Design Example Report

Title	*70 W USB In-Wall Charger using InnoSwitch™4-CZ with PowiGaN™ INN4075C-H182 and ClampZero™ CPZ1062M*
Specification	100 VAC – 132 VAC Input; 5 V / 6.5 A, 9 V / 5 A, 15 V / 4 A, 20 V / 3.5 A Outputs
Application	USB Wall Outlet, Power Strip with USB Charging Ports
Author	Applications Engineering Department
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Summary and Features

- 70 W low profile compact power supply for high power USB Type-A/C port charging
- >94% Full Load Efficiency at nominal Input
- <20 mW system no-load input power
- PowiGaN-based InnoSwitch4-CZ benefits
  - Highly integrated switcher IC with integrated high-voltage switch, synchronous rectification and FluxLink™ feedback
  - Zero voltage switching in both CCM and DCM operating conditions
  - PowiGaN-based integrated MOSFET enables heat sink-less design
  - Fast instantaneous transient response with 0%-100%-0% load step
  - Constant power (CP) profile minimizes charging time with continuous adjustment of output current and voltage
- Low components count (<60)
- Easily meets DOE6 efficiency requirements
- Integrated protection and reliability features
  - Output short-circuit protection
  - OVP, OCP and OTP protection
- Meets 2.0 kV differential surge and EN55022 conducted EMI
- Suitable for compact enclosures with high operating ambient temperature
- Very high power density: 24.9 W/in^3 without enclosure (70 W / 2.24 in X 1.54 in X 0.82 in)

Power Integrations
5245 Hellyer Avenue, San Jose, CA 95138 USA.
Tel: +1 408 414 9200   Fax: +1 408 414 9201
www.power.com

PATENT INFORMATION

The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.power.com. Power Integrations grants its customers a license under certain patent rights as set forth at https://www.power.com/company/intellectual-property-licensing/.`

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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 an off-line 70 W isolated flyback power supply designed to operate at an input voltage range from 100 VAC to 132 VAC within its 4 selectable output ranges (20 V / 3.5 A, 15 V / 4 A, 9 V / 5 A and 5 V / 6.5 A). This power supply uses active clamp topology featuring Power Integrations' InnoSwitch4-CZ (INN4075-H182) partnered with ClampZero (CPZ1062M).

The InnoSwitc4-CZ family of ICs partners with the ClampZero family of active clamp ICs to dramatically improve the efficiency of flyback power converters, particularly those requiring a compact form-factor. This combination of ICs greatly reduces system and primary switch losses, allowing for extremely high power densities.

The InnoSwitch4-CZ family incorporates primary and secondary controllers and safety-rated feedback into a single IC. It also includes multiple protection features including output overvoltage and over-current limiting, and over-temperature shutdown.

DER-949 offers a high low-line efficiency (94%), low component count, and heat sink-less design to meet increasing demands for power savings and small form factor enclosures. It is also suitable for compact enclosures with high operating ambient temperatures due to InnoSwitch4-CZ's excellent thermal performance and the use of a four-layer PCB design.

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

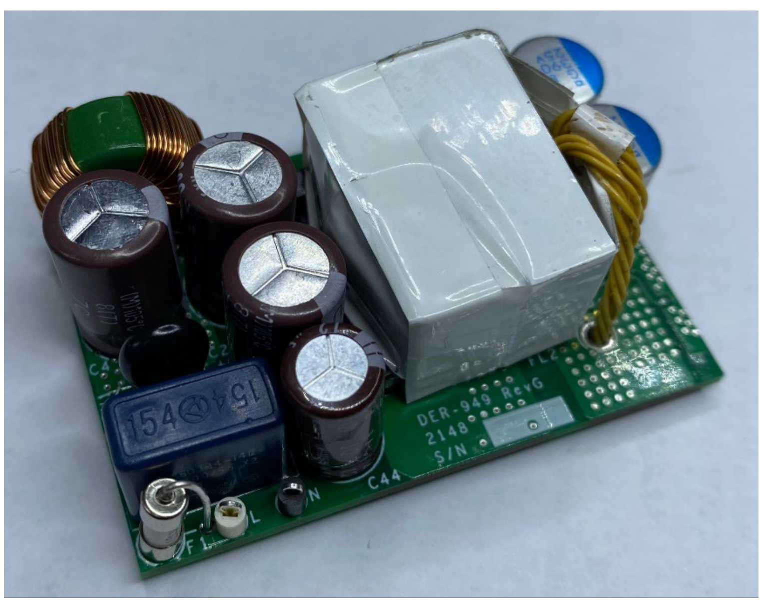


Figure 1 – Populated Circuit Board.

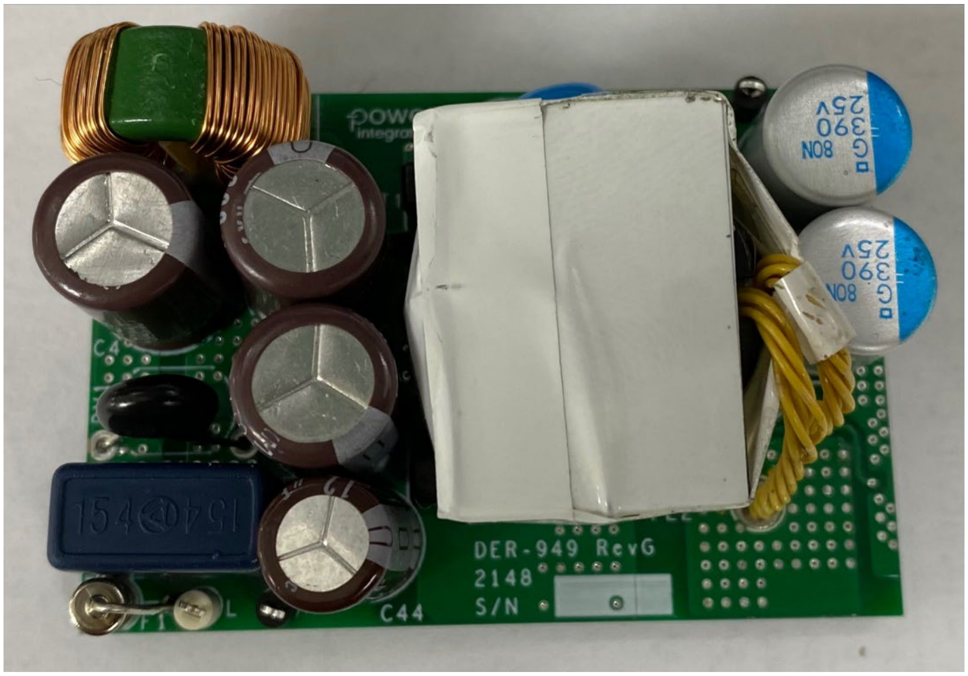


Figure 2 – Populated Circuit Board, Top View.

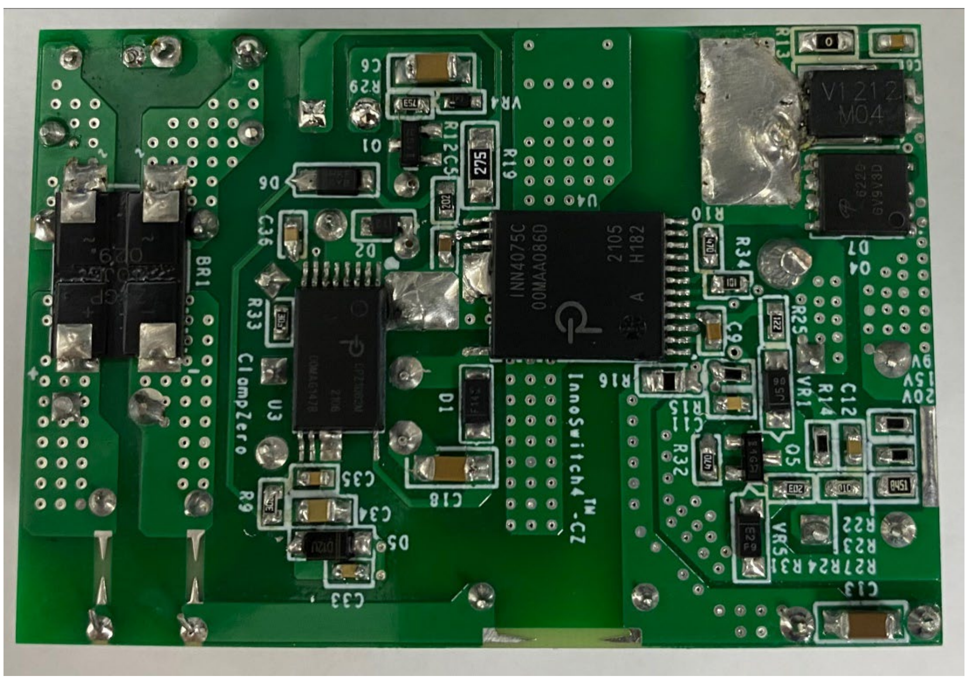


Figure 3 – Populated Circuit Board, Bottom View.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	100	115	132	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	60	63	Hz	
No-load Input Power (115 VAC)			40		mW	Measured at 115 VAC, 5 V Output.
5 V Output						
Output Voltage	V_{OUT}		5		V	±3%
Output Ripple Voltage	V_{RIPPLE}			150	mV	At End of Cable. Cable Needs a Resistance of 100 mΩ.
Output Current	I_{OUT}			6.5	A	20 MHz Bandwidth.
Efficiency	n		91			Measured at 115 VAC.
9 V Output						
Output Voltage	V_{OUT}		9		V	±5%
Output Ripple Voltage	V_{RIPPLE}			150	mV	At End of Cable. Cable Needs a Resistance of 100 mΩ.
Output Current	I_{OUT}			5	A	20 MHz Bandwidth.
Efficiency	n		93		%	Measured at 115 VAC.
15 V Output						
Output Voltage	I_{OUT}		15		V	±5%
Output Ripple Voltage	V_{RIPPLE}			150	mV	At End of Cable. Cable Needs a Resistance of 100 mΩ.
Output Current	I_{OUT}			4	A	20 MHz Bandwidth.
Efficiency	n		94		%	Measured at 115 VAC.
20 V Output						
Output Voltage	V_{OUT}		20		V	±5%
Output Ripple Voltage	V_{RIPPLE}			200	mV	At End of Cable. Cable Needs a Resistance of 100 mΩ.
Output Current	I_{OUT}			3.5	A	20 MHz Bandwidth.
Efficiency	n		94		%	Measured at 115 VAC.

For extended output load requirement at 9 V output.

9 V Output						
Output Voltage	V_{OUT}		9		V	±5%
Output Ripple Voltage	V_{RIPPLE}			200	mV	At End of Cable. Cable Needs a Resistance of 100 mΩ.
Output Current	I_{OUT}			6	A	20 MHz Bandwidth.
Efficiency	n		92		%	Measured at 115 VAC.

3 Schematic

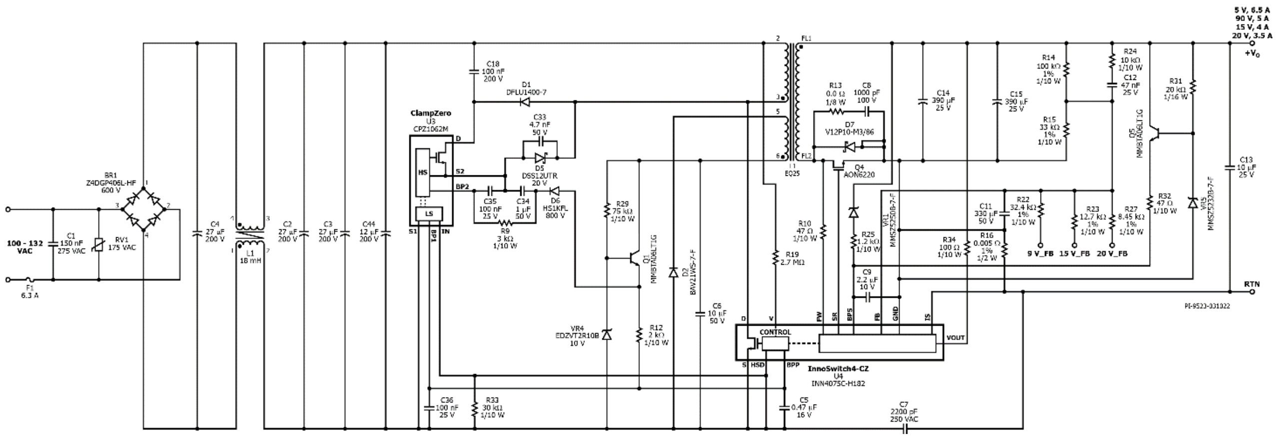


Figure 4 – Schematic.

4 Circuit Description

The circuit is an active clamp flyback power supply with synchronous rectification controlled by InnoSwitch4-CZ IC (U4) using PowiGaN as primary-side switch. Besides the high-voltage PowiGaN switch, the IC incorporates primary-side controller, secondary-side controller and FluxLink feedback signals in one single package. Moreover, it controls the ClampZero IC (U3) for the active clamp operation needed to obtain ultra-high efficiencies. The decreased switching losses allows the InnoSwitch4-CZ IC to operate at high switching frequencies, resulting to smaller magnetics and decreased overall form factor of the power supply.

4.1 *Input EMI Filter and Rectifier*

The input fuse (F1) provides safety protection from component failures. Metal oxide varistor (RV1) help prevents component failure in the event of high-voltage input line surge. The AC input voltage is full wave rectified by the bridge rectifier (BR1) and then filtered by the bulk capacitors (C4, C2, C3 and C44) to provide a smooth DC input voltage supply to the flyback circuitry. Input common mode choke (L1) is connected between C4 and C2 to provide common mode noise filtering and at the same time forms an LC filter circuit with its leakage inductance for differential mode noise filtering. A low ESR electrolytic capacitor is recommended for the bulk capacitors (C2, C3, C4 and C44) for better differential mode noise filtering and higher efficiency. Y capacitor (C7) bypass common mode noise back to the primary power ground. X capacitor (C1) helps reduce the differential mode EMI noise.

4.2 *Primary-side Controller: InnoSwitch4-CZ*

The power transformer (T1) is designed for flyback power conversion. For a better EMI shielding, the primary winding start terminal (pin 3) must be connected to the noisy DRAIN pin of the PowiGaN switch inside InnoSwitch4-CZ and the finish terminal (pin 2) is connected to the positive terminal of the bulk capacitor (C44). Snubber circuit formed by D1 and C18 cuts down leakage voltage spike and help minimize the voltage stress across the PowiGaN switch. Fast recovery diode is recommended for D1.

In contrast with the traditional RCD clamp, this snubber configuration used by InnoSwitch4-CZ does not use resistors to dissipate energy from the leakage inductance. Rather, the energy from the leakage inductance gets stored in C18 and eventually recycled to achieve zero-voltage switching (ZVS) across the PowiGaN. Right before the next turn-on of the PowiGaN, the high-side switch of the ClampZero turns on, causing energy from C18 to flow and charge up the leakage inductance. The current stored across the leakage inductance then forces the output capacitance of the PowiGaN to discharge down to zero, just in time before the PowiGaN turns on again. This ZVS behavior dramatically lowers the switching losses across the PowiGaN, allowing it to operate at much higher frequencies.

The switching pattern of U3 serves as key to achieving ZVS. When the FluxLink signal is received from the secondary-side, the InnoSwitch4-CZ Ic generates a signal coming from its HSD pin to turn on the ClampZero IC (via the IN pin) for a fixed duration, t_{HSD}. During this time, C18 charges the leakage inductance, in case of CCM operation, or both the leakage and magnetizing inductances, in case of DCM operation. After charging the leakage, the ClampZero IC turns off while the InnoSwitch4-CZ IC waits for a certain delay time (t_{LLDL} at lowline input or t_{HLDL} at highline input) before turning on the PowiGaN switch. During this delay time, the voltage stored across the PowiGaN's drain capacitance gets discharged by the leakage inductance, forcing it to go down to zero volts and achieve ZVS operation as the PowiGaN turns on again.

The delay time is fixed when operating at highline, equivalent to t_{HLDL}, while the value for lowline delay time, t_{LLDL}, is programmed via HSD resistor, R33, connected between the HSD pin and the Source pin.

The InnoSwitch4-CZ IC is self-starting, where an internal high-voltage current source coming from the DRAIN pin charges the PRIMARY BYPASS pin (BPP) capacitor C5 that powers the primary-side controller. During normal operation, the primary-side controller is powered via the bias winding of the transformer T1. Output of this bias winding is rectified by diode D2 and filtered by capacitor C6. The bias voltage across C6 powers the linear regulator formed by Zener diode VR4, biasing resistor R29, transistor Q1, and limiting resistor R12. The voltage formed across R12 (Q1 emitter voltage minus BPP shunt voltage) divided by its resistance defines the current supplied to the BPP.

Output regulation is achieved using a modulation technique where the switching frequency, F_{SW}, and primary current limit, I_{LIM}, are adjusted based on the output load. At heavy loads, the primary pulses occur at high F_{SW} and terminates at a high value of I_{LIM} in the selected I_{LIM} range. As the load decreases, both F_{SW} and I_{LIM} also decrease. At light loads or no-load condition, F_{SW} goes down to its minimum value and several pulses get disabled (cycle skipping).

The V pin resistor (R19) serves as input line voltage monitoring. It is connected between high-voltage positive bulk capacitor (C2 and C3) and V pin terminal. The input line voltage is checked to confirm that it is above the brown-in and below the overvoltage shutdown thresholds. The value selected for R19 was 2.74 MΩ to get the optimum efficiency at lowline input voltage.

4.3 *Active Clamp: ClampZero*

Capacitor C36 serves as local decoupling to the BP1 pin of the ClampZero IC, which provides power to its low-side control. Diode D6 and capacitor C34 form a bootstrap circuit to provide the bias for the high-side BP2 pin by getting power from the linear regulator derived from Q1. Resistor R9 serves as current limiting to BP2 (similar in function to R12) while C35 acts as a local decoupling capacitor.

Ultrafast diode D4 prevents current from the leakage inductance to flow through its body diode at the instant the PowiGaN switch of InnoSwitch4-CZ IC turns off.

Signal from the HSD pin of InnoSwitch4-CZ goes to the IN pin of ClampZero IC and is then communicated by the low-side control to the high-side drive to turn on the ClampZero switch. Once on, the ClampZero switch provides an energy path from C18 towards the leakage inductance of T1.

As previously mentioned, the on-time of the ClampZero IC is a constant, defined by t_{HSD}, while the delay time between the ClampZero IC turn-off and the InnoSwitch4-CZ IC turn-on is defined by R33 at lowline (t_{LLDL}) or a fixed value at highline (t_{HLDL}).

4.4 *Secondary-Side Control*

The secondary winding start terminal (FL1) of the transformer (T1) is connected to the positive terminal of output capacitor C14 and C15 while the finish terminal is connected to the DRAIN pin of the SR FET (Q4). The secondary winding voltage is rectified by the SR FET and then filtered by the output capacitors C14 and C15. Leakage voltage spike and ringing across SR FET drain to source during off time is minimized by the secondary RC snubber (R13 and C8). For high efficiency requirement, shorting R13 will help improve the efficiency. Schottky diode D7 helps improve full load efficiency specially at 5 V where output current is highest.

The secondary-side circuity of the IC is initially self-powered by the internal regulator which is supplied by either the secondary winding forward voltage (through FW pin) or by the output voltage (through VO pin). Secondary bypass (BPS) capacitor (C14) connected across the BPS pin and GND pin serves as decoupling capacitor. Linear regulator formed by VR5, Q5, R31, and R32 provides power to BPS under normal operating conditions to minimize heating of InnoSwitch4-CZ IC and contributes to the excellent thermal performance of this design. Aside from this linear regulator, another option is to add a secondary bias winding tuned to 5 V at 20 V output going to BPS.

When the external regulator does not supply enough power or when the output voltage (VO) falls during constant current mode operation, the secondary-side internal regulator will be supplied by the secondary winding forward voltage through FORWARD (FWD) pin resistor (R10). This will maintain the output current regulation down to the minimum BPS pin auto-restart voltage threshold. Below this level the unit enters auto-restart until the output load is reduced. A 47 Ω resistor is recommended for FWD pin resistor (R10) to ensure sufficient IC supply current.

The forward voltage sensed by FWD pin from secondary winding is also used for both handshaking and switching control for the SR FET (Q3), which is driven by the SYNCHRONOUS RECTIFIER DRIVE (SR) pin. The FWD pin voltage is used to determine when to turn off the SR FET in discontinuous conduction mode (DCM). The SR FET is turned off when the voltage drop across the MOSFET falls below $V_{SR(TH)}$. In continuous conduction mode (CCM), the SR FET is turned off just prior to the secondary-side commanding a new switching cycle to the primary.

Output current is sensed by monitoring the voltage drop across resistor R16 between the IS and SECONDARY GROUND pins. The internal constant current sense threshold is approximately 35 mV. Once the internal current sense threshold is exceeded, the device regulates the number of switch pulses to maintain a fixed output current.

Below the CC threshold, the device operates in constant voltage mode. The external resistor divider network (R14 and R15) is used for output voltage sensing to regulate the output voltage. The rest of the lower voltage divider resistors (R22, R23 and R27) are used to set output voltage from 5 V to 9 V, 15 V and 20 V respectively. The internal voltage comparator reference voltage is V_{FB} (1.265 V). A phase boost RC network (R24 and C12) is added to optimize ripple voltage. Zener diode VR1 and R25 serve as overvoltage protection in case all three resistors (R22, R23, and R27) get shorted to GND.

5 PCB Layout

5.1 *Board Specifications*

Board thickness: 0.062” (1.59mm)
Material: FR4
Layers: 4, Copper 2 oz per layer
Finish: Lead Free HASL

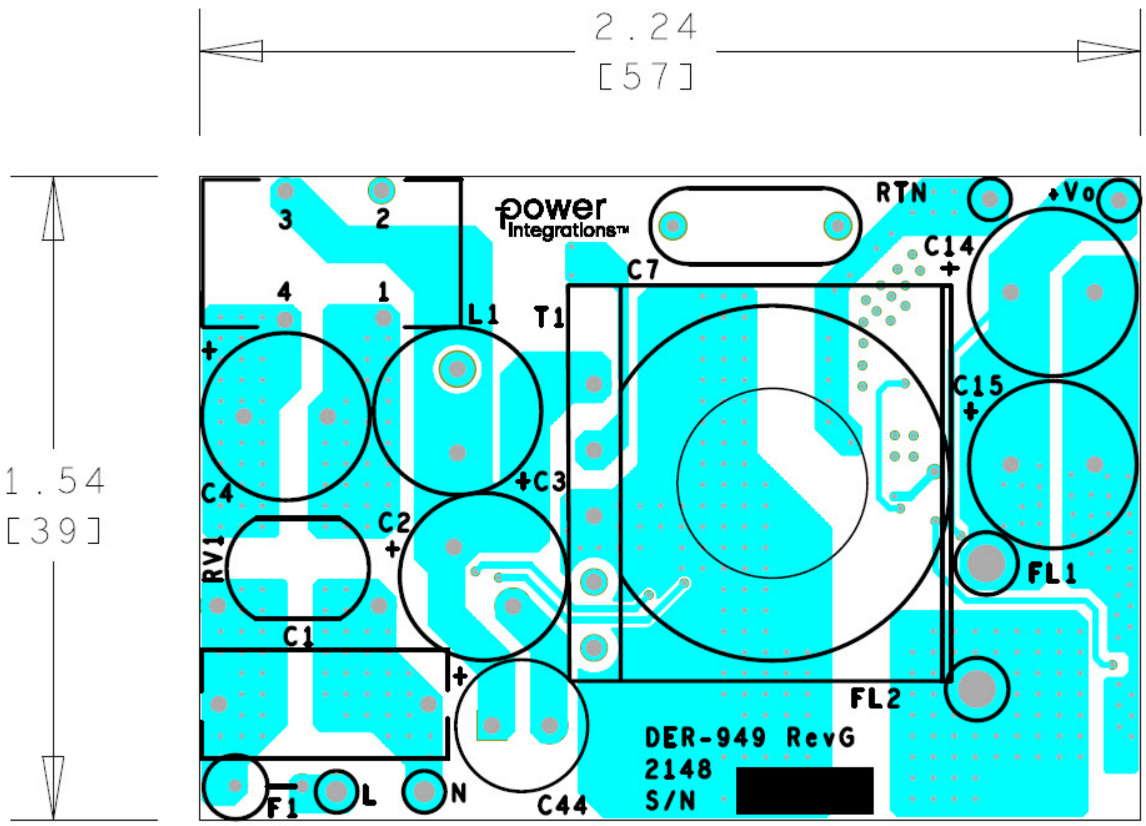


Figure 5 – Top Side.

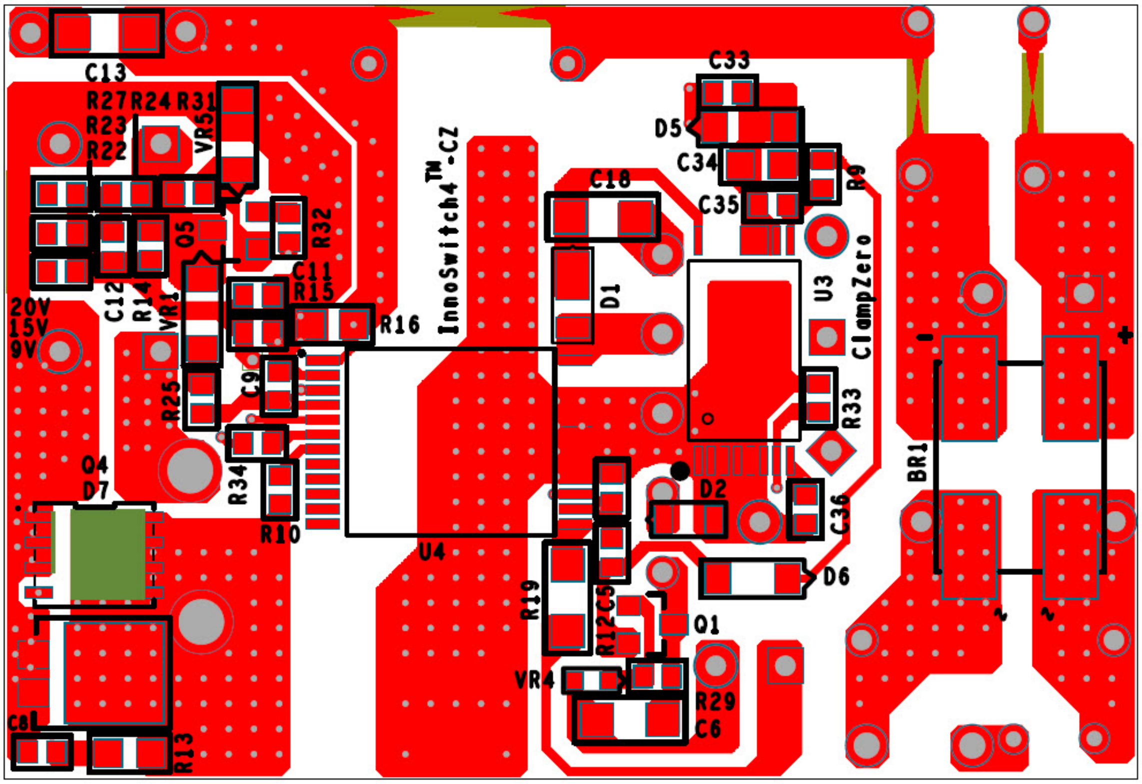


Figure 6 – Bottom Side (flipped).

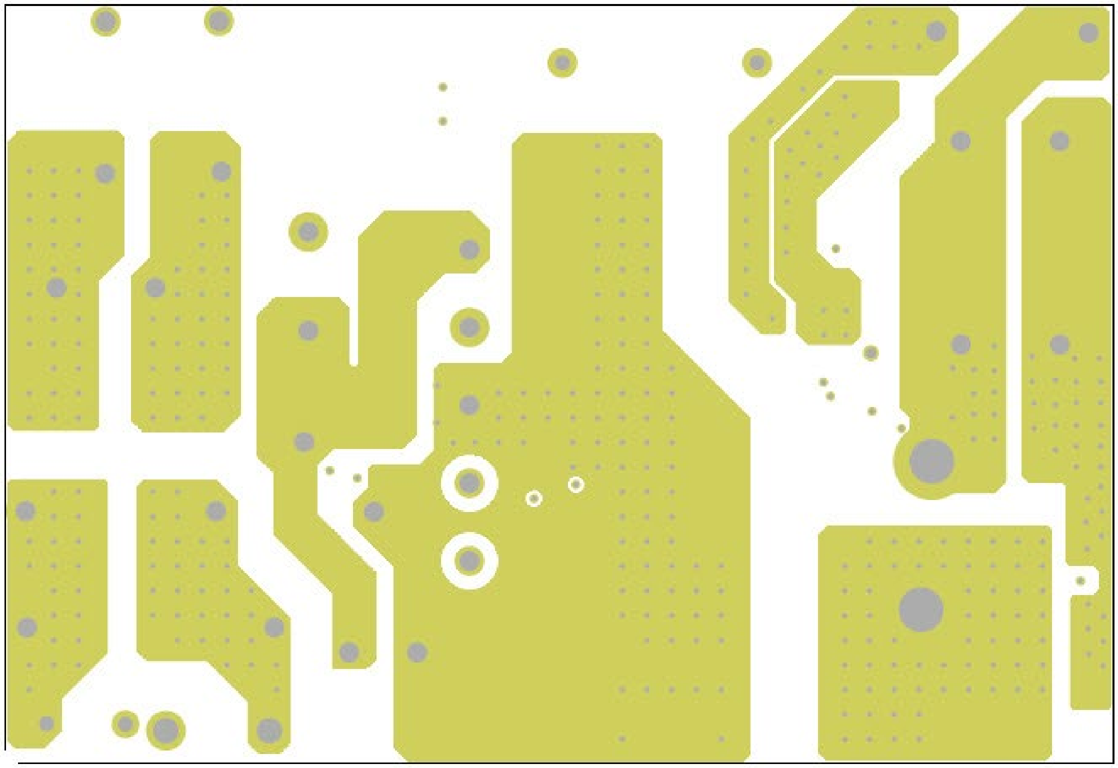


Figure 7 – First Inner Layer, Inner1.

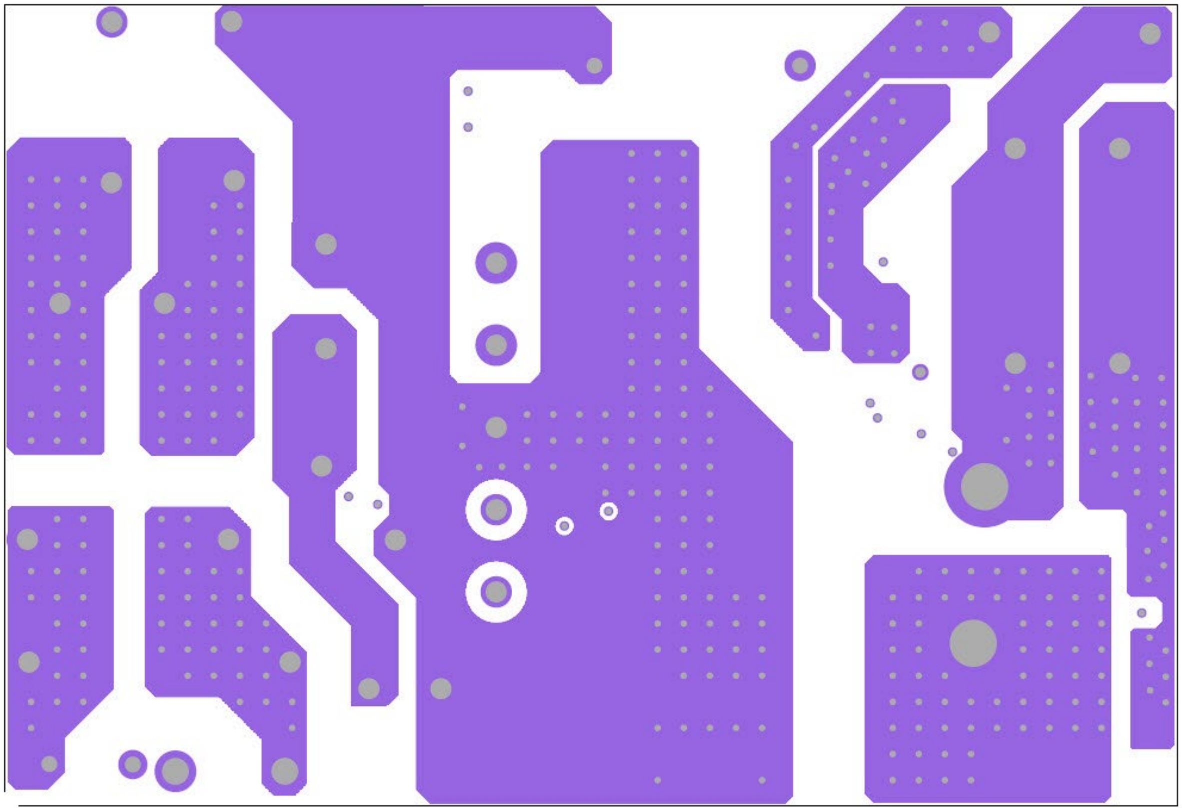


Figure 8 – Second Inner Layer, Inner2.

6 Bill of Materials

6.1 *Electrical Parts*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	RECT BRIDGE, GP, 600 V, 4 A, Z4-D, -55 °C ~ 175 °C (TJ)	Z4DGP406L-HF	Comchip
2	1	C1	150 nF, 275 VAC, Film, X2	LE154-M	OKAYA
3	3	C2 C3 C4	27 μF, 200 V, Electrolytic, (10 x 16),	EKXJ201ELL270MJ16S	Nippon Chemi-Con
4	1	C5	0.47 μF, 10%, 16 V, X7R, 0603	GRM188R71C474KA88D	Murata Electronics
5	1	C6	10 μF, 10%, 50 V, Ceramic, X7R, -55 °C ~ 125 °C, 1206, 0.126" L x 0.063" W (3.20 mm x 1.60 mm)	CL31B106KBHNNNE	Samsung
6	1	C7	2200 pF, ±20%, 250 VAC,X1, Y1, Disc Ceramic	DE1E3KX222MN4AN01F DE1E3RA222MN4AN01F	Murata
7	1	C8	1000 pF, ±10%, 100 V, Ceramic, X7R, 0603	C0603C102K1RACTU	Kemet
8	1	C9	2.2 μF, 10 V, Ceramic, X7R, 0603	GRM188R71A225KE15D	Murata
9	1	C11	330 pF 50 V, Ceramic, X7R, 0603	CC0603KRX7R9BB331	Yageo
10	1	C12	47 nF 25 V, Ceramic, X7R, 0603	CC0603KRX7R8BB473	Yago
11	1	C13	10 μF, 25 V, Ceramic, X7R, 1206	C3216X7R1E106M160AB C3216X7R1E106K160AB	TDK
12	2	C14 C15	390 μF, 25 V, Al Organic Polymer, Gen. Purpose, 20% 10 x 13	APSG250ELL391MJB5S	United Chemi-con
13	1	C18	100 nF, 200 V, Ceramic, X7R, 1206	C1206C104K2RACTU	Kemet
14	1	C33	4.7 nF 50 V, Ceramic, X7R, 0603	CL10B472KB8NNNC	Samsung
15	1	C34	1 μF, 50 V, Ceramic, X5R, 0805	08055D105KAT2A	AVX
16	2	C35 C36	100 nF, 0.1 μF, ±10%, 25 V, Ceramic, X7R, General Purpose, -55°C ~ 125°C, 0603	CL10B104KA8NFNC	Samsung
17	1	C44	12 μF, ±20%, 200 V, Aluminum Electrolytic Radial, Can - 10000 Hrs @ 105 °C, (8 x 17)	EKXE201ELL120MH15D	United Chemi-Con
18	1	D1	400 V, 1 A, Diode SUP FAST 1 A PWRDI 123	DFLU1400-7	Diodes, Inc.
19	1	D2	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
20	1	D5	Diode, Schottky, 20 V, 1 A, SMT, SOD-123FL	DSS12UTR	SMC
21	1	D6	800 V, 1 A, High Efficiency Fast Recovery, SOD-123FL	HS1KFL	Taiwan Semi
22	1	D7	100 V, 12 A, Schottky, SMD, TO-277A	V12P10-M3/86A	Vishay
23	1	F1	6.3 A, 250 V, Slow, 3.6 mm x 10 mm, Axial	087706.3MXEP	Littelfuse
24	1	L1	Custom, CMC, 18 mH @ 10 kHz, Toroidal, 17.5 mm OD x 11.0 mm thick. 40 turns x 2, 0.40 mm wire 190 mΩ max	04291-T231	Sumida
25	2	Q1 Q5	NPN, Small Signal BJT, 80 V, 0.5 A, SOT-23	MMBTA06LT1G	On Semi
26	1	Q4	MOSFET, N-CH, 100 V, 48 A (Tc), 113.5 W (Tc), DFN5X6, 8-DFN (5x6)	AON6220	Alpha & Omega Semi
27	1	R9	RES, 3 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ302V	Panasonic
28	2	R10 R32	RES, 47 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ470V	Panasonic
29	1	R12	RES, 2 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ202V	Panasonic
30	1	R13	RES, 0 Ω, 5%, 1/8 W, Thick Film, 0805	RMCF0805ZT0R00	Stackpole
31	1	R14	RES, 100 kΩ, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1003V	Panasonic
32	1	R15	RES, SMD, 33 kΩ, 1%, 1/10 W, ±100ppm/°C, 0603	RC0603FR-0733KL	Yageo
33	1	R16	RES, 0.005 Ω, ±1%, ½ W, 0805, Current Sense, Thick Film ±300ppm/°C, -55 °C ~ 155 °C	ERJ-6LWFR005V	Panasonic
34	1	R19	RES, 2.7 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ275V	Panasonic
35	1	R22	RES, 32.4 kΩ, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF3242V	Panasonic
36	1	R23	RES, 12.7 kΩ, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1272V	Panasonic
37	1	R24	RES, 10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
38	1	R25	RES, 1.2 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ122V	Panasonic
39	1	R27	RES, 8.45 kΩ, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF8451V	Panasonic
40	1	R29	RES, 75 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ753V	Panasonic

41	1	R31	RES, 20 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ203V	Panasonic
42	1	R33	RES, 30 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ303V	Panasonic
43	1	R34	RES, 100 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ101V	Panasonic
44	1	RV1	175 VAC, 17 J, 7 mm, RADIAL	ERZ-V07D271	Panasonic
45	1	T1	Bobbin, EQ25, 6 pins, 6pri, 0sec	POT-2501	Shenzhen xin yu jia
46	1	U3	ClampZero, MinSOP-16	CPZ1062M	Power Integrations
47	1	U4	InnoSwitch4-CZ, insop-24D	INN4075C-H182	Power Integrations
48	1	VR1	Diode Zener 20 V 500 mW SOD123	MMSZ5250B-7-F	Diodes, Inc.
49	1	VR4	10 V, 5%, 150 mW, SSMINI-2, SC-79, SOD-523, EMD2	EDZVT2R10B	Rohm Semi
50	1	VR5	Diode Zener 5.6 V 500 mW SOD123	MMSZ5232B-7-F	Diodes, Inc.

6.2 *Mechanical Parts*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	2	TP1 TP10	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
2	1	TP2	Test Point, WHT, Miniature THRU-HOLE MOUNT	5002	Keystone
3	1	TP11	Test Point, RED, Miniature THRU-HOLE MOUNT	5000	Keystone

7 Power Transformer Specification (T1)

7.1 Electrical Diagram

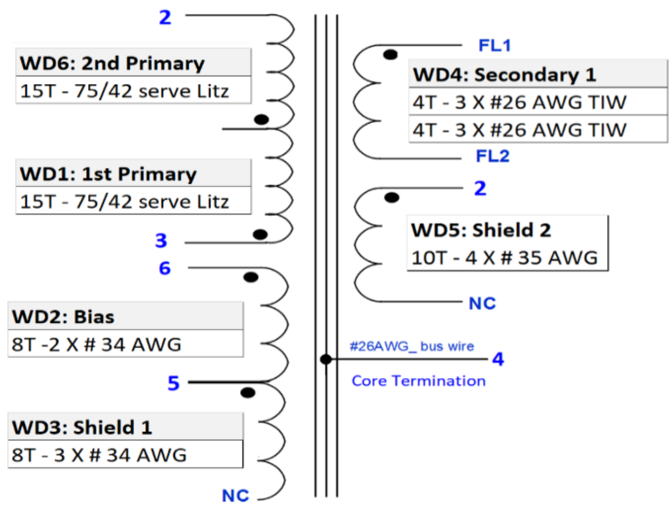


Figure 9 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 2 and 3, with all other windings open.	390 μH± 5%
Resonant Frequency	Between pin 2 and 3, other windings open.	1,000 kHz (Min.)
Primary Leakage Inductance	Between pin 2 and 3, with pins: FL1-FL2 shorted.	4.5 μH (Max.)

7.3 Material List

Item	Description
[1]	Core: EQ25, Ferroxcube: 3C95.
[2]	Bobbin: EQ25-Vert-6pins (6/0); PI#: 25-01136-00.
[3]	Magnet Wire: Served Litz 75/42.
[4]	Magnet Wire: #34 AWG, Double Coated.
[5]	Magnet Wire: #35 AWG, Double Coated.
[6]	Magnet Wire: #26 AWG, Triple Insulated Wire.
[7]	Bus Wire: #26 AWG, Alpha Wire, Tinned Copper.
[8]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 7.5 mm Width.
[9]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 33 mm x 58 mm
[10]	Varnish: Dolph BC-359.

7.4 *Transformer Build Diagram*

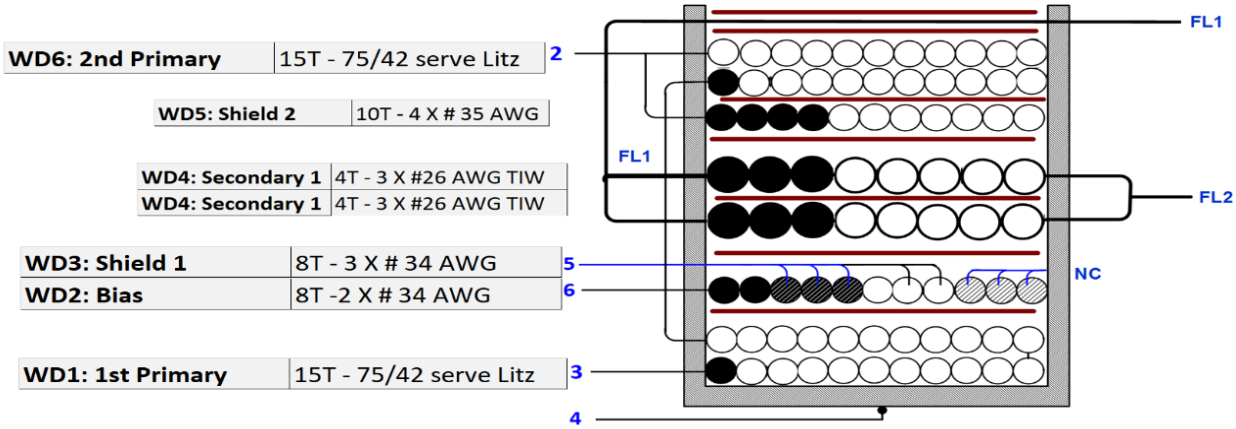
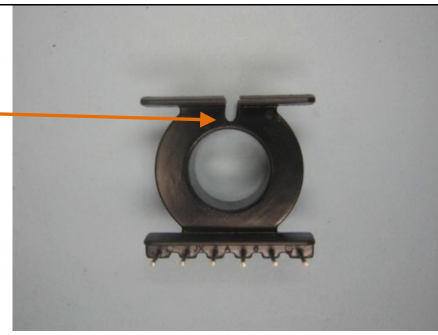
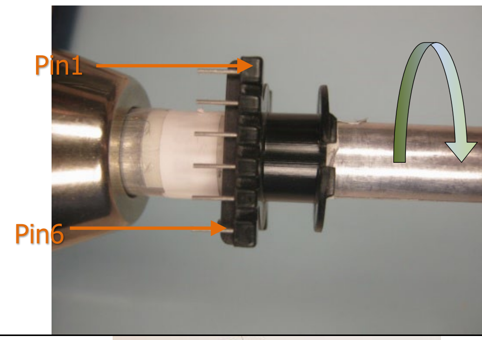


Figure 10 – Transformer Build Diagram.

7.5 *Winding Illustrations*

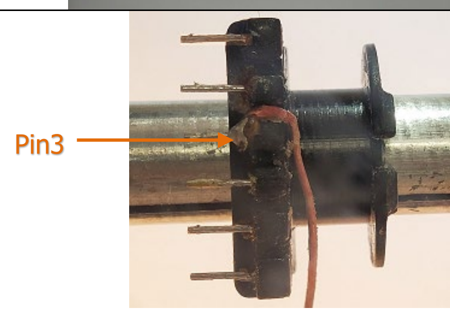
Bobbin Preparation
Make slots with 2.0 mm width on both flanges of secondary-side of bobbin Item [2]. Position the bobbin Item [2] on the mandrel such that the primary-side of the bobbin is on the left side. Winding direction is clock-wise direction for forward direction.



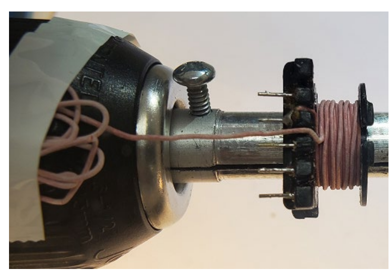


Winding Directions
Bobbin is oriented on winder jig such that terminal Pin 1- 6 are in the left side facing upward. The winding direction is clockwise.

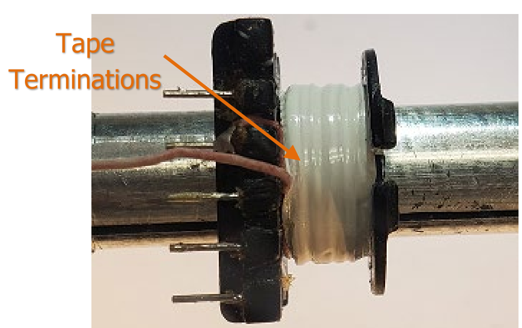
Winding 1- 1st Primary
Use a 75/42 Litz wire, Item [3]. Start at Pin 3 and wind 15 turns evenly in 2 layers.



Set aside an extension on the left side of the bobbin long enough for 15 turns (Winding 6).

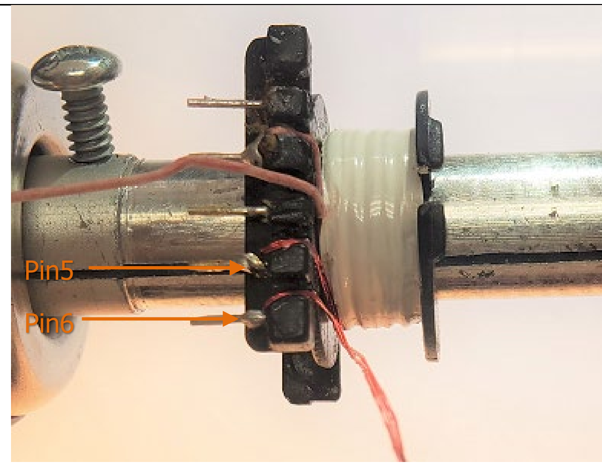


Apply 1 layer of polyester tape, Item [8] for insulation. Start and terminate the tape on the same side as the pins to ensure no additional thickness on the side where the core is placed.



Winding 2 and 3 – Bias and shield 1

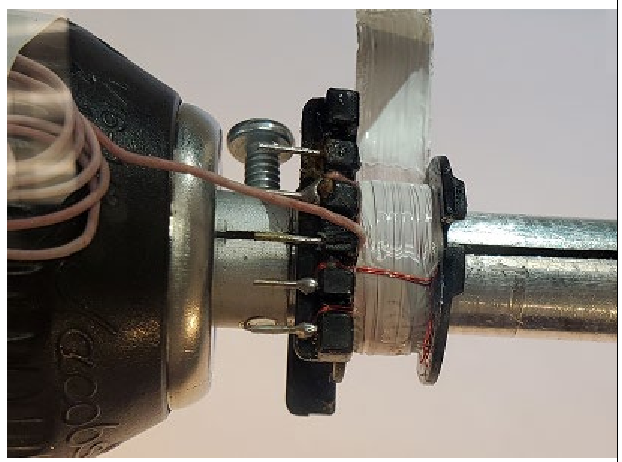
Use magnetic wire, Item [4] - AWG#34 for winding 2 and 3. Prepare bifilar wire for winding 2 and three (trifilar) wires for winding 3. For Winding 2, start at pin 6 while for winding 3, start at pin 5.



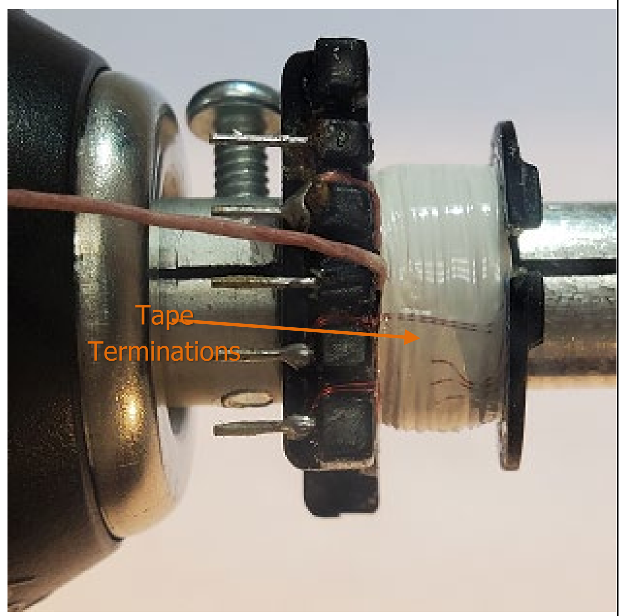
Wind winding 2 and 3 evenly together for 8 turns from left to right.

For winding 2, Finish the winding back to the left on Pin 5.

For winding 3, cut the finish terminal as shown in the figure.



Apply 1 layer of polyester tape, Item [8] for insulation. Start and terminate the tape on the same side as the pins to ensure no additional thickness on the side where the core is placed.



Winding 4- Secondary Winding

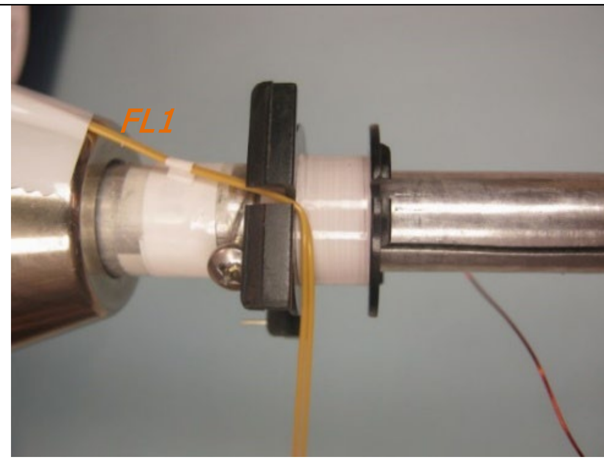
Position the bobbin on the other side with the secondary wire slot facing upward. Use TIW wire Item [6] – AWG#26.

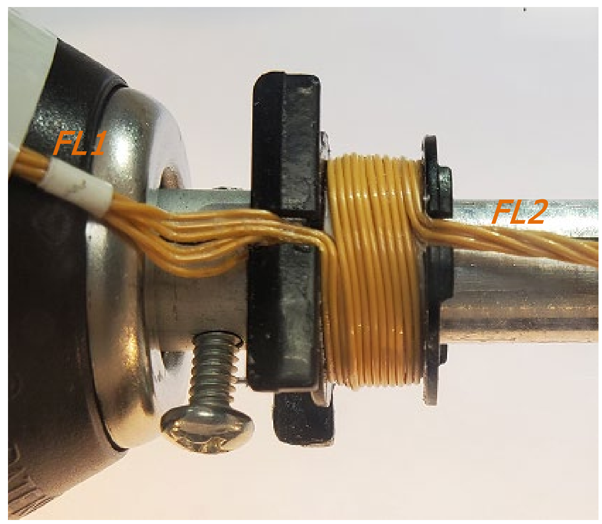
First Layer - Prepare 3 (trifilar) wires and secure 70 mm fly lead (FL1) extension on the left side. Wind 4 turns evenly from left to right. Fix the finish fly lead terminal (FL2) on the right side of the jig and cut with around 70mm wire extension

Apply 1 layer of polyester tape, Item [8] for insulation. Start and terminate the tape on the same side as the start of Winding 4 to ensure there is no additional thickness on the side where the core is placed.

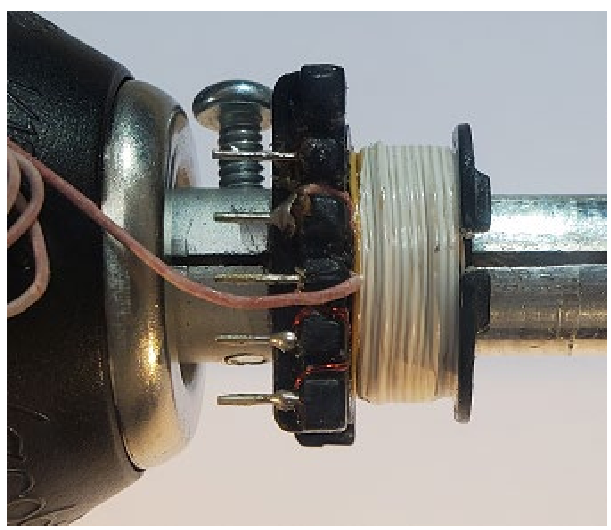
Second Layer – Same with the first layer, prepare 3 (trifilar) wires and secure 70 mm fly lead (FL1) extension on the left side. Wind 4 turns evenly from left to right. Fix the finish fly lead terminal (FL2) on the right side of the jig and cut with around 70mm wire extension.

Combine fly lead wires from first and second layer and add polarity marking.



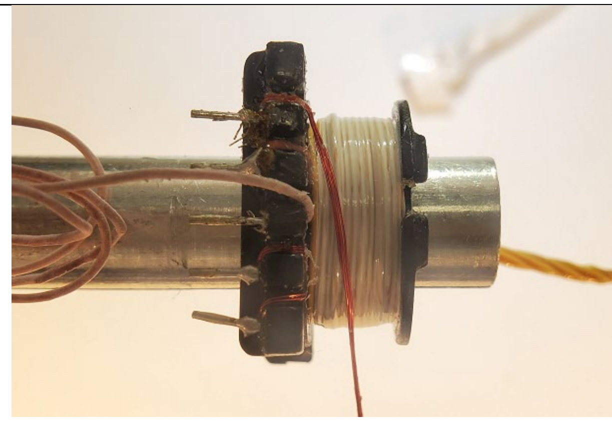


Apply 1 layer of polyester tape, Item [8] for insulation. Start and terminate the tape on the same side as the start of Winding 4 to ensure there is no additional thickness on the side where the core is placed.

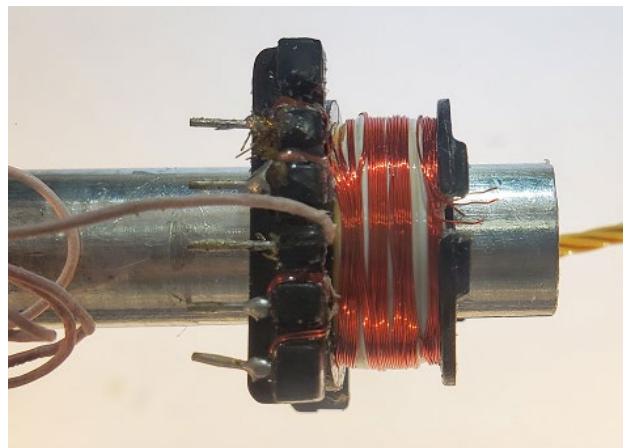


Winding 5- Shield 2

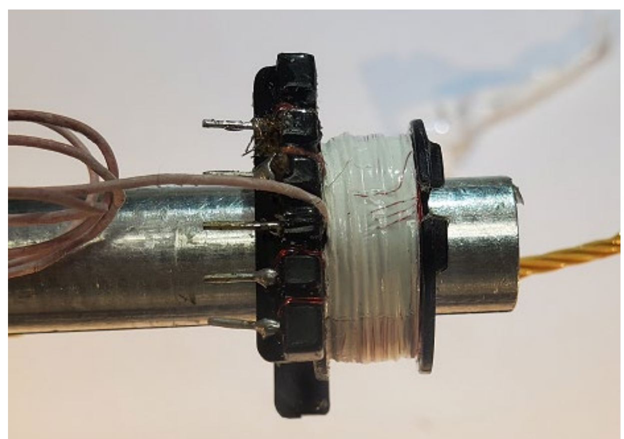
Use magnetic wire, Item 5 - AWG#35. Prepare 4 wires (quadrifilar). Start at Pin 2 and wind 10 turns evenly from left to right for 1 layer.

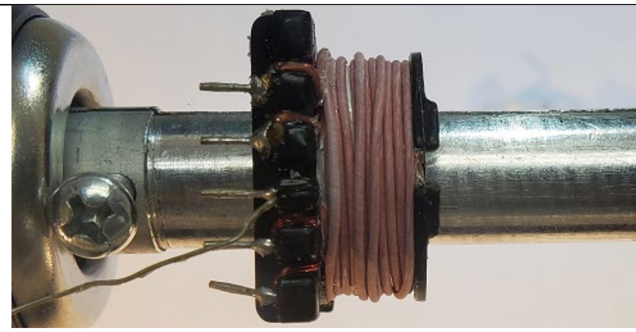
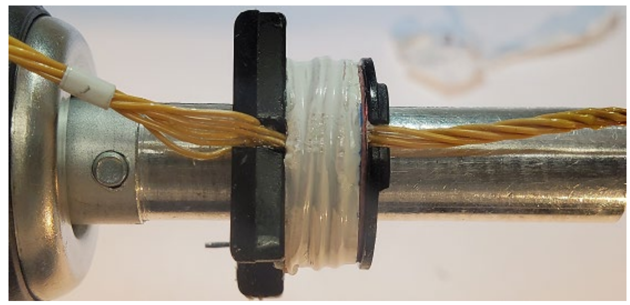
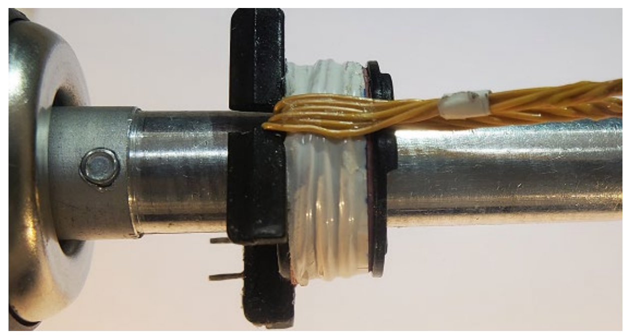
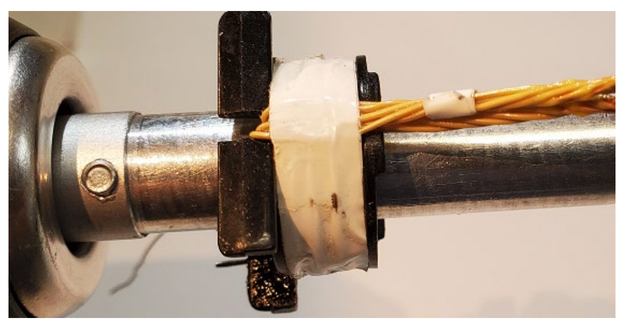


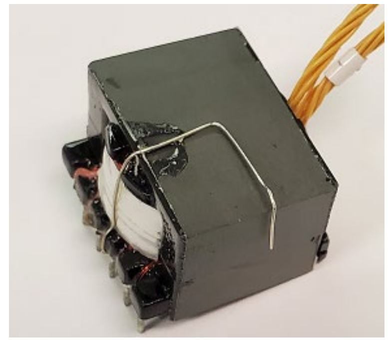
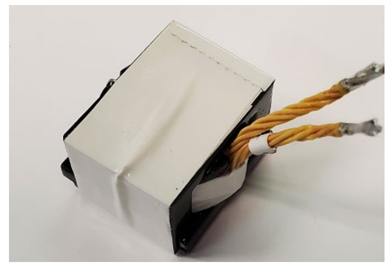
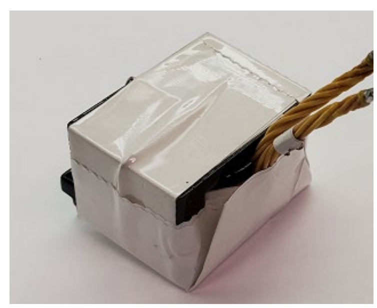
Finish the winding at the right side of the bobbin and cut the wire as shown in the figure.

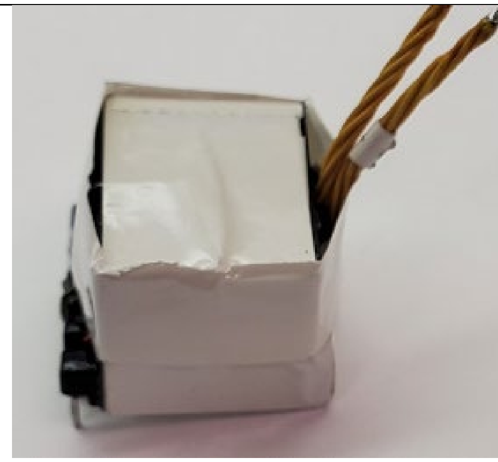
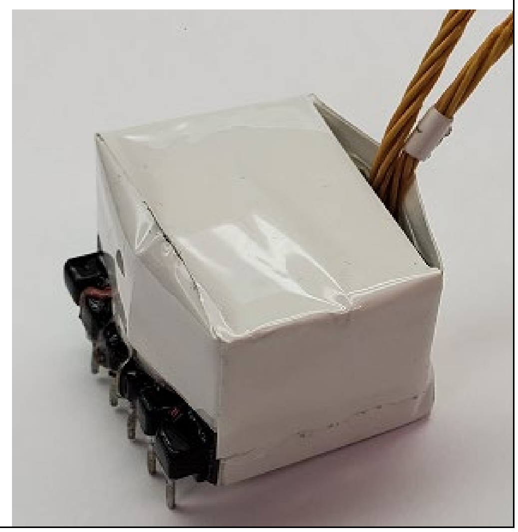


Apply 1 layer of polyester tape, Item [8] for insulation. Start and terminate the tape on the same side as transformer pins to ensure no additional thickness on the side where the core is placed.



Winding 6- 2nd Primary Use the remaining wires set aside from winding 1. Start at the middle of the bobbin and wind 13 turns evenly for 2 layers. Finish the winding on Pin 2	
Apply 1 layer of polyester tape, Item [8] for insulation. Start and terminate the tape on the same side as the start of Winding 6 to ensure there is no additional thickness on the side where the core is placed.	
Secondary Wire Fold the secondary fly lead wires (FL1) from left to right as shown in the figure.	
Apply 1 layer of polyester tape, Item [8] for insulation. Start and terminate the tape on the same side as the start of Winding 6 to ensure there is no additional thickness on the side where the core is placed.	

Core Fixing and Varnishing Prepare a AWG # 26 TIN wire, Item 7. Terminate the wire on Pin 4 and lay it out on top of the core as shown in the figure. Fix top and bottom core together with the TIN wire with tape, Item (9)	 
Safety Insulation Tape Add double layer safety Insulation tapes as shown in the figures.	 

8 Transformer (T1) Spreadsheet

1	ACDC_InnoSwitch4-CZ_USBPD_Flyback_111521; Rev.2.0; Copyright Power Integrations 2021	INPUT	INFO	OUTPUT	UNITS	InnoSwitch4-CZ USB-PD Flyback Design Spreadsheet
2	**APPLICATION VARIABLES**					
3	INPUT_TYPE	AC		AC		Input Type
4	VIN_MIN	100		100	V	Minimum AC input voltage
5	VIN_MAX	132		132	V	Maximum AC input voltage
6	VIN_RANGE			LOW LINE		Input voltage range
7	FLINE			60	Hz	AC Input voltage frequency
8	CAP_INPUT			140.0	uF	Input capacitance
10	**SET-POINT 1**					
11	VOUT1	20.00		20.00	V	Output voltage 1, should be the highest output voltage required
12	IOUT1	3.500		3.500	A	Output current 1
13	POUT1			70.00	W	Output power 1
14	EFFICIENCY1	0.92		0.92		Converter efficiency for output 1
15	Z_FACTOR1	0.50		0.50		Z-factor for output 1
16	TYPE	PDO		PDO		Select whether this set-point is a PDO(Power Delivery Object) or APDO (Additional Power Delivery Object
18	**SET-POINT 2**					
19	VOUT2	15.00		15.00	V	Output voltage 2
20	IOUT2	4.000		4.000	A	Output current 2
21	POUT2			60.00	W	Output power 2
22	EFFICIENCY2	0.89		0.89		Converter efficiency for output 2
23	Z_FACTOR2	0.50		0.50		Z-factor for output 2
24	TYPE	PDO		PDO		Select whether this set-point is a PDO(Power Delivery Object) or APDO (Additional Power Delivery Object
26	**SET-POINT 3**					
27	VOUT3	9.00		9.00	V	Output voltage 3
28	IOUT3	5.000		5.000	A	Output current 3
29	POUT3			45.00	W	Output power 3
30	EFFICIENCY3	0.89		0.89		Converter efficiency for output 3
31	Z_FACTOR3	0.50		0.50		Z-factor for output 3
32	TYPE	PDO		PDO		Select whether this set-point is a PDO(Power Delivery Object) or APDO (Additional Power Delivery Object
34	**SET-POINT 4**					
35	VOUT4	5.00		5.00	V	Output voltage 4
36	IOUT4	6.500		6.500	A	Output current 4
37	POUT4			32.50	W	Output power 4
38	EFFICIENCY4	0.89		0.89		Converter efficiency for output 4
39	Z_FACTOR4	0.50		0.50		Z-factor for output 4
40	TYPE	PDO		PDO		Select whether this set-point is a PDO(Power Delivery Object) or APDO (Additional Power Delivery Object
42	**SET-POINT 5**					
43	VOUT5			0.00	V	Output voltage 5
44	IOUT5			0.000	A	Output current 5
45	POUT5			0.00	W	Output power 5
46	EFFICIENCY5	0.89		0.89		Converter efficiency for output 5
47	Z_FACTOR5	0.50		0.50		Z-factor for output 5
48	TYPE	PDO		PDO		Select whether this set-point is a PDO(Power Delivery Object) or APDO (Additional Power Delivery Object
50	**SET-POINT 6**					
51	VOUT6			0.00	V	Output voltage 6
52	IOUT6			0.000	A	Output current 6
53	POUT6			0.00	W	Output power 6
54	EFFICIENCY6	0.89		0.89		Converter efficiency for output 6
55	Z_FACTOR6	0.50		0.50		Z-factor for output 6

56	TYPE	APDO		APDO		Select whether this set-point is a PDO(Power Delivery Object) or APDO (Additional Power Delivery Object
86	**PRIMARY CONTROLLER SELECTION**					
87	ENCLOSURE	ADAPTER		ADAPTER		Power supply enclosure
88	ILIMIT_MODE	STANDARD		STANDARD		Device current limit mode
89	VDRAIN_BREAKDOWN			750	V	Device breakdown voltage
90	DEVICE_GENERIC	INN4075		INN4075		Device selection
91	DEVICE_CODE			INN4075C		Device code
92	PDEVICE_MAX			80	W	Device maximum power capability
93	RDSON_100DEG			0.54	Ω	Primary switch on-time resistance at 100°C
94	ILIMIT_MIN			2.139	A	Primary switch minimum current limit
95	ILIMIT_TYP			2.300	A	Primary switch typical current limit
96	ILIMIT_MAX			2.461	A	Primary switch maximum current limit
97	VDRAIN_ON_PRSW			0.35	V	Primary switch on-time voltage drop
98	VDRAIN_OFF_PRSW			385.248	V	Peak drain voltage on the primary switch during turn-off
102	**WORST CASE ELECTRICAL PARAMETERS**					
103	FSWITCHING_MAX	88000		88000	Hz	Maximum switching frequency at full load and the valley of the minimum input AC voltage
104	VOR	150.0		150.0	V	Voltage reflected to the primary winding (corresponding to set-point 1) when the primary switch turns off
105	VMIN			113.48	V	Valley of the rectified minimum input AC voltage at full load
106	KP			0.771		Measure of continuous/discontinuous mode of operation
107	MODE_OPERATION			CCM		Mode of operation
108	DUTYCYCLE			0.570		Primary switch duty cycle
109	TIME_ON			8.53	us	Primary switch on-time
110	TIME_OFF			4.39	us	Primary switch off-time
111	LPRIMARY_MIN			374.2	uH	Minimum primary magnetizing inductance
112	LPRIMARY_TYP			393.9	uH	Typical primary magnetizing inductance
113	LPRIMARY_TOL			5.0	%	Primary magnetizing inductance tolerance
114	LPRIMARY_MAX			413.6	uH	Maximum primary magnetizing inductance
116	**PRIMARY CURRENT**					
117	IAVG_PRIMARY			0.646	A	Primary switch average current
118	IPEAK_PRIMARY			2.361	A	Primary switch peak current
119	IPEDESTAL_PRIMARY			0.438	A	Primary switch current pedestal
120	IRIPPLE_PRIMARY			2.361	A	Primary switch ripple current
121	IRMS_PRIMARY			1.008	A	Primary switch RMS current
123	**SECONDARY CURRENT**					
124	IPEAK_SECONDARY			17.708	A	Secondary winding peak current
125	IPEDESTAL_SECONDARY			3.288	A	Secondary winding pedestal current
126	IRMS_SECONDARY			8.548	A	Secondary winding RMS current
127	IRIPPLE_CAP_OUT			5.831	A	Output capacitor ripple current
131	**TRANSFORMER CONSTRUCTION PARAMETERS**					
132	**CORE SELECTION**					
133	CORE	EQ25		EQ25		Core selection. Refer to the "Transformer Construction" tab for the detailed report.
134	CORE NAME			EQ25-3C95		Core code
135	AE			100.0	mm^2	Core cross sectional area
136	LE			41.4	mm	Core magnetic path length
137	AL			5710	nH	Ungapped core effective inductance per turns squared
138	VE			4145	mm^3	Core volume
139	BOBBIN NAME			TBI-235-01091.1206		Bobbin name
140	AW			34.8	mm^2	Bobbin window area
141	BW			8.10	mm	Bobbin width
142	MARGIN			0.0	mm	Bobbin safety margin
144	**PRIMARY WINDING**					
145	NPRIMARY			30		Primary winding number of turns

146	BPEAK			3538	Gauss	Peak flux density
147	BMAX			3218	Gauss	Maximum flux density
148	BAC			1609	Gauss	AC flux density (0.5 x Peak to Peak)
149	ALG			438	nH	Typical gapped core effective inductance per turns squared
150	LG			0.265	mm	Core gap length
152	**PRIMARY BIAS WINDING**					
153	NBIAS_PRIMARY			8		Primary bias winding number of turns
155	**SECONDARY WINDING**					
156	NSECONDARY			4		Secondary winding number of turns
158	**SECONDARY BIAS WINDING**					
159	NBIAS_SECONDARY			2		Secondary bias winding number of turns (not used)
162	**PRIMARY COMPONENTS SELECTION**					
163	**CLAMPZERO**					
164	LLEAK	4.50		4.50	uH	Primary winding leakage inductance
165	CCLAMP			100.0	nF	Primary clamp capacitor
166	RD_CLAMPZERO	30		30	kΩ	HSD resistor
167	TLLDL/THLDL			120.0	ns	HSD resistor programmed delay
168	TIME_CLAMPZERO_OF F_TO_PRIMARY_ON			65.0	ns	Time between the ClampZero FET turn off and the primary FET turns on based on the HSD resistor selection
169	TIME_VDS_VALLEY			43.7	ns	Time taken by the VDS ring to reach its first valley
170	IPEAK_CLAMPZERO			2.330	A	Active clamp peak current
172	**LINE UNDERVOLTAGE/OVERVOLTAGE**					
173	BROWN-IN REQURED	55.00		55.00	V	Required AC RMS/DC line brown-in threshold
174	RLS			2.74	MΩ	Connect two 1.37 MOhm resistors to the V-pin for the required UV/OV threshold
175	BROWN-IN ACTUAL			55.06	V	Actual AC RMS/DC brown-in threshold using standard resistors
176	BROWN-OUT ACTUAL			49.81	V	Actual AC RMS/DC brown-out threshold using standard resistors
177	OVERVOLTAGE_LINE			229.08	V	Actual AC RMS/DC line over-voltage threshold
179	**PRIMARY BIAS WINDING**					
180	VBIAS_PRIMARY			9.00	V	Rectified primary bias voltage at the cable-disconnect (5V) set-point
181	VF_BIAS_PRIMARY			0.70	V	Primary bias winding diode forward drop
182	VREVERSE_BIASDIODE _PRIMARY			89.40	V	Primary bias diode reverse voltage (not accounting parasitic voltage ring)
183	CBIAS_PRIMARY			22	uF	Primary bias winding rectification capacitor
184	CBPP			0.47	uF	BPP pin capacitor
188	**SECONDARY COMPONENTS SELECTION**					
189	**RECTIFIER**					
190	VDRAIN_OFF_SRFET			44.89	V	Secondary rectifier reverse voltage (not accounting parasitic voltage ring)
191	SRFET	AUTO		GKI06109		Secondary rectifier (Logic MOSFET)
192	VBREAKDOWN_SRFET			60	V	Secondary rectifier breakdown voltage
193	RDSON_SRFET			13.1	mΩ	SRFET on time drain resistance at 25degC for VGS=4.4V
195	**SECONDARY BIAS WINDING**					
196	VBIAS_SECONDARY			6.00	V	Rectified secondary bias voltage at full load
197	VF_BIAS_SECONDARY			0.70	V	Secondary bias winding diode forward drop
198	VREVERSE_BIASDIODE _SECONDARY			43.05	V	Secondary bias diode reverse voltage (not accounting parasitic voltage ring)
199	CBIAS_SECONDARY			22	uF	Secondary bias winding rectification capacitor
200	CBPS			2.20	uF	BPS pin capacitor

9 Performance Data

All measurements were performed at room ambient temperature otherwise specified. Please refer to below output voltage selector guide when changing output voltage.

Output Voltage Selector Guide

V_{OUT} = 5 V – All 3 shorting pads are open

V_{OUT} = 9 V – short 9 V pad to GND

V_{OUT} = 15 V – short 15 V pad to GND

V_{OUT} = 20 V – short 20 V pad to GND

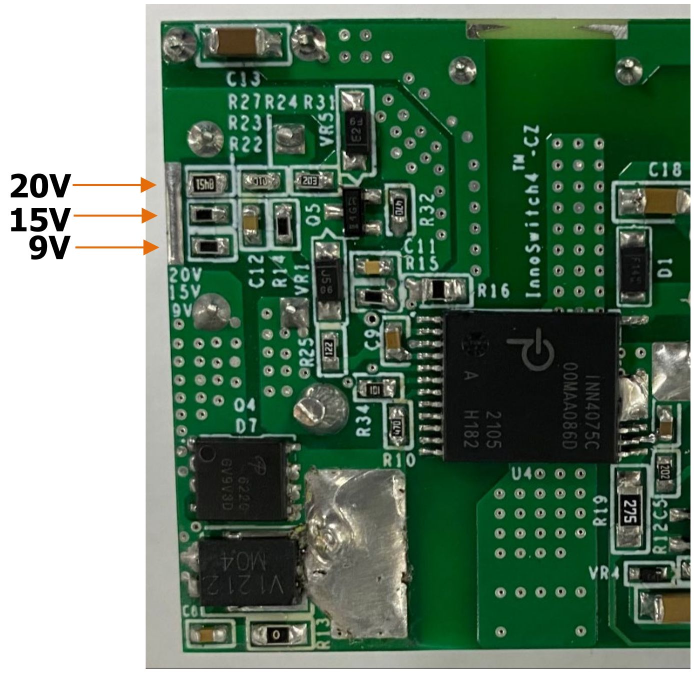


Figure 11 – Output Voltage Selector Guide.

9.1 *System Full Load Efficiency*

Output voltage was measured at PCB output terminal Pin

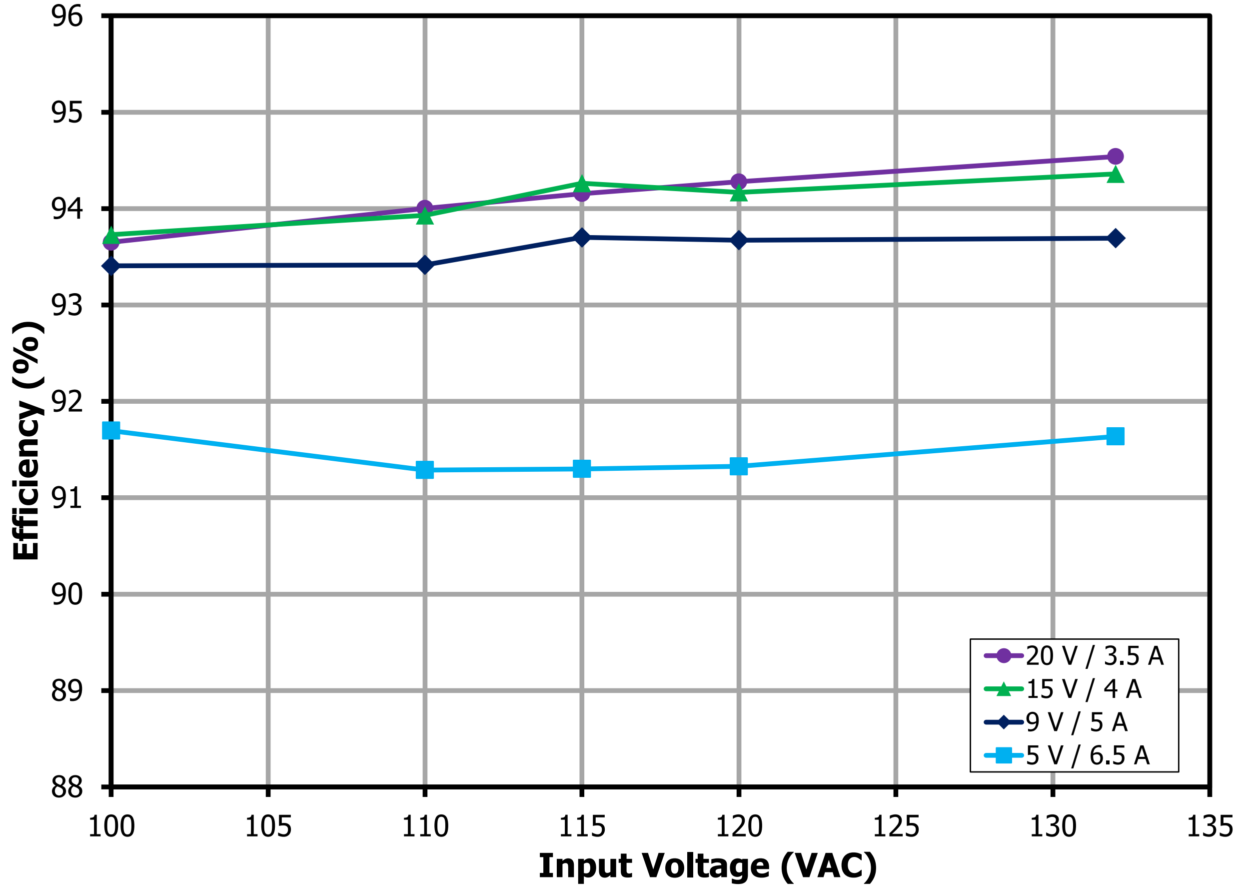


Figure 12 – System Full Load Efficiency vs. Line.

9.2 *Energy Efficiency*

9.2.1 System Average Efficiency

Note: Unit tested with with 5 mins soak time and 1 min soak time per load step.

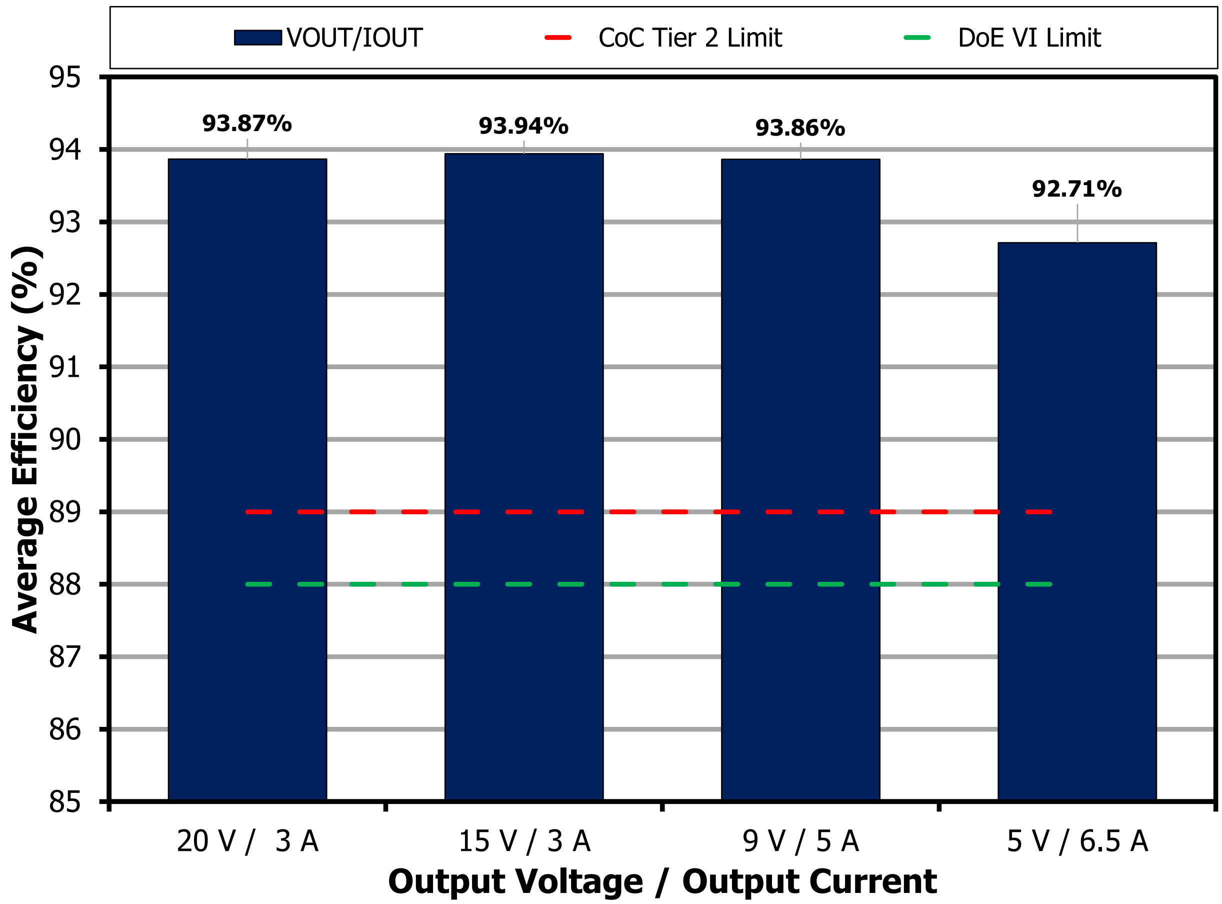


Figure 13 – Average Efficiency at 115 V 60 Hz.

9.2.2 Efficiency at 10% Load

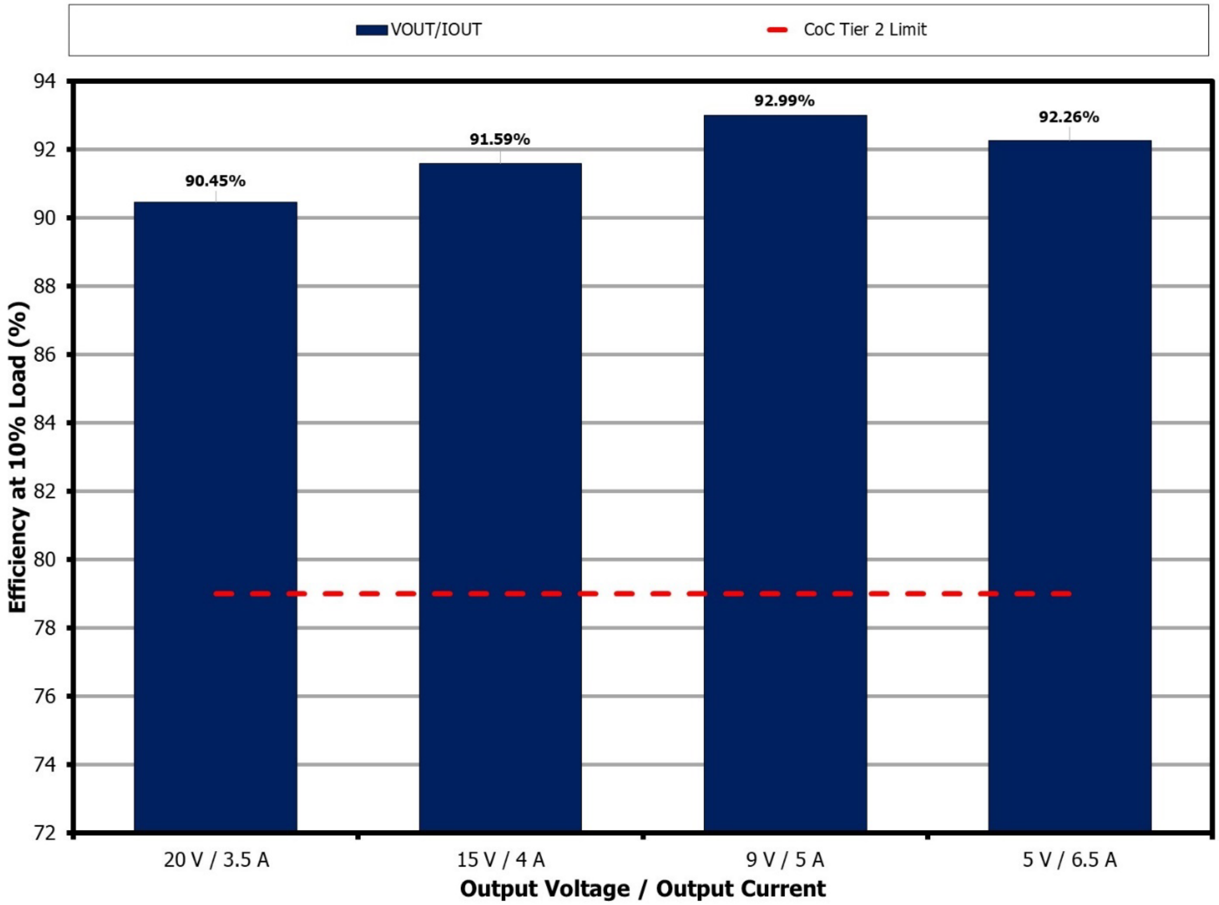


Figure 14 – Efficiency at 10 % Load, 115 VAC 60 Hz.

9.3 *Efficiency vs. Load*

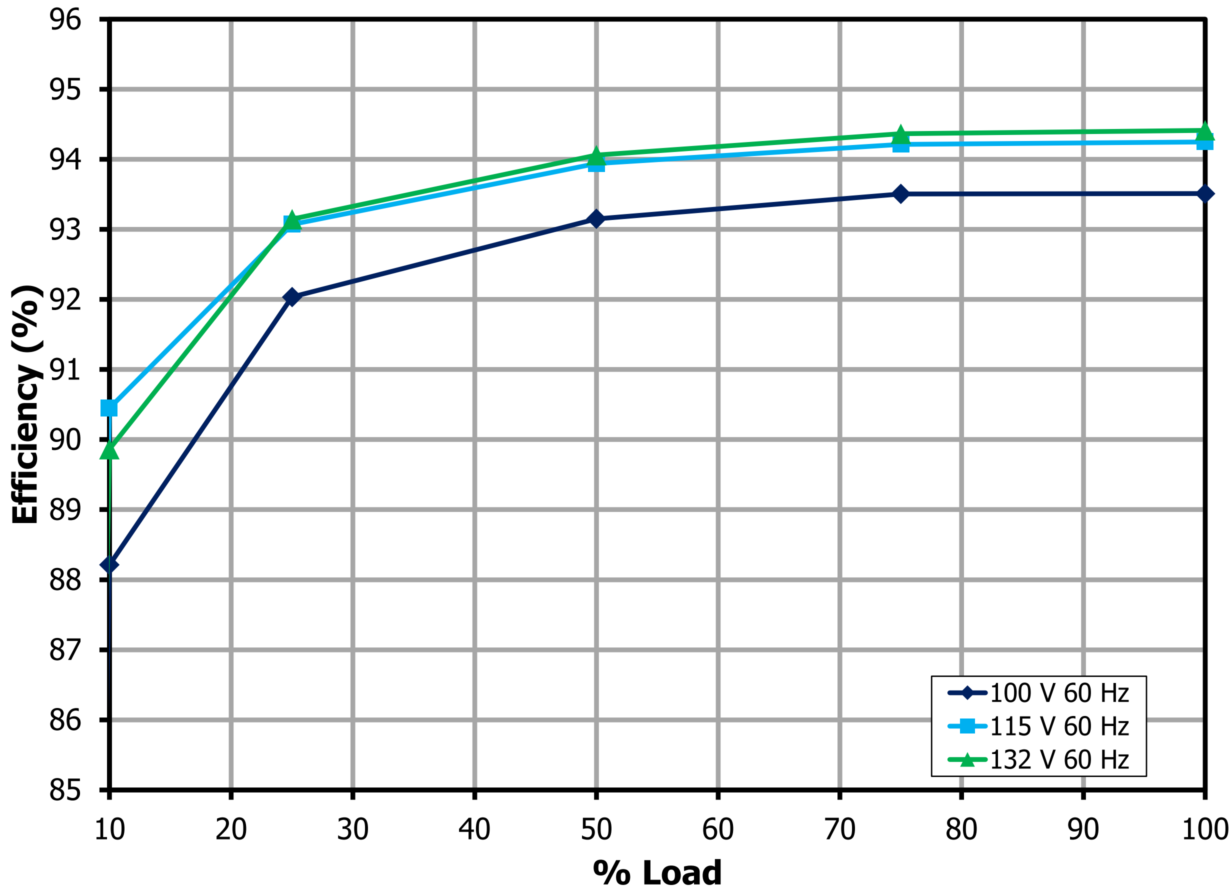


Figure 15 – System Efficiency vs. Load at V_{OUT} = 20 VDC.

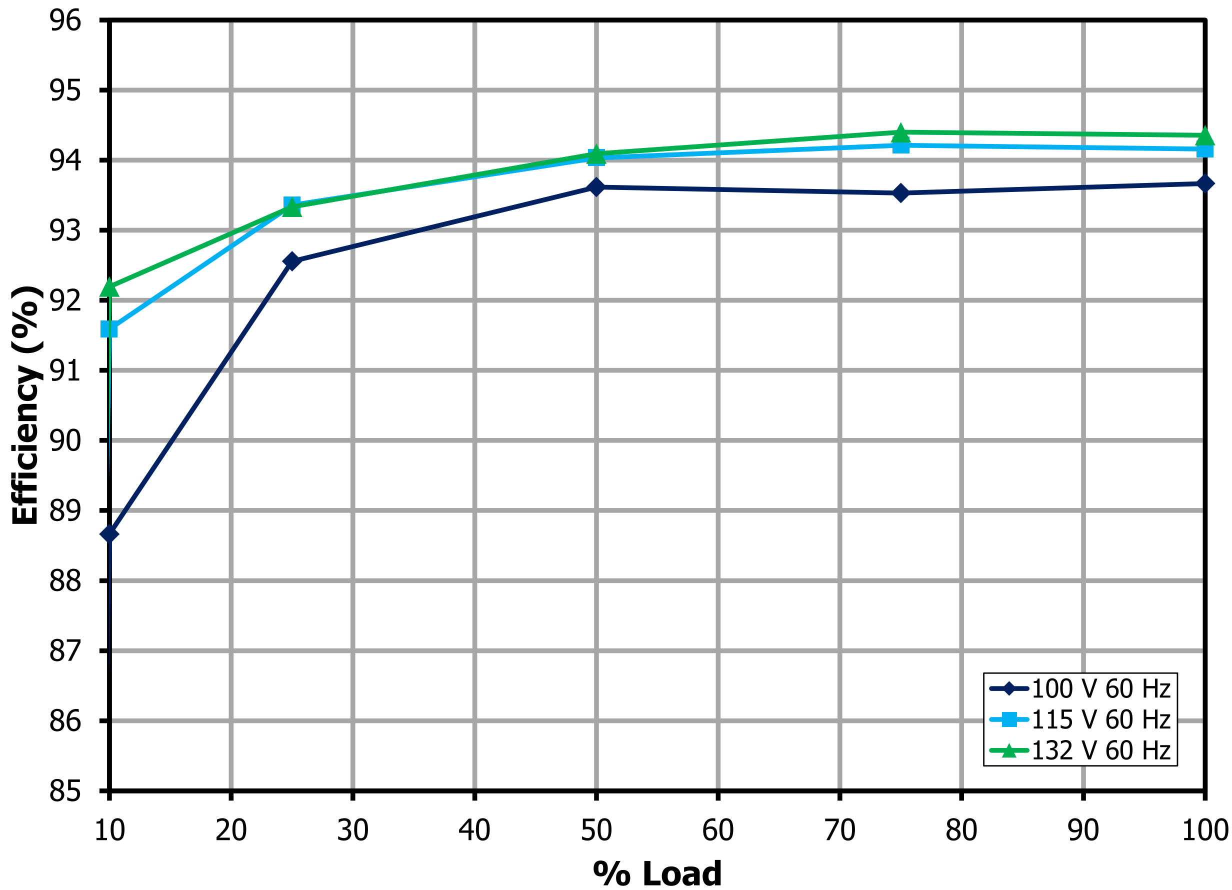


Figure 16 – System Efficiency vs. Load at V_{OUT} = 15 VDC.

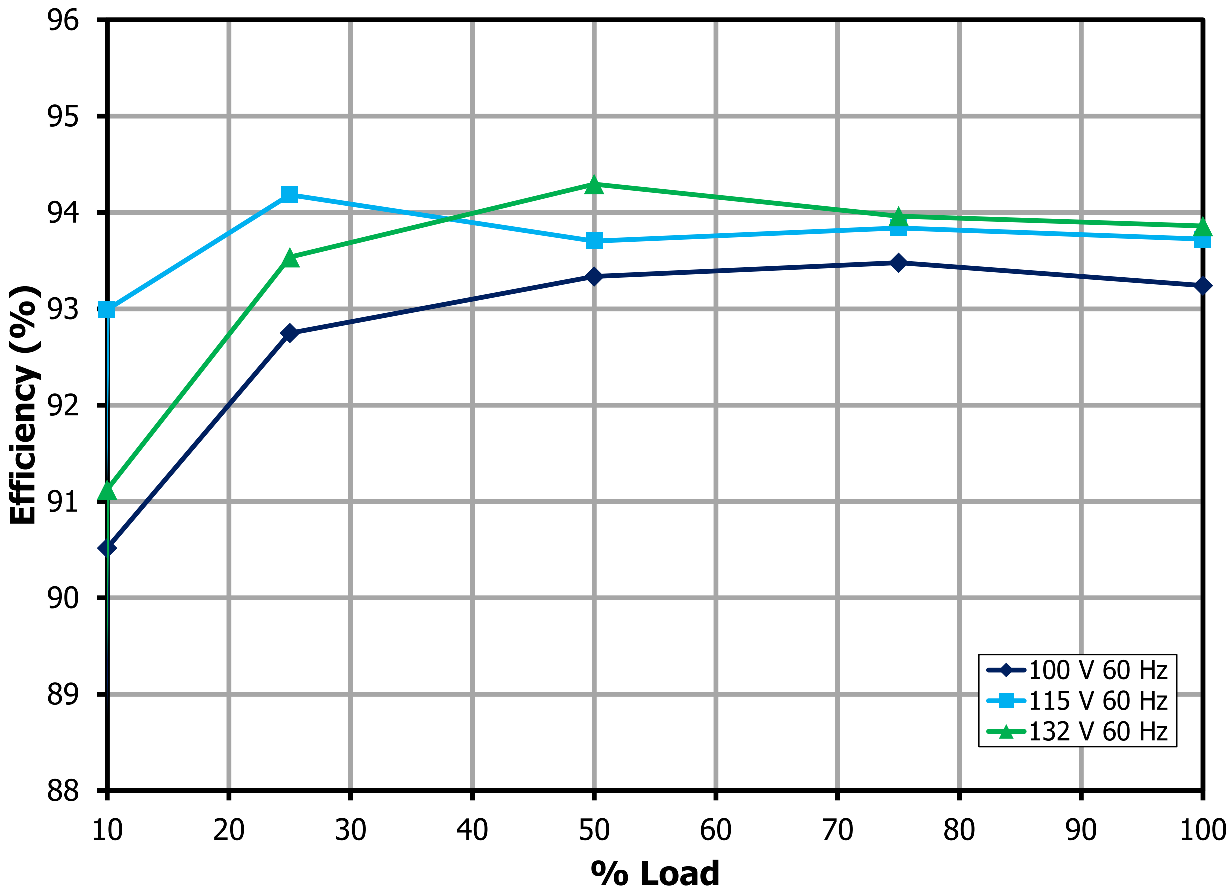


Figure 17 – System Efficiency vs. Load at V_{OUT} = 9 VDC.

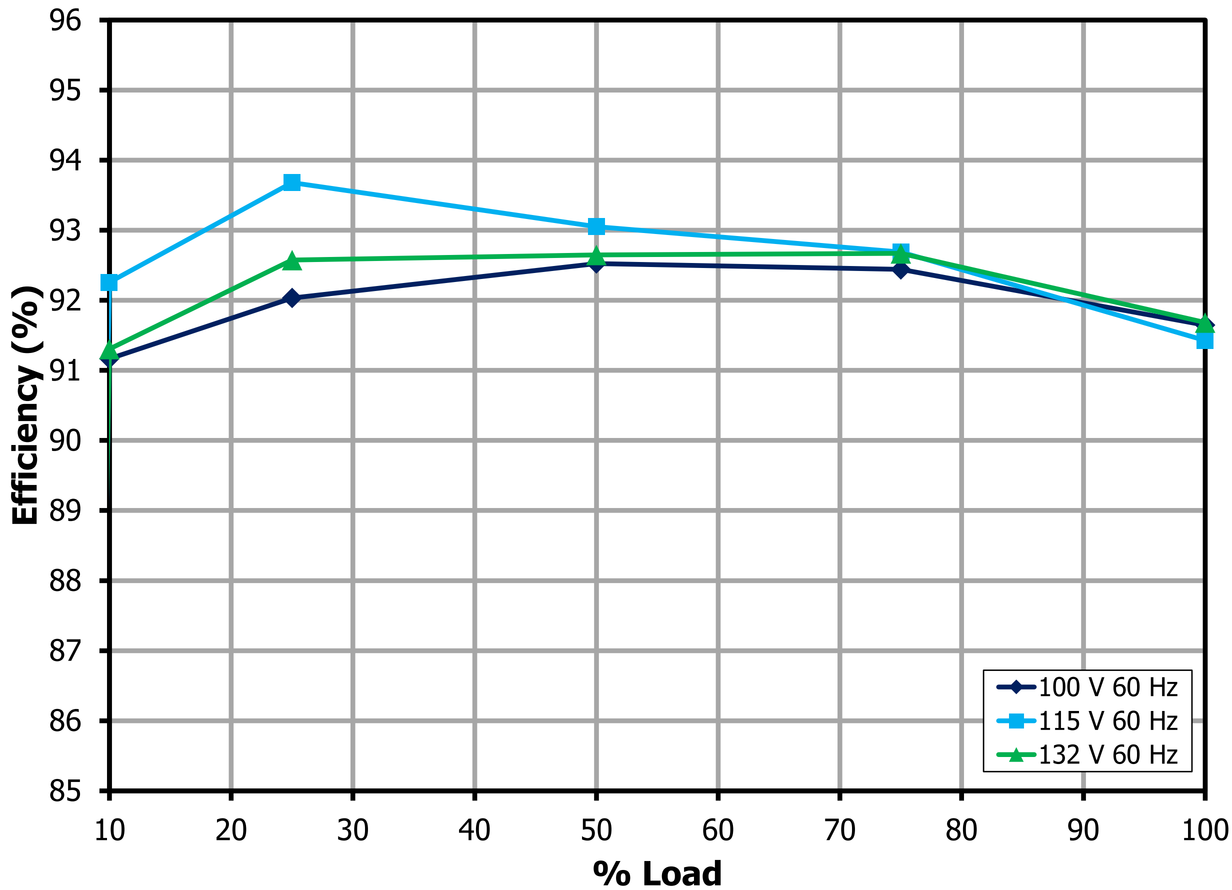


Figure 18 – System Efficiency vs. Load at V_{OUT} = 5 VDC.

9.4 *No-Load Input Power*

Note: Tested at V_{OUT} = 5 V, with 30 seconds soak time every input line.

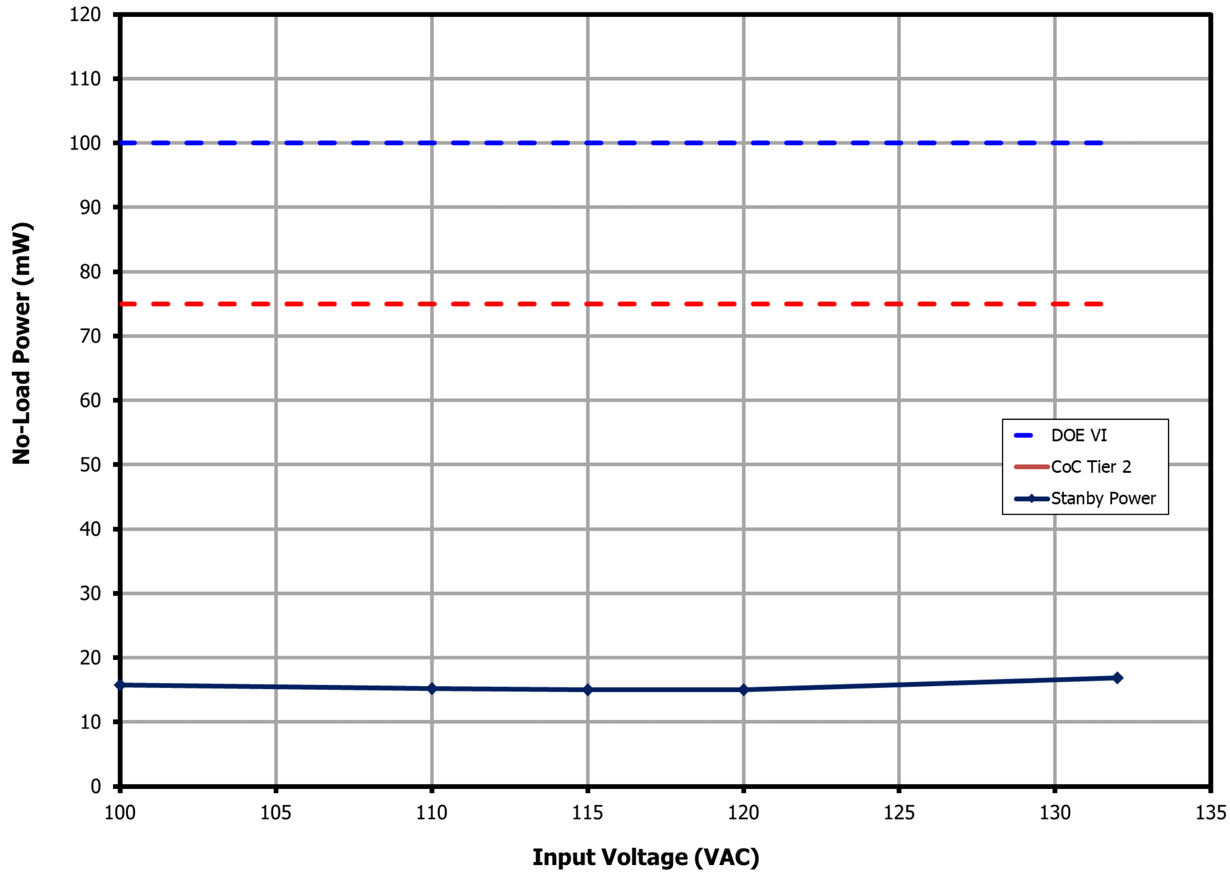


Figure 19 – No-Load Input Power vs. Line at V_{OUT} = 5 V.

9.5 *Output Voltage Load Regulation*

E-load is set at CC Mode Load

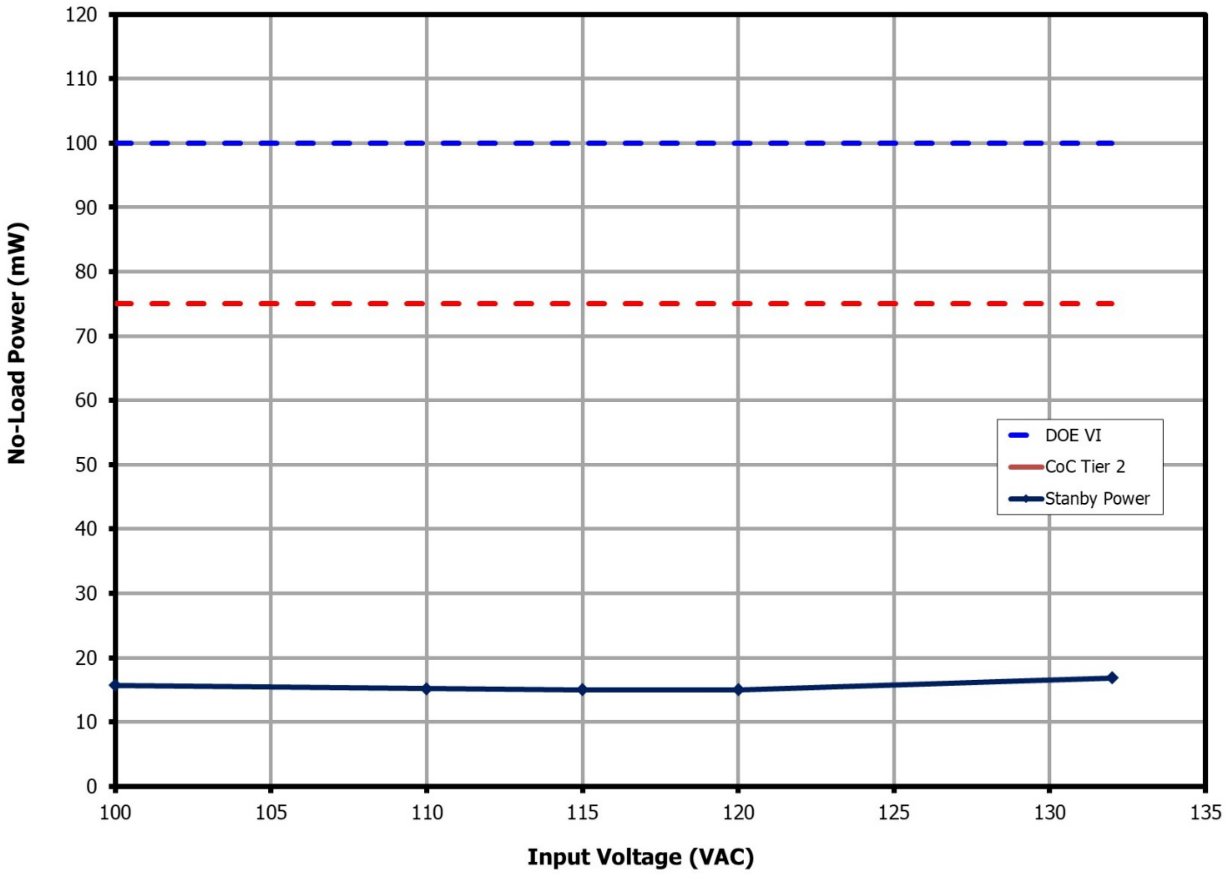


Figure 20 – Voltage Regulation vs. Load at V_{OUT} = 20 VDC / 3.5 A.

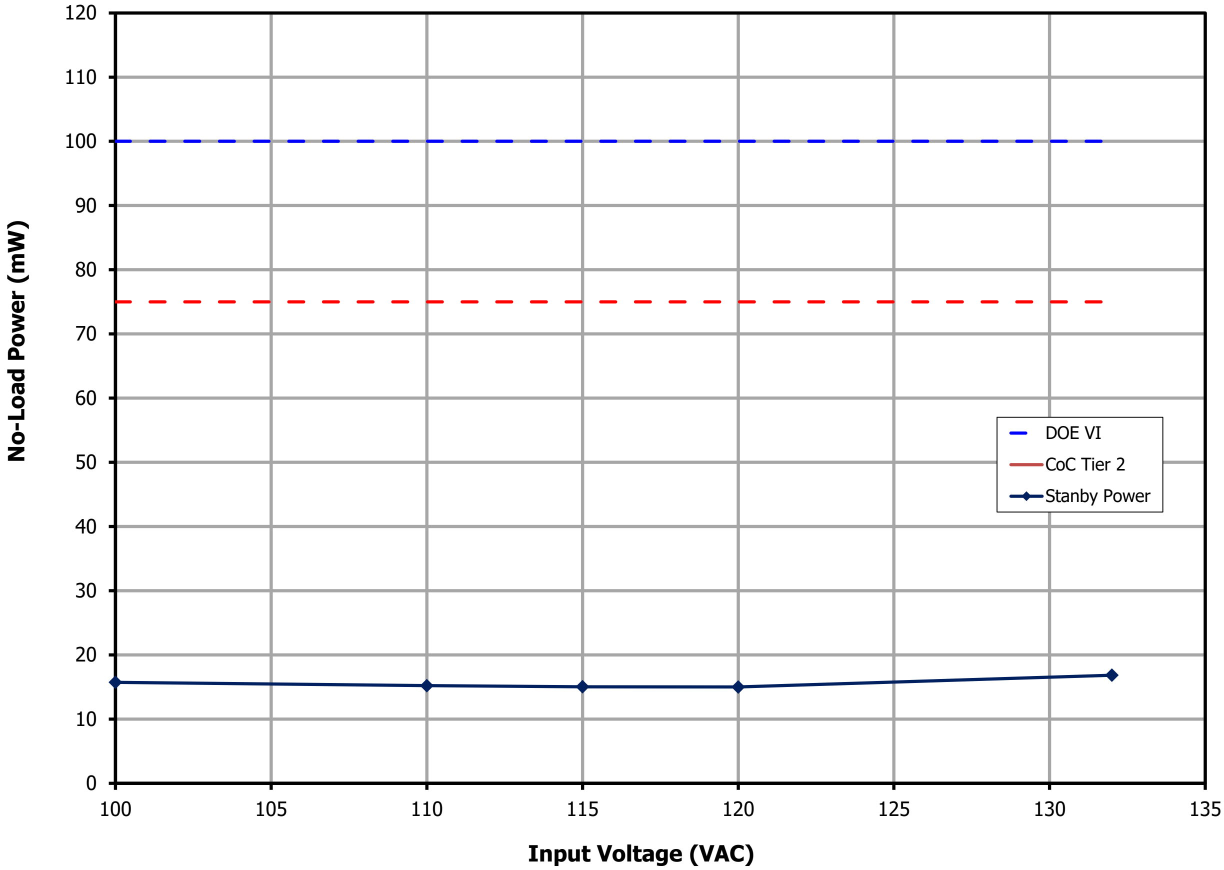


Figure 21 – Voltage Regulation vs. Load at V_{OUT} = 15 VDC / 3 A.

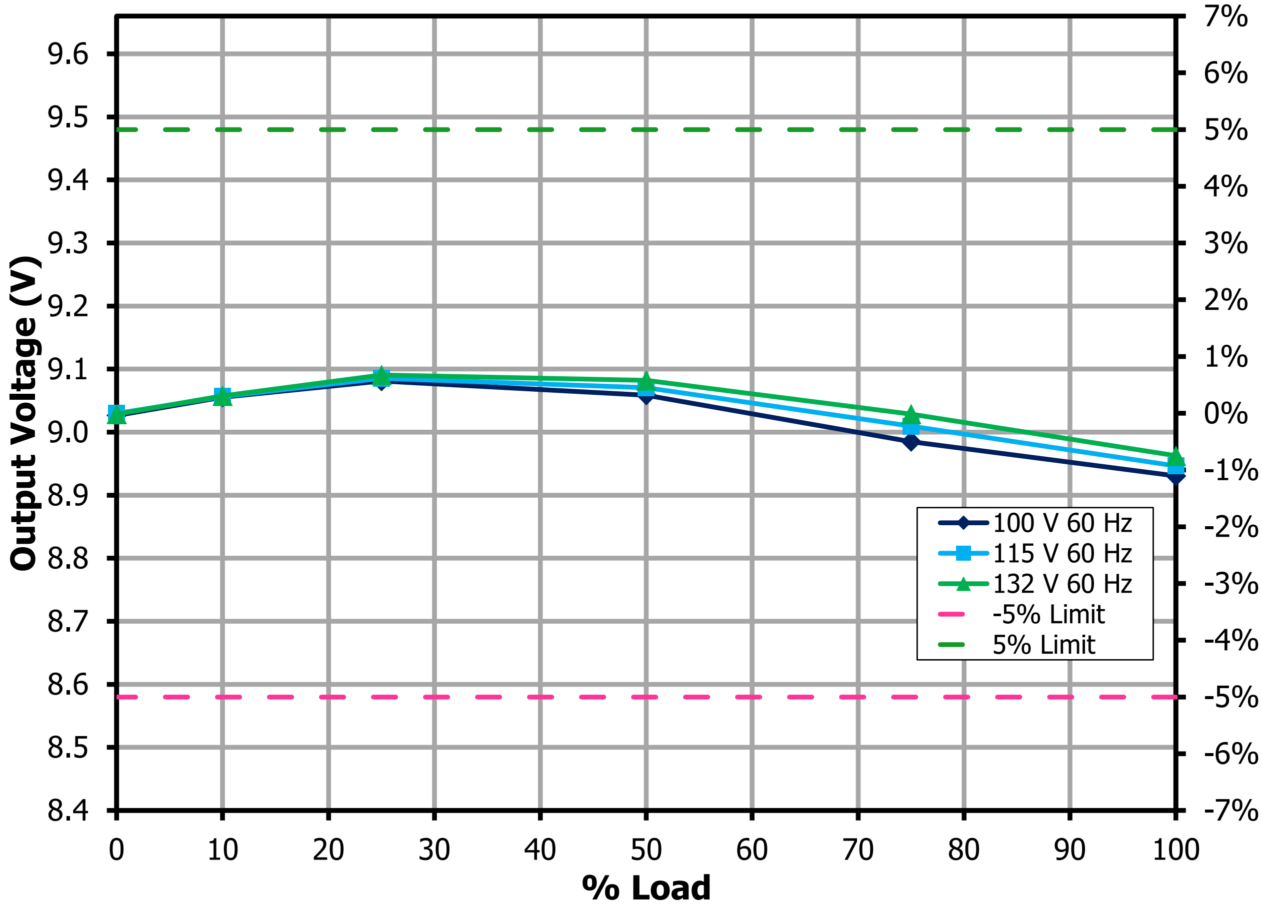


Figure 22 – Voltage Regulation vs. Load at V_{OUT} = 9 VDC / 5 A.

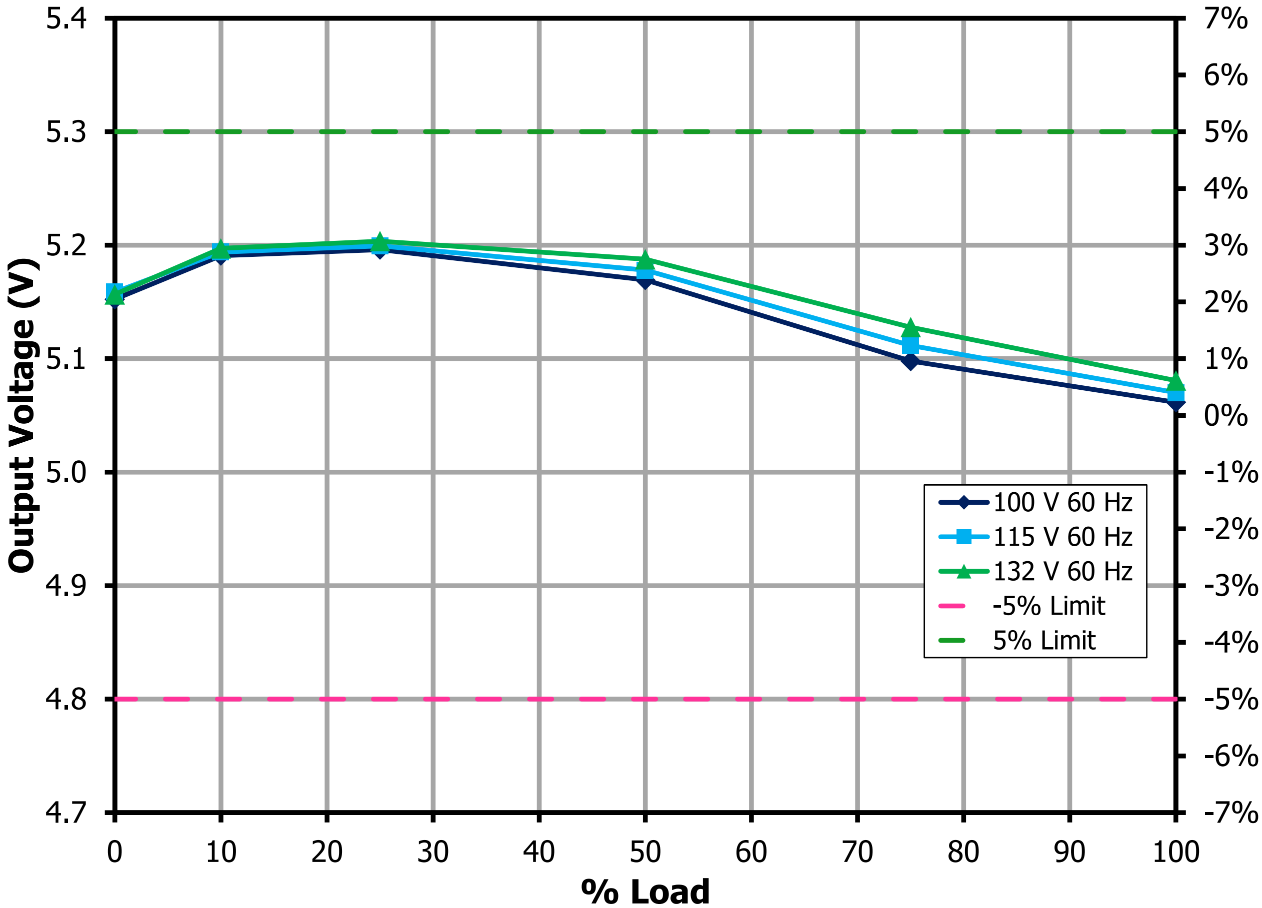


Figure 23 – Voltage Regulation vs. Load at V_{OUT} = 5 VDC / 6.5 A.

9.6 *Test Data*

9.6.1 Electrical Test Data at Full Load

	Inut Setting		Input Measurement			Load Measurement			Efficiency (%)
	Voltage (VAC)	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
20 V / 3.5 A	100	60	99.93	1350.30	74.10	19.83	3499.42	69.39	93.65
	110	60	109.89	1269.10	73.89	19.85	3499.80	69.46	94.00
	115	60	114.95	1233.50	73.87	19.87	3499.80	69.55	94.15
	120	60	119.93	1203.10	73.88	19.90	3499.80	69.65	94.28
	132	60	131.93	1140.30	73.79	19.94	3499.42	69.76	94.54
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	Voltage (VAC)	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
15 V / 4 A	100	60	99.94	1192.20	63.83	14.96	3999.45	59.83	93.73
	110	60	109.90	1123.00	63.76	14.98	3999.08	59.89	93.93
	115	60	114.96	1093.30	63.64	15.00	3999.45	59.99	94.26
	120	60	119.94	1068.90	63.79	15.02	3999.45	60.07	94.17
	132	60	131.94	1016.10	63.75	15.04	3999.08	60.15	94.36
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	Voltage (VAC)	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
9 V / 5 A	100	60	99.96	941.90	47.63	8.90	4999.12	44.49	93.41
	110	60	109.91	894.30	47.68	8.91	4999.50	44.54	93.42
	115	60	114.97	872.30	47.56	8.91	4999.12	44.56	93.70
	120	60	119.95	853.30	47.61	8.92	4999.87	44.60	93.67
	132	60	131.95	811.40	47.63	8.93	4999.50	44.63	93.69
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	Voltage (VAC)	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
5 V / 6.5 A	100	60	99.97	747.40	35.53	5.01	6499.57	32.58	91.70
	110	60	109.92	713.90	35.71	5.02	6499.20	32.60	91.29
	115	60	114.98	697.60	35.73	5.02	6499.57	32.62	91.30
	120	60	119.96	682.60	35.75	5.02	6499.57	32.65	91.33
	132	60	131.96	648.80	35.68	5.03	6499.20	32.70	91.64

9.6.2 Energy Efficiency Test Data

	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
20 V /3.5A	100	3500	114.94	1226.80	73.82	19.88	3499.05	69.57	94.25
	75	2625	114.96	978.70	55.55	19.95	2623.91	52.34	94.21
	50	1750	114.97	719.10	37.31	20.03	1749.53	35.05	93.94
	25	875	114.99	425.40	18.84	20.05	874.39	17.53	93.07
	10	350	115.00	211.64	7.74	20.02	349.68	7.00	90.45
	Average Efficiency at 20 V								**93.87**
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
15 V / 4 A	100	4000	114.96	1091.30	63.72	15.00	3999.45	60.00	94.16
	75	3000	114.97	875.00	47.94	15.06	2999.03	45.17	94.21
	50	2000	114.98	642.80	32.15	15.13	1998.60	30.23	94.03
	25	1000	115.00	383.60	16.21	15.15	998.93	15.13	93.36
	10	400	115.00	184.55	6.58	15.12	398.67	6.03	91.59
	Average Efficiency at 20 V								**93.94**
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
9 V / 5 A	100	5000	114.97	870.10	47.56	8.92	4999.12	44.57	93.72
	75	3750	114.98	700.10	35.88	8.98	3749.62	33.67	93.84
	50	2500	114.99	513.40	24.11	9.04	2499.00	22.59	93.70
	25	1250	115.00	309.40	12.01	9.06	1249.13	11.31	94.18
	10	500	115.00	141.33	4.85	9.03	499.65	4.51	92.99
	Average Efficiency at 20 V								**93.86**
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
5 V / 6.5 A	100	6500	114.98	695.90	35.69	5.02	6499.95	32.63	91.43
	75	4875	114.99	554.90	26.62	5.06	4874.59	24.67	92.69
	50	3250	115.00	412.30	17.91	5.13	3249.97	16.67	93.05
	25	1625	115.00	242.22	8.93	5.15	1624.61	8.37	93.68
	10	650	115.01	108.30	3.62	5.14	649.25	3.34	92.26
	Average Efficiency at 20 V								**92.71**

9.6.3 Electrical Test Data at 20 V / 3.5 A

	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
100 V 60 Hz	100	3500	99.93	1344.50	74.25	19.84	3499.42	69.43	93.51
	75	2625	99.95	1066.70	55.88	19.91	2624.29	52.25	93.51
	50	1750	99.97	779.30	37.58	20.01	1749.15	35.01	93.15
	25	875	99.98	459.80	19.04	20.05	874.01	17.52	92.03
	10	350	99.99	238.41	7.93	20.02	349.31	6.99	88.21
	0	0	100.00	22.25	0.237	20.01	0	0	0.00
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
115 V 60 Hz	100	3500	114.94	1226.80	73.82	19.88	3499.05	69.57	94.25
	75	2625	114.96	978.70	55.55	19.95	2623.91	52.34	94.21
	50	1750	114.97	719.10	37.31	20.03	1749.53	35.05	93.94
	25	875	114.99	425.40	18.84	20.05	874.39	17.53	93.07
	10	350	115.00	211.64	7.74	20.02	349.68	7.00	90.45
	0	0	115.01	21.72	0.217	20.01	0	0	0.00
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
132 V 60 Hz	100	3500	131.92	1133.90	73.92	19.94	3499.42	69.79	94.41
	75	2625	131.94	910.60	55.57	19.98	2624.29	52.44	94.36
	50	1750	131.95	668.00	37.27	20.04	1749.15	35.06	94.06
	25	875	131.97	403.00	18.84	20.06	874.76	17.55	93.15
	10	350	131.98	190.95	7.79	20.02	349.68	7.00	89.86
	0	0	131.98	21.34	0.218	20.01	0	0	0.00

9.6.4 Electrical Test Data at 15 V / 4 A

	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
100 V 60 Hz	100	4000	99.94	1191.50	63.88	14.96	3999.45	59.84	93.67
	75	3000	99.96	947.80	48.18	15.03	2999.03	45.06	93.53
	50	2000	99.97	695.10	32.28	15.11	1999.35	30.22	93.62
	25	1000	99.99	410.40	16.35	15.14	999.30	15.13	92.56
	10	400	100.00	209.00	6.81	15.11	399.42	6.04	88.66
	0	0	100.00	21.26	0.134	15.10	0	0	0.00
	Load Setting		**Input Measurement**			**Load Measurement**			**Efficiency (%)**
	% Load	**Load (A)**	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
115 V 60 Hz	100	4000	114.96	1091.30	63.72	15.00	3999.45	60.00	94.16
	75	3000	114.97	875.00	47.94	15.06	2999.03	45.17	94.21
	50	2000	114.98	642.80	32.15	15.13	1998.60	30.23	94.03
	25	1000	115.00	383.60	16.21	15.15	998.93	15.13	93.36
	10	400	115.00	184.55	6.58	15.12	398.67	6.03	91.59
	0	0	115.01	20.93	0.128	15.10	0	0	0.00
	Load Setting		**Input Measurement**			**Load Measurement**			**Efficiency (%)**
	% Load	**Load (A)**	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
132 V 60 Hz	100	4000	131.94	1012.80	63.77	15.05	3999.08	60.17	94.36
	75	3000	131.95	813.30	47.91	15.08	2999.03	45.23	94.40
	50	2000	131.96	596.60	32.18	15.14	1999.35	30.28	94.09
	25	1000	131.97	361.70	16.23	15.15	999.68	15.15	93.33
	10	400	131.98	165.65	6.55	15.12	399.42	6.04	92.20
	0	0	131.98	20.69	0.129	15.10	0	0	0.00

9.6.5 Electrical Test Data at 9 V / 5 A

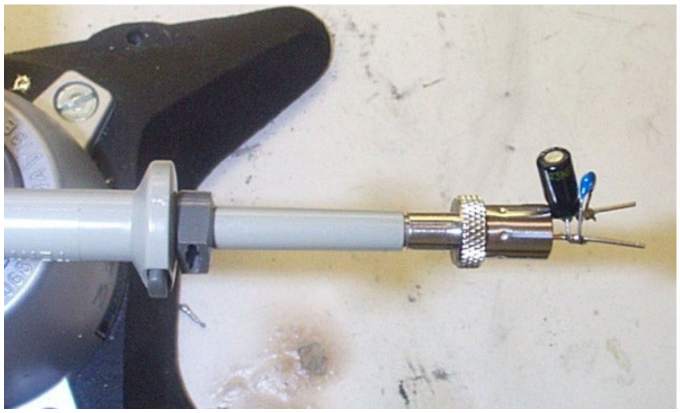
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
100 V 60 Hz	100	5000	99.96	942.40	47.72	8.90	4999.12	44.49	93.24
	75	3750	99.97	756.00	35.92	8.95	3749.62	33.58	93.48
	50	2500	99.98	555.90	24.17	9.03	2498.63	22.56	93.34
	25	1250	99.99	331.50	12.19	9.05	1249.13	11.31	92.75
	10	500	100.00	160.30	4.98	9.03	499.65	4.51	90.52
	0	0	100.00	20.67	0.061	9.00	0	0	0.00
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
115 V 60 Hz	100	5000	114.97	870.10	47.56	8.92	4999.12	44.57	93.72
	75	3750	114.98	700.10	35.88	8.98	3749.62	33.67	93.84
	50	2500	114.99	513.40	24.11	9.04	2499.00	22.59	93.70
	25	1250	115.00	309.40	12.01	9.06	1249.13	11.31	94.18
	10	500	115.00	141.33	4.85	9.03	499.65	4.51	92.99
	0	0	115.01	20.44	0.059	9.00	0	0	0.00
	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
132 V 60 Hz	100	5000	131.95	808.10	47.58	8.93	4999.50	44.66	93.86
	75	3750	131.96	649.60	35.91	9.00	3749.62	33.74	93.96
	50	2500	131.96	480.90	23.99	9.05	2499.00	22.62	94.29
	25	1250	131.98	283.90	12.10	9.06	1249.13	11.32	93.54
	10	500	131.98	127.37	4.95	9.03	499.65	4.51	91.12
	0	0	131.99	20.27	0.062	9.00	0	0	0.00

9.6.6 Electrical Test Data at 5 V / 6.5 A

	Load Setting		Input Measurement			Load Measurement			Efficiency (%)
	% Load	Load (A)	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
100 V 60 Hz	100	6500	99.97	748.00	35.54	5.01	6499.20	32.57	91.65
	75	4875	99.98	599.40	26.62	5.05	4874.96	24.61	92.44
	50	3250	99.99	441.20	17.98	5.12	3249.60	16.64	92.53
	25	1625	100.00	265.80	9.08	5.15	1623.86	8.36	92.03
	10	650	100.00	121.81	3.66	5.14	649.25	3.34	91.17
	0	0	100.01	19.95	0.019	5.10	0	0	0.00
	Load Setting		**Input Measurement**			**Load Measurement**			**Efficiency (%)**
	% Load	**Load (A)**	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
115 V 60 Hz	100	6500	114.98	695.90	35.69	5.02	6499.95	32.63	91.43
	75	4875	114.99	554.90	26.62	5.06	4874.59	24.67	92.69
	50	3250	115.00	412.30	17.91	5.13	3249.97	16.67	93.05
	25	1625	115.00	242.22	8.93	5.15	1624.61	8.37	93.68
	10	650	115.01	108.30	3.62	5.14	649.25	3.34	92.26
	0	0	115.01	19.89	0.021	5.11	0	0	0.00
	Load Setting		**Input Measurement**			**Load Measurement**			**Efficiency (%)**
	% Load	**Load (A)**	V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
132 V 60 Hz	100	6500	131.96	646.40	35.66	5.03	6498.82	32.69	91.68
	75	4875	131.97	518.80	26.71	5.08	4874.59	24.75	92.67
	50	3250	131.97	390.60	18.02	5.14	3249.60	16.70	92.65
	25	1625	131.98	219.06	9.04	5.15	1623.86	8.37	92.57
	10	650	131.98	98.08	3.66	5.15	649.25	3.34	91.31
	0	0	131.98	19.82	0.024	5.11	0	0	0.00

9.7 *Output Ripple Voltage*

Set-up: To measure the ripple, Probe Master 4903-2 voltage probe was used (x1 30 MHz) coupled to a probe adapter (Probe Master 4987BA BNC adapter) affixed with 2 capacitors (0.1 μF / 50 V ceramic and 47 μ F/ 50 V E-cap) connected across the tip and ground as shown below. Oscilloscope was set to AC coupling with frequency bandwidth of 20 MHz. Voltage ripple was measured at the end of 2-feet cable at room ambient temperature (25 ºC).



9.7.1 Output Ripple Voltage vs. Percent Load at 20 V / 3.5 A

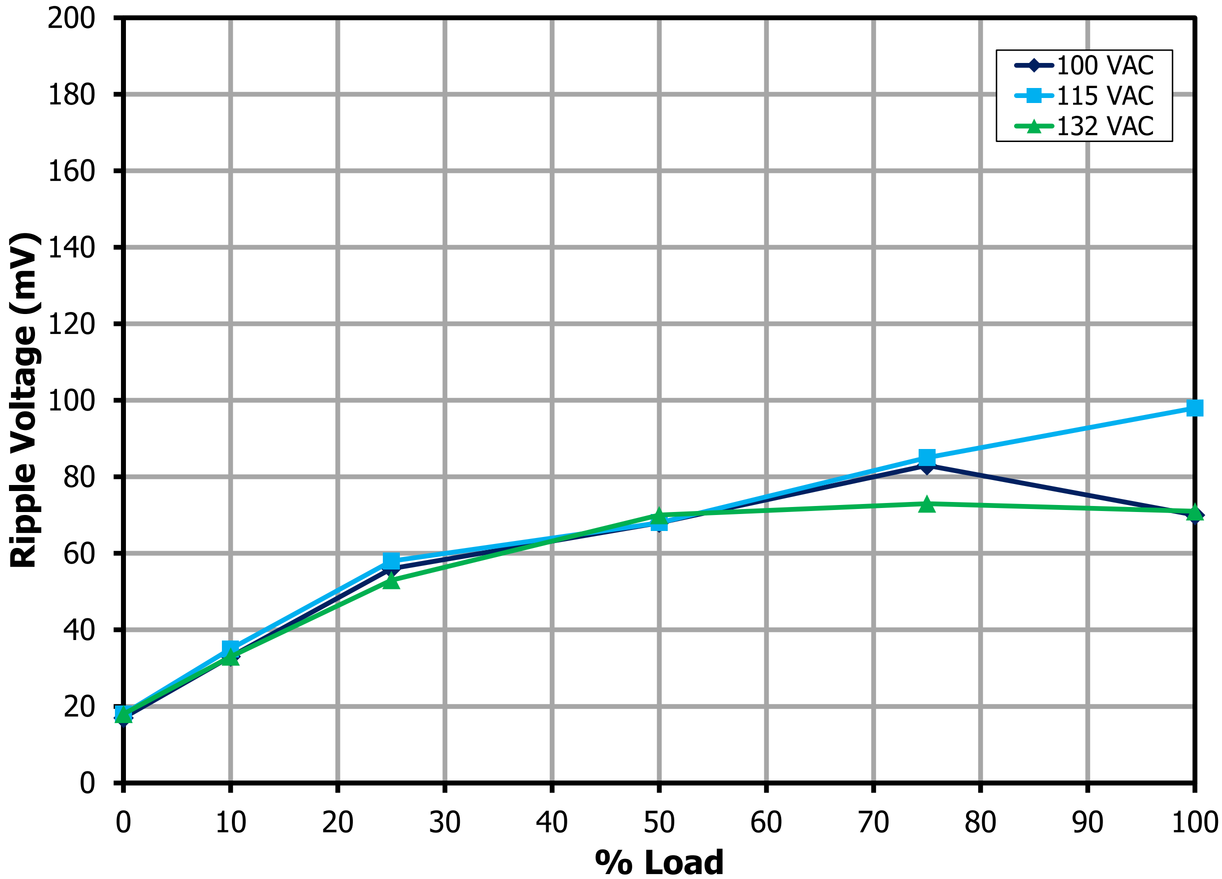


Figure 24 – Ripple Voltage vs. % Load at 20 V.

9.7.2 Output Ripple Voltage vs. Percent Load at 15 V / 4 A

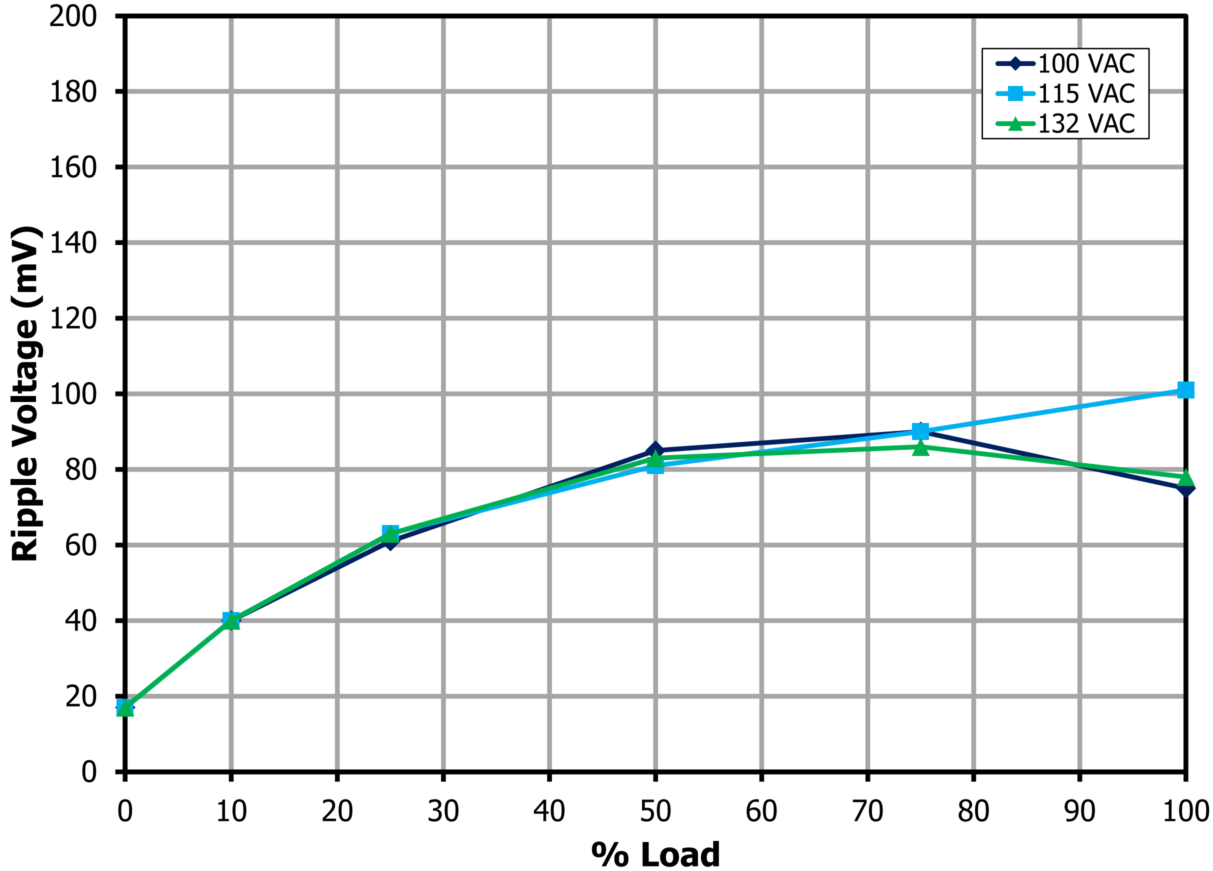


Figure 25 – Ripple Voltage vs. % Load at 15 V.

9.7.3 Output Ripple Voltage vs. Percent Load at 9 V / 5 A

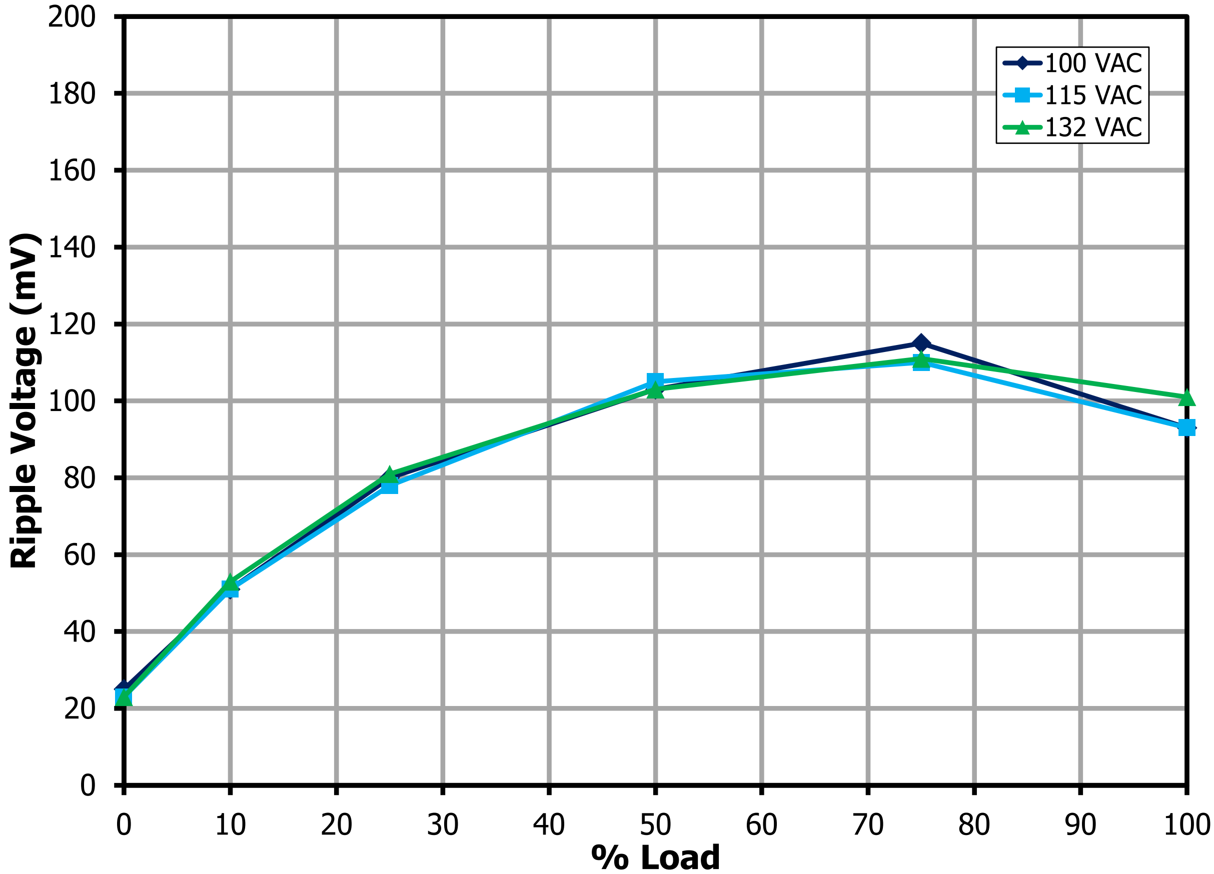


Figure 26 – Ripple Voltage vs. % Load at 9 V.

9.7.4 Output Ripple Voltage vs. Percent Load at 5 V / 6.5 A

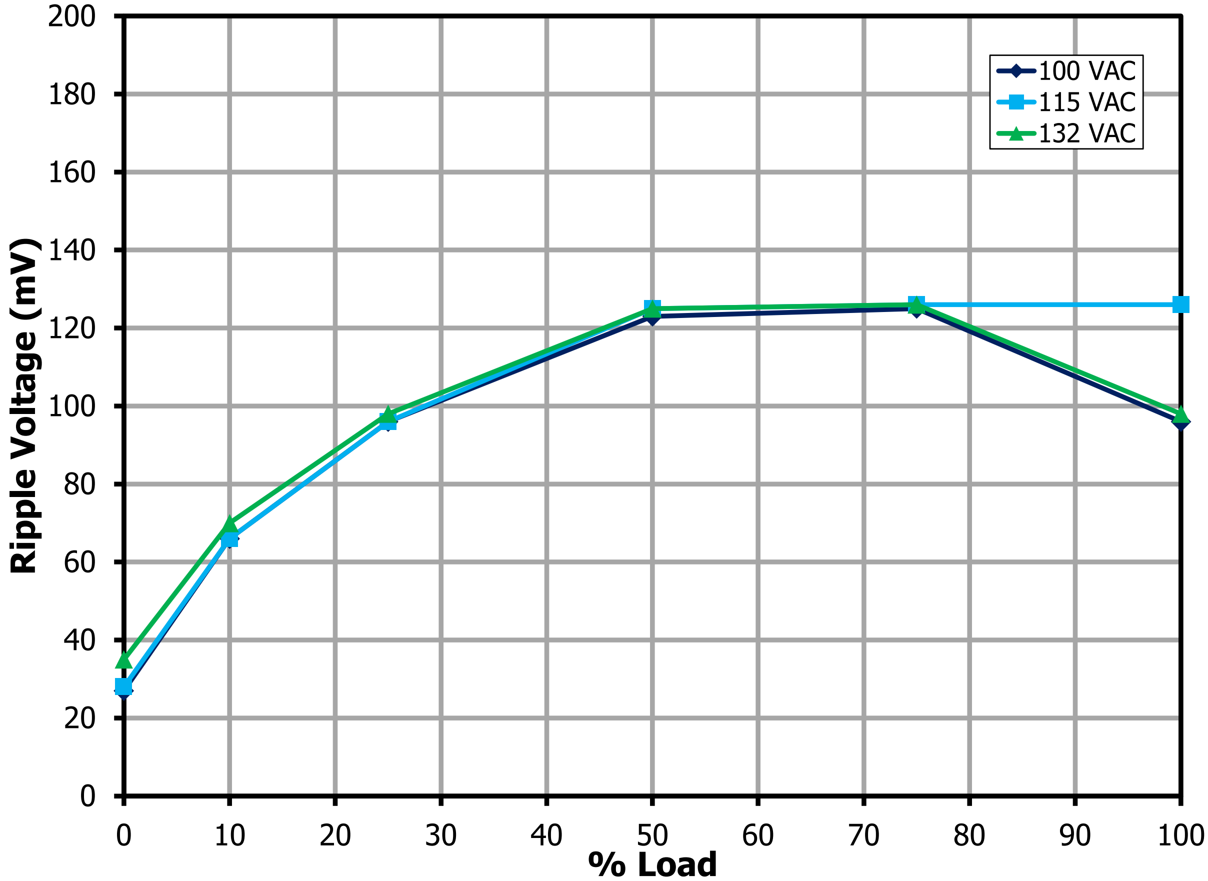


Figure 27 – Ripple Voltage vs. % Load at 5 V.

10 Thermal Performance

10.1 *Thermal Scan at 25 ºC Ambient*

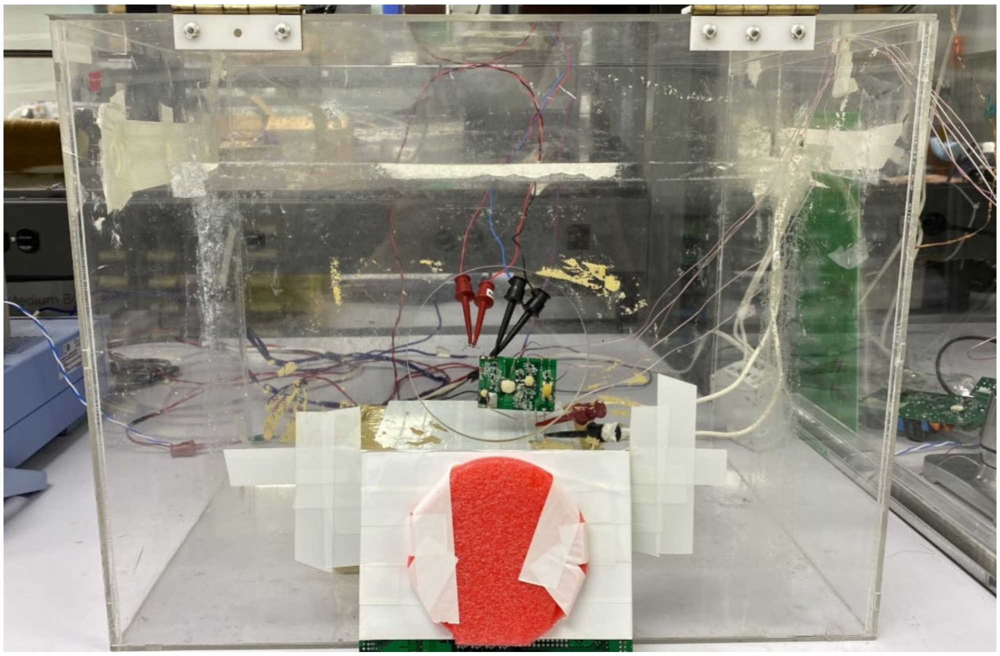


Figure 28 – Test Set-up Picture.

10.1.1 Thermal Scan Summary – 20 V, 3.5 A and Extended loading at 9 V, 6 A

Note: Tested using an IR Camera

20 V, 3.5 A Output			
Component	**Case Temperature (°C)**		
	100 VAC	**115 VAC**	**132 VAC**
U4 – InnoSwitch4-CZ	81	72.8	71.3
Q4 – SRFET	74.2	71.2	70.4
BR1 – Bridge Diode	78	71.4	68
U3 – Clamp Zero	74.9	70.9	70.8
T1 – Main TRF	78.4	74.4	76
Extend Loading 9 V, 6 A Output			
Component	**Case Temperature (°C)**		
	100 VAC	**115 VAC**	**132 VAC**
U4 – InnoSwitch4-CZ (Secondary)	56.4	64.6	68.4
Q4 – SRFET	66.7	68.2	68.2
BR1 – Bridge Diode	57.9	54.9	54
U3– Clamp Zero	53.5	55.8	58.2
T1 – Main TRF (Core)	51.8	43.6	52.6

10.1.2 100 VAC Input 20 V / 3.5 A

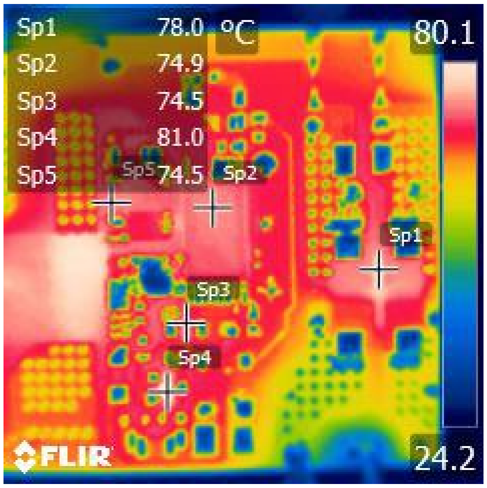


Figure 29 – Primary Bottom Side.

Component	Case Temperature (°C)
U4 - InnoSwitch4-CZ Primary	81
BR1 - Bridge Diode	78
U3 - Clamp Zero	74.9
D2 - Bias Diode	74.5
Q1 - BPP Linear Reg	81
D1 - Snubber Diode	74.5

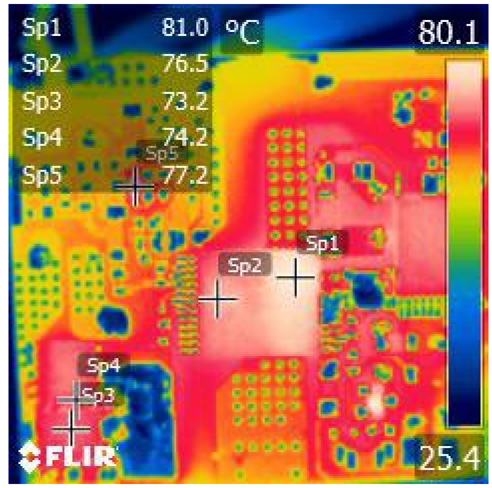


Figure 30 – Secondary Bottom Side.

Component	Case Temperature (°C)
U4 - InnoSwitch4-CZ Secondary	76.5
D7 - Sec Diode	73.2
Q4 - SR FET	74.2
VR1 - BPS Zener	77.2

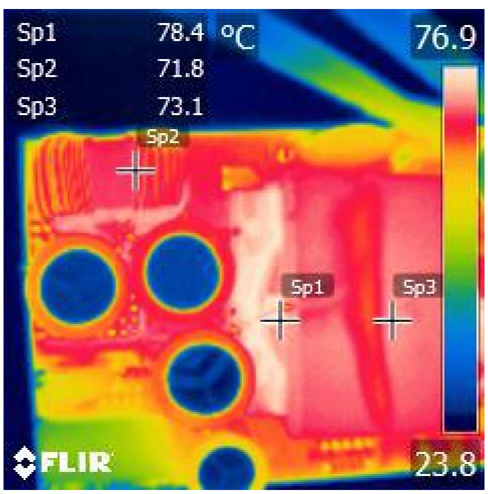


Figure 31 – Top Side.

Component	Case Temperature (°C)
TRF - TIW Wire	78.4
L1 - Input CMC	71.8
TRF - Core	73.1

10.1.3 115 VAC Input 20 V / 3.5 A

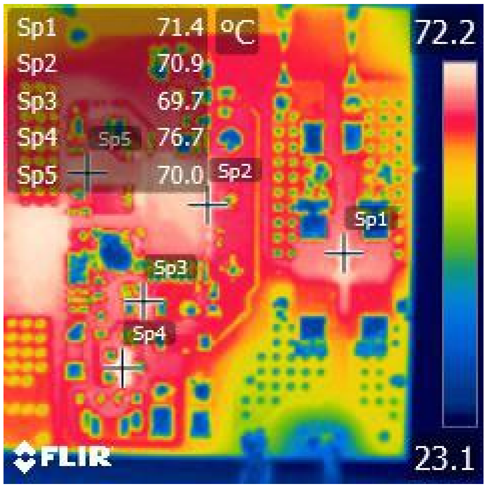


Figure 32 – Primary Bottom Side.

Component	Case Temperature (°C)
U4 - InnoSwitch4-CZ Primary	72.8
BR1 - Bridge Diode	71.4
U3 - Clamp Zero	70.9
D2 - Bias Diode	69.7
Q1 - BPP Linear Reg	76.7
D1 - Snubber Diode	70

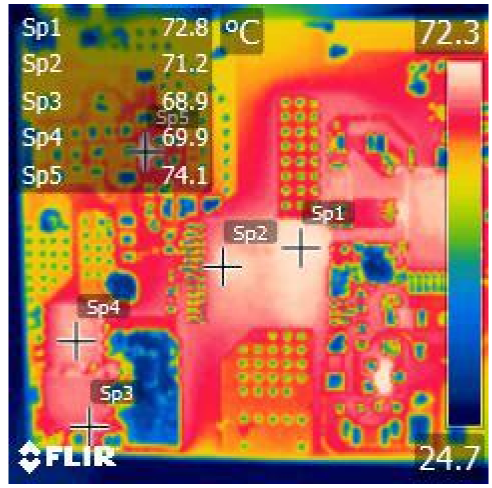


Figure 33 – Secondary Bottom Side.

Component	Case Temperature (°C)
U4 - InnoSwitch4-CZ Secondary	71.2
D7 - Sec Diode	68.9
Q4 - SR FET	69.9
VR1 - BPS Zener	74.1

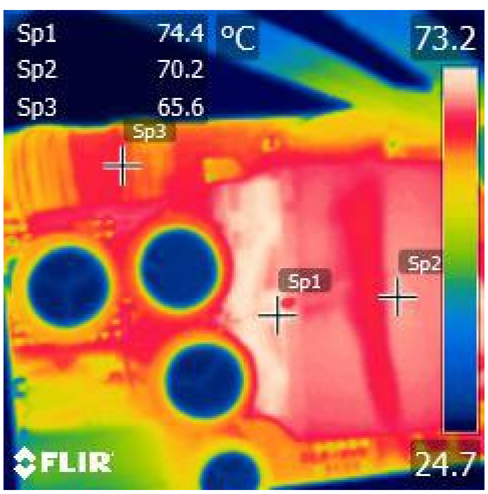


Figure 34 – Top Side.

Component	Case Temperature (°C)
TRF - TIW Wire	74.4
L1 - Input CMC	70.2
TRF - Core	65.6

10.1.4 132 VAC Input 20 V / 3.5 A

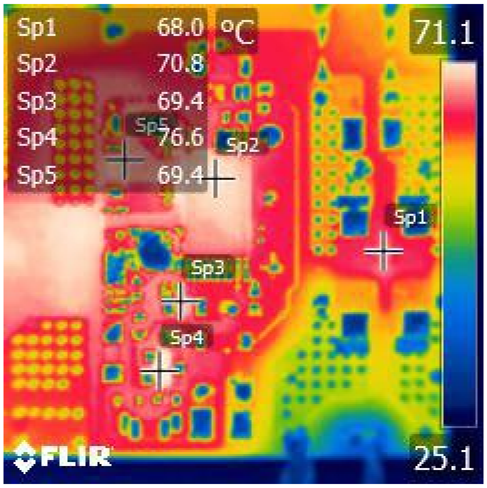


Figure 35 – Primary Bottom Side.

Component	Case Temperature (°C)
U4 - InnoSwitch4-CZ Primary	71.3
BR1 - Bridge Diode	68
U3 - Clamp Zero	70.8
D2 - Bias Diode	69.4
Q1 - BPP Linear Reg	76.6
D1 - Snubber Diode	69.4

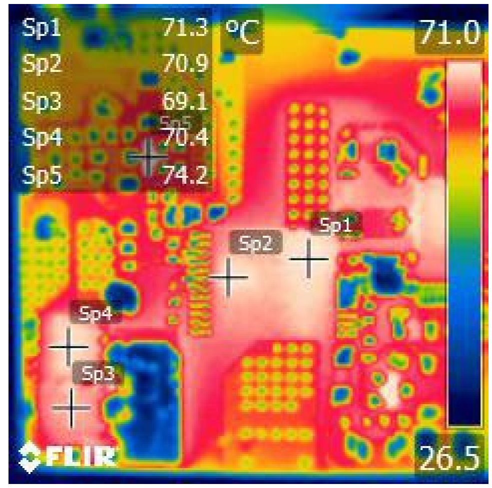


Figure 36 – Secondary Bottom Side.

Component	Case Temperature (°C)
U4 - InnoSwitch4-CZ Secondary	70.9
D7 - Sec Diode	69.1
Q4 - SR FET	70.4
VR1 - BPS Zener	74.2

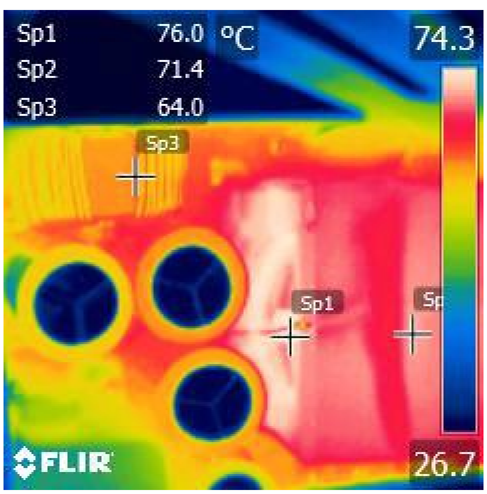


Figure 37 – Top Side.

Component	Case Temperature (°C)
TRF - TIW Wire	76
L1 - Input CMC	71.4
TRF - Core	64

10.2 Thermal Scan with Extended Loading at 9 V / 6 A

10.2.1 100 VAC Input 9 V / 6 A

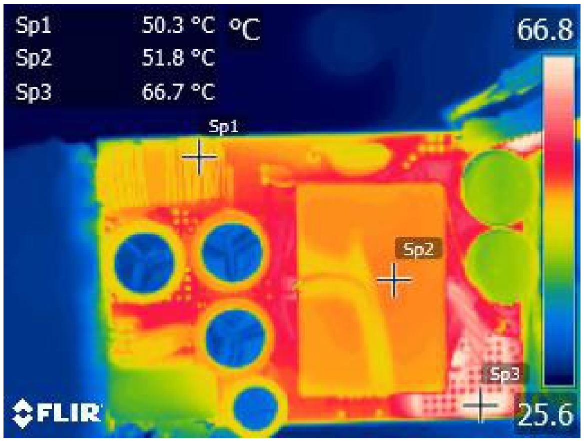


Figure 38 – Top Side.

Component	Case Temperature (°C)
L1 - Input CMC	50.3
TRF - Core	51.8
Sec Copper Area	66.7

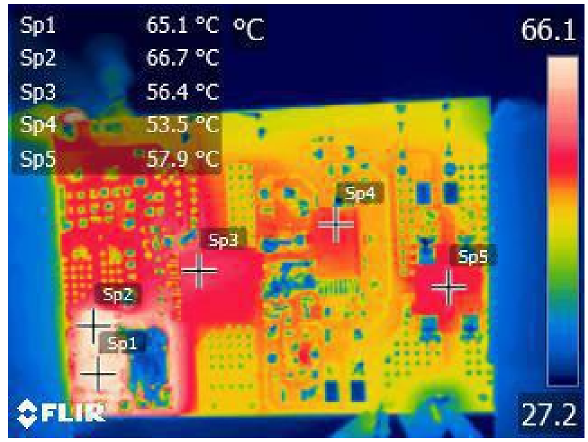


Figure 39 – Bottom Side.

Component	Case Temperature (°C)
D7 - Sec Diode	65.1
Q4 - SR FET	66.7
U4 - InnoSwitch4-CZ Secondary	56.4
U3 - Clamp Zero	53.5
BR1 - Bridge Diode	57.9

10.2.2 115 VAC Input 9 V / 6 A

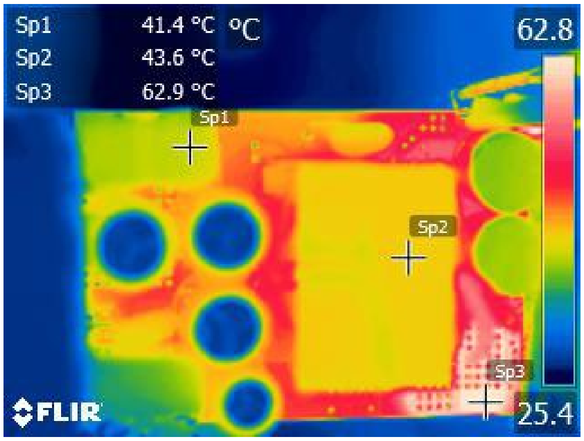


Figure 40 –Top Side.

Component	Case Temperature (°C)
L1 - Input CMC	41.4
TRF - Core	43.6
Sec Copper Area	62.9

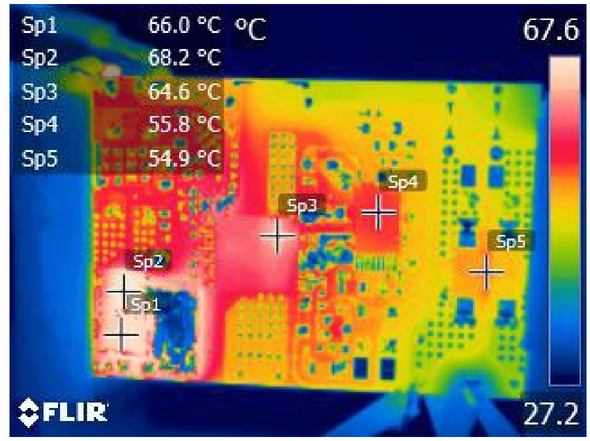


Figure 41 –Bottom Side.

Component	Case Temperature (°C)
D7 - Sec Diode	66
Q4-SR FET	68.2
U4 - InnoSwitch4-CZ Secondary	64.6
U3 - Clamp Zero	55.8
BR1 - Bridge Diode	54.9

10.2.3 132 VAC Input 9 V / 6 A

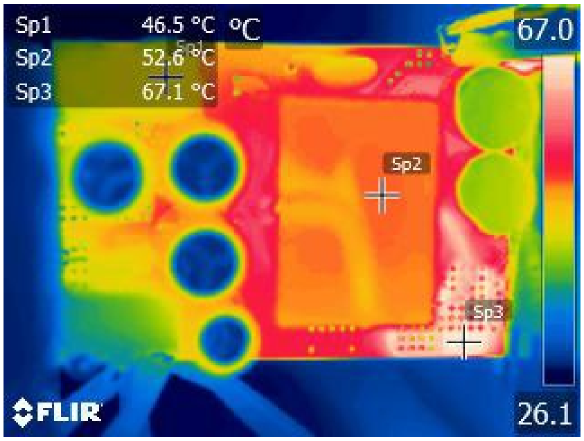


Figure 42 –Top Side.

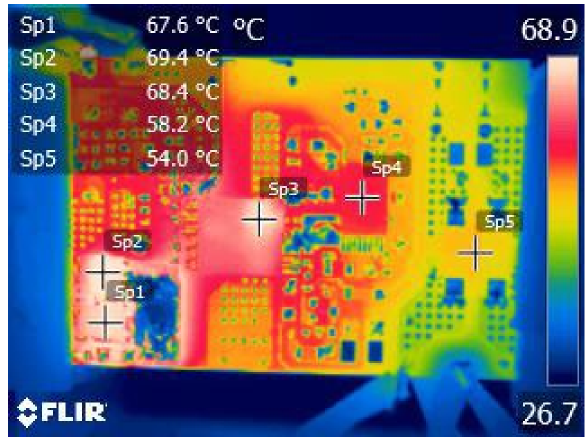


Figure 43 –Bottom Side.

Component	Case Temperature (°C)
L1 - Input CMC	46.5
TRF - Core	52.6
Sec Copper Area	67.1

Component	Case Temperature (°C)
D7 - Sec Diode	67.6
Q4 - SR FET	68.2
U4 - InnoSwitch4-CZ Secondary	68.4
U3 - Clamp Zero	58.2
BR1 - Bridge Diode	54

10.3 Thermal Performance at 50 ºC Ambient

10.3.1 Set-up Picture

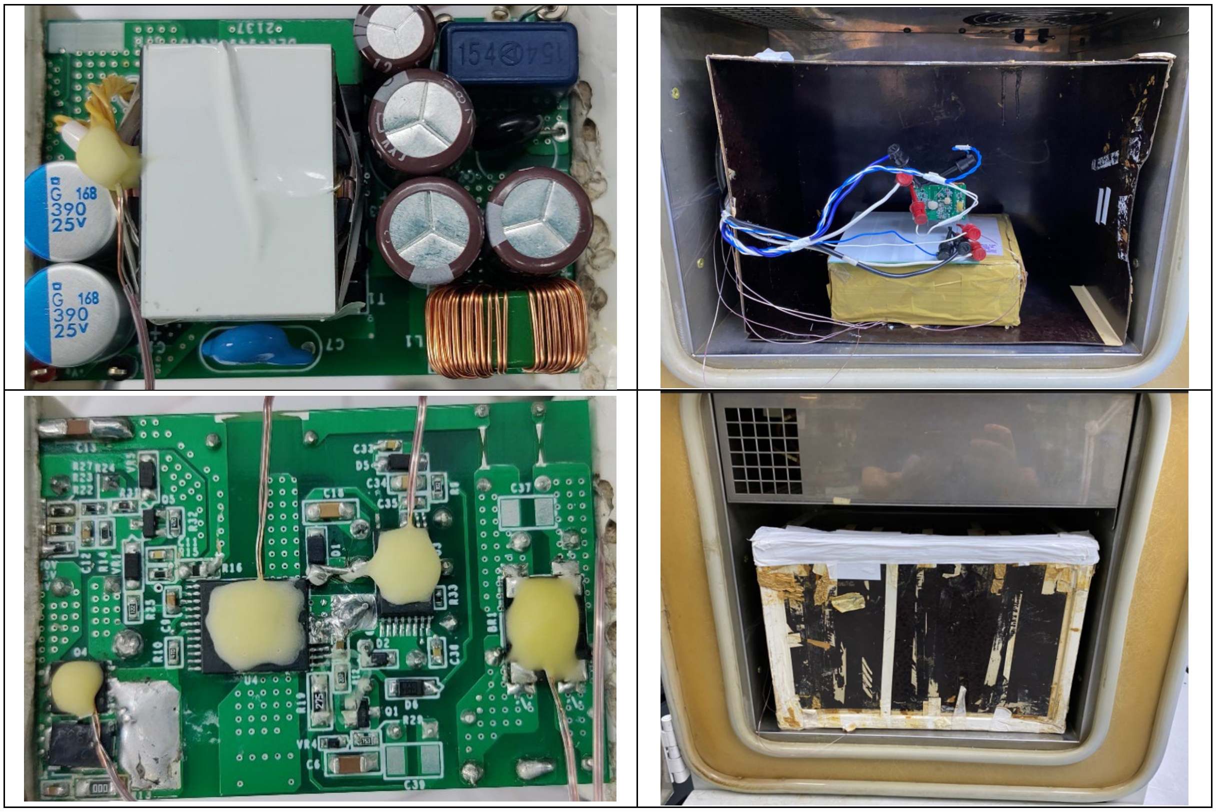


Figure 44 – Tested Using the Environmental Test Chamber**.**

The DUT is placed inside enclosure to prevent airflow.

10.3.2 Thermal Test Summary 20 V, 3.5 A Output at 50 ºC Ambient

Input / Output Condition	Temperature (°C)					
	AMB	T1 (Main TRF)	U4 (InnoSwitch4-CZ)	U3 (ClampZero)	Q4 (SR FET)	BR1
100 VAC 20 V - 3.5 A	53.5	92.3	97.1	90.1	93	89.7
132 VAC 20 V - 3.5 A	53	88.3	87.8	84.7	88.3	81.2
100 VAC 9 V - 5 A	53.7	90.8	93.6	88.5	93.7	86.2
132 VAC 9 V - 5 A	53.1	81.9	80.5	76.3	93.2	72.5
100 VAC 5 V - 6.5 A	53.7	81.9	80.5	76.3	93.2	72.5
132 VAC 5 V - 6.5 A	52.6	80.7	83.4	76.2	92.3	68.7

10.3.3 Thermal Data at 50 ºC Ambient

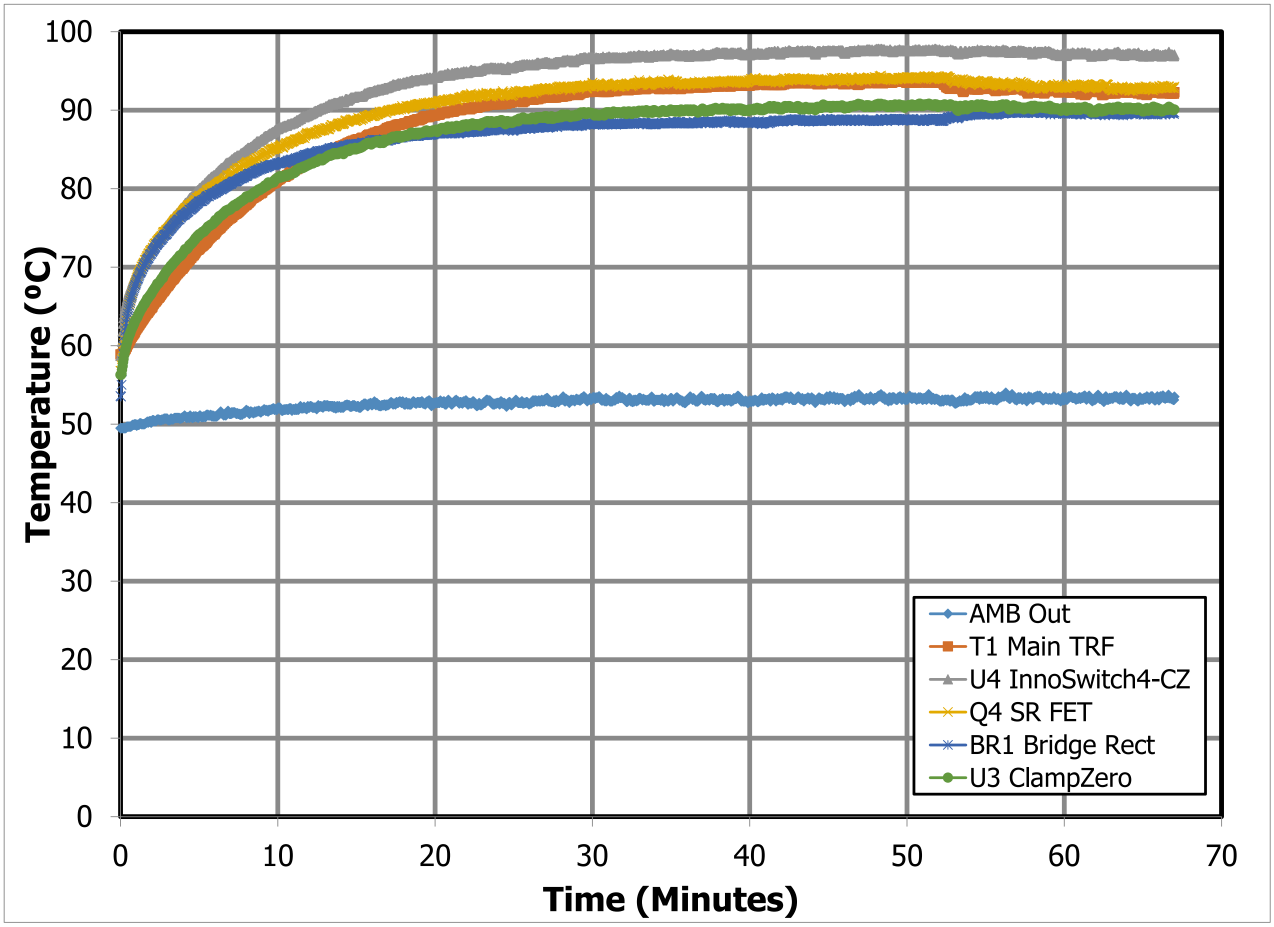


Figure 45 – Thermal Profile at 100 VAC, 20 V / 3.5 A.

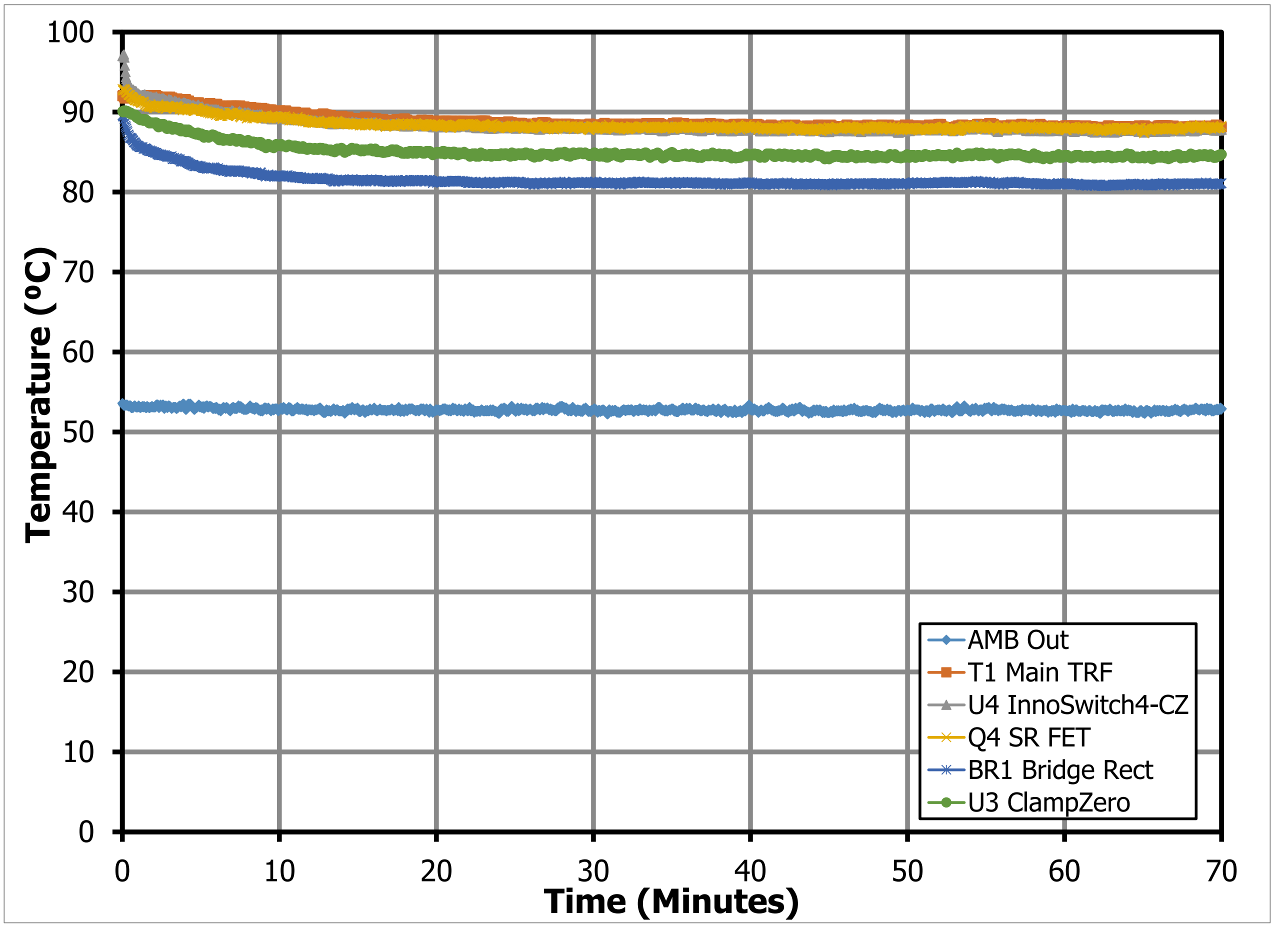


Figure 46 – Thermal Profile at 132 VAC, 20 V / 3.5 A.

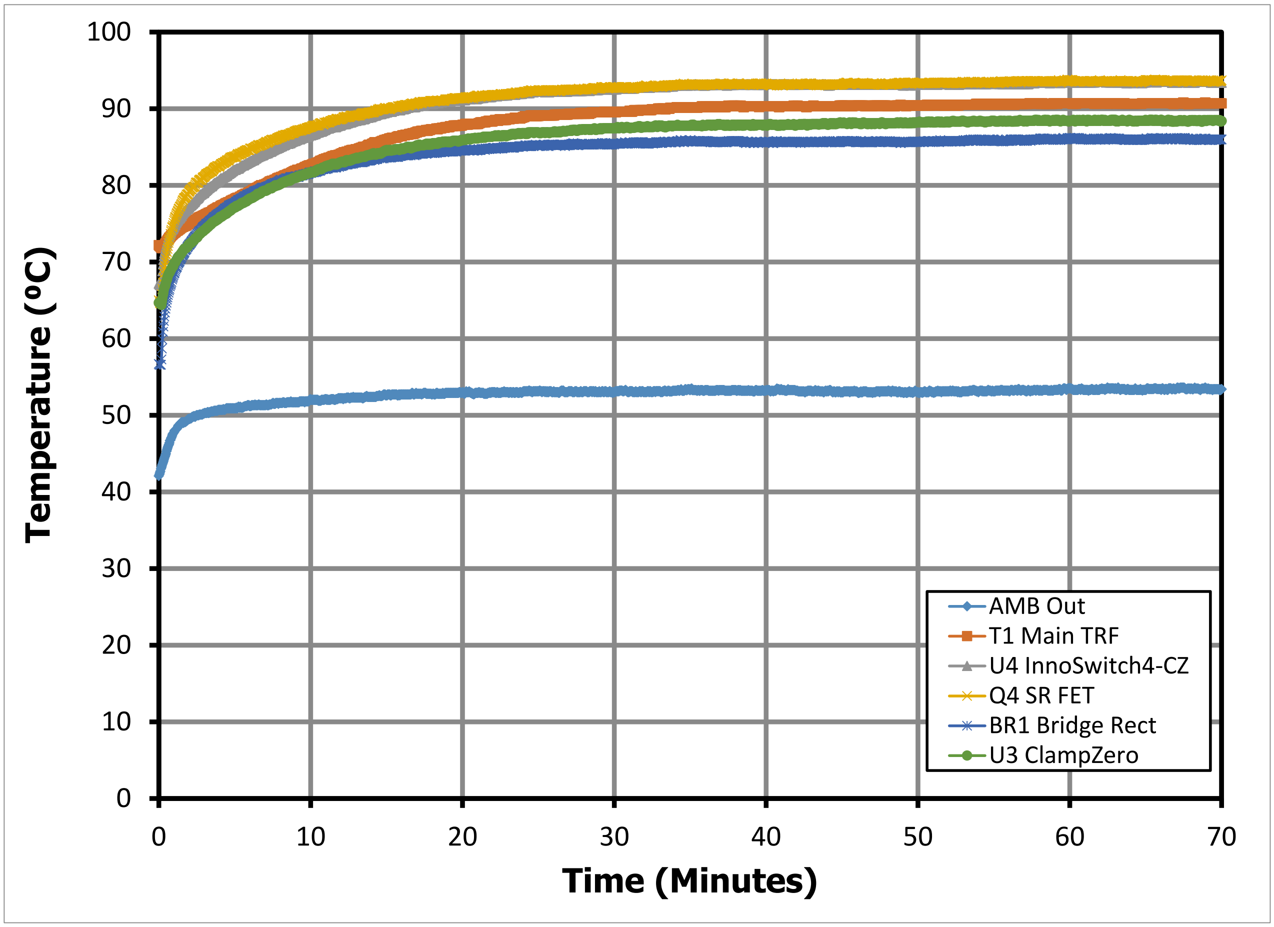


Figure 47 – Thermal Profile at 100 VAC, 9 V / 5 A.

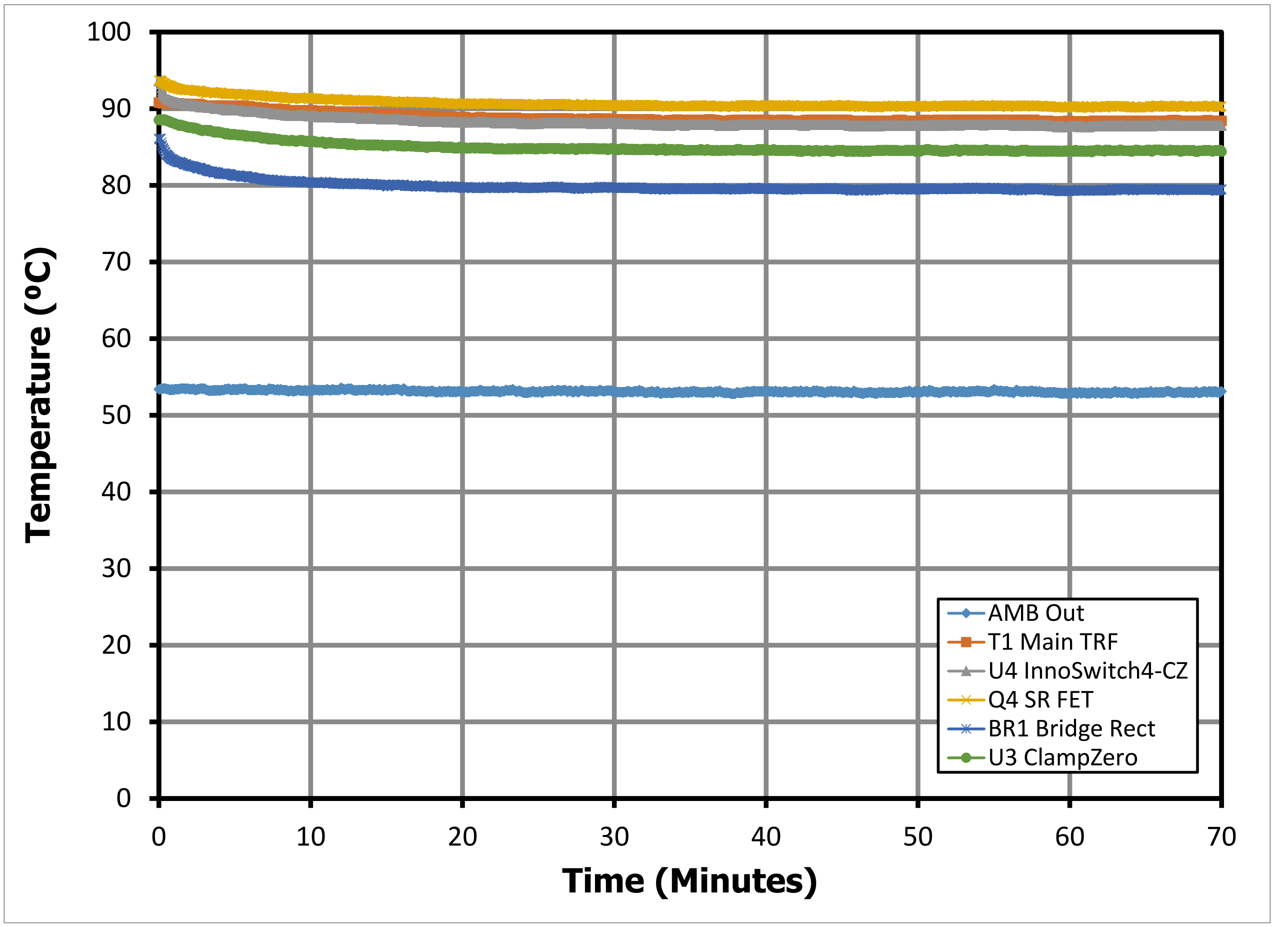


Figure 48 – Thermal Profile at 132 VAC, 9 V / 5 A.

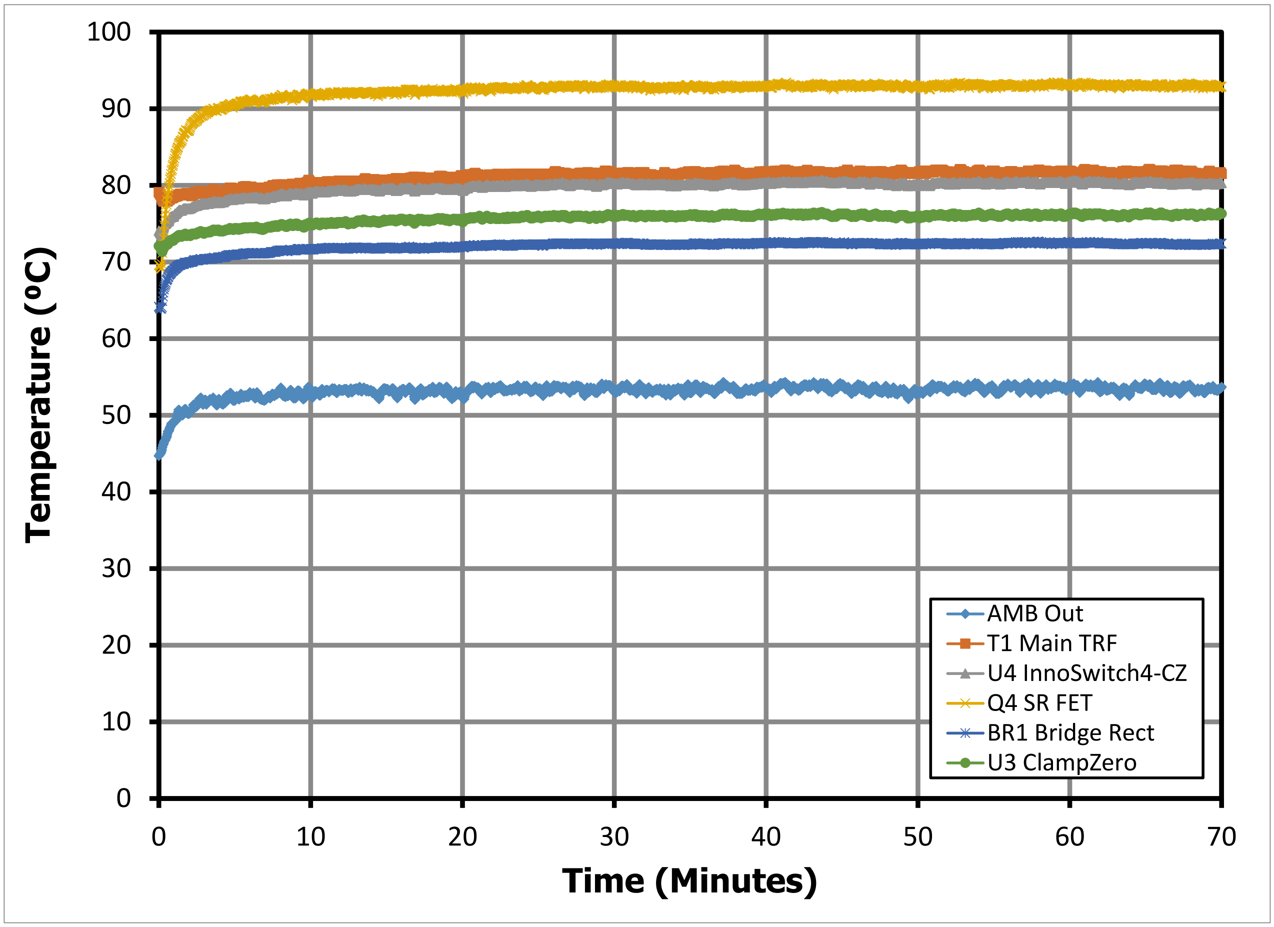


Figure 49 – Thermal Profile at 100 VAC, 5 V / 6.5 A.

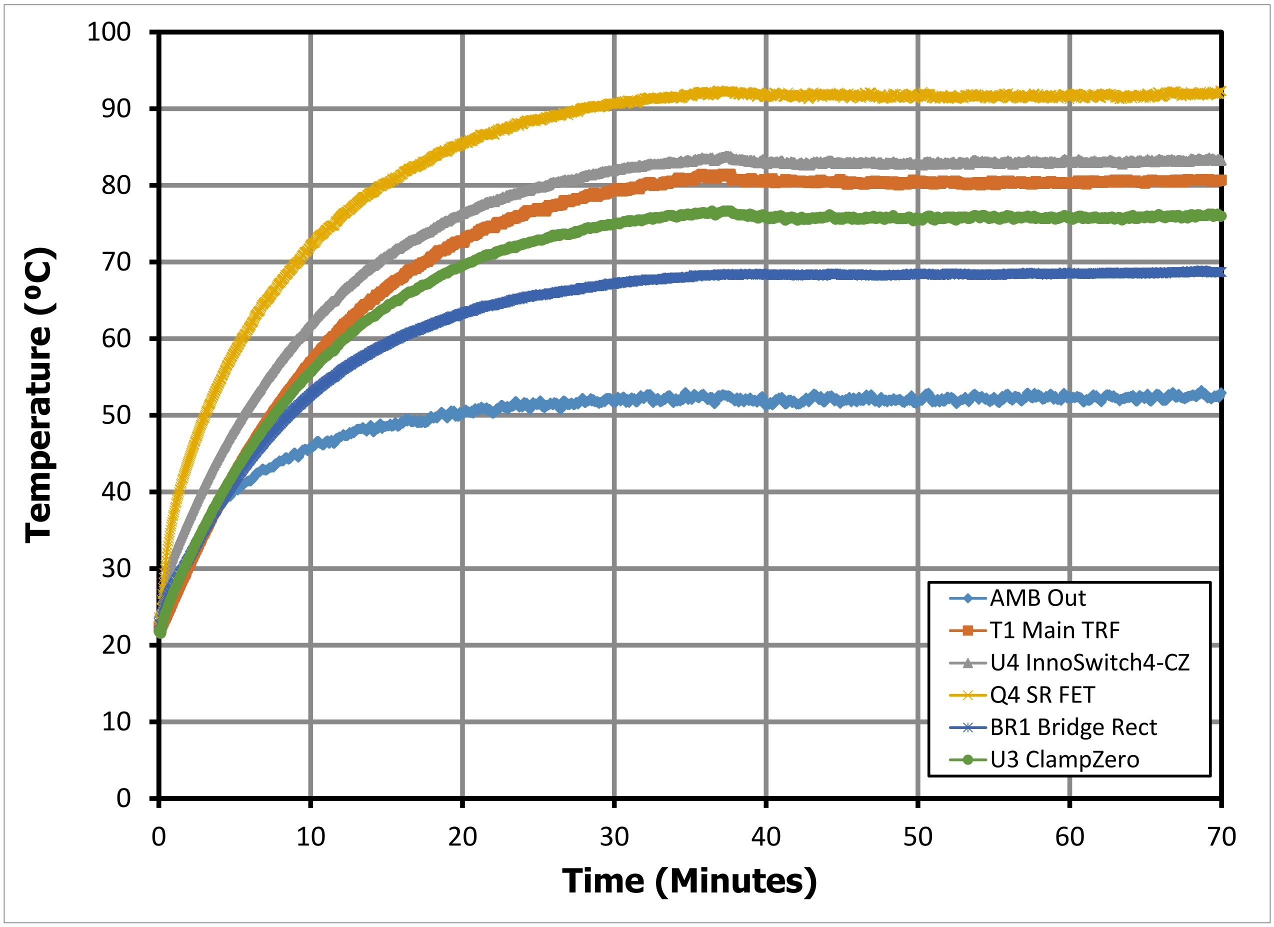


Figure 50 – Thermal Profile at 132 VAC, 5 V / 6.5 A.

11 Waveforms

11.1 *Primary Drain Voltage and Current Waveform*

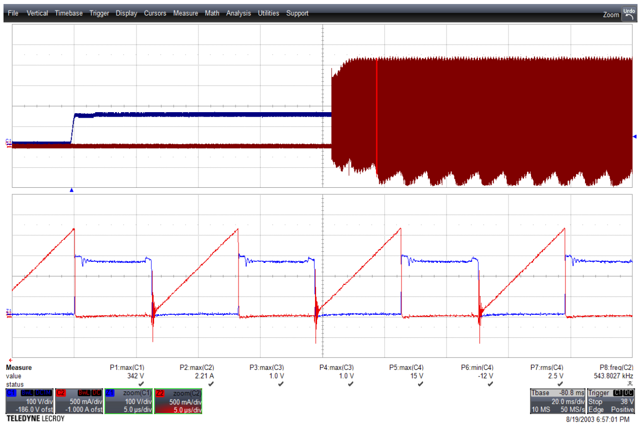


Figure 51 – 100 VAC 60 Hz, 20 V Full Load Start-up.
CH1(Blue): V_{DS}, 100 V / div., 20 ms / div.
CH2(Pink): I_{DS}, 0.5 A / div.
V_{DS} = 342V, I_{DS} = 2.21 A.

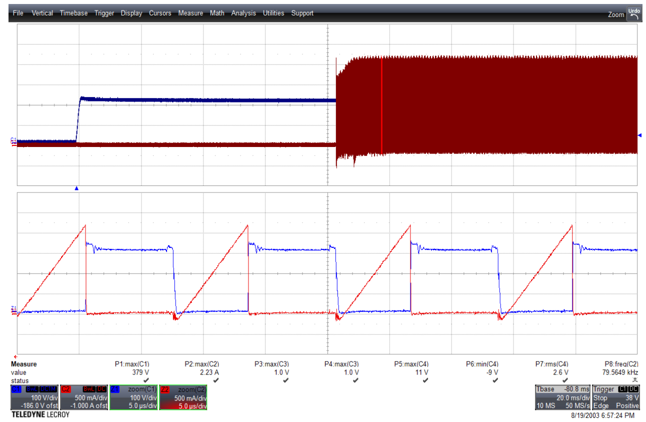


Figure 52 – 132 VAC 60 Hz, 20 V Full Load Start-up.
CH1(Blue): V_{DS}, 100 V / div., 20 ms / div.
CH2(Pink): I_{DS}, 0.5 A / div.
V_{DS} = 379 V, I_{DS} = 2.23 A.

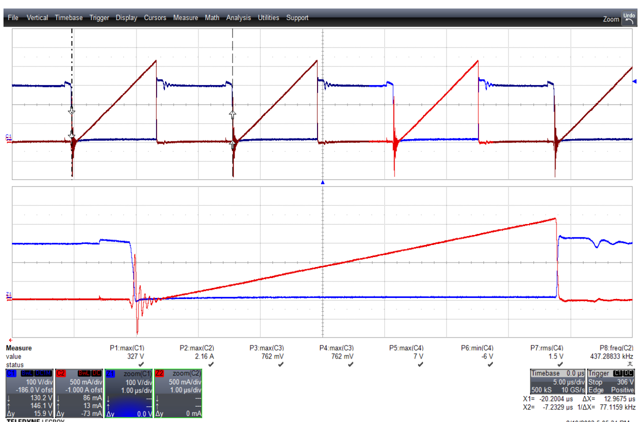


Figure 53 – 100 VAC 60 Hz, 20 V Full Load Normal.
CH1(Blue): V_{DS}, 100 V / div., 5 μs / div.
CH2(Pink): I_{DS}, 0.51 A / div.
V_{DS} = 327 V, I_{DS} = 2.16 A.

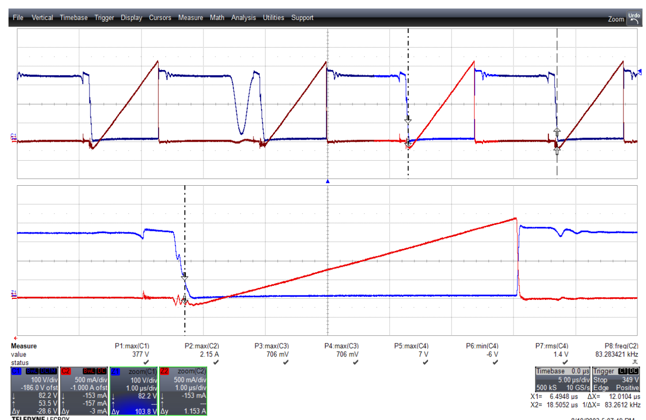


Figure 54 – 132 VAC 60 Hz, 20 V Full Load Normal.
CH1(Blue): V_{DS}, 100 V / div., 5 μs / div.
CH2(Pink): I_{DS}, 0.5 A / div.
V_{DS} = 377 V, I_{DS} = 2.15 A.

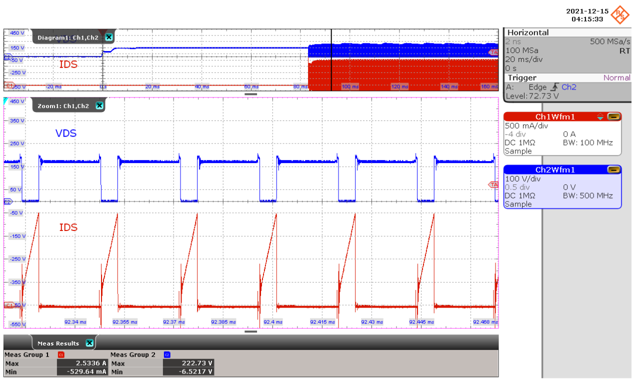


Figure 55 – 100 VAC 60 Hz, 5 V Full Load Start-up.
CH1(Red): I_{DS}, 0.5 A / div., 20 ms / div.
CH2(Blue): V_{DS}, 100 V / div.
V_{DS} = 222 V, I_{DS} = 2.53 A.

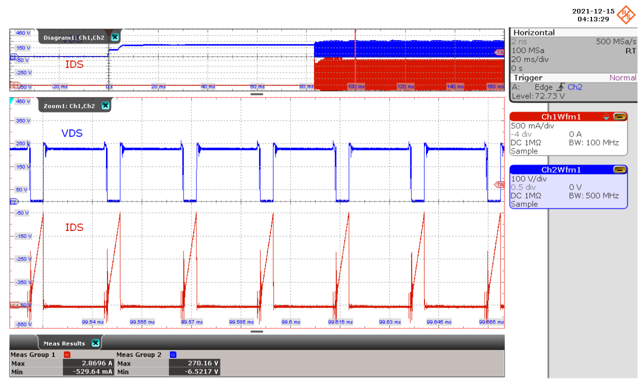


Figure 56 – 132 VAC 60 Hz, 5 V Full Load Start-up.
CH1(Red): I_{DS}, 0.5 A / div., 20 ms / div.
CH2(Blue): V_{DS}, 100 V / div.
V_{DS} = 270.16 V, I_{DS} = 2.87 A.

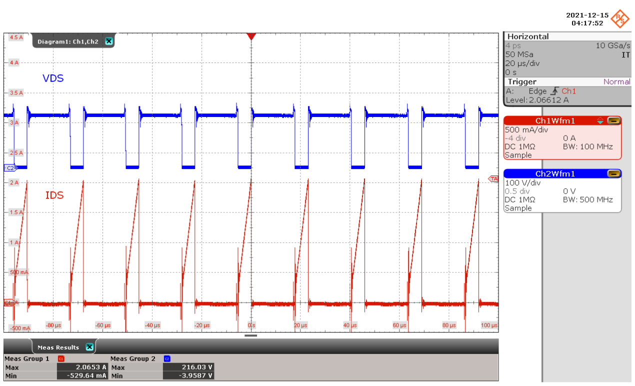


Figure 57 – 100 VAC 60 Hz, 5 V Full Load Normal.
CH1(Red): I_{DS}, 0.5 A / div., 20 μs / div.
CH2(Blue): V_{DS}, 100 V / div.
V_{DS} = 216 V, I_{DS} = 2.07 A.

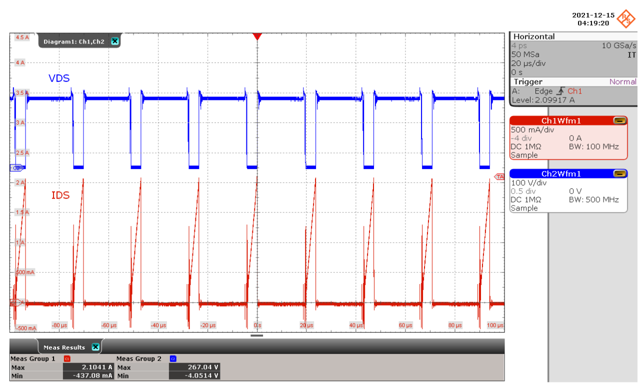


Figure 58 – 132 VAC 60 Hz, 5 V Full Load Normal.
CH1(Blue): V_{DS}, 100 V / div., 20 μs / div.
CH2(Pink): I_{DS}, 1 A / div.
V_{DS} = 267 V, I_{DS} = 2.104 A.

11.2 *SR FET Drain Voltage Waveform*

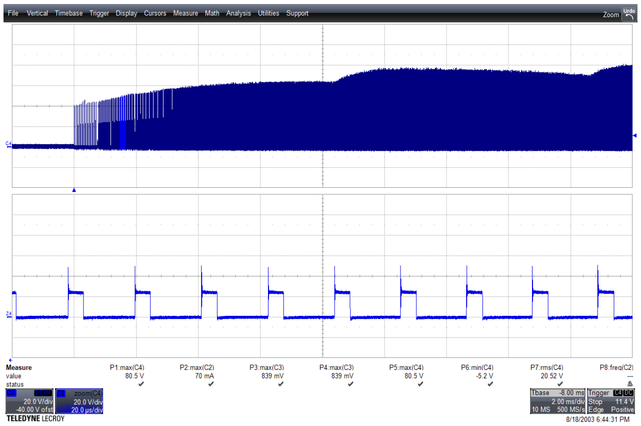


Figure 59 – 100 VAC 60 Hz, 20 V Full Load Start-up.
CH1(Blue): V_{DS}, 20 V / div., 2 ms / div.
V_{DS} = 80.5 V.

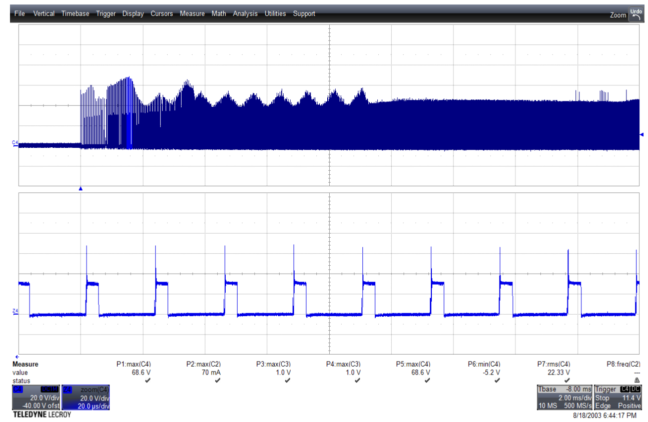


Figure 60 – 132 VAC 60 Hz, 20 V Full Load Start-up.
CH1(Blue): V_{DS}, 20 V / div., 2 ms / div.
V_{DS} = 68.6 V.

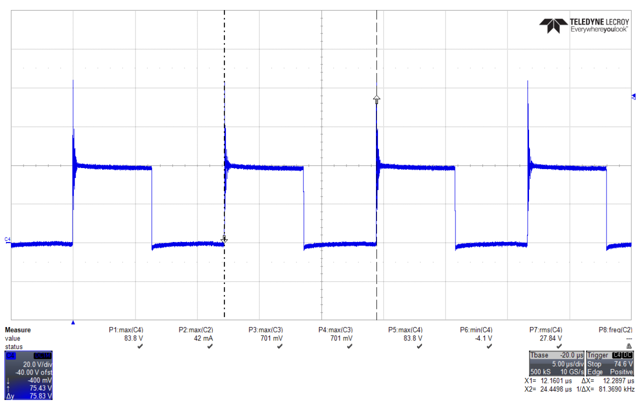


Figure 61 – 100 VAC 60 Hz, 20 V Full Load Normal.
CH1(Blue): V_{DS}, 20 V / div., 5 µs / div.
V_{DS} = 83.8 V.

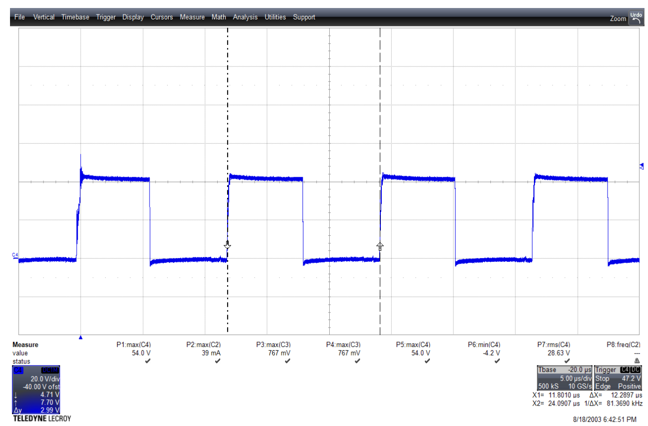


Figure 62 – 132 VAC 60 Hz, 20 V Full Load Normal.
CH1(Blue): V_{DS}, 20 V / div., 5 µs / div.
V_{DS} = 54 V.

11.3 *Start-up Profile*

Tested using an E-load set at constant current mode.

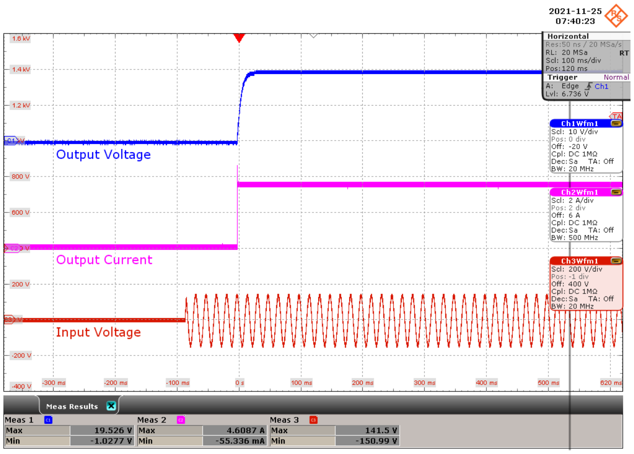


Figure 63 – 100 VAC 60 Hz, 20 V Full Load Start-up.
CH1(Blue): V_{OUT}, 10 V / div.
CH2(Pink): I_{OUT}, 2 A / div.
CH3(Orange): V_{IN}, 200 V / div., 100 ms / div.

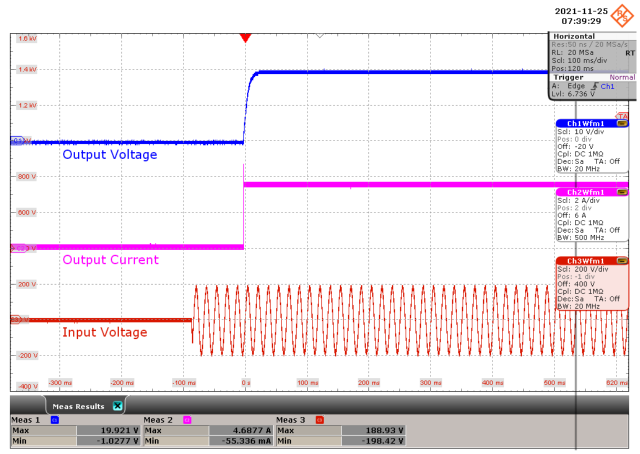


Figure 64 – 132 VAC 60 Hz, 20 V Full Load Start-up.
CH1(Blue): V_{OUT}, 10 V / div.
CH2(Pink): I_{OUT}, 2 A / div.
CH3(Orange): V_{IN}, 200 V / div., 100 ms / div.

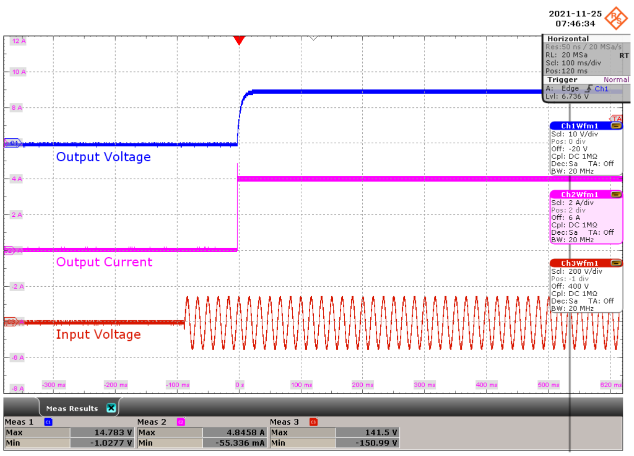


Figure 65 – 100 VAC 60 Hz, 15 V Full Load Start-up.
CH1(Blue): V_{OUT}, 10 V / div.
CH2(Pink): I_{OUT}, 2 A / div.
CH3(Orange): V_{IN}, 200 V / div, 100 ms / div.

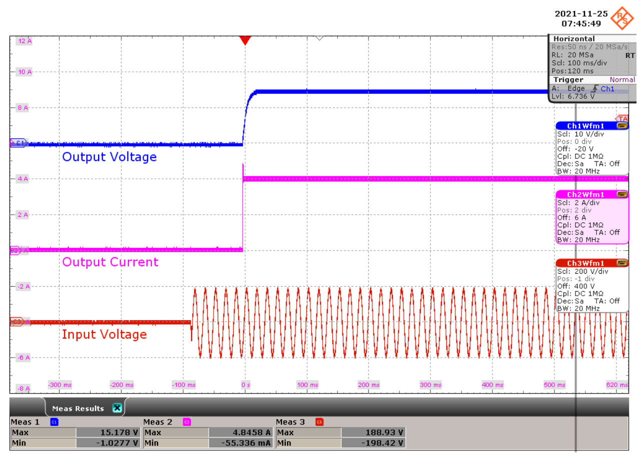


Figure 66 – 132 VAC 60 Hz, 15 V Full Load Start-up.
CH1(Blue): V_{OUT}, 10 V / div.
CH2(Pink): I_{OUT}, 2 A / div.
CH3(Orange): V_{IN}, 200 V / div, 100 ms / div.

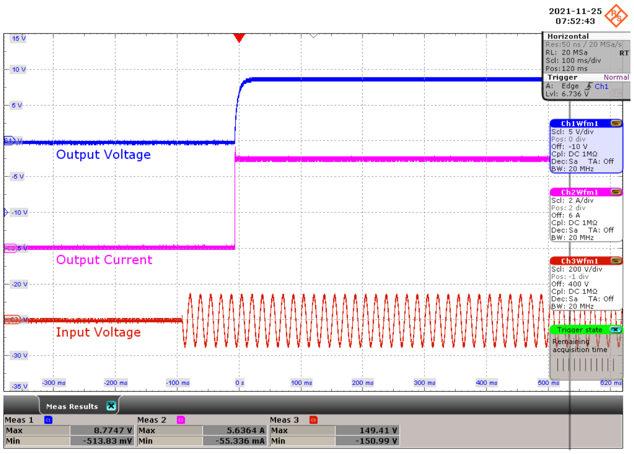


Figure 67 – 100 VAC 60 Hz, 9 V Full Load Start-up.
CH1(Blue): V_{OUT}, 5 V / div.
CH2(Pink): I_{OUT}, 2 A / div.
CH3(Orange): V_{IN}, 200 V / div., 100 ms / div.

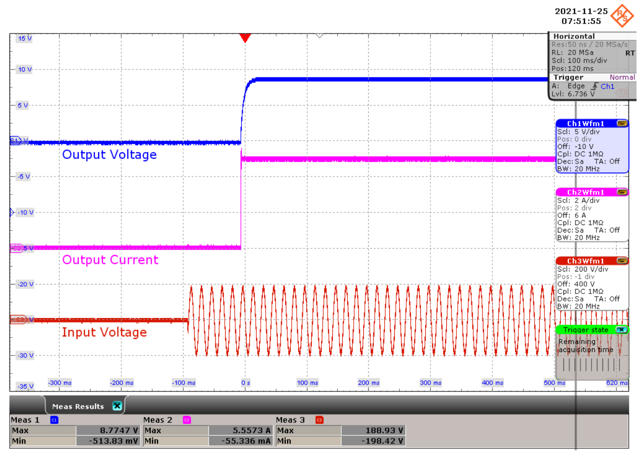


Figure 68 – 132 VAC 60 Hz, 9 V Full Load Start-up.
CH1(Blue): V_{OUT}, 5 V / div.
CH2(Pink): I_{OUT}, 2 A / div.
CH3(Orange): V_{IN}, 200 V / div., 100 ms / div.

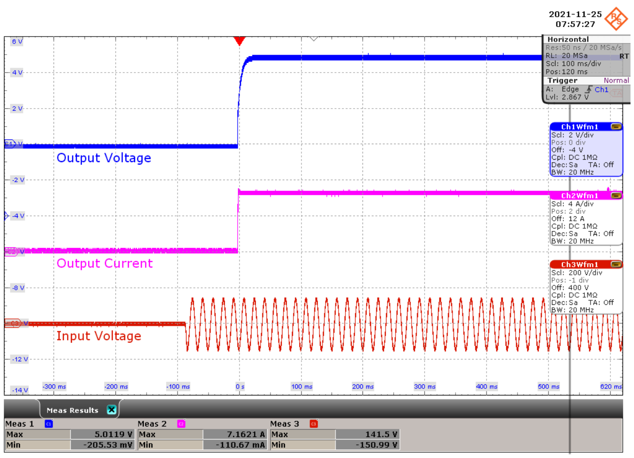


Figure 69 – 100 VAC 60 Hz, 5 V Full Load Start-up.
CH1(Blue): V_{OUT}, 2 V / div.
CH2(Pink): I_{OUT}, 4 A / div.
CH3(Orange): V_{IN}, 200 V / div., 100 ms / div.

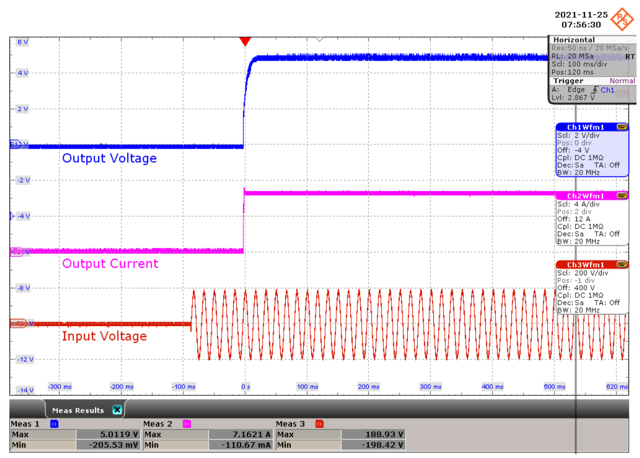


Figure 70 – 132 VAC 60 Hz, 5 V Full Load Start-up.
CH1(Blue): V_{OUT}, 2 V / div.
CH2(Pink): I_{OUT}, 4 A / div.
CH3(Orange): V_{IN}, 200 V / div., 100 ms / div.

11.4 *Transient Load Response*

Tested using an E-Load set at dynamin constant current loading.

11.4.1 Transient Load at V_{OUT} = 20 V

Set-up: Duty Cycle = 50%, Frequency = 100 Hz, Slew Rate = 200 mA / µs

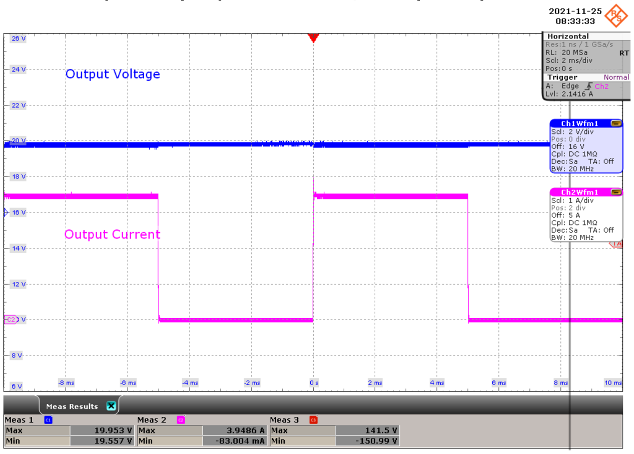


Figure 71 – 100 VAC 60 Hz, 0-3.5 A Transient Load.
CH1(Blue): V_{OUT}, 2 V / div., 2 ms / div.
CH2(Pink): I_{OUT}, 1 A / div.
$V_{OUT(MAX)}$ = 19.95 V, $V_{OUT(MIN)}$ = 19.56 V.

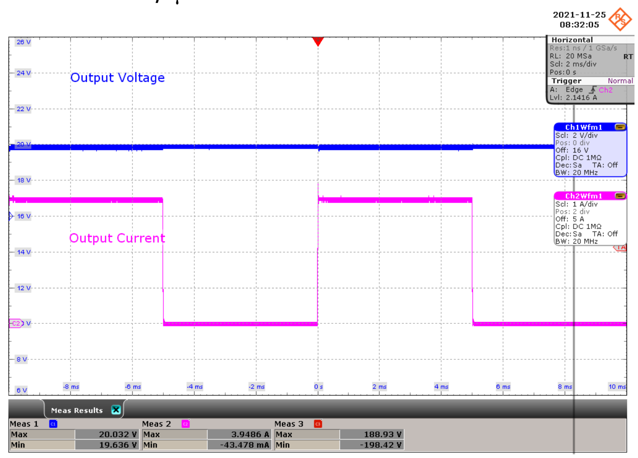


Figure 72 – 132 VAC 60 Hz, 0-3.5 A Transient Load.
CH1(Blue): V_{OUT}, 2 V / div., 2 ms / div.
CH2(Pink): I_{OUT}, 1 A / div.
$V_{OUT(MAX)}$ = 20.03V, $V_{OUT(MIN)}$ = 19.64 V.

11.4.2 Transient Load at V_{OUT} =15 V

Set-up: Duty Cycle = 50%, Frequency = 100 Hz, Slew Rate = 200 mA / µs

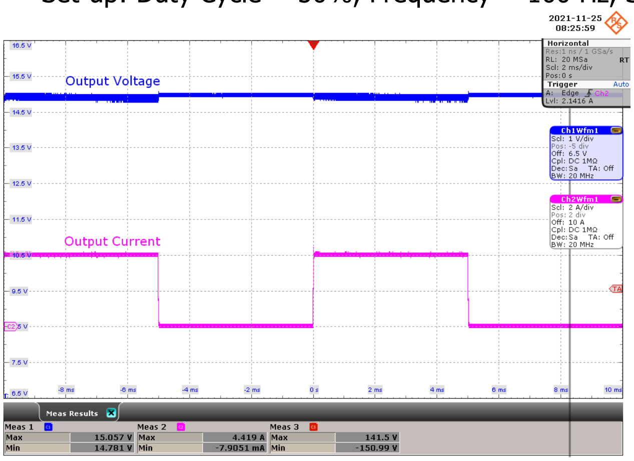


Figure 73 – 100 VAC 60 Hz, 0-4 A Transient Load.
CH1(Blue): V_{OUT}, 1 V / div., 2 ms / div.
CH2(Pink): I_{OUT}, 2 A / div.
$V_{OUT(MAX)}$ = 15.06 V, $V_{OUT(MIN)}$ = 14.78 V.

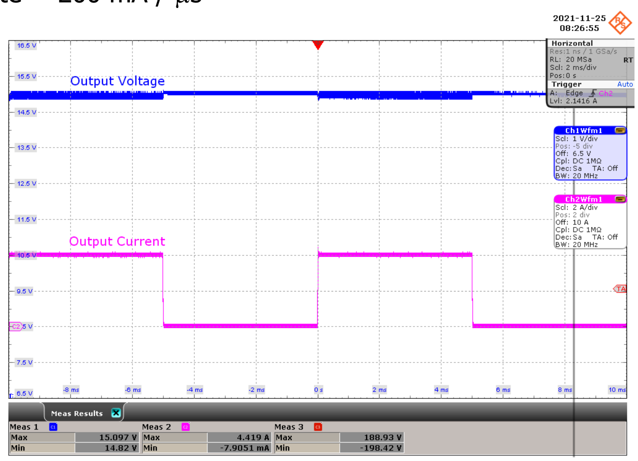


Figure 74 – 132 VAC 60 Hz, 0-4 A Transient Load.
CH1(Blue): V_{OUT}, 1 V / div., 2 ms / div.
CH2(Pink): I_{OUT}, 2 A / div.
$V_{OUT(MAX)}$ = 15.1 V, $V_{OUT(MIN)}$ = 14.82 V.

11.4.3 Transient Load at V_{OUT} =9 V

Set-up: Duty Cycle = 50%, Frequency = 100 Hz, Slew Rate = 200 mA / us

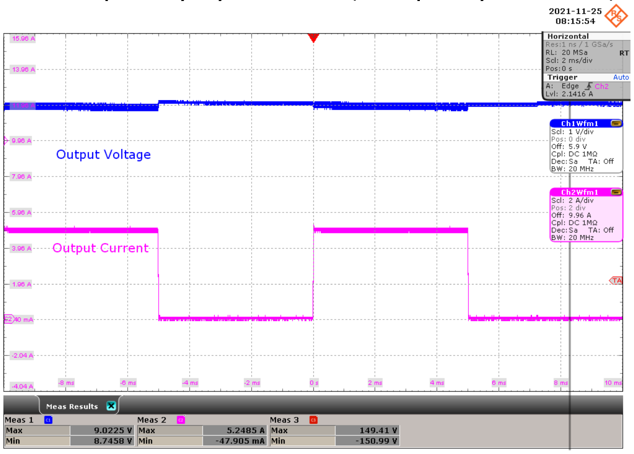


Figure 75 – 100 VAC 60 Hz, 0-5 A Transient Load.
CH1(Blue): V_{OUT}, 1 V / div., 2 ms / div.
CH2(Pink): I_{OUT}, 2 A / div.
$V_{OUT(MAX)}$ = 9.03 V, $V_{OUT(MIN)}$ = 8.75 V.

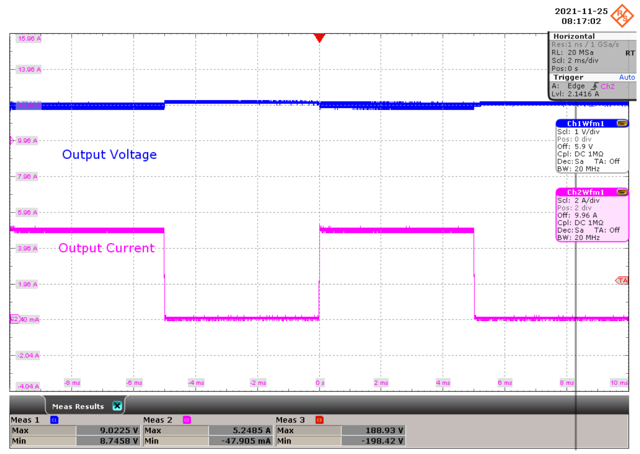


Figure 76 – 132 VAC 60 Hz, 0-5 A Transient Load.
CH1(Blue): V_{OUT}, 1 V / div., 2 ms / div.
CH2(Pink): I_{OUT}, 2 A / div.
$V_{OUT(MAX)}$ = 9.02V, $V_{OUT(MIN)}$ = 8.75 V.

11.4.4 Transient Load at V_{OUT} =5 V

Set-up: Duty Cycle = 50%, Frequency = 100 Hz, Slew Rate = 200 mA / us

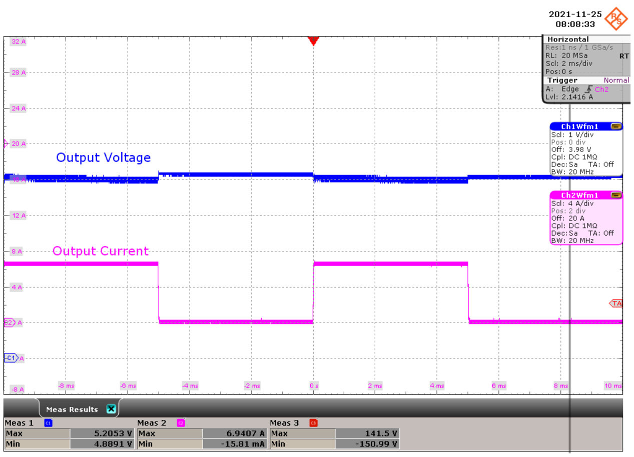


Figure 77 – 100 VAC 60 Hz, 0-6.5 A Transient Load.
CH1(Blue): V_{OUT}, 1 V / div., 2 ms / div.
CH2(Pink): I_{OUT}, 4 A / div.
$V_{OUT(MAX)}$ =5.21 V, $V_{OUT(MIN)}$ = 4.88 V.

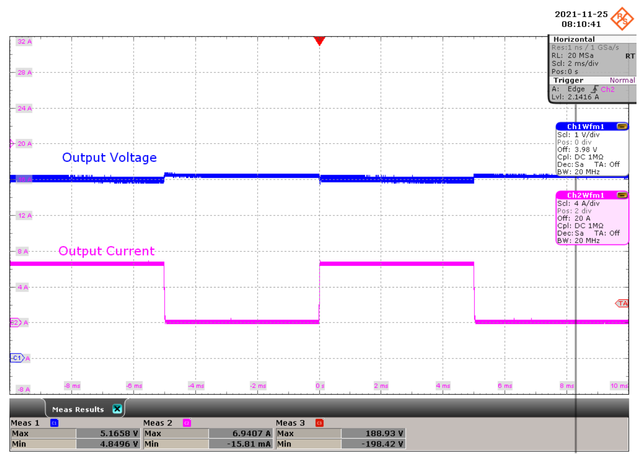


Figure 78 – 132 VAC 60 Hz, 0-6.5 A Transient Load.
CH1(Blue): V_{OUT}, 1 V / div., 2 ms / div.
CH2(Pink): I_{OUT}, 4 A / div.
$V_{OUT(MAX)}$ = 5.17 V, $V_{OUT(MIN)}$ = 4.84 V.

11.5 *Output Ripple Voltage Waveforms*

Tested at room ambient temperature using an E-load at constant current mode setting.

11.5.1 Output Ripple Voltage at V_{OUT} = 20 VDC / 3.5 A

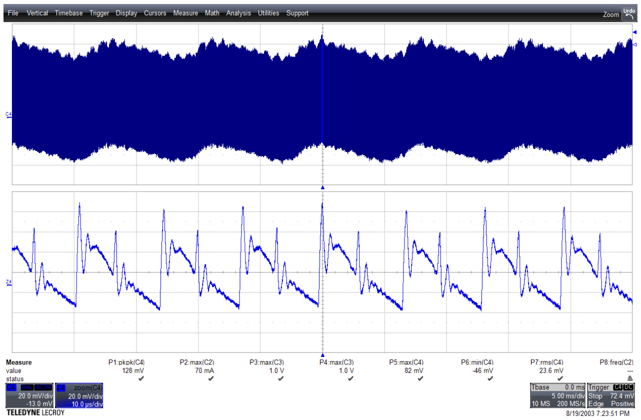


Figure 79 – 100 VAC 60 Hz, Full Load Normal.
Upper:V_{OUT}, 20 mV / div., 5 ms / div.
V_{RIPPLE} = 128 mV.

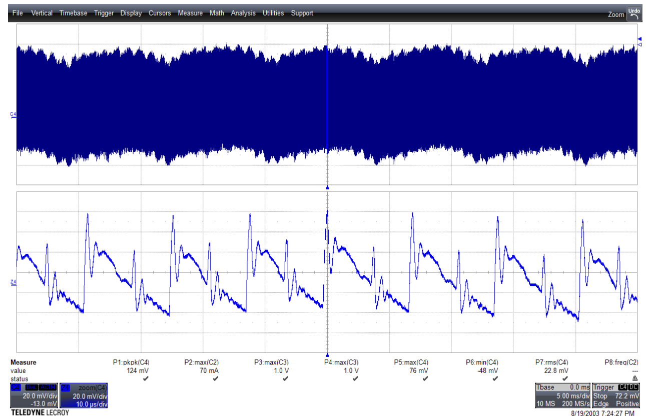


Figure 80 – 132 VAC 60 Hz, Full Load Normal.
Upper:V_{OUT}, 20 mV / div., 10 ms / div.
V_{RIPPLE} = 124 mV.

11.5.2 Output Ripple Voltage at V_{OUT} = 15 VDC / 4 A

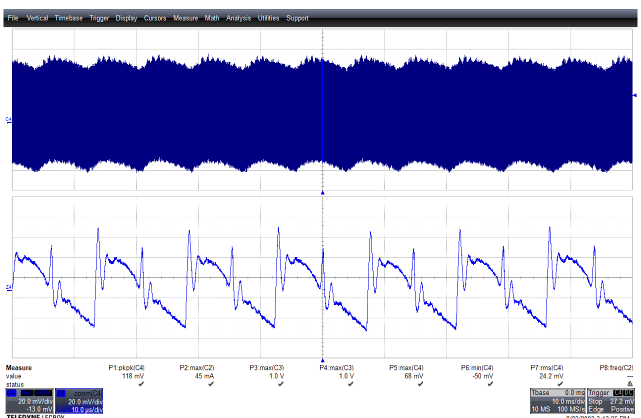


Figure 81 – 100 VAC 60 Hz, Full Load Normal.
Upper:V_{OUT}, 20 mV / div., 10 ms / div.
V_{RIPPLE} = 118 mV.

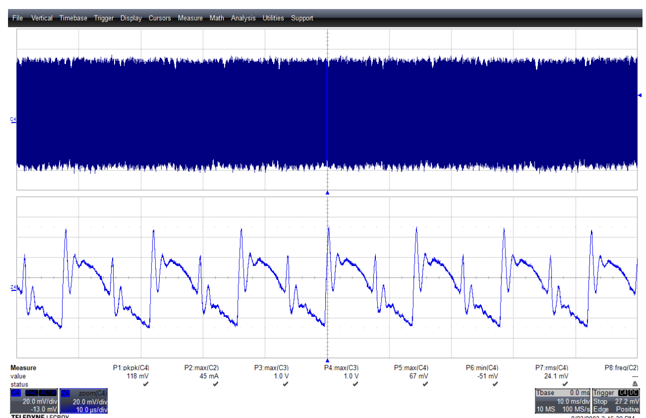


Figure 82 – 132 VAC 60 Hz, Full Load Normal.
Upper:V_{OUT}, 20 mV / div., 10 ms / div.
V_{RIPPLE} = 118 mV.

11.5.3 Output Ripple Voltage at V_{OUT} = 9 VDC / 5 A

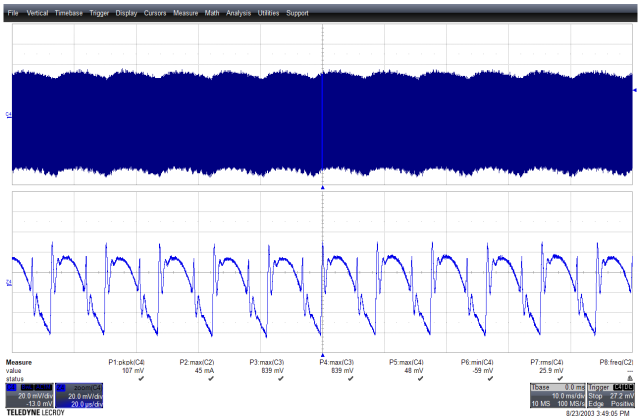


Figure 83 – 100 VAC 60 Hz, Full Load Normal.
Upper:V_{OUT}, 20 mV / div., 10 ms / div.
V_{RIPPLE} = 107 mV.

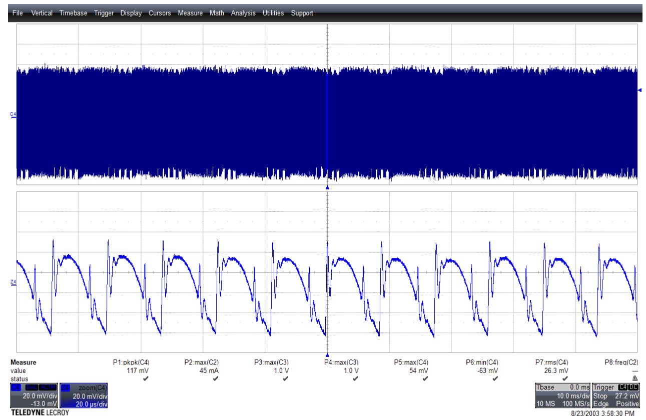


Figure 84 – 132 VAC 60 Hz, Full Load Normal.
Upper:V_{OUT}, 20 mV / div., 10 ms / div.
V_{RIPPLE} = 117 mV.

11.5.4 Output Ripple Voltage at V_{OUT} = 5 VDC / 6.5 A

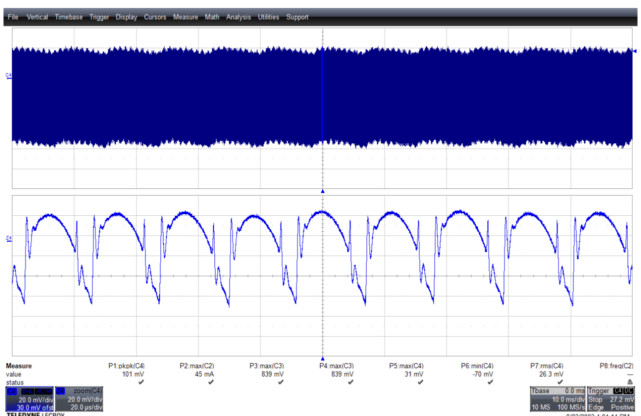


Figure 85 – 100 VAC 60 Hz, Full Load Normal.
Upper:V_{OUT}, 20 mV / div., 10 ms / div.
V_{RIPPLE} = 101 mV.

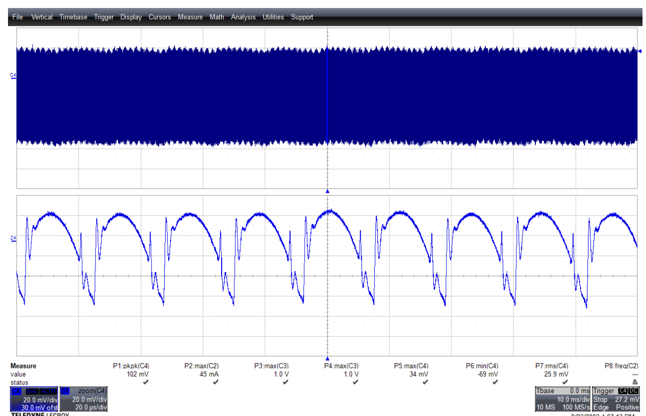


Figure 86 – 132 VAC 60 Hz, Full Load Normal.
Upper:V_{OUT}, 20 mV / div., 10 ms / div.
V_{RIPPLE} = 102 mV.

11.6 *Output Short-Circuit*

11.6.1 Output Short-Circuit

Waveforms are captured during the unit was running with an output shorted

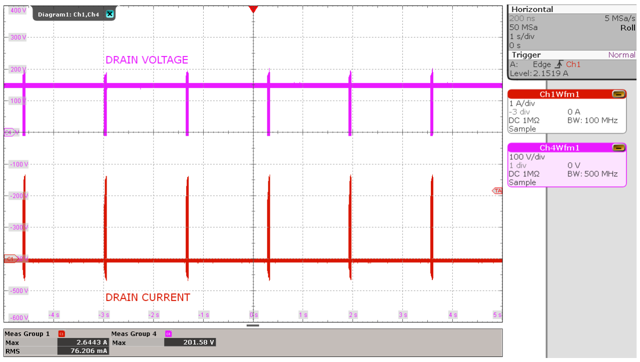


Figure 87 – 100 VAC 60 Hz, Output Short Normal.
CH4(Pink): V_D, 100 V / div., 1 s / div.
CH1(Red): I_D, 1 A / div.

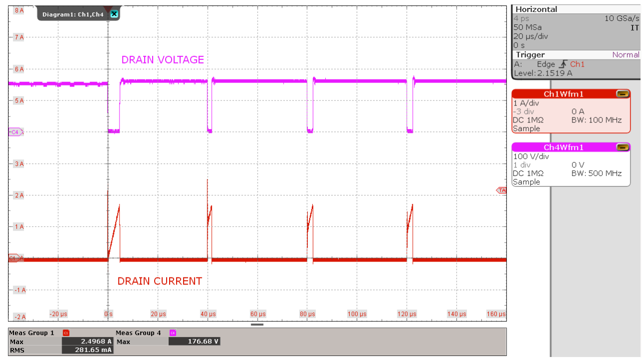


Figure 88 – 100 VAC 60 Hz, Output Short Normal.
Zoom In.
CH4(Pink): V_D, 100 V / div., 20 µs / div.
CH1(Red): I_D, 1 A / div.

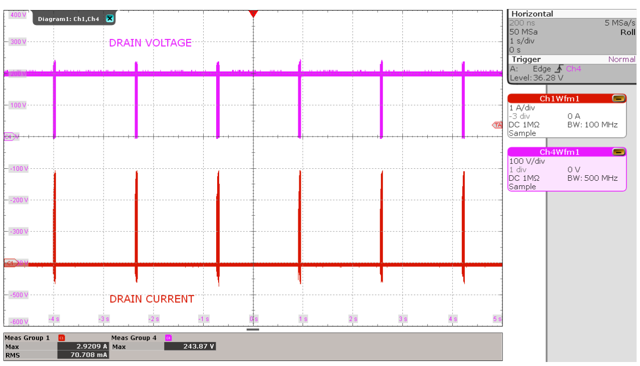


Figure 89 – 132 VAC 60 Hz, Output Short Normal.
CH4(Pink): V_D, 100 V / div., 1 s / div.
CH1(Red): I_D, 1 A / div.

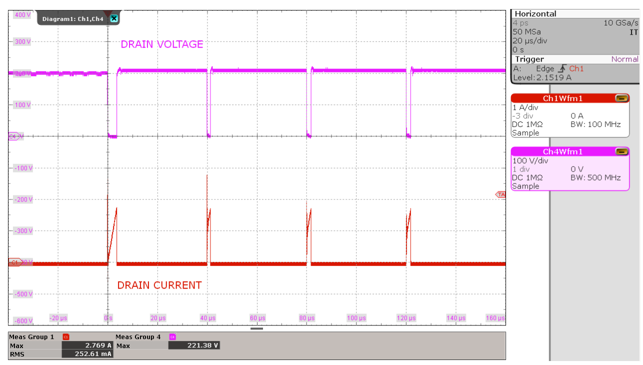


Figure 90 – 132 VAC 60 Hz, Output Short Normal.
Zoom In.
CH4(Pink): V_D, 100 V / div., 20 µs / div.
CH1(Red): I_D, 1 A / div.

11.6.2 Start-Up with Output Shorted

Note: Unit was powered up with output shorted.

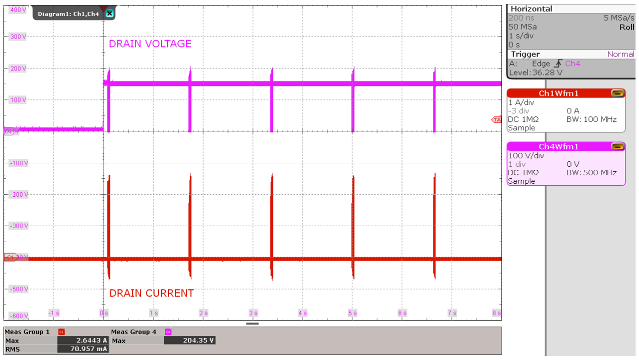


Figure 91 – 100 VAC 60 Hz, Short-Start-up.
CH4(Pink): V_D, 100 V / div., 1 s / div.
CH1(Red): I_D, 1 A / div.

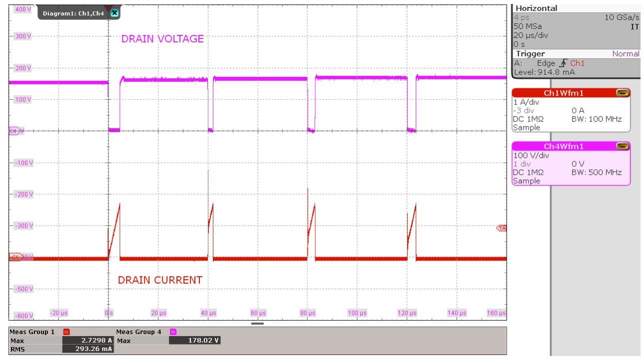


Figure 92 – 100 VAC 60 Hz, Short-Start-up.
Zoom In.
CH4(Pink): V_D, 100 V / div., 20 μs / div.
CH1(Red): I_D, 1 A / div.

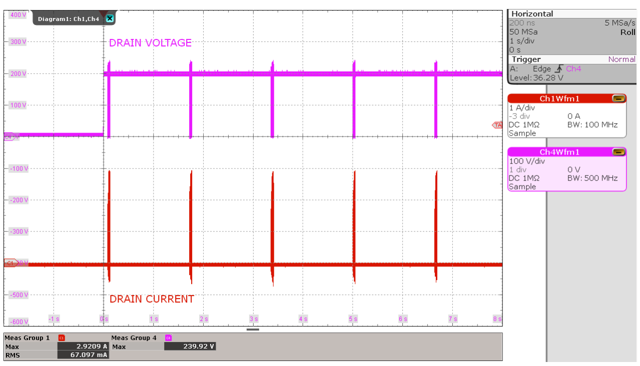


Figure 93 – 132 VAC 60 Hz, Short-Start-up
CH4(Pink): V_D, 100 V / div., 1 s / div.
CH1(Red): I_D, 1 A / div.

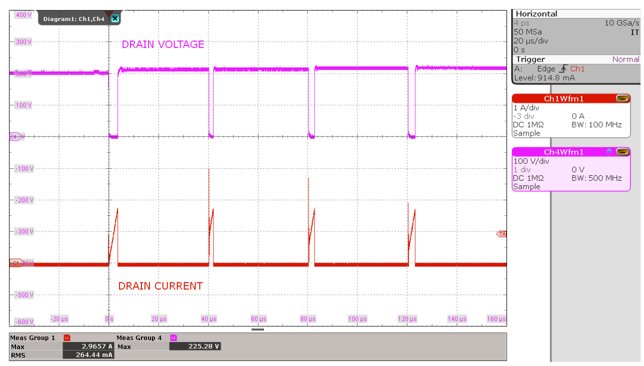


Figure 94 – 132 VAC 60 Hz, Short-Start-up.
Zoom In.
CH4(Pink): V_D, 100 V / div., 20 μs / div.
CH1(Red): I_D, 1 A / div.

12 Conducted EMI

12.1 *Test Set-up*

EMI measurement was done using a resistor load.

12.2 *Equipment and Load Used*

1. Rohde and Schwarz ENV216 two-line V-network.
2. Rohde and Schwarz ESRP EMI test receiver.
3. Variable Voltage Transformer set at 115 VAC

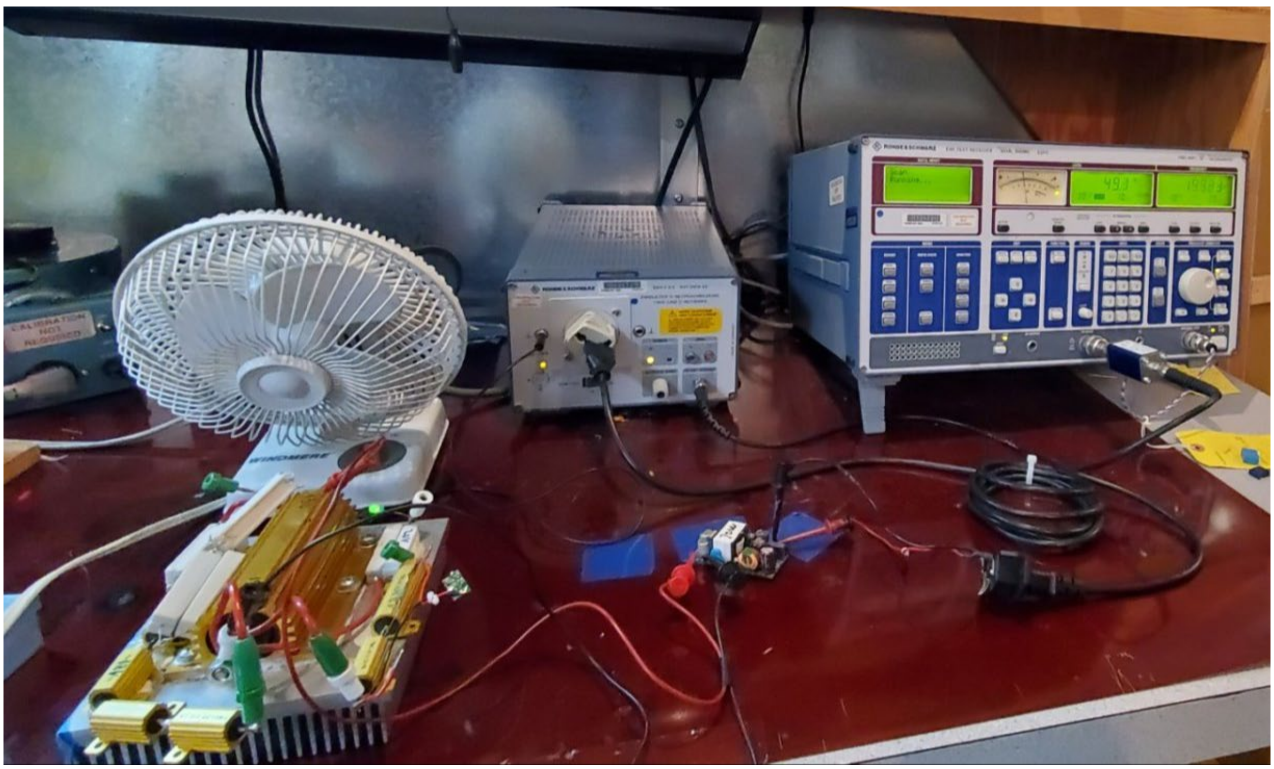
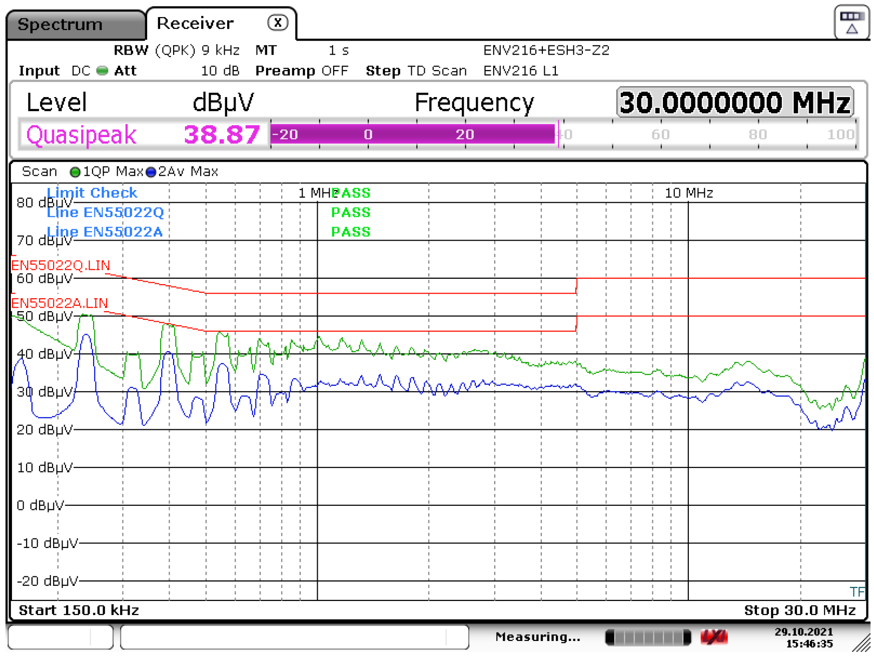


Figure 95 – Conducted EMI Test Set-up.

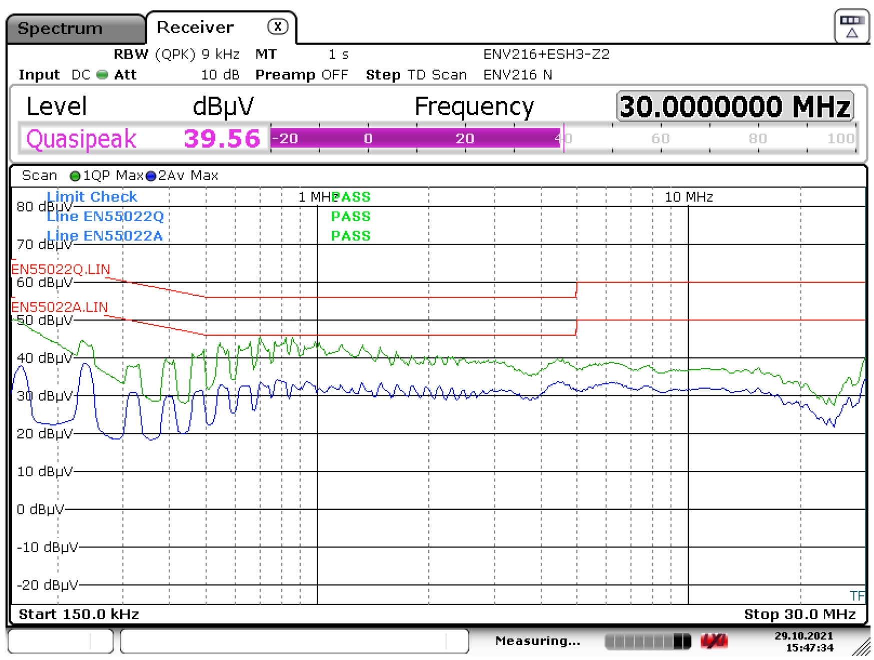
12.3 *Conducted EMI at V_{OUT} = 20 V Full Load with Output Floating*

12.3.1 Output Load: 5.71 Ω (20 V / 3.5 A) Fixed Resistor



Date: 29.OCT.2021 15:46:35

Figure 96 – Conducted EMI (LIVE) at V_{OUT} = 20 V Full Load, 115 VAC 60 Hz, Floating Output.



Date: 29.OCT.2021 15:47:34

Figure 97 – Conducted EMI (NEUTRAL) at V_{OUT} = 20 V Full Load, 115 VAC 60 Hz, Floating Output.

12.4 *Conducted EMI at V_{OUT} = 15 V Full Load with Output Floating*

12.4.1 Output Load: 3.75 Ω (15 V / 4 A) Fixed Resistor

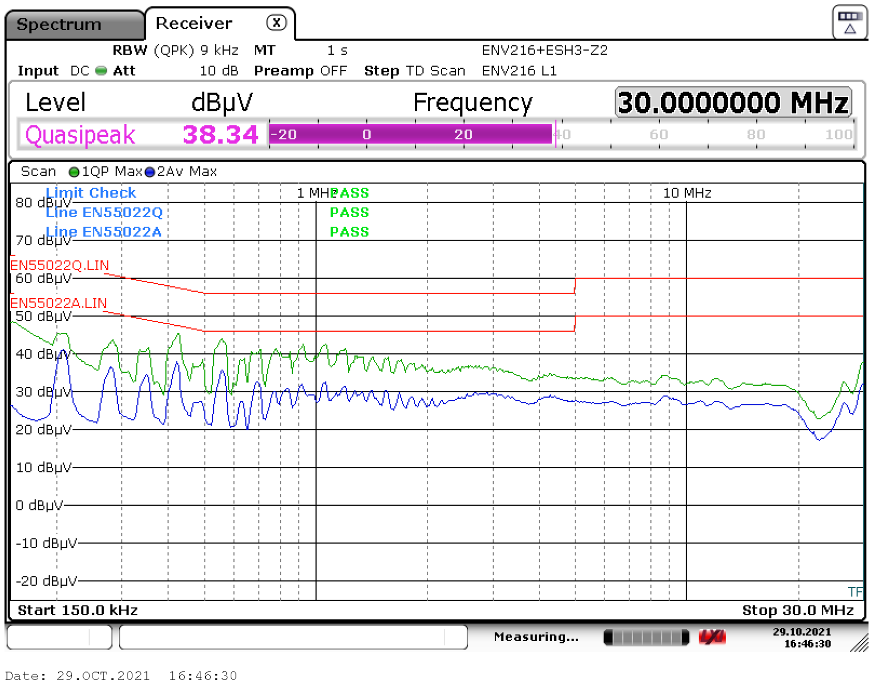


Figure 98 – Conducted EMI (LIVE) at V_{OUT} = 15 V Full Load, 115 VAC 60 Hz, Floating Output.

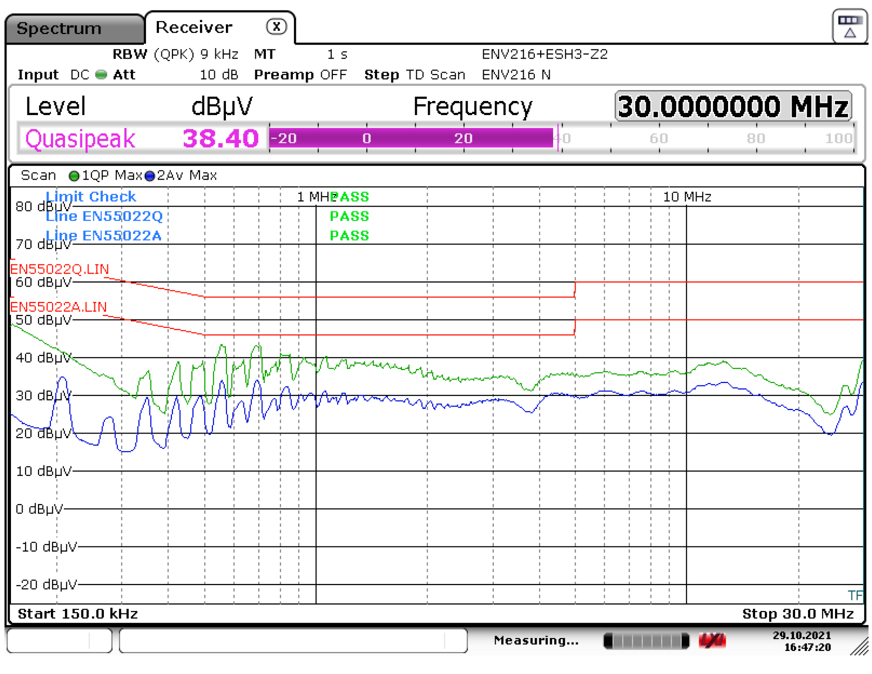


Figure 99 – Conducted EMI (NEUTRAL) at V_{OUT} = 15 V Full Load, 115 VAC 60 Hz, Floating Output.

12.5 *Conducted EMI at V_{OUT} = 9 V Full Load with Output Floating*

12.5.1 Output Load: 1.8 Ω (9 V / 5 A) Fixed Resistor

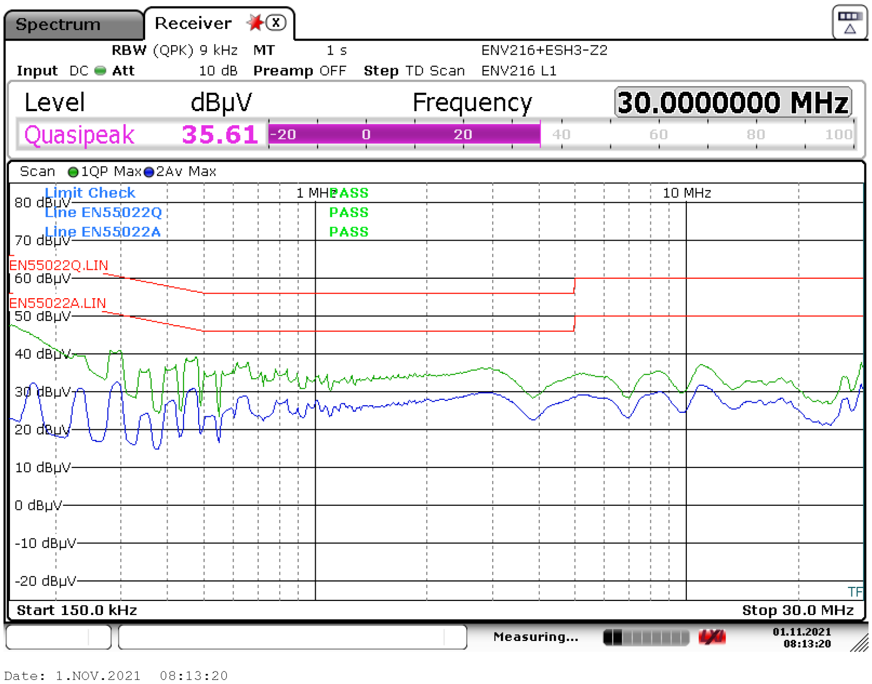


Figure 100 – Conducted EMI (LIVE) at V_{OUT} = 9 V Full Load, 115 VAC 60 Hz, Floating Output.

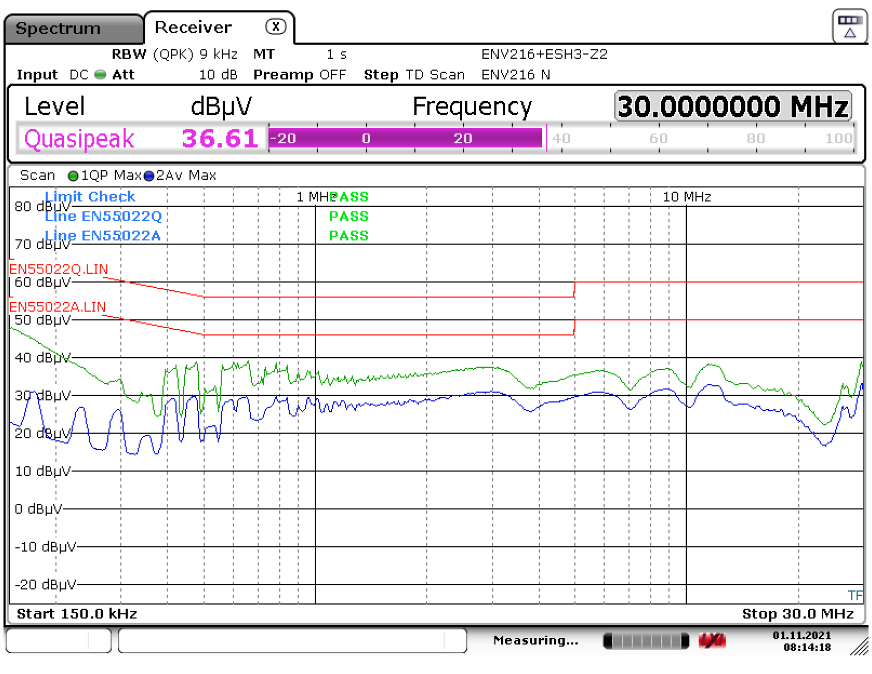


Figure 101 – Conducted EMI (NEUTRAL) at V_{OUT} = 9 V Full Load, 115 VAC 60 Hz, Floating Output.

12.6 *Conducted EMI at V_{OUT} = 5 V Full Load with Output Floating*

12.6.1 Output Load: 0.77 Ω (5 V / 6.5 A) Fixed Resistor

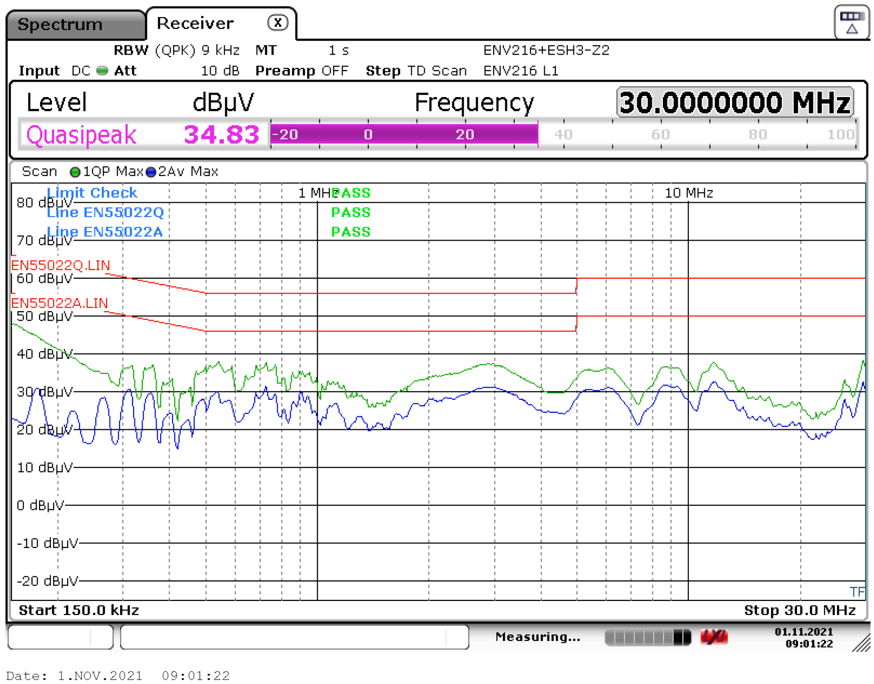


Figure 102 – Conducted EMI (LIVE) at V_{OUT} = 5 V Full Load, 115 VAC 60 Hz, Floating Output

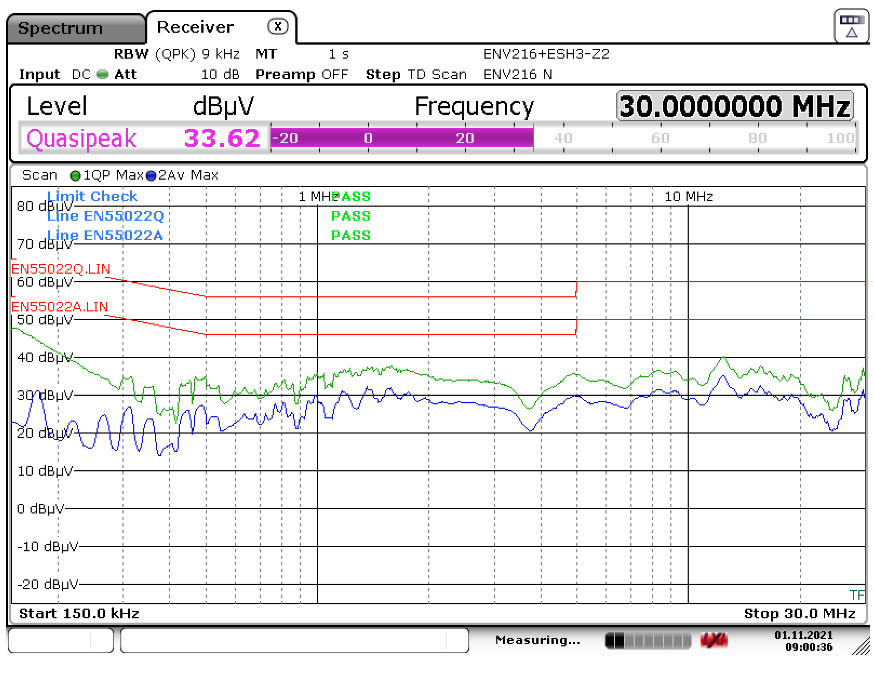


Figure 103 – Conducted EMI (NEUTRAL) at V_{OUT} = 5 V Full Load, 115 VAC 60 Hz, Floating Output

13 Line Immunity

Output Load set at max load (20 V / 3.5 A) using a 5.7 Ω fixed resistor

13.1 *Differential Surge Test Results*

Source Impedance: 2Ω
Repetition Rate: 1/30 s
No. of surge strike per location: 10 strikes

Differential Surge (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2000	120	L to N	0	Pass / Class A
+2000	120	L to N	90	Pass / Class A
+2000	120	L to N	270	Pass / Class A
-2000	120	L to N	0	Pass / Class A
-2000	120	L to N	90	Pass / Class A
-2000	120	L to N	270	Pass / Class A

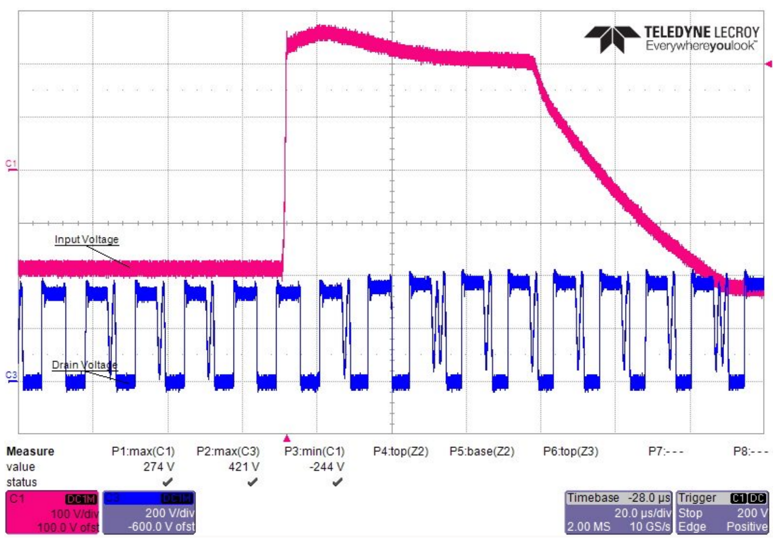


Figure 104 – 120 VAC 60 Hz, +2 kV Differential Surge L-N.
Injection Phase: 90º.
Upper: V_{IN}, 100 V / div.
Lower: V_{DRAIN}, 200 V / div., 20 µs / div.
V_{DS} = 421 V.

13.2 *Ring Wave Surge Test Results*

Source Impedance: 12Ω
Repetition Rate: 1/30 s
No. of surge strike per location: 10 strikes

Differential Ringwave Voltage (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	230	L to N	0	Pass/ Class A
+2500	230	L to N	90	Pass/ Class A
+2500	230	L to N	270	Pass/ Class A
-2500	230	L to N	0	Pass/ Class A
-2500	230	L to N	90	Pass/ Class A
-2500	230	L to N	270	Pass/ Class A

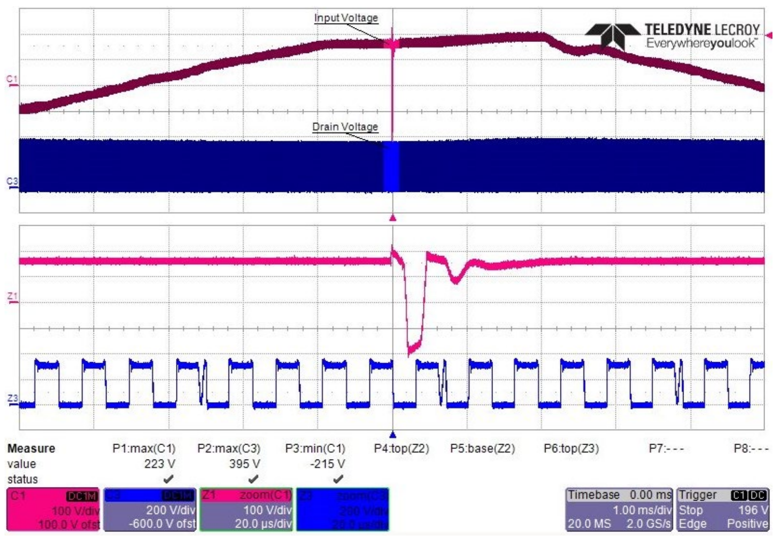


Figure 105 – 120 VAC 60 Hz, 2.5kV Ring Wave L-N.
Injection Phase: 90º.
Upper: V_{IN}, 100 V / div.
Lower: V_{DRAIN}, 200 V / div., 1 ms / div.
V_{DS} = 395 V.

13.3 *Electrical Fast Transients (EFT) Test Results*

Tested at 5 kHz and 100 kHz EFT Burst frequency. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage.

13.3.1 5 kHz EFT

Test Voltage (V)	Input Voltage (VAC)	Test Time (s)	Frequency (kHz)	Burst Duration (ms)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)	Remarks
2000	115	60	5	15	L to N	0	Pass	No AR/No damage
-2000	115	60	5	15	L to N	0	Pass	No AR/No damage
2000	115	60	5	15	L to N	90	Pass	No AR/No damage
-2000	115	60	5	15	L to N	90	Pass	No AR/No damage
2000	115	60	5	15	L to N	270	Pass	No AR/No damage
-2000	115	60	5	15	L to N	270	Pass	No AR/No damage
4000	115	60	5	15	L to N	0	Pass	No AR/No damage
-4000	115	60	5	15	L to N	0	Pass	No AR/No damage
4000	115	60	5	15	L to N	90	Pass	No AR/No damage
-4000	115	60	5	15	L to N	90	Pass	No AR/No damage
4000	115	60	5	15	L to N	270	Pass	No AR/No damage
-4000	115	60	5	15	L to N	270	Pass	No AR/No damage

13.3.2 100 kHz EFT

Test Voltage (V)	Input Voltage (VAC)	Test Time (s)	Frequency (kHz)	Burst Duration (μs)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)	Remarks
2000	115	60	100	750	L to N	0	Pass	No AR / No Damage
-2000	115	60	100	750	L to N	0	Pass	No AR / No Damage
2000	115	60	100	750	L to N	90	Pass	No AR / No Damage
-2000	115	60	100	750	L to N	90	Pass	No AR / No Damage
2000	115	60	100	750	L to N	270	Pass	No AR / No Damage
-2000	115	60	100	750	L to N	270	Pass	No AR / No Damage
4000	115	60	100	750	L to N	0	Pass	With AR / No Damage
-4000	115	60	100	750	L to N	0	Pass	No AR / No Damage
4000	115	60	100	750	L to N	90	Pass	With AR / No Damage
-4000	115	60	100	750	L to N	90	Pass	No AR / No Damage
4000	115	60	100	750	L to N	270	Pass	No AR / No Damage
-4000	115	60	100	750	L to N	270	Pass	No AR / No Damage

14 ESD

Unit was subjected to ±8 kV ESD contact discharge test and ±8 kV ESD to ±15 kV ESD air discharge test. An LED indicator connected across the resistor load was used to observe the output behavior during to ESD. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage.

Note: Output Load set at max load (20 V / 3 A) using a 6.67 Ω Fixed Resistor

14.1 *ESD Contact Discharge 20 V 3.5 A Output (End of Output Cable)*

No.	Test Voltage (kV)	No. of Strikes	Discharge Location	Remarks	Pass / Fail
1	+8	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	-8	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass

14.2 *ESD Contact Discharge 5 V 6.5 A Output (End of Output Cable)*

No.	Test Voltage (kV)	No. of Strikes	Discharge Location	Remarks	Pass / Fail
1	+8	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	-8	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass

14.3 *ESD Air Discharge 20 V 3.5 A Output (End of Output Cable)*

No.	Test Voltage (kV)	No. of Strikes	Discharge Location	Remarks	Pass / Fail
1	+8	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	-8	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	+12	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	-12	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	+15	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	-15	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass

14.4 *ESD Air Discharge 5 V 6.5 A Output (End of Output Cable)*

No.	Test Voltage (kV)	No. of Strikes	Discharge Location	Remarks	Pass / Fail
1	+8	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	-8	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	+12	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	-12	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	+15	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
1	-15	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass

15 Brown-Out / Brown-Out Recovery Test

No abnormal overheating or voltage overshoot/undershoot was observed during and after 0.5 V / s. The unit works normally after the brown-out test.

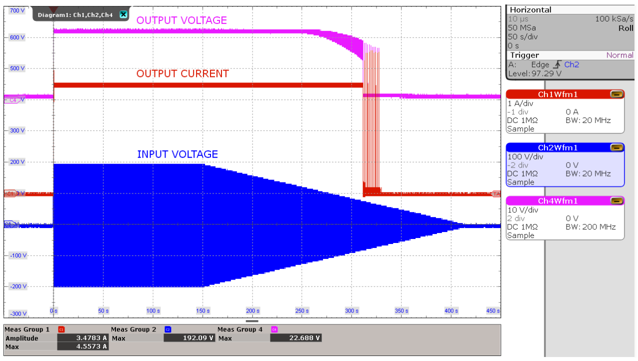


Figure 106 – Brown-Out at V_{OUT} = 20 V.
V_{IN} = 132 V – 0 V, Slew Rate = 0.5 V / s.
CH1(Red): I_{OUT}, 1 A / div., 50 s / div.
CH2(Blue): V_{IN}, 100 V / div.
CH4(Pink): V_{OUT}, 10 V / div.

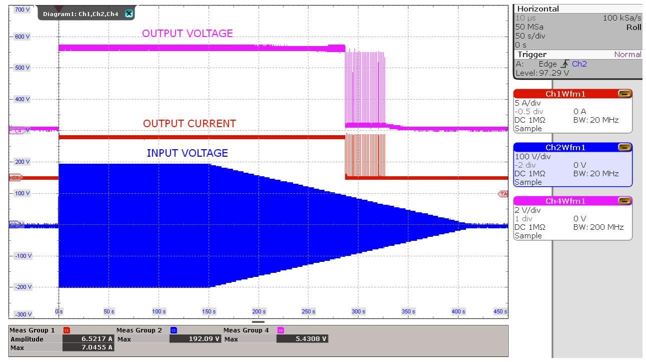


Figure 107 – Brown-in at V_{OUT} = 5 V.
V_{IN} = 0 V – 132 V, Slew Rate = 0.5 V / s.
CH1(Red): I_{OUT}, 5 A / div., 50 s / div.
CH2(Blue): V_{IN}, 100 V / div.
CH4(Pink): V_{OUT}, 2 V / div.

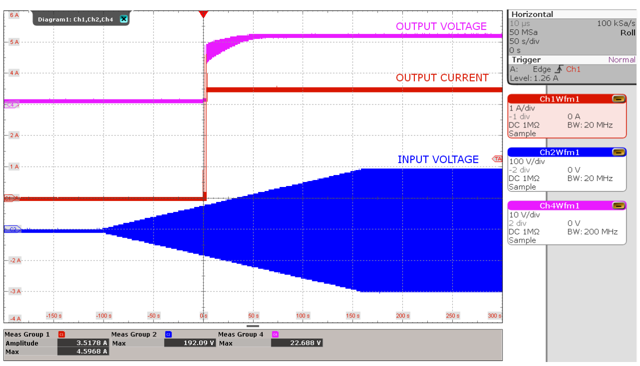


Figure 108 – Brown-Out at V_{OUT} = 20 V.
V_{IN} = 132 V – 0 V, Slew Rate = 0.5 V / s.
CH1(Red): I_{OUT}, 1 A / div., 50 s / div.
CH2(Blue): V_{IN}, 100 V / div.
CH4(Pink): V_{OUT}, 10 V / div.

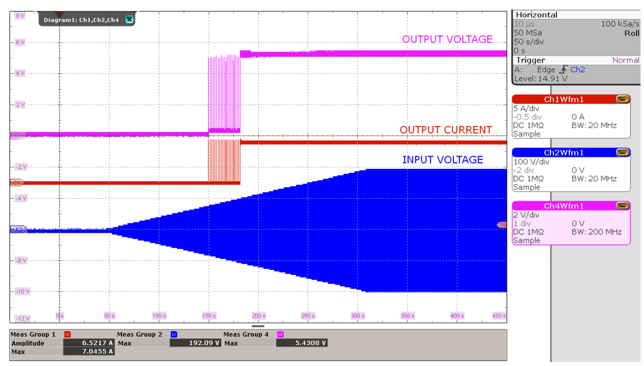


Figure 109 – Brown-in at V_{OUT} = 5 V.
V_{IN} = 0 V – 132 V, Slew Rate = 0.5 V / s.
CH1(Red): I_{OUT}, 5 A / div., 50 s / div.
CH2(Blue): V_{IN}, 100 V / div.
CH4(Pink): V_{OUT}, 2 V / div.

16 Revision History

Date	Author	Revision	Description and Changes	Reviewed
23-Mar-22	MGM/MB	1.0	Initial release	Apps & Mktg

For the latest updates, visit our website: www.power.com

Power Integrations Worldwide Sales Support Locations

WORLD HEADQUARTERS
5245 Hellyer Avenue
San Jose, CA 95138, USA.
Main: +1-408-414-9200
Customer Service:
Worldwide: +1-65-635-64480
Americas: +1-408-414-9621
e-mail: usasales@power.com

CHINA (SHANGHAI)
Rm 2410, Charity Plaza, No. 88,
North Caoxi Road,
Shanghai, PRC 200030
Phone: +86-21-6354-6323
e-mail: chinasales@power.com

CHINA (SHENZHEN)
17/F, Hivac Building, No. 2, Keji
Nan 8th Road, Nanshan District,
Shenzhen, China, 518057
Phone: +86-755-8672-8689
e-mail: chinasales@power.com

GERMANY (AC-DC/LED Sales)
Einsteinring 24
85609 Dornach/Aschheim
Germany
Tel: +49-89-5527-39100
e-mail: eurosales@power.com

GERMANY (Gate Driver Sales)
HellwegForum 1
59469 Ense
Germany
Tel: +49-2938-64-39990
e-mail: igbt-driver.sales@
power.com

INDIA
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
e-mail: indiasales@power.com

ITALY
Via Milanese 20, 3rd. Fl.
20099 Sesto San Giovanni (MI) Italy
Phone: +39-024-550-8701
e-mail: eurosales@power.com

JAPAN
Yusen Shin-Yokohama 1-chome Bldg.
1-7-9, Shin-Yokohama, Kohoku-ku
Yokohama-shi,
Kanagawa 222-0033 Japan
Phone: +81-45-471-1021
e-mail: japansales@power.com

KOREA
RM 602, 6FL
Korea City Air Terminal B/D,
159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728 Korea
Phone: +82-2-2016-6610
e-mail: koreasales@power.com

SINGAPORE
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
e-mail:
singaporesales@power.com

TAIWAN
5F, No. 318, Nei Hu Rd.,
Sec. 1
Nei Hu District
Taipei 11493, Taiwan R.O.C.
Phone: +886-2-2659-4570
e-mail: taiwansales@power.com

UK
Building 5, Suite 21
The Westbrook Centre
Milton Road
Cambridge
CB4 1YG
Phone: +44 (0) 7823-557484
e-mail: eurosales@power.com