45 W power supply using CoolSET™ SiP ICE184EM

REF_45W1_ZVS_184EM

About this document

Scope and purpose

This application note describes a dual output power supply using Infineon's latest CoolSET™ System in Package (SiP) ICE184EM. The power supply is designed with a universal AC input line and two outputs (isolated +12 V/3.75 A and non-isolated +15 V/0.15 A).

Highlights of this power supply:

- Overall high efficiency to meet energy efficiency requirements
- Simplified circuitry with high-level integration of power control and protection features
- Auto-restart protection scheme to minimize interruption and enhance the end user experience
- Secondary controlled primary LDO circuit to reduce component counts
- Zero voltage switching (ZVS) technology to boost efficiency performance

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
- Telecom

Table of contents

1 Introduction

This document describes a 12 V / 3.75 A and 15 V / 0.15 A power supply using Infineon's latest CoolSET™ SiP ICE184EM. This reference design demonstrates high power efficiency and cost-effectiveness, made possible by the high-level integration capabilities of CoolSET™ SiP.

Table 1 lists the general home appliance system requirements for auxiliary power supply and the Infineon solution using ICE184EM.

Table 1 General home appliance system requirement and reference design solution

	General system requirement	Reference design solution – ICE184EM
1	High efficiency to meet energy efficiency requirements	Primary zero voltage switching and secondary optimal synchronous rectifier control
2	Simplified circuitry with high-level integration	Primary 800 V MOSFET, primary and secondary controller, and communication integrated in a DSO-27 package
3	Minimize interruption to enhance end user experience	All protections are defined to enter auto-restart mode

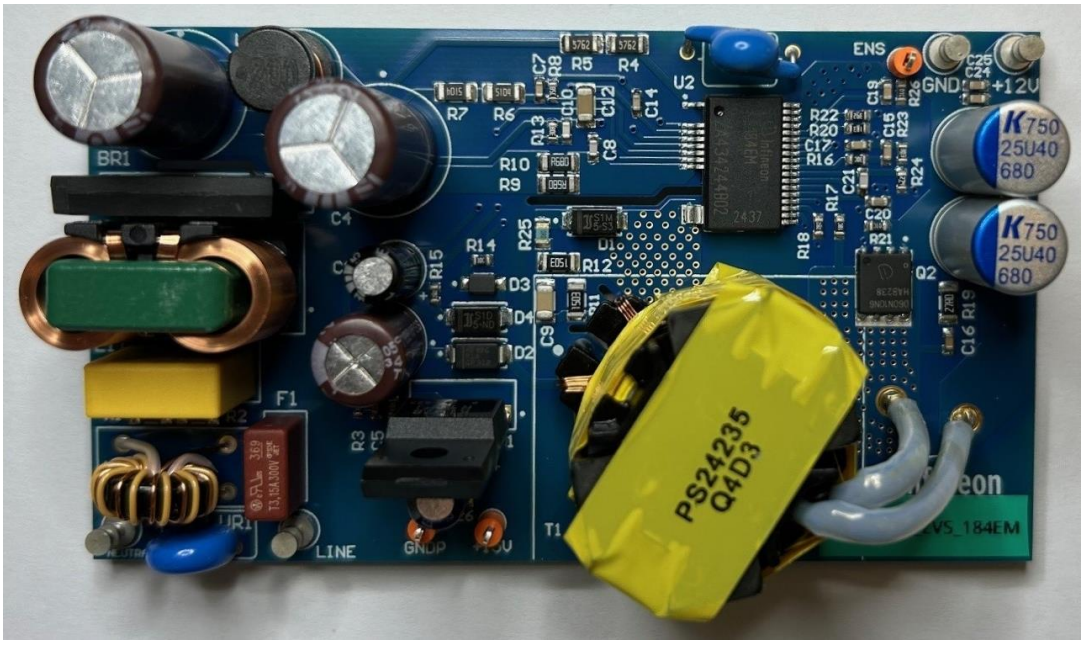
The main 12 V output supplies power to the system hardware such as motor drives, fans, and compressors. Additionally, a non-isolated 15 V output is obtained through the LDO at the primary side, which is typically used to supply gate drive circuits. A unique feature of this reference board is its ability to switch the primary side LDO on/off via the secondary side ENS signal at any time according to the system requirement. This approach offers several benefits, including:

- Reduced circuit and component count
- Retain PCB space
- Lower system standby power consumption

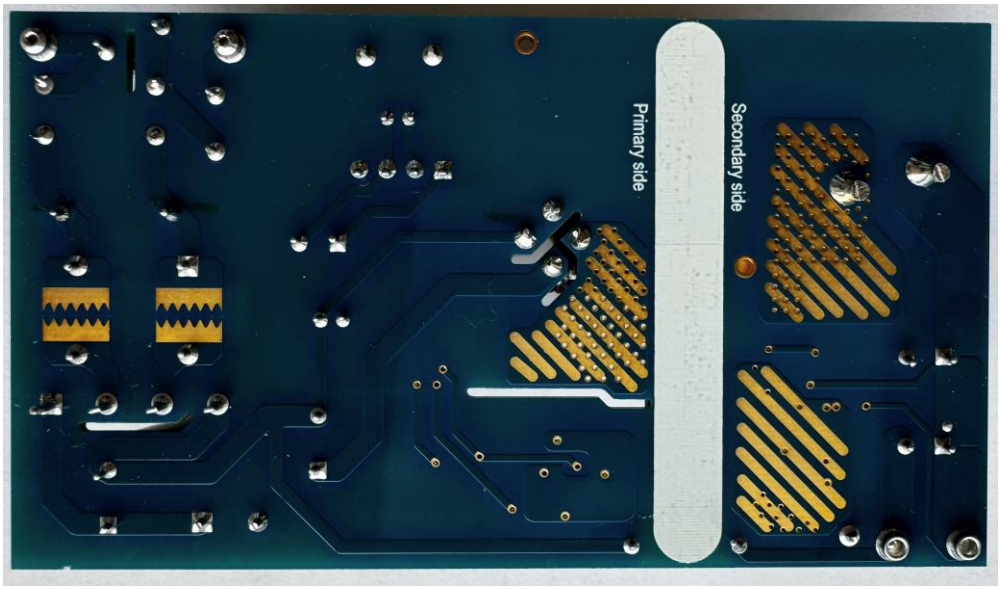
By eliminating the need for extra isolation components, the reference board results in a more efficient, compact, and cost-effective solution for system designers.

2 Reference board

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



Top side of the board



Bottom side of the board

Figure 1 Photograph of REF_45W1_ZVS_184EM

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 REF_45W1_ZVS_184EM

Description	Symbol	Min.	Typ.	Max.	Units	Comments
Input						
Voltage	V_{IN}	90	–	264	V AC	Two wires (no PE)
Frequency	f_{LINE}	47	50/45	64	Hz	–
Line Overvoltage	V_{IN_OVP}	–	277	–	V AC	–
Output						
Output voltage 1	V_{OUT1}	–	12	–	V	±1 percent (isolated)
Output current 1	I_{OUT1}	–	3.75	–	A	–
Output voltage ripple 1	$V_{RIPPLE1}$	–	–	240	mV	Peak to peak
Output voltage 2	V_{OUT2}	–	15	–	V	±1 percent (non-isolated)
Output current 2	I_{OUT2}	–	0.15	–	A	–
Overcurrent protection (12 V)	I_{OCP}	–	–	5.6	A	–
Total output power	P_{OUT}	–	45	–	W	Two outputs
Efficiency						
Maximum load efficiency	η	–	92	–	%	Measured at 230 V AC
Environmental						
Conducted EMI	–		6		dB	Margin, CISPR 22 class B
ESD						EN 61000-4-2
Contact discharge	–		±8		kV	–
Air discharge	–		±15		kV	–
Surge immunity						EN 61000-4-5
Differential mode	–		±2		kV	–
Common mode	–		±4		kV	–
PCB size	–		80 x 50		mm2	L x W
Ambient temperature	Ta	–	–	50	°C	Convection cooling

4 Circuit diagram

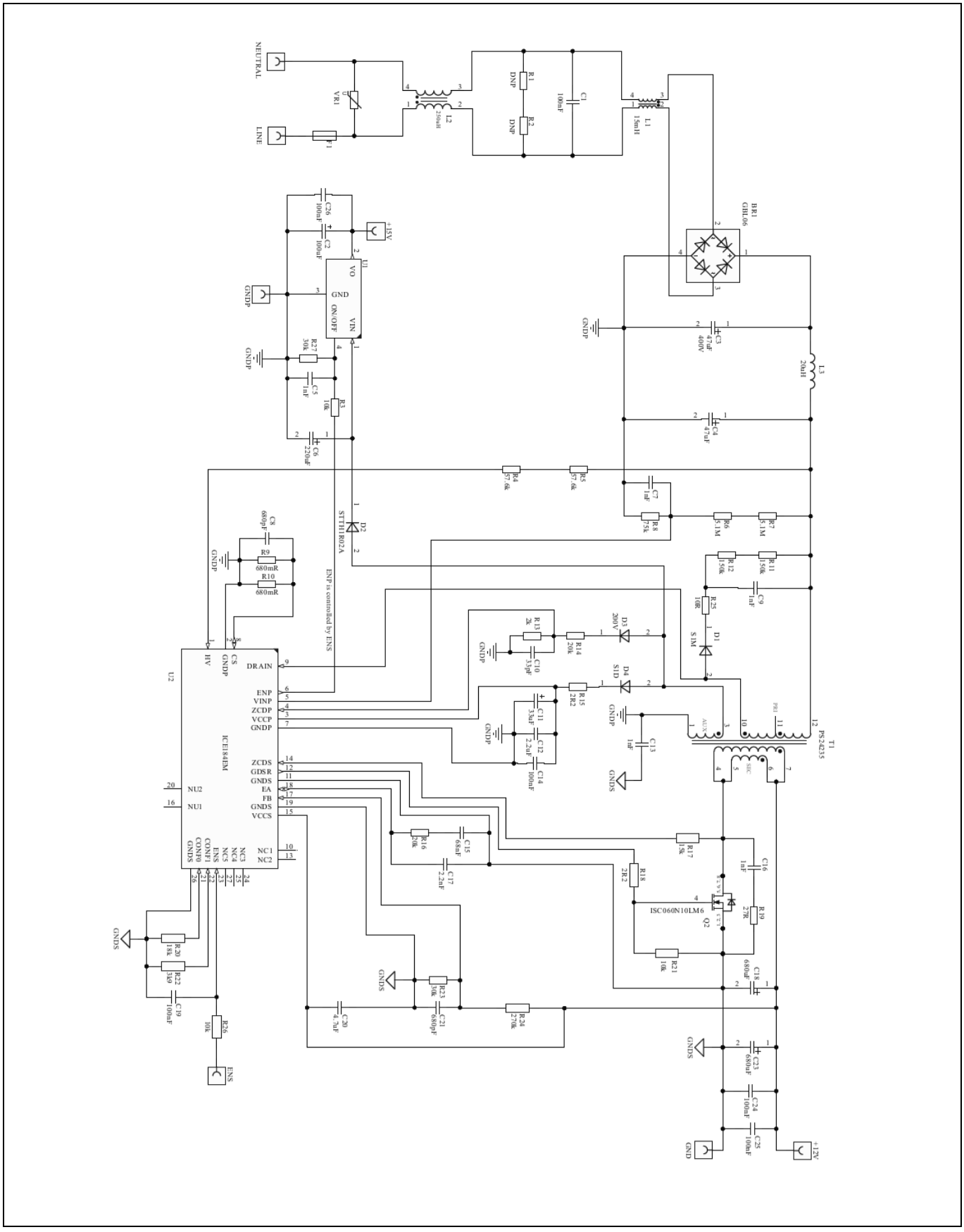


Figure 2 Schematic of REF_45W1_ZVS_184EM

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, check the IC datasheet [2] and design guide [1].

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 V AC ~ 264 V AC range. The F1 fuse 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 chokes L1 and 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 (capacitor C3, C4, and inductor L3).

5.2 CoolSET™ SiP power stage

The flyback converter power stage consists of a power transformer, primary power MOSFET, secondary synchronous rectifier (SR) MOSFET, secondary output capacitors, and filtering component if possible. Primary and secondary side power management are separated for isolated power supply domains (VCCP, GNDP and VCCS, GNDS). ICE184EM provides reinforced and safe isolated communication between primary and secondary sides.

5.2.1 CoolSET™ SiP primary side

CoolSET™ SiP ICE184EM integrates a 950 V startup cell at the primary side, IC is self-starting through the startup resistors (R4, R5) in series with this startup cell to charge the VCCP pin capacitor (C11) when AC is applied. These startup resistors (R4, R5), together with ZCDP pin external configuration resistor R_{ZCDPL} (R13), determine 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

Select Option 2 with R_{ZCDPL} (R13) = 2kΩ, then the brown-in voltage can be estimated as:

$$V_{BI} = (R_{HV} + R_{HVshunt}) \times I_{HV\_BI} = (115\ \text{k}\Omega + 1\ \text{k}\Omega) \times 1\ mA = 116\ V$$

Equation 1

and the brown-out voltage can be estimated as:

$$V_{BO} = (R_{HV} + R_{HVshunt}) \times I_{HV\_BO} = (115\ \text{k}\Omega + 1\ \text{k}\Omega) \times 0.7\ mA = 81\ V$$

Equation 2

Moreover, R13 and R14 resistors offer zero crossing detection during the soft-start period and primary-sensed output overvoltage protection.

$$V_{OUT\_OVP} = \left(\frac{(R_{ZCDPH} + R_{ZCDPL}) \times V_{ZCDP\_OVP\_min}}{R_{ZCDPL}} + V_{Daux)}\right) \times \frac{N_{SEC}}{N_{AUX}} - V_{Dsec}$$
$$= \left(\frac{(2k\Omega + 20k\Omega) \times 2.05V}{2k\Omega} + 0.3\,V\right) \times \frac{4}{6} - 0.1\,V \approx 15\,V$$

Equation 3

Where,

N_{MAIN} : Number of primary turns

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 over-voltage level

C10 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 $V_{ZCDPthr}$ (typically 100 mV). Therefore, the power switch can be turned on at the valley point of the drain-source voltage. This is normally done through experimentation.

A 33 uF capacitor for C11 is applied to ensure stable system operation and enough break time for auto-restart protection. The VCCP resistor R15 is placed as noise attenuation in case of severe voltage spike coupling from transformer during surge test.

The AC line overvoltage protection is detected by sensing the bus capacitor voltage through the V_{INP} pin via the divider resistors R6, R7, and R8. Once the V_{INP} pin voltage is higher than the line overvoltage threshold V_{VINP_LOVP}, the controller enters the line overvoltage protection and releases the protection mode after the V_{INP} pin voltage is lower than V_{VINP_LOVP}.

Estimated LOVP voltage is calculated:

$$V_{BUS\_OVP} = V_{VINP\_LOVP} \times \frac{R8+R6+R7}{R8} = 2.80\,V \times \frac{75\,k\Omega+5100\,k\Omega+5100\,k\Omega}{75\,k\Omega} = 383\,V$$

Equation 4

A low-cost RCD clamp consist of the D1 diode and R11, R12, and R25 resistors and the C9 capacitor is implemented to suppress the peak drain voltage when turning off the power switch inside U2. 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™ SiP ICE184EM starts to take over the PWM control when output voltage reaches 95% of its regulation target. The ICE184EM PWM control is based on sensing the reflected voltage from the primary side via the ZCDS pin and the error amplifier output EA voltage. ICE184EM-integrated PWM and SR control ensures that the timing of the SR power switch (Q2) 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 enables zero voltage switching operation on 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_{MIAN} / 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

R22 is connected to CONF1 and serves as R_{SET1}, which is to preset the operation relevant parameters. Default selection is Option 1 in Table 5, R22 is set as 3.9 kΩ. There are four parameters that can be adjusted via R_{SET1} to optimize hysteretic mode performance.

By selecting different V_{EA_EHM} values, user can tune the power level of hysteretic mode; higher V_{EA_EHM} values enable higher hysteretic power. In hysteretic mode, precise control over the pulse width and timing is crucial for achieving optimal standby power. The pulse width is determined by the $V_{EA\_PWM\_HM}$ value, while the pulse starting and ending points are controlled by V_{EA_HMon} and V_{EA_HMoff}. By carefully adjusting these values, the hysteretic power can be fine-tuned to achieve the lowest standby power consumption.

Table 5 Resistance for R_{SET1}

R_{SET1}	3.9 kΩ	6.8 kΩ	12.0 kΩ	18.0 kΩ	27.0 kΩ	39.0 kΩ
EA voltage threshold for entering hysteretic mode (V_{EA_EHM})	0.586 V	0.586 V	0.605 V	0.605 V	0.624 V	0.624 V
EA voltage for pulses during hysteretic mode ($V_{EA\_PWM\_HM}$)	800 mV	900 mV	900 mV	800 mV	900 mV	800 mV
EA voltage hysteretic mode on threshold (V_{EA_HMon})	1.2 V	1.2 V	1.2 V	1.25 V	1.2 V	1.25 V
EA voltage hysteretic mode off threshold (V_{EA_HMoff})	0.9 V	0.9 V	0.9 V	0.8 V	0.9 V	0.8 V

A compensation network consisting of C15, C17, and R16 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]. This resource provides a comprehensive explanation of the calculations.

To minimize output voltage ripple, the choice of output capacitors is crucial. For C18 and C23, low equivalent series resistance (ESR) type capacitors are recommended. In addition, capacitors C24 and C25 are added to suppress high frequency noise.

5.3 Enable output signal

In this design, the ENP pin on the primary side is connected to the enable pin of a low dropout regulator (LDO). This connection allows the ENP pin to be fully controlled by the ENS signal from the secondary side, shown in Figure 3.

This approach offers two significant benefits:

1. Eliminates the need for isolated circuitry to transfer the signal from the secondary side to the primary side, simplifying the overall design and reducing component count
2. Enables the LDO output to be disabled when not required, resulting in a significant reduction in standby power loss

A straightforward relationship exists between the two signals:

- When the ENS logic is 1, the ENP logic is also 1
- When the ENS logic is 0, the ENP logic is also 0

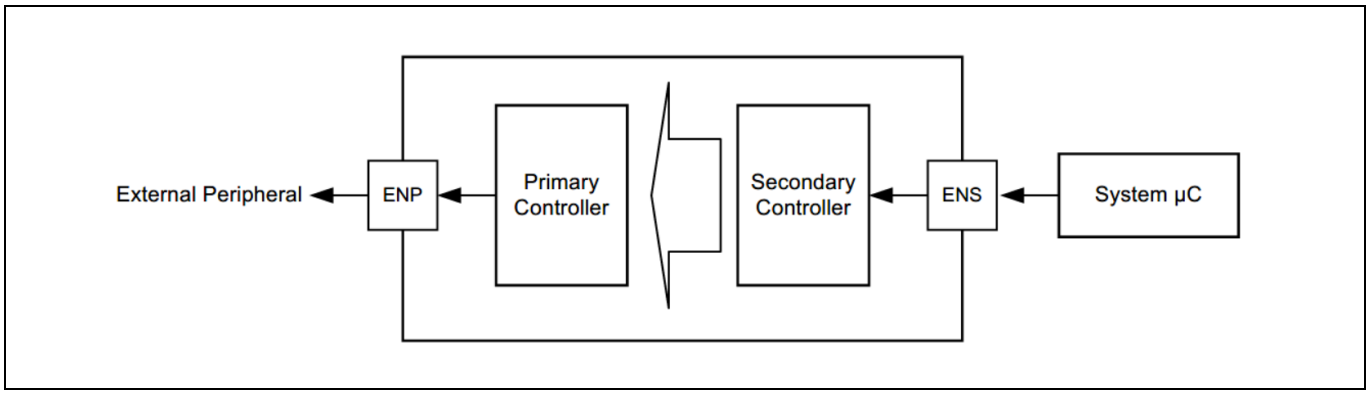


Figure 3 Enable output signal

6 PCB layout

45 W PCB layouts are shown below.

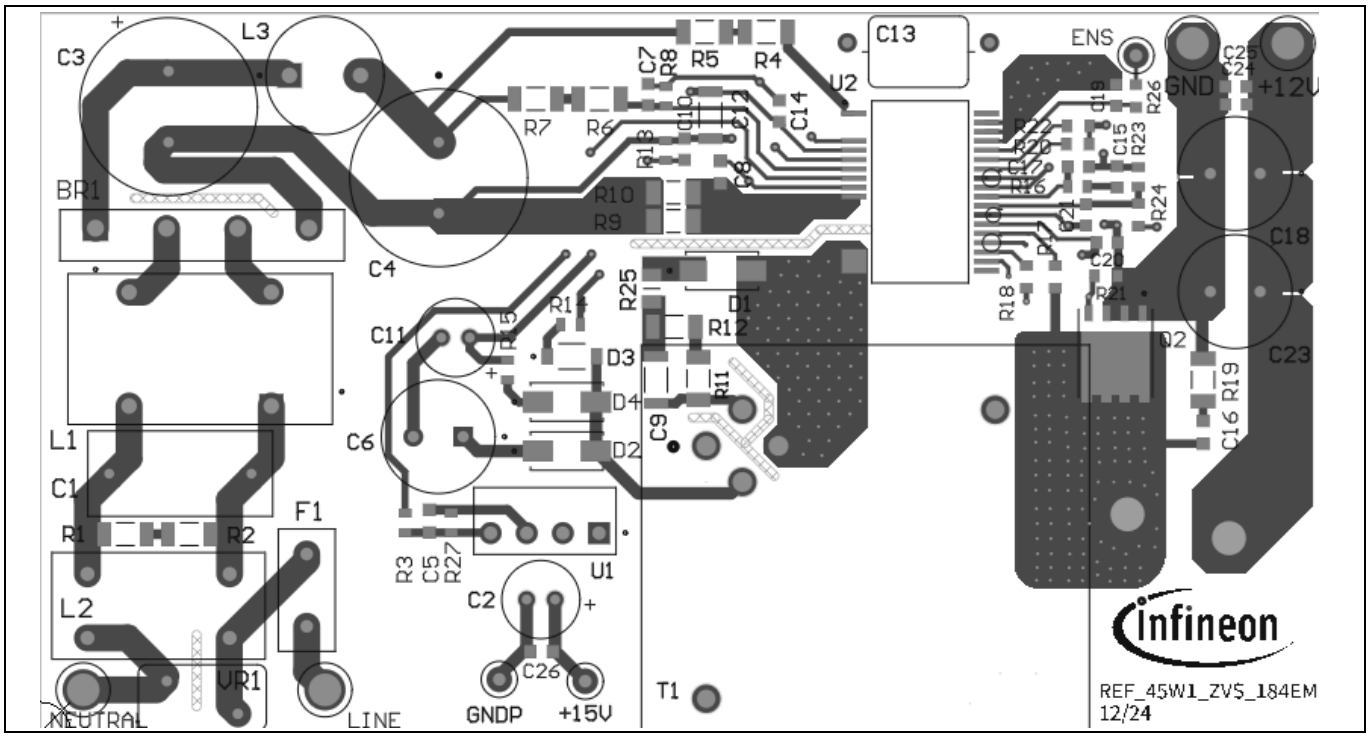


Figure 4 Top-side PCB

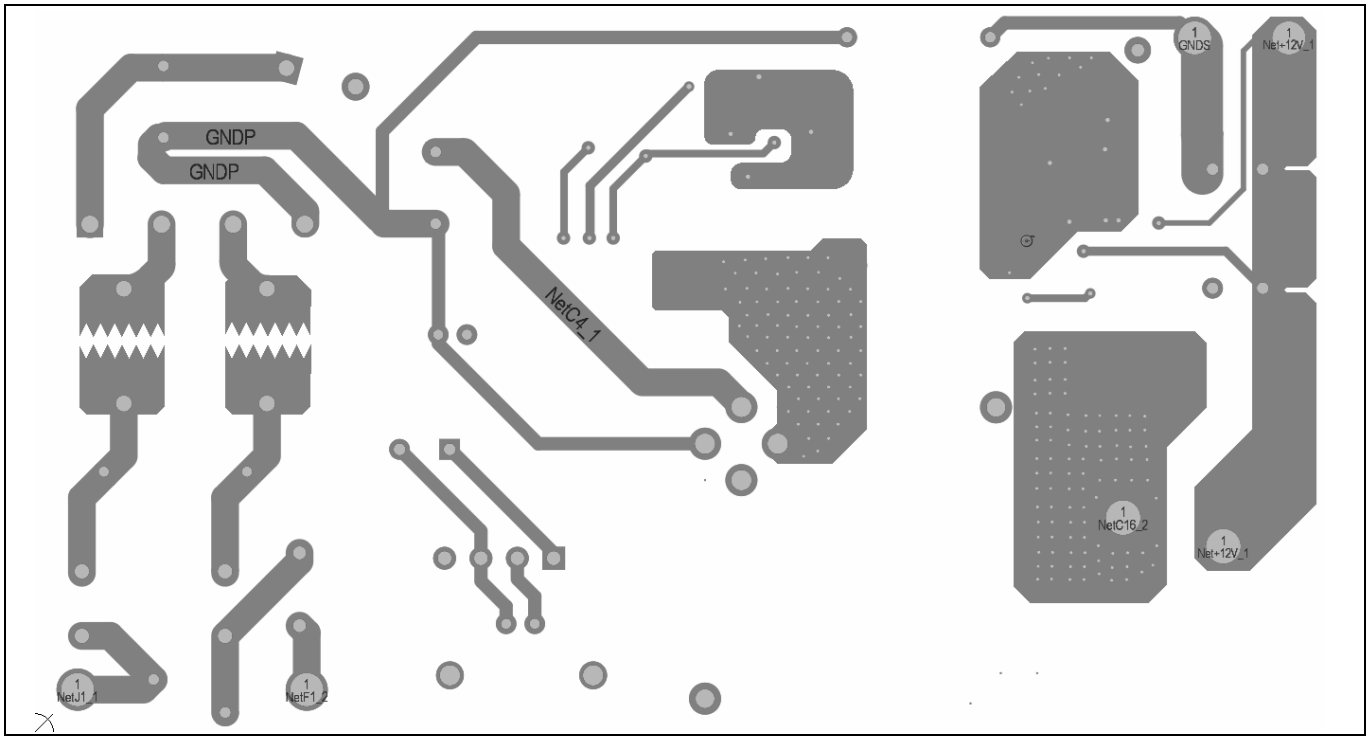


Figure 5 Bottom-side PCB

PCB layout

PCB layout is crucial to a successful design. Following are some recommendations:

1. Minimize the loop with pulse shape current or voltage, such as the loop formed by the bus voltage source, primary winding, main power switch, and current sense resistor or the loop consisting of the secondary winding, output diode, and output capacitor, or the loop of the V_{CC} power supply
2. Star the ground at the bulk capacitor: all primary grounds should be connected to the ground of the bulk capacitor separately at one point. This can reduce the switching noise entering the sensitive pins of the CoolSET™ SiP device. The primary star ground can be split into several groups:
   - Combine signal (all small signal grounds connecting to the controller GNDP pin such as the filter capacitor C7, C8, and C10) and power ground (current sense resistor R8 and R9)
   - V_{VCCP} ground includes the VCCP capacitor C11 ground and the auxiliary winding ground, pin 1 of the power transformer
   - EMI return ground includes the Y capacitor for isolated flyback application
   - DC ground from the bridge rectifier BR1
   - CoolSET™ SiP primary side GNDP pin 2 and pin 7 are recommended to jointly connected to a PCB copper plate, and then star connected to Bulk Cap Ground
3. CoolSET™ SiP secondary side GNDS pin 11, pin 19 and pin 26 are recommended to jointly connected to a PCB copper plate, and then star connected to SR MOSFET source pin
4. Place the filter capacitor (C14, C20) close to the controller ground (GNDP and GNDS) to reduce the switching noise coupled into the controller
5. High voltage (HV) trace clearance: HV traces like startup and drain traces should maintain sufficient spacing to the nearby traces to avoid arcing
6. Keep a minimum of 232 mm^2 copper area at both the primary drain pin and secondary GNDS for enhanced thermal performance of the CoolSET™ SiP

7 Bill of materials

Table 6 BOM

No.	Designator	Description	Manufacturer	Part number	Qty
1	BR1	BRIDGE RECT 1PHASE 600 V 4 A GBL	Taiwan Semicon	GBL06	1
2	C1	Safety Capacitors 0.1 uF 10% 310VAC	DGCX	MX2104KQ3C20GB2000R	1
3	C2	CAP ALUM 100UF 20% 25 V RADIAL	KEMET	ESK107M025AC3AA	1
4	C3, C4	CAP ALUM 47UF 20% 400 V RADIAL	YMIN	KCMS2002G470MF	2
5	C5, C7, C16	MLCC - SMD/SMT 1 nF 100 V 10% 0603	–	–	3
6	C6	CAP ALUM 220UF 20% 35 V RADIAL	KEMET	ESE227M035AG3AA	1
7	C8, C21	MLCC - SMD/SMT 680 pF 100 V 10% 0603	–	–	2
8	C9	MLCC - SMD/SMT 1000 PF 1 KV 10% 1206	MuRata	GRM31BR72H102KW01	1
9	C10	MLCC - SMD/SMT 50 V 33 pF C0G 0603 10%	–	–	1
10	C11	CAP ALUM 33UF 20% 50 V RADIAL	KEMET	ESH336M050AC3AA	1
11	C12	MLCC - SMD/SMT 100 V 2.2 uF X7R 1206 10%	–	–	1
12	C13	Safety Capacitors 440 V 1000pF Y5V 20% LS=10mm	KEMET	C901U102MZVDBA7317	1
13	C14, C19, C24, C25, C26	MLCC - SMD/SMT 100 nF 50 V 10% 0603	–	–	5
14	C15	MLCC - SMD/SMT 50V 68 nF X7R 0603 10%	–	–	1
15	C17	MLCC - SMD/SMT 50V 2.2 nF X7R 0603 10%	–	–	1
16	C18, C23	CAP ALUM POLY 680UF 20% 16V RADIAL	Chemi-Con	A750KW687M1EAAE016	2
17	C20	MLCC - SMD/SMT 25 V 4.7 uF X5R 0603 10%	–	–	1
18	D1	DIODE GEN PURP 1 KV 1 A SMA	Diotec	S1M	1
19	D2	DIODE 200 V 1 A DO214AC	ST	STTH1R02A	1
20	D3	Diode 200 V 1 A Surface Mount SOD-123 W	Nexperia	PMEG200G10ELRX	1
21	D4	DIODE GEN PURP 200 V 1 A SMA	Diotec	S1D	1
22	F1	Time Lag Fuse, 300 V, 3.15 A	Littelfuse	36913150000	1
23	L1	Common Mode Standard 4 Pins, 15 mH	lucky-tenda	TD1515-15.0mH, vertical	1
24	L2	Common Mode Standard 4 Pins, 250 uH	Endela	L-10-0179	1
25	L3	Radial Leaded Wire Wound Inductor WE-TI, 20 Uh	Würth Elektronik	7447720200	1
26	Q2	MOSFET Transistor, 97 A, 100 V, 8-Pin TDSON	Infineon	ISC060N10NM6ATMA1	1
27	R3, R21, R26	Resistors - SMD CRGP 0603 10K 1% SMD Resistor	–	–	3
28	R4, R5	Resistors - SMD 1/4 watt 57.6 KOhm 1206 1%	–	–	2
29	R6, R7	Resistors - SMD 5.1M 1206 1%	–	–	2
30	R8	Resistors - SMD 75 KOhm 100 mW 0603 1%	–	–	1
31	R9, R10	Resistors - SMD 1/4 watt 0.68 Ohm 1206 1%	–	–	2
32	R11, R12	Resistors - SMD 1/4 watt 150 KOhm 1206 1%	–	–	2
33	R13	Resistors - SMD 1/10 watt 2 KOhm 0603 1%	–	–	1
34	R14, R16	Resistors - SMD 20 KOhm 100 mW 0603 1%	–	–	2
35	R15, R18	Resistors - SMD 2.2 Ohm 100 mW 0603 1%	–	–	2
36	R17	Resistors - SMD 15 KOhm 100 mW 0603 1%	–	–	1

Bill of materials

No.	Designator	Description	Manufacturer	Part number	Qty
37	R19	Resistors - SMD ¼ watt 27 Ohm 1206 1%	–	–	1
38	R20	Resistors - SMD 18 KOhm 100 mW 0603 1%	–	–	1
39	R22	Resistors - SMD 3.9 KOhm 100 mW 0603 1%	–	–	1
40	R23, R27	Resistors - SMD 30 KOhm 100 mW 0603 1%	–	–	2
41	R24	Resistors - SMD 270 KOhm 100 mW 0603 1%	–	–	1
42	R25	Resistors - SMD 1/4 watt 10 Ohm 0805 1%	KOA	RK73H2ATTD10R0F	1
43	T1	RM10 10-Terminal EXT, THT, Vertical	Sumida	PS24-236	1
44	U1	4 Terminal Low Drop Voltage Regulator	KEC	KIA78R15PI	1
45	U2	CoolSET™ SiP	Infineon	ICE184EM	1
46	VR1	VARISTOR 510 V 1.75 KA DISC 7 MM	Epcos	B72207S2321K101	1
47	NEUTRAL, LINE, +12V, GND	Solder Terminal, Double Turret, .109 Long	Keystone	1502-2	4
48	ENS, +15V, GNDP	Test Point THT, Orange	Keystone	5003	3

8 Transformer specification

8.1 Electrical diagram and coil build

Manufacturer and part number: Sumida (PS24-235)

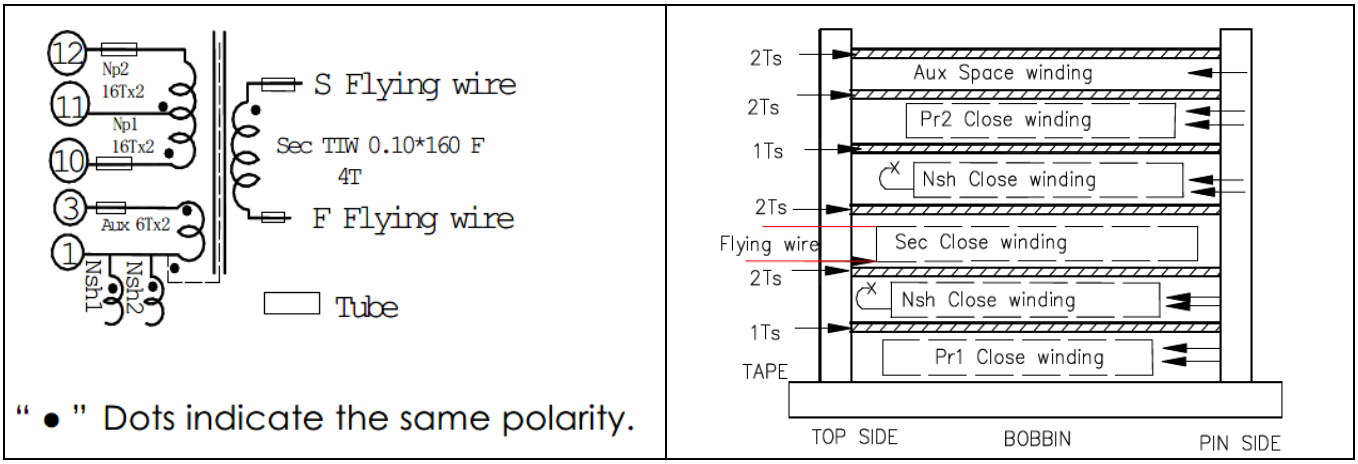


Figure 6 Electrical diagram and coil build

8.2 Electrical specifications

Electrical characteristic (at 25℃, unless of otherwise specified)

Items	Specification	Measuring conditions
Inductance (10-12)	360μH±10% Within	100kHz/0.1V
DCR (10-12)	Max. 280mΩ	
DCR (S Fly wire-F Fly wire)	Max. 4.5mΩ	
DCR (3-1)	Max. 130mΩ	
Hi top (1,3,10,11,12)-(S Fly wire, F Fly wire)	AC 3000Vrms	50/60Hz, 1mA, 2s
Hi top (1,3)-(10,11,12)	AC 1000Vrms	50/60Hz, 1mA, 2s
Turns ratio (10-12):(S Fly wire-F Fly wire):(1-3)	32:4:6 ±3%	

Figure 7 Electrical diagram

9 Measurement data and graphs

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

9.1 Efficiency result

Efficiency data have been taken under +12 V load condition. +15 V LDO is disabled during the test. For no load input power consumption, refer to the “45 W power supply using CoolSET™ SiP ICE184LM” application note [4], which excludes the impact of LDO circuity.

Table 7 Efficiency data

Input (V AC/Hz)	Load percentage	P_{IN} (W)	V_{O1} (V)	I_{O1} (A)	P_{OUT} (W)	Efficiency (%)	Average efficiency (%)
90 V AC/60 Hz	25%	12.45	12.07	0.94	11.33	91.02	91.25
	50%	24.50	12.07	1.86	22.49	91.77	
	75%	37.12	12.07	2.82	34.02	91.66	
	100%	49.85	12.05	3.75	45.14	90.56	
115 V AC/60 Hz	25%	12.44	12.06	0.94	11.33	91.06	91.83
	50%	24.62	12.07	1.88	22.67	92.06	
	75%	36.86	12.06	2.82	34.01	92.29	
	100%	49.14	12.06	3.75	45.16	91.91	
230 V AC/50 Hz	25%	12.50	12.06	0.94	11.33	90.64	92.19
	50%	24.53	12.06	1.88	22.66	92.38	
	75%	36.60	12.06	2.82	34.00	92.89	
	100%	48.63	12.05	3.75	45.15	92.85	
264 V AC/50 Hz	25%	12.57	12.06	0.94	11.33	90.16	92.00
	50%	24.60	12.06	1.88	22.66	92.13	
	75%	36.63	12.06	2.82	34.00	92.82	
	100%	48.61	12.05	3.75	45.15	92.88	

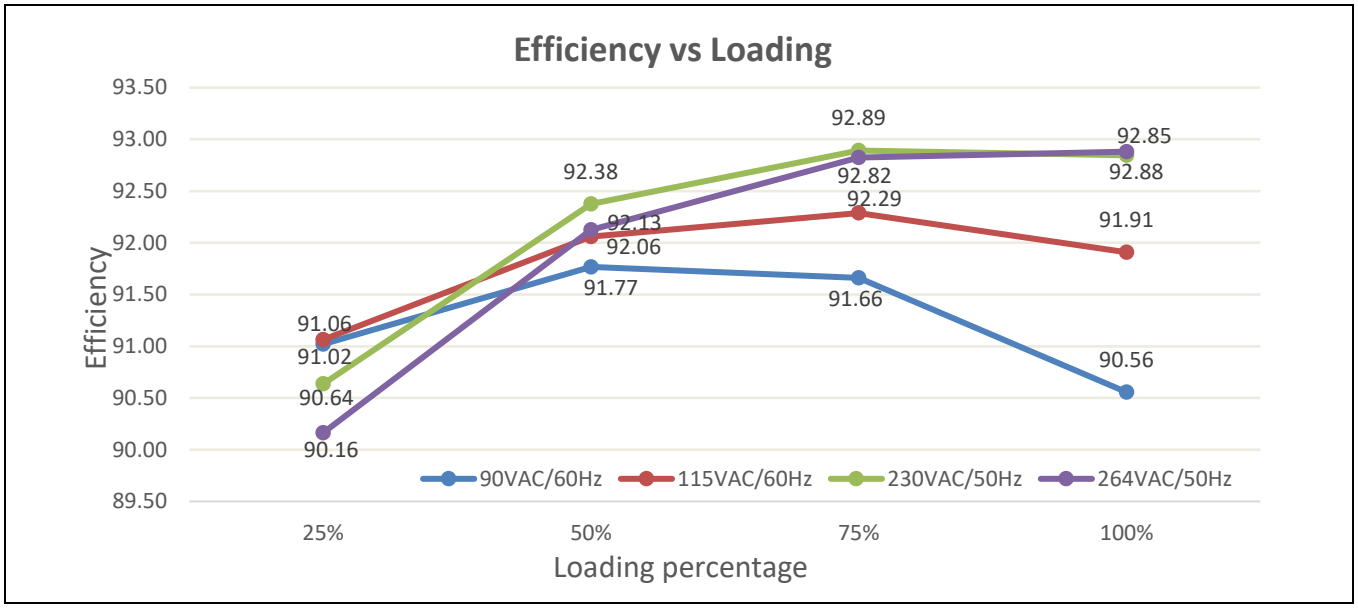


Figure 8 Efficiency vs Loading

9.2 ESD immunity (EN 61000-4-2)

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

Table 8 System ESD test result

Description	ESD test	Level	Number of strikes		Test result
			V_{O1}	GNDS	
230 V AC, 45 W	Contact	±8 kV	10	10	Pass
	Air	±15 kV	10	10	Pass

9.3 Surge immunity (EN 61000-4-5)

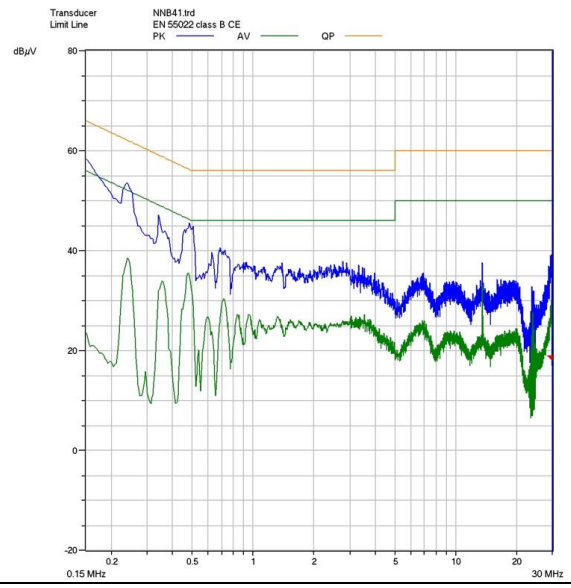
The reference board was subjected to a surge immunity test according to EN 61000-4-5 level 4 (±2 kV DM and ±4 kV CM). It was tested at full load (resistive load) and met criteria A. (Normal performance within the specification limits)
Disable input line OVP to avoid mistriggering while testing ±4 kV CM.

Table 9 System lightning surge immunity test result

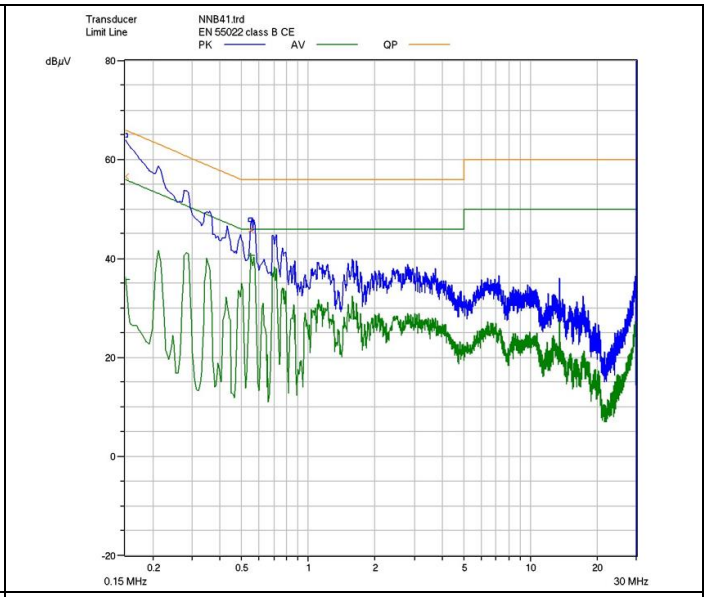
Description	Test	Level		Number of strikes				Test result
				0°	90°	180°	270°	
230 V AC, 45 W	DM	±2 kV	L → N	3	3	3	3	Pass
	CM	±4 kV	L → G	3	3	3	3	Pass
		±4 kV	N → G	3	3	3	3	Pass

9.4 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 reference board was tested at full load (resistive load) at input voltages 115 V AC and 230 V AC.



Conducted emissions at 115 V AC



Conducted emissions at 230 V AC

Figure 9 Conducted emissions

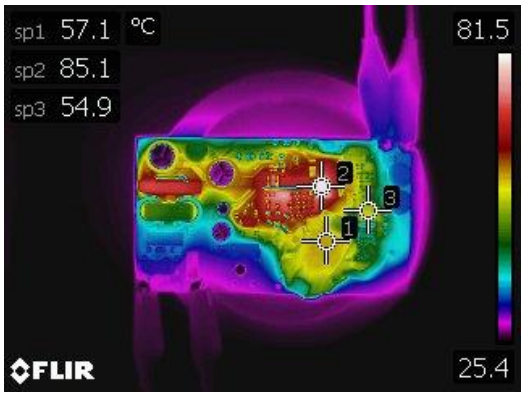
9.5 Thermal measurement

The thermal testing of the reference board was executed in open air without forced ventilation at an ambient temperature of 25°C. An infrared thermography camera (FLIR-T62101) was used to capture the thermal reading of critical components. The measurements were taken at the maximum load running for one hour. The tested input voltages were 90 V AC and 264 V AC.

Table 10 Component temperature at full load under T_a = 25°C

Circuit code	Major component	Input voltage 90 V AC	Input voltage 264 V AC
		Temperature (°C)	Temperature (°C)
T1	Main transformer	57.1	61.1
BR1	Bridge diode	69.1	44.2
U2	ICE184EM	85.1	65.0
Q2	SR MOSFET	54.9	56.8
RCD	Primary side RCD snubber	77.2	68.9

90 V AC maximum load and 25°C ambient



264 V AC maximum load and 25°C ambient

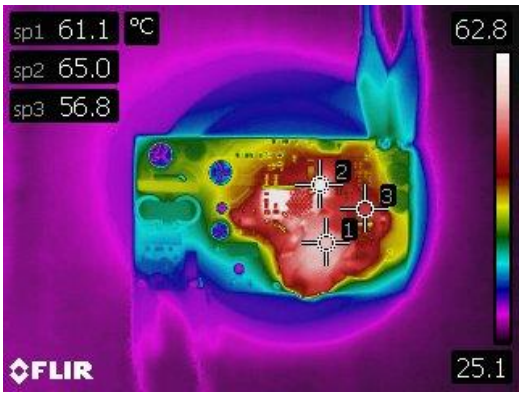


Figure 10 Thermal image of REF_45W1_ZVS_184EM

10 Waveforms and scope plots

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

10.1 Startup at full load

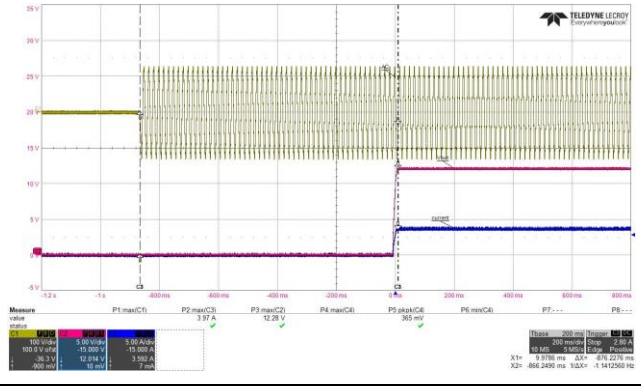
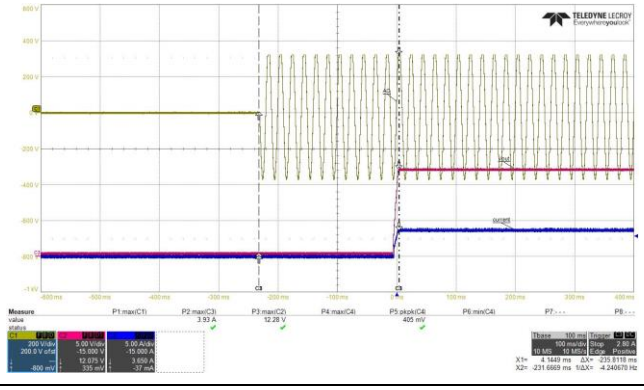
	
C1 (yellow) : AC-line voltage C2 (purple) : +12 V output voltage C3 (blue) : +12 V output current	C1 (yellow) : AC-line voltage C2 (purple) : +12 V output voltage C3 (blue) : +12 V output current
90 V AC startup time at full load is around 850 ms	264 V AC startup time at full load is around 250 ms
The board can start up as expected over 90~264 V AC, output voltage smoothly rises and regulates at 12 V	

Figure 11 Startup at full load

10.2 Switching waveform at full load

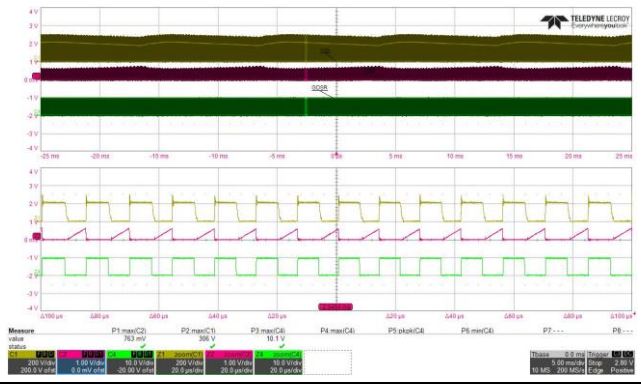
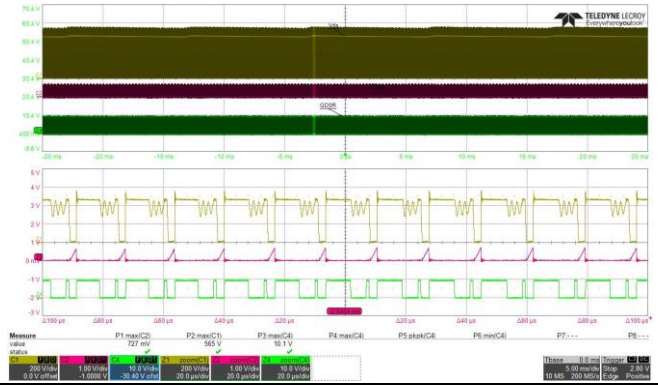
	
C1 (yellow) : Drain voltage (V_{DS}) C2 (purple) : CS voltage (V_{CS}) C4 (green) : SR gate signal (V_{GDSR})	C1 (yellow) : Drain voltage (V_{DS}) C2 (purple) : CS voltage (V_{CS}) C4 (green) : SR gate signal (V_{GDSR})
V_{IN} = 90 V AC, full load; the first valley is measured (QR = 1 at low line)	V_{IN} = 264 V AC, full load; the third valley is measured (QR = 3 at high line with ZVS switching)
CoolSET™ SiP ICE184EM operates quasi-resonant valley switching at low line and together with zero voltage switching at high line	

Figure 12 Switching waveform at full load

10.3 SR FET voltage at full load

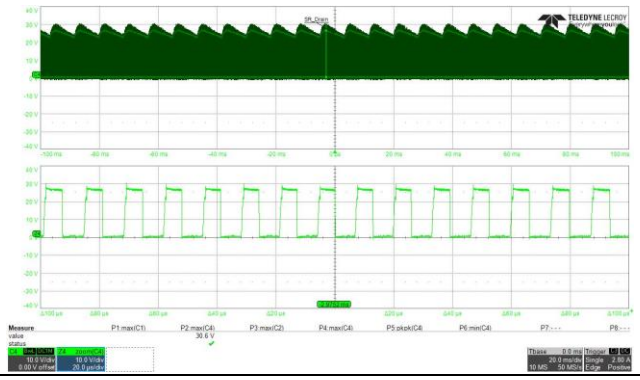
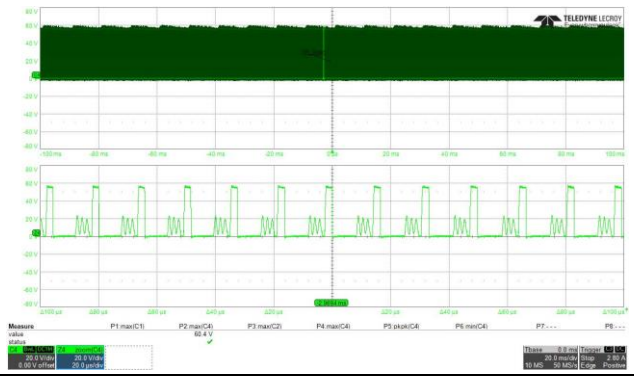
	
C4 (green) : SR Drain voltage(V_{SR_Drain})	C4 (green) : SR Drain voltage(V_{SR_Drain})
V_{IN} = 90 V AC, full load. Maximum Drain voltage is around 30.6 V	V_{IN} = 264 V AC, full load. Maximum Drain voltage is around 60.4 V
The measured SR MOSFET voltage stress at 264 Vac input is well below its voltage rating thanks to ZVS feature.	

Figure 13 SR FET voltage

10.4 Output ripple voltage at full load

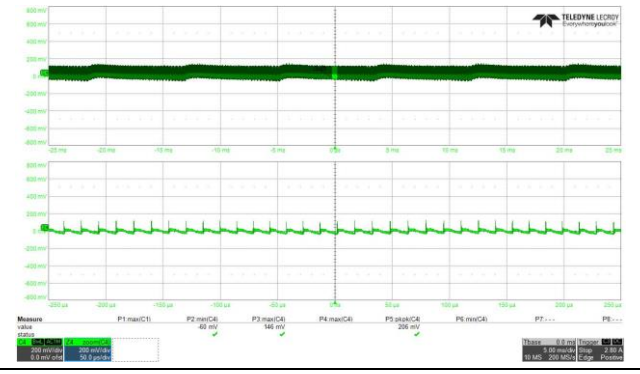
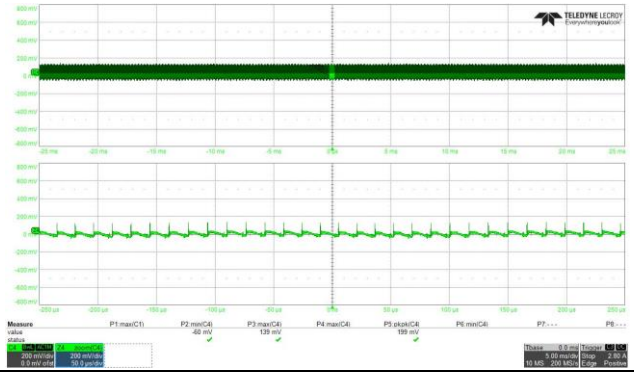
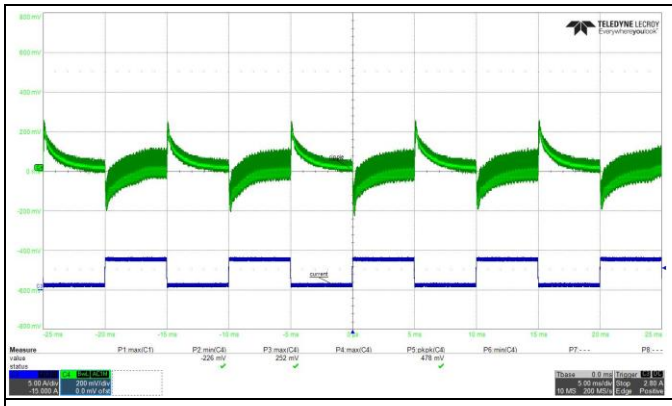
	
C4 (green) : +12 V output ripple voltage	C4 (green) : +12 V output ripple voltage
V_{IN} = 90 V AC, full load. V_{ripple_pk} for +12 V output voltage: 206 mV	V_{IN} = 264 V AC, full load. V_{ripple_pk} for +12 V output voltage: 199 mV

Figure 14 Output ripple voltage at full load (20 MHz bandwidth and 47 µF electrolytic capacitor in parallel with 0.1 µF ceramic capacitor)

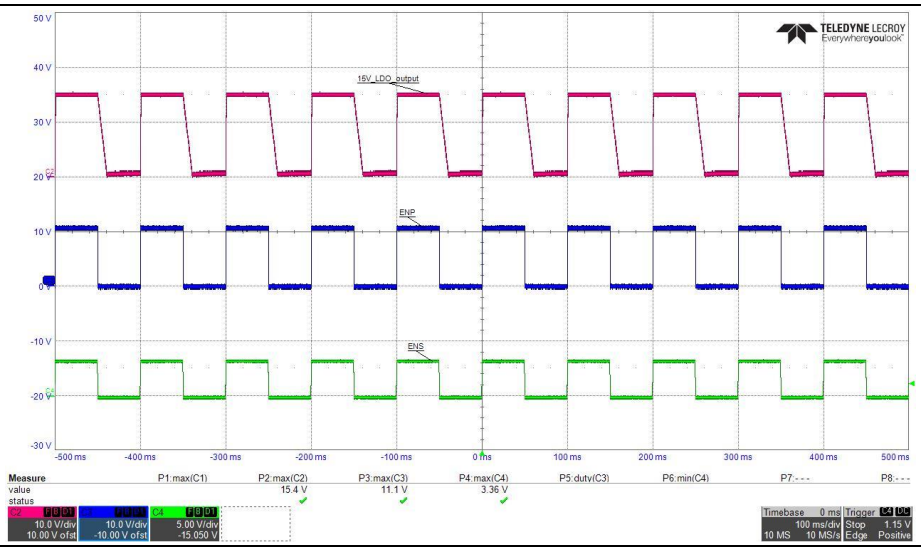
10.5 Load-transient response



C3 (blue) : Load current C4 (green) : +12 V output ripple voltage	C3 (blue) : Load current C4 (green) : +12 V output ripple voltage
V_{IN} = 90 V AC V_{ripple_max} for +12 V output voltage: 252 mV V_{ripple_min} for +12 V output voltage: -226 mV	V_{IN} = 264 V AC V_{ripple_max} for +12 V output voltage: 259 mV V_{ripple_min} for +12 V output voltage: -252 mV

Figure 15 Load-transient response (+12 V output load change from 10 percent to 100 percent at 0.4 A/µs slew rate, 100 Hz; 20 MHz bandwidth and 47 µF electrolytic capacitor in parallel with 0.1 µF ceramic capacitor)

10.6 ENS functionality



C2 (purple) : +15V LDO output voltage C2 (blue) : ENP C4 (green) : ENS
ENP is fully controlled by the ENS signal to switch on/off the primary side LDO output. With this feature, no more isolated circuity is required for sending signal from the secondary side to primary side. Meanwhile, it reduces component count, PCB space, and standby power loss

Figure 16 ENS functionality

11 Appendix: Transformer design spreadsheet

Table 11 Transformer design spreadsheet

Input parameters			**Unit**	**Value**
Input	Minimum AC input voltage	V_{ACMin}	[V]	90
Input	Maximum AC input voltage	V_{ACMax}	[V]	264
Input	Line frequency	f_{AC}	[Hz]	60
Input	DC ripple voltage	$V_{DC\ Ripple}$	[V]	35
Input	Output voltage	V_{OUT}	[V]	12
Input	Output current	I_{OUT}	[A]	3.75
Input	Maximum output power for over-load protection	P_{OUTMax}	[W]	54
Result	Nominal output power	P_{OUTNor}	[W]	45
Input	Voltage drop across SR MOSFET(Qs)	$V_{F\ SR}$	[V]	0.1
Input	Estimated efficiency under low line & full load condition	η		0.9
Result	Estimated total capacitance on Drain pin	C_{Drain}	[pF]	200
Input	Select transformer turns ratio	n		8
Result	Reflection voltage	V_R	[V]	96.8
Input	V_{VCCP} voltage	V_{VCCP}	[V]	18
Input	Forward voltage of V_{CC} diode	V_{Daux}	[V]	0.3
Input	CoolSET™ SiP		ICE184EM	
Input	Low line min. switching frequency	f_S	[Hz]	48000
Input parameter calculation				
Result	Max. input power	P_{INMax}	[W]	60.00
Result	Input RMS current	I_{AC_RMS}	[A]	1.111
Result	Max. DC input voltage	$V_{DC\ Max\_Pk}$	[V]	373.35
Result	Min. peak input voltage (with ripple voltage)	V_{DCMin_Pk}	[V]	127.28
Result	Min. DC input voltage	V_{DCMin}	[V]	90.19
Result	Discharging time for half line cycle	T_D	[ms]	6.32
Result	Required energy during discharging time	W_{IN}	[Ws]	0.38
Result	Max. duty cycle	D_{Max}		0.5177
Post calculation with input capacitor				
Result	Calculated input capacitance	C_{IN_cal}	[µF]	98.66
Input	Select input capacitor	C_{IN}	[µF]	94
Transformer parameter calculation				
Result	Primary inductance	L_P	[H]	3.572E-04
Result	Average input current of primary inductor	I_{AV}	[A]	1.29
Result	Ripple current of primary inductor	ΔI	[A]	2.723
Result	Peak current of primary inductor	I_{P_Max}	[A]	2.65
Result	Min. current of primary inductor	I_{Valley}	[A]	0.0
Result	RMS current of primary inductor	I_{P_RMS}	[A]	1.08

Select core type				
Input	Core information	Core type		RM10
		Core material		TPW33
	Maximum flux density	B_{Max}	[T]	0.35
	Minimum magnetic cross-section	A_{min}	[mm²]	98
	Bobbin width	BW	[mm]	10.49
	Winding cross-section	A_N	[mm²]	45
	Average length of turn	l_N	[mm]	38.61
Winding calculation				
Result	Number of primary turns	N_{MAIN}	Turns	27.56
Input	choose number of primary turns	N_{MAIN}	Turns	32
Result	Number of secondary turns	N_{SEC}	Turns	4.00
Input	choose number of secondary turns	N_{SEC}	Turns	4.0
Result	Number of V_{VCCP} turns	N_{AUX}	Turns	6.05
Input	choose number of auxiliary turns	N_{AUX}	Turns	6
Result	V_{VCCP} voltage	V_{VCCP}	[V]	17.85
Post calculation				
Result	Post calculation for reflection voltage	V_R	[V]	96.80
Result	Post calculation for max. duty cycle	D_{Max}		0.50
Result	Post calculation for max. flux density	B_{Max}	[T]	0.301
Result	Post calculation for max. turn-on time	$T_{ON\_MAX\_CAL}$	[us]	10.48
Result	Max. turn-on time controlled by IC (system config)	$T_{ON\_MAX\_POWER}$	[us]	11.17
Transformer winding design				
Input	Margin according to safety standard	M	[mm]	0
Input	Copper space factor	f_{Cu}		0.3
Input	Primary winding area factor	AF_{NP}		0.6
Input	Secondary winding area factor	AF_{NS}		0.35
Input	Auxiliary winding area factor	AF_{NVcc}		0.05
Primary winding				
Input	Insulation thickness	INS	[mm]	0.02
Result	Area of primary wire	A_p	[mm²]	0.25
Result	Diameter of primary wire	Dia.	[mm]	0.57
Result	Wire size	AWG		23
Input	selected Wire Size	AWG		28
Input	Number of parallel Wire	Np		2
Result	Diameter of selected primary wire	Dia.	[mm]	0.32
Result	Effective copper area of primary		[mm²]	0.1642
Result	Primary current density	Sp	[A/mm²]	6.60
Result	Effective bobbin width	BW_e	[mm]	10.5
Result	Diameter of primary wire including insulation	Od_p	[mm]	0.36

Result	Max. primary turns/layer	NL_P	Turns/layer	14
Result	Primary layers	Ln_P	Layers	3
Secondary winding				
Input	Insulation thickness	INS	[mm]	0.2
Result	Area of secondary wire	A_S	[mm^2]	1.18
Result	Diameter of secondary wire	Dia.	[mm]	1.23
Result	Wire size	AWG		16
Input	selected Wire Size	AWG		38
Input	Number of parallel Wire	Np		160
Result	Diameter of secondary wire	Dia.	[mm]	0.10
Result	Effective copper area of secondary		[mm^2]	1.3046
Result	Secondary current density	S_S	[A/mm^2]	6.61
Result	Effective bobbin width	BW_E	[mm]	10.5
Result	Diameter of secondary wire including insulation	Od_S	[mm]	1.69
Result	Max. secondary turns/layer	NL_S	Turns/layer	6
Result	Secondary layers	Ln_S	Layers	1

References

[1] Infineon Technologies AG: Datasheet – CoolSET™ SiP1EM

[2] Infineon Technologies AG: Application note – Design Guide for ZVS QR flyback using CoolSET™ SiP

[3] Infineon Technologies AG: Calculation Tool for CoolSET™ SiP

[4] Infineon Technologies AG: Application note – *45 W power supply using CoolSET™ SiP ICE184LM*

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