Title	**50 W Flyback Converter with Two Independently Regulated Outputs Using InnoMux™2-EP IMX2378F-H415**
Specification	90 VAC – 265 VAC Input; 12 V / 1.67 A and 24 V / 1.25 A Outputs
Application	Independently Regulated Multi-Output PSU
Author	Applications Engineering Department
Document Number	RDR-1043
Date	November 23, 2024
Revision	C

Summary and Features

Unique single-stage, multi-output flyback architecture enabling:

- High efficiency across line.
- Accurate independently regulated 12 V and 24 V outputs.
  - ±1% voltage accuracy across line and load
- Safety features
  - Output overvoltage protection (OVP)
  - Thermal protection with hysteretic shutdown
  - Input voltage monitor with brown-in/brown-out and line overvoltage protection

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Important Note:

Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

1 Introduction

This document is an engineering report describing a switch-mode power supply (SMPS) intended for appliances, industrial applications, or smart meters, and utilizes the IMX2378F-H415 from the InnoMux2-EP family of ICs.

The power supply has two Constant Voltage (CV) outputs: 1.67 A, 12 V and 1.25 A, 24 V, and can deliver a total maximum output power of 50 W, across universal mains input (90 VAC to 265 VAC). This design shows the high efficiency and accurate output regulation achieved by the multiplexing power control algorithm of the InnoMux-2 IC. The design demonstrates a high level of integration and high efficiency possible for a multi-output design using this technology.

The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, and performance data.

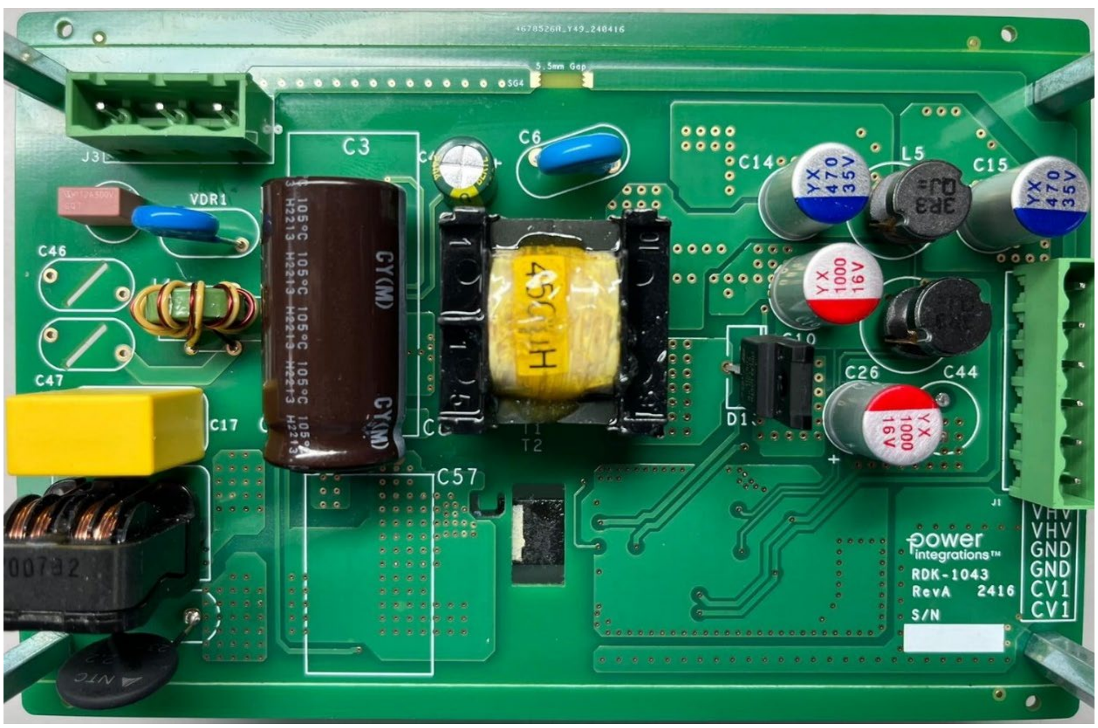


Figure 1 – Populated Circuit Board Photograph, Top.

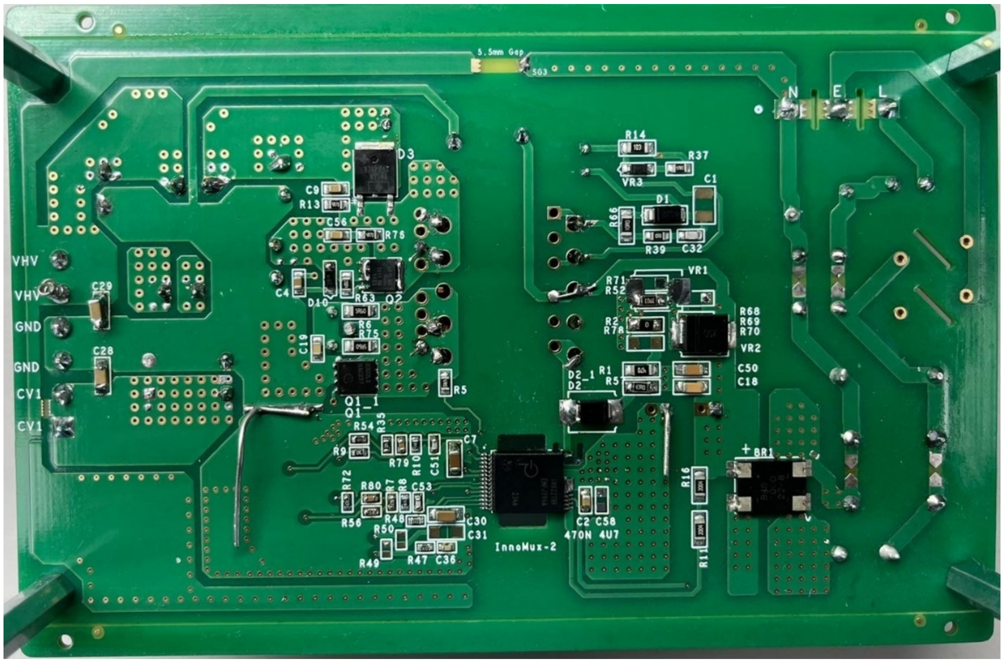


Figure 2 – Populated Circuit Board Photograph, Bottom.

2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. The actual performance is illustrated in the results section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		265	VAC	3 Wire Input.
Frequency	f_{LINE}	47	50/60	64	Hz	
Output						
Output Voltage 1	V_{OUT1}	11.4	12	12.6	V	±5%.
Output Ripple Voltage 1	$V_{RIPPLE1}$			240	mV	±1%, 20 MHz Bandwidth.
Output Current 1	I_{OUT1}	0		1.67	A	
Output Voltage 2	V_{OUT2}	22.8	24	25.2	V	±5%.
Output Ripple Voltage 2	$V_{RIPPLE2}$			480	mV	±2%, 20 MHz Bandwidth.
Output Current 2	I_{OUT2}	0		1.25	A	
Output Power	P_{OUT}		50		W	
Efficiency						
Full Load	η		90		%	Measured at 230 VAC, 25 ºC.
Standby Input Power				<0.3	W	Measured at 230 VAC 25 ºC, 5 V 30 mA.
Environmental						
Ambient Temperature	T_{AMB}	0		40	ºC	Free Convection, Sea Level.

Table 1 – Power Supply Specifications.

3 Schematic

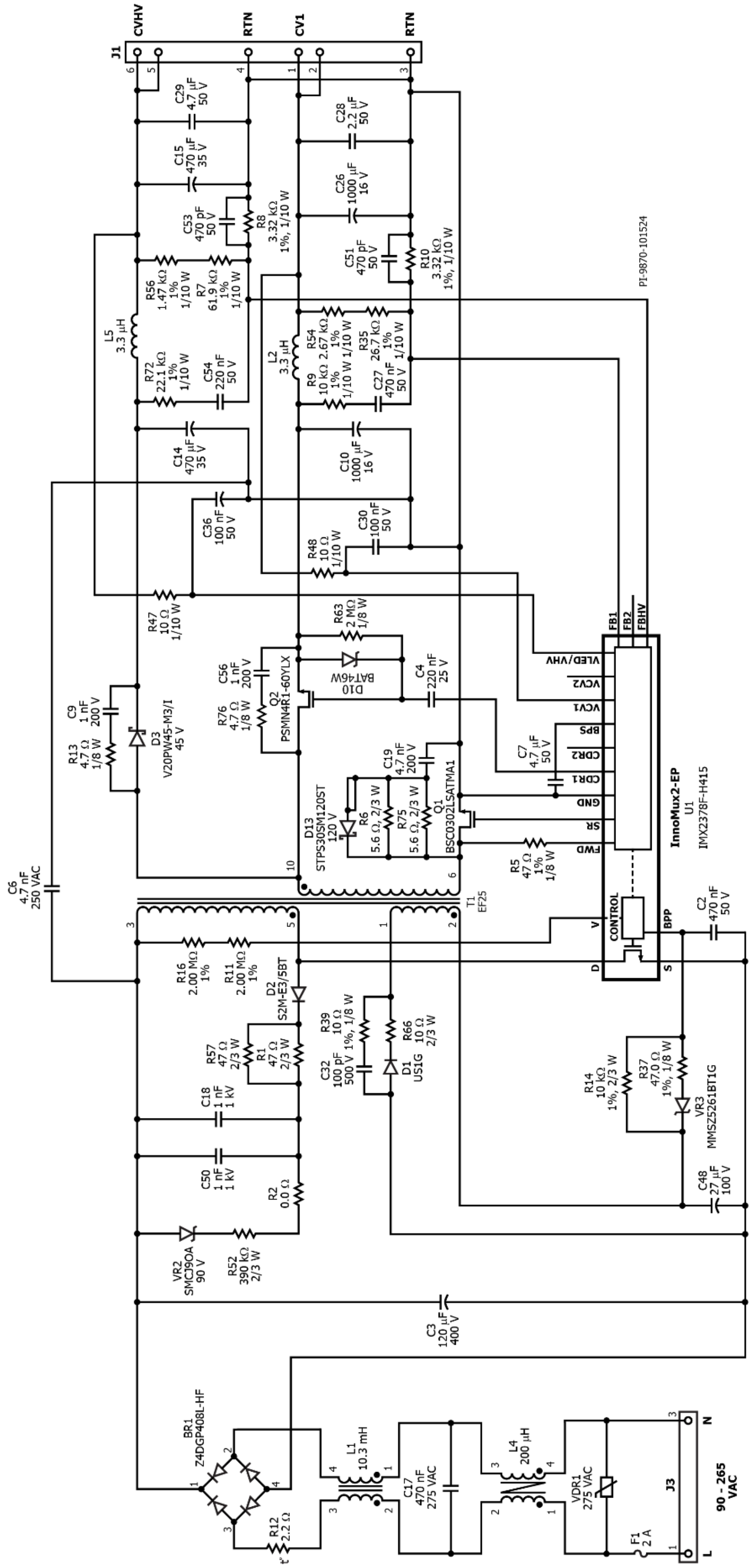


Figure 3 – Schematic

4 Circuit Description

4.1 Input Rectifier and EMI Filter

A two-stage EMI filter is used, L1 and C17, for the lower frequency range and L4, C46, C47 for the high frequency range.

The bulk storage capacitor C3 provides DC voltage smoothing after the bridge rectifier BR1. Varistor VDR1 provides protection against differential voltage surges. Resistor R12 (NTC) limits the inrush current during power up. Fuse F1 protects the PSU from drawing excessive current from the mains in the event of catastrophic circuit failure.

4.2 Primary-Side

4.2.1 Primary Switch Switching Circuit

The transformer primary is connected between the input DC bus (TXPRI+) and the drain D of the integrated primary switch of the InnoMux2-EP IC (U1, pin 28). The primary current loop closes at the negative terminal of C2 via the S pin (tab) of U1 (pin 19). An R2CD type primary clamp (D2, R1, R57, R2, R52, VR2, C18 and C50) is used to limit the peak drain voltage on the primary switch induced by the transformer leakage inductance and output trace inductance when the switch turns off.

4.2.2 Primary-Side Controller Power Source and OVP Protection

The primary-side controller is part of the InnoMux2-EP IC (U1) single chip solution. It is self-starting, using an internal high-voltage current source connected to the DRAIN pin to charge the BPP capacitor, C2, when AC voltage is first applied to the converter input. During normal operation (steady-state), the primary-side of the controller is powered from an auxiliary winding on the main transformer. The voltage across this winding is rectified and filtered using diode D1 and capacitor, C48. Resistor R66 limits transient current. The primary auxiliary output is then connected to the BPP pin via current limiting resistor R14.

4.2.3 Primary-Side OVP, Brown-In and Brown-Out Protection

Primary-side output overvoltage protection (OVP) is implemented by a Zener diode, VR3 and series resistor, R37. In the event of an uncontrolled overvoltage at the output, the increased voltage across the bias winding causes the Zener diode, VR3, to conduct increasing the current into the BPP pin. If this current exceeds I_{SD} = 7.5 mA, the OVP protection is triggered, and the controller implements a latched shutdown.

Resistors, R11 and R16, provide line voltage sensing for brown-in and brown-out and are set to approximately 75 VAC and 65 VAC respectively.

4.2.4 Primary Peak Current Limit

The value of capacitor C2 is used to set the maximum primary current to STANDARD or to INCREASED level. In this case, 470 nF capacitance sets the primary-side controller peak current limit to its STANDARD level of 1.7 A.

4.3 Secondary-Side

The secondary-side of the InnoMux2-EP IC (U1) is powered from the BPS rail which is internally regulated to 5 V. Capacitor C7 is a local decoupling capacitor.

4.3.1 Primary to Secondary-Side Communication

The secondary-side of the InnoMux2-EP IC (U1) sends switching requests to the primary-side controller via the internal FluxLink™ galvanically isolated communication channel.

4.3.2 InnoMux2-EP Power Supply

During start-up the InnoMux2-EP secondary-side controller is powered from VHV via R47. There is a local decoupling capacitor C36 connected close to the VHV pin of U1. Resistor R47 and C36 are optional and provide additional ESD protection. An internal regulator lowers the VHV voltage to 5 V and supplies it to the BPS bus (U1, pin 6).

In steady state, when the voltage on VCV1 (U1, pin 11) rises above the BPS source threshold $V_{BPS(VCV1)}$ (~7.9 V), the power input of the internal BPS regulator is switched from VHV to VCV1. Resistor R48 and capacitor C30 provide local decoupling and ESD protection.

4.3.3 Synchronous Rectifier (SR) MOSFET Drive

The SR pin is used to drive the SR MOSFET (Q1) when the transformer is delivering energy to the secondary circuit. The gate voltage of the SR MOSFET is reduced before the end of secondary discharge, to keep sufficient SOURCE to DRAIN voltage across the SR MOSFET. This prevents premature turn-off of the SR MOSFET.

In DCM operation the SR MOSFET (Q1) is turned on for a short period of time shortly before the primary switch is turned on. This action generates a reverse current in the CV1 secondary winding, which then causes a reverse current flow in the transformer on the primary-side due to commutation when the SR MOSFET is turned off. This reverse current discharges the voltage across the primary switch until the voltage is close to zero, allowing the primary switch to turn on at zero-voltage. This is termed SR-ZVS and substantially reduces switching loss.

4.3.4 Selection MOSFET Drive for Q2

The gate drive amplitude for the selection MOSFET Q2 is approximately equal to the voltage on the BPS rail (5 V). Consequently, logic level MOSFETs must be used. When CDR1 is low, capacitor C4 is charged up to the level of V_{CV1} from CV1 output via diode D10. When the selection MOSFET Q2 needs to be turned on, CDR1 pin voltage is raised from GND to BPS, causing the gate voltage of the selection MOSFET to rise to $V_{CV1}+V_{BPS}$.

4.3.5 Output Control

Rectification for the CV1 output is provided by the synchronous rectifier MOSFET (Q1) and the CV1 selection MOSFET (Q2). To ensure low output ripple voltage, a Π – type LC filter

(C10, C26 and L2) is employed. A low ESR capacitor, C10, is used in the first stage to mitigate the ripple current. Capacitor, C26, is an Al-polymer type to minimize switching noise. Additionally, a multilayer ceramic (MLC) capacitor C28 is connected across the CV1 output terminals to provide a low-impedance bypass for high-frequency noise.

Output rectification for the CVHV output is provided by SR FET (Q1) and diode (D3). Very low-ESR capacitors, C14 and C15, provide energy storage and filtering at the output. An inductor, L5, is inserted between C14 and C15 to reduce the ripple and noise at the CVHV output.

The RC snubber network (R6, R75, C19 and D13) serves to dampen high-frequency ringing across the SR MOSFET Q1. This ringing is a result of the transformer leakage inductance and the secondary trace inductance oscillating with the MOSFET parasitic capacitance. The RC snubber network, R76 and C56, dampens high-frequency ringing across the CV1 selection MOSFET Q2, while the RC snubber network, R13 and C9, reduce high-frequency transient voltage across the CVHV diode (D3).

When both the selection MOSFET (Q2) and the SR FET (Q1) are turned on, the transformer secondary winding turns ratios are set such that the voltage on the anode of D3 is below VCVHV. As a result, D3 remains reverse-biased, ensuring that all the transformer energy is directed to the CV1 output through Q1.

When the selection MOSFET (Q2) is turned off, and SR MOSFET (Q1) is turned on, the voltage on the anode of D3 rises until it is forward-biased. In this state, all the transformer energy is then directed to CVHV output.

The VCV1 output voltage is set by R35, R54, R10 and C51 with control provided to FB1 (U1, pin 1). Loop compensation is necessary due to the use of L2 and is provided by R9 and C27. The VCVHV output voltage is set by R7, R56, R8 and C53 with the control signal provided to FBHV (U1, pin 8). Loop compensation is necessary due to the use of L5 and is provided by R72 and C54.

5 PCB Layout

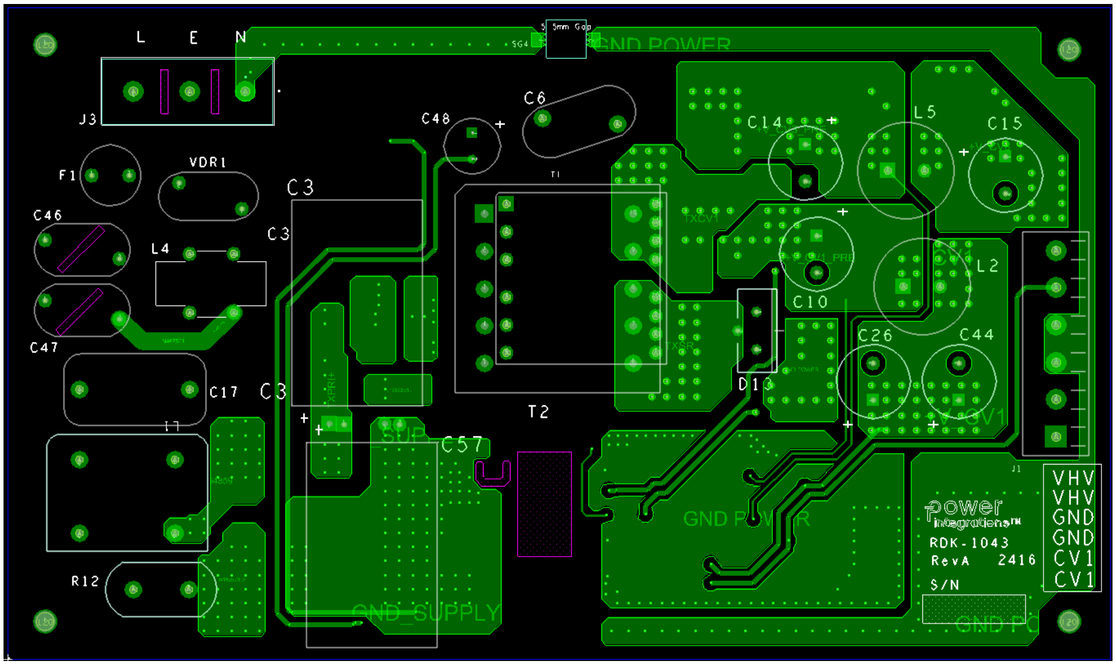


Figure 4 – Printed Circuit Board Layout, Top.

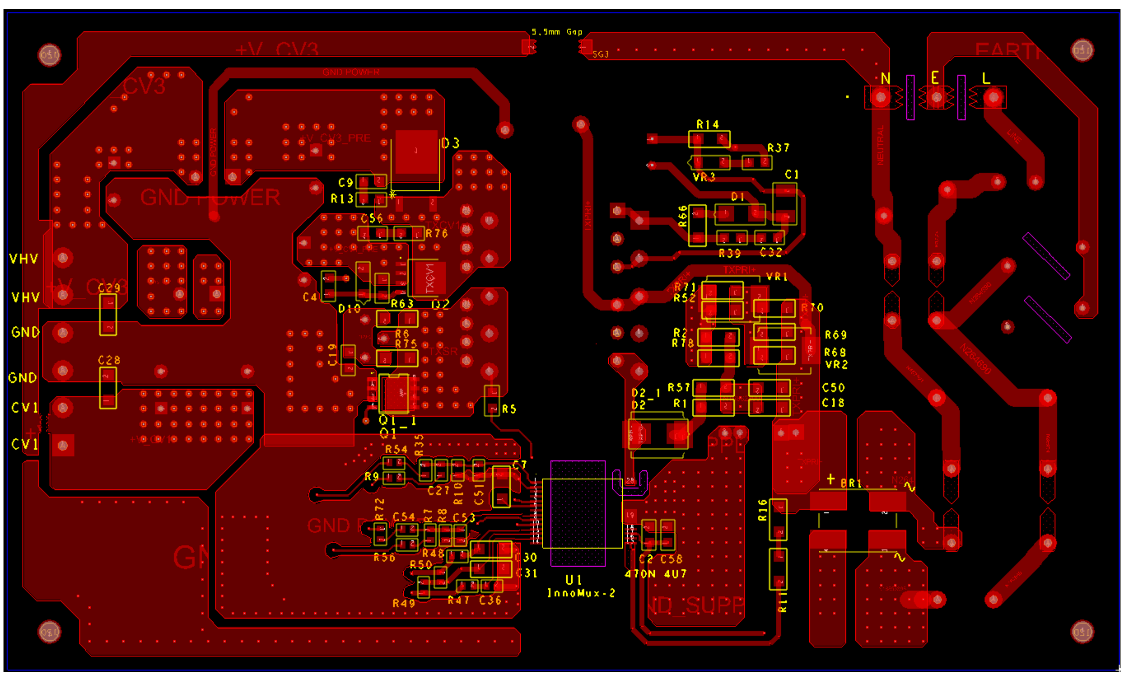


Figure 5 – Printed Circuit Board Layout, Bottom.

6 Bill of Materials

Item	Ref Des	Description	Mfg Part Number	Mfg
1	BR1	RECT BRIDGE, GP, 800V, 4A, Z4-D	Z4DGP408L-HF	Comchip Tech
2	C2	470 nF, ±10%,50 V, Ceramic, X7R, 0805	CL21B474KBFVPNE	Samsung
3	C3	120 uF, 400 V, Electrolytic, (18 x 35.5)	UPT2G121MHD6	Nichicon
4	C4	220 nF, 25 V, Ceramic, X7R, 0805	CC0805KRX7R8BB224	Yageo
5	C6	4.7 nF, Ceramic, Y1	440LD47-R	Vishay
6	C7	4.7 uF, 50 V, Ceramic, X7R, 1206	UMK316AB7475KL-T	Taiyo Yuden
7	C9	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX Corp
8	C10	1000 µF, ±20%, 16 V, Aluminum - Polymer Capacitors Radial, Can, 12mOhm 5000 Hrs @ 105°C, (10 x 13)	16SEPF1000M+T	Panasonic
9	C14	470 uF, 35 V, Electrolytic, Low ESR, 23 mOhm, (10 x 20)	UHD35470MPD	Nichicon
10	C15	470 uF, 35 V, Electrolytic, Low ESR, 23 mOhm, (10 x 20)	UHD35470MPD	Nichicon
11	C17	470 nF, 275 VAC, Film, X2	80-R46KI347050P1M	Kemet
12	C18	1 nF, 1000 V, Ceramic, X7R, 1206	CC1206KKX7RCBB102	Yageo
13	C19	4.7 nF, 200 V, Ceramic, X7R, 0805	08052C472KAT2A	AVX Corp
14	C26	1000 µF, ±20%, 16 V, Aluminum - Polymer Capacitors Radial, Can, 12mOhm 5000 Hrs @ 105°C, (10 x 13)	16SEPF1000M+T	Panasonic
15	C27	470 nF, 50 V, Ceramic, X7R, 0603	UMK107B7474KA-TR	Taiyo Yuden
16	C28	2.2 uF, ±10%,50 V, Ceramic, X7R, 1206 (3216 Metric)	CL31B225KBHNNNE	Samsung
17	C29	4.7 uF, 50 V, Ceramic, X7R, 1206	UMK316AB7475KL-T	Taiyo Yuden
18	C30	100 nF, 50 V, Ceramic, X7R, 1206	CC1206KRX7R9BB104	Yageo
19	C32	100 pF, 500 V, Ceramic, NP0, 0805	501R15N101KV4T	Johanson Die
20	C36	0.1 µF (100 nF) ±10% 50V Ceramic Capacitor X7R 0603 (1608 Metric)	GCM188R71H104KA57D	Murata
21	C48	27 uF, ±20%, 100 V, Al Electrolytic, Gen. Purpose, Can, (8mm x 13mm)	EEU-FS2A270B	Panasonic
22	C50	1 nF, 1000 V, Ceramic, X7R, 1206	CC1206KKX7RCBB102	Yageo
23	C51	470 pF, ±10%, 50V, Ceramic, X7R, 0603 (1608 Metric), 0.063" L x 0.031" W (1.60mm x 0.80mm)	CL10B471KB8NFNC	Samsung
24	C53	470 pF, ±10%, 50V, Ceramic, X7R, 0603 (1608 Metric), 0.063" L x 0.031" W (1.60mm x 0.80mm)	CL10B471KB8NFNC	Samsung
25	C54	220 nF 50 V, Ceramic, X7R, 0603	CGA3E3X7R1H224K	TDK Corp
26	C56	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX Corp
27	D1	DIODE ULTRA FAST, GPP, 400V, 1A SMA	US1G-13-F	Diodes, Inc
28	D2	Diode 1000 V 1.5A Surface Mount DO-214AA (SMB)	S2M-E3/5BT	Vishay
29	D3	Diode, Schottky, 45 V, 20A, Surface Mount SlimDPAK, TO-252AE	V20PW45-M3/I	Vishay
30	D10	DIODE, SCHOTKY, 100V, 0.075A, SOD123	BAT46W-TP	Micro Com
31	D13	Diode, Schottky, 120 V, 30 A, Through Hole, TO-220AB	STPS30SM120ST	ST
32	F1	2 A,250V, Slow, TR5	37212000411	Wickman
33	J1	CONN TERM BLOCK 5.08MM 6POS, Screw - Leaf Spring, Wire Guard	OSTTA064163	On Shore Tech
34	J3	3 Position Wire to Board Terminal Block, Horizontal with Board, 0.300" (7.62mm) Through Hole	282845-3	TE Connect
35	L1	CMC 10.3MH 2.0A 0.15OHM WIDE IMP	SSR21NVS-M20103	KEMET
36	L2	FIXED IND, 3.3UH, ±20%,5.2A, 16 MOHM, TH	ELC-10E471L	PANASONIC
37	L4	Custom 200 uH CMC	TSD-5240	Premier Magnetics
38	L5	FIXED IND, 3.3UH, ±20%,5.2A, 16 MOHM, TH	ELC-10E471L	PANASONIC
39	Q1	MOSFET, N-Channel 120 V 12A (Ta), 99A (Tc) 156W (Tc) Surface Mount PG-TDSON-8-7, TDSON-8-7	BSC0302LSATMA1	Infineon
40	Q2	MOSFET, N-Channel 60 V 100A (Tc) 238W (Tc) Surface Mount LFPAK56, Power-SO8, SC-100, SOT-669, SOT-669-4	PSMN4R1-60YLX	Nexperia
41	R1	RES, 47 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J470V	Panasonic
42	R2	RES, 0 R, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEY0R00V	Panasonic
43	R5	RES, 47.0 R, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF47R0V	Panasonic
44	R6	RES, 5.6 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J5R6V	Panasonic

45	R7	RES, 61.9 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF6192V	Panasonic
46	R8	RES, 3.32 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF3321V	Panasonic
47	R9	RES, 10.0 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1002V	Panasonic
48	R10	RES, 3.32 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF3321V	Panasonic
49	R11	RES, 2.00 M, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
50	R12	Inrush Current Limiter, 2.2 Ohms ±20%, 7 A, 0.591" (15.00mm)	B57237S0229M051	EPCOS - TDK
51	R13	RES, 4.7 R, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ4R7V	Panasonic
52	R14	RES, 10 k, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J103V	Panasonic
53	R16	RES, 2.00 M, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
54	R35	RES, 26.7 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF2672V	Panasonic
55	R37	RES, 47.0 R, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF47R0V	Panasonic
56	R39	RES, 10 R, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF10R0V	Panasonic
57	R47	RES, 10 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ100V	Panasonic
58	R48	RES, 10 R, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ100V	Panasonic
59	R52	RES, 390 k, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J394V	Panasonic
60	R54	RES, 2.67 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF2671V	Panasonic
61	R56	RES, 1.47 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1471V	Panasonic
62	R57	RES, 47 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J470V	Panasonic
63	R63	RES, 2 M, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ205V	Panasonic
64	R66	RES, 10 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J100V	Panasonic
65	R72	RES, 22.1 k, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF2212V	Panasonic
66	R75	RES, 5.6 R, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J5R6V	Panasonic
67	R76	RES, 4.7 R, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ4R7V	Panasonic
68	T1	Custom Transformer	POL-INN063	Premier Magnetics
69	U1	InnoMux2-EP, IMX2378F, InSOP-T28D	IMX2378F-H415	Power Integrations
70	VDR1	275 VAC, 45 J, 10 mm, RADIAL	V275LA10P	Littlefuse
71	VR2	Tvs Diode, Unidirectional, 90V Reverse Standoff, 146V Clamp, 10.3A Ipp, Surface Mount SMC (DO-214AB)	SMCJ90A	TAIWAN SEMI
72	VR3	DIODE ZENER 47V 500MW SOD123	MMSZ5261BT1G	ON Semi

Table 2 – Bill of Materials.

7 Transformer (T1) Specification

7.1 Core Information

E 25/13/7 (EF 25)

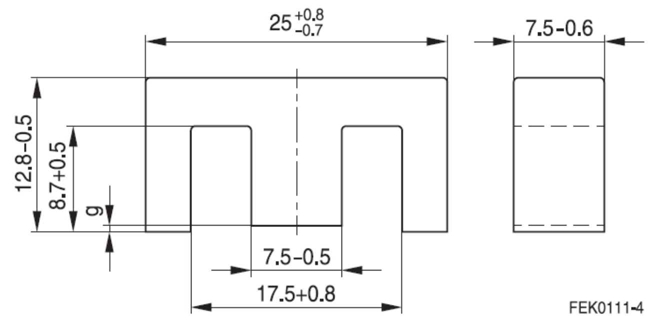
Core **B66317**

- To IEC 63093-8
- Delivery mode: single units

Magnetic characteristics (per set)

$\Sigma l/A = 1.1\ mm^{-1}$
$l_e = 57.5\ mm$
$A_e = 52.5\ mm^2$
$A_{min} = 51.5\ mm^2$
$V_e = 3020\ mm^3$

Approx. weight 16 g/set



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Material	A_L value nH	μ_e	P_V W/set	Ordering code
N30	2900 +30/–20%	2530		B66317G0000X130
N27	1750 +30/–20%	1520	< 0.59 (200 mT, 25 kHz, 100 °C)	B66317G0000X127
N87	1850 +30/–20%	1620	< 1.60 (200 mT, 100 kHz, 100 °C)	B66317G0000X187
N97	1950 +30/–20%	1700	< 1.40 (200 mT, 100 kHz, 100 °C)	B66317G0000X197

Figure 6 – EF25 Core Information.

7.2 Bobbin Information

E 25/13/7 (EF 25)	
Accessories	B66208

Horizontal version (B66208B,B66208R)

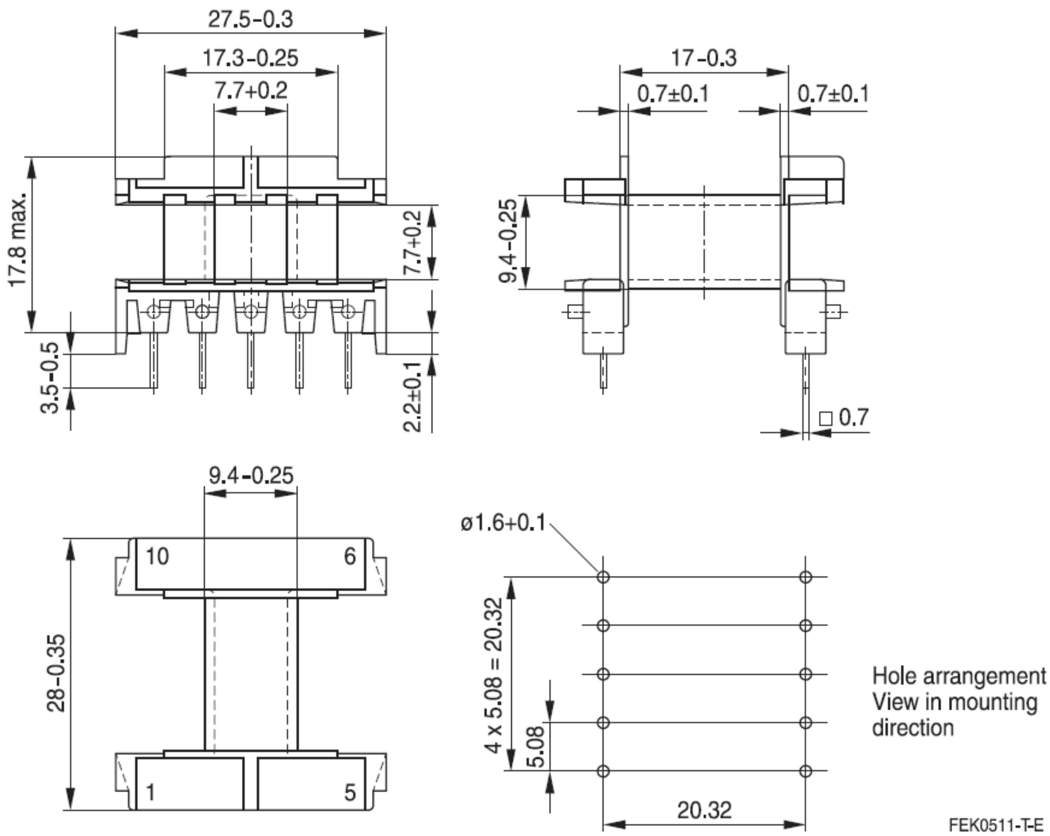


Figure 7 – EF25 Bobbin Information.

7.3 Electrical Winding Diagram

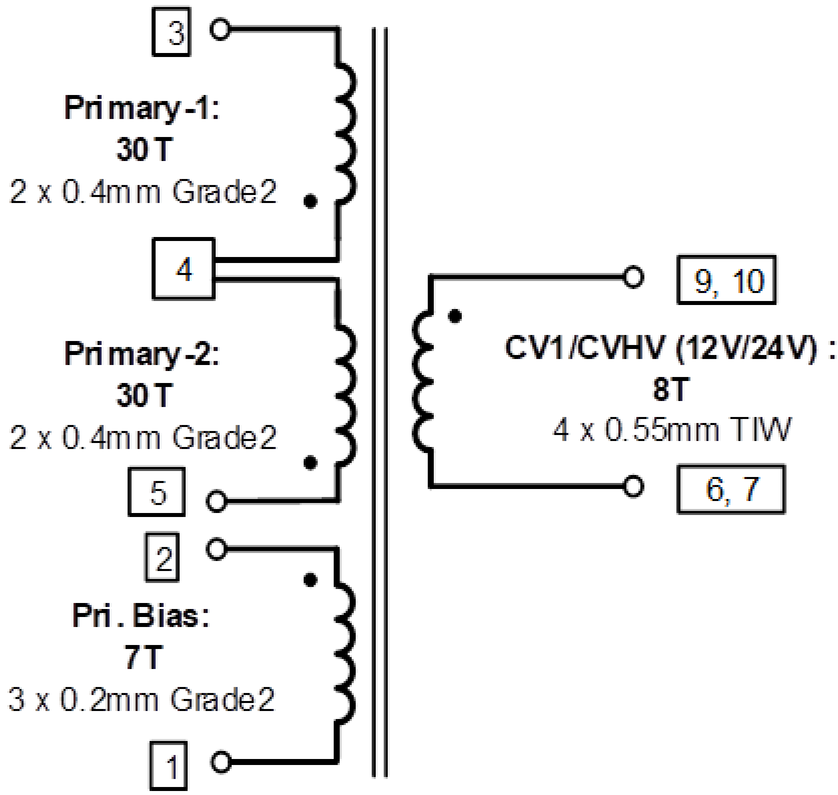


Figure 8 – Transformer Electrical Diagram.

7.4 Transformer Electrical Specification

Parameter	Condition	Spec.
Electrical strength	1 second, 60 Hz from pins 1-5 to 6-10.	3000 VAC
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 3 and 5, with all other windings open.	450 µH ±5%
Resonant Frequency	Between pin 3 and 5, other windings open.	1,100 kHz (Min.)
Primary Leakage Inductance	Between pin 3 and 5, with all secondary 6, 7, 8, 9 and 10 shorted.	10 µH (Max.)

Table 3 – Transformer Electrical Specifications.

7.5 Winding Stack Diagram

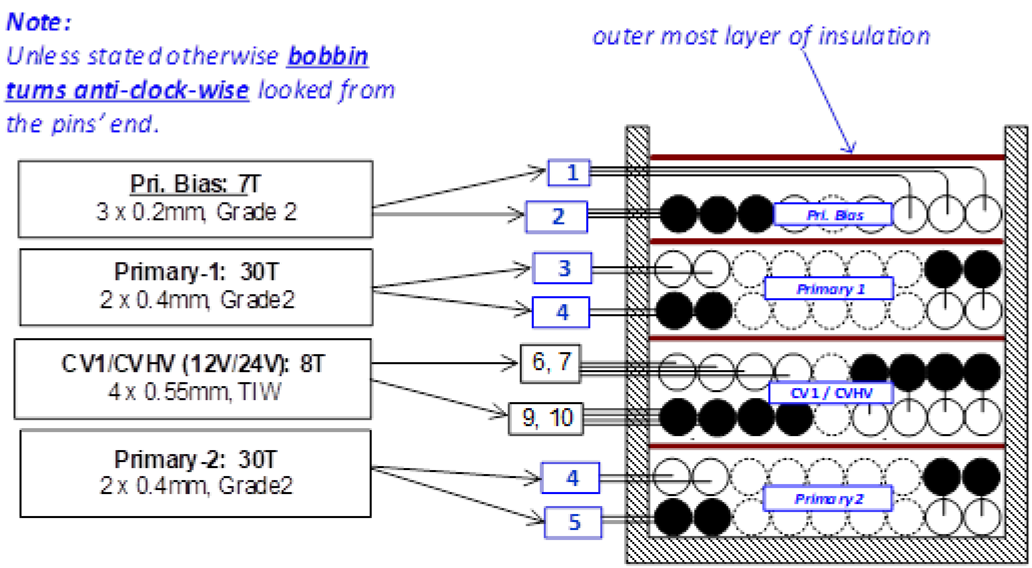


Figure 9 – Transformer Build Diagram.

7.6 List of Materials

Item	Description
[1]	Core: EF25.
[2]	Bobbin with Cover: EF25, 10pins (5/5).
[3]	Magnet Wire: 0.2 mm, Grade 2 ECW.
[4]	Magnet Wire: 0.4 mm, Grade 2 ECW.
[5]	TEX-E Wire: 0.55 mm, Triple Insulated.
[6]	Tape: 3M 1298 Polyester Film, 1 mil thick, 11.5 mm Wide.
[7]	Tape: 3M 1298 Polyester Film, 1 mil thick, 12 mm Wide.
[8]	Tape: 3M 1298 Polyester Film, 1 mil thick, 8.5 mm Wide.
[9]	Varnish: Recommended, E962-A (alternative: Dolph BC-359).
[10]	Glue: Recommended, H907 (alternative: Devcon 5-minute Epoxy).

Table 4 – Transformer Materials List.

8 Transformer Design Spreadsheet

InnoMux2_EP_031924; Rev.1.5; Copyright Power Integrations 2024	**INPUT**	**INFO**	**OUTPUT**	**UNITS**	**DESCRIPTION**
Power Supply Basic Parameters					RDK-1043, TX=EF25, revA4
OUTPUT CONFIGURATION	CV1_CVHV		CV1_CVHV		Output configuration
DC INPUT VOLTAGE	NO		NO		Yes = DC input; No = AC input
VAC MIN			90	V	Minimum AC input voltage
VAC NOM			115	V	Nominal AC input voltage
VAC MAX			265	V	Maximum AC input voltage
PO			50.04	W	Total output power @ nominal load condition
PIN			56.86	W	Input power @ nominal load condition
PTRF			53.79	W	Power processed by the transformer @ nominal load condition
FL			60	Hz	AC line frequency
VMAX			374.8	V	Maximum rectified input voltage
N			0.88		Estimated converter efficiency
Z			0.55		Secondary loss allocation
USE SR	Auto		YES		Use synchronous rectification
Input Section					
CIN	120		120	uF	Input capacitance
VMIN			100.8	V	Minimum DC input voltage calculated at VAC MIN and nominal power
VMIN AVG			115.5	V	Rectified average input voltage calculated at VAC MIN and nominal power
CV1 Specification					
OUTPUT TYPE			CV		Output control type
VOUT CV1	12.00		12.00	V	CV1 voltage
IOUT CV1	1.670		1.670	A	CV1 current
IOUT CV1 [PEAK POWER]	1.670		1.670	A	CV1 current for peak power requirement
CONNECTION TYPE CV1	Auto		SINGLE_WINDING		Winding connection type
CVHV Specification					
OUTPUT TYPE			CVHV		Output control type
VOUT CVHV	24.00		24.00	V	CVHV voltage
IOUT CVHV	1.250		1.250	A	CVHV current
IOUT CVHV [PEAK POWER]	1.250		1.250	A	CVHV current for peak power requirement
CONNECTION TYPE CVHV	SINGLE_WINDING		SINGLE_WINDING		Winding connection type
Other Design Conditions					
FS TARGET	100.00		100.00	kHz	Target maximum frequency at VMIN and peak power
KP TARGET	0.810		0.810		Minimum KP target at VMIN and peak power
BP MAX			0.33	T	Maximum allowed peak flux density at VMIN and peak power
MAXIMUM VOR	190.0		190.0	V	Reflected output voltage maximum limit
PI Device Variables					
DEVNAME	Auto		IMX2378F-H415		Device name
BVDSS			750	V	Drain to source breakdown voltage
PACKAGE			InSOP 28D		Device package
DEVICE_MODE	Standard		Standard		Device current limit mode
ILIMIT TOL	5.00		5.00	%	Current limit tolerance
ILIMIT MIN		Info	1.615	A	The specified ILIMIT MIN differs from the datasheet's value.
ILIMIT TYP	1.700	Info	1.700	A	Standard part: 1.6 A. Custom feature code necessary. Please contact local PI Sales Office for further details.

ILIMIT MAX		Info	1.785	A	The specified ILIMIT MAX differs from the datasheet's value.
FS LIMIT			110.00	kHz	Controller maximum switching frequency in steady-state condition
FS ABS MAX			145.00	kHz	Controller absolute maximum switching frequency in transitory condition
RDSON			0.78	Ohm	Drain to source on-time resistance
VDS			0.92	V	On-state drain to source voltage
Transformer Parameters					
Core and Bobbin Parameters					
CR TYPE	Custom		Custom		Core type (Compare transformer values against datasheet as it may differ per manufacturer.)
CR PN	EF25		EF25		Core part number
BB TYPE	EF25		EF25		Bobbin type
PRIMARY PINS	5		5		Number of primary pins in the bobbin
SECONDARY PINS	5		5		Number of secondary pins in the bobbin
BW	15.60		15.60	mm	Bobbin width
BFW	3.95		3.95	mm	Bobbin height
AE	52.5		52.5	mm^2	Core cross-sectional area
LE	57.5		57.5	mm	Core magnetic path length
VE	3020.0		3020.0	mm^3	Core volume
AL	1750		1750	nH/T^2	Ungapped core specific inductance
Inductance and Core Gap					
LP TOL			5.00	%	Primary inductance tolerance
LP MIN			427.7	uH	Minimum primary inductance
LP TYP			450.2	uH	Nominal primary inductance
LP MAX			472.7	uH	Maximum primary inductance
LG			0.490	mm	Estimated gap length
Construction Parameters					
NP	60		60		Primary winding total number of turns
NS SINGLE WINDING	8		8		Single winding output number of turns
BM			0.260	T	Maximum flux density in steady-state conditions (@FS MAX) and nominal power condition
BP			0.276	T	Peak flux density in transitory conditions (@FS ABS MAX)
VOR CV1			90.0	V	Primary reflected output voltage during CV1 output conduction
VOR CVHV			187.5	V	Primary reflected output voltage during CVHV output conduction
VOR MARG CVHV-CV1 ACTUAL			97.50	V	Minimum actual VOR margin between CVHV output and CV2 output reflected voltage
Operating Parameters Worst (Nominal Power)					
FS MAX		Warning	101	kHz	Calculated switching frequency exceeds target. Increase FS TARGET or relax hard engine bounds
FS MIN			77	kHz	Minimum operating switching frequency across all tolerance corners
KP		Warning	0.763		Calculated KP is below target. Decrease KP TARGET or relax hard engine bounds
VOR MAX			187.5	V	Actual maximum reflected voltage
DMAX			0.533		Maximum duty cycle
TON			6.828	us	Maximum controller ON time
TOFF			6.096	us	Minimum controller OFF time
VDRAIN PEAK			632	V	Estimated off-state drain to source peak voltage (considers 70 V spike)
VDRAIN PLATEAU			562	V	Off-state drain to source plateau voltage
VDS ON			1.00	V	On-state drain to source voltage
IAVG PRIMARY			0.54	A	Primary switch average current

IAVG DIODE BRIDGE			0.48	A	Average diode bridge current (DC input current)
Peak Currents (Nominal Power)					
PRIMARY IP			1.75	A	Peak primary current @ nominal load condition
CV1 OUTPUT IP			8.63	A	CV1 output peak current @ nominal load condition
CVHV OUTPUT IP			13.14	A	CVHV output peak current @ nominal load condition
RMS Currents (Nominal Power)					
INPUT IRMS			1.17	A	Input RMS current @ nominal load condition
PRIMARY IRMS			0.79	A	Primary winding RMS current @ nominal load condition
CV1 OUTPUT IRMS			3.35	A	CV1 RMS current @ nominal load condition
CV1 OUTPUT WINDING IRMS			5.00	A	CV1 winding RMS current @ nominal load condition
CVHV OUTPUT IRMS			3.72	A	CVHV RMS current @ nominal load condition
CVHV OUTPUT WINDING IRMS			3.72	A	CVHV winding RMS current @ nominal load condition
Ripple Currents (Nominal Power)					
INPUT I RIPPLE RMS			1.07	A	Input capacitor RMS ripple current @ nominal load condition
CV1 I RIPPLE RMS			2.91	A	CV1 output RMS ripple current @ nominal load condition
CVHV I RIPPLE RMS			3.50	A	CVHV output RMS ripple current @ nominal load condition
Bias Parameters					
Primary Bias					
NB	7		7	turns	Primary bias winding turns
V BIAS MIN			9.8	V	Minimum primary bias voltage
V BIAS MAX			21.2	V	Maximum primary bias voltage
VFD BIAS PRI			0.70	V	Primary bias rectifier voltage forward drop
PIV BIAS PRI			64.9	V	Primary bias rectifier peak inverse voltage
R BIAS			12.12	kOhms	Bias resistor
IBPP MIN			0.40	mA	Bias current at V BIAS MIN
IBPP MAX			1.33	mA	Bias current at V BIAS MAX
USE OUTPUT OVP	NO		NO		Use output overvoltage protection on primary bias
Component Ratings					
Secondary Switches					
CVHV RECTIFIER	Diode		Diode		CVHV rectifier type
SR PRV			62.0	V	Synchronous rectifier maximum peak reverse voltage
SR IRMS			5.00	A	Synchronous rectifier RMS current
SF CV1			24.0	V	CV1 selection FET maximum peak reverse voltage
OBD CVHV			24.0	V	CVHV blocking diode maximum peak reverse voltage
OBD VF CVHV			1.00	V	CVHV output blocking diode forward voltage drop

9 Performance

9.1 Full Load Efficiency vs. Line

Full load efficiency vs. line voltage is shown below. NTC resistor was shorted for all efficiency testing. Tests were performed for combinations of:

- Nominal line voltage (90 V, 115 V, 230 V, 265 V).
- CV1 = 12 V @ 1.67 A.
- CVHV = 24 V @ 1.25 A.

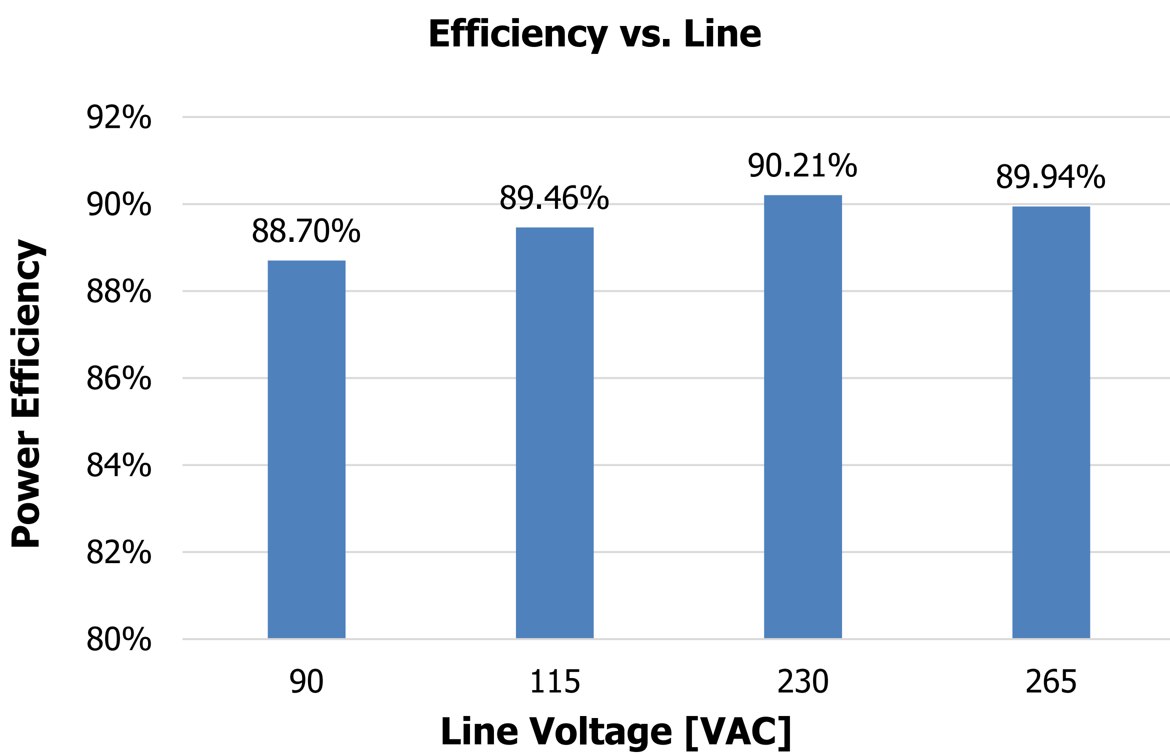


Figure 10 – Full Power Efficiency vs. Line Voltage at Room Temperature.

9.2 Efficiency vs. Load

The efficiency vs. load measurements is shown below. NTC resistor was shorted for all efficiency testing Tests were performed for a combination of :

- Nominal line voltage (90 V, 115 V, 230 V, 265 V).
- CV1 = 12 V @ 1.67 A (0 to 100% with 5% load increment).
- CVHV = 24 V @ 1.25 A (0 to 100% with 5% load increment).

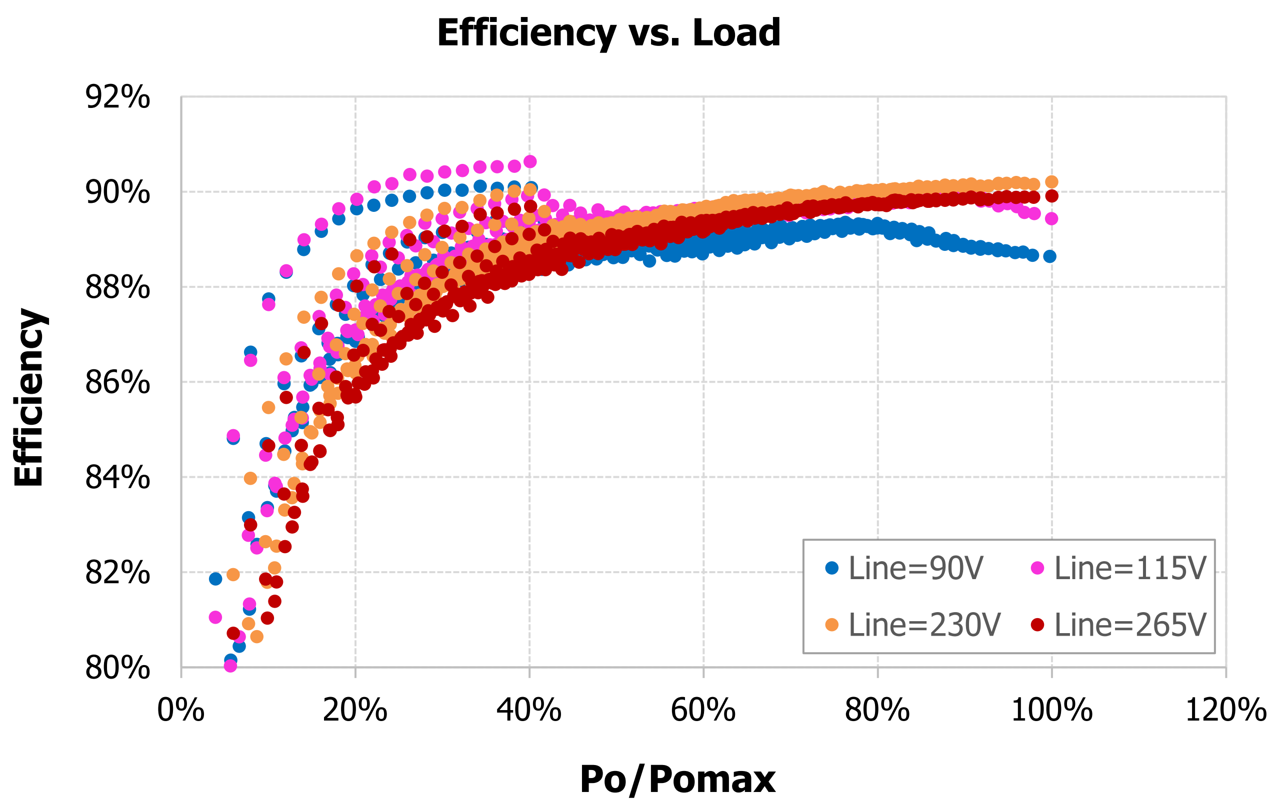
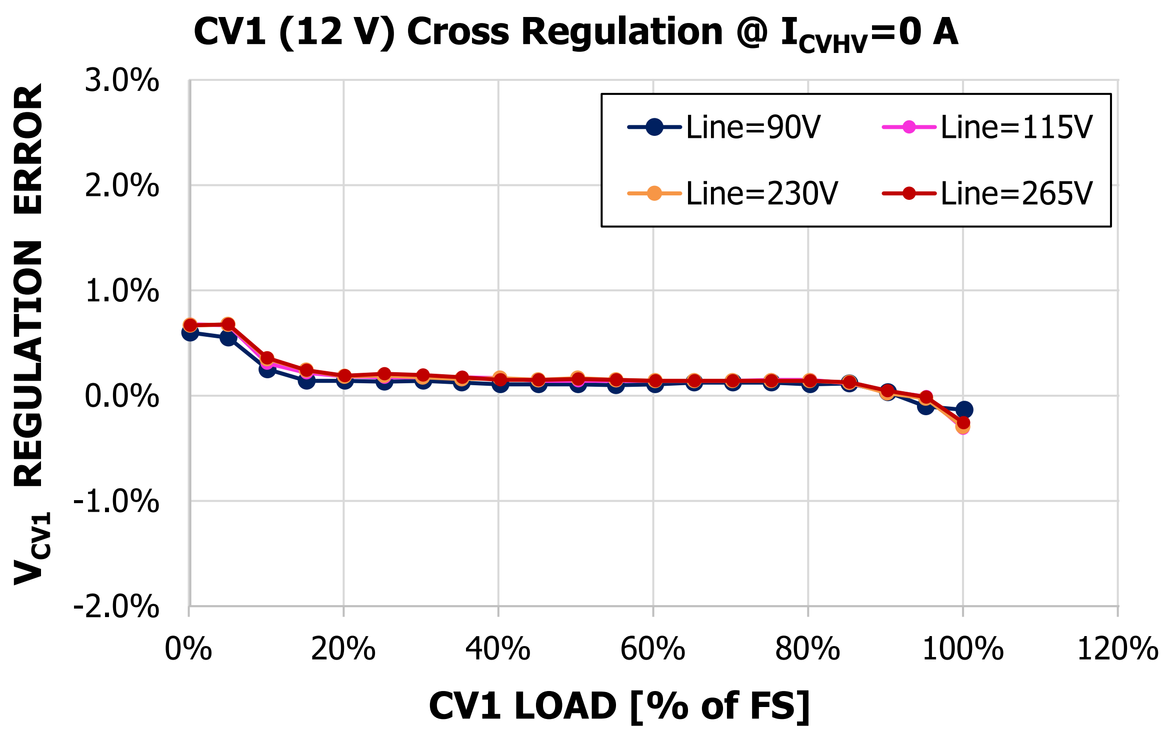


Figure 11 – Efficiency vs. Load for All Line Inputs, Room Temperature.

9.3 Output Load Regulation

The CV1 output voltage regulation error vs. load are shown below. Results were obtained for combinations of:

- Nominal line voltage (90 V, 115 V, 230 V, 265 V)
- CV1 = 12 V @ 1.67 A (0 to 100% with 5% load increment)
- CVHV = 24 V @ 0 A and 1.25 A



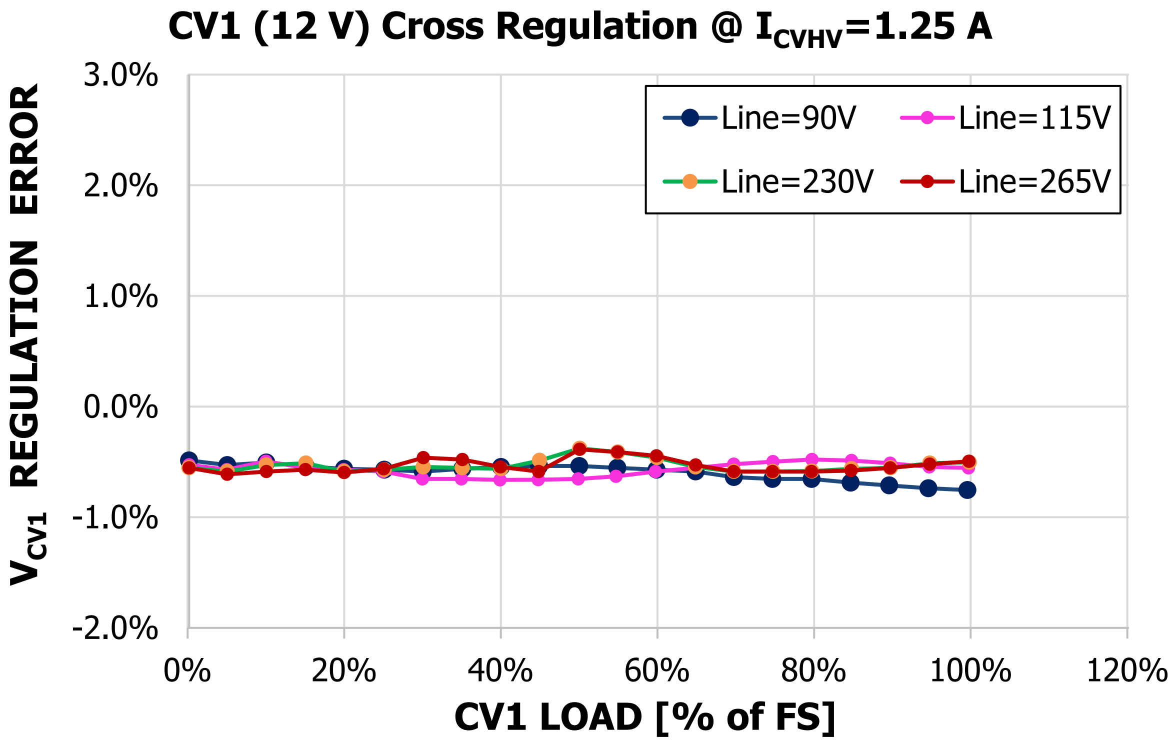
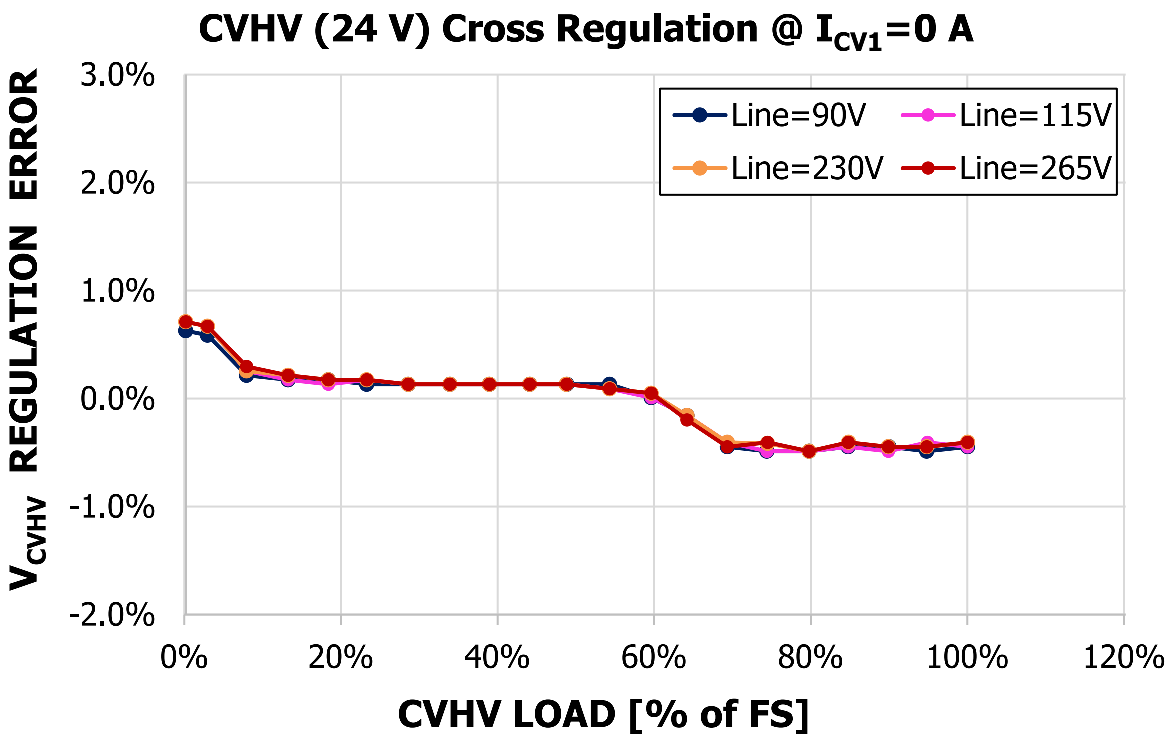


Figure 12 – CV1 Output Voltage Error vs. Output Load, Room Temperature.

The CVHV output voltage regulation error vs. load are shown below. Results were obtained for combinations of:

- Nominal line voltage (90 V, 115 V, 230 V, 265 V)
- CVHV = 24 V @ 1.25 A (0 to 100% with 5% load increment)
- CV1 = 12 V @ 0 A and 1.67 A



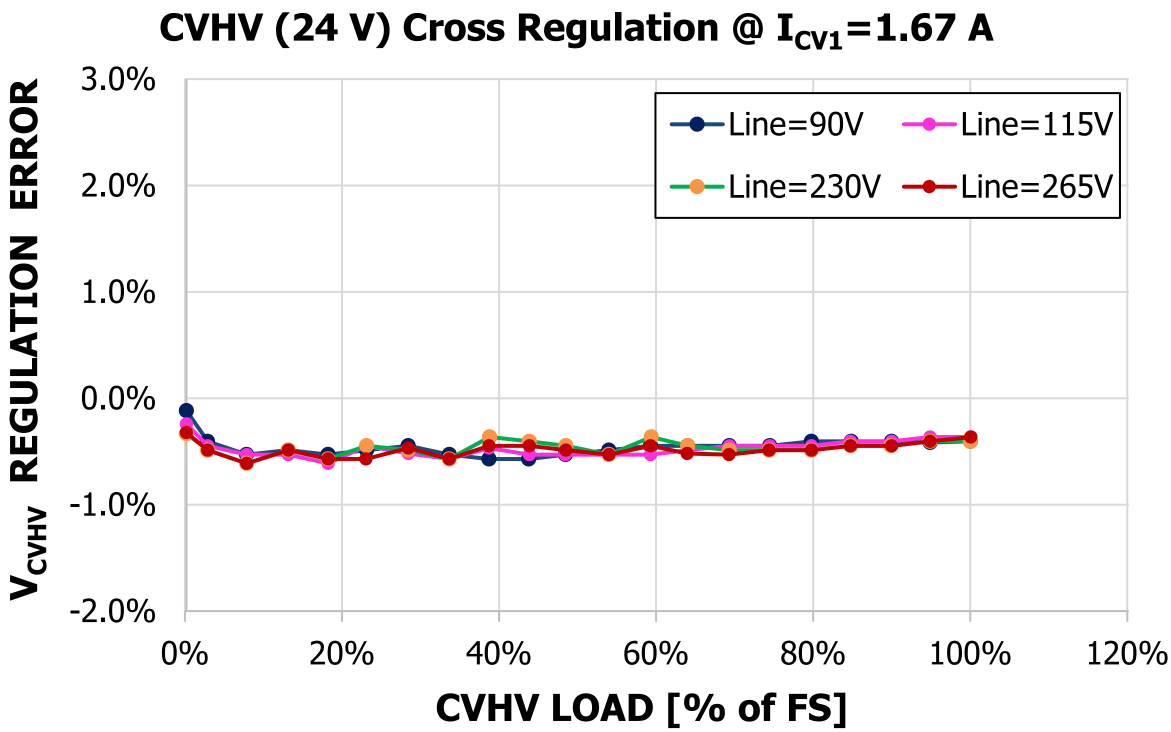


Figure 13 – CVHV Output Voltage Error vs. Output Load, Room Temperature.

9.4 No-Load and Standby Input Power (I_{CVHV} = 0 A)

The output power vs. input power in standby is shown below. Results were obtained for combinations of:

- Nominal line voltage (90 V, 115 V, 230 V, 265 V)
- CVHV output = 0 A
- CV1 output = 0 mW to 350 mW

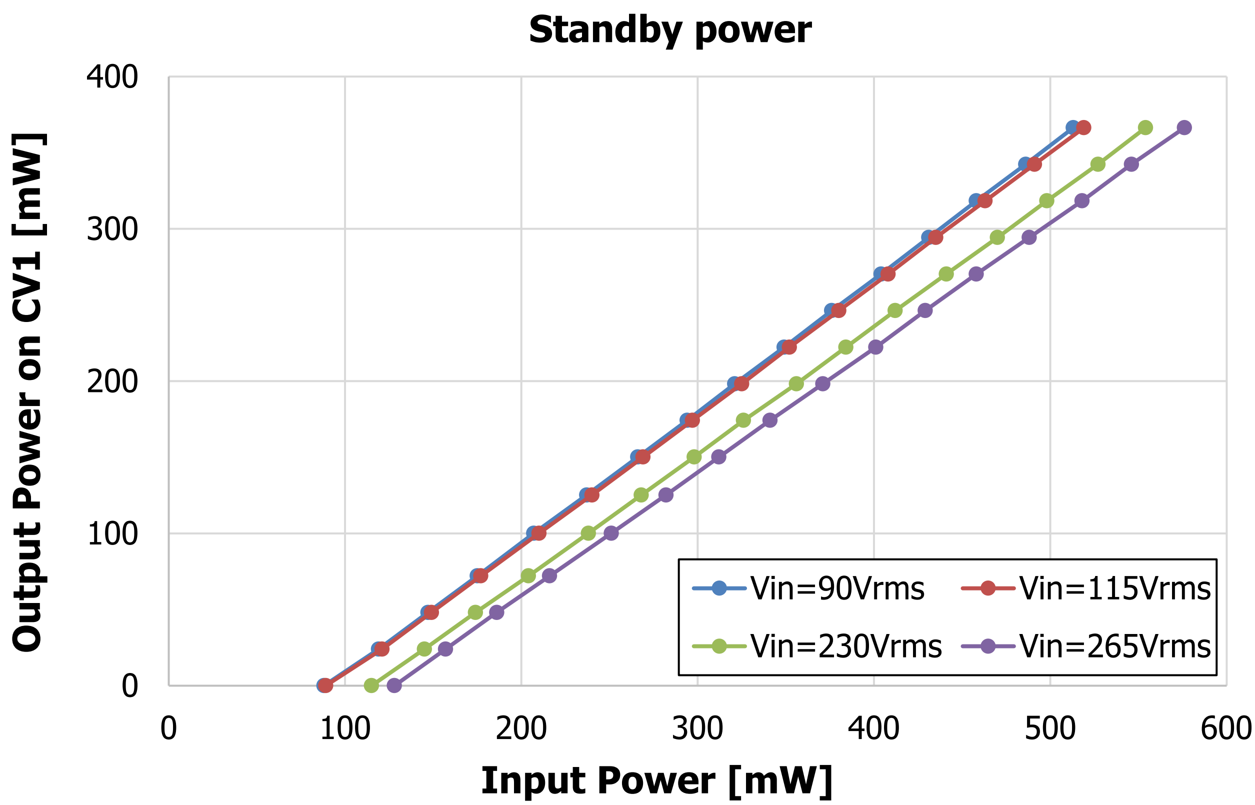


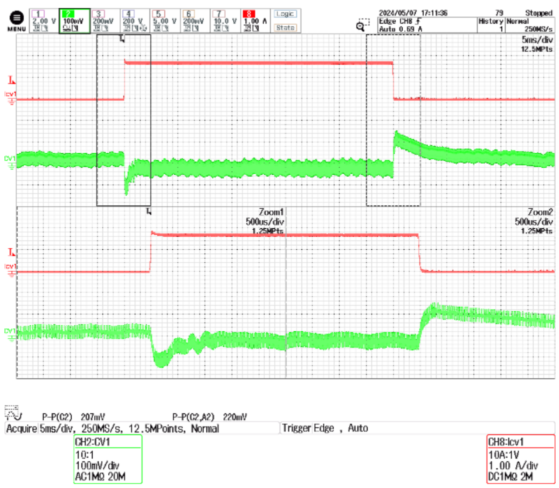
Figure 14 – Standby Power Consumption vs. Input Line Voltage, Room Temperature.

9.5 Load Transient Response

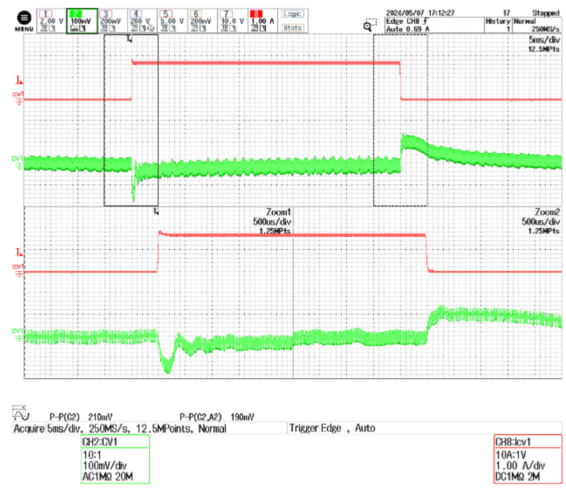
9.5.1 CV1 Step Load Transient

A load transient test was performed on power supply under the following conditions:

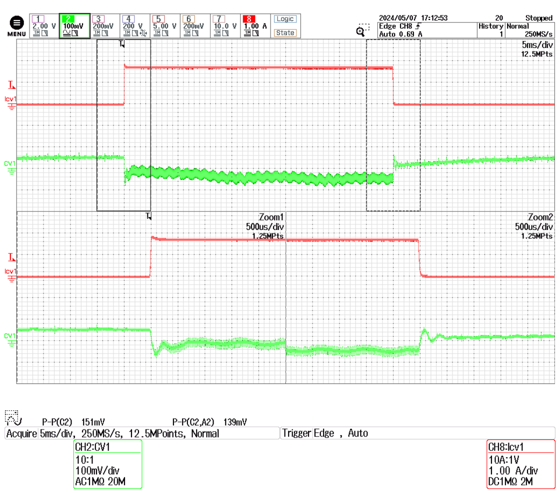
- Line input voltage 90 VAC, 265 V
- CV1 load step between 0 A and 1.67 A (0% and 100% load)
- CVHV = 0 A (0% load); 1.25 A (100% load)



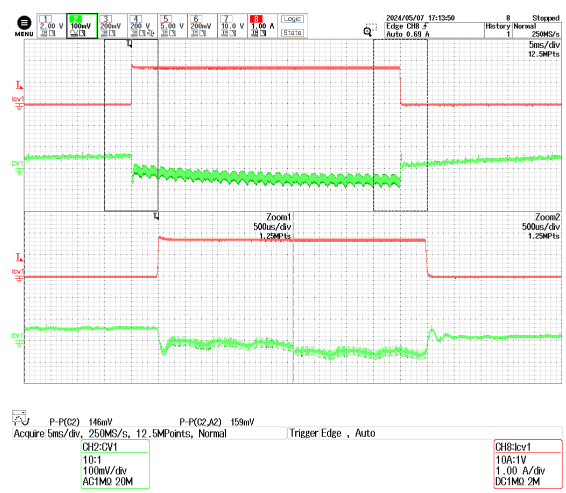
90 VAC, ICV1 **=** 0 A -> 1.67 A (100%) -> 0 A.
ICVHV = 1.25 A.
Overshoot: 220 mV (1.8%).
Undershoot: -207 mV (-1.7%).



265 VAC, ICV1 **=** 0 A -> 1.67 A (100%) -> 0 A.
ICVHV = 1.25 A.
Overshoot: 190 mV (1.6%).
Undershoot: -210 mV (-1.8%).



90 VAC, ICV1 = 0 A -> 1.67 A (100%) -> 0 A.
ICVHV = 0 A.
Overshoot: 139 mV (1.2%).
Undershoot: -151 mV (-1.3%).



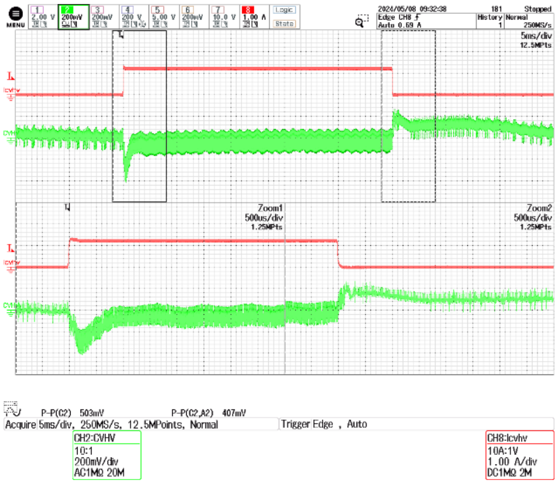
265 VAC, ICV1 = 0 A -> 1.67 A (100%) -> 0 A.
ICVHV = 0 A.
Overshoot: 159 mV (1.3%).
Undershoot**:** -146 mV (-1.2%).

Figure 15 – CV1 (12 V) Load Transient.

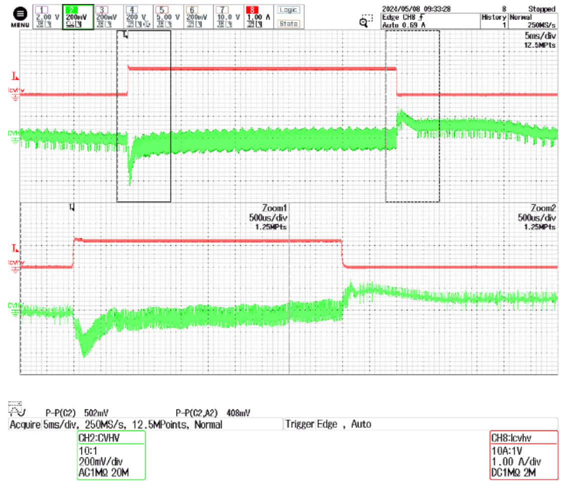
9.5.2 CVHV Step Load Transient

A load transient test was performed on power supply under the following test conditions:

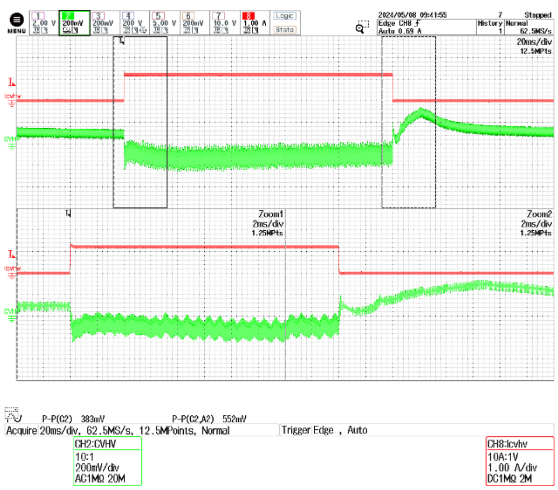
- Line input voltage = 90 VAC, 265 VAC
- CV1 = 0 A, 1.67 A
- CVHV load step from 63 mA to 1.25 A and back to 63 mA



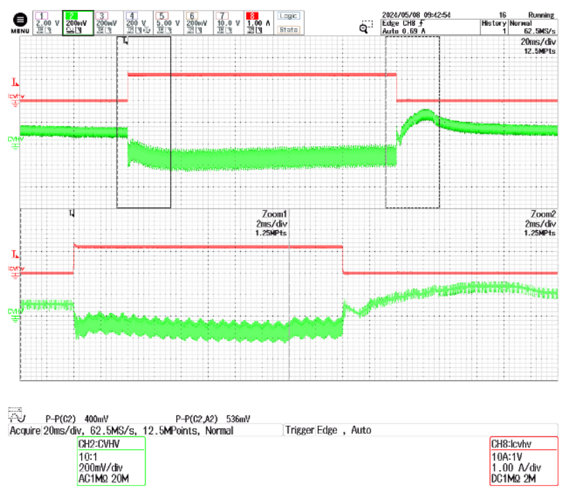
90 VAC, ICVHV = 63 mA -> 1.25 A -> 63 mA.
ICV1 = 1.67 A.
Overshoot: 407 mV (1.7%).
Undershoot: -503 mV (-2.1%).



265 VAC, ICVHV = 63 mA -> 1.25 A -> 63 mA.
ICV1 = 1.67 A.
Overshoot: 408 mV (1.7%).
Undershoot: -502 mV (-2.1%).



90 VAC, ICVHV = 63 mA -> 1.25 A -> 63 mA.
ICV1 = 0 A.
Overshoot: 552 mV (2.3%).
Undershoot: -383 mV (-1.6%).



265 VAC, ICVHV = 63 mA -> 1.25 A -> 63 mA.
ICV1 = 0 A.
Overshoot: 536 mV (2.2%).
Undershoot: -400 mV (-1.7%).

Figure 16 – CVHV (24 V) Load Transient.

9.6 Switching Waveforms

9.6.1 Primary Switch Maximum Voltage

The primary switch (U1) maximum voltage test was performed on power supply under the following test conditions:

- Line input voltage 265 VAC;
- Full load on both outputs:
  - CV1 = 12 V @ 1.67 A
  - CVHV = 24 V @ 1.25 A
- 100 MHz bandwidth selected on the oscilloscope.

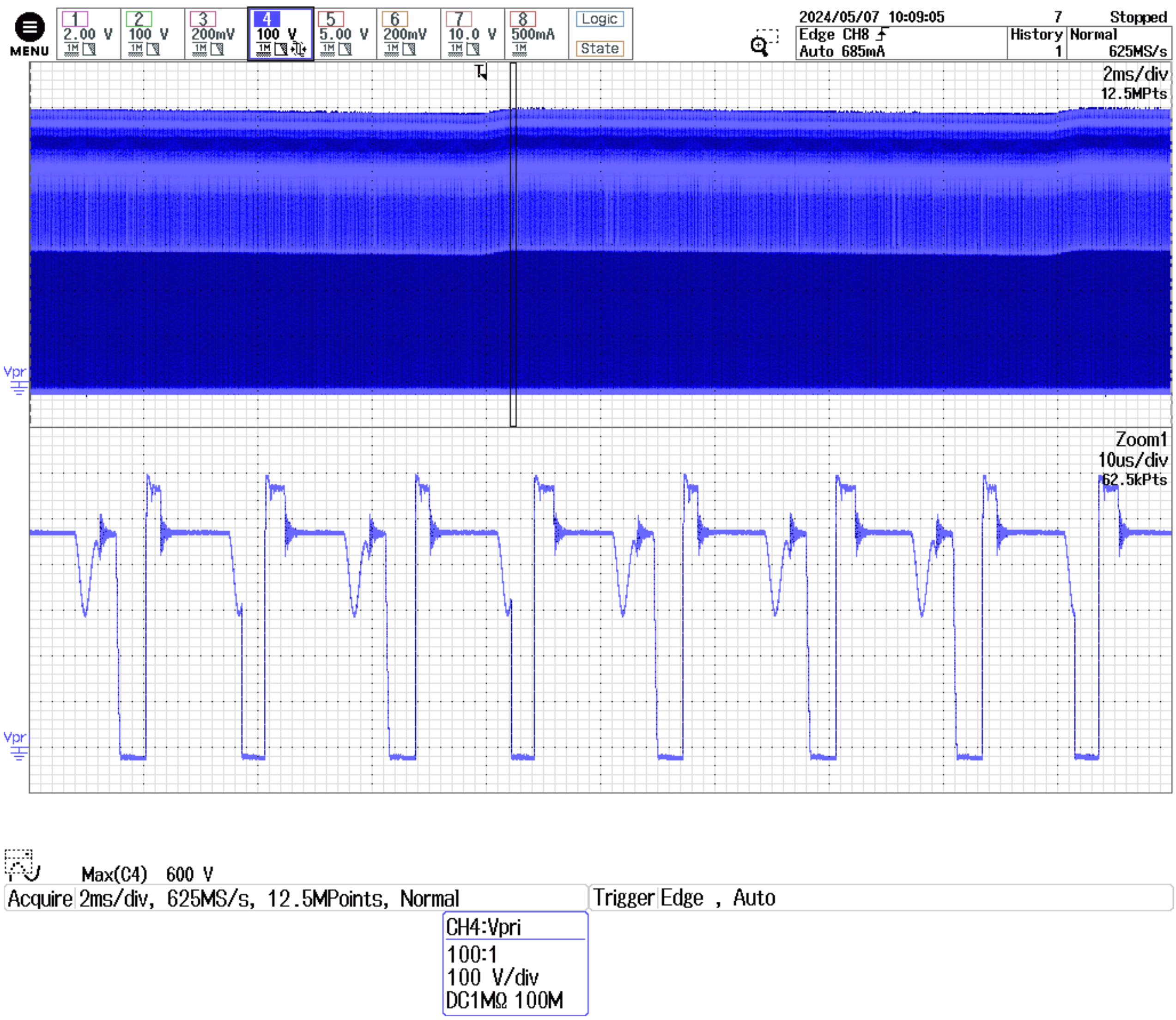


Figure 17 – Primary Switch Worst Case Peak Voltage, V_{PRI_PK} = 600 V

9.6.2 SR FET Voltage Waveform

The SR FET (Q1) maximum voltage test was performed on power supply covering below test conditions:

- 265 VAC input line voltage
- CV1 (12 V) load step from 0 A to 1.67 A
- CVHV (24 V) full load to 1.25 A
- 100 MHz bandwidth selected on the oscilloscope.

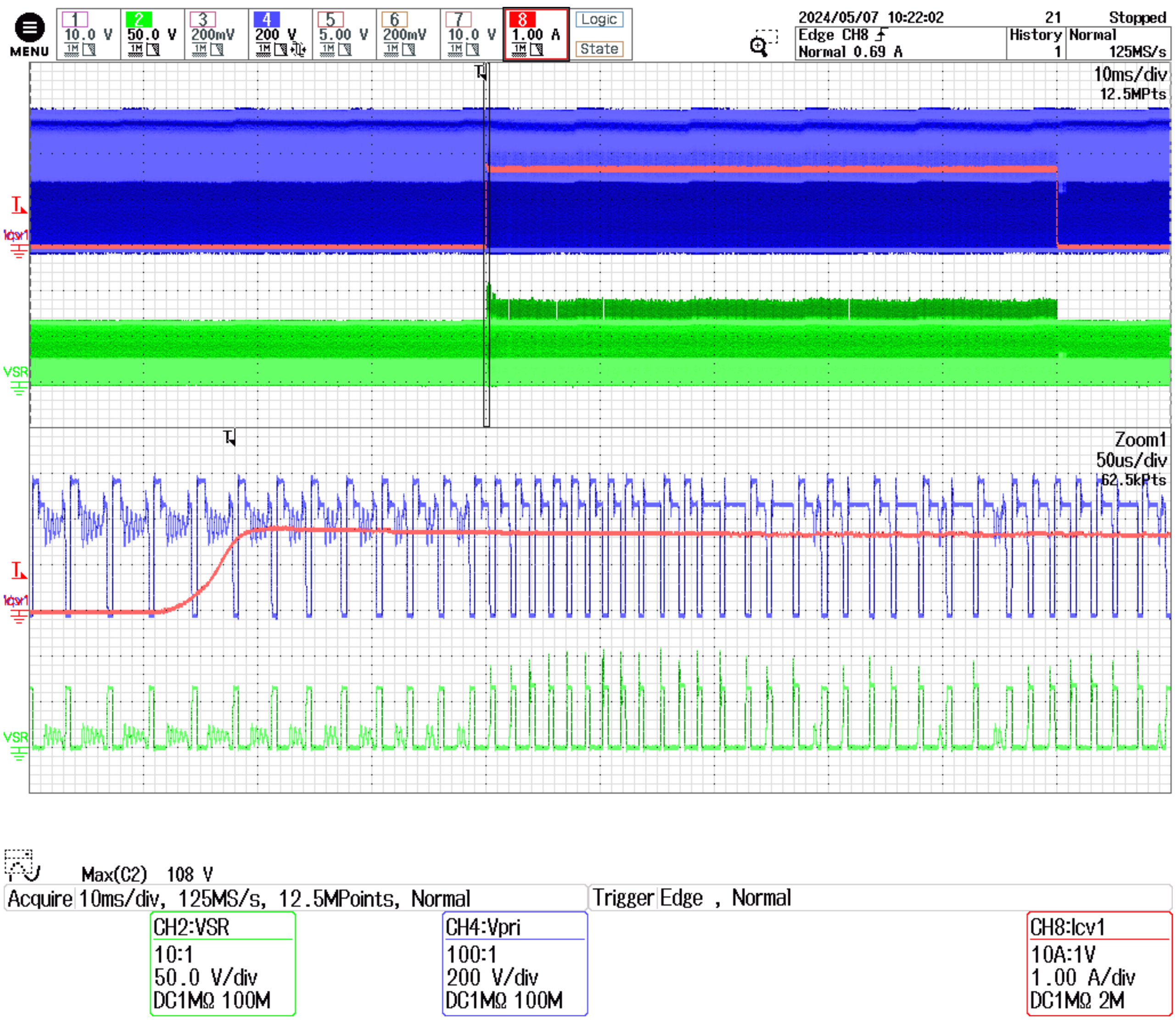


Figure 18 – SR FET Worst Case Peak Voltage, V_{SR_PK} = 108 V

9.6.3 Selection FET Voltage Waveform

The Selection FET (Q2) maximum voltage test was performed on power supply covering below test conditions:

- 265 VAC input line voltage
- Startup with full load on both outputs:
  - CV1 = 12 V @ 1.67 A
  - CVHV = 24 V @ 1.25 A
- 100 MHz bandwidth selected on the oscilloscope.

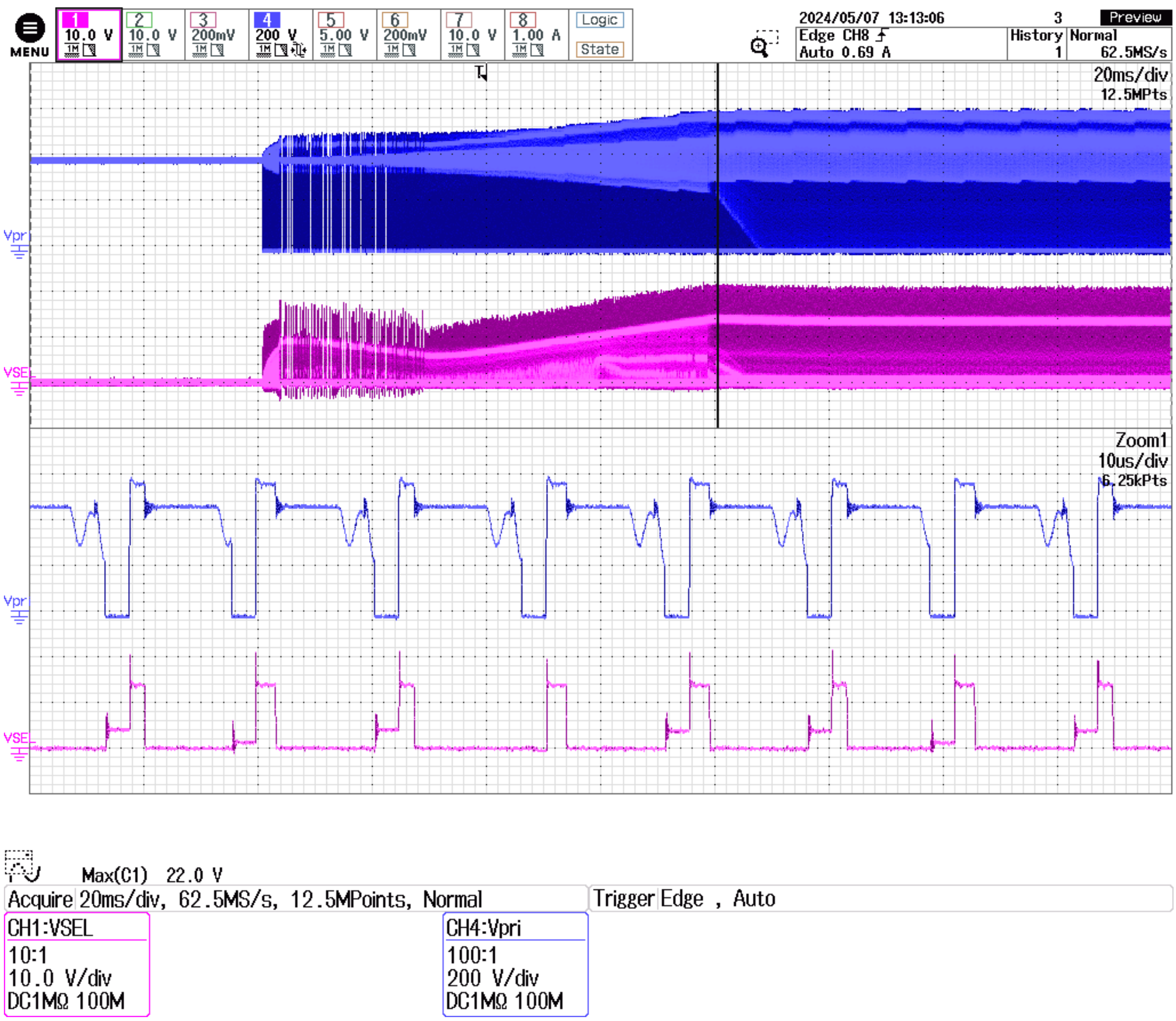


Figure 19 – Selection FET Worst Case Peak Voltage, V_{SEL_PK} = 22.0 V.

9.6.4 CVHV Diode Reverse Voltage Waveform

The CVHV Diode (D3) maximum reverse voltage test was performed on the power supply under the following test conditions:

- 265 VAC input line voltage
- Start-up with full load on both outputs:
    - CV1 = 12 V @ 1.67 A
    - CVHV = 24 V @ 1.25 A
- 100 MHz bandwidth selected on the oscilloscope.

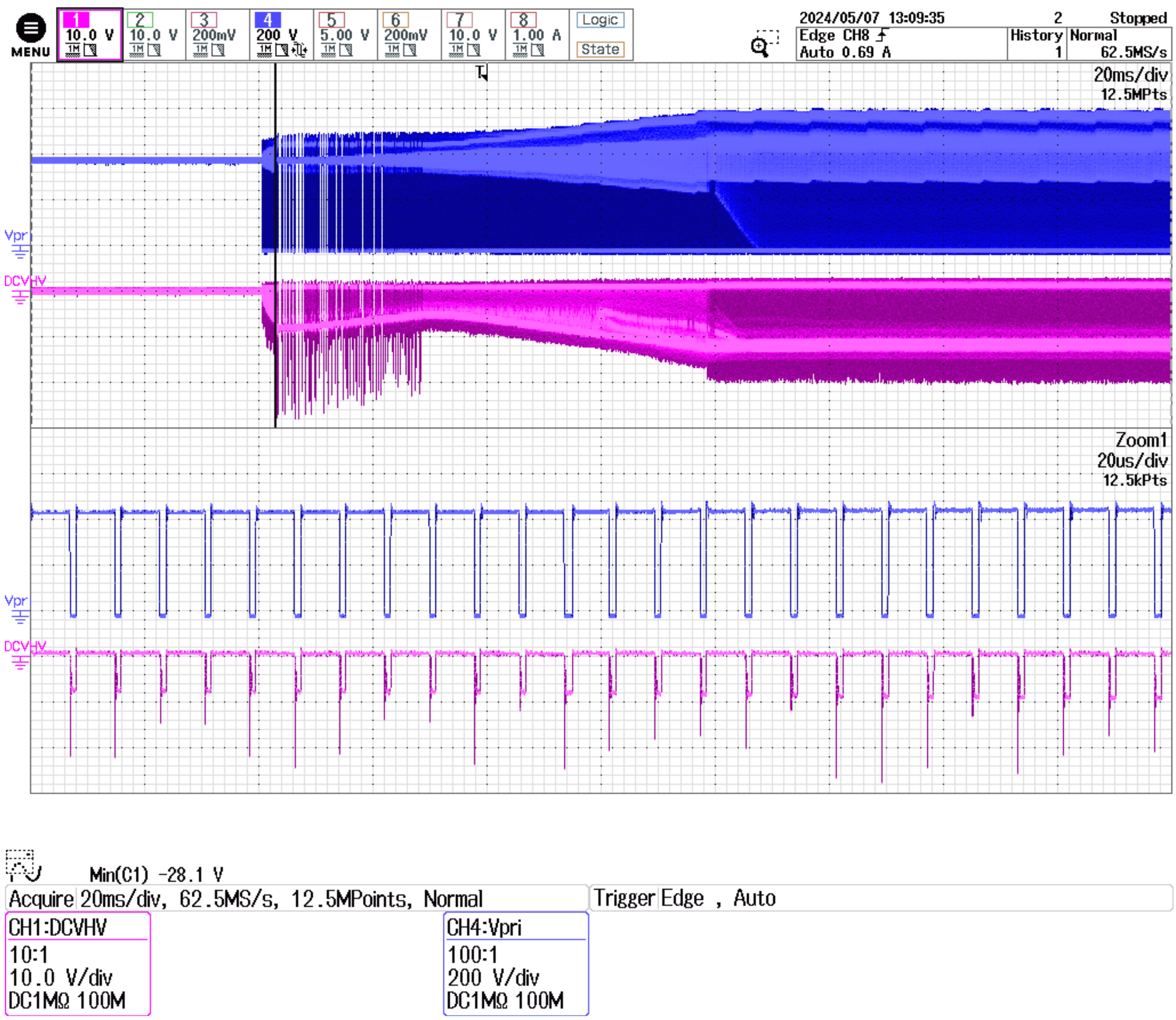


Figure 20 – CVHV Diode Worst Case Reverse Voltage, V_{D3_PK} = 29.98 V

9.6.5 BPP Rectifier Diode Reverse Voltage Waveform

A BPP rectifier diode (D1) maximum reverse voltage test was performed on the power supply under the following test conditions:

- 265 VAC input line voltage
- Start-up with full load on both outputs:
    - CV1 = 12 V @ 1.67 A
    - CVHV = 24 V @ 1.25 A
- 100 MHz bandwidth selected on the oscilloscope.

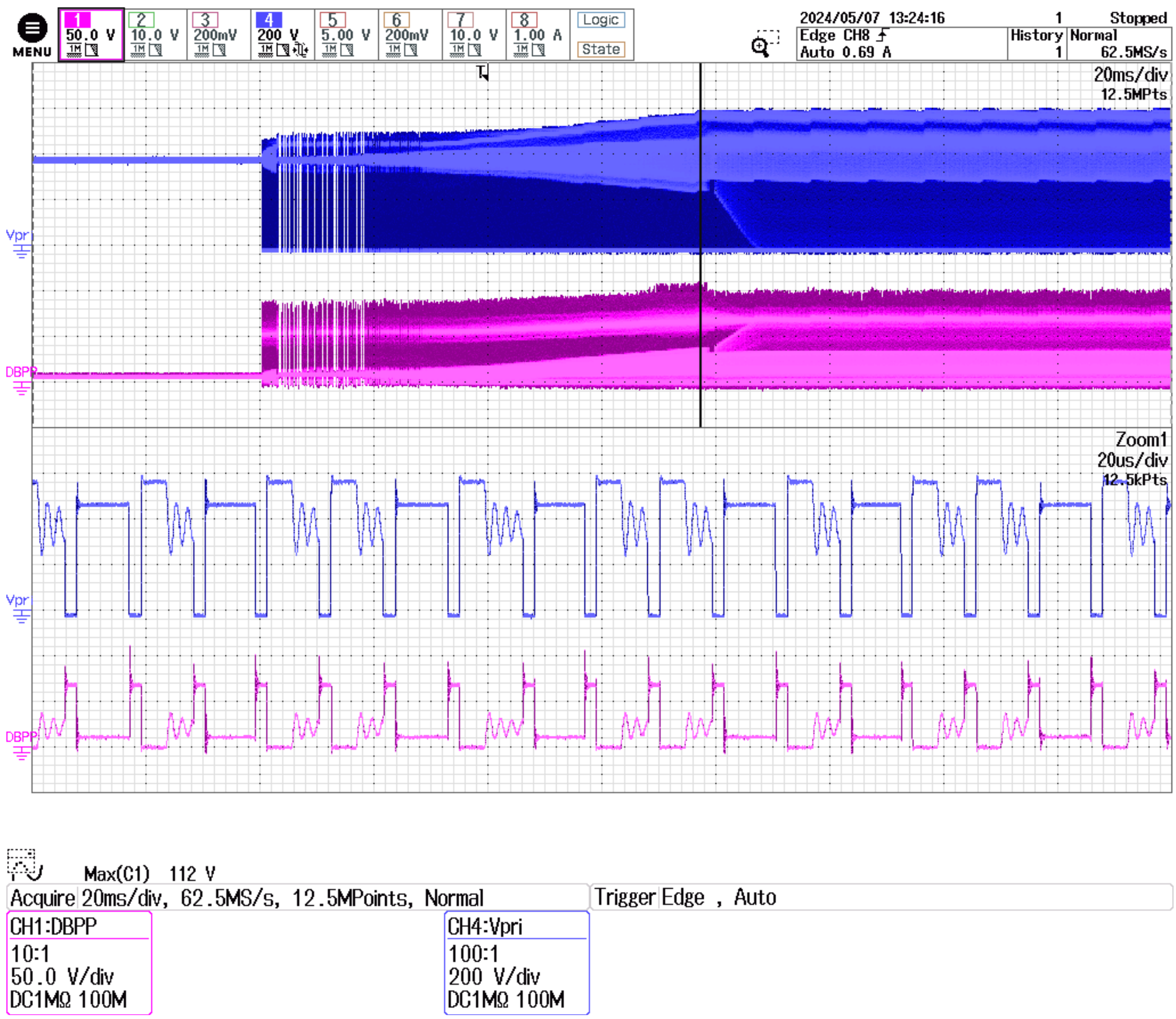


Figure 21 – BPP Rectifier Diode Worst Case Reverse Voltage, V_{D1_PK} = 112 V.

9.6.6 Primary Switching Frequency

The primary switching frequency of the converter varies depending on the line and load conditions. Frequency was measured under maximum load at minimum line input (90 VAC). Maximum switching frequency occurs at the minimum bulk voltage with a maximum instantaneous frequency of 90.3 kHz. Under the same conditions over a mains cycle, the average switching frequency was 88.6 kHz.

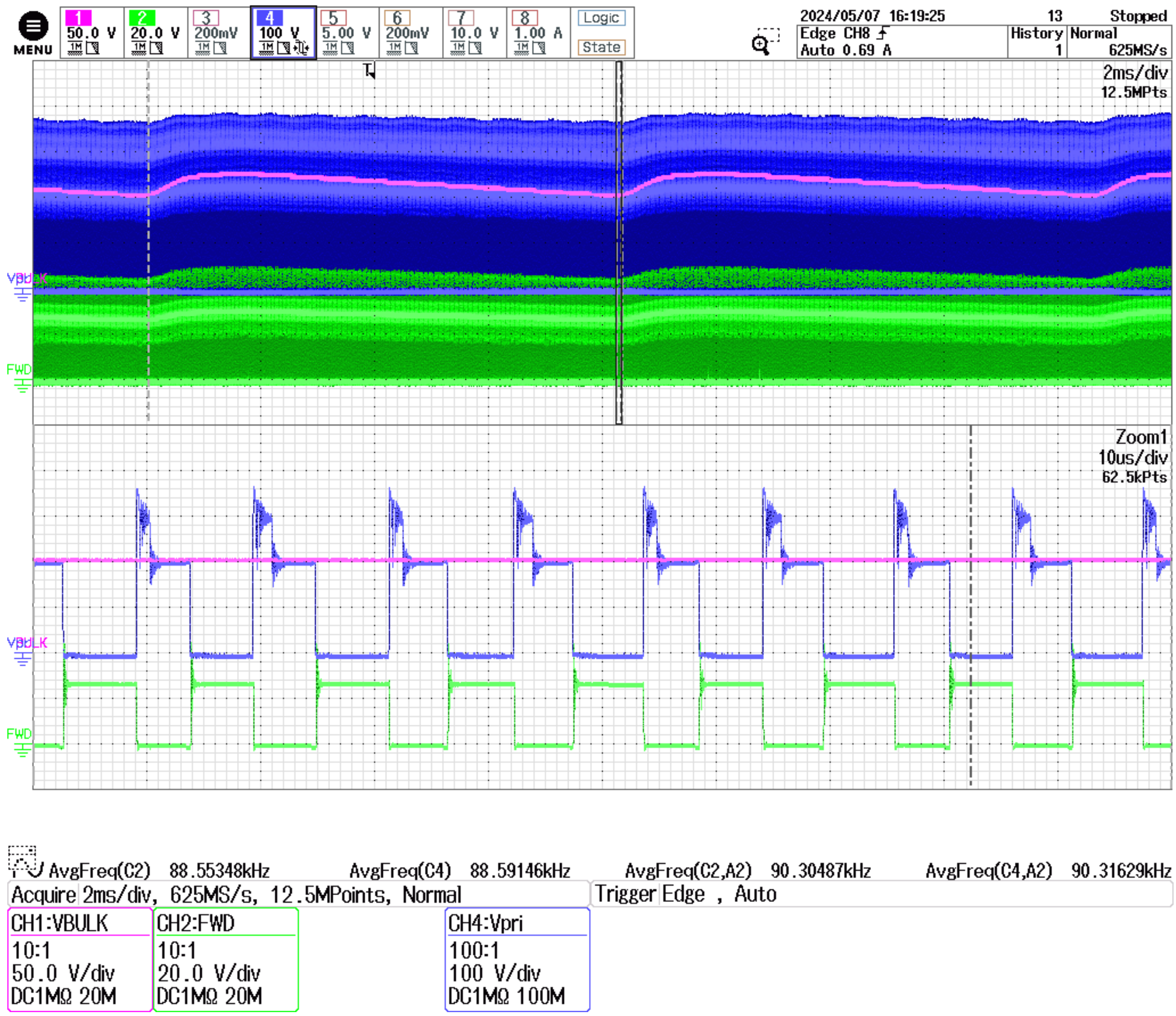


Figure 22 – Primary Switching Frequency at 90 VAC Input Line Voltage.

9.6.7 Maximum Voltage Stress

The voltage waveforms on each key component, i.e. MOSFETs & diodes, were checked to confirm that maximum voltage stress was below the component ratings. The maximum voltage stress can happen under different combinations of input mains voltages or and output loads, and during startup up or during transient conditions steps. Most applications require 10% ~ 20% margin between the maximum voltages and component Abs-max. ratings. The below table shows voltage stress on the key components under worst-case conditions:

Component	Part Number	Component Rating [V]	Maximum Voltage Stress	
			[V]	[%]
InnoMux2 (U1)	IMX2378F-H415	750	600	**80%**
SR FET (Q1)	BSC0302LS	120	108.0	**90%**
Selection FET (Q2)	PSMN4R1-60YL	60	22.0	**37%**
CVHV Diode (D3)	V20PW45	45	28.1	**62%**
BPP Diode (D1)	US1G	400	112	**28%**

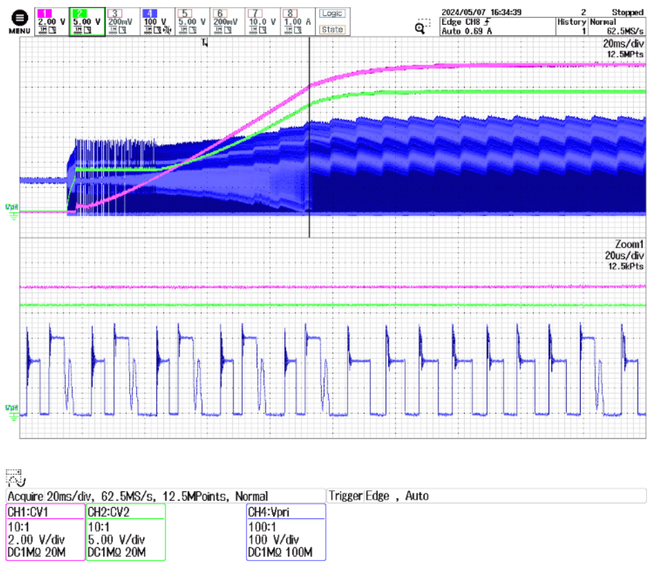
Table 5 – Maximum Voltages on the key components.

9.7 Start-Up

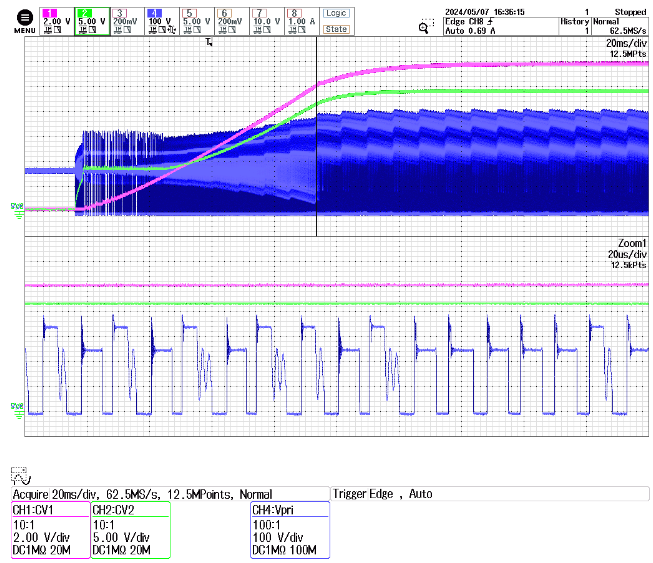
9.7.1 Full Load Start-up

A full load start-up test was performed on power supply under the test conditions shown below.

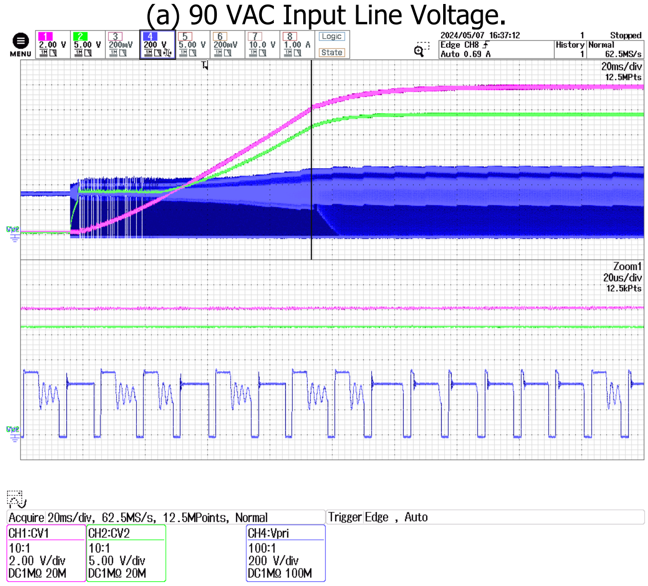
- Each nominal line voltage (90 V, 115 V, 230 V, 265 V)
- Full load on both outputs:
  - CV1 = 12 V @ 1.67 A
  - CVHV = 24 V @ 1.25 A



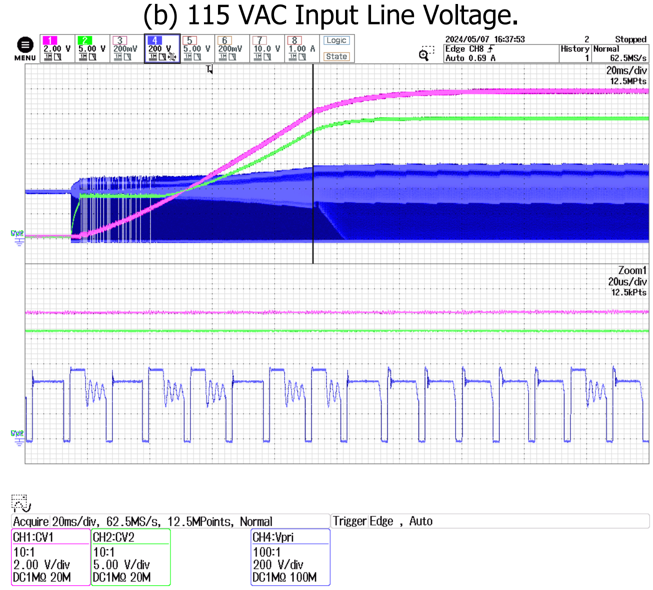
(a) 90 VAC Input Line Voltage.



(b) 115 VAC Input Line Voltage.



(c) 230 VAC Input Line Voltage.



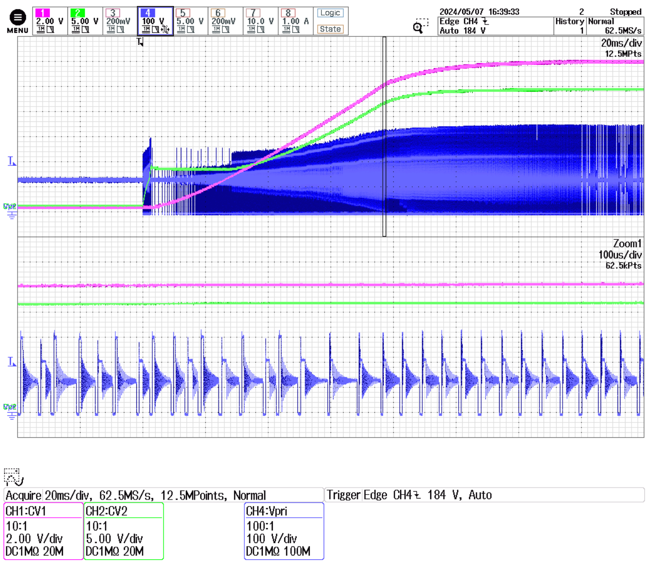
(d) 265 VAC Input Line Voltage.

Figure 23 – Full Load Start-up.

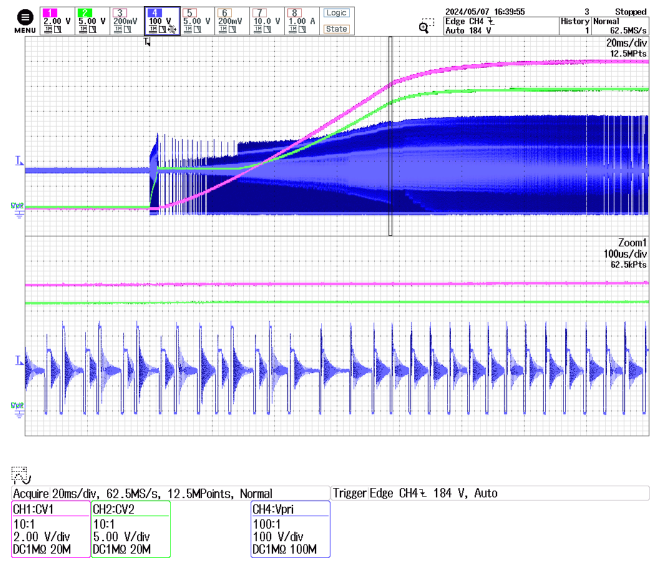
9.7.2 No-Load Start-up

A no load start-up test was performed on power supply under the following test conditions

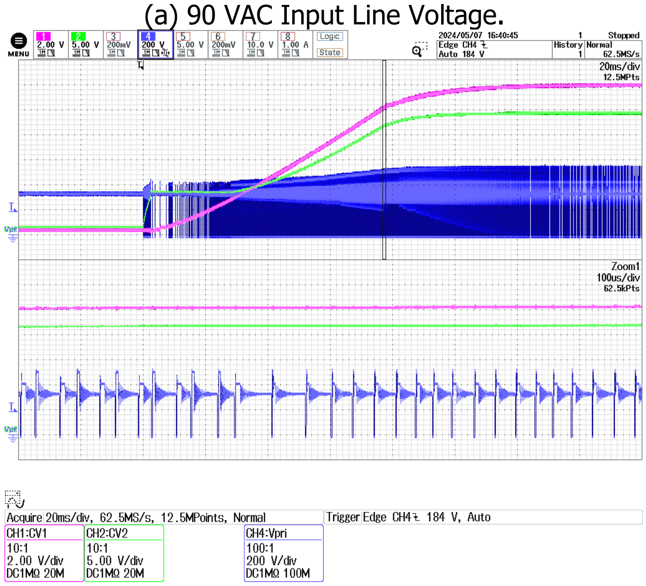
- Each nominal line voltage (90 V, 115 V, 230 V, 265 V)
- No load on either output:
    - CV1 = 12 V @ 0 A
    - CVHV = 24 V @ 0 A



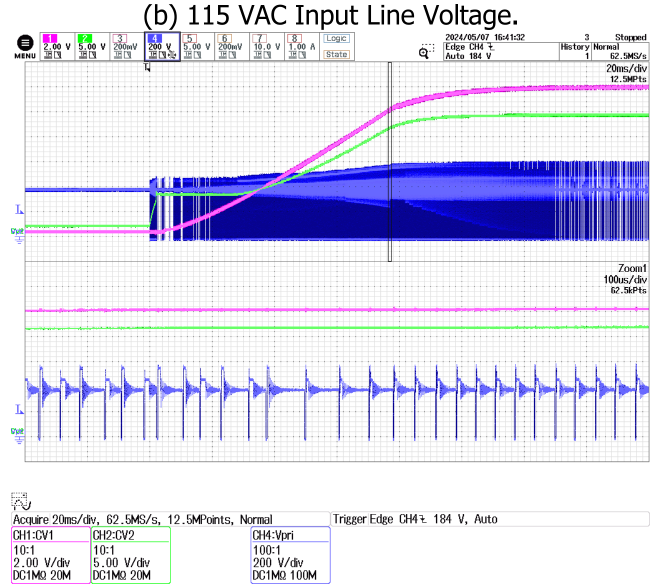
(a) 90 VAC Input Line Voltage.



(b) 115 VAC Input Line Voltage.



(c) 230 VAC Input Line Voltage.



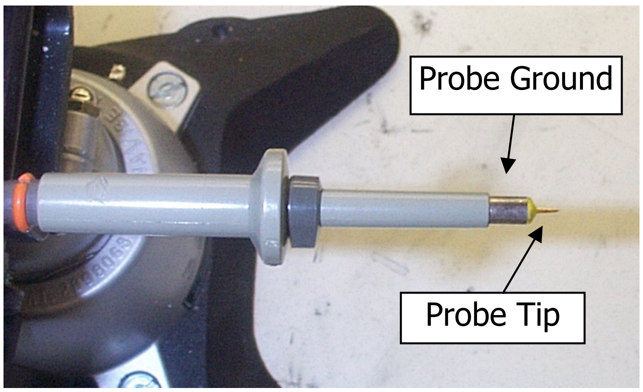
(d) 265 VAC Input Line Voltage.

Figure 24 – No-load Start-up.

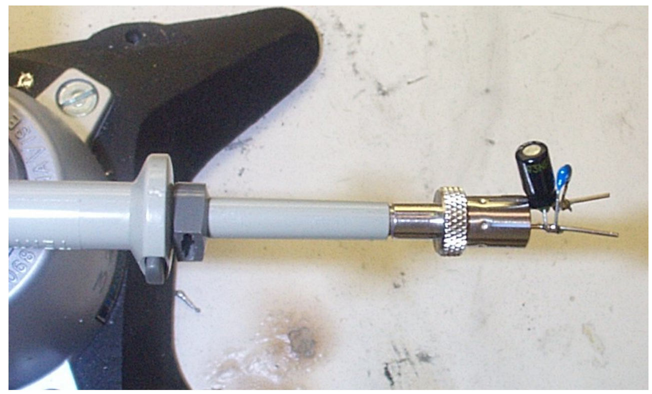
9.8 Output Ripple Measurements

9.8.1 Ripple Measurement Technique

For DC output ripple measurements, a modified oscilloscope test probe was utilized to reduce noise pick-up. The probe adapter is shown in the figures below. It includes a coaxial cable with two parallel capacitors connected to the points of measurement. The capacitors include a 0.1 μF / 100 V ceramic type and a 10 μF / 50 V aluminum electrolytic type. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be ensured.



End Cap and Ground Lead Removed.



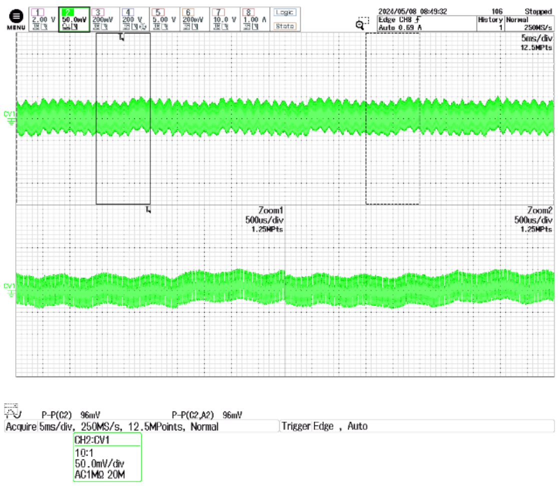
Oscilloscope Probe with Probe Master (www.probemaster.com) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added)

Figure 25 – Oscilloscope Probe Prepared for Ripple Measurement.

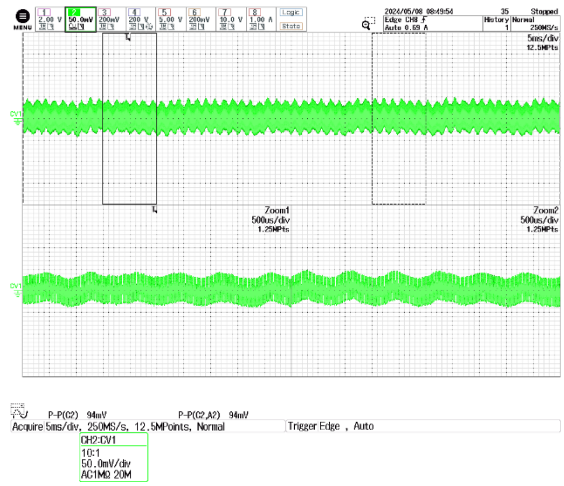
9.8.2 CV1 and CVHV Output Ripple

The CV1 and CVHV output ripple are tested under the following conditions:

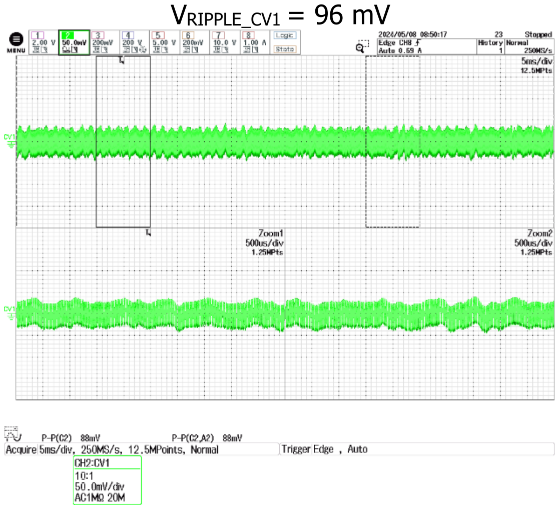
- Nominal line voltage (90 V, 115 V, 230 V, 265 V)
- CV1 = 12 V @ 1.67 A
- CVHV = 24 V @ 1.25 A
- 20 MHz bandwidth selected on the oscilloscope



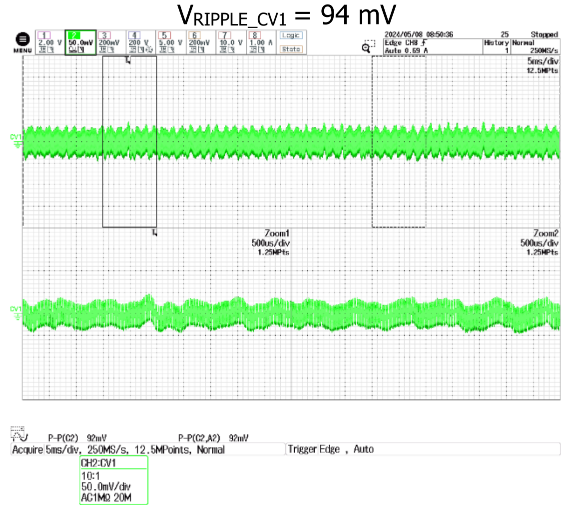
(a) 90 VAC Input Line Voltage
V_{RIPPLE_CV1} = 96 mV



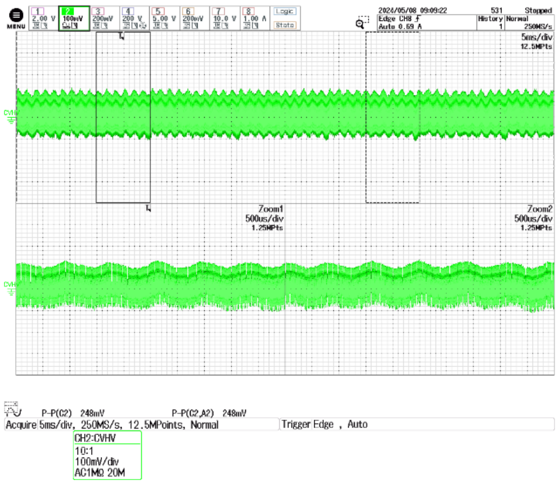
(b) 115 VAC Input Line Voltage
V_{RIPPLE_CV1} = 94 mV



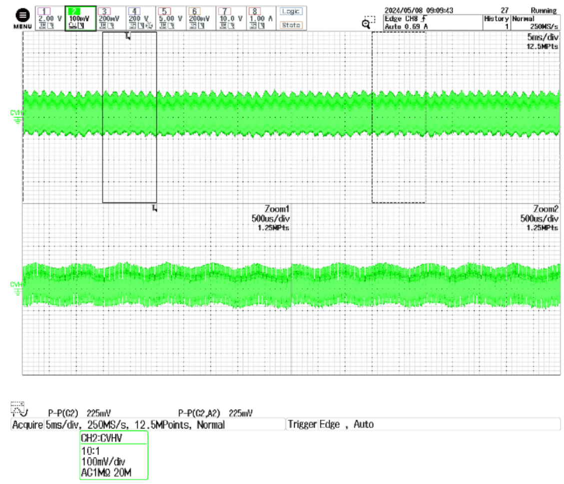
(c) 230 VAC Input Line Voltage
V_{RIPPLE_CV1} = 88 mV



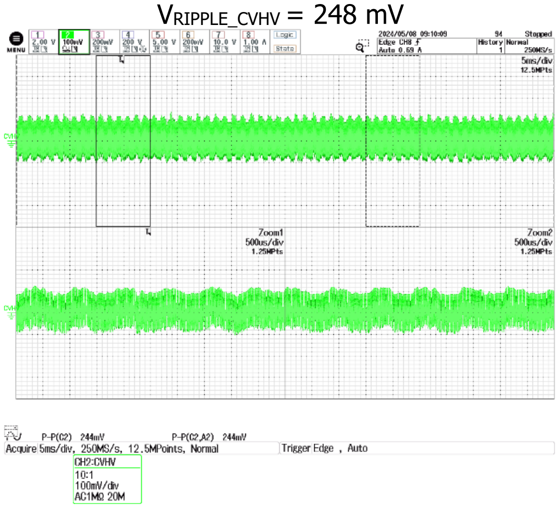
(d) 265 VAC Input Line Voltage
V_{RIPPLE_CV1} = 92 mV



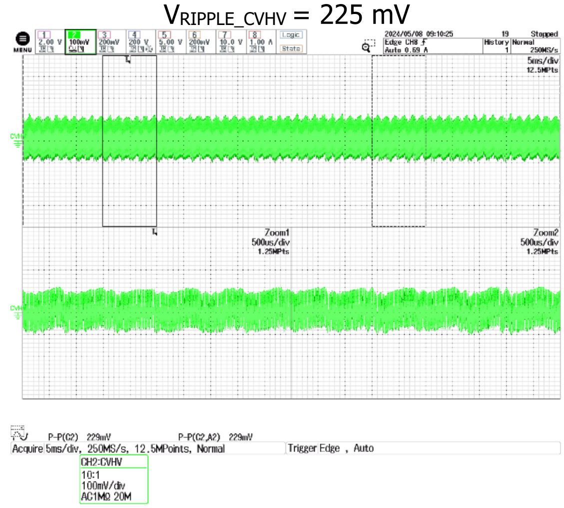
(e) 90 VAC Input Line Voltage
V_{RIPPLE_CVHV} = 248 mV



(f) 115 VAC Input Line Voltage
V_{RIPPLE_CVHV} = 225 mV



(g) 230 VAC Input Line Voltage
V_{RIPPLE_CVHV} = 244 mV

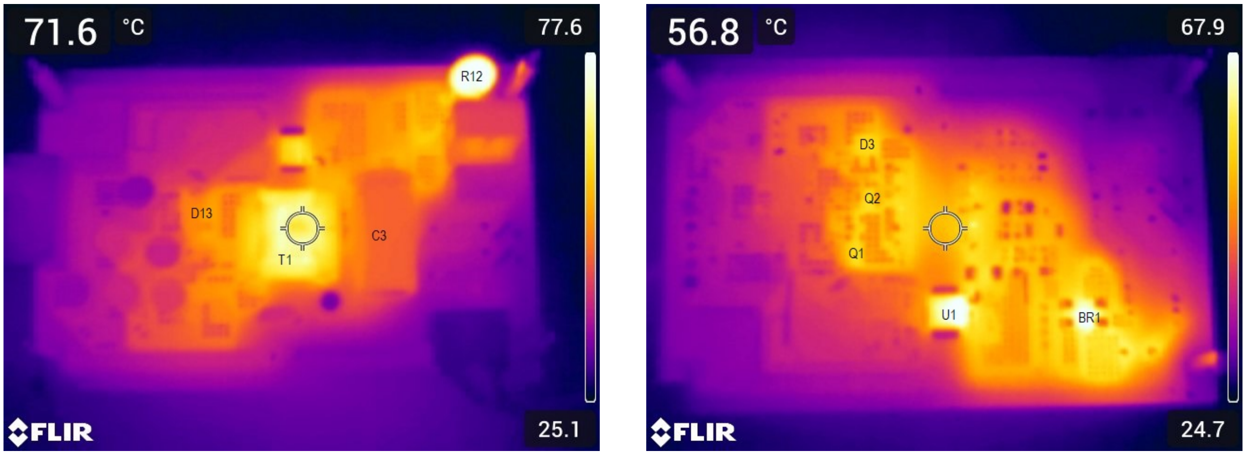


(h) 265 VAC Input Line Voltage
V_{RIPPLE_CVHV} = 229 mV

Figure 26 – VCV1 and VCVHV Ripple and Noise.

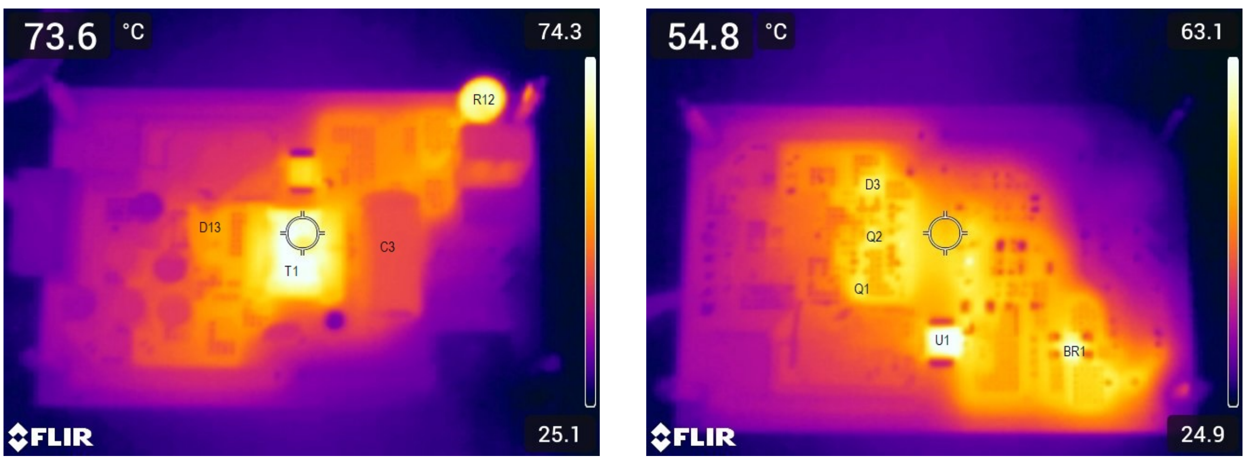
9.9 Thermal Performance

There are no external heatsinks required for this design. PCB copper is used for cooling of the InnoMux2-EP IC. No forced air-cooling was deployed during any test. The temperatures of the hottest component in the assembly are shown below.



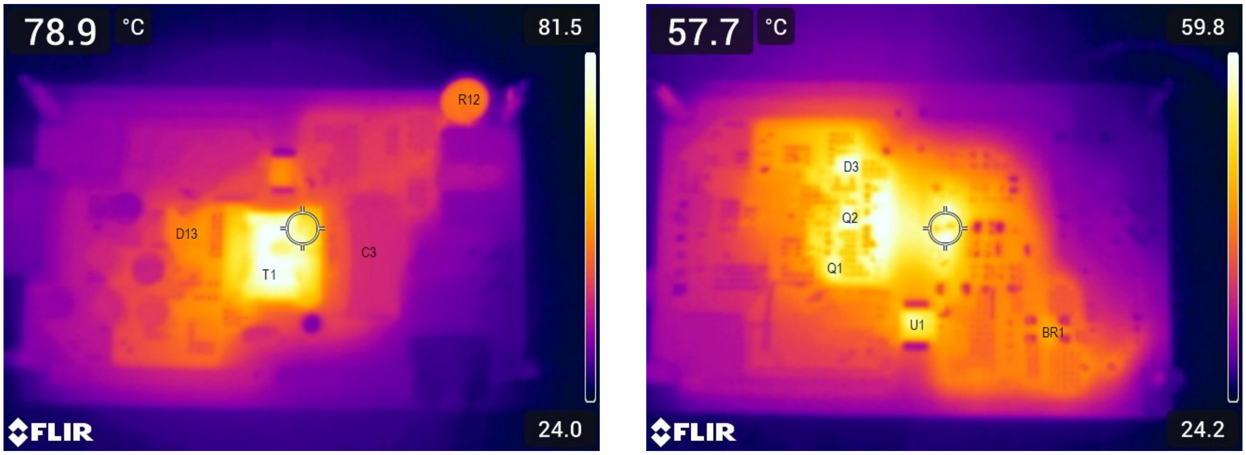
(a) Top View (b) Bottom View

Figure 27 – Thermal Image, 90 VAC, Full Power.



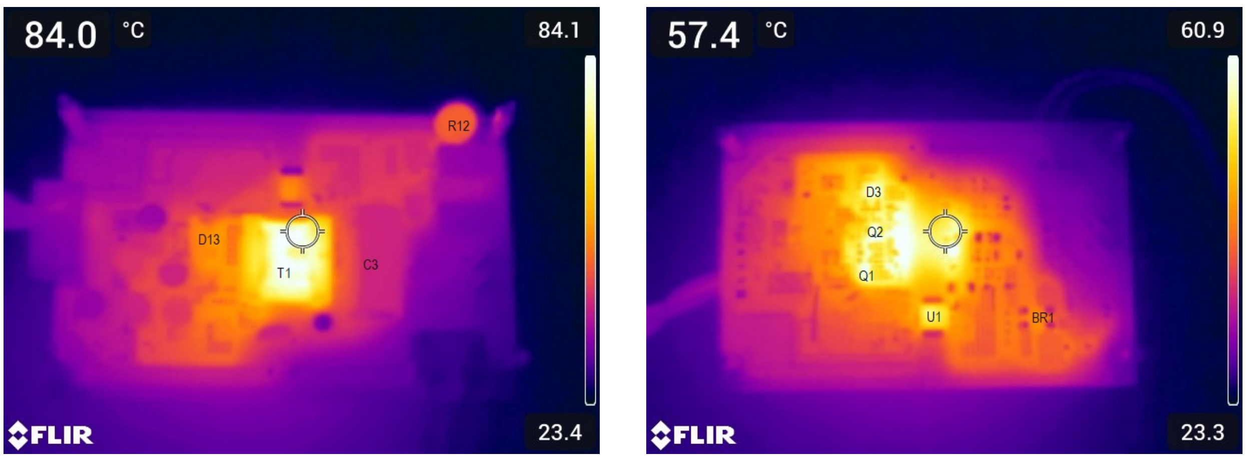
(a) Top View (b) Bottom View

Figure 28 – Thermal Image, 115 VAC, Full Power.



(a) Top View (b) Bottom View

Figure 29 – Thermal Image, 230 VAC, Full Power.



(a) Top View (b) Bottom View

Figure 30 – Thermal Image, 265 VAC, Full Power.

Component	Description	Component Temperatures [˚C]			
		Vin = 90 V	Vin = 115 V	Vin = 230 V	Vin = 265 V
U1	InnoMux2	71.5	62.5	57.3	60.6
Q2	Selection FET	60.5	57.8	61.2	64.2
D3	CVHV Diode	59.5	58.8	60.6	62.9
Q1	SR FET	60.1	58.2	59.7	63.8
BR1	Bridge	69.4	61.9	46.5	47.2
D13	SR snub diode	56.8	54.5	58.0	57.8
T1	Trf winding	75.6	74.4	83.7	85.1
T1	Trf core	71.6	69.2	78.5	79.5
R12	NTC	79.1	70.6	53.1	50.4
C3	Bulk Capacitor	49.6	44.5	41.1	41.1
	Ambient	24.4	23.9	23.7	22.0

Table 6 – Component Temperatures, 90 VAC, 115 VAC, 230 VAC and 265 VAC, Full Power.

9.10 Audible Noise

Audible noise vs. load measurements are shown below. These were obtained for combinations of:

- Low and high mains line voltages (115 V, 230 V).
- CV1 = 12 V @ 1.67 A (0 to 100% with 3% load increment).
- CVHV = 24 V @ 1.25 A (0 to 100% with 3% load increment).
- NTC resistor and input CMCs shorted.

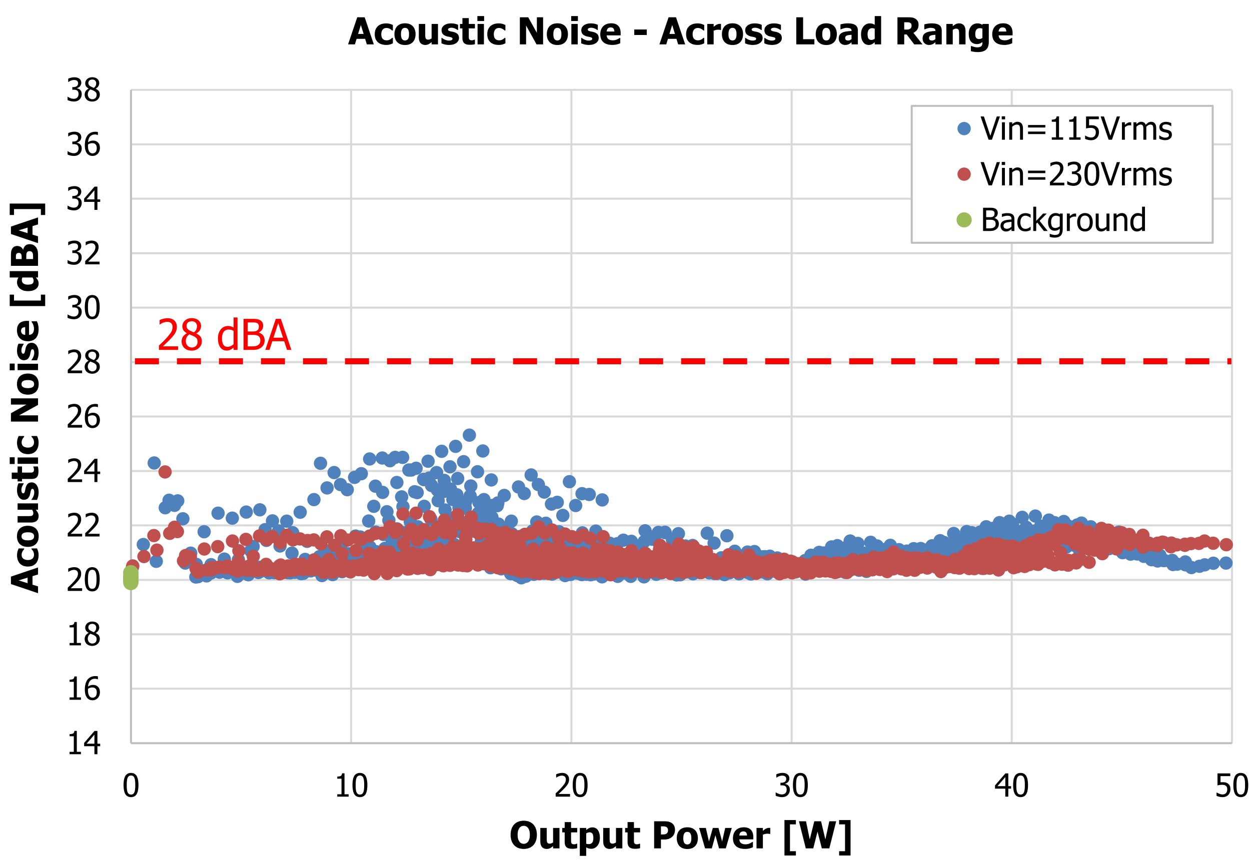


Figure 31 – Audible Noise in Operation mode.

The Audible noise vs. output power at standby mode measurements are shown below. These were obtained for combinations of:

- Low and high mains line voltages (115 V, 230 V).
- CVHV output = 0 A
- CV1 output = 0 mW to 250 mW
- NTC resistor and input CMCs were shorted.

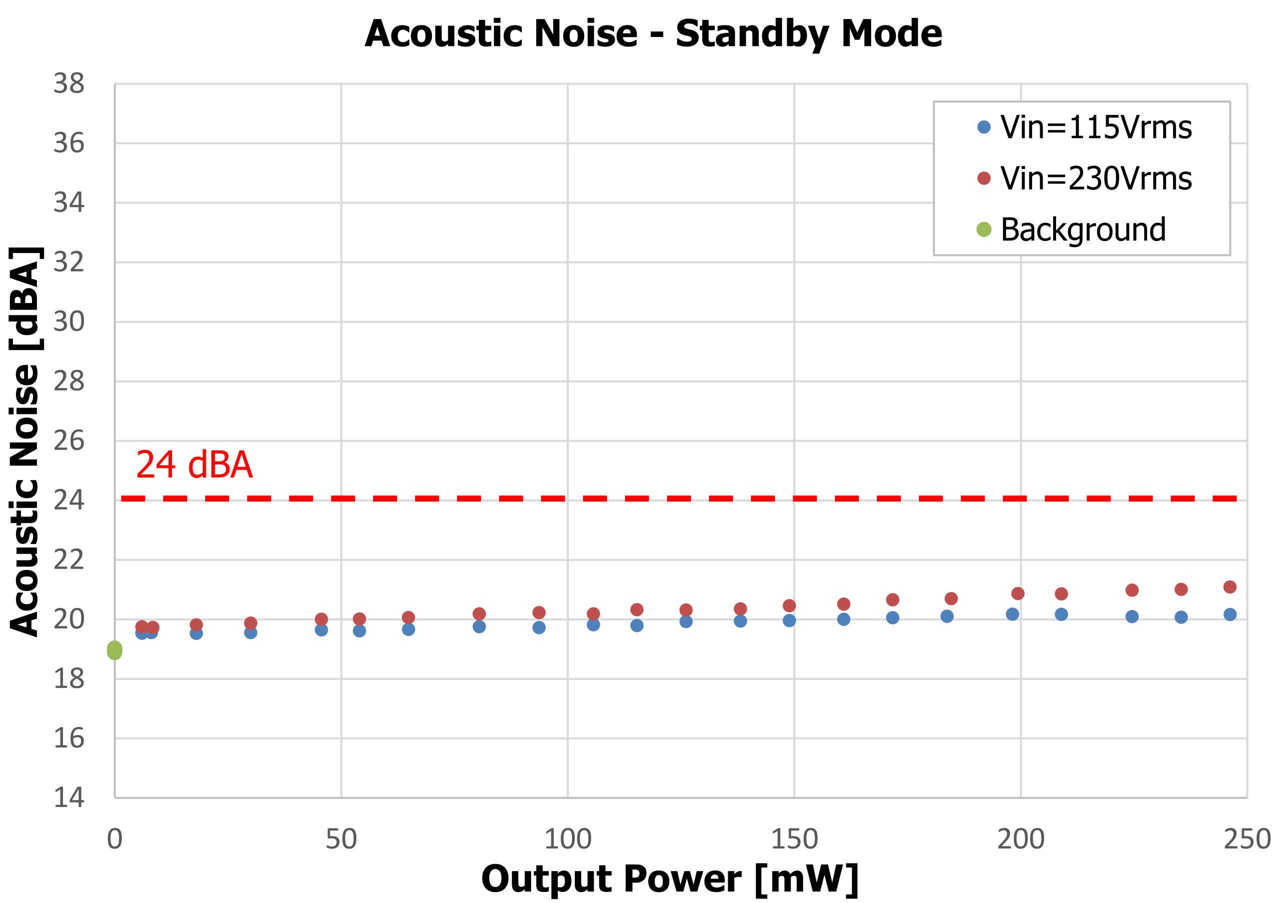
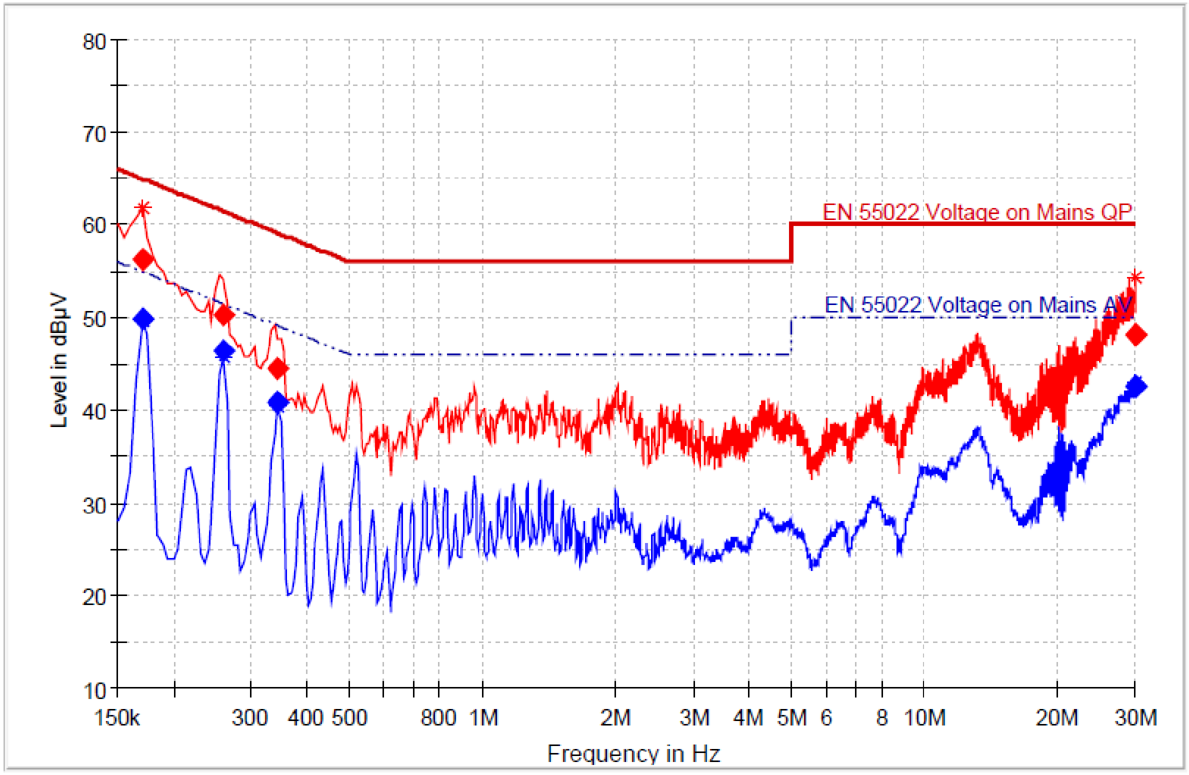


Figure 32 – Standby Power Consumption vs. Input Line Voltage, Room Temperature.

9.11 Conducted Emissions

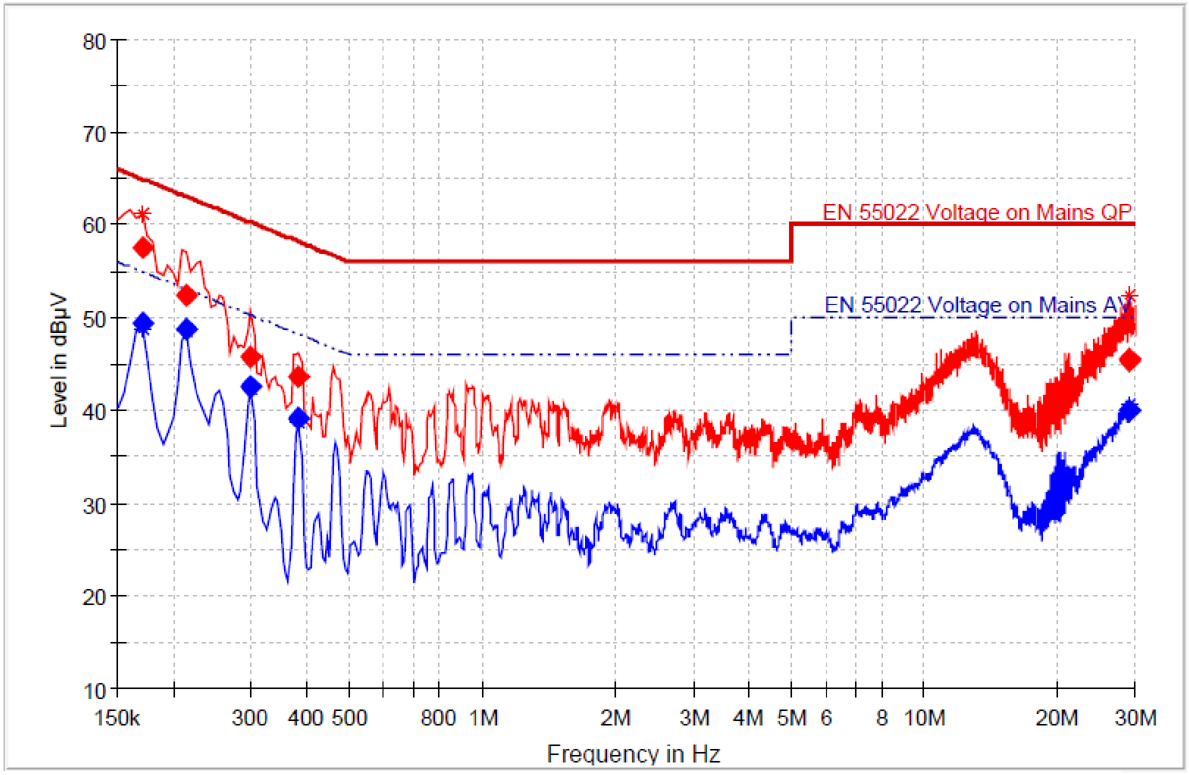
Conducted emissions test results are shown below. These were obtained under the following conditions:

- Low and high mains line voltages (115 V, 230 V).
- CV1 = 12 V @ 1.67 A.
- CVHV = 24 V @ 1.25 A.
- NTC resistor shorted.



Frequency (MHz)	QuasiPeak (dBµV)	Average (dBµV)	Limit (dBµV)	Margin (dB)	Bandwidth (kHz)	Line	Filter	Corr. (dB)
0.170000	---	49.72	54.96	5.24	10.000	L1	ON	20.3
0.170000	56.23	---	64.96	8.73	10.000	N	ON	20.3
0.260000	50.23	---	61.43	11.20	10.000	N	ON	20.3
0.260000	---	46.44	51.43	4.99	10.000	N	ON	20.3
0.345000	44.40	---	59.08	14.68	10.000	L1	ON	20.4
0.345000	---	40.91	49.08	8.17	10.000	L1	ON	20.4
29.855000	---	42.54	50.00	7.46	10.000	N	ON	20.4
29.855000	48.01	---	60.00	11.99	10.000	N	ON	20.4
29.875000	---	42.56	50.00	7.44	10.000	N	ON	20.4
29.875000	48.04	---	60.00	11.96	10.000	N	ON	20.4

Figure 33 – Conducted Emission result @ Vin = 115 VAC



Frequency (MHz)	QuasiPeak (dBµV)	Average (dBµV)	Limit (dBµV)	Margin (dB)	Bandwidth (kHz)	Line	Filter	Corr. (dB)
0.170000	---	49.48	54.96	5.48	10.000	L1	ON	20.3
0.170000	57.49	---	64.96	7.47	10.000	N	ON	20.3
0.215000	---	48.83	53.01	4.18	10.000	L1	ON	20.3
0.215000	52.42	---	63.01	10.59	10.000	L1	ON	20.3
0.300000	---	42.48	50.24	7.77	10.000	L1	ON	20.3
0.300000	45.81	---	60.24	14.44	10.000	L1	ON	20.3
0.385000	---	39.06	48.17	9.11	10.000	N	ON	20.4
0.385000	43.63	---	58.17	14.54	10.000	N	ON	20.4
29.090000	---	40.01	50.00	9.99	10.000	N	ON	20.4
29.090000	45.41	---	60.00	14.59	10.000	N	ON	20.4
29.140000	---	39.99	50.00	10.01	10.000	N	ON	20.4
29.140000	45.45	---	60.00	14.55	10.000	N	ON	20.4

Figure 34 – Conducted Emission result @ Vin = 230 VAC

10 Revision History

Date	Author	Revision	Description & Changes	Reviewed
10-May-24	YL	A	Initial Release.	Apps & Mktg
22-Oct-24	YL	B	Updated schematic and major updates on contents	Apps & Mktg
23-Nov-24	YL	C	BOM Update	Apps & Mktg

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