Design Example Report

Title	*60 W Isolated Flyback Power Supply Using InnoSwitch™3-EP PowiGaN™ INN3629C*
Specification	90 VAC – 480 VAC Input; 12 V / 5 A Output
Application	Industrial Application
Author	Applications Engineering Department
Document Number	DER-1025
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Revision	1.0

Summary and Features

- Off-line CV/CC QR flyback integrated switcher IC with 1250 V PowiGaN and synchronous rectification for higher efficiency
- <30 mW no-load input power @ 230 VAC
- Very high average efficiency
    - >92 % at 115 VAC and 230 VAC
    - >91 % from 90 VAC up to 480 VAC
- Very high full-load efficiency
    - >91 % at 115 VAC and 92 % at 230 VAC
- No optocoupler increases reliability
- Meets EN550022 and CISPR-22 Class B conducted EMI with >6db margin

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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 engineering report describes a 12 V / 5 A power supply using the InnoSwitch™3 PowiGaN™ INN3629C-H606 IC. This design shows a high-power density and efficiency that is possible due to the high level of integration of the InnoSwitch3 controller and PowiGaN providing exceptional performance.

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

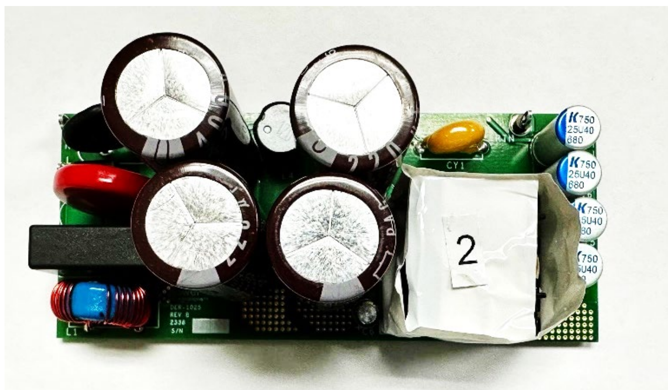


Figure 1 – Populated Circuit Board Photograph, Top.

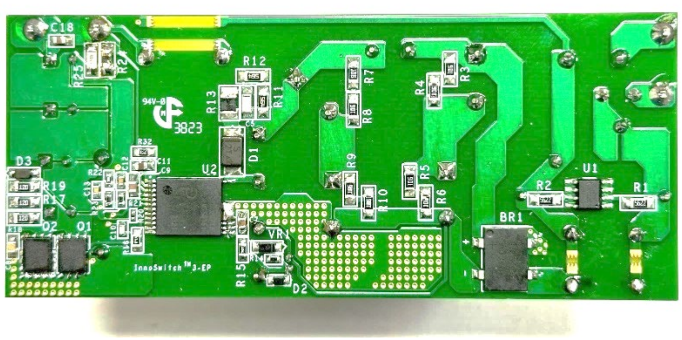


Figure 2 – Populated Circuit Board Photograph, Bottom.

2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the result section.

Description	Symbol	Min	Nom	Max	Units	Comment
Input						
Voltage	V_{IN}	90	115/230	480	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power				<30	mW	230 VAC input
Output						
Output Voltage	V_{OUT}	11.4	12	12.6	V	± 5%
Output Ripple Voltage	V_{RIPPLE}			120	mV	20 MHz Bandwidth, at 25 Deg°C Ambient
Output Current	I_{OUT}		5		A	
Total Output Power						
Continuous Output Power	P_{OUT}		60		W	
Efficiency	η		91 92 92 90 90			Average @ 90 VAC Average @ 115 VAC Average @ 230 VAC Average @ 265 VAC Average @ 420 VAC
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Surge (Differential)				6	kV	1.2/50 µs Surge, IEC 61000-4-5, Impedance: 2 Ω Class A
Ring Wave Surge Test				6	kV	
Ambient Temperature	T_{AMB}	0		40	ºC	Free Convection, Sea Level.

3 Schematic

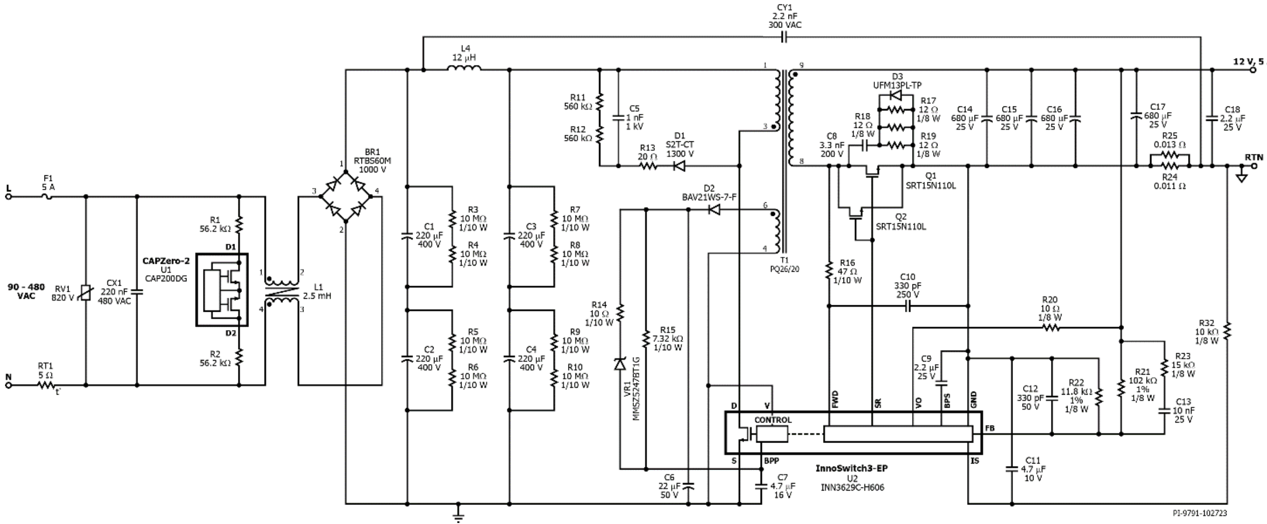


Figure 3 – Schematic.

4 Circuit Description

The InnoSwitch3-EP IC combines primary, secondary and feedback circuits in a single surface mounted off-line flyback switcher IC. The IC incorporates PowiGaN primary switch, primary-side controller, secondary-side controller for synchronous rectification and Fluxlink™ technology that eliminates the need for an optocoupler needed on a secondary sensed feedback system. InnoSwitch3 operates in Quasi-Resonant to achieve high efficiency.

4.1 Input EMI Filtering

Fuse F1 isolates the circuit and provides protection from component failure while RT1 reduces inrush current. Varistor RV1 clamps input voltage spike from input surge voltage. X capacitor C1 and common mode choke L1 attenuate common mode noise. Bridge rectifier BR1 rectifies the AC line voltage and provides a full wave rectified DC across the input filter capacitor C1, C2, C3 and C4. L4 connected in between input filter capacitors form input pi-filter. It attenuates both common and differential mode noise. The Capzero™-2 IC (U1), with bleeding resistors, R1 and R2, is used to discharge the stored energy in CX1 meeting safety requirement with low no load input power.

4.2 InnoSwitch3 IC Primary

One end of the transformer (T1) primary is connected to the rectified DC bus; the other is connected to the drain terminal of the switch inside the InnoSwitch3 (U3). A low-cost R2CD clamp formed by diode D1, resistors R11, R12, R13, and capacitor C5 limits the peak drain voltage of U2 at the instant of turn off the switch inside U2. The clamp helps to dissipate the energy stored in the leakage reactance of transformer T1.

The IC is self-starting, using an internal high-voltage current source to charge the BPP pin capacitor (C7) when AC is first applied. During normal operation, the primary-side block is powered from an auxiliary winding on the transformer T1. Output of the auxiliary (or bias) winding is rectified using diode D2 and filtered using capacitor C6. Resistor R15 limits the current being supplied to the BPP pin of the InnoSwitch3 (U2).

Zener diode VR1 in series with R14 offers primary sensed output overvoltage protection. In a flyback converter, output of the auxiliary winding tracks the output voltage of the converter. In case of overvoltage at output of the converter, the auxiliary winding voltage increases and causes breakdown of VR1 which then causes a current to flow into the BPP pin of InnoSwitch3-EP IC U1. If the current flowing into the BPP pin increases above the I_{SD} threshold, the InnoSwitch3 controller will undergo auto-restart to protect itself from any damage.

4.3 InnoSwitch3 IC Secondary

The secondary-side of the InnoSwitch3-EP IC provides output voltage, output current sensing and drive to the SRFET providing synchronous rectification. The secondary of the transformer is rectified by SRFET Q1, Q2 and filtered by output capacitors C14, C15, 16, and C17. High frequency ringing during switching transients that would otherwise create radiated EMI is reduced via an RCD snubber R17, R18, R19, C8 and D3. Diode D3 was used to minimize power dissipation in resistors R17, R18 and R19.

The gate of Q1 and Q2 are turned on by secondary-side controller inside IC U1, based on the winding voltage sensed via resistor R16 and fed into the FWD pin of the IC. The FWD pin is also used to supply the secondary side of IC U1 when the VOUT pin is below threshold value. Capacitor C10 prevents high-voltage spike on the FWD pin.

The secondary-side of the IC is self-powered from either the secondary winding forward voltage or the output voltage. Capacitor C19 connected to the BPS pin of InnoSwitch3-EP IC U2 provides decoupling for the internal circuitry.

Output current is sensed by monitoring the voltage drop across resistor R24 and R25 in parallel between the IS and GND pins with a threshold of approximately 36 mV to reduce losses. Capacitor C11 and resistor R32 provide filtering on the IS pin from external noise.

The device operates in constant voltage mode before reaching the current limit. During constant voltage mode operation, output voltage regulation is achieved through sensing the output voltage via divider resistors R21 and R22. The voltage across R22 is fed into the FB pin with an internal reference voltage threshold of 1.265 V. Output voltage is regulated to achieve a voltage of 1.265 V on the FB pin. Capacitor C12 provides decoupling from high frequency noise affecting FB pin, while C13 and R23 is the feedforward network to speed up the response time to lower the output ripple. Resistor R20 in series with VO pin acts as protection when common mode surge and ESD is injected in the output pins.

5 PCB Layout

PCB copper thickness is 2.0 oz.
PCB Material Thickness is 1.6 mm.
PCB Material is FR4.

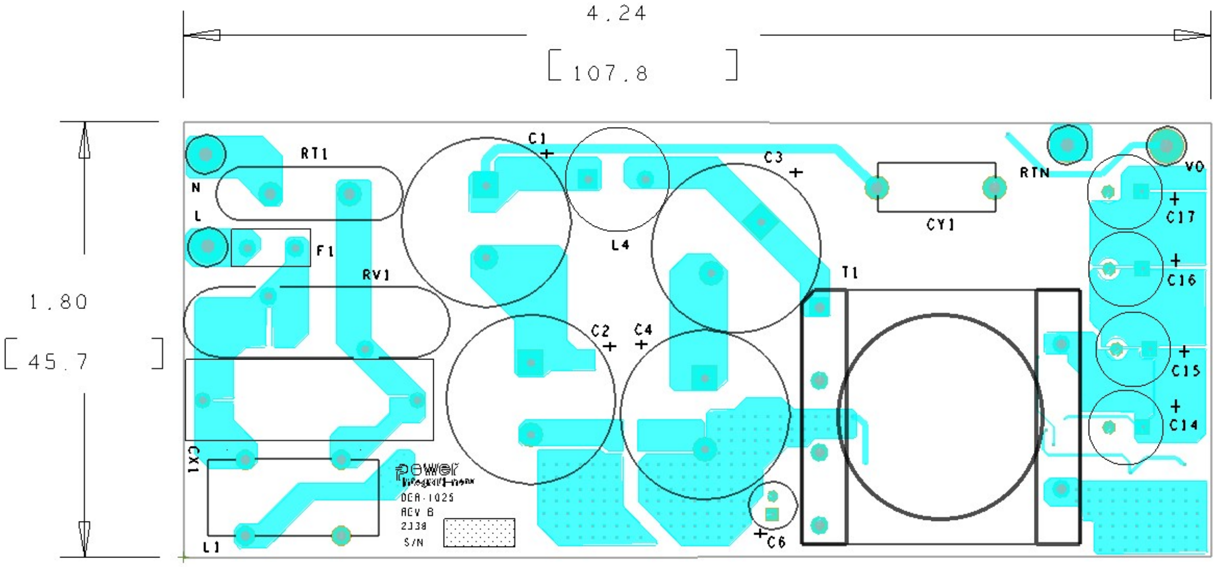


Figure 4 – Printed Circuit Layout, Top.

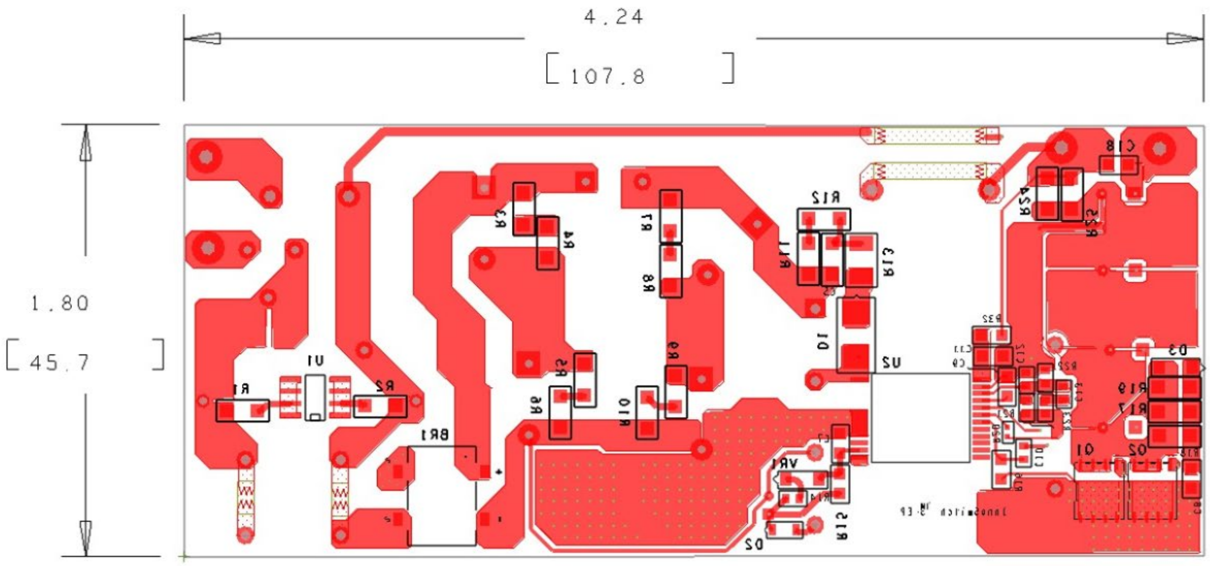


Figure 5 – Printed Circuit Layout, Bottom.

6 Bill of Materials

Item	QTY	Part Ref	Value	Mfg Part Number	Description	Mfg	Part Number
1	1	BR1	RTBS60M	RTBS60M	Bridge Rectifier, Single Phase, Standard, 1 kV, 4-SMD, Gull Wing	Taiwan Semiconductor	15-01826-00
2	4	C1 C2 C3 C4	220 uf	EPAG401ELL221MM45S	220 µF, 400 V, Aluminum Electrolytic Capacitors, Radial, Can, 2000 Hrs @ 105°C, (18 x 45mm)	United Chemi-Con	20-01926-00
3	1	C5	1 nF	C1206C102KDGACAUTO	1000pF, ±10%, 1000V (1kV), Ceramic Capacitor, C0G, NP0 1206 (3216 Metric)	Kemet	20-01391-00
4	1	C6	22 uF	EEU-FM1H220H	22 µF, 50 V, Aluminum Electrolytic Capacitors, Radial, Can (5 x 11), LS 2 mm	Panasonic Electronic	20-02059-00
5	1	C7	4.7 uF	CL21B475KOFNNNE	4.7 uF, 16 V, Ceramic, X7R, 0805 (2012 Metric)	Samsung Electro-Mechanics	20-09166-00
6	1	C8	3.3 nF	08052C332KAT2A	3.3 nF, 200 V, Ceramic, X7R, 0805	AVX Corp	20-00956-00
7	1	C9	2.2 uF	CL21B225KAFNFNE	2.2 µF, ±10%, 25V, Ceramic Capacitor X7R, 0805 (2012 Metric)	Samsung Electro-Mechanics	20-01594-00
8	1	C10	330 pF	CGA3E3C0G2E331J080AA	330 pF ±5% 250V Ceramic Capacitor C0G, NP0 0603 (1608 Metric)	TDK Corp	20-01651-00
9	1	C11	4.7 uF	LMK212B7475KGHT	4.7µF ±10% 10V Ceramic Capacitor X7R 0805 (2012 Metric)	Taiyo Yuden	20-01487-00
10	1	C12	330 pF	CC0603KRX7R9BB331	330 pF 50 V, Ceramic, X7R, 0603	Yageo	20-08676-00
11	1	C13	10 nF	CL10B103KA8NFNC	10 nF, 0.01µF, ±10%, 25V, Ceramic Capacitor, X7R, General Purpose, -55°C ~ 125°C, 0603 (1608 Metric)	Samsung Electro-Mechanics	20-09120-00
12	4	C14 C15 C16 C17	680 uF	A750KW687M1EAAE016	680 µF, ±20%, 25 V, Aluminum - Polymer Capacitors Radial, Can 16mOhm 2000 Hrs @	KEMET	20-01579-00
13	1	C18	2.2 uF	CL21B225KAFVPNE	2.2 uF, ±10%, 25V, X7R, r, -55°C ~ 125°C, 0805 (2012 Metric)	Samsung Electro-Mechanics	20-09264-00
14	1	CX1	220n	F339X142248MIP2T0	0.22 µF, ±20%, Film Capacitor 480V 1000V (1kV) Polypropylene (PP), Metallized Radial,26mmL x 8.5mmW x 18mmH x 22.5mmLS	Vishay	20-01879-00
15	1	CY1	2.2 nF	AY1222M47Y5UC63L0	CAP, 2200pF, ±20% ,760VAC, Ceramic Capacitor Y5U (E) Radial, Disc	Vishay/ BC Components	20-01427-00
16	1	D1	S2T-CT	S2T-CT	Diode, Standard, 1300 V, 2A, Surface Mount SMB, (DO-214AA)	Diotec Semiconductor	15-01834-00
17	1	D2	BAV21WS-7-F	BAV21WS-7-F	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	Diode Inc.	15-00385-00
18	1	D3	UFM13PL-TP	UFM13PL-TP	DIODE, GEN PURP, 200V, 1A, SOD-123F, SOD123FL	Micro Commercial Co.	15-01801-00
19	1	F1	5 A	RST 5	5 A, 250 V, Slow, Long Time Lag,RST	Belfuse	40-00052-00
20	1	L1	2.5 mH	32-00454-00	2.5 mH, Toroidal Common Mode Input Choke,L1, custom, DER-1025, wound on 32-00331-00 core	Power Integrations	32-00454-00
21	1	L4	12 uH	RFB1010-120L	Fixed Inductor, 12 µH @100KHz,± 10%, 5.1 A, Unshielded, Ferrite, Radial,-40°C ~ 85°C, 11 x 11.5mm	Coilcraft	30-00482-00
22	2	Q1 Q2	SRT15N110LD56	SRT15N110LD56TR-G	MOSFET, N-Channel 150 V, 80 A (Ta), 157 W (Ta), Surface Mount 8-PDFN (5x6)	Shenzhen Sanrise Technology	50-00445-00
23	2	R1 R2	56.2 k	ERJ-8ENF5622V	RES, 56.2 k, 1%, 1/4 W, Thick Film, 1206	Panasonic	05-00361-00
24	8	R3 R4 R5 R6 R7 R8 R9 R10	10 M	RC1206FR-0710ML	RES, 10 M, 5%, 1/4 W, Thick Film, 1206	YAGEO	05-01445-00
25	2	R11 R12	560 k	ERJ-P08J564V	RES, 560 k, 5%, 2/3 W, Thick Film, 1206	Panasonic	05-01418-00
26	1	R13	20	CRCW121020R0JNEA	RES, 20 Ohm, ±5%, 0.5W, 1/2W, 1210 (3225 Metric), Thick Film	Vishay Dale	05-06460-00
27	1	R14	10	ERJ-3EKF10R0V	RES, 10 R, 1%, 1/10 W, Thick Film, 0603	Panasonic	05-00886-00
28	1	R15	7.32 k	ERJ-6ENF7321V	RES, 7.32 k, 1%, 1/8 W, Thick Film, 0805	Panasonic	05-03389-00
29	1	R16	47.0	ERJ-6ENF47R0V	RES, 47.0 R, 1%, 1/8 W, Thick Film, 0805	Panasonic	05-03476-00
30	3	R17 R18 R19	12	ERJ-P08J120V	RES, 12 R, 5%, 2/3 W, Thick Film, 1206	Panasonic	05-01306-00
31	1	R20	10	ERJ-2RKF10R0X	RES, 10 R, 1%, 1/10 W, Thick Film, 0402	Panasonic	05-05596-00
32	1	R21	102 k	ERJ-3EKF1023V	RES, 102 k, 1%, 1/10 W, Thick Film, 0603	Panasonic	05-01175-00
33	1	R22	11.8 k	ERJ-3EKF1182V	RES, 11.8 k, 1%, 1/10 W, Thick Film, 0603	Panasonic	05-03189-00
34	1	R23	15 k	ERJ-3EKF1502V	RES, 15 k, 1%, 1/10 W, Thick Film, 0603	Panasonic	05-03199-00
35	1	R24	0.011	ERJ-8CWFR011V	0.011 Ohm, ±1%, ±75ppm/°C, 1W, 1206 (3216 Metric), Automotive AEC-Q200, Current	Panasonic Electronic Components	05-06466-00
36	1	R25	0.013 Ohms	UCR18EVHFSR013	RES, 13 mOhms, ±1%, 0.5W, 1/2W, Chip Resistor 1206 (3216 Metric) Automotive AEC-	Rohm Semiconductor	05-07020-00
37	1	R32	10	ERJ-6ENF10R0V	RES, 10 R, 1%, 1/8 W, Thick Film, 0805	Panasonic	05-00492-00
38	1	RT1	5	CL-30	NTC Thermistor, 2.5 Ohms, 8 A	Thermometrics	90-00032-00
39	1	RV1	820V	V20E510P	510VAC, 10 kA, 365 J, disc 20 mm, RADIAL	Littlefuse	85-00069-00
40	1	T1	PQ26/20	B65878E0012D001	Bobbin, PQ26/20, Vertical, 12 pins	EPCOS (TDK)	25-01140-00
41	1	U1	CAP200DG	CAP200DG	CAPZero-2, CAP200DG, SO-8C	Power Integrations	10-00958-00
42	1	U2	INN3629C-H606	INN3629C-H606	INN3629C-H606, INNO3 Switch Integrated Circuit, InnoSwitch-3EP_1250V, InSOP24D	Power Integrations	10-01474-00
43	1	VR1	MMSZ5247BT1G	MMSZ5247BT1G	DIODE, ZENER, 17V, ±5%, 500mW, SOD123,SOD-123	ON Semi	15-01362-00

Test points							
44	1	VO	RED	5010	Test Point, RED,THRU-HOLE MOUNT	Keystone	35-00043-00
45	2	N RTN	BLK	5011	Test Point, BLK,THRU-HOLE MOUNT	Keystone	35-00042-00
46	1	L	WHT	5012	Test Point, WHT,THRU-HOLE MOUNT	Keystone	35-00044-00

7 Transformer Specification

7.1 Electrical Diagram

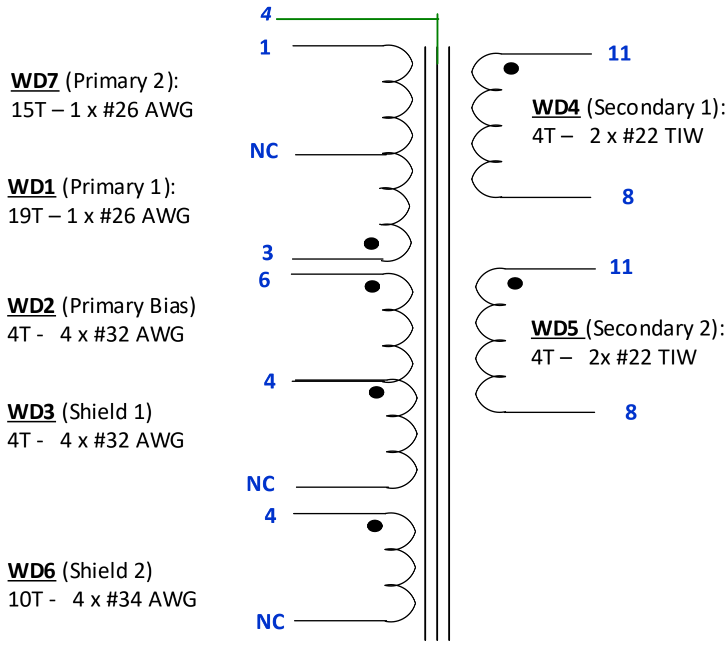


Figure 6 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Parameter	Condition	Spec
Electrical Strength	60 Hz 1 second, from pins ,1,3,4,6 to pins 8,9.	3000 VAC
Nominal Primary Inductance	Measured at 1 V pk-pk, typical switching frequency, between pin 3 to pin 1, with all other Windings open.	620 uH ±5.0%
Maximum Primary Leakage	Measured between pin 3 to pin 1, with all other Windings shorted.	6 uH

7.3 Materials List

Item	Description
[1]	Core: PQ2620, TDK-PC95.
[2]	Bobbin: PQ26/20-Vert-12pin s(6/6); PI#: 25-01140-00.
[3]	Magnet wire: #26 AWG, double coated.
[4]	Magnet wire: #32 AWG, double coated.
[5]	Magnet wire: #34 AWG, double coated.
[6]	Magnet wire: #22 AWG, Triple Insulated Wire.
[7]	Bus wire: #28AWG, Alpha wire, tinned copper.
[8]	Tape: 3M 13450-F, Polyester Film, 1 mil thickness, 9.3mm width.
[9]	Tape: 3M 13450-F, Polyester Film, 1 mil thickness, 19.0 mm width.
[10]	Tape: 3M 13450-F, Polyester Film, 1 mil thickness, 25.0 mm width.
[11]	Varnish: Dolph BC-359.

7.4 Transformer Build Diagram

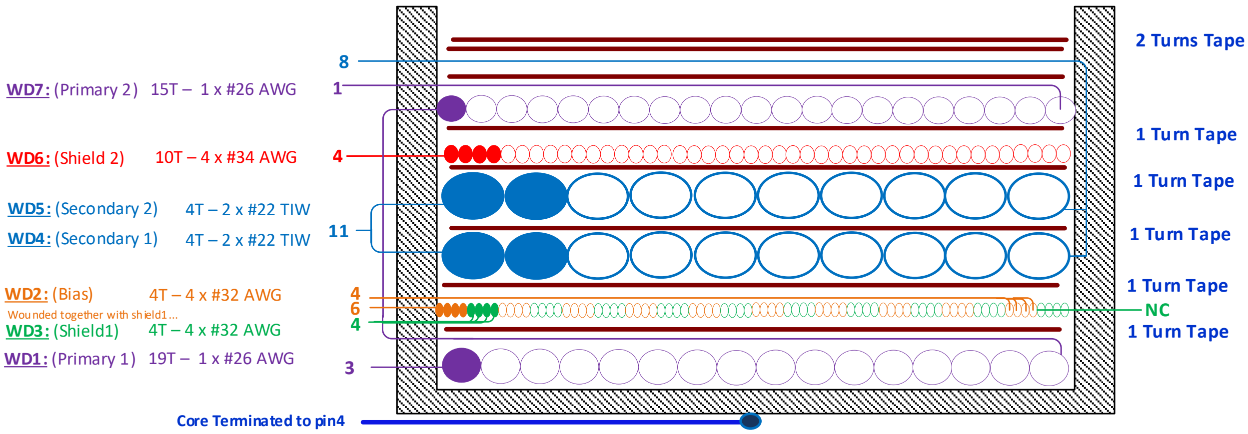
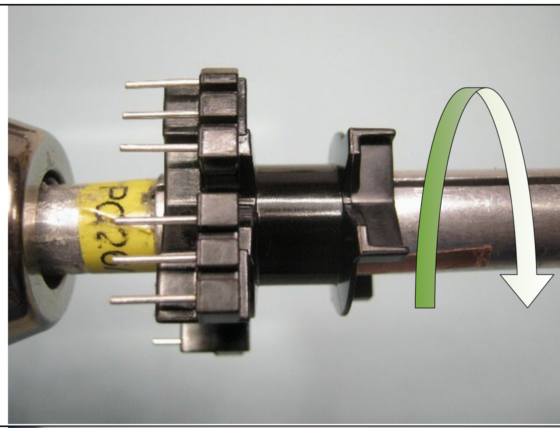
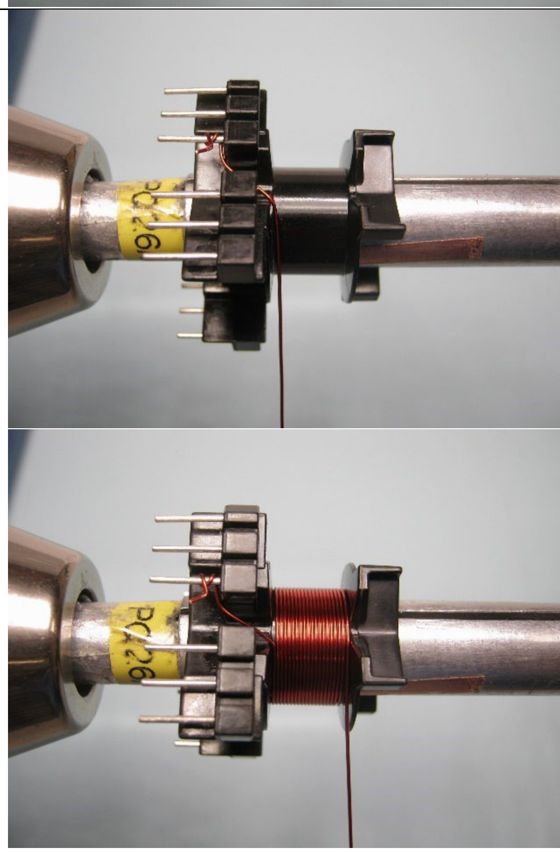


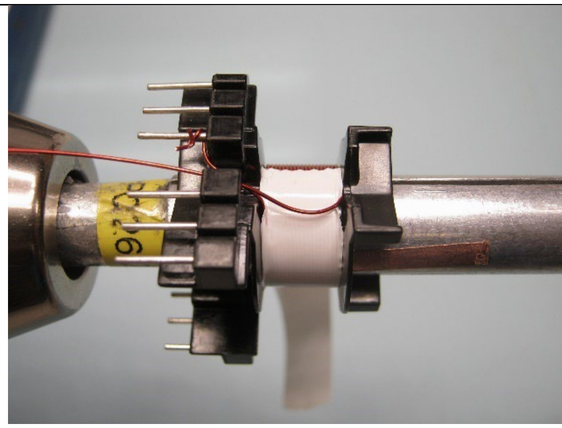
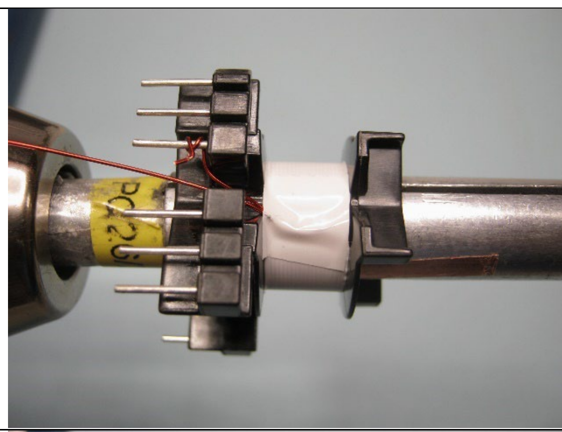
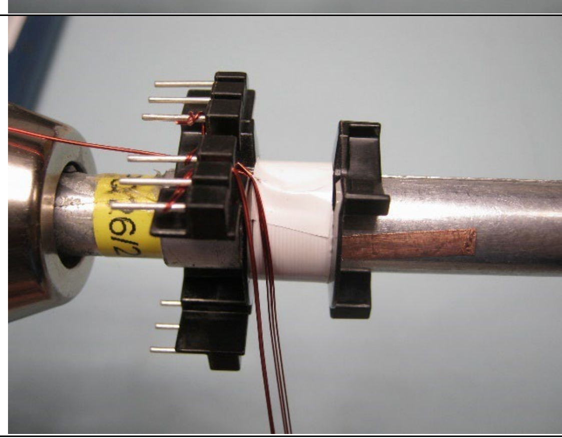
Figure 7 – Transformer Electrical Diagram.

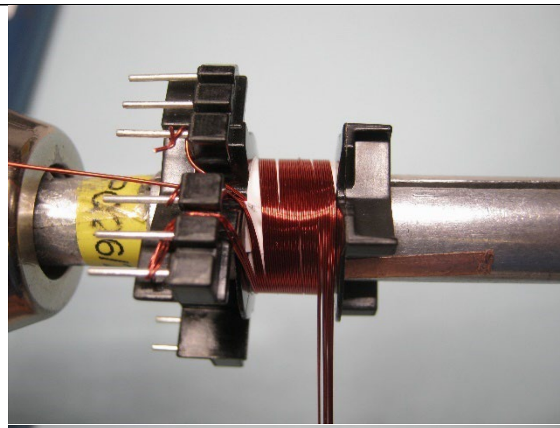
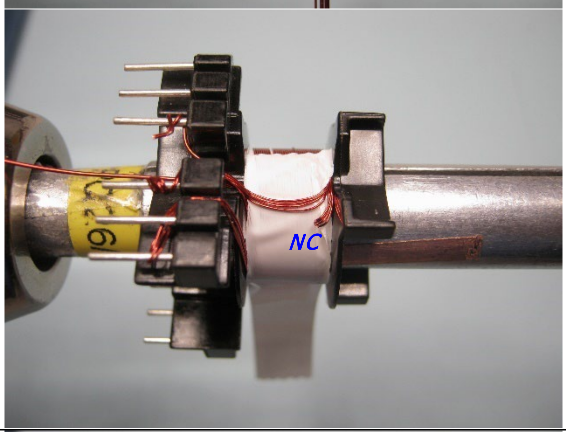
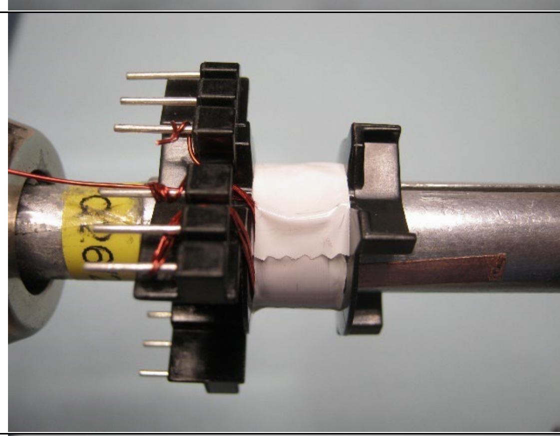
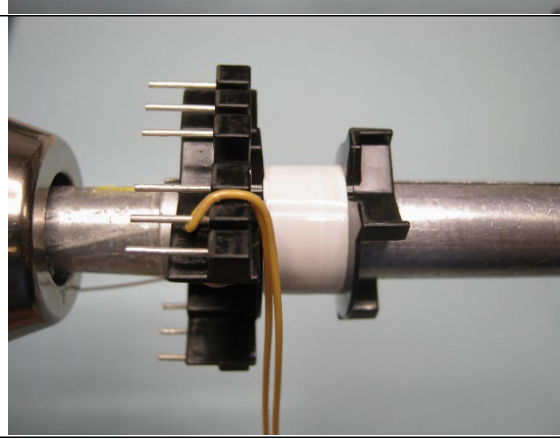
7.5 Transformer Winding Instructions

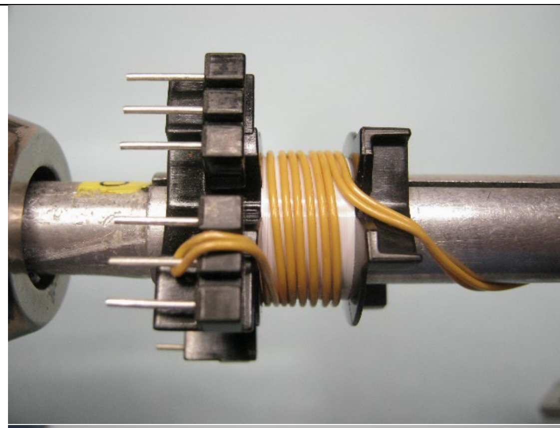
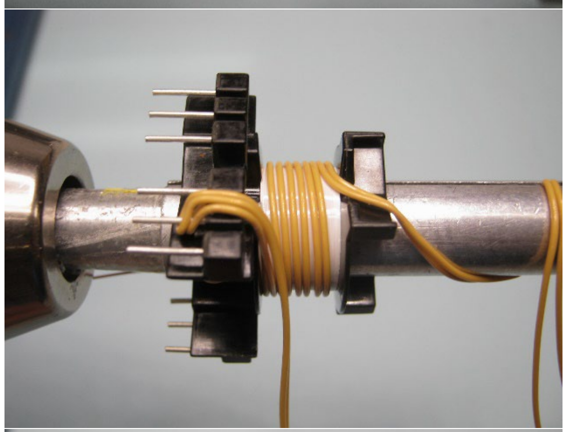
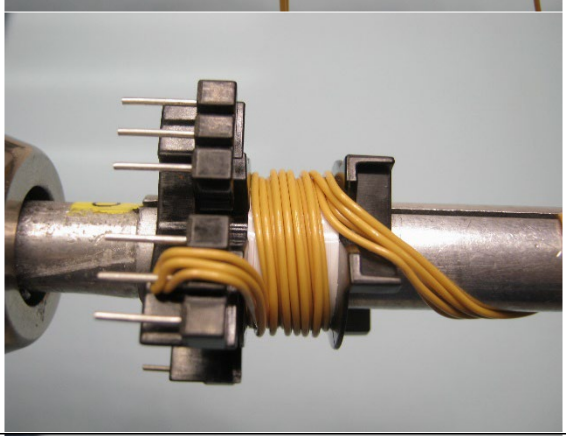
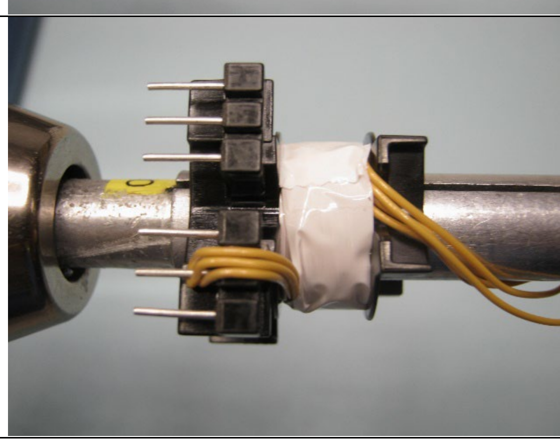
Winding Preparation	Position the bobbin item [2] on the mandrel such that the primary side of the bobbin is on the left side. Winding direction is clockwise direction for forward direction.
WD1 1st Primary	Start at pin 3, wind 19 turns of wire item [3] in 1 layer, with tight tension, from left to right. At the last turn, bring the wire back to left, and leave enough length of wire-floating for WD7-2nd Primary.
Insulation	1 layer of tape item [8].
WD2: Bias & WD3: Shield1	Use 4 wires item [4] start at pin 6 for Bias winding, also use 4 wires same item [4] start at pin 4 for Shield1 winding. Wind all 8 wires in parallel, at the 4th turn: - bring 4 wires for Bias winding to the left and terminate at pin 4, - cut short 4 wires for Shield1 Winding as No-Connect.
Insulation	1 layer of tape item [8].
WD4 & WD5 Sec1 & Sec2	Start at pin 11, wind 4 bi-filar turns of wire item [6] from left to right. At the last turn exit at right slot and leave ~ 25mm of wires floating for WD4 -Secondary 1. Repeat winding same as above for WD5-Secondary 2.
Insulation	1 layer of tape item [8].
WD6 Shield2	Start at pin 4, wind 10 quad-filar turns of wire item [5], from left to right. At the last turn, cut short to leave as No-Connect.
Insulation	1 layer of tape item [8].
WD7 2nd Primary	Use floating wire from WD1-1st Primary, wind 15 turns from left to right. At the last turn, bring the wire back to left and finish at pin 1.
Insulation	
Finish	1 layer of tape item [8]. Bring 4 wires floating from WD4-Secondary1 and WD5-Secondary2 to left and terminate at pin 8. Gap core halves to get 620 uH. Use tape item [9] to cover one side of core as shown in the picture below, only for bottom secondary side. Solder pin 4 with bus-wire item [7] then lean along core halves and secure with tape. Use 2 layers of tape item [9] horizontally to secure the cores. Varnish with item [11]. Use a wide tape item [10] to envelop bottom and secondary side part of the bobbin.

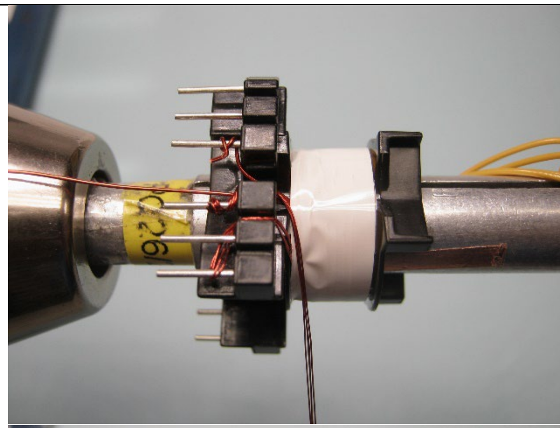
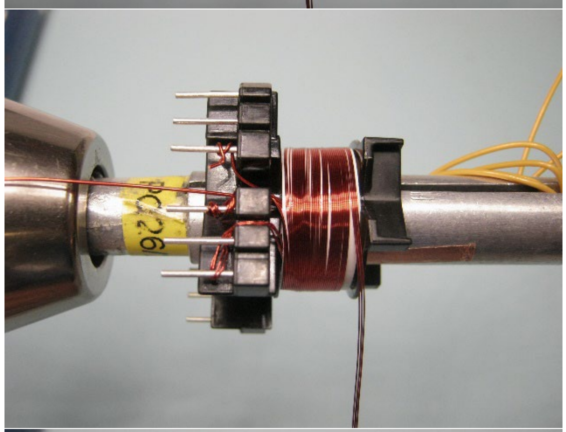
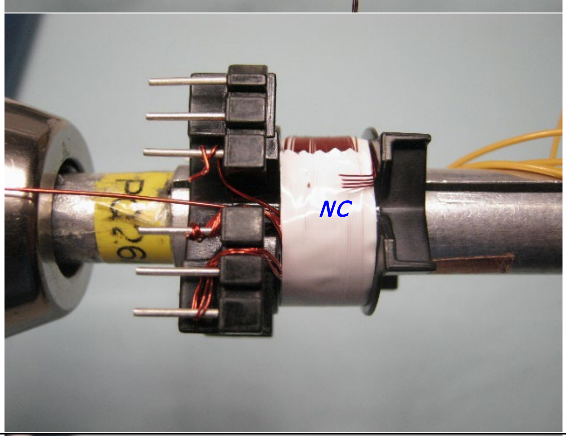
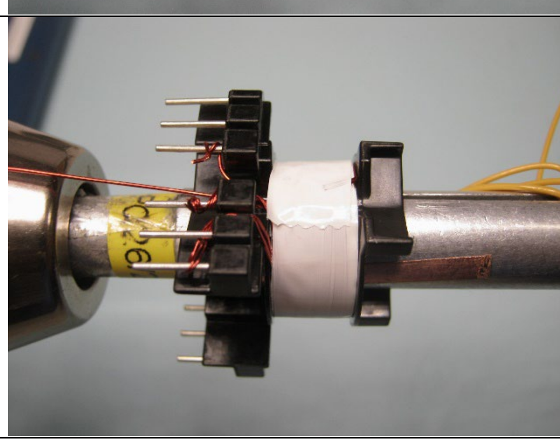
7.6 Winding Illustrations

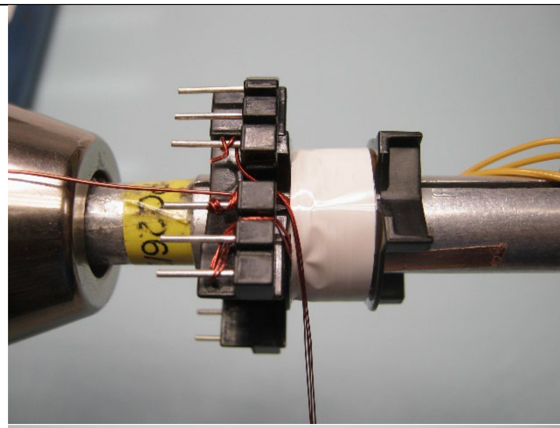
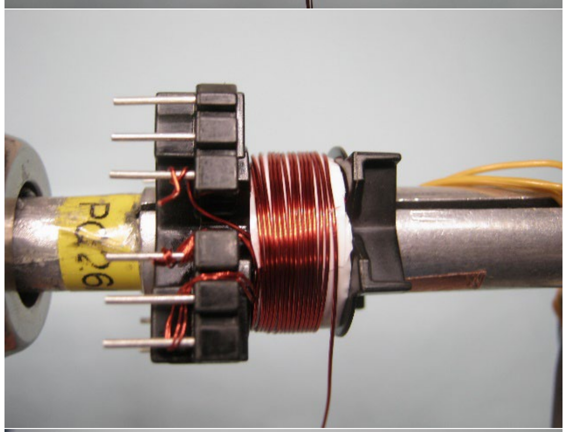
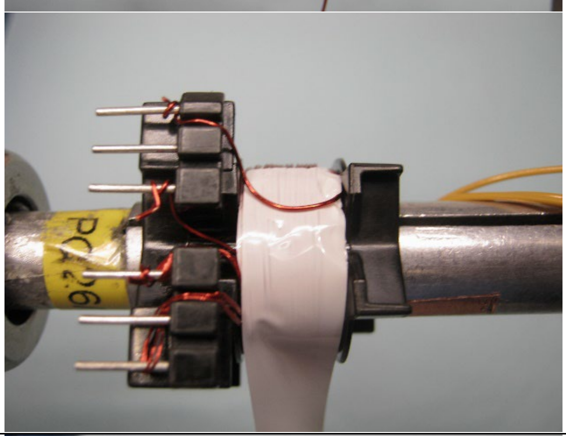
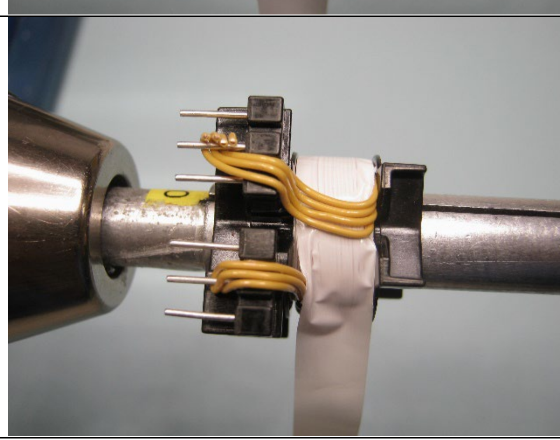
Winding Preparation		Position the bobbin item [2] on the mandrel such that the primary side of the bobbin is on the left side. Winding direction is clockwise direction for forward direction.
WD1 **1^{st} Primary**		Start at pin 3, wind 19 turns of wire item [3] in 1 layer, with tight tension, from left to right. At the last turn, bring the wire back to left, and leave enough length of wire-floating for WD7-2^{nd} Primary.

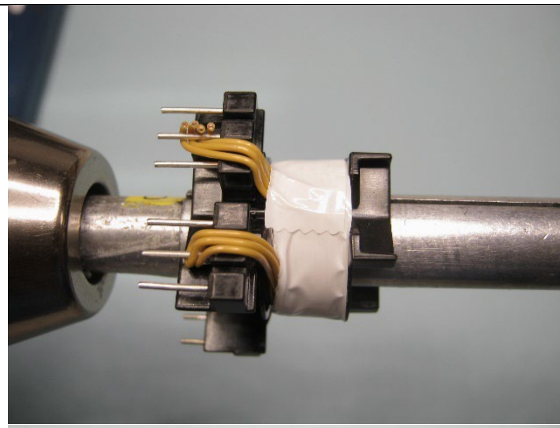
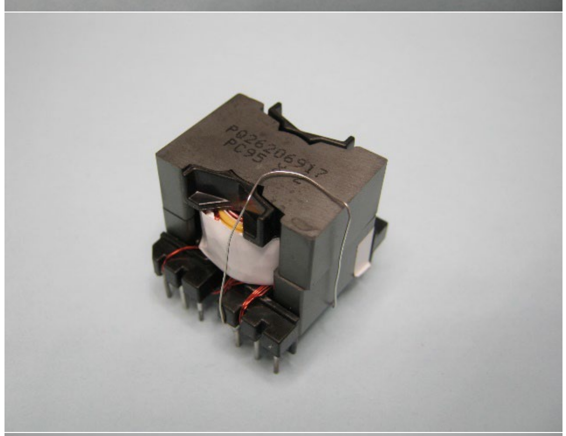
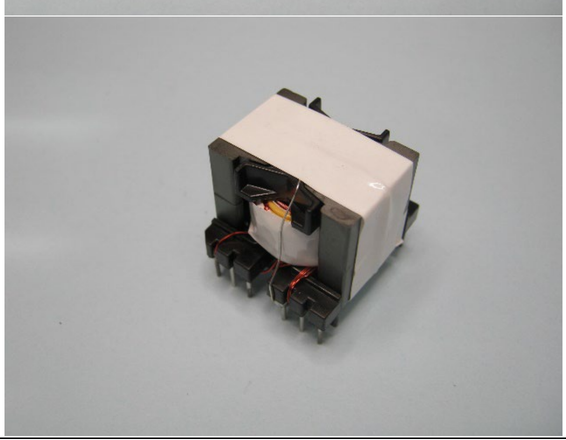
		
Insulation		1 layer of tape item [8].
WD2: Bias & WD3: Shield1		Use 4 wires item [4] start at pin 6 for Bias winding, also use 4 wires same item [4] start at pin 4 for Shield1 winding. Wind all 8 wires in parallel, at the 4th turn: - bring 4 wires for Bias winding to the left and terminate at pin 4,

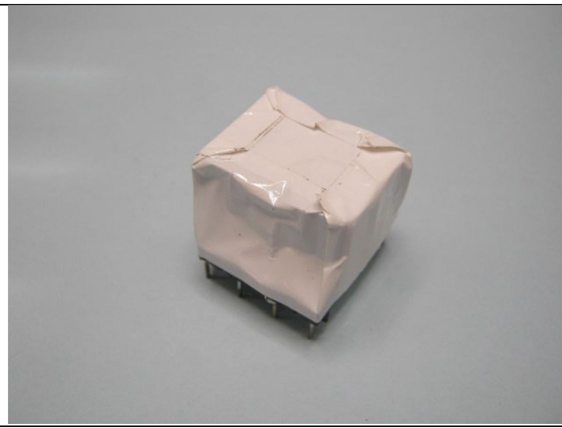
	 	- cut short 4 wires for Shield1 Winding as No-Connect.
Insulation		1 layer of tape item [8].
WD4 & WD5 Sec1 & Sec2		Start at pin 11, wind 4 bi-filar turns of wire item [6] from left to right. At the last turn exit at right slot and leave ~ 25mm of wires floating for WD4 - Secondary 1. Repeat winding same as above for WD5-Secondary 2.

	  	
Insulation		1 layer of tape item [8].

WD6 **Shield2**	   	Start at pin 4, wind 10 quad-filar turns of wire item [5], from left to right. At the last turn, cut short to leave as No-Connect.
Insulation		1 layer of tape item [8].

WD7 **2nd Primary**	  	Use floating wire from WD1-1st Primary, wind 15 turns from left to right. At the last turn, bring the wire back to left and finish at pin 1.
		

Finish	   	1 layer of tape item [8]. Bring 4 wires floating from WD4-Secondary1 and WD5-Secondary2 to left and terminate at pin 8. Gap core halves to get 620uH. Use tape item [9] to cover one side of core as shown in the picture beside, only for bottom secondary side. Solder pin 4 with bus-wire item [7] then lean along core halves and secure with tape. Use 2 layers of tape item [9] horizontally to secure the cores. Varnish with item [11]. Use a wide tape item [10] to envelop bottom and secondary side part of the bobbin.

8 Transformer Design Spreadsheet

ACDC_InnoSwitch3-EP900V_Flyback_100623; Rev.1.5; Copyright Power Integrations 2023	***INPUT***	***INFO***	***OUTPUT***	***UNITS***	***InnoSwitch3-EP 900V Flyback Design Spreadsheet***
APPLICATION VARIABLES					Design Title
VIN_MIN	90		90	V	Minimum AC input voltage
VIN_MAX	480		480	V	Maximum AC input voltage
VIN_RANGE			WIDE RANGE UNIVERSAL		Range of AC input voltage
LINEFREQ			60	Hz	AC Input voltage frequency
CAP_INPUT	180.0		180.0	uF	Input capacitor
VOUT			12.00	V	Output voltage at the board
PERCENT_CDC			0		load
IOUT	5.000		5.000	A	Output current
POUT			60.00	W	Output power
EFFICIENCY	0.88		0.88		given that the converter is switching at the valley of the rectified minimum input AC voltage
FACTOR_Z			0.50		Z-factor estimate
ENCLOSURE			OPEN FRAME		Power supply enclosure
PRIMARY CONTROLLER SELECTION					
ILIMIT_MODE	INCREASED		INCREASED		Device current limit mode
DEVICE_GENERIC	AUTO		INN36X9C		Generic device code
DEVICE_CODE			INN3639C		Actual device code
POUT_MAX			75	W	Power capability of the device based on thermal performance
RDSON_100DEG			0.58	Ω	at 100 degC
ILIMIT_MIN			1.980	A	switch
ILIMIT_TYP			2.130	A	switch
ILIMIT_MAX			2.279	A	switch
VDRAIN_BREAKDOWN	1250		1250	V	Device breakdown voltage
VDRAIN_ON_PRSW			0.35	V	Primary switch on time drain voltage
VDRAIN_OFF_PRSW			802.4	V	Peak drain voltage on the primary switch during turn-off
WORST CASE ELECTRICAL PARAMETERS					
FSWITCHING_MAX	68000		68000	Hz	load and valley of the rectified minimum AC input voltage
VOR	100.0		100.0	V	primary when the primary switch turns off
VMIN			105.37	V	at full load
KP			0.66		Measure of continuous/discontinuous mode of operation
MODE_OPERATION			CCM		Mode of operation
DUTYCYCLE			0.488		Primary switch duty cycle
TIME_ON			11.69	us	Primary switch on-time
TIME_OFF			7.53	us	Primary switch off-time
LPRIMARY_MIN			588.2	uH	Minimum primary inductance
LPRIMARY_TYP			619.2	uH	Typical primary inductance

LPRIMARY_TOL			5.0	%	Primary inductance tolerance
LPRIMARY_MAX			650.1	uH	Maximum primary inductance
PRIMARY CURRENT					
IPEAK_PRIMARY			2.082	A	Primary switch peak current
IPEDESTAL_PRIMARY			0.631	A	Primary switch current pedestal
IAVG_PRIMARY			0.610	A	Primary switch average current
IRIPPLE_PRIMARY			1.661	A	Primary switch ripple current
IRMS_PRIMARY			0.936	A	Primary switch RMS current
SECONDARY CURRENT					
IPEAK_SECONDARY			17.696	A	Secondary winding peak current
IPEDESTAL_SECONDARY			5.360	A	Secondary winding current pedestal
IRMS_SECONDARY			8.152	A	Secondary winding RMS current
TRANSFORMER CONSTRUCTION PARAMETERS					
CORE SELECTION					
CORE	PQ26/20	Info	PQ26/20		Refer to the Transformer Parameters tab to verify fit factor
CORE CODE			B65877B0000R095		Core code
AE			122.30	mm^2	Core cross sectional area
LE			44.40	mm	Core magnetic path length
AL			6300	nH/turns^2	Ungapped core effective inductance
VE			5435.0	mm^3	Core volume
BOBBIN			B65878E0012D001		Bobbin
AW			33.00	mm^2	Window area of the bobbin
BW			9.00	mm	Bobbin width
MARGIN			0.0	mm	Safety margin width (Half the primary to secondary creepage distance)
PRIMARY WINDING					
NPRIMARY			34		Primary turns
BPEAK			3647	Gauss	Peak flux density
BMAX			3211	Gauss	Maximum flux density
BAC			1255	Gauss	AC flux density (0.5 x Peak to Peak)
ALG			536	nH/turns^2	inductance
LG			0.263	mm	Core gap length
SECONDARY WINDING					
NSECONDARY			4		Secondary turns
OD_SECONDARY_BARE			1.150	mm	Secondary winding wire outer diameter without insulation
CMA_SECONDARY			251	Cmil/A	Secondary winding wire CMA
BIAS WINDING					
NBIAS			4		Bias turns

PRIMARY COMPONENTS SELECTION					
LINE UNDERVOLTAGE					
BROWN-IN REQURED			81.0	V	threshold
RLS			7.48	MΩ	the V-pin for the required UV/OV threshold
BROWN-IN ACTUAL			45.3 - 79.8	V	Actual AC RMS brown-in range
BROWN-OUT ACTUAL			34.9 - 65.4	V	Actual AC RMS brown-out range
LINE OVERVOLTAGE					
OV_TARGET			482.4	V	overvoltage will trigger. For High Line desings, brown-in threshold might need to be lowered to get the required overvoltage
RV_BIAS_ENABLED	AUTO		YES		increase Line OV threshold without increasing Line UV
RV_BIAS			280	kΩ	Biasing resistor between BPP and V pins of the device
OVERVOLTAGE_LINE			488 - 573	V	Actual AC RMS line over-voltage range
BIAS DIODE					
VBIAS	9.0	Info	9.0	V	to supply the BP pin: Increase the rectified bias voltage to a value higher than 10V
VF_BIAS			0.70	V	Bias winding diode forward drop
VREVERSE_BIASDIODE			88.70	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
CBIAS			22	uF	Bias winding rectification capacitor
CBPP			4.70	uF	BPP pin capacitor
SECONDARY COMPONENTS					
RFB_UPPER			100.00	kΩ	Upper feedback resistor (connected to the first output voltage)
RFB_LOWER			11.80	kΩ	Lower feedback resistor
CFB_LOWER			330	pF	capacitor
MULTIPLE OUTPUT PARAMETERS					
OUTPUT 1					
VOUT1			12.00	V	Output 1 voltage
IOUT1			5.00	A	Output 1 current
POUT1			60.00	W	Output 1 power
IRMS_SECONDARY1			8.152	A	Root mean squared value of the secondary current for output 1
IRIPPLE_CAP_OUTPUT1			6.438	A	Current ripple on the secondary waveform for output 1
NSECONDARY1			4		Number of turns for output 1
VREVERSE_RECTIFIER1			91.70	V	SRFET reverse voltage (not accounting parasitic voltage ring) for output 1
SRFET1	AUTO		AON7254		output 1
VF_SRFET1			0.330	V	1
VBREAKDOWN_SRFET1			150	V	SRFET breakdown voltage for output 1
RDSON_SRFET1			66.0	mΩ	SRFET on-time drain resistance at 25degC and VGS=4.4V for output 1

9 Performance Data

All the performance data has been taken on the board unless otherwise specifically mentioned.

9.1 Average Efficiency

	Test	Average	Average	10% Load
Output Voltage (V)	Power [W]	DOE6 Limit (%)	CoC v5 Tier 2 (%)	CoC v5 Tier 2 (%)
12	60	88.00	89.00	79.00

9.2 Average and 10% Efficiency at 90 VAC Input

Input: 90 VAC							
Load	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency	Average Efficiency	COC5T2 Limit
(%)	(W)	(V)	(A)	(W)	(%)	(%)	(%)
100	65.78	11.96	4.99	59.73	90.80	**91.91**	89
75	49.02	12.00	3.75	44.98	91.75		
50	32.58	12.09	2.49	30.06	92.26		
25	16.22	12.11	1.24	15.06	92.82		
10	6.46	12.10	0.50	5.99	92.70	---	79

9.3 Average and 10% Efficiency at 115 VAC Input

Input: 115 VAC							
Load	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency	Average Efficiency	COC5T2 Limit
(%)	(W)	(V)	(A)	(W)	(%)	(%)	(%)
100	65.24	12.00	4.99	59.92	91.84	**92.79**	89
75	48.63	12.04	3.75	45.11	92.76		
50	32.33	12.10	2.49	30.10	93.10		
25	16.13	12.12	1.24	15.08	93.46		
10	6.45	12.10	0.50	5.99	92.87	---	79

9.4 Average and 10% Efficiency at 230 VAC Input

Input: 230 VAC							
Load	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency	Average Efficiency	COC5T2 Limit
(%)	(W)	(V)	(A)	(W)	(%)	(%)	(%)
100	64.01	12.02	4.99	60.01	93.76	**93.65**	89
75	48.35	12.11	3.75	45.37	93.82		
50	32.15	12.12	2.49	30.15	93.79		
25	16.20	12.14	1.24	15.10	93.21		
10	6.57	12.11	0.50	6.01	91.45	---	79

9.5 Average and 10% Efficiency at 265 VAC Input

Input: 265 VAC							
Load	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency	Average Efficiency	COC5T2 Limit
(%)	(W)	(V)	(A)	(W)	(%)	(%)	(%)
100	64.31	12.07	4.99	60.29	93.76	**93.49**	89
75	48.37	12.10	3.75	45.35	93.77		
50	32.21	12.12	2.49	30.15	93.62		
25	16.27	12.14	1.24	15.10	92.81		
10	6.63	12.11	0.50	6.00	90.50	---	79

9.6 Average and 10% Efficiency at 480 VAC Input

Input: 480 VAC							
Load	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}	Efficiency	Average Efficiency	COC5T2 Limit
(%)	(W)	(V)	(A)	(W)	(%)	(%)	(%)
100	65.31	12.10	4.99	60.43	92.53	**91.28**	89
75	49.26	12.12	3.75	45.43	92.22		
50	33.05	12.15	2.49	30.23	91.46		
25	16.99	12.14	1.24	15.10	88.89		
10	7.08	12.13	0.50	6.01	84.86	---	79

9.7 Full Load Line Regulation

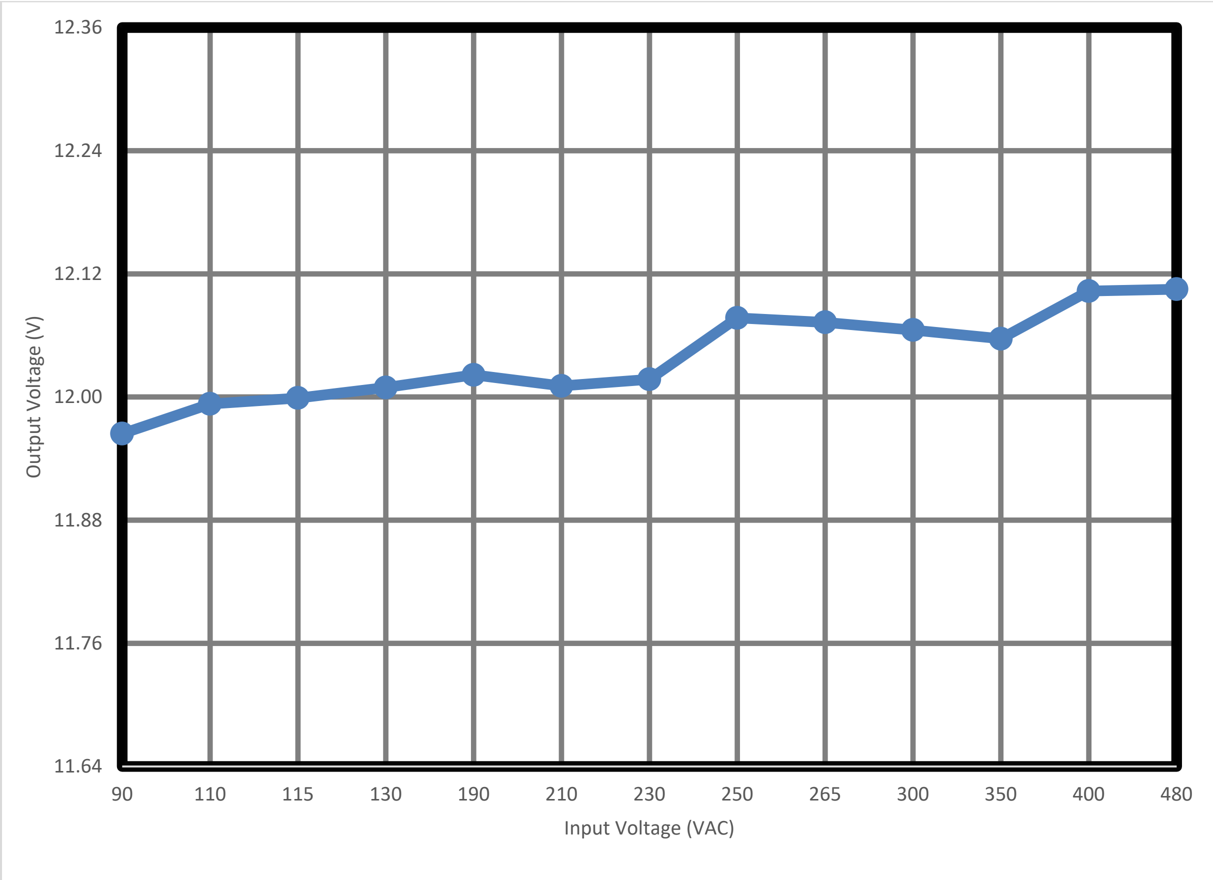


Figure 8 – Full Load Line Regulation.

9.1 Full-load Efficiency vs. Line

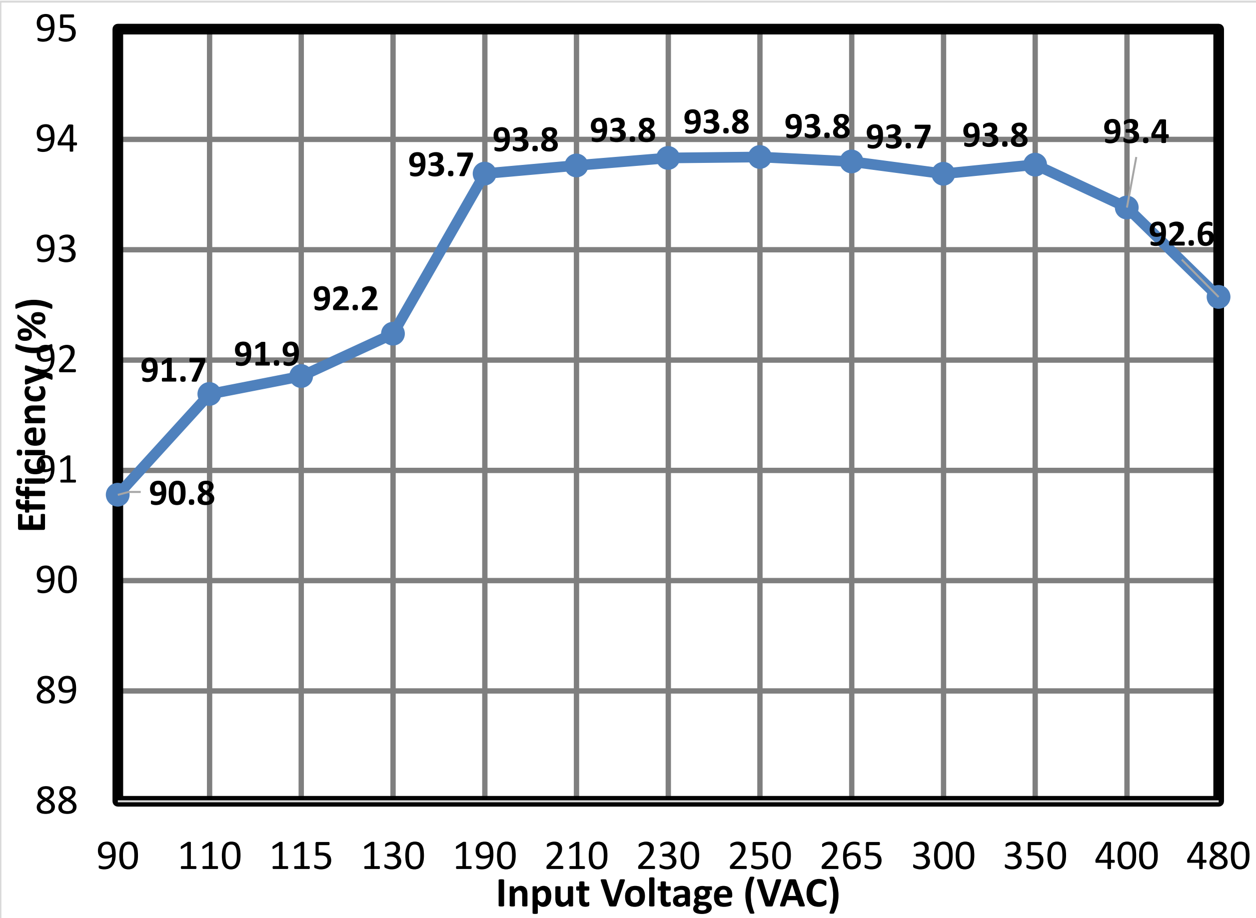


Figure 9 – Full-load Efficiency vs. Line, Room Ambient.

9.1 Efficiency vs. Load

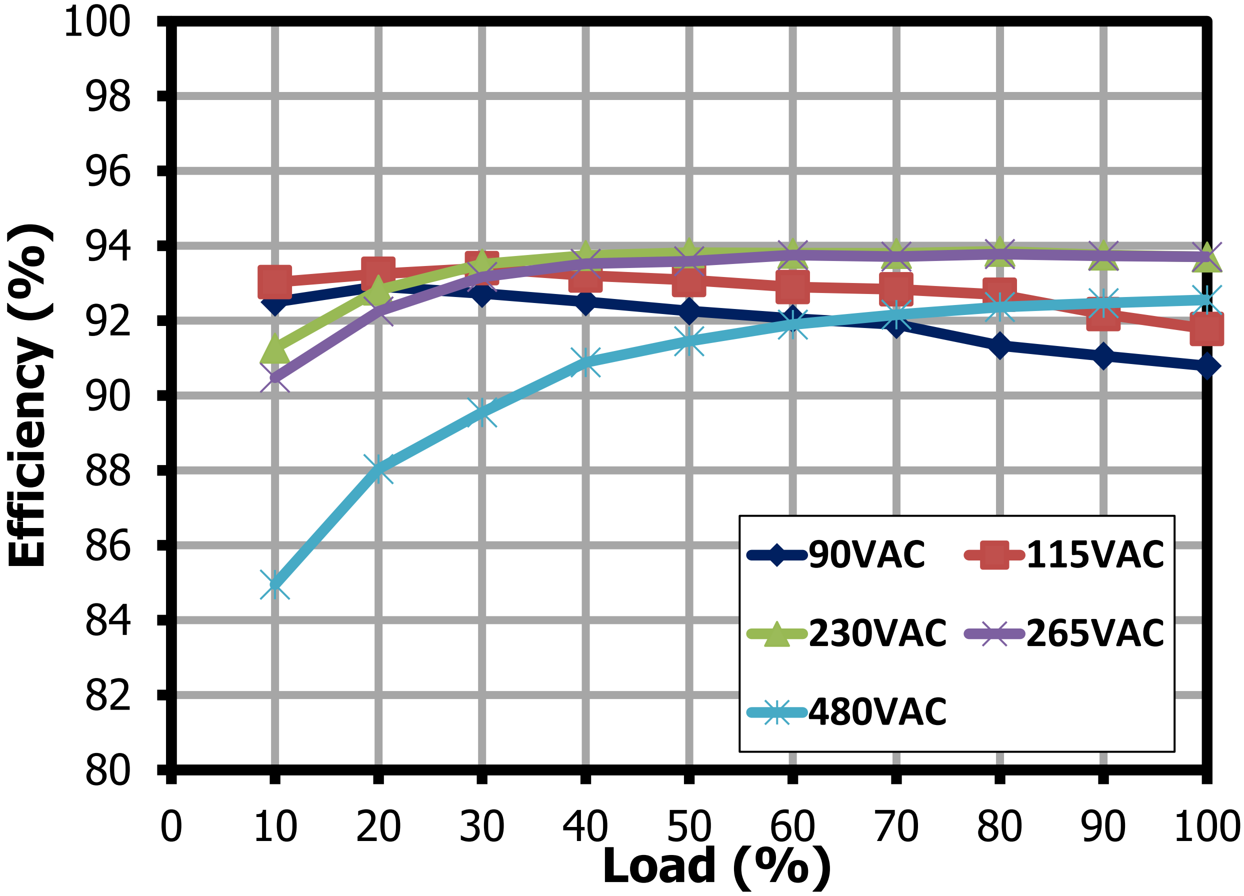


Figure 10 – Efficiency vs. Load, Room Ambient.

9.2 No-Load Input Power

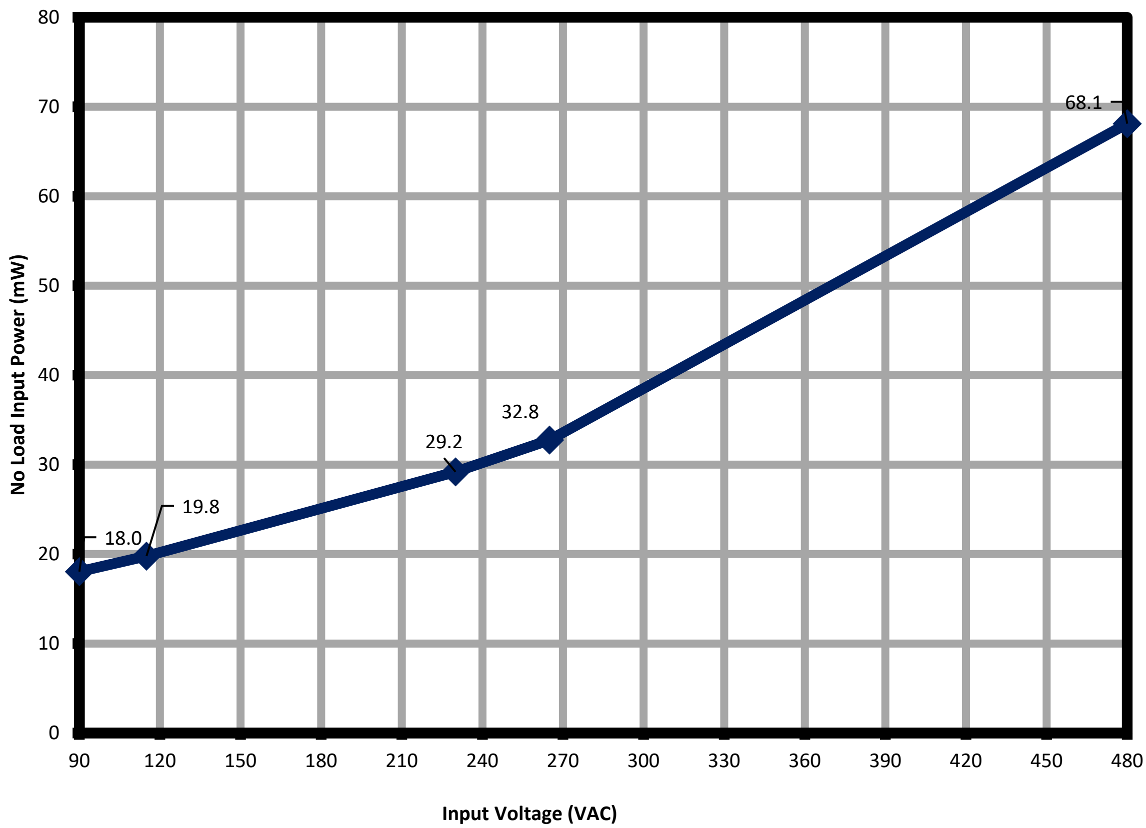


Figure 11 – No-Load Input Power vs. Input Line Voltage, Room Temperature.

10 Thermal Performance

Thermal performance is measured inside a thermal chamber at ambient temp of 0 ºC, 25 ºC and 40 ºC using a data logger.

10.1 90 VAC, 60 W at 0 ºC Ambient

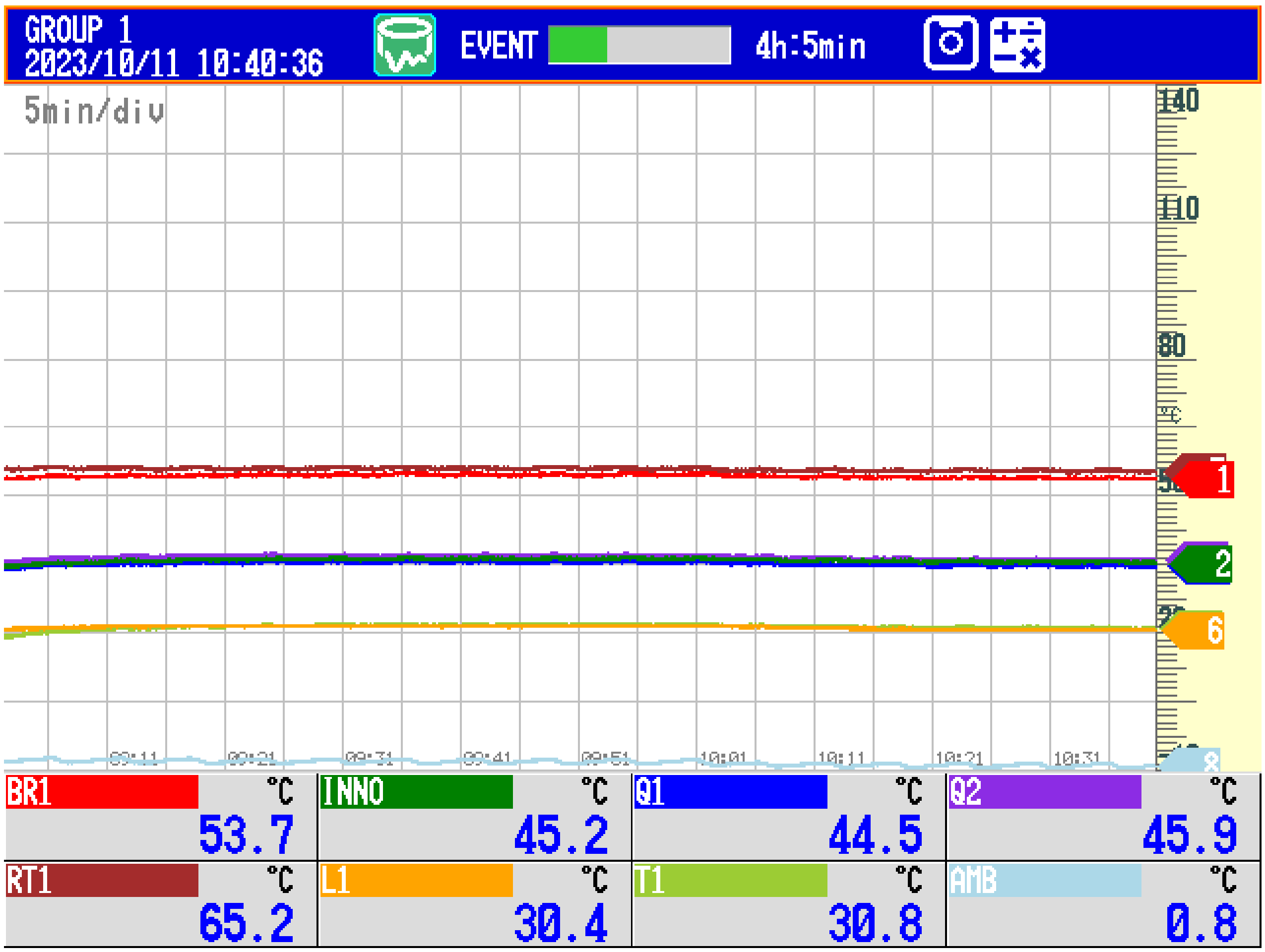


Figure 12 – Thermal Performance at 90 VAC Input.

10.2 480 VAC, 60 W at 0 ºC Ambient

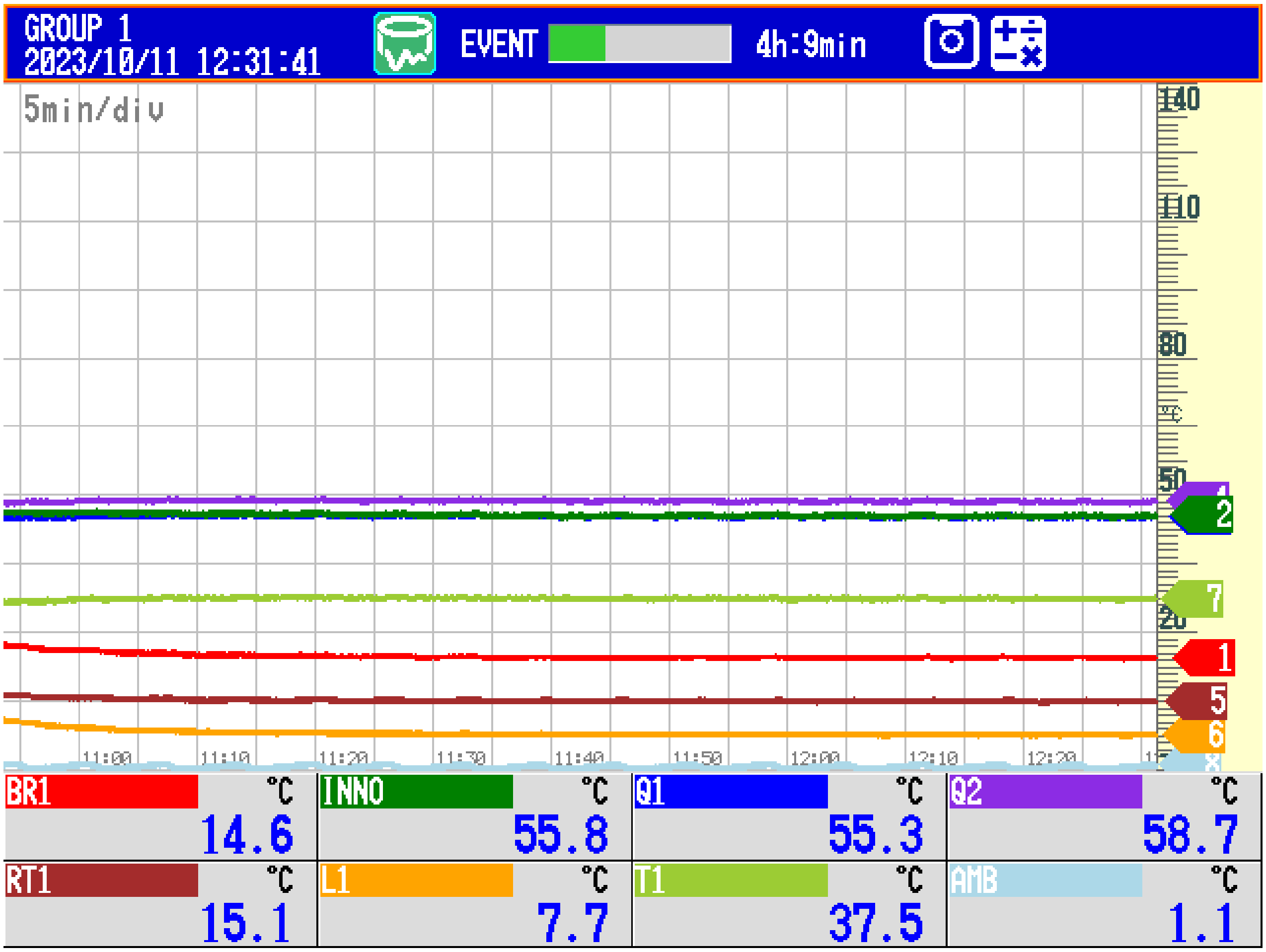


Figure 13 – Thermal Performance at 480 VAC Input.

10.3 90 VAC, 60 W at 25 ºC Ambient

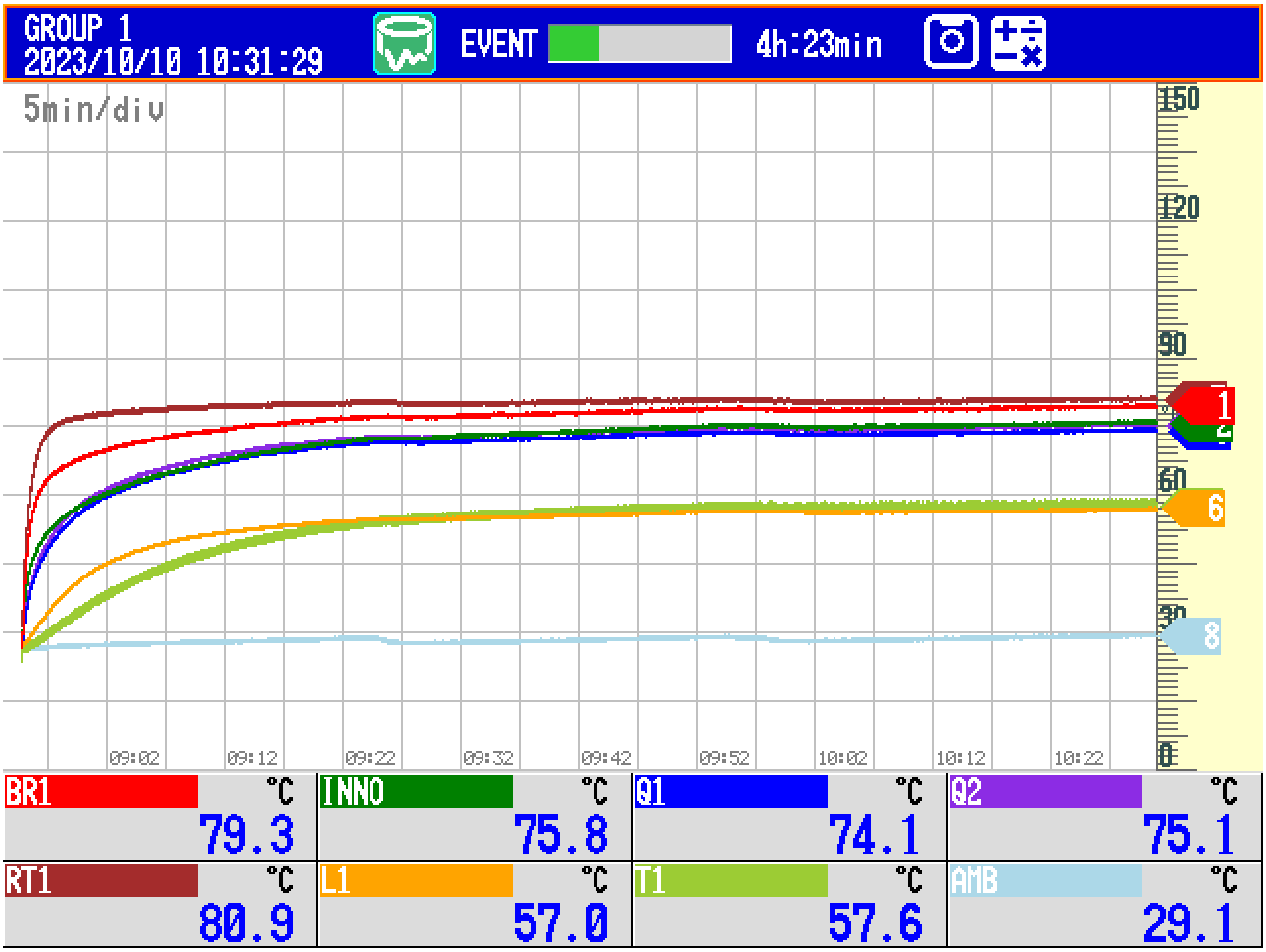


Figure 14 – Thermal Performance at 90 VAC Input.

10.4 480 VAC Input, 60 W at 25 ºC Ambient

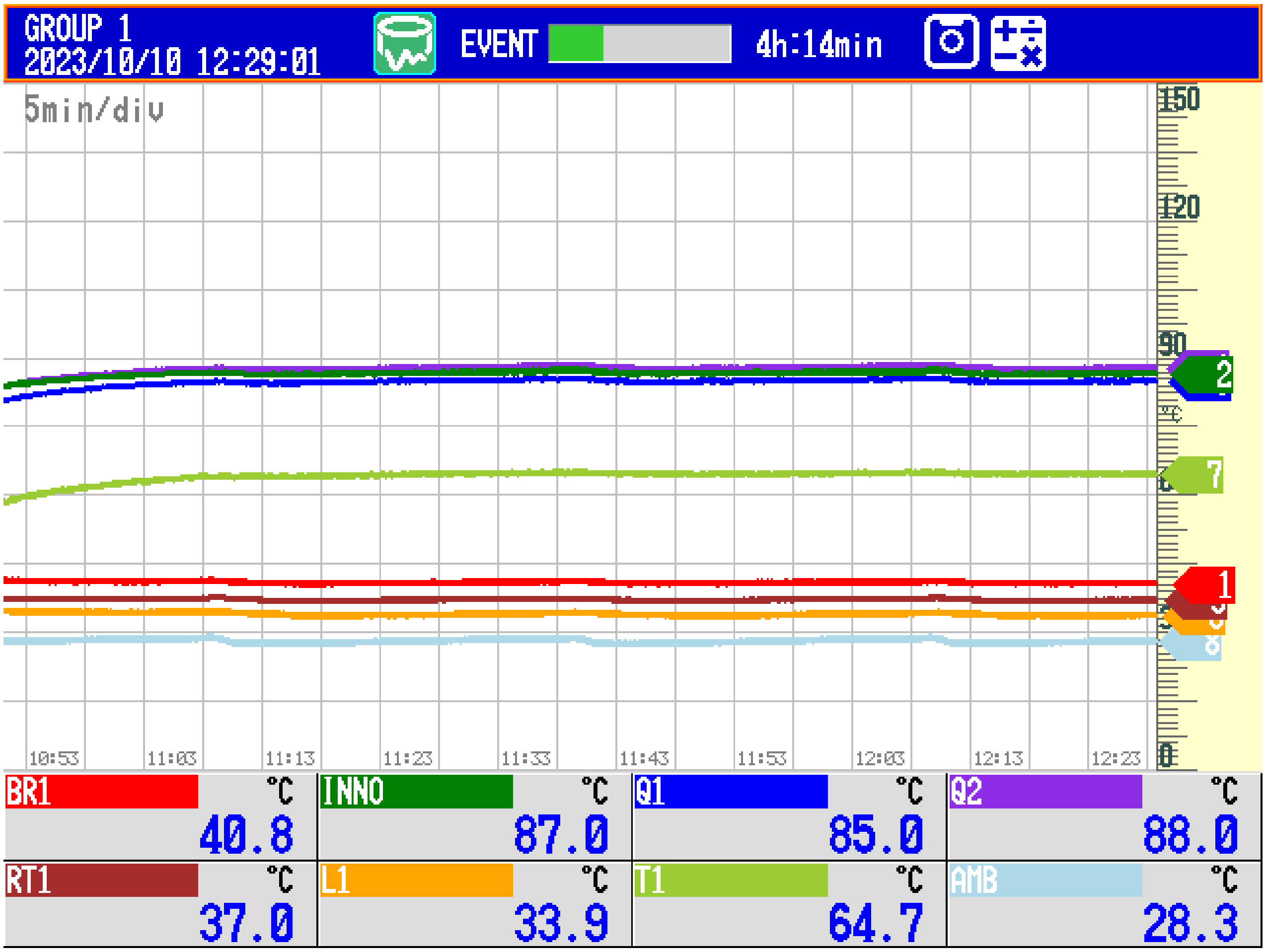


Figure 15 – Thermal Performance at 480 VAC Input.

10.5 90 VAC Input, 60 W at 40 ºC Ambient

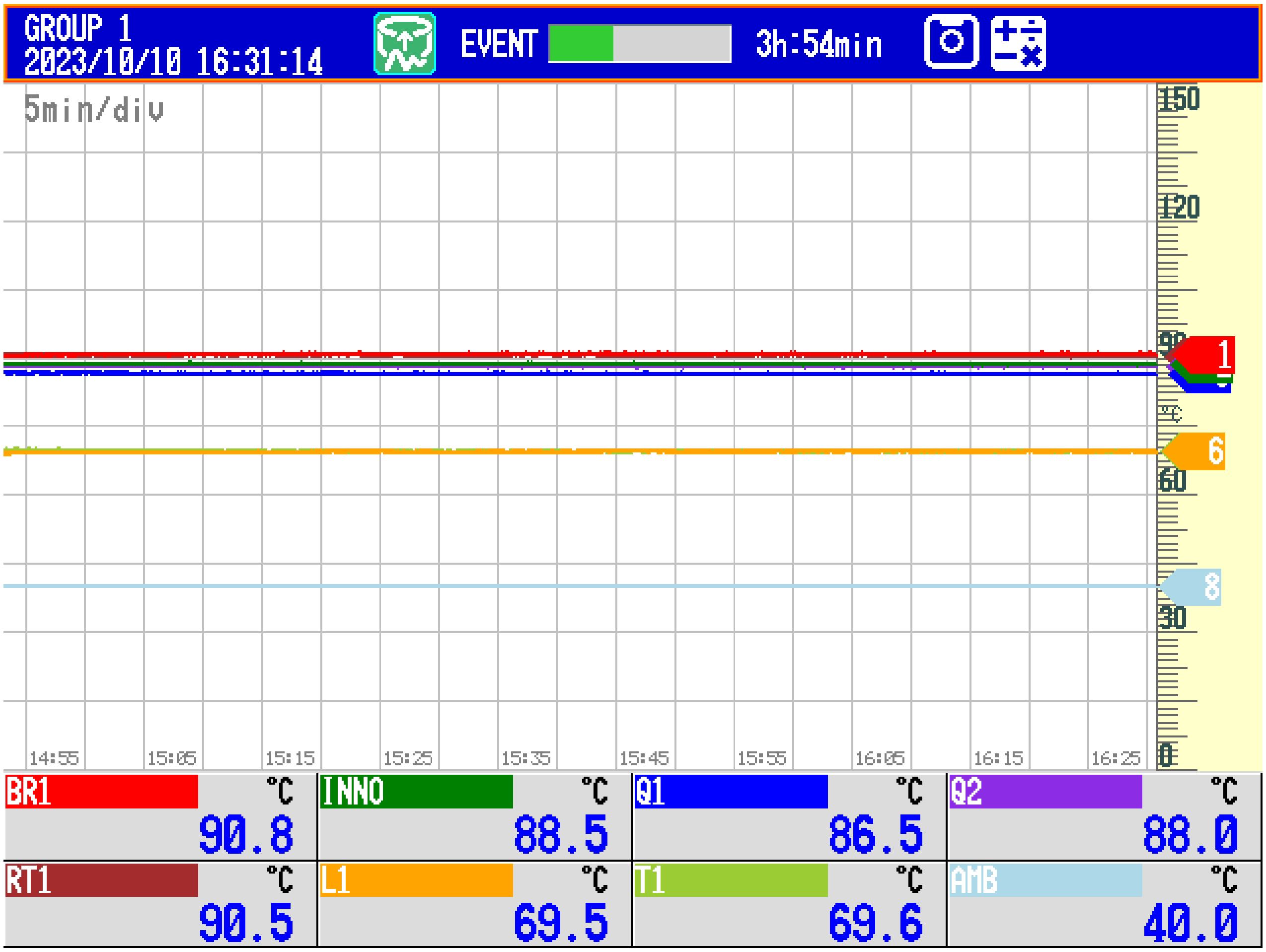


Figure 15 – Thermal Performance at 90 VAC Input.

10.6 480 VAC Input, 60 W at 40 ºC Ambient

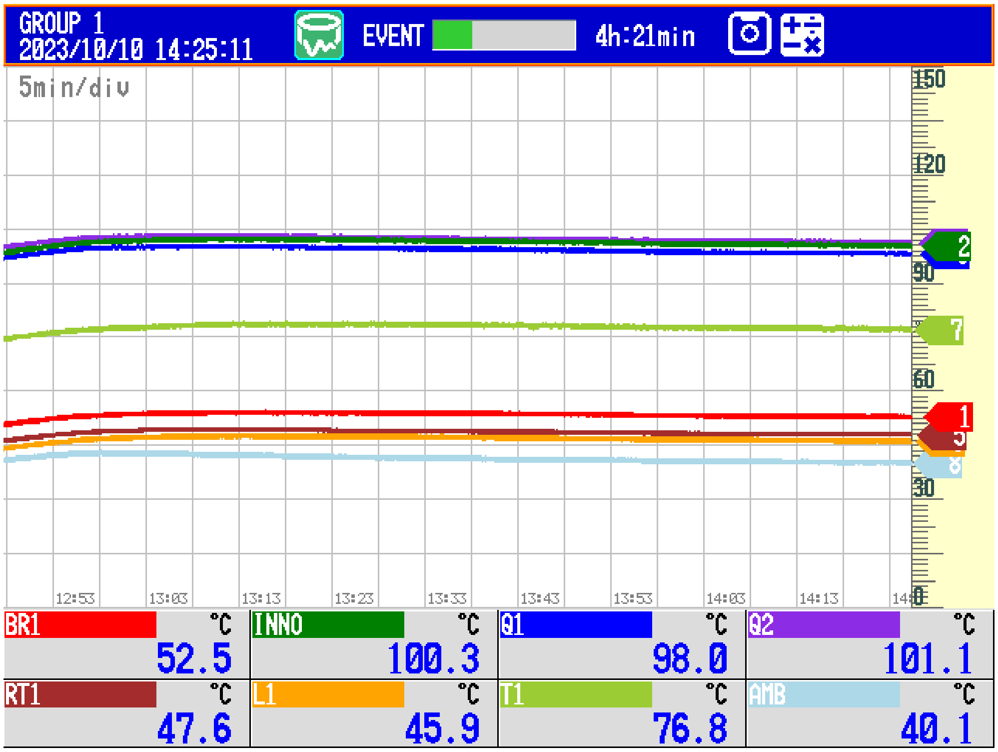


Figure 16 – Thermal Performance at 480 VAC Input.

11 Waveforms

11.1 Output Voltage Start-up Waveforms at Room Temperature

11.1.1 CC Load

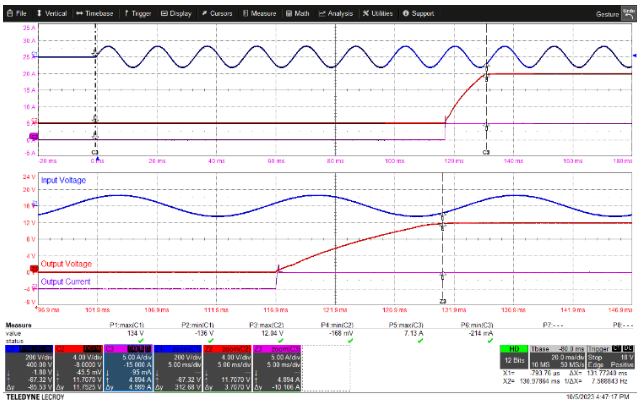


Figure 16 – 90 VAC 60 Hz, Io = 5 A (Full-Load, CC)
CH1: Input Voltage: 200 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.04 V
Output Voltage, Rise Time = 14.09 ms
Start-up Time = 131.77 ms

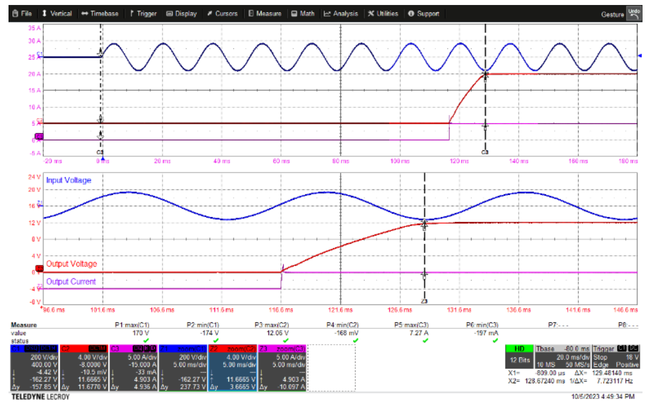


Figure 17 – 115 VAC 60 Hz, Io = 5 A (Full-Load, CC).
CH1: Input Voltage: 200 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.06 V
Output Voltage, Rise Time = 12.10 ms
Start-up Time = 129.48 ms

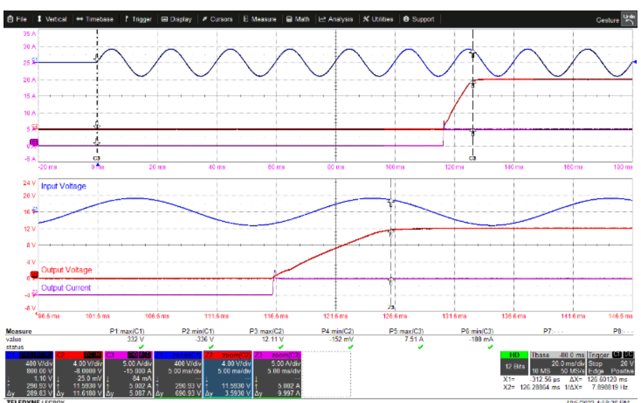


Figure 18 – 230 VAC 60 Hz, Io = 5 A (Full-Load, CC).
CH1: Input Voltage: 400 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.11 V
Output Voltage, Rise Time = 10.02 ms
Start-up Time = 126.60 ms

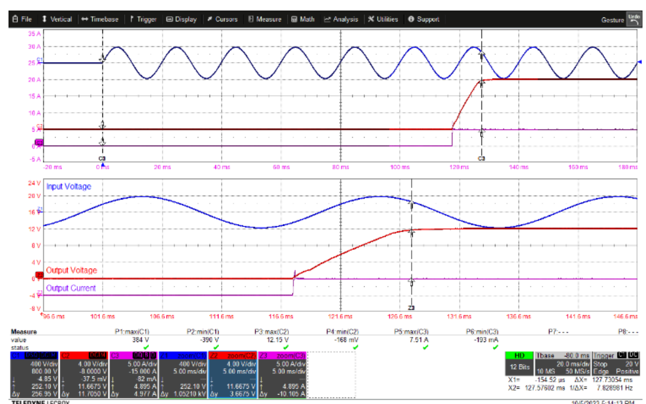


Figure 19 – 265 VAC 60 Hz, Io = 6 A (Full-Load, CC).
CH1: Input Voltage: 400 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.15 V
Output Voltage, Rise Time = 9.99 ms
Start-up Time = 127.73 ms

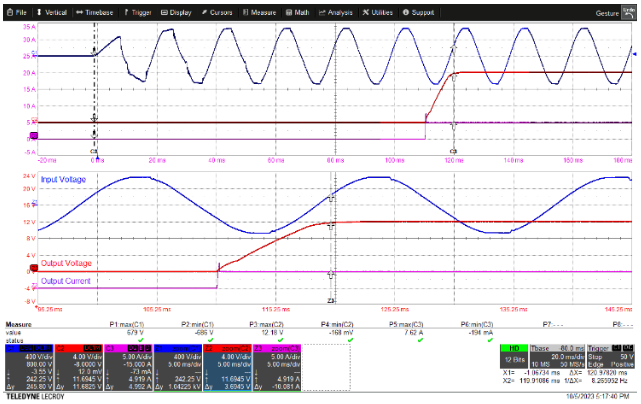


Figure 20 – 480 VAC 60 Hz, Io = 5 A (Full-Load, CC).
CH1: Input Voltage: 400 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.18 V
Output Voltage, Rise Time = 9.64 ms
Start-up Time = 120.98 ms

11.1.2 CR Load

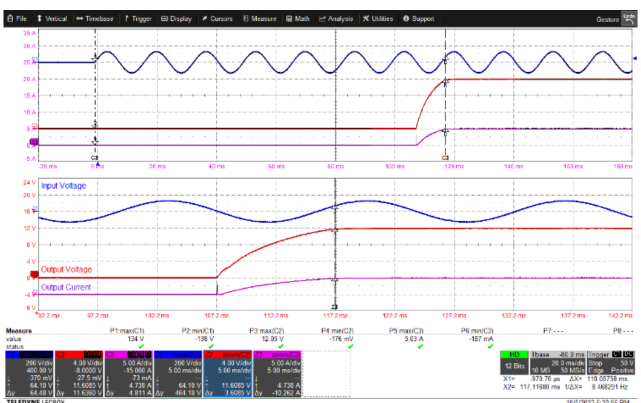


Figure 21 – 90 VAC 60 Hz, Ro= 2.4 Ω (Full-Load, CR).
CH1: Input Voltage: 200 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.05 V
Output Voltage, Rise Time = 9.89 ms
Start-up Time = 118.09 ms

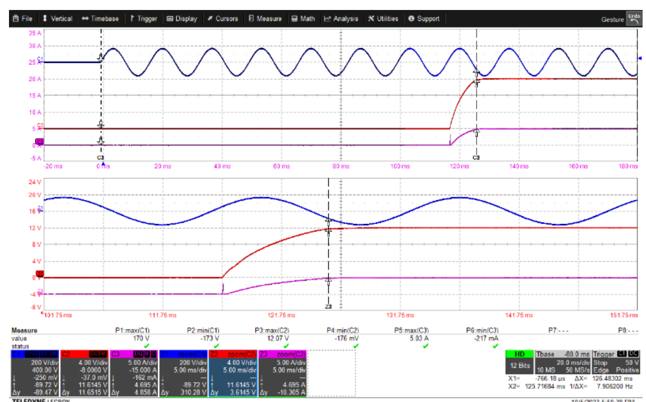


Figure 22 – 115 VAC 60 Hz, Ro= 2.4 Ω (Full-Load, CR).
CH1: Input Voltage: 200 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.07 V
Output Voltage, Rise Time = 8.94 ms
Start-up Time = 126.48 ms

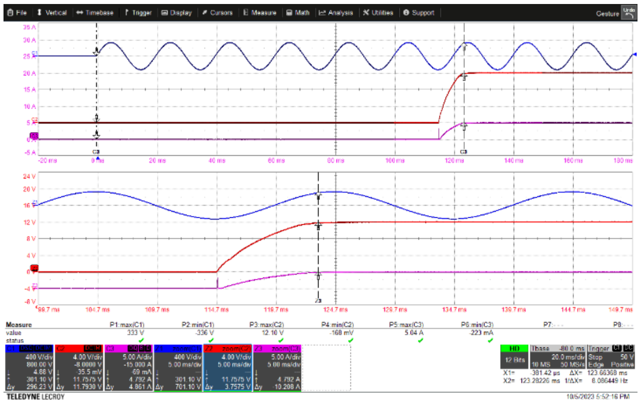


Figure 23 – 230 VAC 60 Hz, Ro= 2.4 Ω (Full-Load, CR).
CH1: Input Voltage: 400 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.10 V
Output Voltage, Rise Time = 8.58 ms
Start-up Time = 123.66 ms

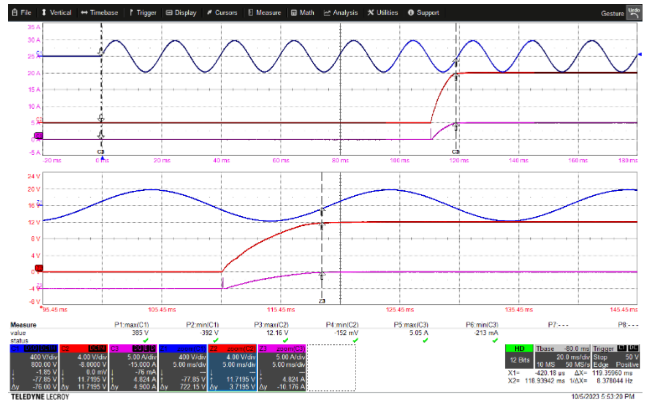


Figure 24 – 265 VAC 60 Hz, Ro= 2.4 Ω (Full-Load, CR).
CH1: Input Voltage: 400 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.16 V
Output Voltage, Rise Time = 8.43 ms
Start-up Time = 119.36 ms

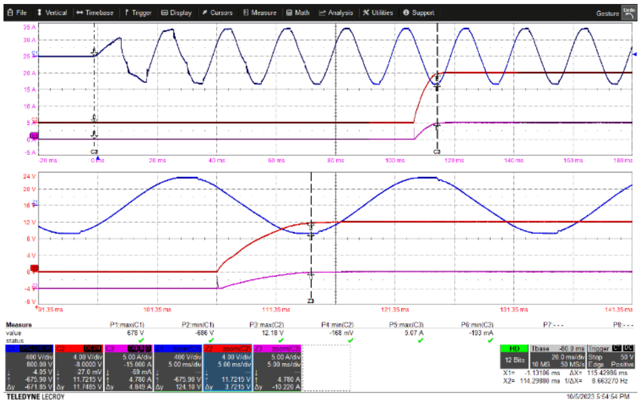


Figure 25 – 480 VAC 60 Hz, Ro= 2.4 Ω (Full-Load, CR).
CH1: Input Voltage: 400 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.18 V
Output Voltage, Rise Time = 7.95 ms
Start-up Time = 115.43 ms

11.1.3 No-Load

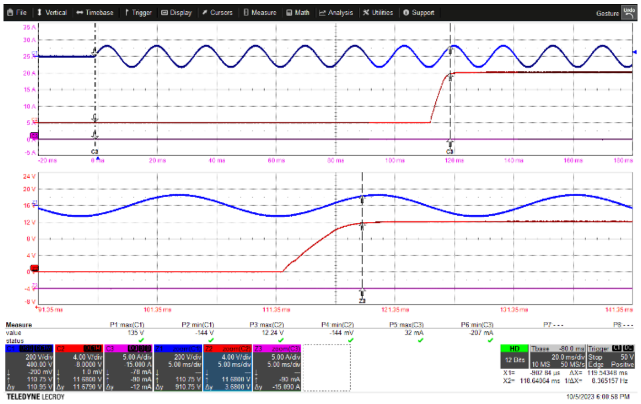


Figure 26 – 90 VAC 60 Hz, Io= 0 A (No - Load)
CH1: Input Voltage: 200 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.24 V
Output Voltage, Rise Time = 6.74 ms
Start-up Time = 119.54 ms

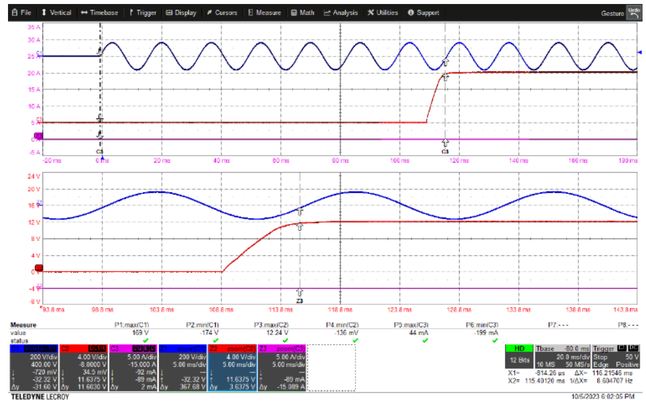


Figure 27 – 115 VAC 60 Hz, Io= 0 A (No - Load)
CH1: Input Voltage: 200 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.24 V
Output Voltage, Rise Time = 6.48 ms
Start-up Time = 116.22 ms

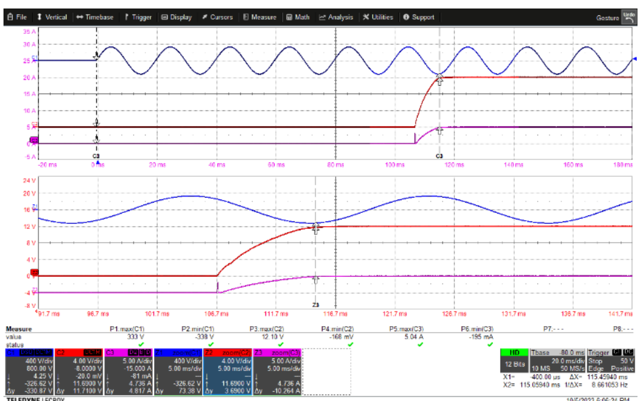


Figure 28 – 230 VAC 50 Hz, Io = 0 A (No- Load).
CH1: Input Voltage: 400 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.10 V
Output Voltage, Rise Time = 6.31 ms
Start-up Time = 115.46 ms

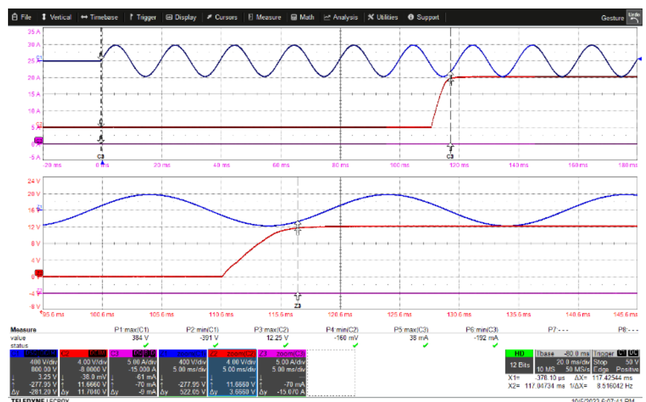


Figure 29 – 265 VAC 50 Hz, Io = 0 A (No- Load).
CH1: Input Voltage: 400 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.25 V
Output Voltage, Rise Time = 6.44 ms
Start-up Time = 117.42 ms

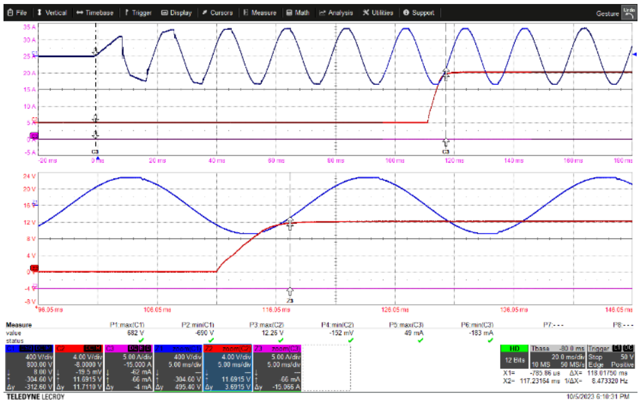


Figure 30 – 480 VAC 50 Hz, Io = 0 A (No- Load).
CH1: Input Voltage: 400 V / div., 20 ms / div
CH2: Output Voltage: 4 V / div., 20 ms / div
CH3: Output Current: 5 A / div., 20 ms / div
Zoom: 5 ms / div
Output Voltage, Max = 12.26 V
Output Voltage, Rise Time = 6.11 ms
Start-up Time = 118.02 ms

11.2 Load Transient Response (On Board)

11.2.1 0 – 100 % Load Step

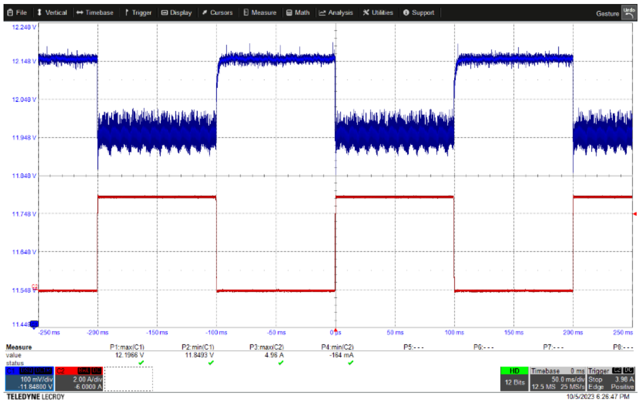


Figure 31 – 90 VAC; Io = 0A – 5A (0-100%) Load Step
CH1: Output Voltage: 100 mV / div, 50 ms / div
CH2: Output Current: 2 A / div, 50 ms / div
V_{MAX}: 12.20 V
V_{MIN}: 11.85V

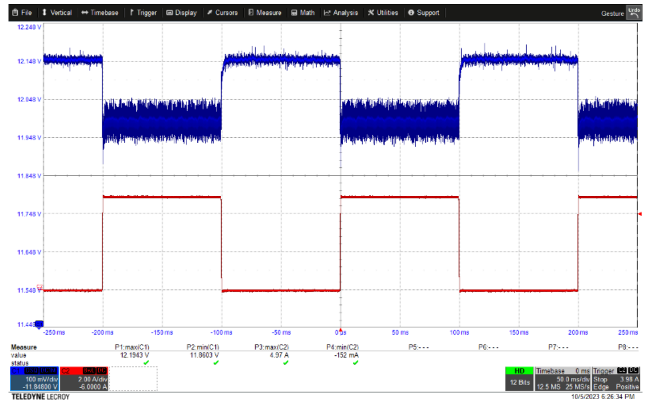


Figure 32 – 115 VAC; Io = 0A – 5A (0-100%) Load Step
CH1: Output Voltage: 100 mV / div, 50 ms / div
CH2: Output Current: 2 A / div, 50 ms / div
V_{MAX}: 12.19 V
V_{MIN}: 11.86 V

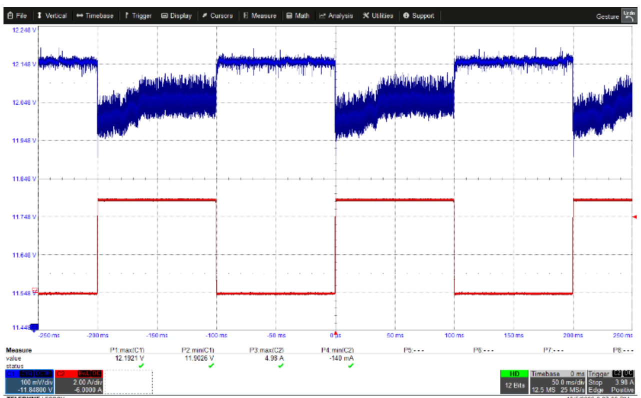


Figure 33 – 230 VAC; Io = 0A – 5A (0-100%) Load Step
CH1: Output Voltage: 100 mV / div, 50 ms / div
CH2: Output Current: 2 A / div, 50 ms / div
V_{MAX}: 12.19 V
V_{MIN}: 11.90 V

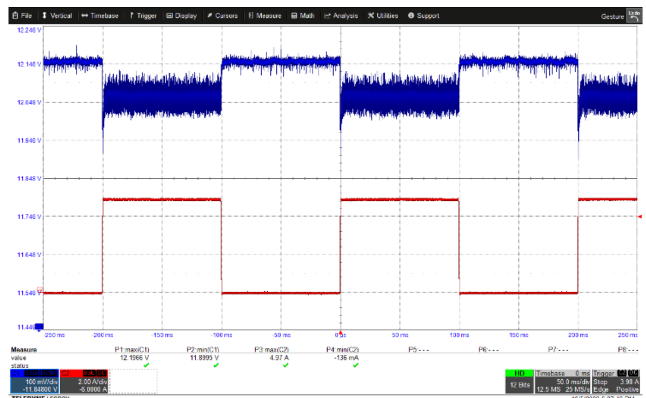


Figure 34 – 265 VAC; Io = 0A – 5A (0-100%) Load Step
CH1: Output Voltage: 100 mV / div, 50 ms / div
CH2: Output Current: 2 A / div, 50 ms / div
V_{MAX}: 12.20 V
V_{MIN}: 11.90 V

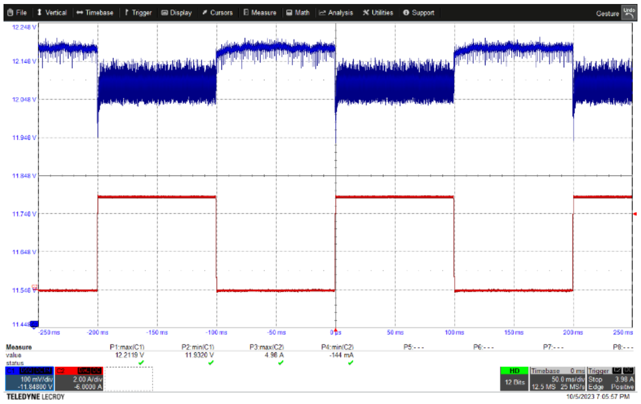


Figure 35 – 480 VAC; Io = 0A – 5A (0-100%) Load Step
CH1: Output Voltage: 100 mV / div, 50 ms / div
CH2: Output Current: 2 A / div, 50 ms / div
V_{MAX}: 12.21 V
V_{MIN}: 11.93 V

11.2.2 50 % – 100 % Load Step

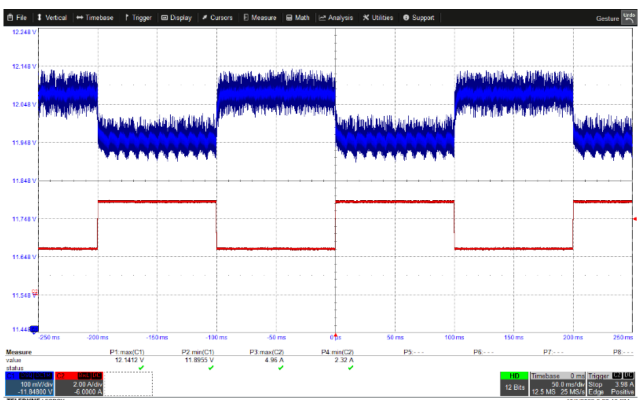


Figure 36 – 90 VAC; Io = 2.5A – 5A (50-100%) Load Step
CH1: Output Voltage: 100 mV / div, 50 ms / div
CH2: Output Current: 2 A / div, 50 ms / div
V_{MAX}: 12.14 V
V_{MIN}: 11.89 V

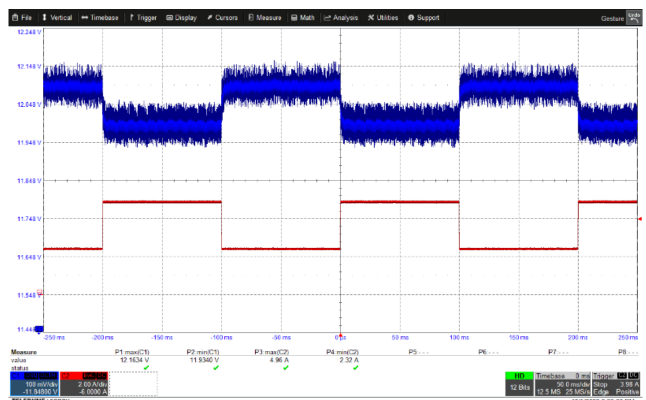


Figure 37 – 115 VAC; Io = 2.5A – 5A (50-100%) Load Step
CH1: Output Voltage: 100 mV / div, 50 ms / div
CH2: Output Current: 2 A / div, 50 ms / div
V_{MAX}: 12.16 V
V_{MIN}: 11.93 V

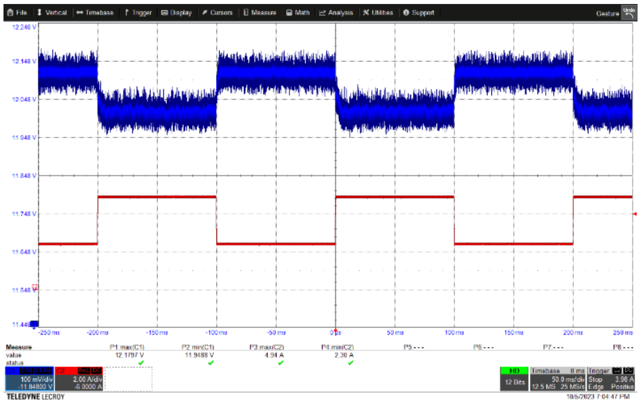


Figure 38 – 230 VAC; Io = 2.5A – 5A (50-100%) Load Step
CH1: Output Voltage: 100 mV / div, 50 ms / div
CH2: Output Current: 2 A / div, 50 ms / div
V_{MAX}: 12.18 V
V_{MIN}: 11.95 V

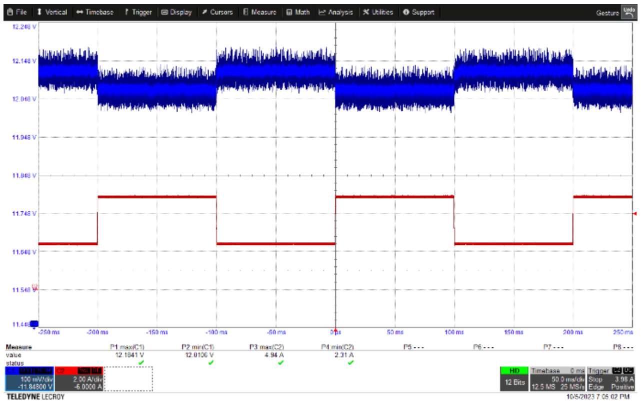


Figure 39 – 265 VAC; Io = 2.5A – 5A (50-100%) Load Step
CH1: Output Voltage: 100 mV / div, 50 ms / div
CH2: Output Current: 2 A / div, 50 ms / div
V_{MAX}: 12.18 V
V_{MIN}: 12.01 V

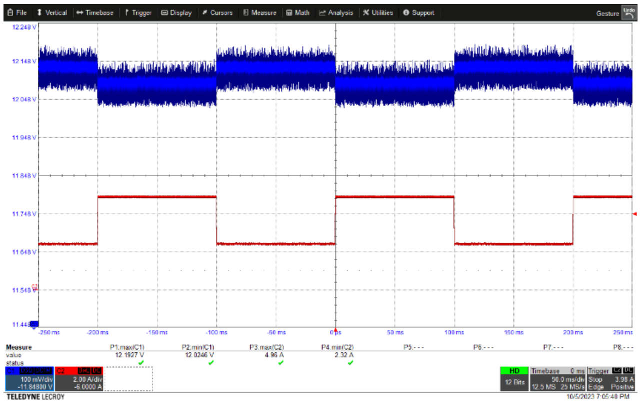


Figure 40 – 480 VAC; Io = 2.5A – 5A (50-100%) Load Step
CH1: Output Voltage: 100 mV / div, 50 ms / div
CH2: Output Current: 2 A / div, 50 ms / div
V_{MAX}: 12.19 V
V_{MIN}: 12.02 V

11.3 InnoSwitch Switching Waveforms

11.3.1 Drain Voltage and Current at Start-up Operation

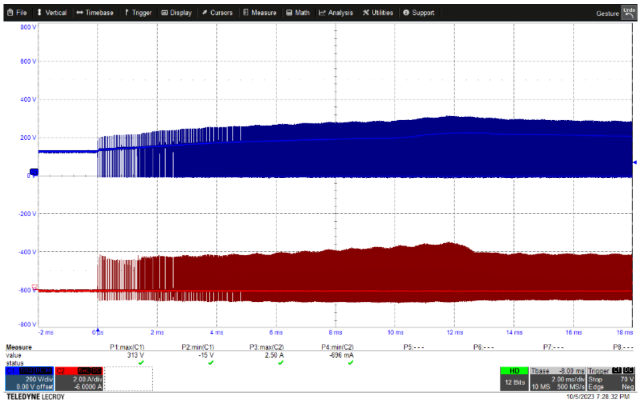


Figure 41 – 90 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 200 V / div, 2 ms / div
CH 2: Drain Current: 2 A / div, 2 ms / div
Drain voltage, Max = 313 V
Drain current, Max = 2.50 A

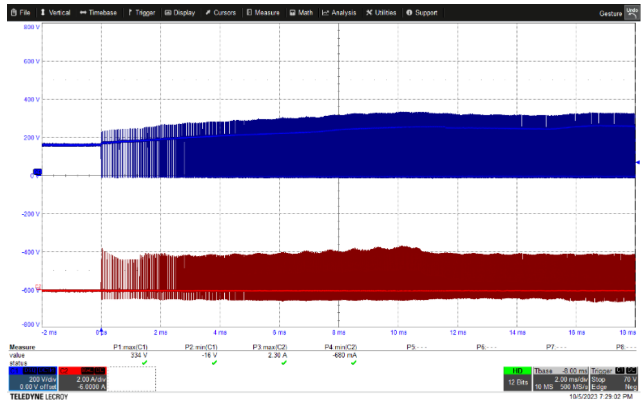


Figure 42 – 115 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 200 V / div, 2 ms / div
CH 2: Drain Current: 2 A / div, 2 ms / div
Drain voltage, Max = 334 V
Drain current, Max = 2.30 A

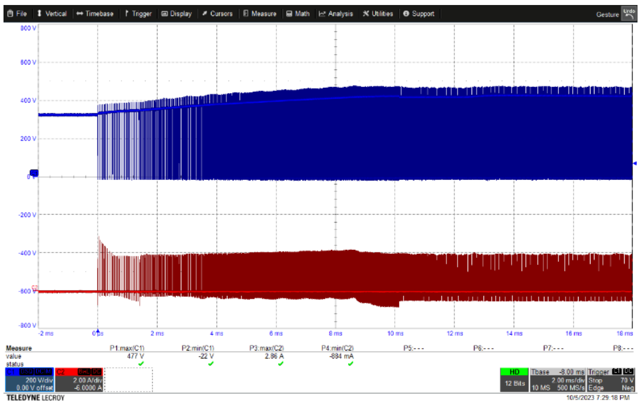


Figure 43 – 230 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 200 V / div, 2 ms / div
CH 2: Drain Current: 2 A / div, 2 ms / div
Drain voltage, Max = 477 V
Drain current, Max = 2.86 A

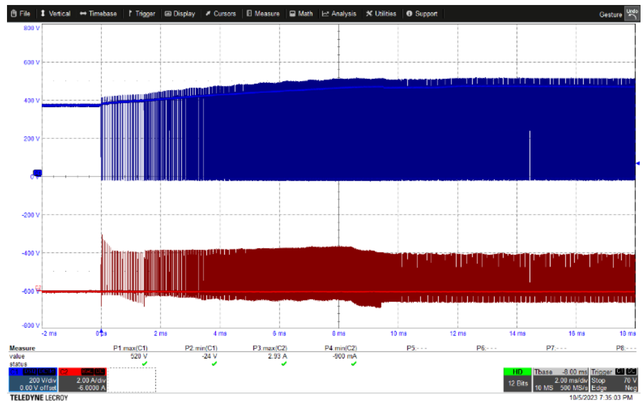


Figure 44 – 265 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 200 V / div, 2 ms / div
CH 2: Drain Current: 2 A / div, 2 ms / div
Drain voltage, Max = 520 V
Drain current, Max = 2.93 A

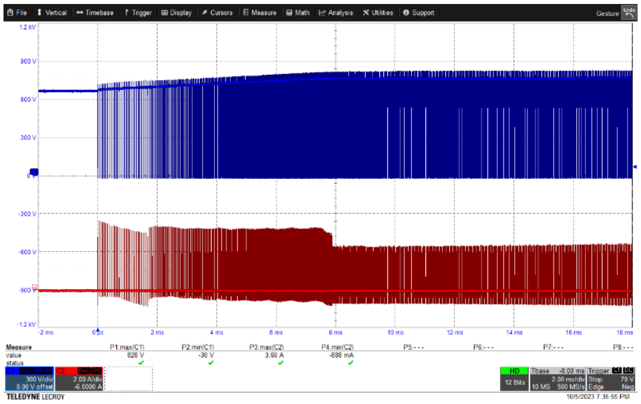


Figure 45 – 480 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 200 V / div, 2 ms / div
CH 2: Drain Current: 2 A / div, 2 ms / div
Drain voltage, Max = 828 V
Drain current, Max = 3.6 A

11.3.2 Drain Voltage and Current at Normal Operation

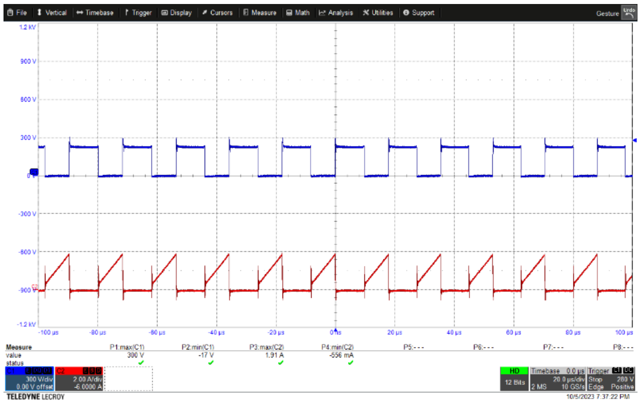


Figure 46 – 90 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 200 V / div, 10 µs / div
CH 2: Drain Current: 2 A / div, 10 µs / div
Drain voltage, Max = 300 V
Drain current, Max = 1.91 A

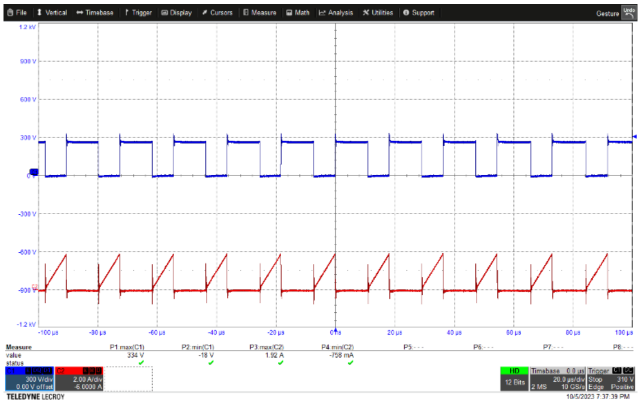


Figure 47 – 115 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 200 V / div, 10 µs / div
CH 2: Drain Current: 2 A / div, 10 µs / div
Drain voltage, Max = 334 V
Drain current, Max = 1.92 A

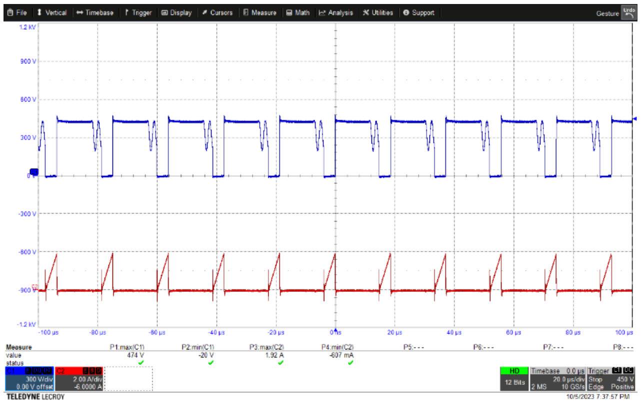


Figure 48 – 230 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 200 V / div, 2 ms / div
CH 2: Drain Current: 2 A / div, 2 ms / div
Drain voltage, Max = 474 V
Drain current, Max = 1.92 A

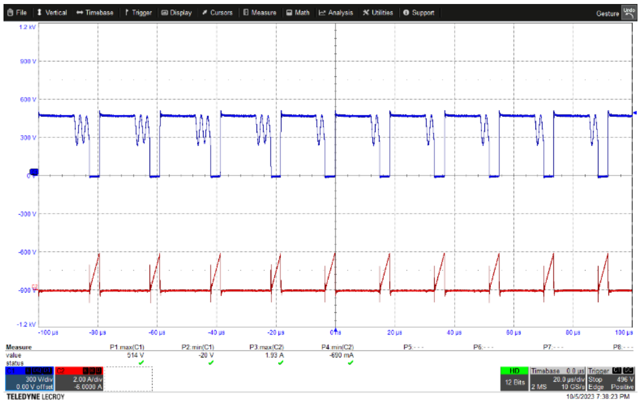


Figure 49 – 265 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 200 V / div, 2 ms / div
CH 2: Drain Current: 2 A / div, 2 ms / div
Drain voltage, Max = 514 V
Drain current, Max = 1.93 A

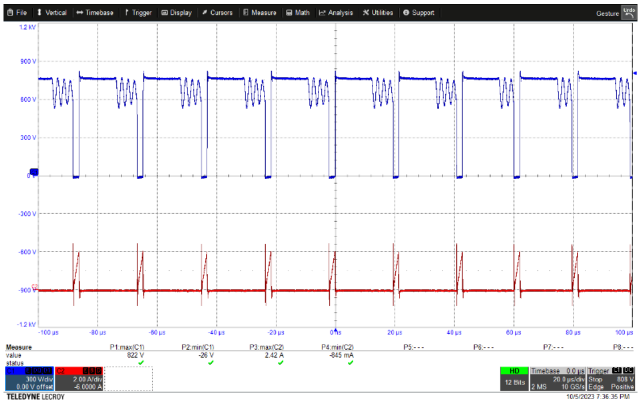


Figure 50 – 480 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 200 V / div, 2 ms / div
CH 2: Drain Current: 2 A / div, 2 ms / div
Drain voltage, Max = 822 V
Drain current, Max = 2.42 A

11.3.3 Drain Voltage and Current with Output Short

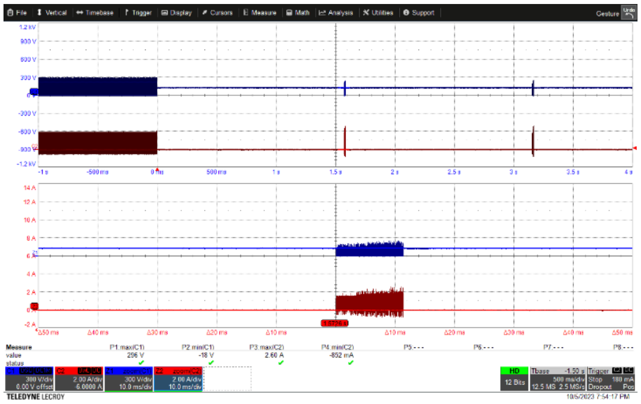


Figure 51 – 90 VAC
CH1: Drain Voltage: 200 V / div, 500 ms/div
CH2: Drain Current: 2 A / div, 500 ms/div
Zoom: 10 ms / div

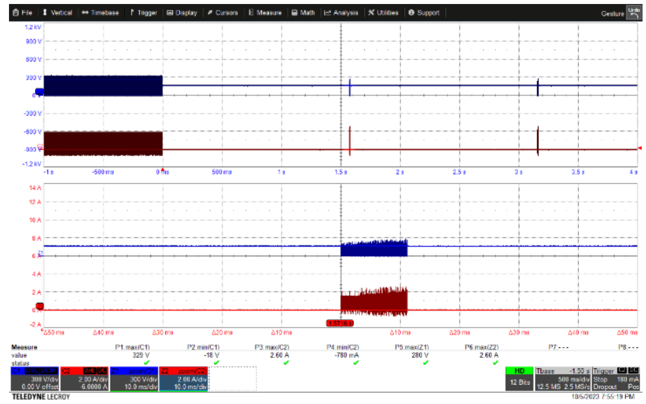


Figure 52 – 115 VAC
CH1: Drain Voltage: 200 V / div, 500 ms/div
CH2: Drain Current: 2 A / div, 500 ms/div
Zoom: 10 ms / div

Figure 53 – 230 VAC
CH1: Drain Voltage: 200 V / div, 500 ms/div
CH2: Drain Current: 2 A / div, 500 ms/div
Zoom: 10 ms / div

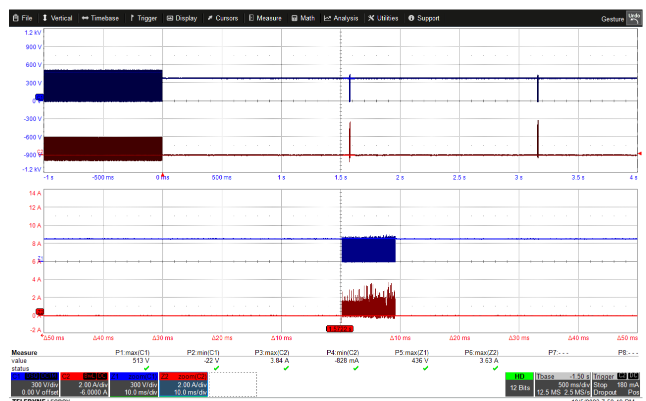


Figure 54 – 265 VAC
CH1: Drain Voltage: 200 V / div, 500 ms/div
CH2: Drain Current: 2 A / div, 500 ms/div
Zoom: 10 ms / div

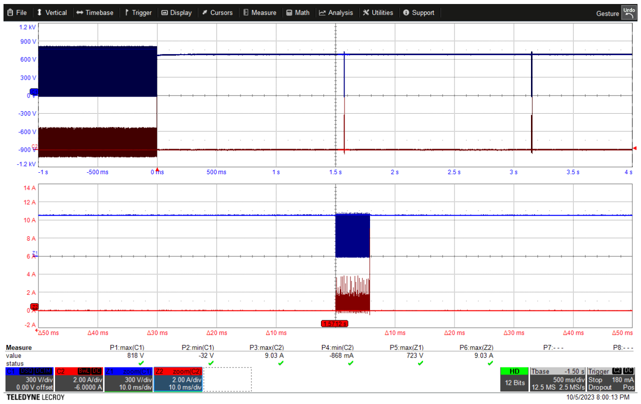


Figure 55 – 480 VAC
CH 1: Drain Voltage: 200 V / div, 500 ms / div
CH 2: Drain Current: 2 A / div, 500 ms / div
Zoom: 10 ms / div

11.4 SRFET Switching Waveforms

11.4.1 SR FET Voltage and Current at Start-up

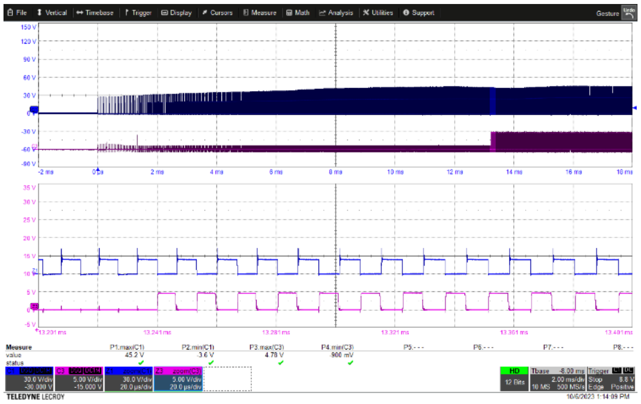


Figure 56 – 90 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 30 V / div, 2 ms / div
CH 3: Gate Voltage: 5 V / div, 2 ms / div
Zoom: 20 µs
SRFET Drain Voltage, Max. = 45.2 V

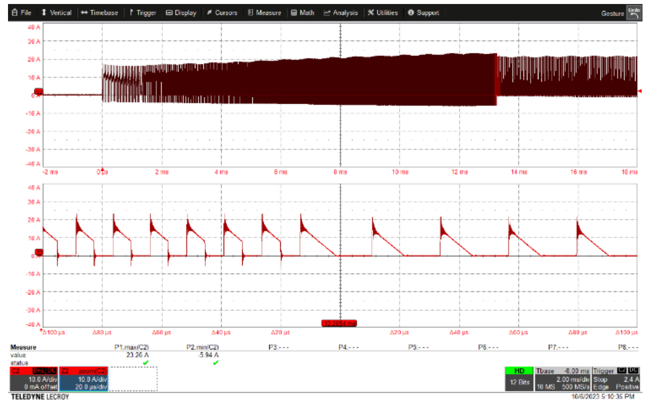


Figure 57 – 90 VAC, Io = 5 A (Full-Load)
CH 2: Drain Current: 10 A / div, 2 ms / div
Zoom: 20 µs
SRFET Drain Current, Max. = 23.26 A

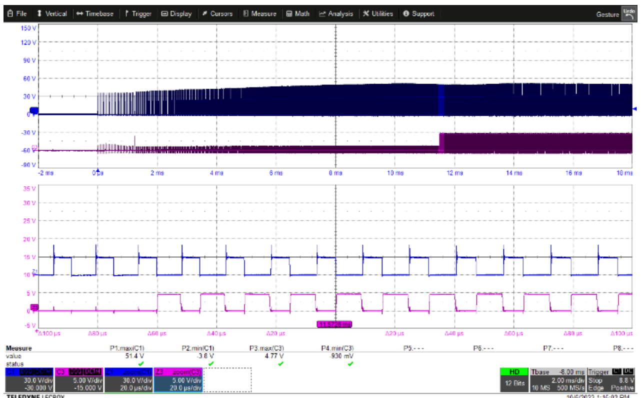


Figure 58 – 115 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 30 V / div, 2 ms / div
CH 3: Gate Voltage: 5 V / div, 2 ms / div
Zoom: 20 µs
SRFET Drain Voltage, Max. = 51.4 V

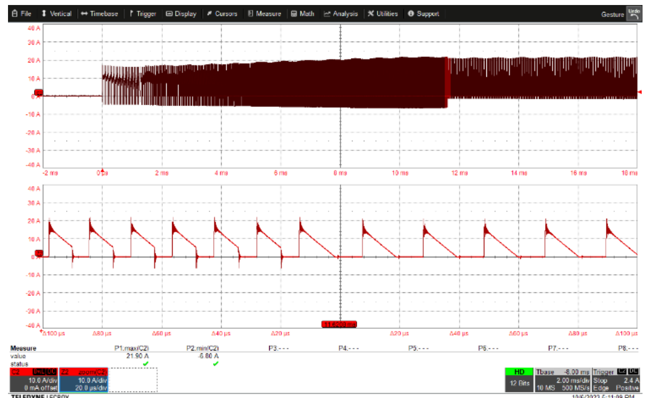


Figure 59 – 115 VAC, Io = 5 A (Full-Load)
CH 2: Drain Current: 10 A / div, 2 ms / div
Zoom: 20 µs
SRFET Drain Current, Max. = 21.9 A

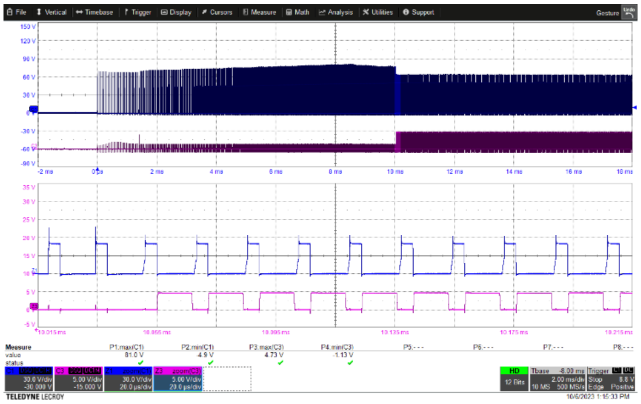


Figure 60 – 230 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 30 V / div, 2 ms / div
CH 3: Gate Voltage: 5 V / div, 2 ms / div
Zoom: 20 µs
SRFET Drain Voltage, Max. = 81.0 V

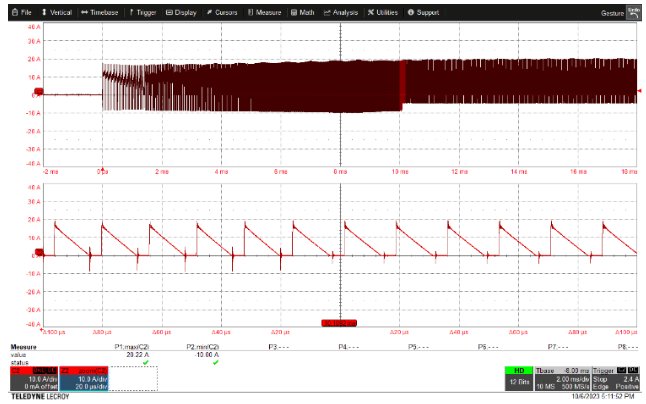


Figure 61 – 230 VAC, Io = 5 A (Full-Load)
CH 2: Drain Current: 10 A / div, 2 ms / div
Zoom: 20 µs
SRFET Drain Current, Max. = 20.2 A

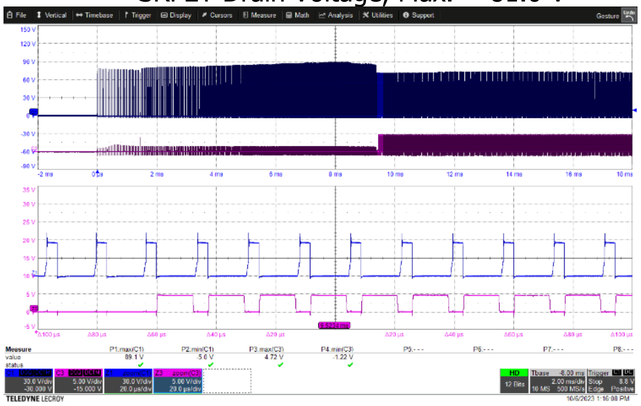


Figure 62 – 265 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 30 V / div, 2 ms / div
CH 3: Gate Voltage: 5 V / div, 2 ms / div
Zoom: 20 µs
SRFET Drain Voltage, Max. = 89.1 V

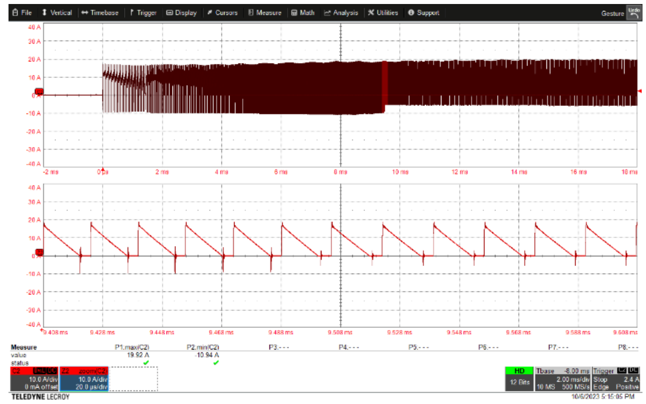


Figure 63 – 265 VAC, Io = 5 A (Full-Load)
CH 2: Drain Current: 10 A / div, 2 ms / div
Zoom: 20 µs
SRFET Drain Current, Max. = 19.9 A

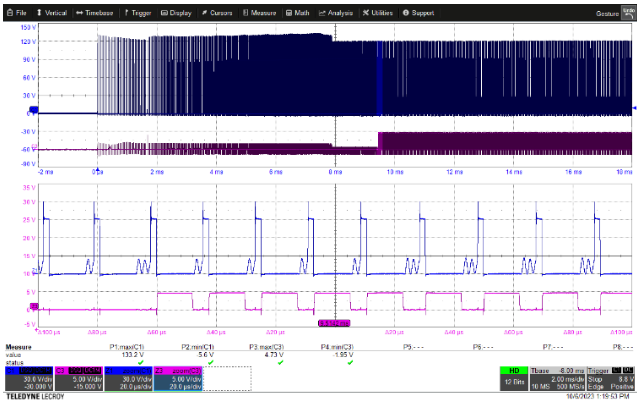


Figure 64 – 420 VAC, Io = 5 A (Full-Load)
CH 1: Drain Voltage: 30 V / div, 2 ms / div
CH 3: Gate Voltage: 5 V / div, 2 ms / div
Zoom: 20 µs
SRFET Drain Voltage, Max. = 133.2 V

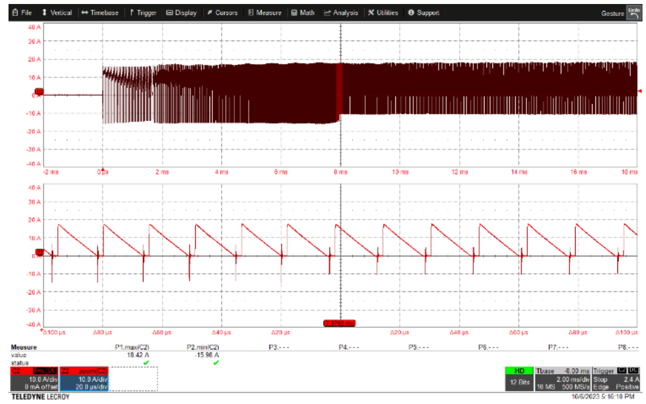


Figure 65 – 420 VAC, Io = 5 A (Full-Load)
CH 2: Drain Current: 10 A / div, 2 ms / div
Zoom: 20 µs
SRFET Drain Current, Max. = 18.42 A

11.4.2 SR FET Voltage and Current at Normal Operations

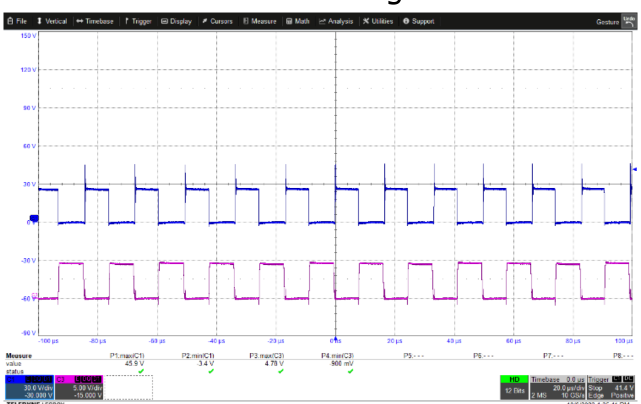


Figure 66 – 90 VAC, Io = 5 A (Full-Load).
CH 1: Drain Voltage: 30 V / div, 20 µs / div
CH 3: Gate Voltage: 5 V / div, 20 µs / div
SRFET Drain Voltage, Max. = 45.9 V.

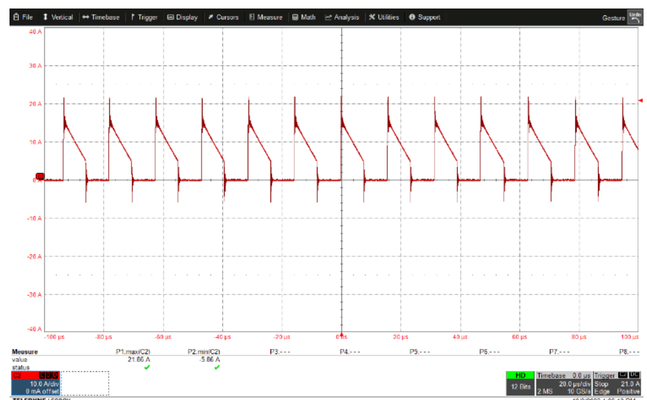


Figure 67 – 90 VAC, Io = 5 A (Full-Load).
CH 2: Drain Current: 10 A / div, 20 µs / div
SRFET Drain Current, Max. = 21.9 A.

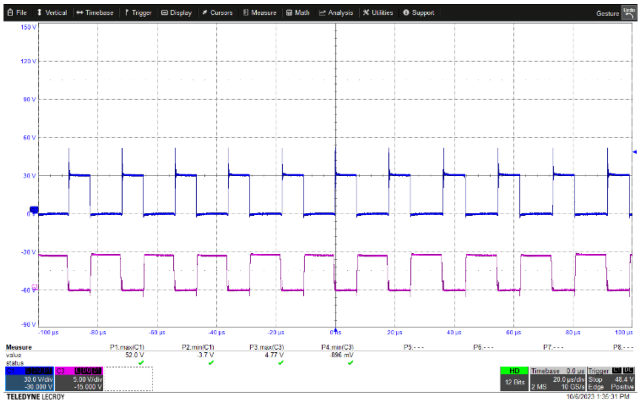


Figure 68 – 115 VAC, Io = 5 A (Full-Load).
CH 1: Drain Voltage: 30 V / div, 20 µs / div
CH 3: Gate Voltage: 5 V / div, 20 µs / div
SRFET Drain Voltage, Max. = 52 V.

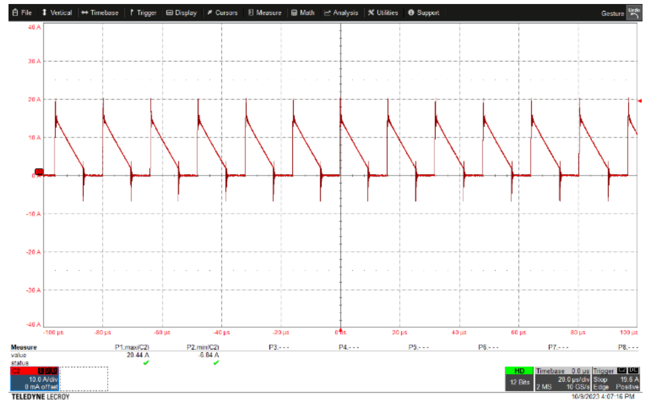


Figure 69 – 115 VAC, Io = 5 A (Full-Load).
CH 2: Drain Current: 10 A / div, 20 µs / div
SRFET Drain Current, Max. = 20.44 A.

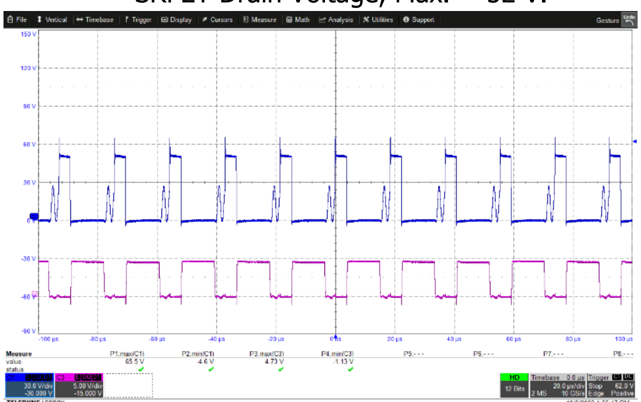
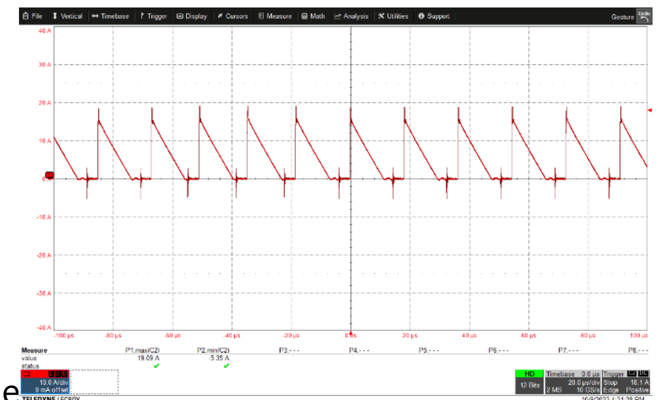


Figure 70 – 230 VAC, Io = 5 A (Full-Load).
CH 1: Drain Voltage: 30 V / div, 20 µs / div
CH 3: Gate Voltage: 5 V / div, 20 µs / div
SRFET Drain Voltage, Max. = 65.5 V.



e

Figure 71 – 230 VAC, Io = 5 A (Full-Load).
CH 2: Drain Current: 10 A / div, 20 µs / div
SRFET Drain Current, Max. = 19.1 A.

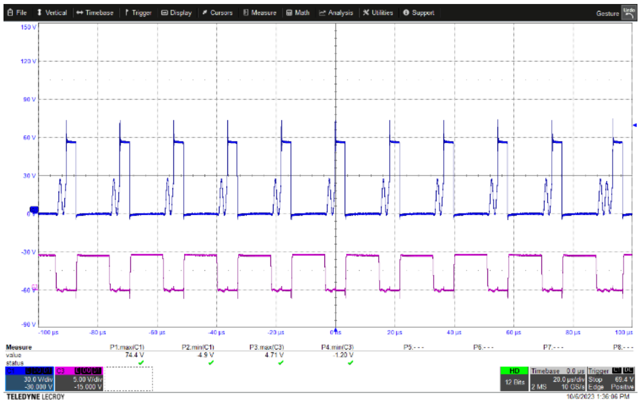


Figure 72 – 265 VAC, Io = 5 A (Full-Load).
CH 1: Drain Voltage: 30 V / div, 20 µs / div
CH 3: Gate Voltage: 5 V / div, 20 µs / div
SRFET Drain Voltage, Max. = 74.4 V.

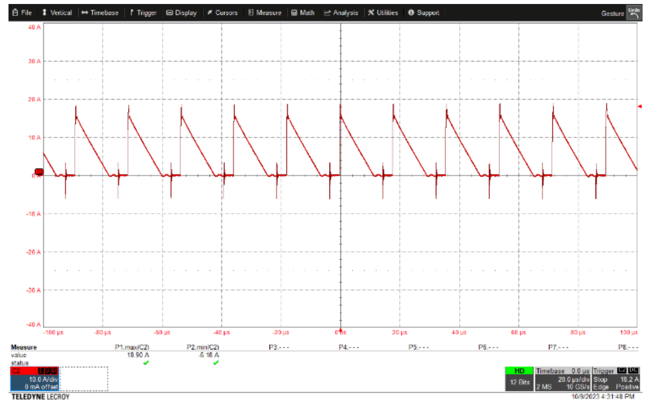


Figure 73 – 265 VAC, Io = 5 A (Full-Load).
CH 2: Drain Current: 10 A / div, 20 µs / div
SRFET Drain Current, Max. = 18.9 A.

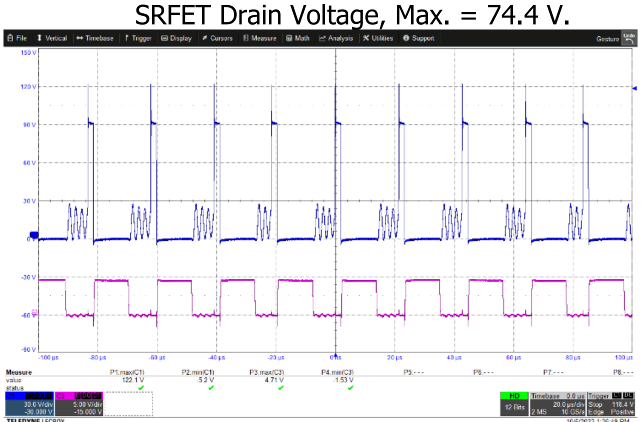


Figure 74 – 480 VAC, Io = 5 A (Full-Load).
CH 1: Drain Voltage: 30 V / div, 20 µs / div
CH 3: Gate Voltage: 5 V / div, 20 µs / div
SRFET Drain Voltage, Max. = 122 V.

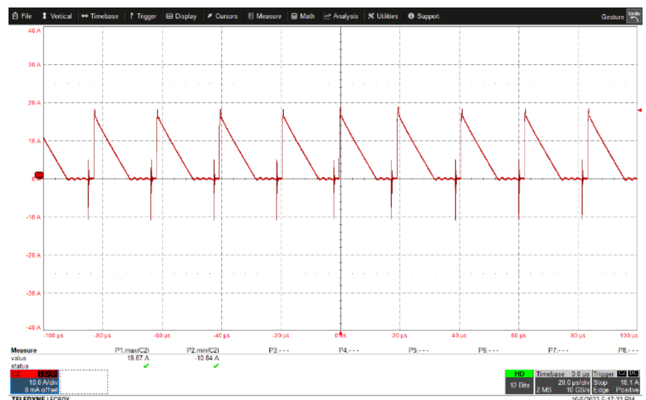


Figure 75 – 480 VAC, Io = 5 A (Full-Load).
CH 2: Drain Current: 10 A / div, 20 µs / div
SRFET Drain Current, Max. = 18.9 A.

11.5 Output Ripple Measurements

11.5.1 Ripple Measurement Technique

For DC output ripple measurements, a modified oscilloscope test probe must be utilized in order to reduce spurious signals due to pick-up. Details of the probe modification are provided in the Figures below.

The PP026 probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 μF/50 V ceramic type and one (1) 47 μF/50 V aluminum electrolytic. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).

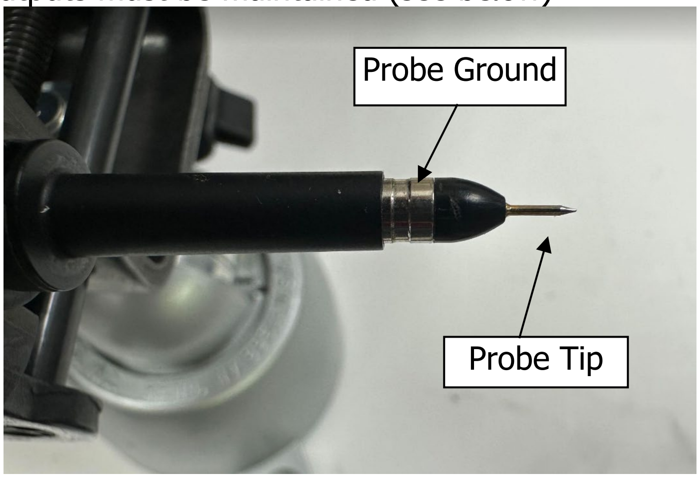


Figure 76 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

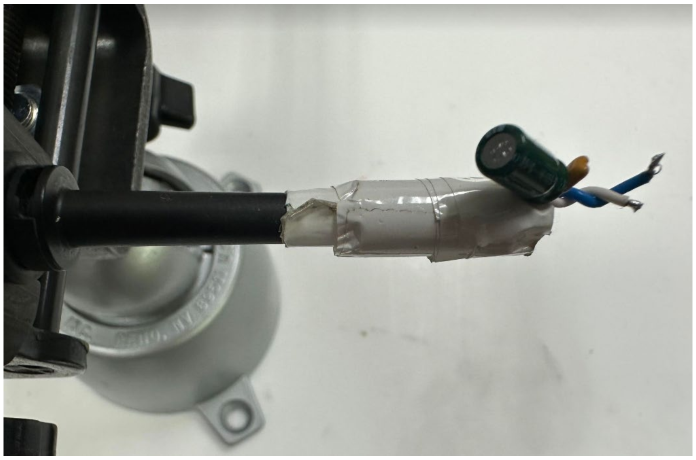


Figure 77 – Oscilloscope Probe with BNC Adapter

(https://www.teledynelecroy.com/probes/passive-probes/pp026-1)

11.5.2 Ripple Waveforms (Measured on Board)

11.5.2.1 100% Load

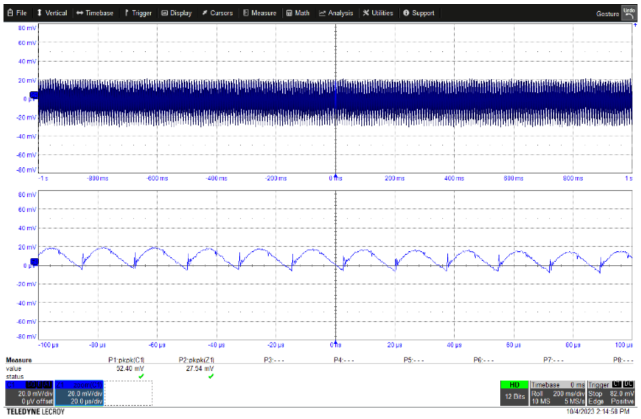


Figure 78 – 90 VAC Input, 100% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 52.4 mVpp

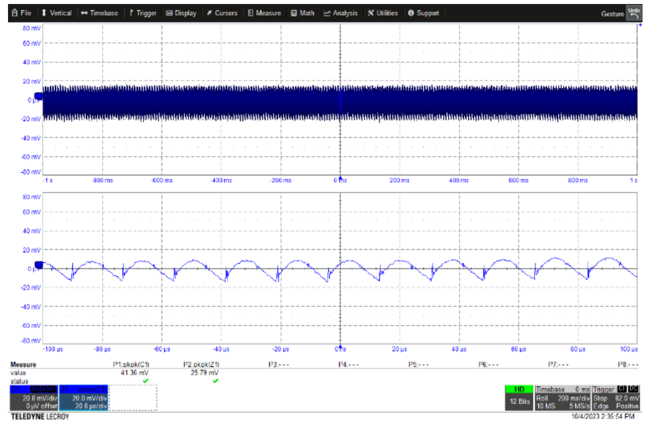


Figure 79 – 115 VAC Input, 100% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 41.36 mVpp

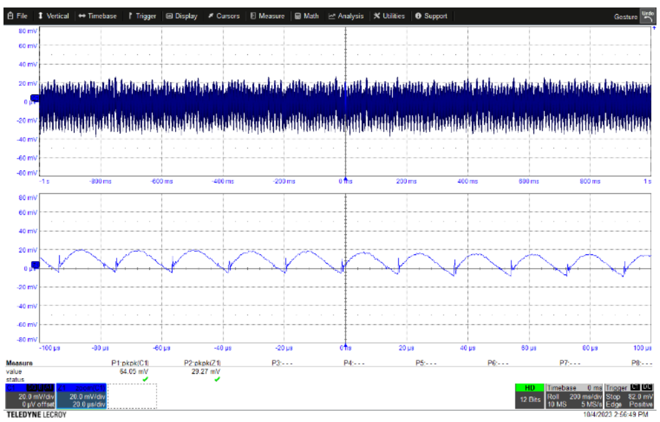


Figure 80 – 230 VAC Input, 100% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 64.05 mVpp

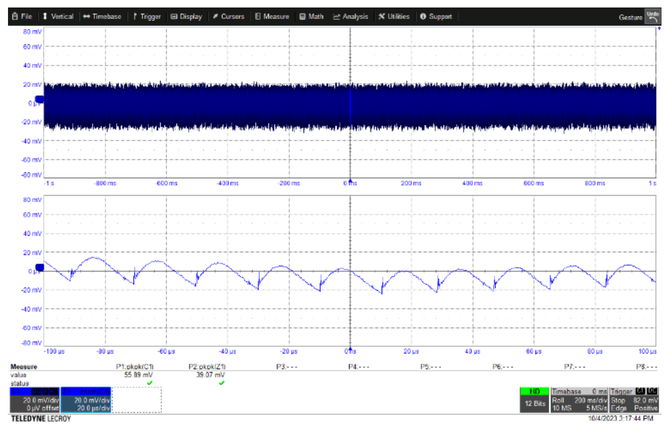


Figure 81 – 265 VAC Input, 100% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 55.89 mVpp

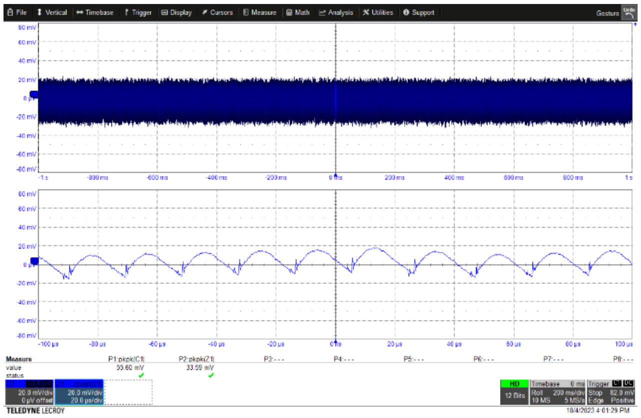


Figure 82 – 480 VAC Input, 100% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 55.60 mVpp

11.5.2.2 50% Load

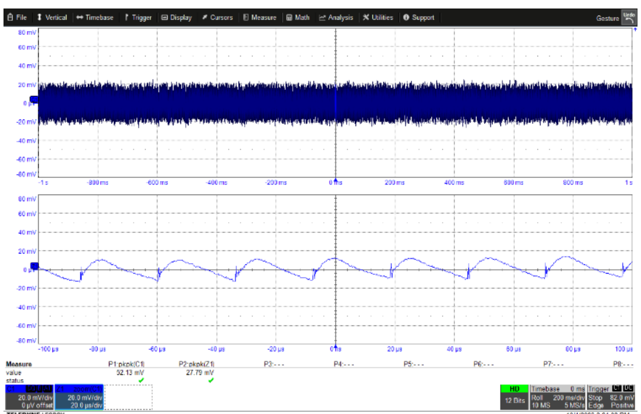


Figure 83 –90 VAC Input, 50% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 52.13 mVpp

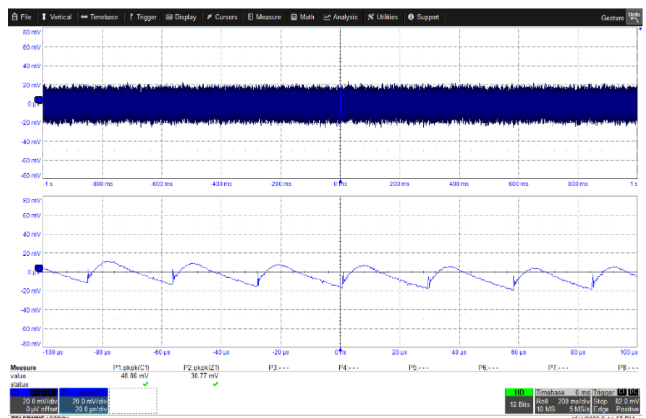


Figure 84 – 115 VAC Input, 50% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 48.86 mVpp

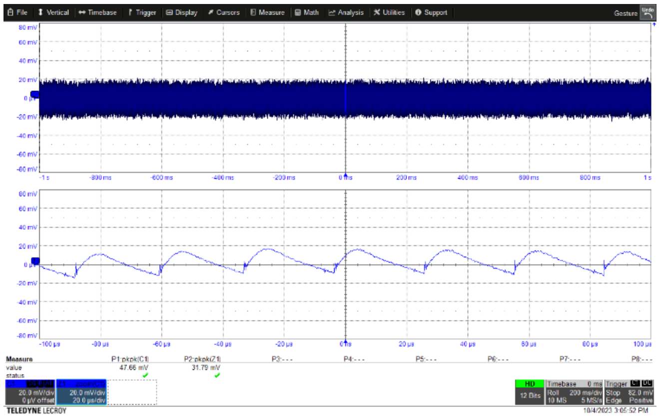


Figure 85 – 230 VAC Input, 50% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 47.66 mVpp

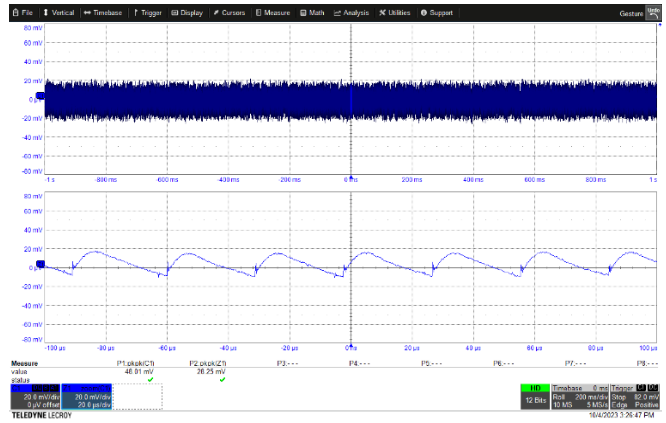


Figure 86 – 265 VAC Input, 50% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 48.01 mVpp

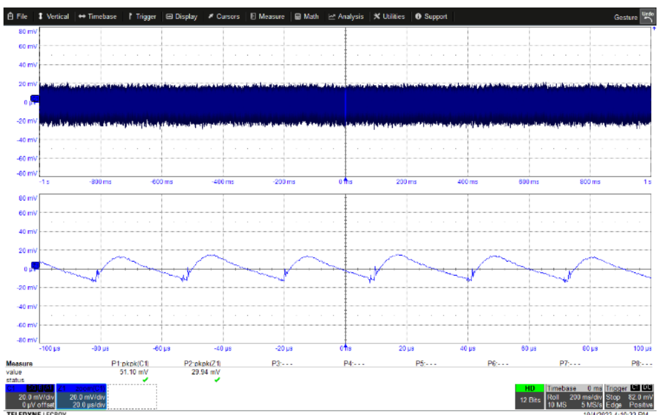


Figure 87 – 480 VAC Input, 50% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 51.10 mVpp

11.5.2.3 10% Load

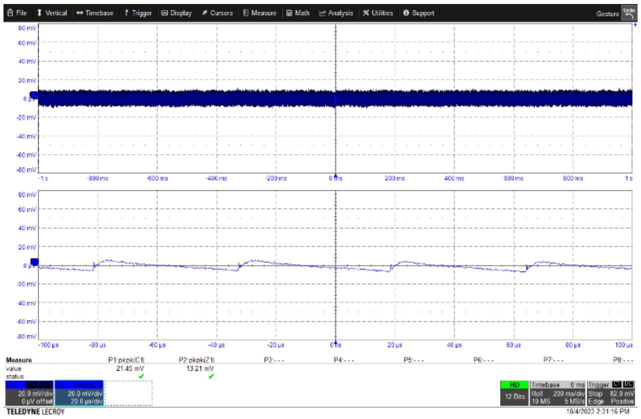


Figure 88 –90 VAC Input, 10% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 21.45 mVpp

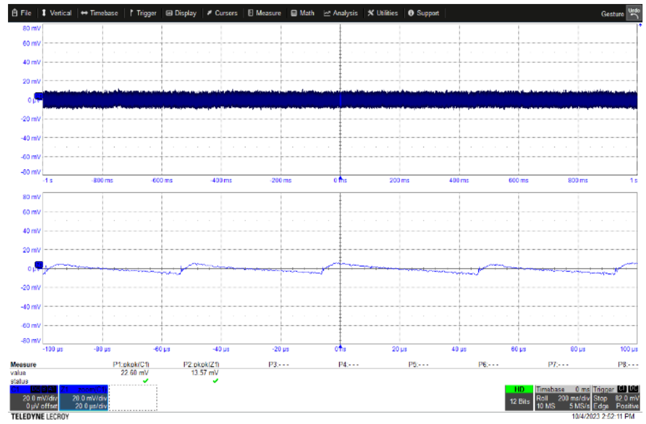


Figure 89 – 115 VAC Input, 10% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 22.60 mVpp

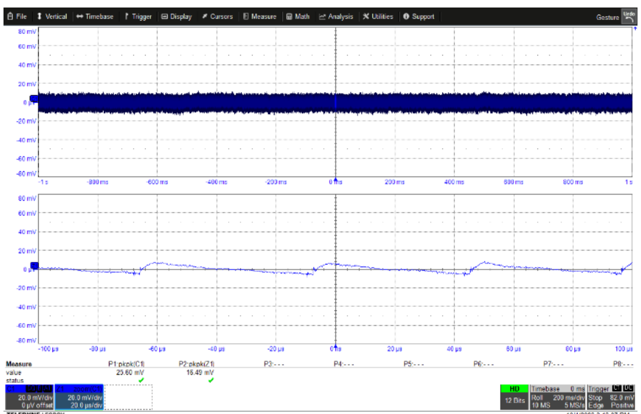


Figure 90 – 230 VAC Input, 10% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 25.60 mVpp

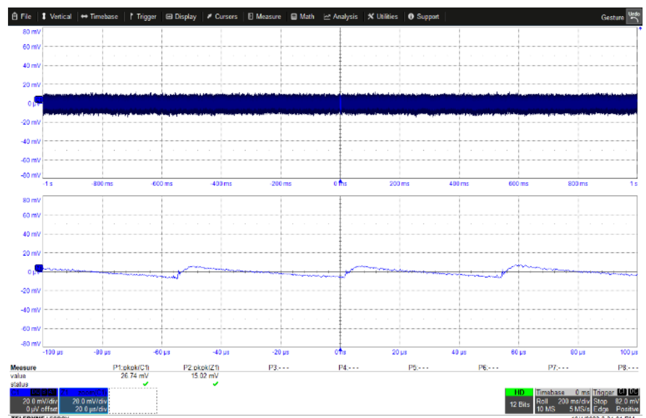


Figure 91 – 265 VAC Input, 10% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 26.74 mVpp

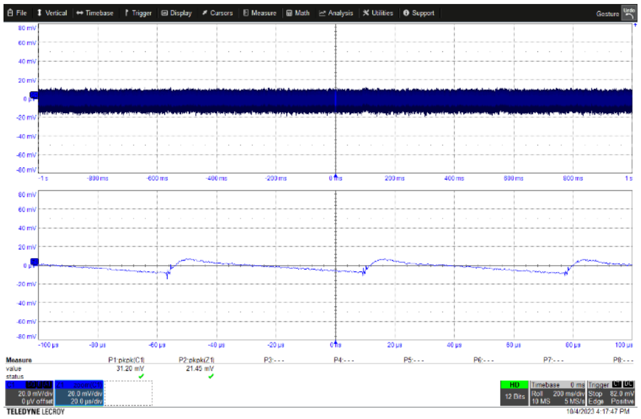


Figure 92 – 420 VAC Input, 10% Load.
V_{OUT}, 20 mV / div., 200 ms / div.
Zoom: 20 µs.
Voltage Ripple: 31.20 mVpp

11.5.3 Output Voltage Ripple

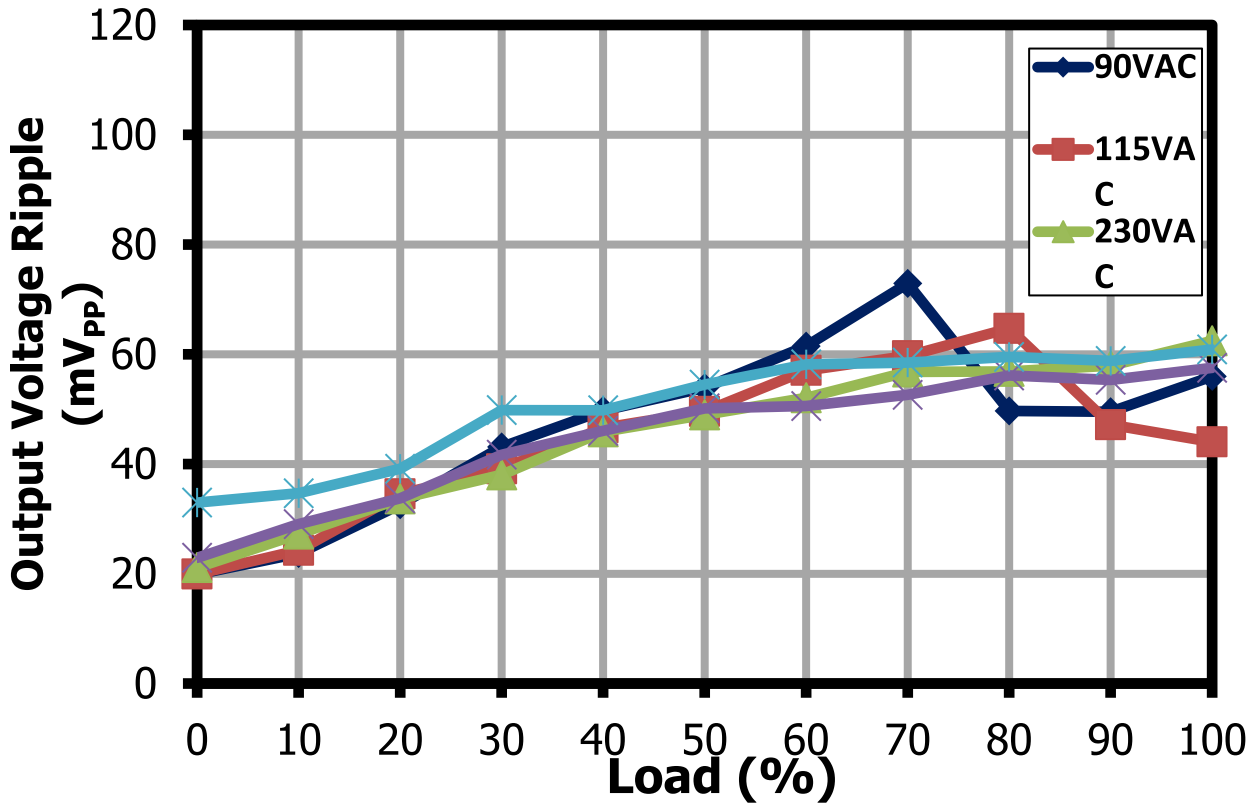
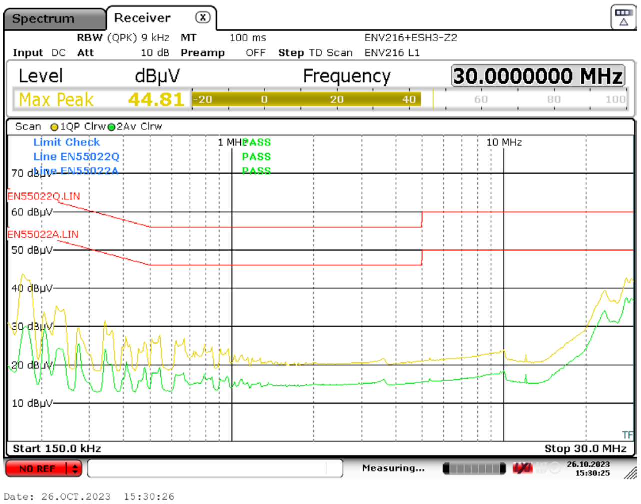


Figure 93 – Output Voltage Ripple**.**

12 Conducted EMI

12.1 Floating Output

12.1.1 VIN: 115 VAC



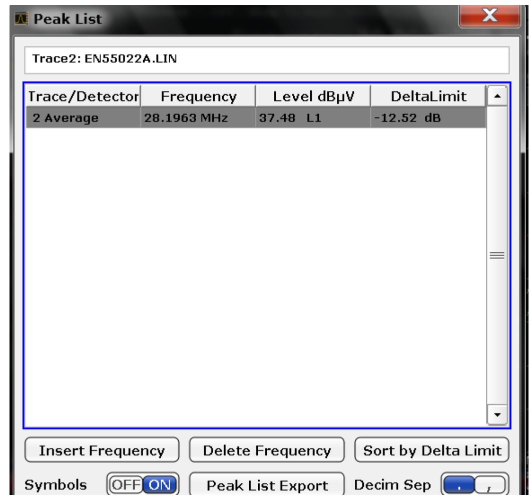
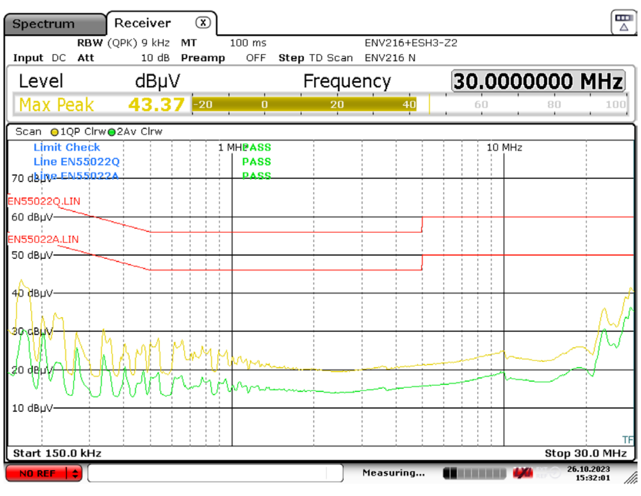


Figure 94 – Floating Output EMI, Line, 12 V / 100% Load.



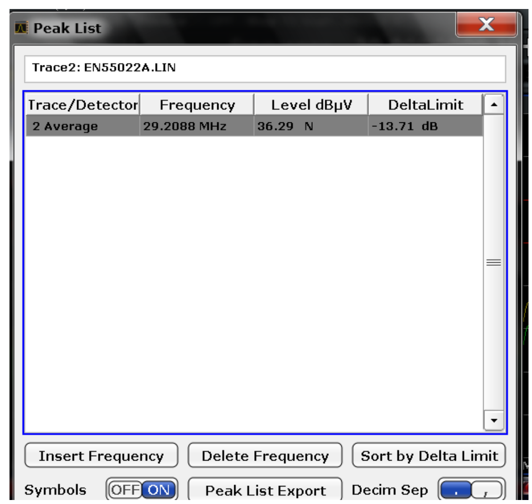


Figure 95 – Floating Output EMI, Neutral, 12 V / 100% Load.

12.1.2 VIN: 230 VAC

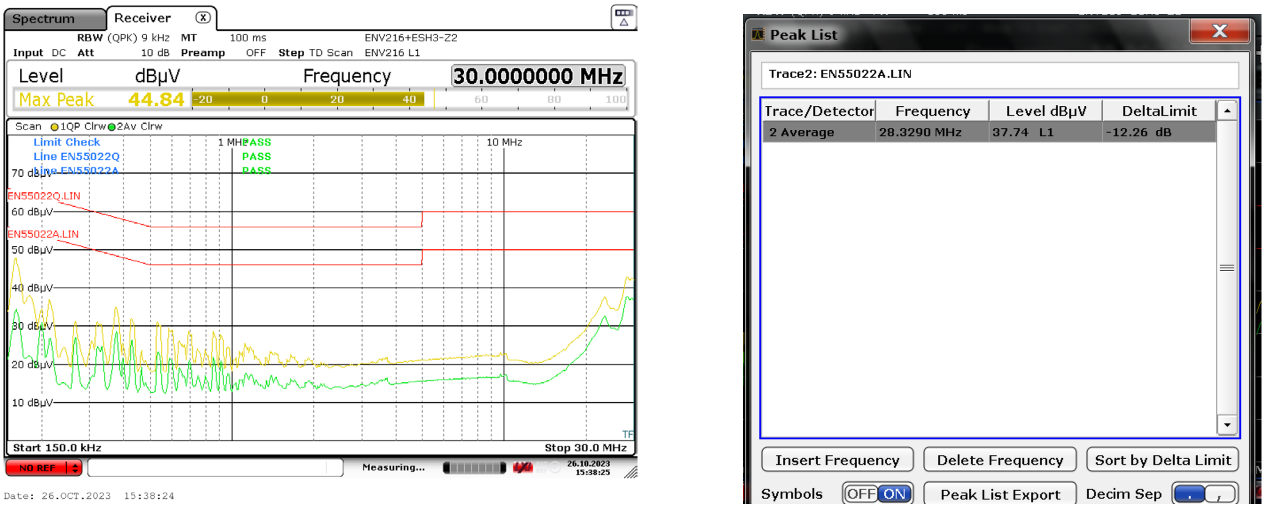


Figure 96 – Floating Output EMI, Line, 12 V / 100% Load.

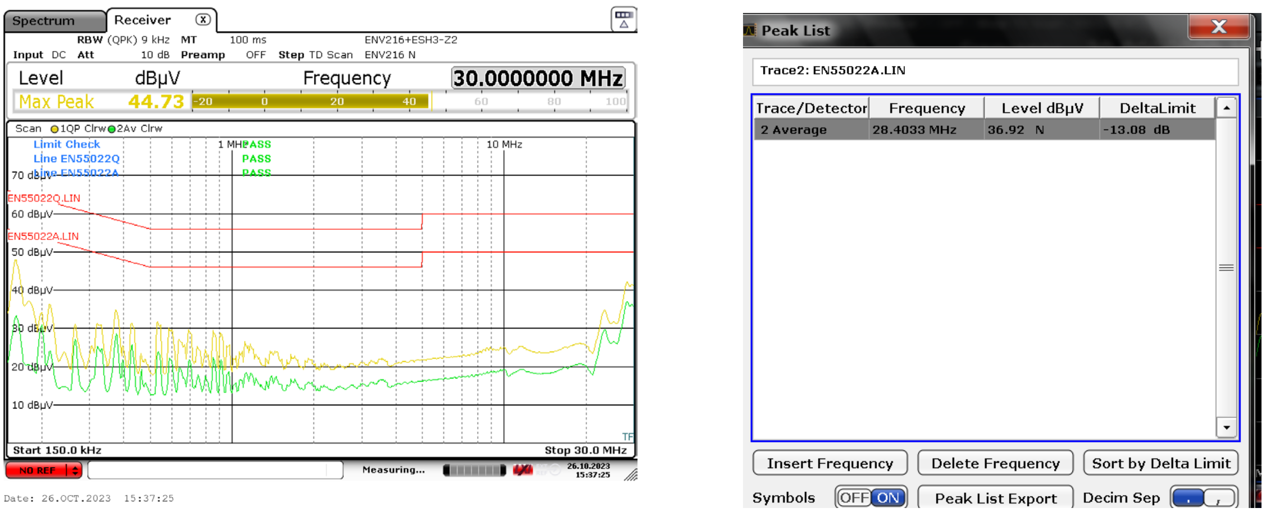


Figure 97 – Floating Output EMI, Neutral, 12 V / 100% Load.

12.2 Grounded Output

12.2.1 VIN: 115 VAC

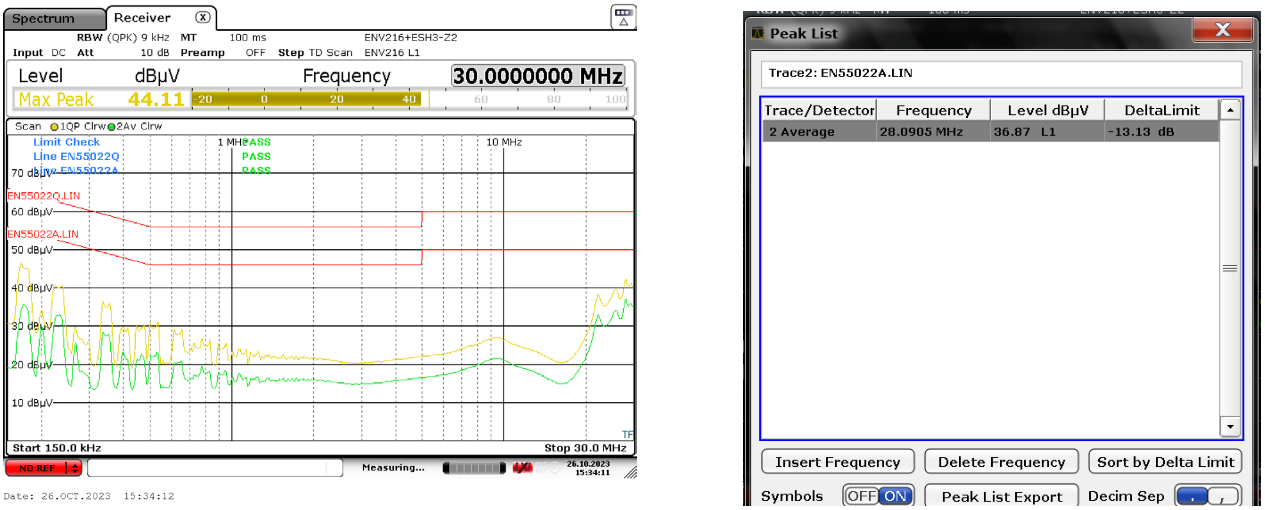


Figure 98 – Grounded Output EMI, Line, 12 V / 100% Load.

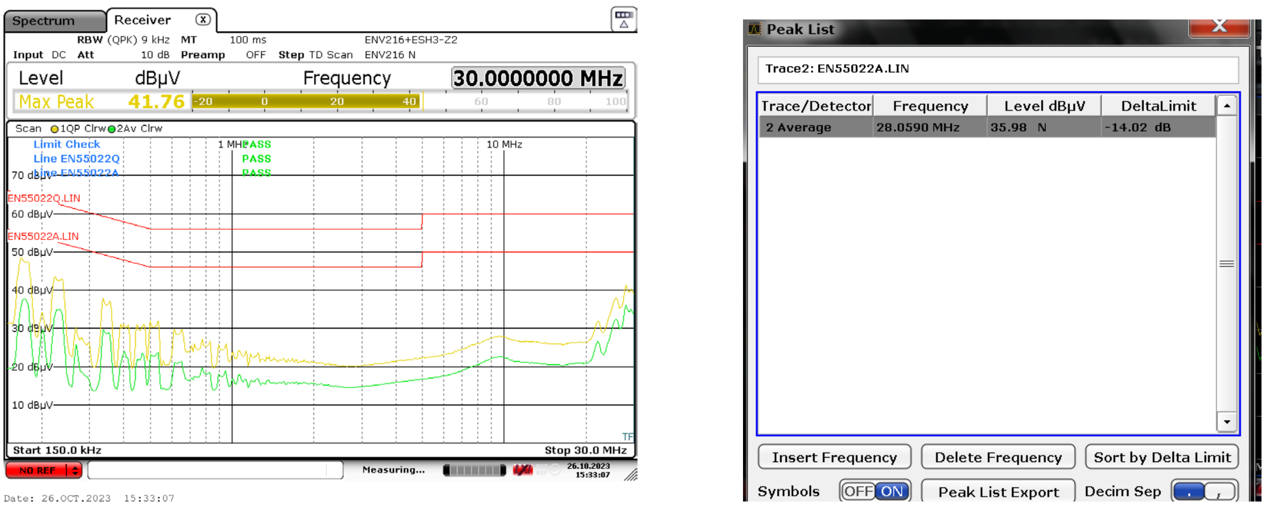
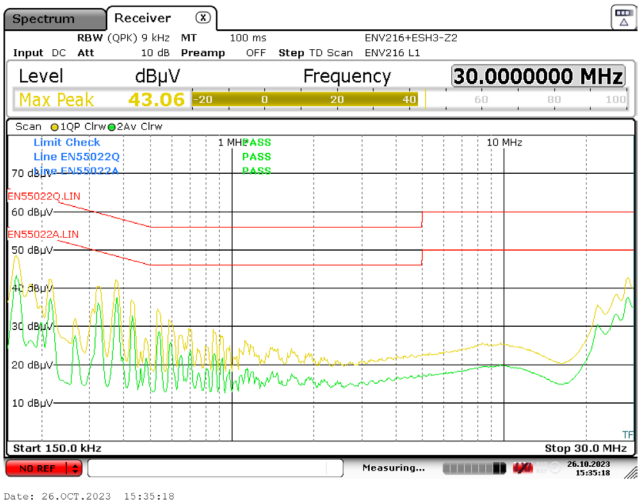
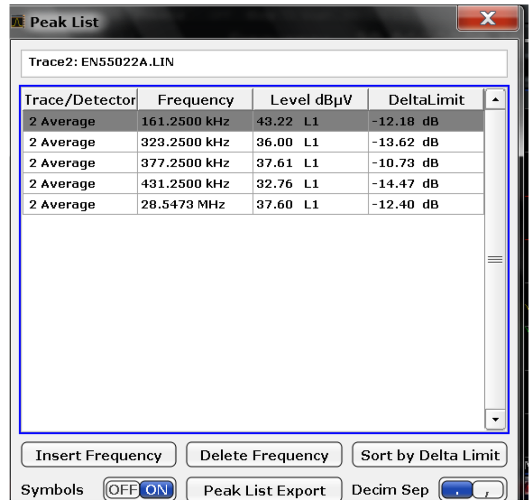


Figure 99 – Grounded Output EMI, Neutral, 12 V / 100% Load.

12.2.2 VIN: 230 VAC





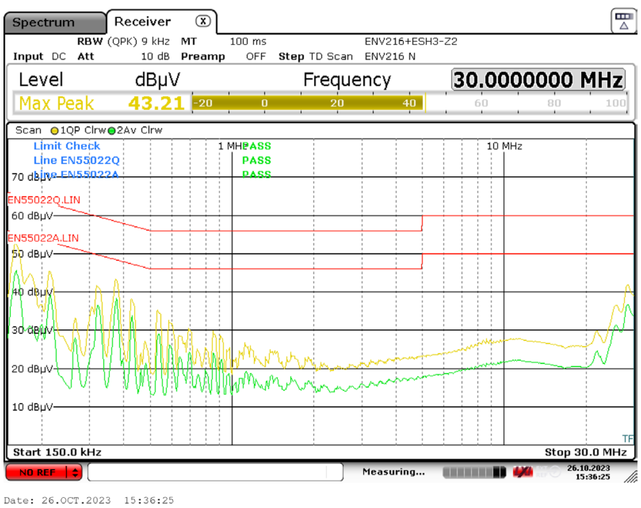
Peak List

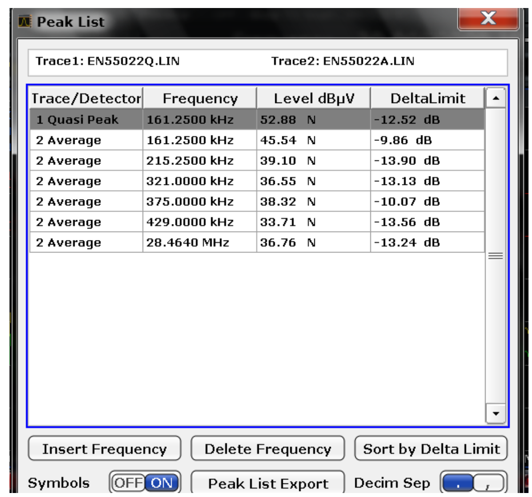
Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	161.2500 kHz	43.22 L1	-12.18 dB
2 Average	323.2500 kHz	36.00 L1	-13.62 dB
2 Average	377.2500 kHz	37.61 L1	-10.73 dB
2 Average	431.2500 kHz	32.76 L1	-14.47 dB
2 Average	28.5473 MHz	37.60 L1	-12.40 dB

Insert Frequency | Delete Frequency | Sort by Delta Limit
Symbols OFF ON | Peak List Export | Decim Sep

Figure 100 – Floating Output EMI, Line, 12 V / 100% Load.





Peak List

Trace1: EN55022Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	161.2500 kHz	52.88 N	-12.52 dB
2 Average	161.2500 kHz	45.54 N	-9.86 dB
2 Average	215.2500 kHz	39.10 N	-13.90 dB
2 Average	321.0000 kHz	36.55 N	-13.13 dB
2 Average	375.0000 kHz	38.32 N	-10.07 dB
2 Average	429.0000 kHz	33.71 N	-13.56 dB
2 Average	28.4640 MHz	36.76 N	-13.24 dB

Insert Frequency | Delete Frequency | Sort by Delta Limit
Symbols OFF ON | Peak List Export | Decim Sep

Figure 101 – Floating Output EMI, Neutral, 12 V / 100% Load.

13 Line Surge

13.1 Differential Mode Test

13.1.1 115 VAC Input

Surge Voltage (V)	Phase Angle (º)	IEC Coupling	Generator Impedance (Ω)	Number Strikes	Result
+6000	90	L, N	2	10	Pass
–6000	90	L, N	2	10	Pass
+6000	180	L, N	2	10	Pass
–6000	180	L, N	2	10	Pass
+6000	270	L, N	2	10	Pass
–6000	270	L, N	2	10	Pass

13.1.2 230 VAC Input

Surge Voltage (V)	Phase Angle (º)	IEC Coupling	Generator Impedance (Ω)	Number Strikes	Result
+6000	90	L, N	2	10	Pass
–6000	90	L, N	2	10	Pass
+6000	180	L, N	2	10	Pass
–6000	180	L, N	2	10	Pass
+6000	270	L, N	2	10	Pass
–6000	270	L, N	2	10	Pass

13.2 Ring Wave Surge

13.2.1 115 VAC Input

Surge Voltage (V)	Phase Angle (º)	IEC Coupling	Generator Impedance (Ω)	Number Strikes	Result
+6000	90	L, N → PE	12	10	Pass
–6000	90	L, N → PE	12	10	Pass
+6000	180	L, N → PE	12	10	Pass
–6000	180	L, N → PE	12	10	Pass
+6000	270	L, N → PE	12	10	Pass
–6000	270	L, N → PE	12	10	Pass

13.2.2 230 VAC Input

Surge Voltage (V)	Phase Angle (º)	IEC Coupling	Generator Impedance (Ω)	Number Strikes	Result
+6000	90	L, N → PE	12	10	Pass
–6000	90	L, N → PE	12	10	Pass
+6000	180	L, N → PE	12	10	Pass
–6000	180	L, N → PE	12	10	Pass
+6000	270	L, N → PE	12	10	Pass
–6000	270	L, N → PE	12	10	Pass

14 EFT

Surge Voltage (V)	Phase Angle (º)	IEC Coupling	Frequency (kHz)	Burst Time	Reception Time (ms)	Step Duration (s)	Result
+4000	90	L, N - PE	5	15 ms	300	120	Pass
–4000	90	L, N - PE	5	15 ms	300	120	Pass
+4000	180	L, N - PE	5	15 ms	300	120	Pass
–4000	180	L, N - PE	5	15 ms	300	120	Pass
+4000	270	L, N - PE	5	15 ms	300	120	Pass
–4000	270	L, N - PE	5	15 ms	300	120	Pass
+4000	90	L, N - PE	100	750 µs	300	120	Pass
–4000	90	L, N - PE	100	750 µs	300	120	Pass
+4000	180	L, N - PE	100	750 µs	300	120	Pass
–4000	180	L, N - PE	100	750 µs	300	120	Pass
+4000	270	L, N - PE	100	750 µs	300	120	Pass
–4000	270	L, N - PE	100	750 µs	300	120	Pass

15 ESD

Passed ±16.5 kV air discharge and ±8.8 kV contact discharge at both output positive and negative terminals, under full load condition for both 115VAC and 230 VAC.

15.1 115 VAC

Air Discharge (kV)	Point of Discharge	Number of Strikes	No. of Auto-Restart	Test Result
+ 2	V_{OUT} (+)	10	0/10	PASS
- 2		10	0/10	PASS
+ 2	V_{OUT} (-)	10	0/10	PASS
- 2		10	0/10	PASS
+ 4	V_{OUT} (+)	10	0/10	PASS
- 4		10	0/10	PASS
+ 4	V_{OUT} (-)	10	0/10	PASS
- 4		10	0/10	PASS
+ 6	V_{OUT} (+)	10	0/10	PASS
- 6		10	0/10	PASS
+ 6	V_{OUT} (-)	10	0/10	PASS
- 6		10	0/10	PASS
+ 8	V_{OUT} (+)	10	0/10	PASS
- 8		10	0/10	PASS
+ 8	V_{OUT} (-)	10	0/10	PASS
- 8		10	0/10	PASS
+ 8.8	V_{OUT} (+)	10	0/10	PASS
- 8.8		10	0/10	PASS
+ 8.8	V_{OUT} (-)	10	0/10	PASS
- 8.8		10	0/10	PASS

15.2 115 VAC

Air Discharge (kV)	Point of Discharge	Number of Strikes	No. of Auto-Restart	Test Result
+ 8	V_{OUT} (+)	10	0/10	PASS
- 8		10	0/10	PASS
+ 8	V_{OUT} (-)	10	0/10	PASS
- 8		10	0/10	PASS
+ 10	V_{OUT} (+)	10	0/10	PASS
- 10		10	0/10	PASS
+ 10	V_{OUT} (-)	10	0/10	PASS
- 10		10	0/10	PASS
+ 12	V_{OUT} (+)	10	0/10	PASS
- 12		10	0/10	PASS
+ 12	V_{OUT} (-)	10	0/10	PASS
- 12		10	0/10	PASS
+ 14	V_{OUT} (+)	10	0/10	PASS
- 14		10	0/10	PASS
+ 14	V_{OUT} (-)	10	0/10	PASS
- 14		10	0/10	PASS
+ 15	V_{OUT} (+)	10	0/10	PASS
- 15		10	0/10	PASS
+ 15	V_{OUT} (-)	10	0/10	PASS
- 15		10	0/10	PASS
+ 16.5	V_{OUT} (+)	10	0/10	PASS
- 16.5		10	0/10	PASS
+ 16.5	V_{OUT} (-)	10	0/10	PASS
- 16.5		10	0/10	PASS

15.3 230 VAC

Contact Discharge (kV)	Point of Discharge	Number of Strikes	No. of Auto-Restart	Test Result
+ 2	V_{OUT} (+)	10	0/10	PASS
- 2		10	0/10	PASS
+ 2	V_{OUT} (-)	10	0/10	PASS
- 2		10	0/10	PASS
+ 4	V_{OUT} (+)	10	0/10	PASS
- 4		10	0/10	PASS
+ 4	V_{OUT} (-)	10	0/10	PASS
- 4		10	0/10	PASS
+ 6	V_{OUT} (+)	10	0/10	PASS
- 6		10	0/10	PASS
+ 6	V_{OUT} (-)	10	0/10	PASS
- 6		10	0/10	PASS
+ 8	V_{OUT} (+)	10	0/10	PASS
- 8		10	0/10	PASS
+ 8	V_{OUT} (-)	10	0/10	PASS
- 8		10	0/10	PASS
+ 8.8	V_{OUT} (+)	10	0/10	PASS
- 8.8		10	0/10	PASS
+ 8.8	V_{OUT} (-)	10	0/10	PASS
- 8.8		10	0/10	PASS

15.4 230 VAC

Air Discharge (kV)	Point of Discharge	Number of Strikes	No. of Auto-Restart	Test Result
+ 8	V_{OUT} (+)	10	0/10	PASS
- 8		10	0/10	PASS
+ 8	V_{OUT} (-)	10	0/10	PASS
- 8		10	0/10	PASS
+ 10	V_{OUT} (+)	10	0/10	PASS
- 10		10	0/10	PASS
+ 10	V_{OUT} (-)	10	0/10	PASS
- 10		10	0/10	PASS
+ 12	V_{OUT} (+)	10	0/10	PASS
- 12		10	0/10	PASS
+ 12	V_{OUT} (-)	10	0/10	PASS
- 12		10	0/10	PASS
+ 14	V_{OUT} (+)	10	0/10	PASS
- 14		10	0/10	PASS
+ 14	V_{OUT} (-)	10	0/10	PASS
- 14		10	0/10	PASS
+ 15	V_{OUT} (+)	10	0/10	PASS
- 15		10	0/10	PASS
+ 15	V_{OUT} (-)	10	0/10	PASS
- 15		10	0/10	PASS
+ 16.5	V_{OUT} (+)	10	0/10	PASS
- 16.5		10	0/10	PASS
+ 16.5	V_{OUT} (-)	10	0/10	PASS
- 16.5		10	0/10	PASS

16 Revision History

Date	Author	Revision	Description & Changes	Reviewed
27-Oct-23	JMR	1	First Release	

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