 V 8A GBU	Onsemi	GBU8J	1
2	C1	Safety capacitors 310 VAC 0.33 µF 20%	DGCX	MX2334KQ3C30GB2000R	1
3	C2, C4	Aluminum electrolytic capacitors - Radial leaded 82 µF 450 V	Rubycon	450HXW82MEFR16X2	2
4	C3	MLCC - SMD/SMT 100 Volts 820 pF CGO/NPO 1% 0603	–	–	1
5	C5, C20	MLCC - SMD/SMT 50 Volts 680 pF X7R 10% 0603	–	–	2
6	C6	MLCC - SMD/SMT 1000 pF 1 KV 10% 1206	–		1
7	C7	MLCC - SMD/SMT 5 0Volts 33 pF X7R 10% 0603	–	–	1
8	C8, C9	Aluminum electrolytic capacitors - Radial leaded 22 µF 35 V	BERYL	RG035M220LO5*11TA-1A1E	2
9	C10	MLCC - SMD/SMT 100 nF 50 VDC 10% 1206 X7T	–	–	1
10	C11	Safety capacitors 1500 pF 310 V 20%	Yageo	C741U152MSWDCA7317	1
11	C12	MLCC - SMD/SMT 50 Volts 68 nF X7R 10% 0603	–	–	1
12	C13	MLCC - SMD/SMT 100 Volts 220 pF X7R 10% 0603	–	–	1
13	C14, C19	MLCC - SMD/SMT 100 nF 50 V 10% 1206	–	–	2
14	C15	MLCC - SMD/SMT 50 Volts 1.5 nF X7R 10% 0603	–	–	1
15	C16, C18	CAP ALUM POLY 1200 µF 20% 16 V T/H	Nichicon	RNL1C122MDS1KX	2
16	C17	MLCC - SMD/SMT 10 µF 50 V 10% 1206	–	–	1
17	C21	MLCC - SMD/SMT 100 nF 50 V 10% 0603	–	–	1
18	C23	CAP ALUM POLY 270 µF 20% 16V T/H	Panasonic Electronics	16SEPF270M	1
19	CONF	Connector header through hole 2 position 0.100" (2.54 mm)	Samtec	TSW-102-08-G-S	1
20	D2	Surface mount rectifier 1.0 A/1000 V	–	S1M	1
21	D3, D4	DIODE Schottky 200 V 1 A DO214AC	Micro Commercial Co	SS1200-LTP	2
22	D5	Chip LED Waterclear, size 0603, blue	Würth Elektronik	150060BS75003	1
23	D6	Zener diode 22 V 500 mW ±2% surface mount SOD-123	Vishay	MMSZ5251C-E3-08	1
24	Drain, GNDP, GNDS	Test point THT, white	Keystone Electronics Corp.	5012	3
25	EA, ENP, FB, GDSR, VCCP, ZCDP	Test point THT, white	Keystone Electronics Corp.	5002	6
26	F1	Time lag fuse, 300 V, 3.15 A	Littelfuse	36913150000	1

7 Bill of materials

No.	Symbol	Description	Manufacturer	Part number	Qty
27	GNDS, +12V, LINE, NEUTRAL	Solder terminal, double turret, .109 long	Keystone Electronics Corp.	1502-2	4
28	L1	Inductor Common mode standard polarization core 4 pins, 275 µH	Endela Electronics	L-13-0100	1
29	L2	Inductor Common mode standard polarization core 4 pins, 10 mH	Tenda	TD1515-10MH 0.2*1.5	1
30	L3	Radial leaded wire wound inductor WE-TI, 10 µH 4.70 A	Würth Elektronik	7447452100	1
31	L4	'SMD WE-HCC HCur Cube8070 1µH 17A 2.95 mΩ	Würth Electronik	7443340100	1
32	NTC1	Power NTC 2.5 Ω Y kink bulk	Bourns	BN-LG08Y2R5MYB	1
33	Q1	SIPMOS small-signal transistor	Infineon Technologies	BSS127H6327XTSA 2	1
34	Q3	Power-transistor, optimized for high performance SMPS	Infineon Technologies	ISC027N10NM6AT MA1	1
35	Q4	Bipolar transistors - SOT-23, 45 V, 800 mA, NPN	Diotec	BC817-25	1
36	R1, R2	Thick film resistors - SMD 1/4 Watt 1.2 MΩ 1206 5%	–		2
37	R3, R4	Thick film resistors - SMD 50 kΩ 250 mW 1206 1%	–	–	2
38	R5	Thick film resistors - SMD 17.4 Ω 100 mW 0603 1%	–	–	1
39	R6, R7	Thick film resistors - SMD 1/4 Watt 1.3 MΩ 1206 1%	–	–	2
40	R8, R9	Thick film resistors - SMD 1206 0.39 Ω 1%	Bourns	CRL1206-FW-R390ELF	2
41	R10, R11	Thick film resistors - SMD 1/4 Watt 150 kΩ 1206 1%	–	–	2
42	R12	Thick film resistors - SMD 2 kΩ 1% 0603	–	–	1
43	R13, R18	Thick film resistors - SMD 22 kΩ 1% 0603	–	–	2
44	R14, R15	Thick film resistors - SMD 15 kΩ 100 mW 0603 1%	–	-	2
45	R16	Thick film resistors - SMD 0603 2.2 Ω 1%	–	–	1
46	R17	Thick film resistors - SMD 1/4 Watt 51 Ω 1206 5%	–	–	2
47	R19	Thick film resistors - SMD 10 kΩ 100 mW 0603 1%	–	–	1
48	R20	Thick film resistors - SMD 18 kΩ 1% 0603	–	–	1
49	R21	Thick film resistors - SMD 3.9 kΩ 1% 0603	–	–	1
50	R22	Thick film resistors - SMD 20 kΩ 100 mW 0603 1%	–	–	1
51	R23	Thick film resistors - SMD 180 kΩ 0603 1%	–	–	1
52	R24	Thick film resistors - SMD 5.1 kΩ 100 mW 0603 1%	–	–	1

7 Bill of materials

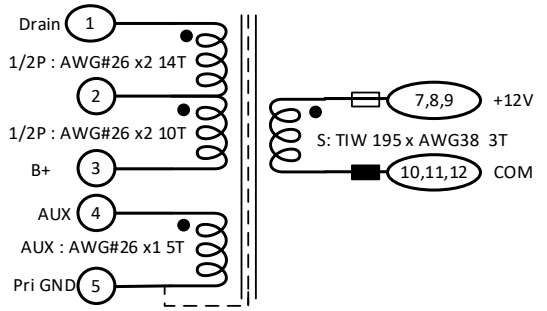
No.	Symbol	Description	Manufacturer	Part number	Qty
53	R25	Thick film resistors - SMD 1/4 Watt 15 Ω 1206 1%	–	–	1
54	R26	Thick film resistors - SMD 0 Ω 0603	–	–	1
55	R27	Thick film resistors - SMD 120 kΩ 0805	–	–	1
56	T1	Transformer PQ3220, Lp = 230 µH	Würth Electronik	750345653	1
57	U1	CoolSET™ SIP ICE189LM	Infineon Technologies	ICE189LM	1
58	VR1	Varistors 275 VAC 10% 7 mm	Bourns	CV275K7BL1	1
59	X1	Through hole jumper, 10.16 mm pitch, 2 pins	Samtec	JL-400-25-T	1

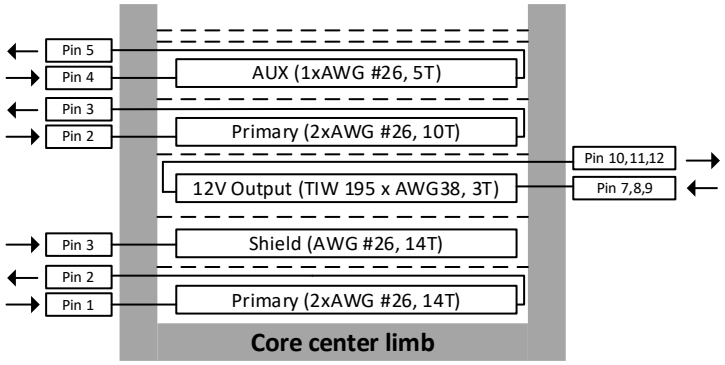
8 Transformer specification

8.1 Electrical diagram and coil structure

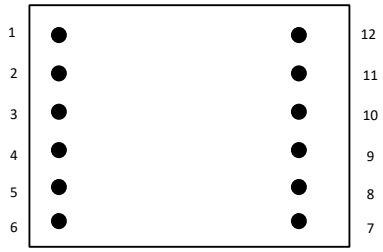
- Manufacturer and part number: Würth Electronik (750345653)

Core: PQ3220, L_p = 230 µH, 24T: 3T: 5T (N_p: N_{s1}: N_{aux})





Top view (PQ3220)



Wire size requirement :

Start	Stop	No. of turns	Wire Size	Layer
1	2	14	2 x AWG#26	1/2 Primary
5		14	1 x AWG#26	Shield
7,8,9	10,11,12	3	TIW 195xAWG#38	Secondary
2	3	10	2 x AWG#26	1/2 Primary
4	5	5	1 x AWG#26	AUX

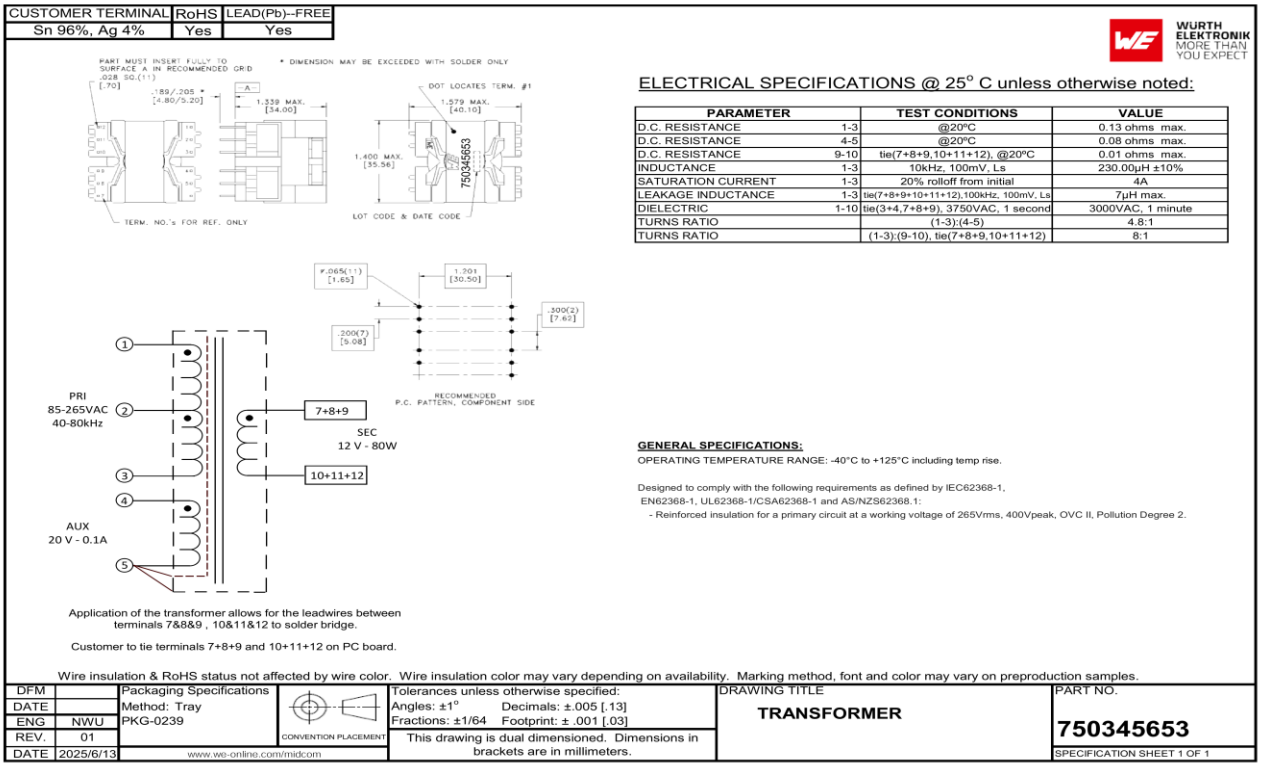


Figure 5 Electrical diagram and coil structure

9 Test results

All performance data is measured at room temperature T_a = 25°C unless otherwise specifically mentioned.

9.1 Efficiency

The NTC1 is shorted and the output LED D5 indicator is removed during the efficiency test.

Table 7 Efficiency result

Input (V_{AC}/Hz)	Loading	P_{in} (W)	V_{out} (V)	I_{out} (A)	P_{out} (W)	Eff η (%)	Avg. η (%)
90/60	10%	9.33	12.02	0.71	8.54	91.66	
	25%	22.81	12.04	1.77	21.31	93.41	92.72
	50%	45.60	12.04	3.53	42.51	93.22	
	75%	69.16	12.03	5.32	64.02	92.57	
	100%	92.78	12.03	7.07	85.04	91.66	
115/60	10%	9.35	12.04	0.71	8.52	91.13	
	25%	22.76	12.04	1.77	21.31	93.60	93.38
	50%	45.28	12.04	3.53	42.50	93.87	
	75%	68.61	12.04	5.32	64.04	93.35	
	100%	91.76	12.03	7.07	85.06	92.71	
230/50	10%	9.50	12.04	0.71	8.54	89.92	
	25%	22.94	12.04	1.77	21.31	92.85	93.68
	50%	45.23	12.04	3.53	42.49	93.93	
	75%	68.04	12.03	5.32	64.02	94.09	
	100%	90.55	12.02	7.07	84.98	93.85	
264/50	10%	9.55	12.04	0.71	8.54	89.50	
	25%	23.02	12.04	1.77	21.31	92.59	93.62
	50%	45.30	12.04	3.53	42.50	93.82	
	75%	68.03	12.03	5.32	64.02	94.11	
	100%	90.49	12.02	7.07	85.03	93.97	

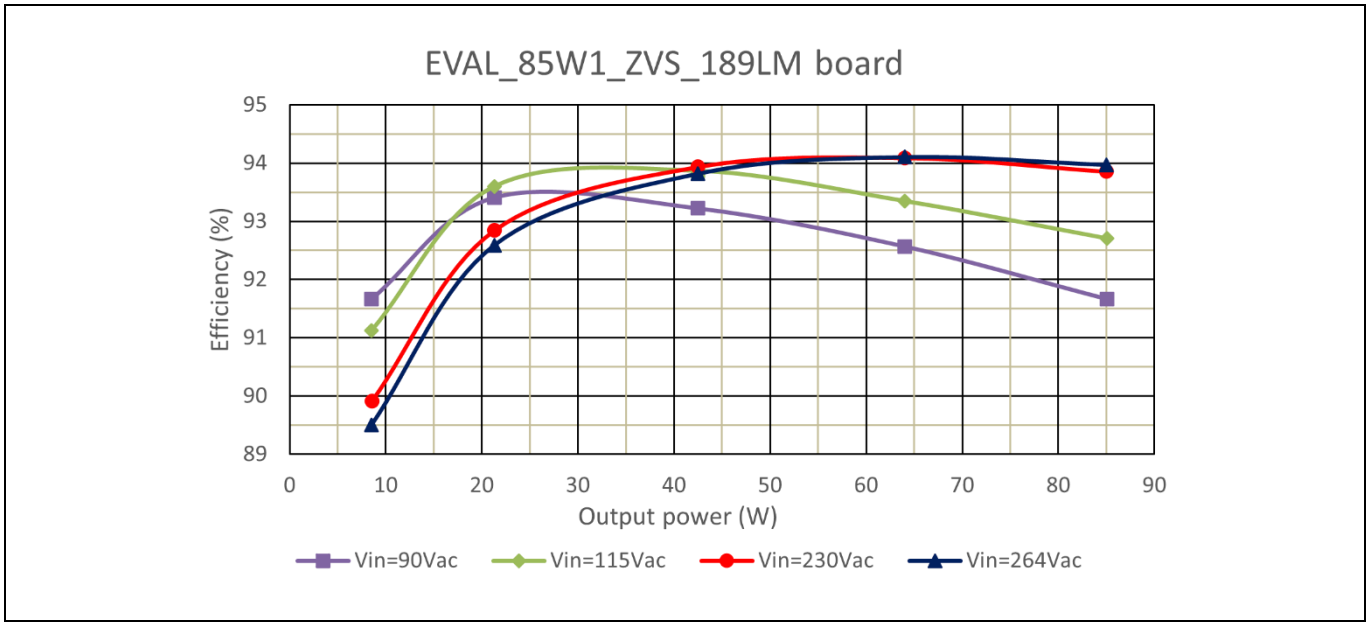


Figure 6 Efficiency vs. output power

9.2 Standby power

The NTC1 is shorted and the output LED D5 indicator is removed during the standby power test.

Table 8 Standby power result

Input (V_{AC}/Hz)	Loading (%)	Vout (V)	Pin (mW)
90/60	0	12.03	13.39
115/60	0	12.03	16.98
230/50	0	12.04	39.98
264/50	0	12.04	50.21

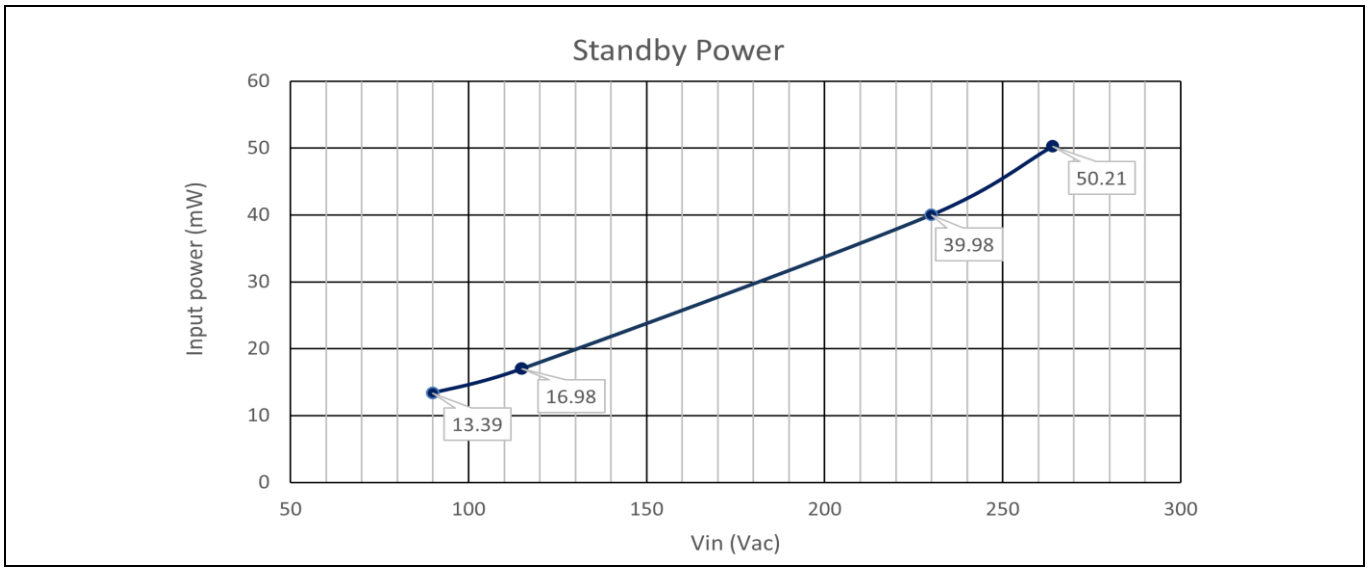


Figure 7 Standby power during no load

9.3 Line and load regulation

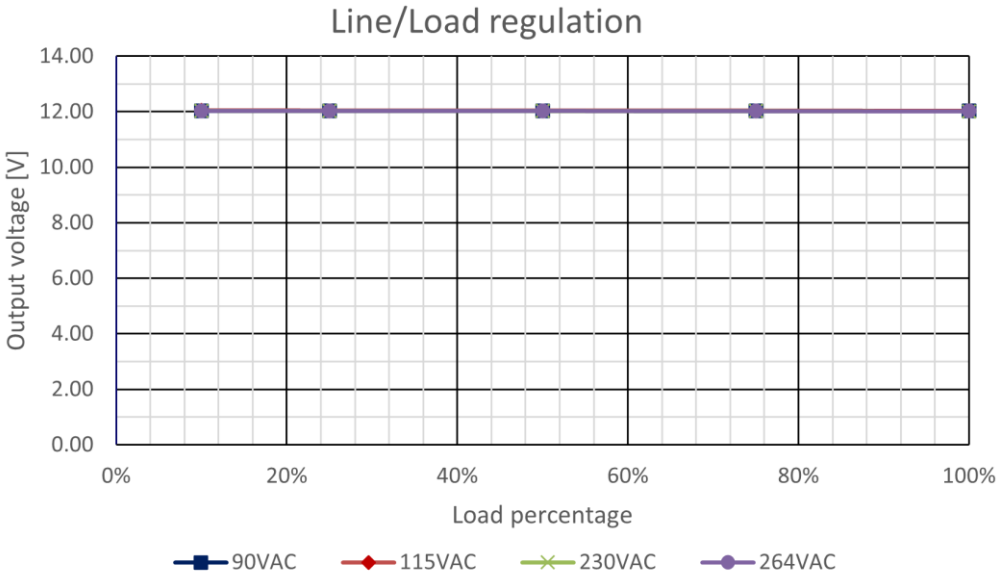


Figure 8 Line and load regulation

9.4 ESD immunity (EN 61000-4-2)

The evaluation board was subjected to ESD testing according to EN 61000-4-2 level 3 (±8 kV contact discharge and ±15 kV air discharge test). It is tested at full load (resistive load) and meets criteria A (normal performance within the specification limits).

Table 9 System ESD test result

Description	ESD test	Level 3	Number of strikes				Test result
			+ V_{out}	-V_{out}	L	N	
230 V_{AC} 85 W	Contact discharge	±8 kV	10	10	10	10	Pass
	Air discharge	±15 kV	10	10	10	10	Pass

9.5 Surge immunity (EN 61000-4-5)

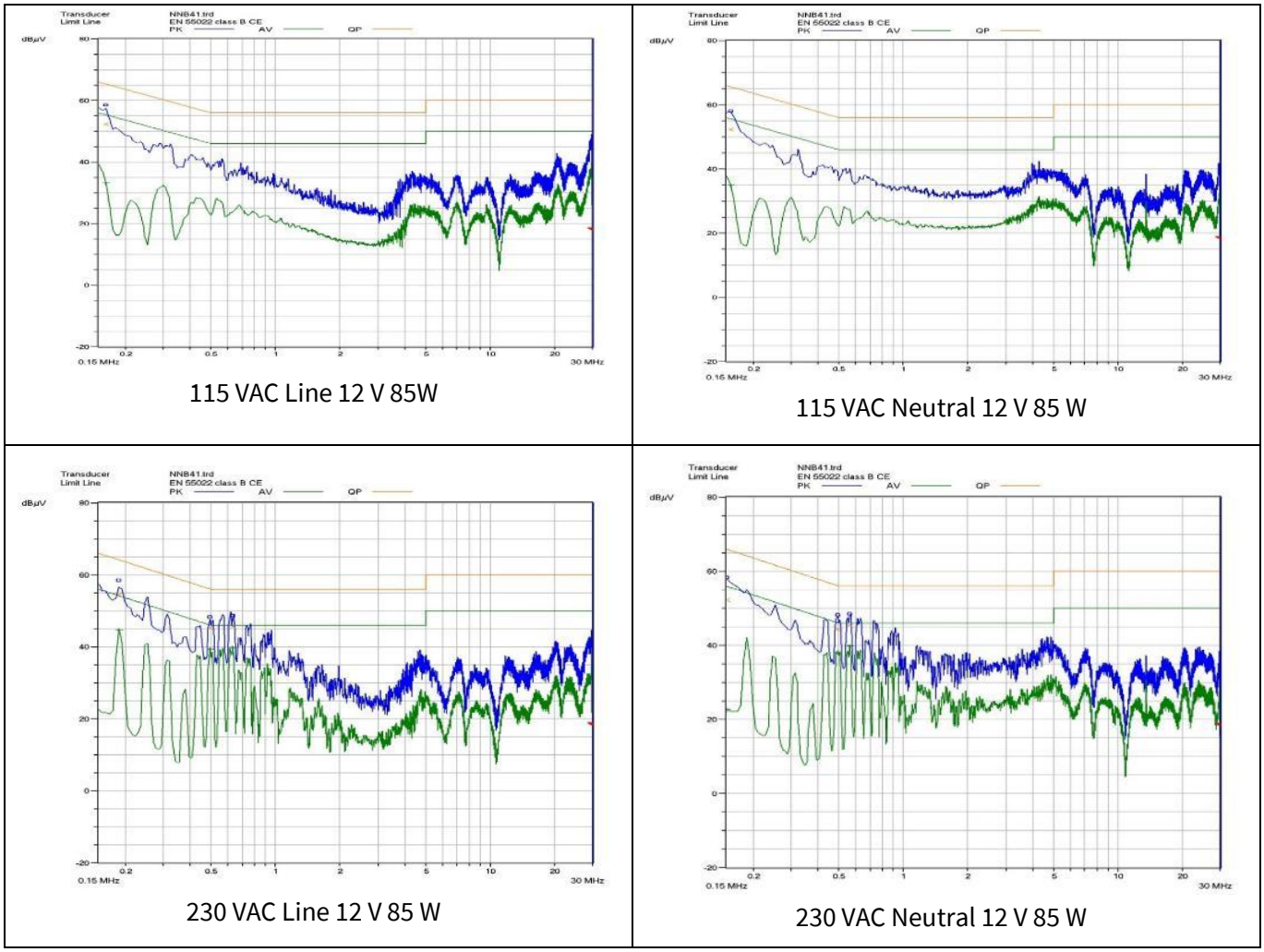
The evaluation board is subjected to a surge immunity testing according to EN 61000-4-5 level 4 (±2 kV Differential mode and ±4 kV Common mode test). It is tested at full load (resistive load) and meets criteria A (normal performance within the specification limits).

Table 10 System surge immunity test result

Description	ESD test	Level 4		Number of strikes				Test result
				0°	90°	180°	270°	
230 V_{AC} 85 W	Differential mode	±2 kV	L - N	3	3	3	3	Pass
	Common mode	±4 kV	L - G	3	3	3	3	Pass
		±4 kV	N - G	3	3	3	3	Pass

9.6 Conducted electromagnetic interference (EN 55022 Class B)

The conducted EMI was measured by Schaffner SMR4503 and followed the test standard EN55022 (CISPR 22) Class B. The evaluation board was tested at full load (resistive load) at input voltages of 115 VAC and 230 VAC.



115 VAC Line 12 V 85W

115 VAC Neutral 12 V 85 W

230 VAC Line 12 V 85 W

230 VAC Neutral 12 V 85 W

Figure 9 Conducted EMI

9.7 Thermal measurement

The thermal test of the open-frame evaluation board was done using an infrared thermography camera (FLIR-T420) at an ambient temperature of 27°C. The measurements were taken after one hour load running.

Table 11 Temperature of critical components (at ambient temperature 27°C)

No.	Major component	90 V_{AC} 85 W (°C) Figure 10	264 V_{AC} 85 W (°C) Figure 11
1	U1 (ICE189LM) – sp1 (left)	74.4°C	55.7°C
2	RCD clamper – sp2 (left)	83.9°C	66.7°C
3	Q3 (SR MOSFET) - sp3 (left)	62.8°C	59.7°C
4	Bridge rectifier (BR1) – sp1 (right)	81.1°C	48.4°C
5	T1 core (Transformer) - sp2 (right)	61.6°C	62.3°C
6	T1 wire (Transformer) - sp3 (right)	65.6°C	67.5°C

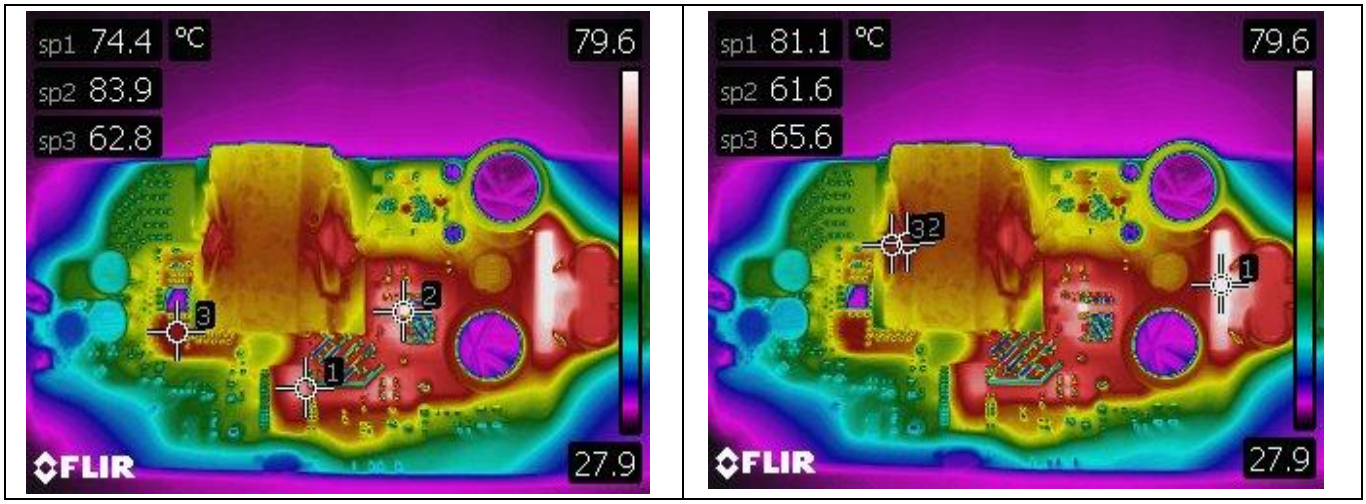


Figure 10 Infrared thermal image. Input: 90 V_{AC}; output: 85 W at 12 V

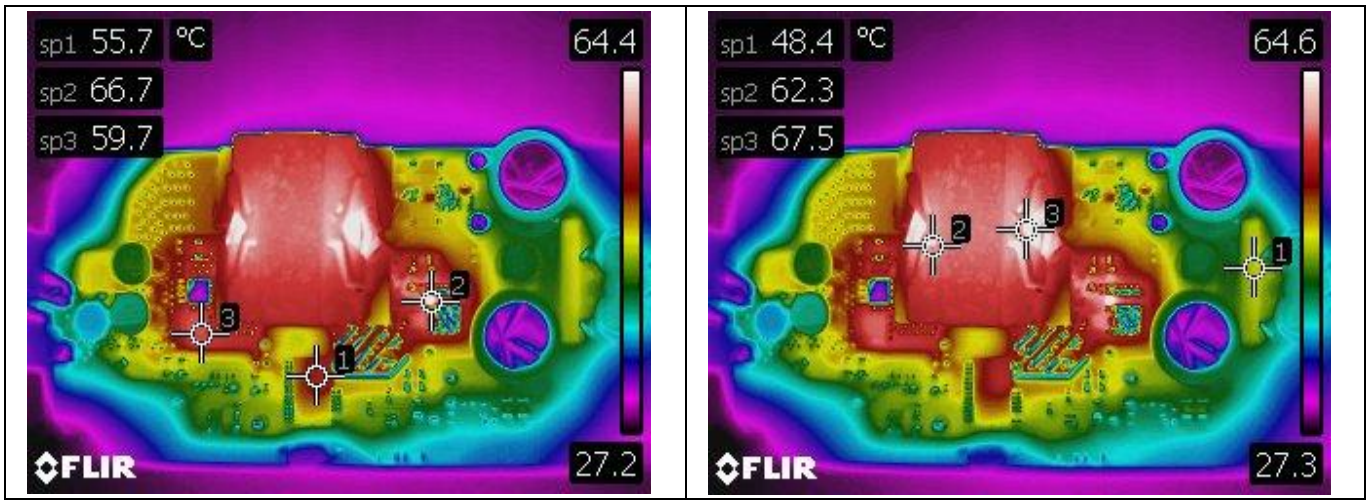


Figure 11 Infrared thermal image. Input: 264 V_{AC}, output: 85 W at 12 V

10 Waveforms and scope plots

All waveforms and scope plots were recorded with a Teledyne LeCroy 8054 oscilloscope.

10.1 Startup with maximum load

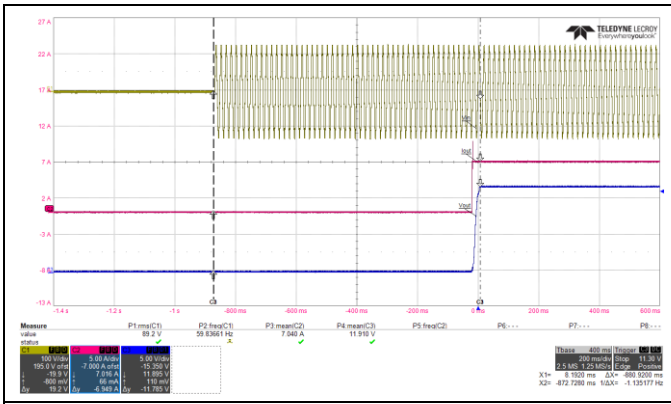
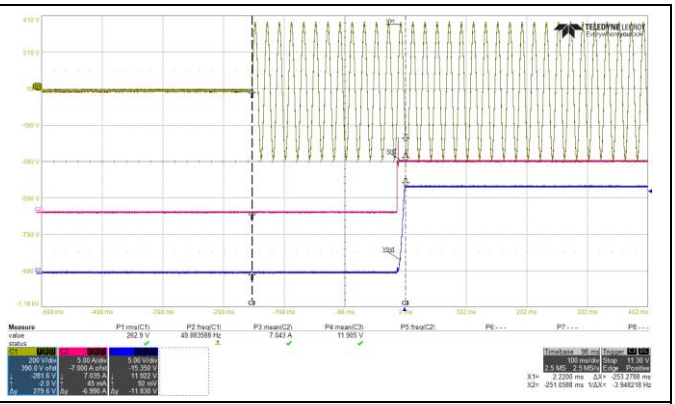
	
C1 (yellow) : AC line voltage (V_{in}) C2 (red) : Output current (I_{out}) C3 (blue) : Output voltage (V_{out})	C1 (yellow) : AC line voltage (V_{in}) C2 (red) : Output current (I_{out}) C3 (blue) : Output voltage (V_{out})
Start-up time at 90 VAC and Full load ≈ 0.88 s	Start-up time at 264 VAC and Full load ≈ 0.25 s
The board can start up as expected over 90 VAC ~ 264 VAC, output voltage smoothly rises, and regulates at 12 V.	

Figure 12 Startup

10.2 Soft-start

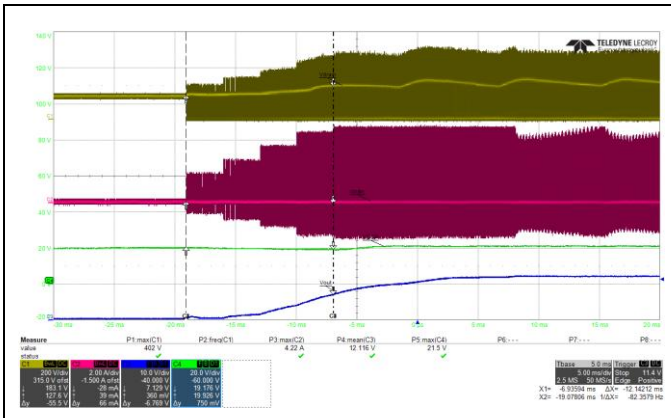
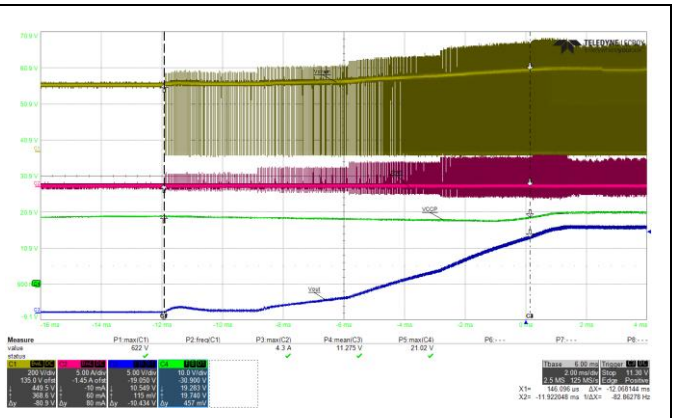
	
C1 (yellow) : Drain voltage (V_{DRAIN}) C2 (red) : Drain current (I_{DRAIN}) C3 (blue) : Output voltage (V_{out}) C4 (green) : VCCP voltage (V_{VCCP})	C1 (yellow) : Drain voltage (V_{DRAIN}) C2 (red) : Drain current (I_{DRAIN}) C3 (blue) : Output voltage (V_{out}) C4 (green) : VCCP voltage (V_{VCCP})
Soft-start time at 90 VAC and Full load ≈ 12.14 ms	Soft-start time at 264 VAC and Full load ≈ 12.16 ms
The soft start time ends at around 12 ms as per design.	

Figure 13 Soft-start

10.3 Primary SiC MOSFET drain voltage and current at maximum load

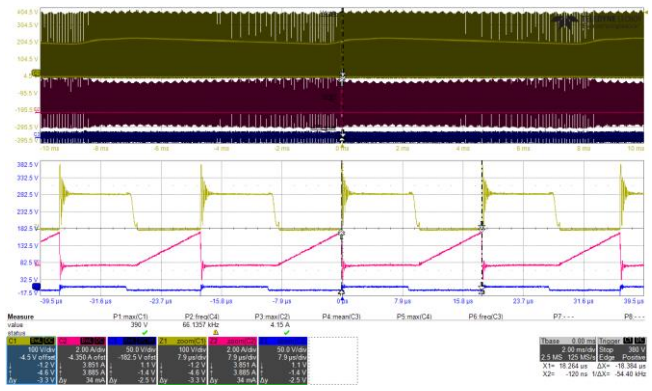
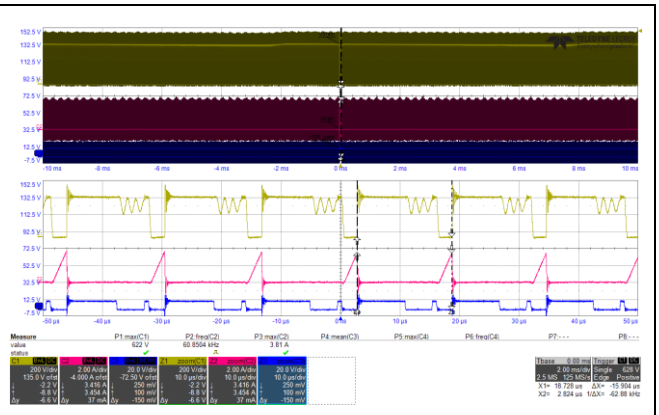
	
C1 (yellow) : Drain voltage (V_{DRAIN}) C2 (red) : Drain current (I_{DRAIN}) C3 (blue) : SR gate voltage (V_{SRGD})	C1 (yellow) : Drain voltage (V_{DRAIN}) C2 (red) : Drain current (I_{DRAIN}) C3 (blue) : SR gate voltage (V_{SRGD})
V_{Drain_peak} at 90 VAC 85 W load = 390 V I_{DRAIN_peak} at 90 VAC 85 W load = 4.15 A f_{sw} = 66.1 kHz	V_{Drain_peak} at 264 VAC 85 W load = 622 V I_{DRAIN_peak} at 264 VAC 85 W load = 3.81 A f_{sw} = 60.85 kHz
ICE189LM operates at Quasi-Resonant mode at 90 VAC and zero-voltage mode at 264 VAC.	

Figure 14 Primary SiC MOSFET drain voltage and drain current at maximum load

10.4 SR MOSFET drain voltage at maximum load

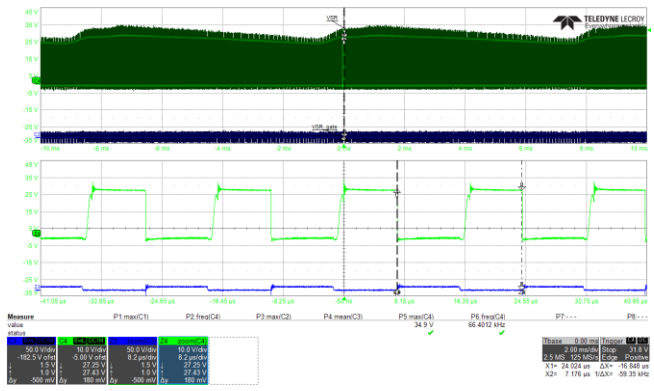
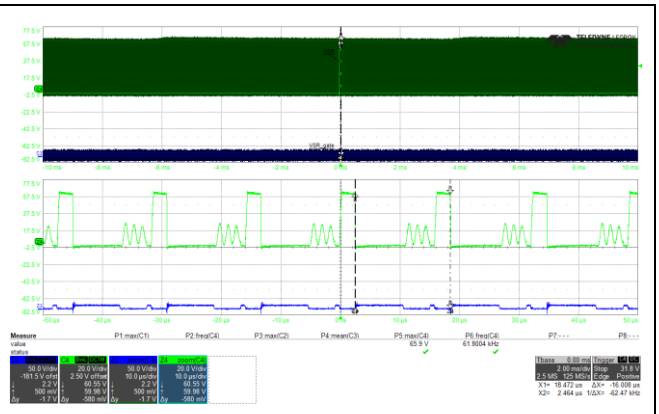
	
C3 (blue) : SR gate voltage (V_{SRGD}) C4 (green) : SR drain voltage (V_{SR_DRAIN})	C3 (blue) : SR gate voltage (V_{SRGD}) C4 (green) : SR drain voltage (V_{SR_DRAIN})
$V_{SR_Drain_peak}$ at 90 VAC 85W load = 34.9 V f_{sw} = 66.4 kHz	$V_{SR_Drain_peak}$ at 264 VAC 85W load = 65.9 V f_{sw} = 61.8 kHz
ICE189LM operates at Quasi-Resonant mode at 90 VAC and zero-voltage mode at 264 VAC.	

Figure 15 SR MOSFET drain voltage at maximum load

10.5 Output ripple voltage at maximum load

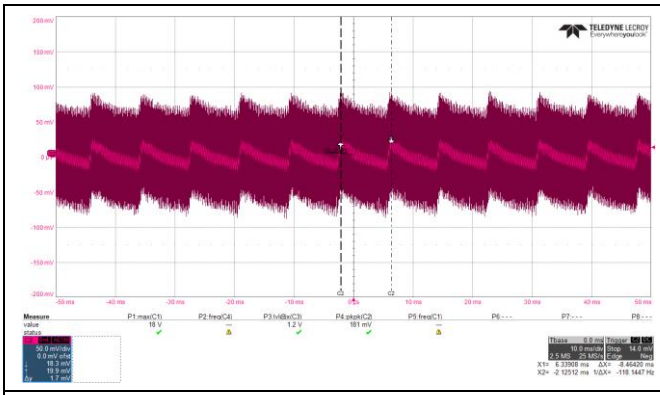
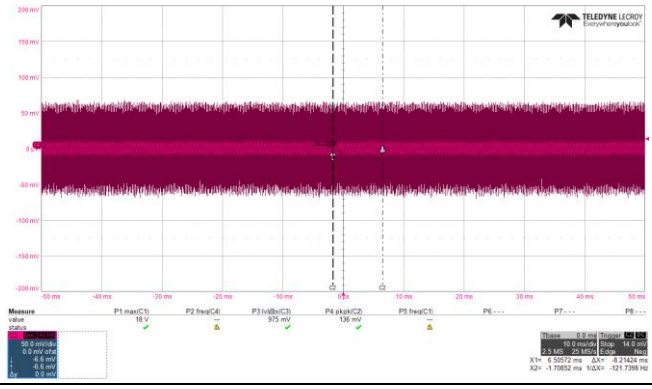
	
C2 (red): 12 V output ripple voltage (V_{Out_ripple})	C2 (red): 12 V output ripple voltage (V_{Out_ripple})
12 $V_{ripple_pk_pk}$ at 90 VAC = 181 mV_{pk-pk} Probe terminal with decoupling capacitors of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW	12 $V_{ripple_pk_pk}$ at 264 VAC = 136 mV_{pk-pk} Probe terminal with decoupling capacitors of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW
The output ripple measured is around 1.5% of the output voltage.	

Figure 16 Output ripple voltage at maximum load

10.6 Hysteretic mode operation

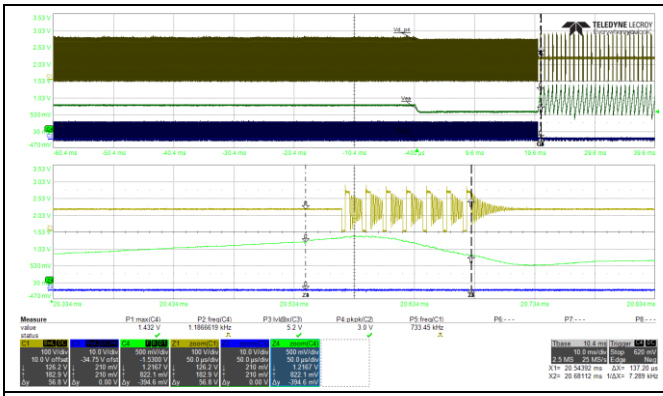
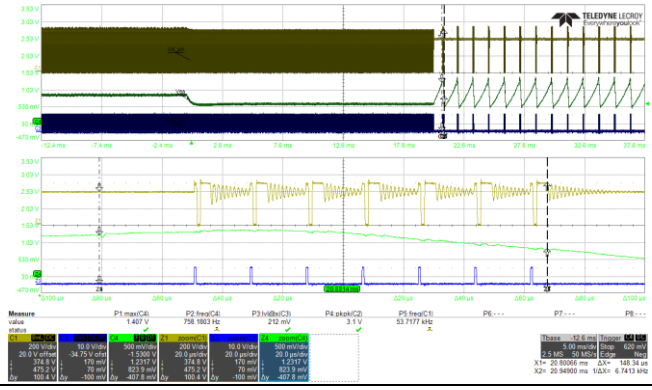
	
C1 (yellow) : Drain voltage (V_{DRAIN}) C3 (blue) : SR Gate (V_{SR_gate}) C4 (green) : EA (V_{EA})	C1 (yellow) : Drain voltage (V_{DRAIN}) C3 (blue) : SR Gate (V_{SR_gate}) C4 (green) : EA (V_{EA})
90 VAC, 8.4 W -> 2.4 W load Operation at f_{osc_ABM} = 55.5 kHz	264 VAC, 8.4 W -> 1.2 W load Operation at f_{osc_ABM} = 53.7 kHz
When the load reduces to < 3% load, the system enters the Hysteretic mode to reduce the power loss.	

Figure 17 Hysteretic mode operation

10.7 Overload protection (auto-restart)

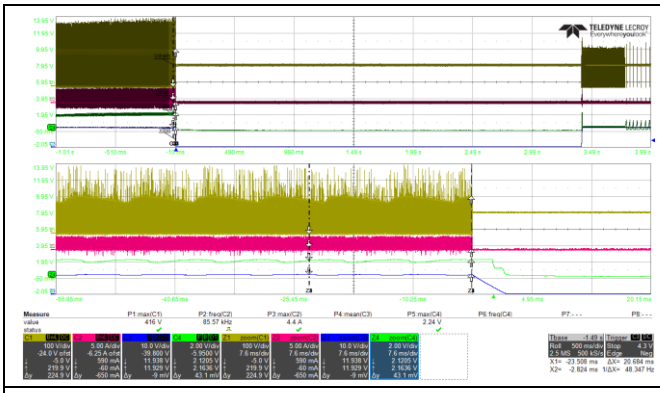
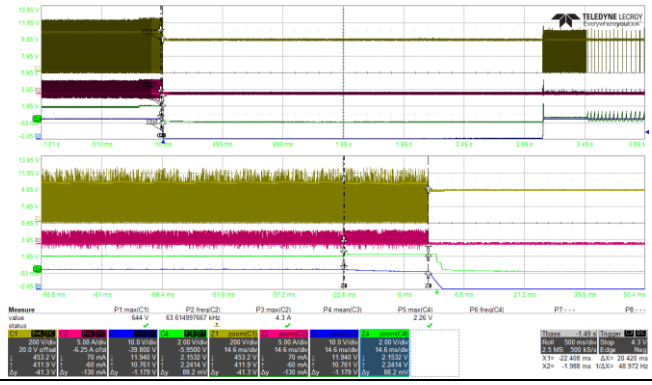
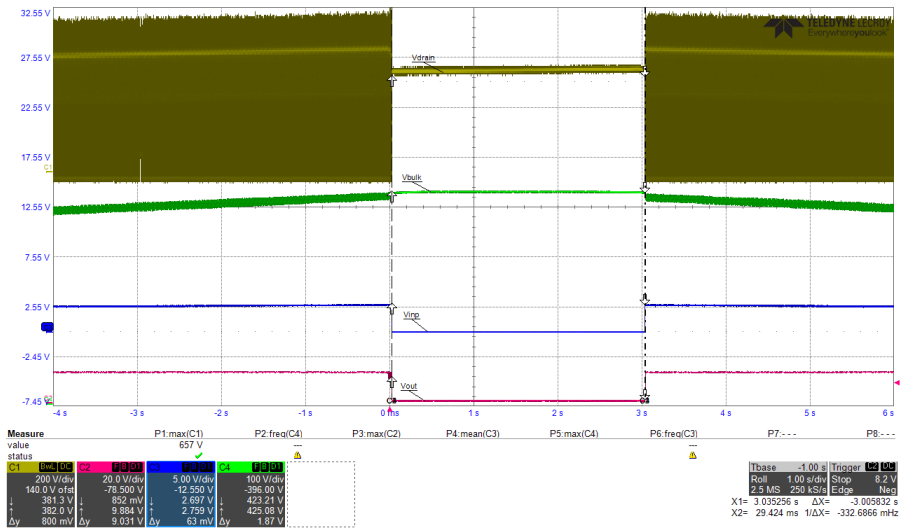
	
C1 (yellow) : Drain voltage (V_{DRAIN}) C2 (red) : Drain current (I_{DRAIN}) C3 (blue) : Output voltage (V_{OUT}) C4 (green) : EA (V_{EA})	C1 (yellow) : Drain voltage (V_{DRAIN}) C2 (red) : Drain current (I_{DRAIN}) C3 (blue) : Output voltage (V_{OUT}) C4 (green) : EA (V_{EA})
90 VAC, 50 W load steps to 108 W load. System enters Auto restart protection when V_{EA} > 2.1 V and blanking time 20 ms	264 VAC, 50 W load steps to 108 W load. System enters Auto restart protection when V_{EA} > 2.1 V and blanking time 20 ms
System enters overload protection when the load steps to 108 W	

Figure 18 Overload protection test

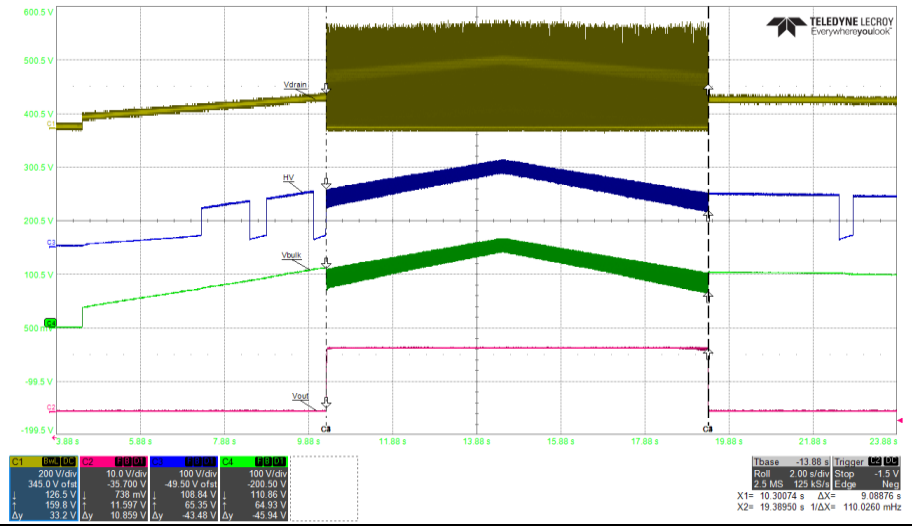
10.8 Line OVP



C1 (yellow) : Drain voltage (V_{DRAIN}) C2 (red) : Output voltage (V_{OUT}) C3 (blue) : VINP (V_{VINP}) C4 (green) : Bulk capacitor voltage (V_{BUS})
Increase the input voltage from 250 VAC to 300 VAC and decrease back to 250 VAC. Line OVP is measured at V_{BUS} > 425 VDC when the V_{VINP} > 2.7 V. System enters non switch Auto restart protection and the switching resumes when V_{BUS} < 423 VDC
System enters line OVP protection as expected

Figure 19 Line OVP test

10.9 Brown-in and brown-out



C1 (yellow)	: Drain voltage (V_{DRAIN})
C2 (red)	: Output voltage (V_{OUT})
C3 (blue)	: HV (V_{HV})
C4 (green)	: Bulk capacitor voltage (V_{BUS})

System in full load. Increase the input voltage from 30 VAC to 120 VAC and decrease back to 30 VAC. Brown-in is measured at V_{BUS} > 110 VDC and Brownout is measured at V_{BUS} < 65 VDC. System is at non switch Auto restart protection before the Brown-in and resumes switching after Brown-in. When the bulk capacitor voltage drops below Brown-out, the system enters non switch Auto restart

System enters Brown-in and Brown-out protection as expected

Figure 20 Brown-in and brown-out test

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References

[1] Infineon Technologies AG: *CoolSET™ SiP ICE189LM datasheet*; Available online

[2] Infineon Technologies AG: *Design guide for ZVS QR flyback using CoolSET™ SiP*; Available online

Revision history

Document revision	Date	Description of changes
V 1.0	2026-06-02	Initial release
V 1.1	2026-11-03	Revised typo in BOM, schematic, and transformer specification

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Edition: 2026-11-03

Published by
Infineon Technologies AG
Am Campeon 1-15
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