Reference Design Report

Title	**15 W Automotive Power Supply Using InnoSwitch3-AQ INN3996CQ and Qspeed LQ10N200CQ with Planar Transformer**
Specification	40 VDC – 500 VDC Input; 15 V / 1 A Output
Application	Traction Inverter Gate-Driver Power Supply or Emergency Power Supply
Author	Automotive Systems Engineering Department
Document Number	RDR-1109Q
Date	May 28, 2026
Revision	1

Summary and Features

- Ultra-compact design for 400 VDC Automotive Battery Electric Vehicle (BEV) applications
- Low component count (only 36 electrical components)
- InSOP24 (C) package provides >5 mm Drain to Source pin spacing
- Wide-range start-up and operating voltage from <100 VDC to 500 VDC
- Planar transformer with reinforced isolation up to 500 VDC input and complies with Hi-Pot requirements (IEC-60664-1 and IEC-60664-4)
- ≥70% full load efficiency across the input voltage range
- Accurate secondary-side regulation without optocouplers
- Provides continuous 15 W output from -40 °C to 85 °C
- Comprehensive fault protection, including output current limit and short-circuit
- Uses automotive-qualified AEC-Q surface-mount (SMD) components
- Low profile: 16.8 mm high

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/.

Table of Contents

1 Introduction 5
2 Design Specification 7
  2.1 Electrical Specification 7
  2.2 Isolation 8
  2.3 Environmental Specification 8
3 Schematic 9
4 PCB Layout 10
  4.1 PCB Specification 10
5 Bill of Materials 14
6 Transformer Specification 16
  6.1 Electrical Diagram 16
  6.2 Electrical Specifications 17
  6.3 Material List 17
7 Transformer Design Spreadsheet 18
8 Hi-Pot Testing for Transformer 24
9 Performance Data 26
  9.1 No-Load Input Power 27
  9.2 Efficiency 28
  9.3 Load Regulation 29
10 Thermal Performance 30
  10.1 Thermal Data at 85 °C Ambient 30
  10.2 Thermal Data at 25 °C Ambient 32
11 Waveforms 34
  11.1 Start-Up Waveforms 34
    11.1.1 Output Voltage and Current at 25 °C Ambient 34
    11.1.2 InnoSwitch3-AQ Drain Voltage and Current at 25 °C Ambient 36
    11.1.3 Q-Speed Diode Voltage and Current at 25 °C Ambient 38
  11.2 Steady-State Waveforms 40
    11.2.1 Switching Waveforms at 25 °C Ambient 40
  11.3 Load Transient Response 46
    11.3.1 Output Voltage Ripple with 0% - 50% - 0% Transient Load at 25 °C Ambient 47
    11.3.2 Output Voltage Ripple with 50% - 100% - 50% Transient Load at 25 °C Ambient 48
    11.3.3 Output Voltage Ripple with 10% - 90% - 10% Transient Load at 25 °C Ambient 49
  11.4 Output Ripple Measurements 50
    11.4.1 Ripple Measurement Technique 50
    11.4.2 Output Voltage Ripple Waveforms at 25 °C Ambient 51
    11.4.3 Output Ripple vs. Load at 25 °C Ambient 52
12 Maximum Output Power Derating 53
  12.1 Continuous Output Power 53
13 Revision History 55

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

1 Introduction

This engineering report describes a 15 W single-output automotive power supply for electric vehicles with a 400 V battery system. The design supports an ultra-wide input range of 40 VDC to 500 VDC and uses the 900 V rated INN3996CQ from the InnoSwitch™3-AQ family of ICs in an isolated flyback configuration. Likewise, the design uses the LQ10N200CQ from the Qspeed™ automotive qualified diode family for secondary rectification to serve as a low-cost solution for an Emergency Power Supply (EPS) application.

The design uses a planar transformer with reinforced isolation between the primary (high-voltage input) and secondary (low-voltage output) sides that comply with Hi-Pot test requirements. The planar transformer provides a low-profile design, ideal for applications with strict height constraints. It also offers low assembly cost and excellent transformer parameter repeatability compared to conventional wire-wound transformers.

This document contains the power supply specification, schematic, printed circuit board (PCB) layout, bill of materials (BOM), details of the magnetics, and initial performance data.

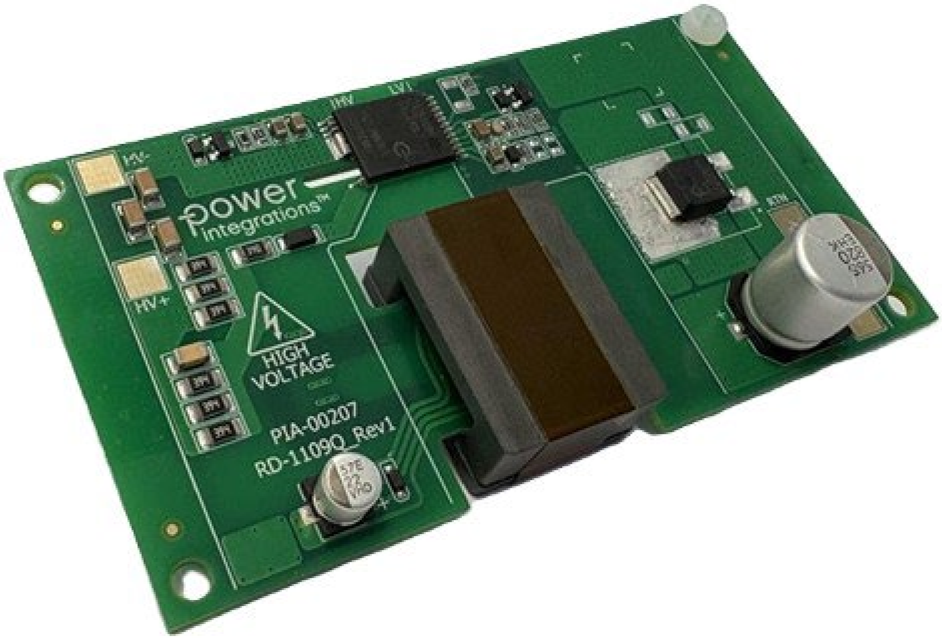


Figure 1 – Oblique View.

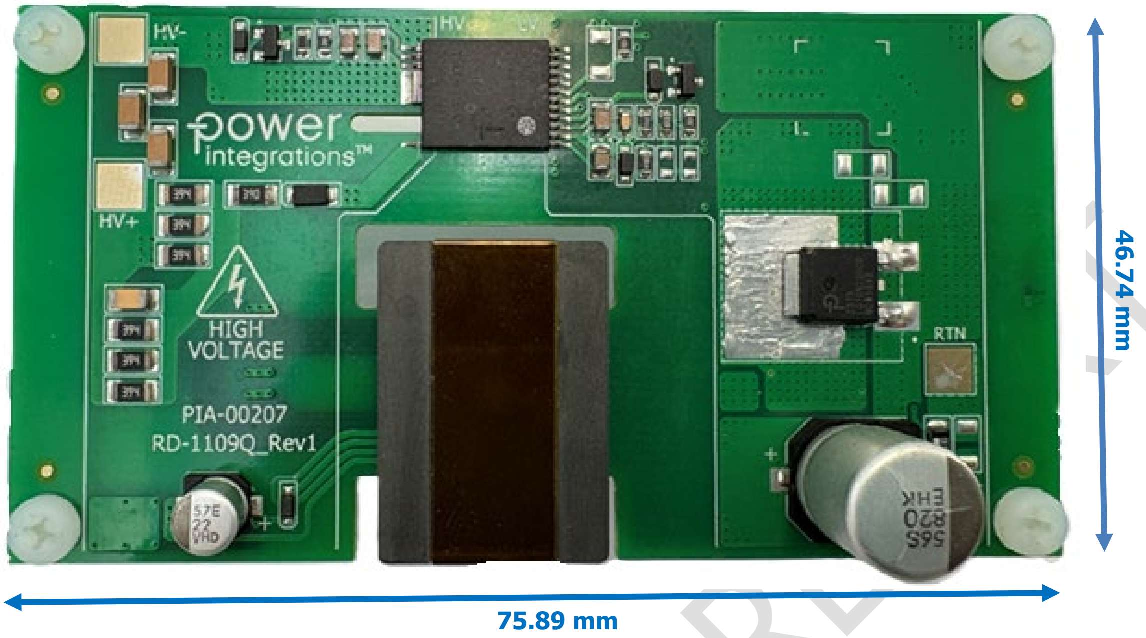


Figure 2 – Top View.

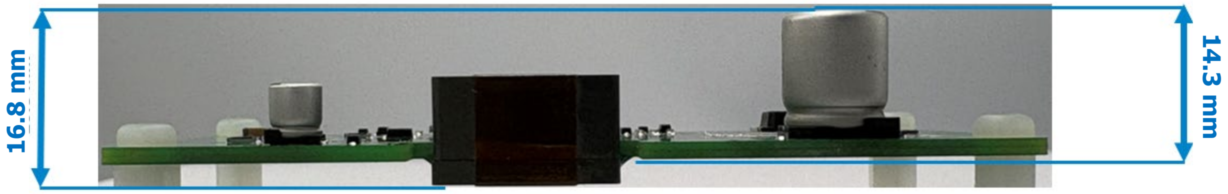


Figure 3 – Side View.

2 Design Specification

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

2.1 Electrical Specification

Description	Symbol	Min	Typ	Max	Units
Input Parameters					
Positive DC-Link Input Voltage Referenced to HV-	V_{IN}	40	400	500	VDC
Output Parameters					
Output Voltage Parameters					
Regulated Output Voltage	V_{OUT}	14.25	15	15.75	V
Output Voltage Load and Line Regulation	V_{REG}	-5		+5	%
Ripple Voltage Measured on Board	V_{RIPPLE}			500	mV
Output Current Parameters					
Output Current at 100 VDC – 500 VDC Input	I_{OUT}		1		A
Output Current at 40 VDC Input			0.67		
Output Power Parameters					
Continuous Output Power at 100 VDC – 500 VDC Input	P_{OUT}		15		W
Continuous Output Power at 40 VDC Input			10		
Output Overshoot and Undershoot During Dynamic Load Condition					
0%-50%-0% Transient Load 50%-100%-50% Transient Load 10%-90%-10% Transient Load	ΔV_{OUT}	-5		+5	%
Operating Parameters					
Operating Switching Frequency	f_{SW}			95	kHz

Table 1 – Electrical Specifications.

2.2 Isolation

Description	Symbol	Min	Typ	Max	Units
Maximum Blocking Voltage of INN3996CQ	$\mathbf{BV_{DSS}}$			900	V
System Voltage	$\mathbf{V_{SYSTEM}}$			720	V
Working Voltage	$\mathbf{V_{WORKING}}$			500	V
Pollution Degree	**PD**			2	
CTI for FR4	**CTI**	175			
Rated Impulse Voltage	$\mathbf{V_{IMPULSE}}$			4	kV
Altitude Correction Factor for h_a	$\mathbf{c_{ha}}$			1.59	
Technical Cleanliness				1.0	mm
Basic Clearance Distance Requirement	$\mathbf{CLR_{BASIC}}$	5.8			mm
Reinforced Clearance Distance Requirement	$\mathbf{CLR_{REINFORCED}}$	9.8			mm
Basic Creepage Distance Requirement for PCB	$\mathbf{CLR_{BASIC(PCB)}}$	5.8			mm
Reinforced Creepage Distance Requirement for PCB	$\mathbf{CLR_{REINFORCED(PCB)}}$	9.8			mm
Isolation Test Voltage Between Primary and Secondary-Side for 60s	$\mathbf{V_{ISO}}$			5656	V_{RMS}

Table 2 – Isolation Electrical Specifications.

2.3 Environmental Specification

Description	Symbol	Min	Typ	Max	Units
Ambient Temperature	$\mathbf{T_a}$	-40		105	°C
Altitude of Operation	$\mathbf{h_a}$			5500	m

Table 3 – Isolation Electrical Specifications.

3 Schematic

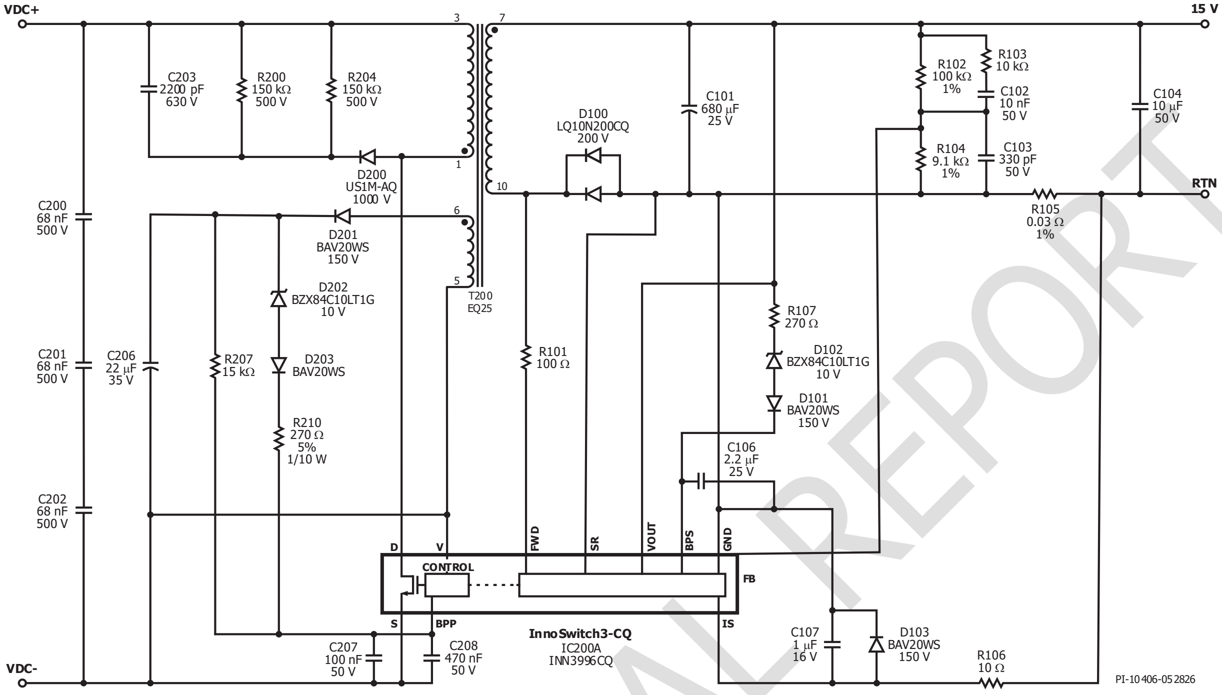


Figure 4 – Schematic.

4 PCB Layout

4.1 PCB Specification

Layer:	Six (6)
Board Material:	FR4
Board Thickness:	1.6 mm
Copper Thickness:	1 oz

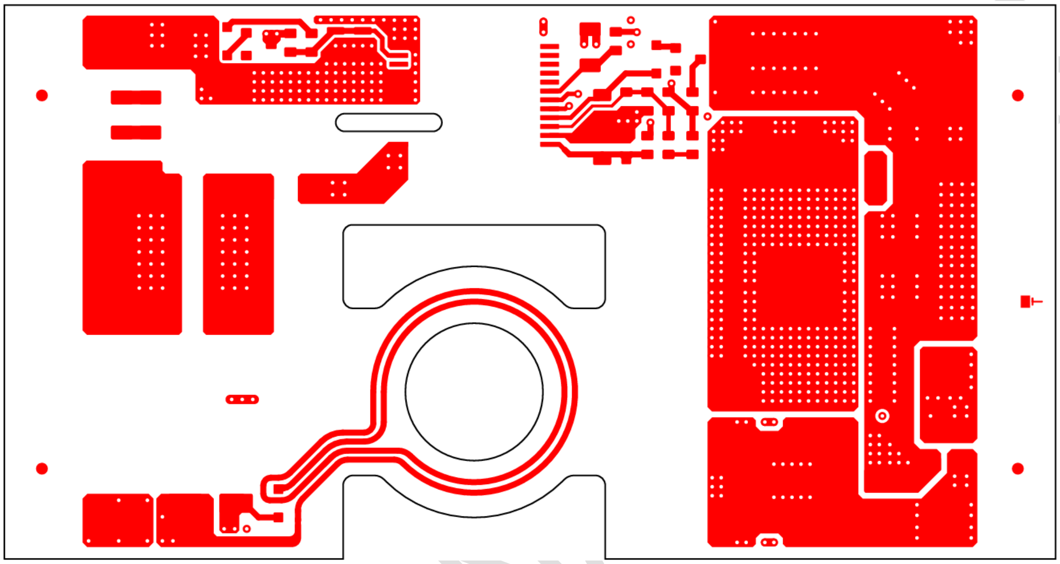


Figure 5 – RDK-1109Q Top Layer PCB Layout.

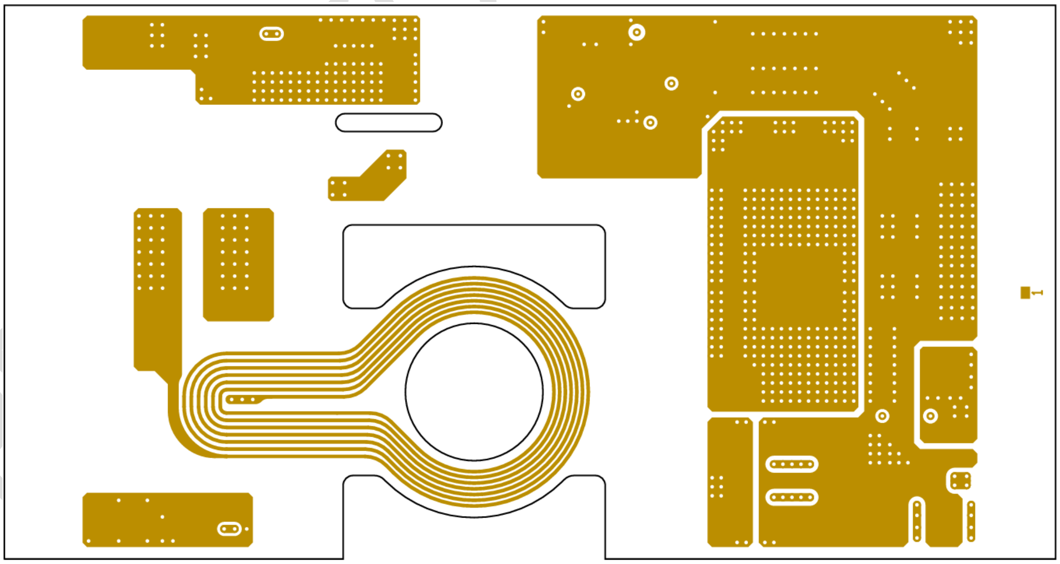


Figure 6 – RDK-1109Q Mid-Layer 1 PCB Layout.

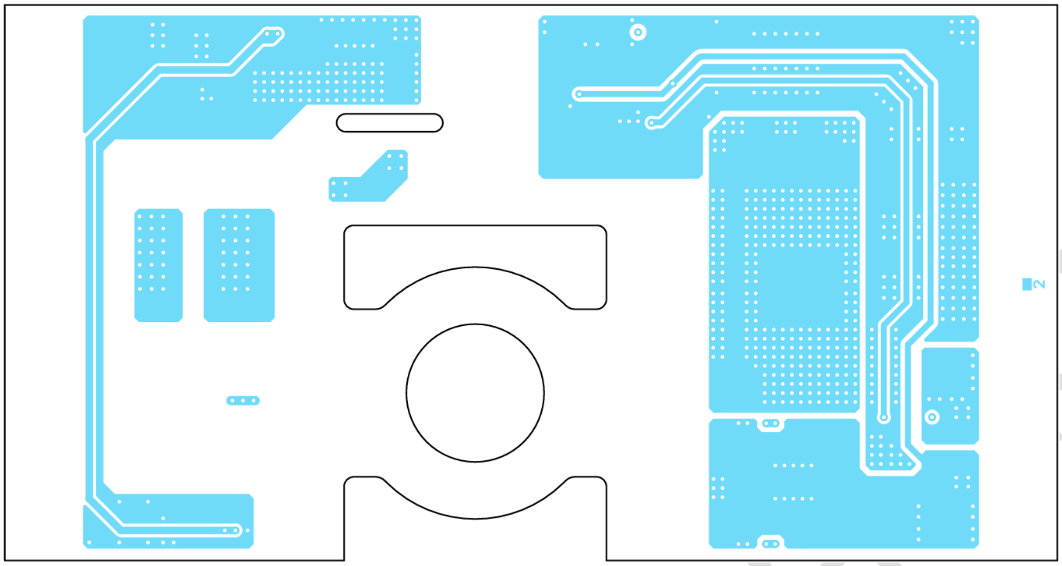


Figure 7 – RDK-1109Q Mid-Layer 2 PCB Layout.

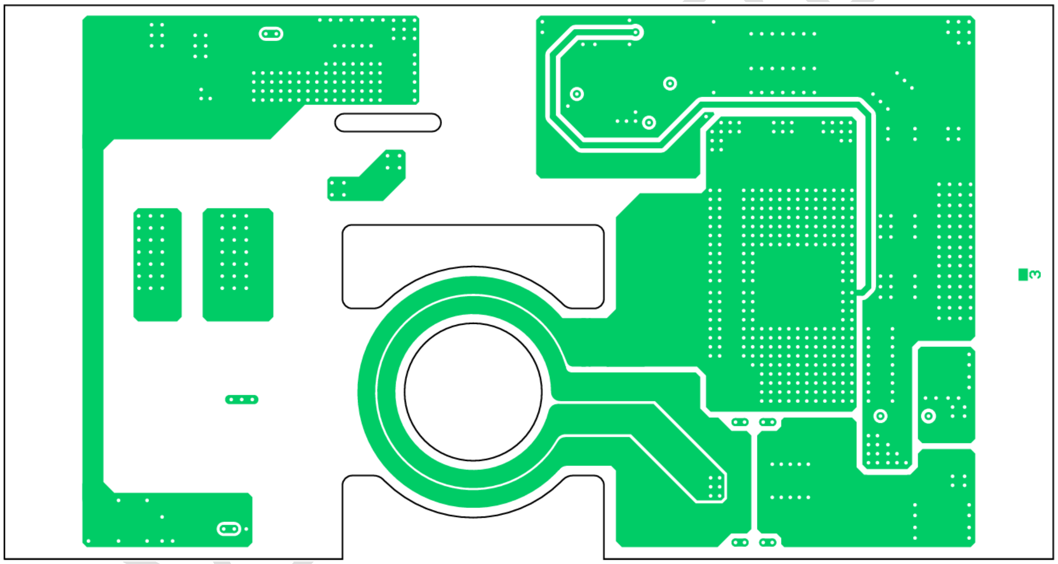


Figure 8 – RDK-1109Q Mid-Layer 3 PCB Layout.

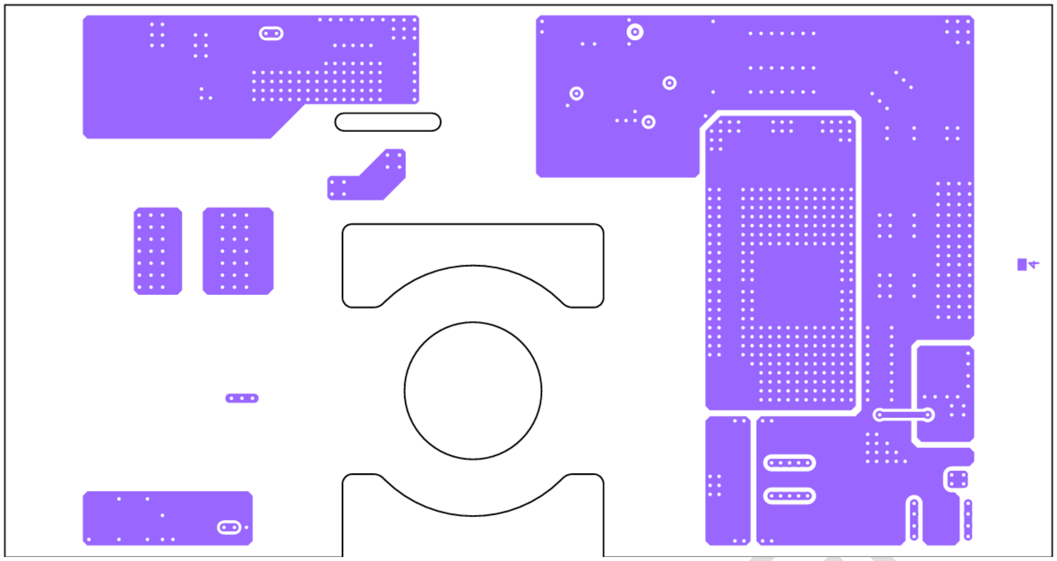


Figure 9 – RDK-1109Q Mid-Layer 4 PCB Layout.

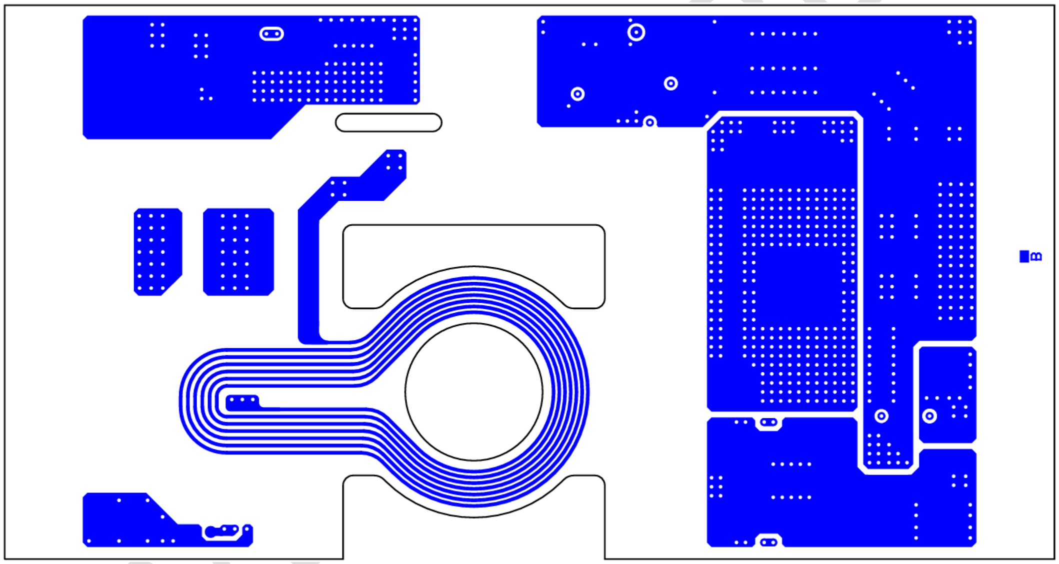


Figure 10 – RDK-1109Q Bottom Layer PCB Layout.

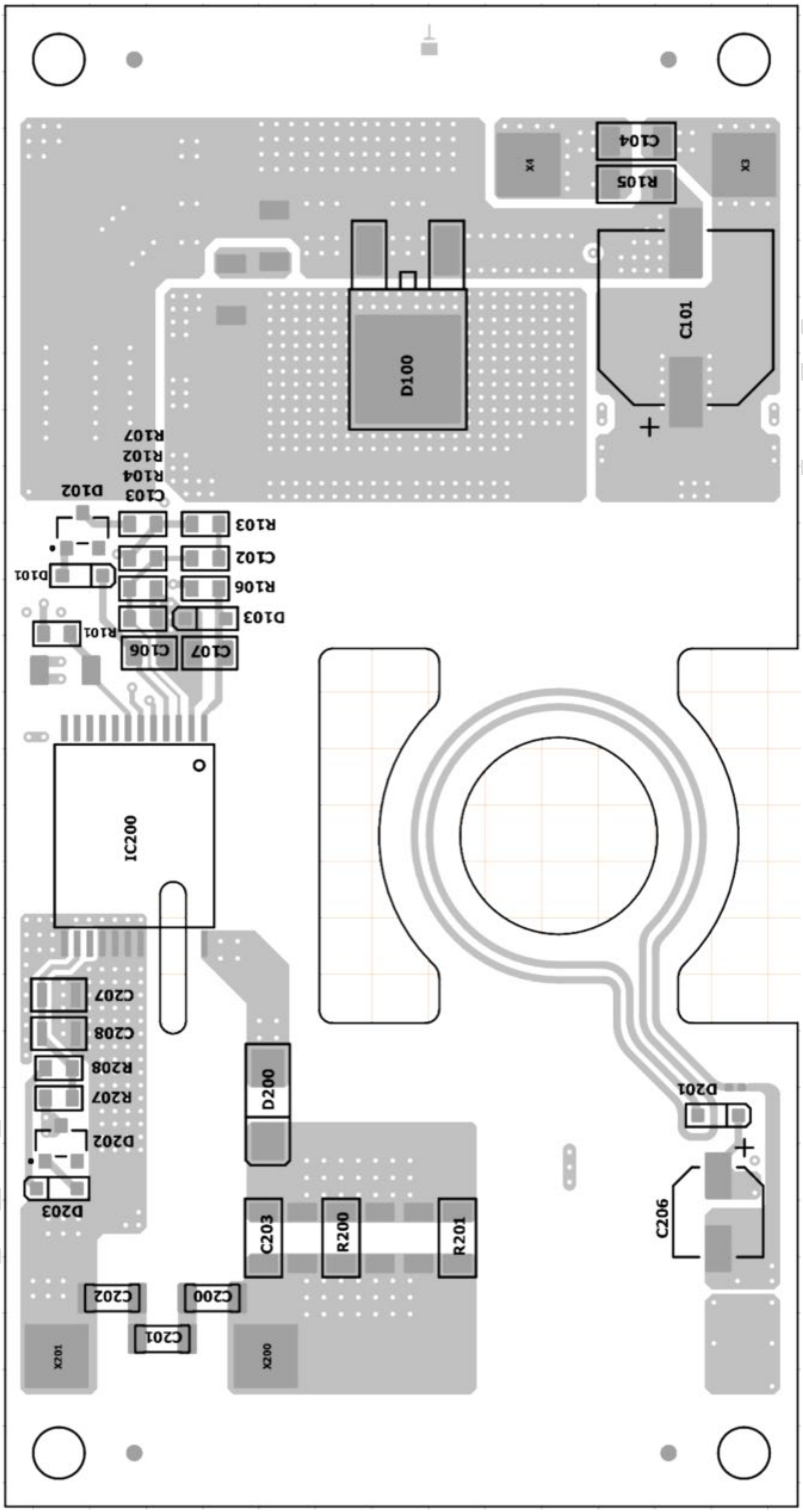


Figure 11 – RDK-1109Q PCB Assembly.

5 Bill of Materials

Item	Qty.	Designator	Description	Mfr. Part Number	Manufacturer
1	1	C101	Polymer Aluminum Capacitor 680u 25 V 20% AEC-Q200	HHXK250ARA681MJA0G	Chemi-Con
2	1	C102	Multilayer Ceramic Capacitors MLCC -SMD/SMT 10n X7R 50 V 20% 0603 AEC-Q200	C0603C103M5RACAUTO	KEMET
3	1	C103	Multilayer Ceramic Capacitors MLCC -SMD/SMT 330p X7R 50 V 10% 0603 AEC-Q200	06035C331K4T2A	KYOCERA AVX
4	1	C104	Multilayer Ceramic Capacitors MLCC -SMD/SMT 10u X7R 50 V 10% 1206 AEC-Q200	CGA5L1X7R1H106K160AC	TDK
5	1	C106	Multilayer Ceramic Capacitors MLCC -SMD/SMT 2u2 X7R 25 V 10% 0805 AEC-Q200	CGA4J3X7R1E225K125AE	TDK
6	1	C107	Multilayer Ceramic Capacitors MLCC -SMD/SMT 1u X7R 25 V 10% 0805 AEC-Q200	CL21B105KAFVPNE	Samsung Electro-Mechanics
7	3	C200, C201, C202	Multilayer Ceramic Capacitors MLCC -SMD/SMT 68n X7R 500 V 10% 1206 AEC-Q200	C1206C683KCRACAUTO	KEMET
8	1	C203	Multilayer Ceramic Capacitors MLCC -SMD/SMT 2200p X7R 630 V 10% 1206 AEC-Q200	CGA5H4X7R2J222K115AA	TDK
9	1	C206	Polymer Aluminum Capacitor 22u 35 V 20% AEC-Q200	HHXD350ARA220ME61G	Chemi-Con
10	1	C207	Multilayer Ceramic Capacitors MLCC -SMD/SMT 100n X7R 50 V 20% 0805 AEC-Q200	CGA4J2X7R1H104M125AE	TDK
11	1	C208	Multilayer Ceramic Capacitors MLCC -SMD/SMT 470n X7R 50 V 10% 0805 AEC-Q200	CGA4J3X7R1H474K125AE	TDK
12	1	D100	Diode 200 V 10 A Surface Mount DPAK AEC-Q101	LQ10N200CQ	Power Integrations
13	4	D101, D103, D201, D203	Diode 200 V 200 mA Surface Mount SOD-323 AEC-Q101	BAV20WS	Panjit
14	2	D102, D202	Zener Diode 10 V 250 mW ±6% Surface Mount SOT-23 AEC-Q101	BZX84C10LT1G	On Semi
15	1	D200	Diode 1000 V 1 A Surface Mount DO-214AC AEC-Q101	US1M-AQ	Diotec Semiconductor
16	1	IC200	CV/CC QR Flyback Switcher IC with Integrated 900 V Switch and FluxLink Feedback for Automotive Applications	INN3999CQ	Power Integrations
17	1	R101	100 Ohms ±5% 0.1 W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	RMCF0603JT100R	Stackpole Electronics Inc
18	1	R102	100 kOhms ±1% 0.1 W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	RMCF0603FT100K	Stackpole Electronics Inc
19	1	R103	10 kOhms ±5% 0.1 W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	AC0603JR-0710KL	YAGEO
20	1	R104	9.1 kOhms ±1% 0.1 W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	RMCF0603FT9K10	Stackpole Electronics Inc
21	1	R105	30 mOhms ±1% 0.25 W, 1/4 W Chip Resistor 1206 (3216 Metric) Current Sense	WSL1206R0300FEA	Vishay
22	1	R106	10 Ohms ±1% 0.1 W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	RMCF0603FT10R0	Stackpole Electronics Inc
23	2	R107, R208	270 Ohms ±5% 0.125 W, 1/8W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	RK73B1JTTD271J	KOA
24	2	R200, R201	150 kOhms ±5% 500V, 0.667 W, 2/3W Chip Resistor 1206 (3216 Metric) Automotive AEC-Q200 Thick Film	ERJ-P08J154V	Panasonic
25	1	R207	15 kOhms ±5% 0.1 W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	ERJ-3GEYJ153V	Panasonic

26	1	T200	15 W Power Transformer	EQ25	Power Integrations
27	1	T200-Core	3C95 Ferrite Core	EQ25-3C95	Ferroxcube
28	1	T200-Core	3C95 Ferrite Core	PLT25/18/2-3C95	Ferroxcube
29	1	Z1	Printed Circuit Board	PIA-00207	Power Integrations

Table 4 – RDK-1109Q Bill of Materials

6 Transformer Specification

6.1 Electrical Diagram

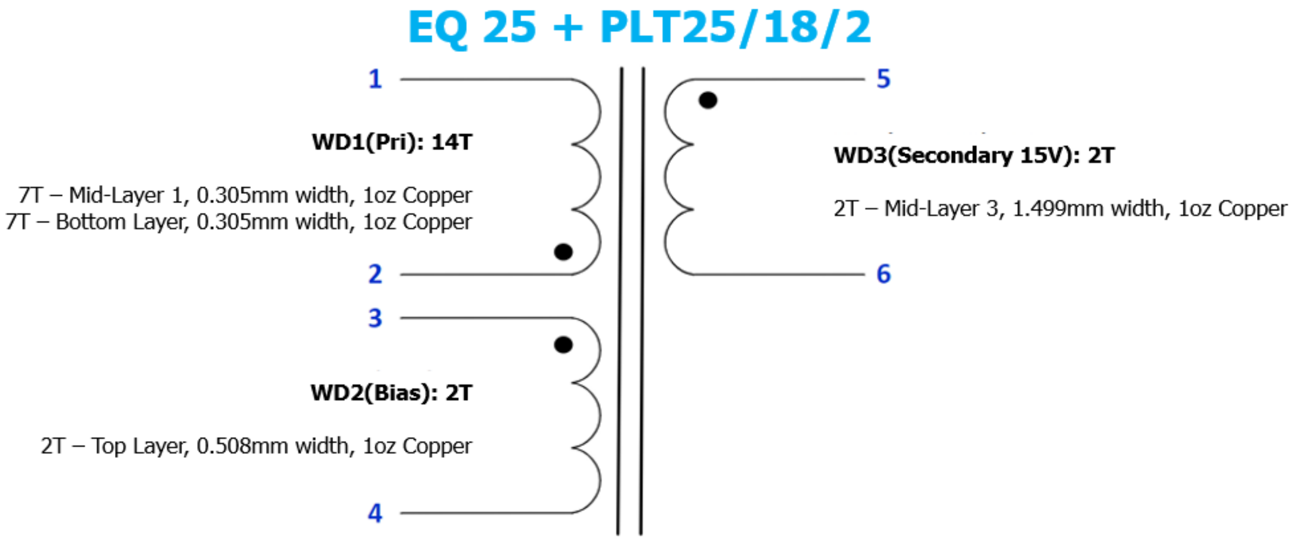


Figure 12 – Transformer Electrical Diagram.

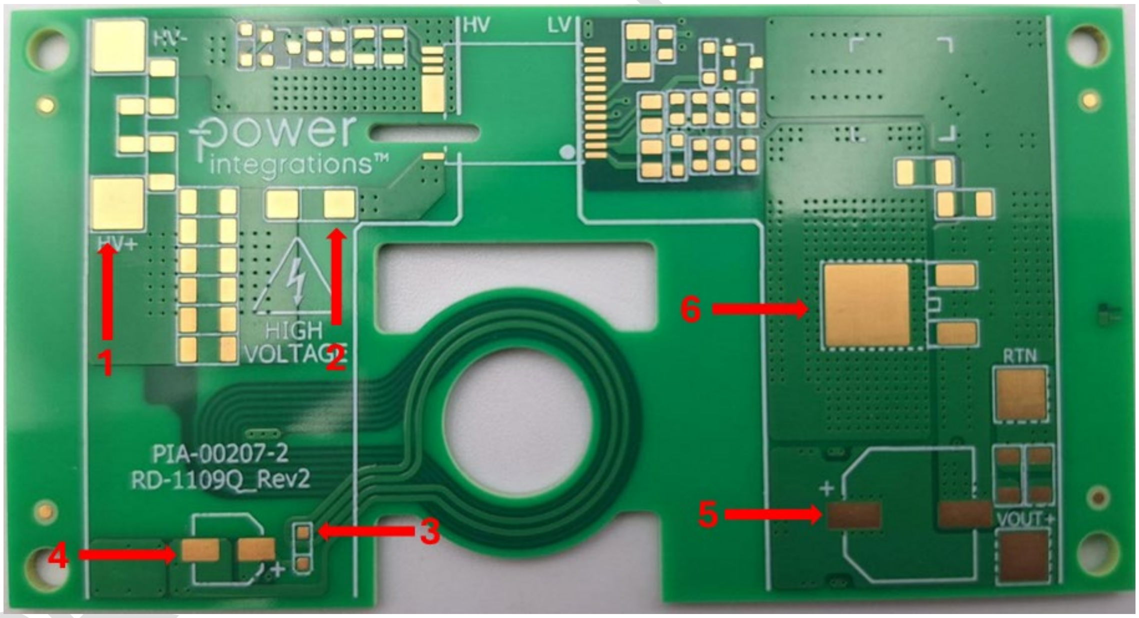


Figure 13 – RDK-1109Q Planar Transformer Test Nodes.

6.2 Electrical Specifications

Parameter	Conditions	Min	Typ	Max	Units
Power	Output power secondary-side		15		W
Input voltage VDC	Flyback Topology	40	400	500	VDC
Switching frequency				95	kHz
Duty Cycle				54.3	%
Turns Ratio (N_P :N_s)			7		
Primary Winding Resistance ($R_{DC,PRI}$)	All windings open			1.93	Ω
Secondary Winding Resistance ($R_{DC,SEC}$)				61.2	mΩ
Coupling capacitance	Primary-side to secondary-side Measured at 1 VPK-PK, 100 kHz frequency, between node 2 to node 6, with nodes 1 - 2 shorted and nodes 5 - 6 shorted at 25 °C			25.7	p_F
Primary inductance	Measured at 1 VPK-PK, 100 kHz frequency, between node 1 to node 2, with all other windings open at 25 °C		308.3		μ_H
Part-to-part tolerance	Tolerance of Primary Inductance	-7.0		7.0	%
Primary leakage inductance	Measured between node 1 to node 2, with all other windings shorted.			3.89	μ_H

Table 5 – Transformer (T200) Electrical Specifications.

6.3 Material List

Item	Description	Qty.	UOM	Material	Manufacturer
[1]	Core: EQ25	1	PC	3C95 (or equivalent)	Ferroxcube
[2]	Core: PLT25/18/2	1	PC	3C95 (or equivalent)	Ferroxcube
[3]	3M Polyimide Film Tape 5413		mm	3M 5413 0.625" X 36YD (or equivalent)	3M

Table 6 – Transformer (T200) Material List.

7 Transformer Design Spreadsheet

1	DCDC_InnoSwitch3AQ _Flyback_012226; Rev.4.5; Copyright Power Integrations 2025	INPUT	INFO	OUTPUT	UNITS	InnoSwitch3-AQ Flyback Design Spreadsheet
2	**APPLICATION VARIABLES**					
3	VOUT	15.00		15.00	V	Output Voltage
4	**OPERATING CONDITION 1**					
5	VINDC1	100.00		100.00	V	Input DC voltage 1
6	IOUT1	1.000		1.000	A	Output current 1
7	POUT1		Info	15.00	W	The device is capable of delivering 14 W at the specified input voltage. Verify thermal performance.
8	EFFICIENCY1	0.85		0.85		Converter efficiency for output 1
9	Z_FACTOR1	0.50		0.50		Z-factor for output 1
11	**OPERATING CONDITION 2**					
12	VINDC2	400.00		400.00	V	Input DC voltage 2
13	IOUT2	1.000		1.000	A	Output current 2
14	POUT2			15.00	W	Output power 2
15	EFFICIENCY2	0.85		0.85		Converter efficiency for output 2
16	Z_FACTOR2	0.50		0.50		Z-factor for output 2
18	**OPERATING CONDITION 3**					
19	VINDC3	500.00		500.00	V	Input DC voltage 3
20	IOUT3	1.000		1.000	A	Output current 3
21	POUT3			15.00	W	Output power 3
22	EFFICIENCY3	0.85		0.85		Converter efficiency for output 3
23	Z_FACTOR3	0.50		0.50		Z-factor for output 3
67	TEMPERATURE_AMBIENT	105.0		105.0	°C	System ambient temperature
71	**PRIMARY CONTROLLER SELECTION**					
72	ILIMIT_MODE	STANDARD		STANDARD		Device current limit mode
73	VDRAIN_BREAKDOWN	900		900	V	Device breakdown voltage
74	DEVICE_GENERIC			INN39X6		Device selection
75	DEVICE_CODE	INN3996CQ		INN3996CQ		Device code
76	PDEVICE_MAX			20	W	Device maximum power capability
77	RDSON_25DEG			2.80	Ω	Primary switch on-time resistance at 25 °C
78	RDSON_125DEG			4.50	Ω	Primary switch on-time resistance at 125 °C
79	ILIMIT_MIN			1.100	A	Primary switch minimum current limit
80	ILIMIT_TYP			1.250	A	Primary switch typical current limit
81	ILIMIT_MAX			1.400	A	Primary switch maximum current limit
82	VDRAIN_ON_PRSW			0.74	V	Primary switch on-time voltage drop

83	VDRAIN_OFF_PRSW			720	V	Peak drain voltage on the primary switch during turn-off at maximum input DC voltage and allowable leakage ring
84	VCLAMP	220.0		220.0	V	Voltage across clamp circuit
85	CU_AREA_INNO	0.36		0.36	in2	Primary switch copper cooling area
86	TEMP_INNO_MIN			128.82	°C	Device minimum operating temperature with respect to ambient, observed at 400 V VINDC
87	TEMP_INNO_MAX		Warning	160.52	°C	Device OTP can be triggered, consider lowering down the full load switching frequency or increasing the copper cooling area
91	**WORST CASE ELECTRICAL PARAMETERS**					
92	FSWITCHING_MAX	95000		95000	Hz	Maximum switching frequency at full load and minimum DC input voltage
93	VOR	105.0		105.0	V	Voltage reflected to the primary winding (corresponding to set-point 1) when the primary switch turns off
94	KP			2.420		Measure of continuous/discontinuous mode of operation
95	MODE_OPERATION			DCM		Mode of operation
96	DUTYCYCLE			0.304		Primary switch duty cycle
97	TIME_ON_MIN			0.628	us	Minimum primary switch on-time
98	TIME_ON_MAX			4.33	us	Maximum primary switch on-time
99	TIME_OFF			7.36	us	Primary switch off-time
100	LPRIMARY_MIN			286.7	uH	Minimum primary magnetizing inductance
101	LPRIMARY_TYP			308.3	uH	Typical primary magnetizing inductance
102	LPRIMARY_TOL	7.0		7.0	%	Primary magnetizing inductance tolerance
103	LPRIMARY_MAX			329.9	uH	Maximum primary magnetizing inductance
105	**PRIMARY CURRENT**					
106	IAVG_PRIMARY			0.164	A	Primary switch average current
107	IPEAK_PRIMARY			1.327	A	Primary switch peak current
108	IPEDESTAL_PRIMARY			0.000	A	Primary switch current pedestal
109	IRIPPLE_PRIMARY			1.327	A	Primary switch ripple current
110	IRMS_PRIMARY			0.381	A	Primary switch RMS current
114	**TRANSFORMER CONSTRUCTION PARAMETERS**					
115	CORE SELECTION					
116	CORE	Custom	Info	Custom		Please add your custom core in the magnetics database, and load it via Select from DB option

117	CORE NAME	EQ-25		EQ-25		Core code
118	AE	89.7		89.7	mm^2	Core cross sectional area
119	LE	26.4		26.4	mm	Core magnetic path length
120	AL	7130		7130	nH	Ungapped core effective inductance per turns squared
121	VE	2370		2370	mm^3	Core volume
128	**PRIMARY WINDING**					
129	NPRIMARY			14		Primary winding number of turns
130	BPEAK			3764	Gauss	Peak flux density
131	BMAX			3426	Gauss	Maximum flux density
132	BAC			1713	Gauss	AC flux density (0.5 x Peak to Peak)
133	ALG			1573	nH	Typical gapped core effective inductance per turns squared
134	LG		Info	0.056	mm	The core gap length is less that 0.1mm and may be difficult to manufacture
136	**SECONDARY WINDING**					
137	NSECONDARY	2		2		Secondary winding number of turns
139	**BIAS WINDING**					
140	NBIAS			2		Bias winding number of turns
144	**PRIMARY COMPONENTS SELECTION**					
145	**LINE UNDERVOLTAGE/OVERVOLTAGE**					
146	UVOV Type	UV Only		UV Only		Input Undervoltage/Overvoltage protection type
147	**UNDERVOLTAGE PARAMETERS**					
148	BROWN-IN REQUIRED			95.00	V	Required DC bus brown-in voltage threshold
149	UNDERVOLTAGE ZENER DIODE	BZM55C9V1		BZM55C9V1		Undervoltage protection zener diode
150	VZ			9.10	V	Zener diode reverse voltage
151	VR			6.80	V	Zener diode reverse voltage at the maximum reverse leakage current
152	ILKG			2.00	uA	Zener diode maximum reverse leakage current (at high ambient temperatures, typically 125 degC)
153	ILKG_MIN			0.10	uA	Zener diode minimum reverse leakage current (at low ambient temperatures, typically 25 degC)
154	BROWN-IN ACTUAL			63.83 - 94.45	V	Actual brown-in voltage range using standard resistors considering tolerances due to part and temperature variations
155	BROWN-OUT ACTUAL			57.06 - 84.67	V	Actual brown-out voltage range using standard resistors considering

						tolerances due to part and temperature variations
156	**OVERVOLTAGE PARAMETERS**					
157	OVERVOLTAGE REQUIRED		Info		V	For UV Only design, overvoltage feature is disabled
158	OVERVOLTAGE DIODE		Info			OV diode is used only for the overvoltage protection circuit
159	VF				V	OV diode forward voltage
160	VRRM				V	OV diode reverse voltage
161	PIV				V	OV diode peak inverse voltage
162	LINE_OVERVOLTAGE				V	For UV Only design, line overvoltage feature is disabled
163	**DC BUS SENSE RESISTORS**					
164	RLS_H			2.72	MΩ	Connect four 681 kOhm DC bus upper sense resistors to the V-pin for the required UV/OV threshold
165	RLS_L			124.00	kΩ	DC bus lower sense resistor to the V-pin for the required UV/OV threshold
168	**BIAS WINDING**					
169	VBIAS	12.00		12.00	V	Rectified bias voltage
170	VF_BIAS			0.70	V	Bias winding diode forward drop
171	VREVERSE_BIASDIODE			83.43	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
172	CBIAS			22	uF	Bias winding rectification capacitor
173	CBPP			0.47	uF	BPP pin capacitor
177	**SECONDARY COMPONENTS SELECTION**					
178	FEEDBACK COMPONENTS					
179	RFB_UPPER			100.00	kΩ	Upper feedback resistor (connected to the output terminal)
180	RFB_LOWER			9.31	kΩ	Lower feedback resistor
181	CFB_LOWER			330	pF	Lower feedback resistor decoupling capacitor
185	**MULTIPLE OUTPUT PARAMETERS**					
186	OUTPUT 1					
187	VOUT1			15.00	V	Output 1 voltage
188	IOUT1			1.000	A	Output 1 current
189	POUT1			15.00	W	Output 1 power
190	IRMS_SECONDARY1			2.596	A	Root mean squared value of the secondary current for output 1
191	IRIPPLE_CAP_OUTPUT1			2.396	A	Current ripple on the secondary waveform for output 1
192	NSECONDARY1			2		Number of turns for output 1

193	VREVERSE_RECTIFIER1			86.43	V	SRFET reverse voltage (not accounting parasitic voltage ring) for output 1
194	SRFET1	AUTO		DMT15H017LPS-13		Secondary rectifier (Logic MOSFET) for output 1
195	NUM_SRFET1	2		2		Number of SRFETs in parallel for output 1
196	VF_SRFET1			0.80	V	SRFET typical on-time drain voltage for output 1
197	VBREAKDOWN_SRFET1			150	V	SRFET breakdown voltage for output 1
198	RDSON_SRFET1			37.0	mΩ	SRFET estimated on-time drain resistance at 100°C and VGS=4.4V for output 1
199	RTHJA_SRFET1			53.00	°C/W	SRFET max. thermal impedance for output 1
200	TEMP_SRFET1_MIN			110.7	°C	SRFET minimum operating temperature for output 1 (for each SRFET in parallel) with respect to ambient, observed at 100V VINDC
201	TEMP_SRFET1_MAX			111.7	°C	SRFET maximum operating temperature for output 1 (for each SRFET in parallel) with respect to ambient, observed at 100V VINDC
254	PO_TOTAL			15.00	W	Total power of all outputs
255	NEGATIVE OUTPUT	N/A		N/A		If negative output exists, enter the output number; e.g. If VO2 is negative output, select 2
259	**INPUT VOLTAGE SET-POINTS ANALYSIS**					
260	**TOLERANCE CORNER**					
261	USER_VINDC	500		500	V	Input DC voltage corner to be evaluated
262	USER_ILIMIT	MAX		1.400	A	Current limit corner to be evaluated
263	USER_LPRIMARY	MIN		286.7	uH	Primary inductance corner to be evaluated
265	**OPERATING CONDITION SELECTION**					
266	POUT	15.00		15.00	W	Output power to be evaluated
267	EFFICIENCY			0.85		Converter efficiency to be evaluated
268	Z FACTOR			0.50		Z-factor to be evaluated
269	FSWITCHING			64645	Hz	Maximum switching frequency at the output power to be evaluated.
270	KP			4.059		Measure of continuous/discontinuous mode of operation
271	MODE_OPERATION			DCM		Mode of operation
272	DUTYCYCLE			0.049		Primary switch duty cycle
273	TIME_ON			0.761	us	Primary switch on-time
274	TIME_OFF			14.708	us	Primary switch off-time
276	**PRIMARY CURRENT**					
277	IAVG_PRIMARY			0.033	A	Primary switch average current

278	IPEAK_PRIMARY			1.327	A	Primary switch peak current
279	IPEDESTAL_PRIMARY			0.000	A	Primary switch current pedestal
280	IRIPPLE_PRIMARY			1.327	A	Primary switch ripple current
281	IRMS_PRIMARY			0.170	A	Primary switch RMS current
283	**MAGNETIC FLUX DENSITY**					
284	BPEAK			3271	Gauss	Peak flux density
285	BMAX			3030	Gauss	Maximum flux density
286	BAC			1515	Gauss	AC flux density (0.5 x Peak to Peak)

Table 7 – RDR-1109Q PIXls Speadsheet.

8 Hi-Pot Testing for Transformer

Hi-Pot testing measures the dielectric breakdown of the primary-to-secondary isolation used in the transformer. This test is done to assess the ability of the insulation to withstand steady-state working voltage stresses. Hi-Pot testing also checks for the existence of damage in the isolation barrier.

Figure 14 shows the test profile used to evaluate the planar transformer of RDK-1109Q.

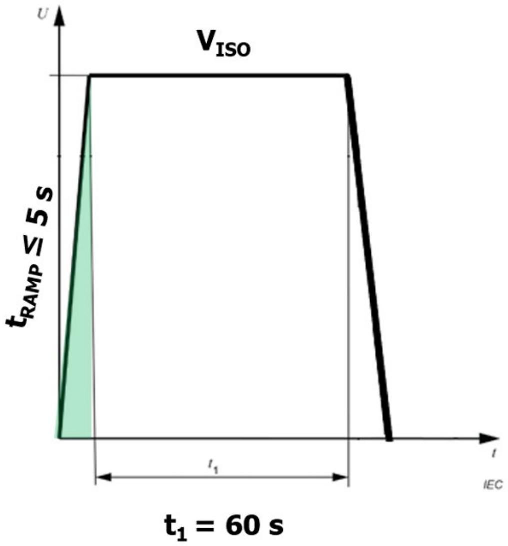


Figure 14 – Hi-Pot Test Profile of RDK-1109Q.

The unit under test was tested with an isolation voltage of 4000 VRMS to 6400 VRMS with a 5-second ramp-up and 60-second dwell time. The isolation test was done between nodes 1 to 6 at 25 °C ambient, with nodes 1-4 and 5-6 shorted. Refer to section 7.1 for the transformer electrical diagram.

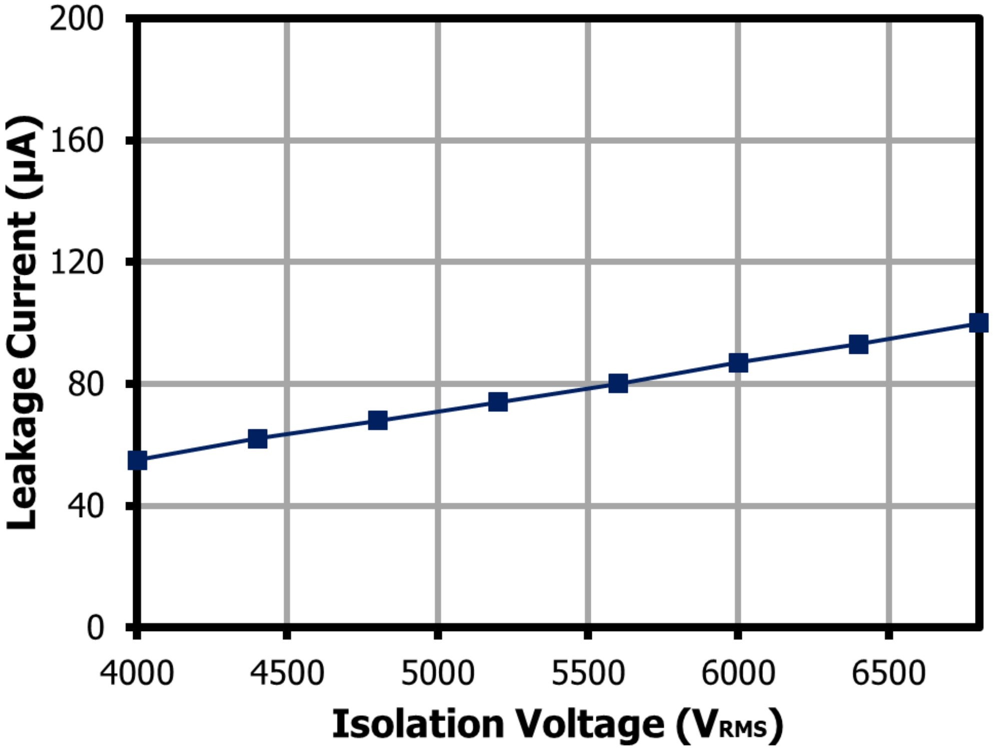


Figure 15 –Isolation Voltage vs. Leakage Current (25 °C Ambient)

Note: The leakage current across the isolation barrier above is due to the primary to secondary coupling capacitance. When the high voltage 60 Hz AC test voltage is applied, current flows through this capacitance (~25 pF). Under DC voltage conditions, this leakage is not present (<3 µA measured)

9 Performance Data

1. Measurements were taken with the unit under test inside a thermal chamber.
2. The RDK-1109Q board was placed inside a box within the thermal chamber to eliminate the effects of airflow.

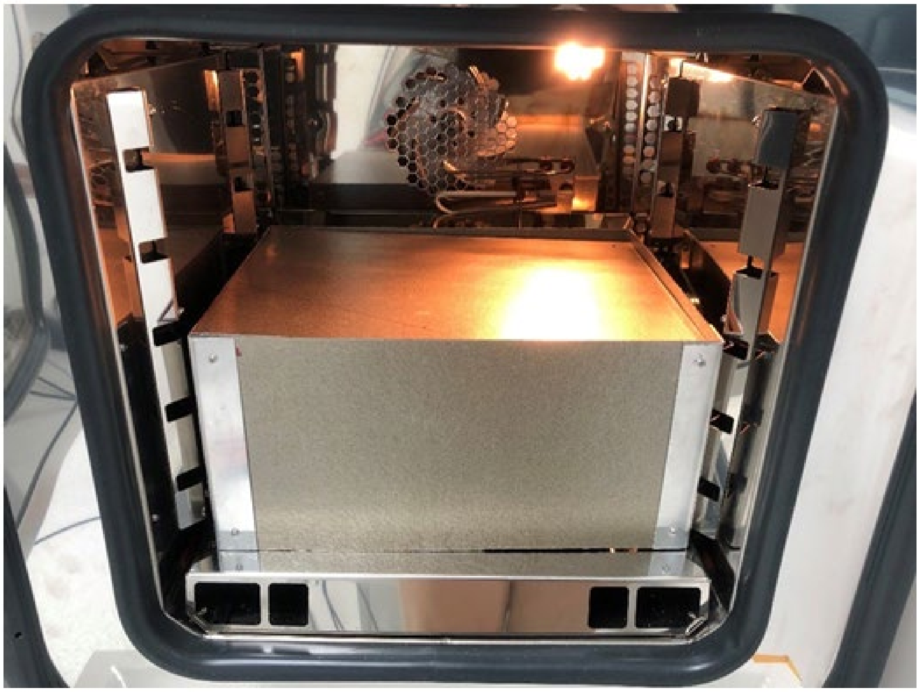


Figure 16 – Unit under test placed inside a box to eliminate the effect of airflow.

3. The RDK board was allowed to stabilize for 5 minutes at full load at the start of every test sequence. For each loading condition, the RDK-1109Q test board was allowed to stabilize for 1 minute before measurements were taken.

9.1 No-Load Input Power

Figure 17 shows the schematic for the no-load input power measurement set-up. The voltmeter was placed before the ammeter to prevent the voltmeter bias current from affecting the input current measurements. A Chroma Digital Power Meter 66205 was used to measure the current and voltage.

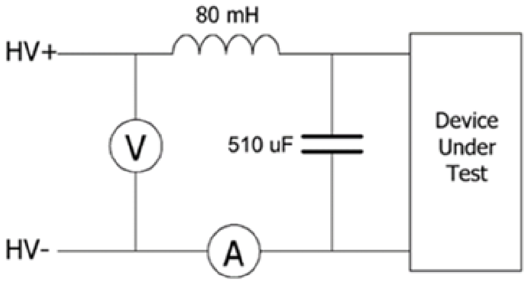


Figure 17 – No-Load Input Power Measurement Diagram.

The unit was allowed to stabilize for ten minutes for each test before measurements were started. The leakage current through the DC-Link capacitor was measured before testing and subtracted from the measured no-load input current. The average voltage across the inductor was assumed to be negligible due to the inductor's very low Direct Current Resistance (DCR) (40 mΩ) and low input current. AC losses in the inductor were also assumed to be negligible since the input current was DC.

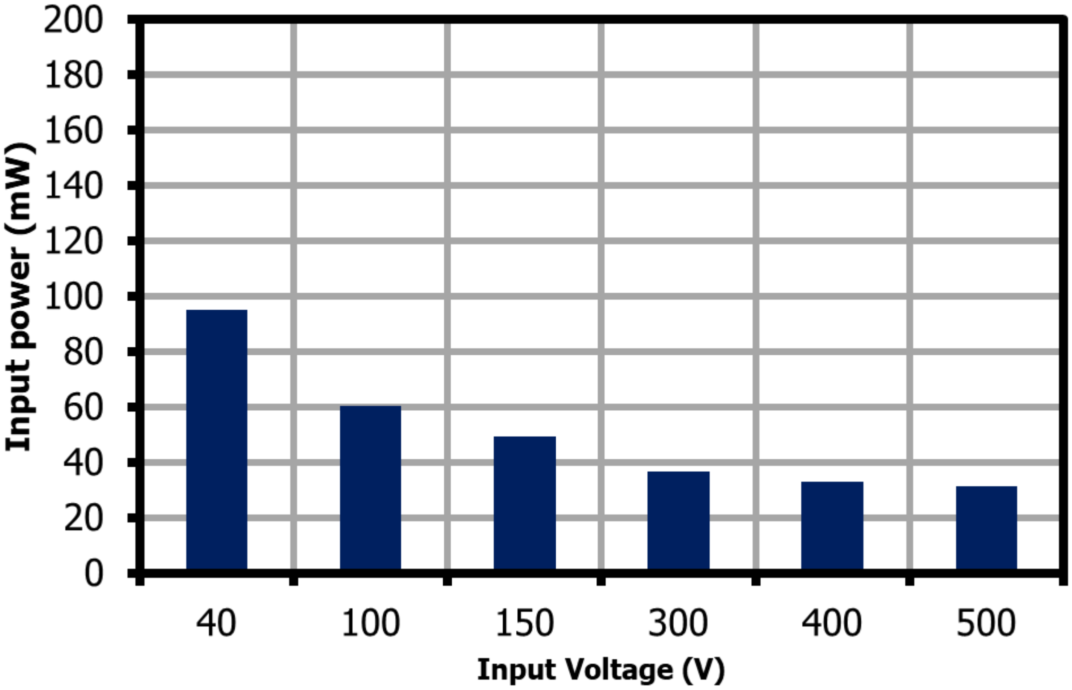


Figure 18 – No-Load Input Power vs. Input Voltage (25 °C Ambient).

9.2 Efficiency

Efficiency across load describes how output loading affects the overall efficiency of the power supply. 100% load was defined at the 1 A (full load) output current. The test set-up used 100 V – 500 V V_{IN}, and 0.67 A (full load) output current for 40 V V_{IN}.

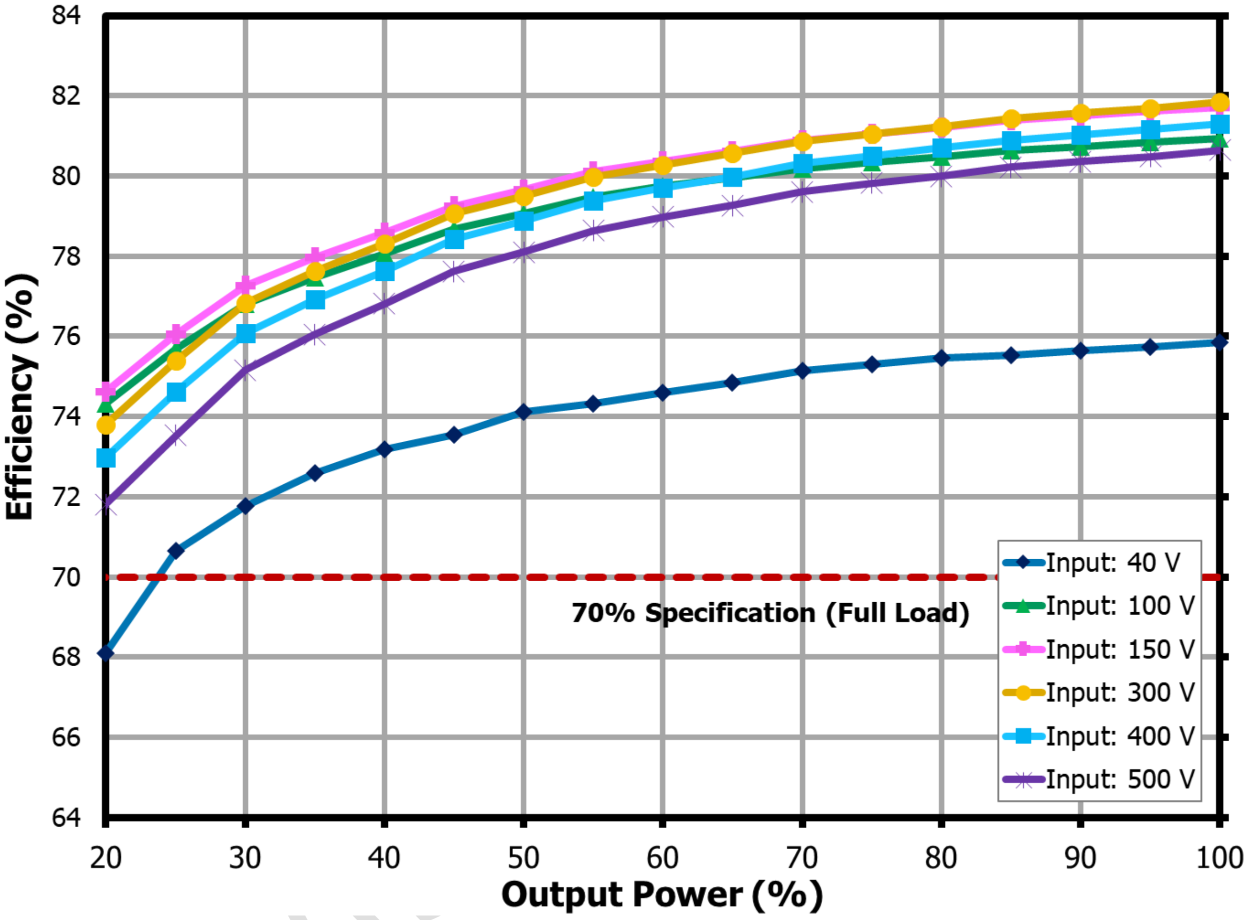


Figure 19 – Efficiency vs. Load at Different Input Voltages (25 °C Ambient).

9.3 Load Regulation

Load regulation describes how a change in load affects output voltage. 100% load was defined at the 1 A (full load) output current. The test set-up used 100 V – 500 V V_{IN}, and the 0.67 A (full load) output current for 40 V V_{IN}.

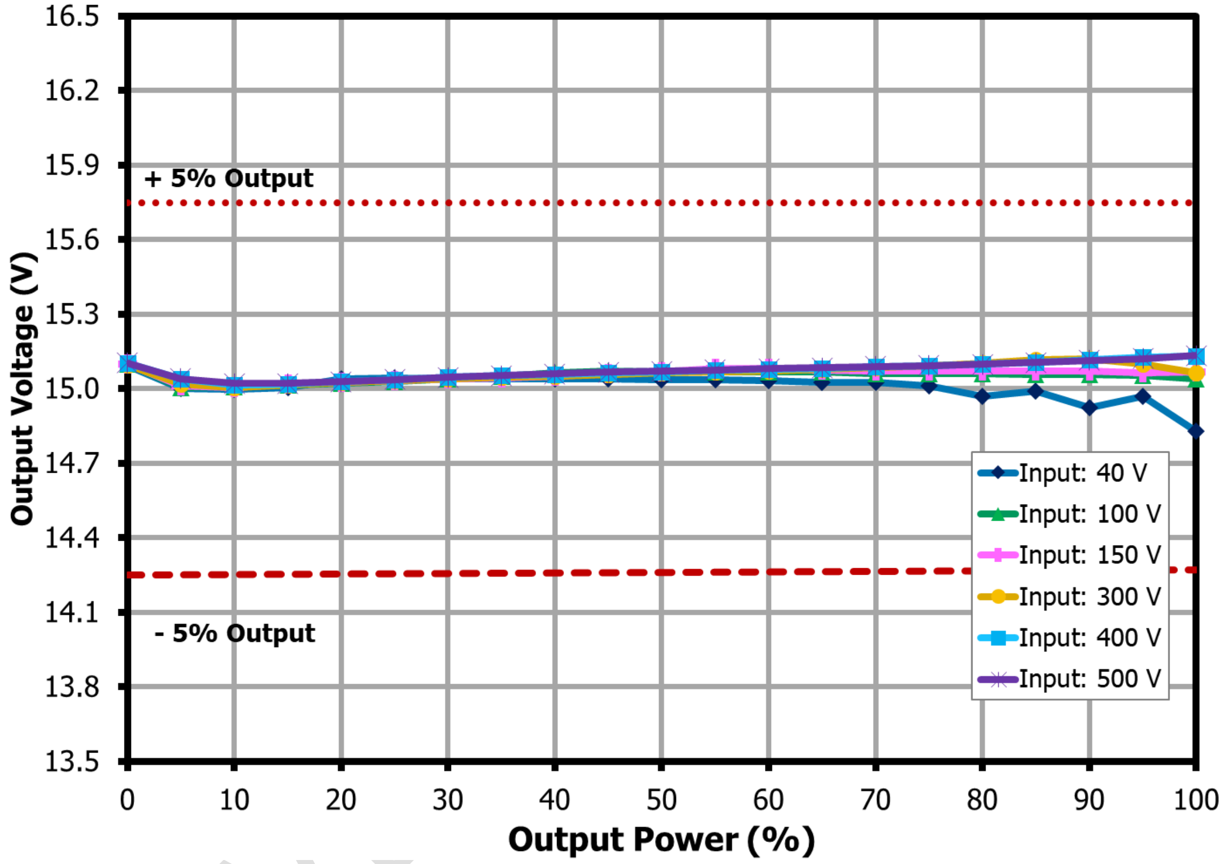


Figure 20 – Output Regulation vs. Load at Different Input Voltages (25 °C Ambient).

10 Thermal Performance

10.1 Thermal Data at 85 °C Ambient

The unit was placed inside a thermal chamber and was allowed to stabilize at 100% load for at least 1 hour. Table 8 shows the test setup for thermal measurement.

Critical Components	**Temperature (°C)**		
	40VDC	**100VDC**	**500VDC**
INN3996CQ (IC200)	125	119	122
LQ10N200CQ (D100)	102	107	108
Transformer Winding (T200)	101	104	108
Transformer Core (T200)	110	110	109
Primary Snubber Resistor (R200)	112	114	115
Primary Snubber Diode (D200)	112	113	120
Output Capacitor (C101)	93.3	117	95.9
Bias Capacitor (C206)	95.1	95.2	96.3

Table 8 – Thermal Data at 85 °C at Different Input Voltages.

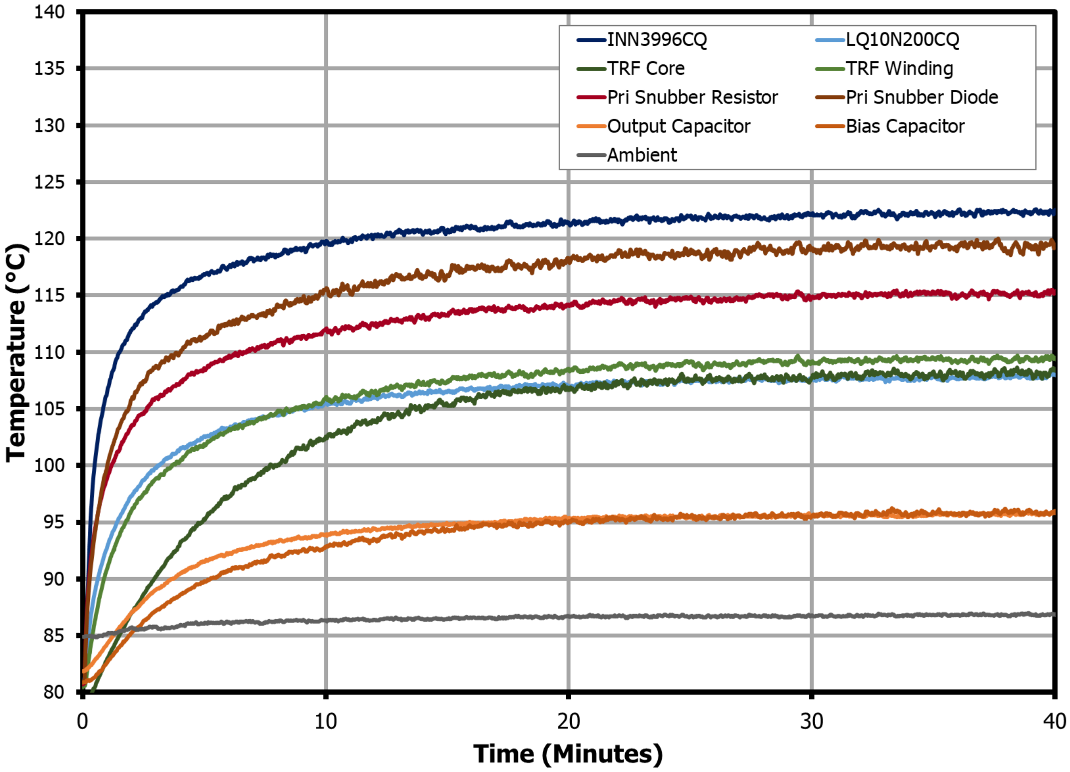


Figure 21 – Component Temperatures at 85 °C Ambient, 500 VDC Input, 1 A Load.

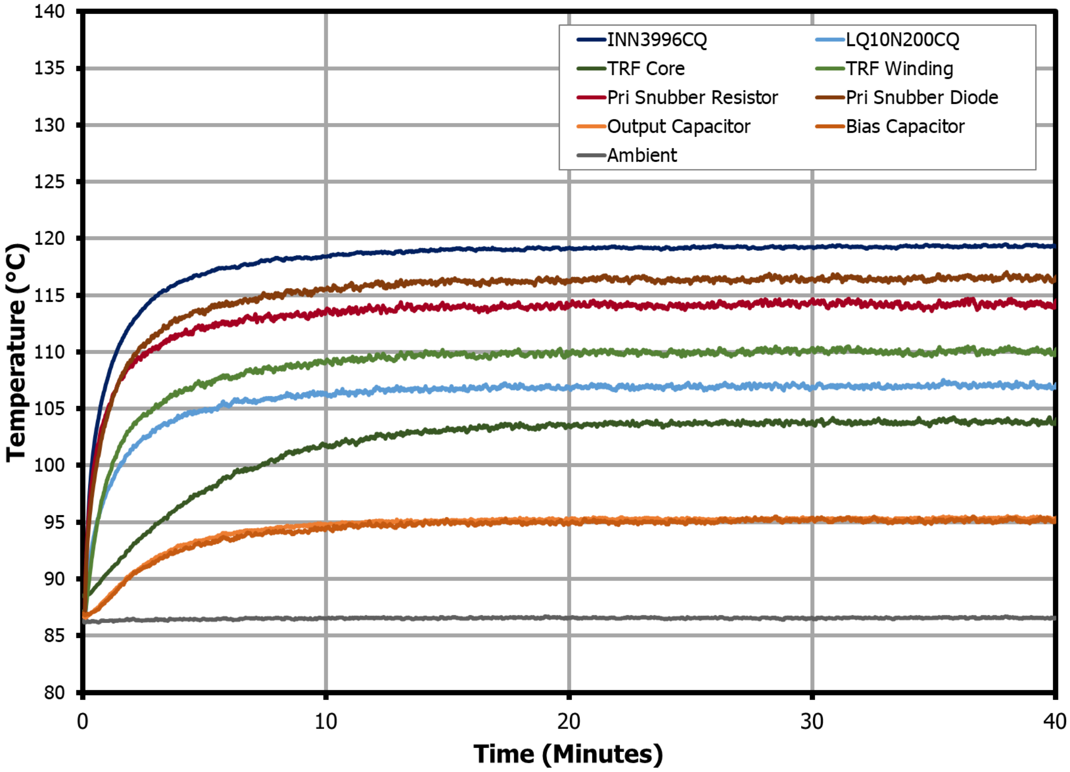


Figure 22 – Component Temperatures at 85 °C Ambient, 100 VDC Input, 1 A Load.

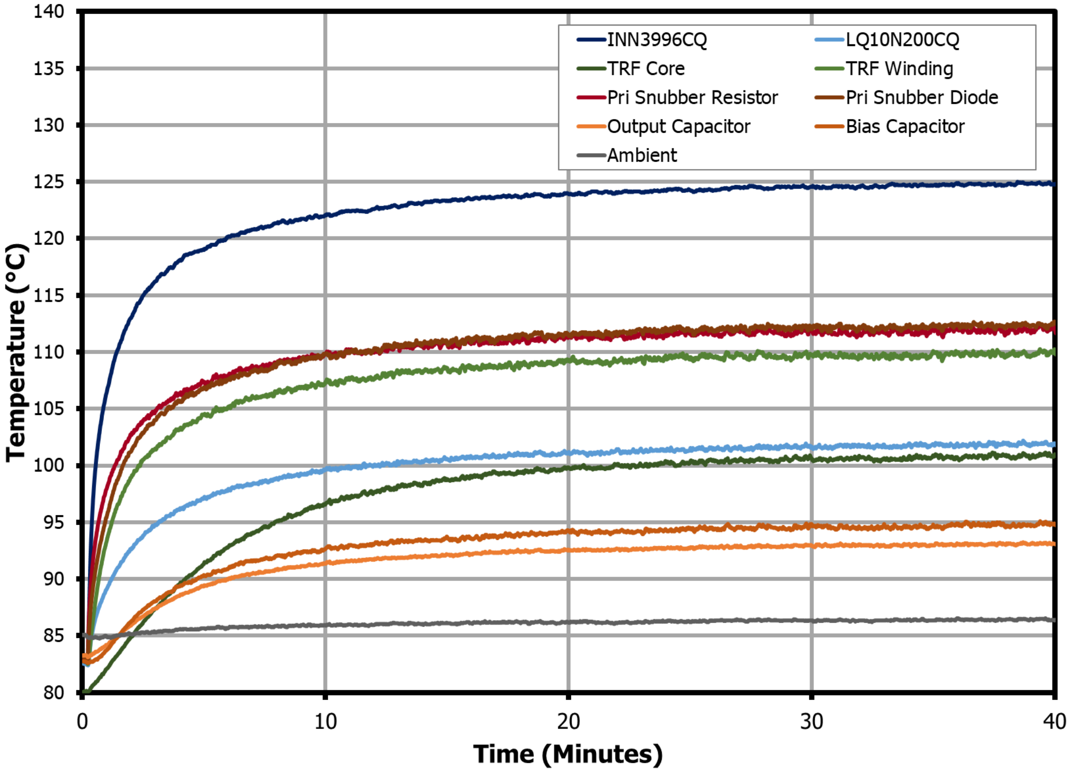


Figure 23 – Component Temperatures at 85 °C Ambient, 40 VDC Input, 0.67 A Load.

10.2 Thermal Data at 25 °C Ambient

The following thermal scans were captured using a Fluke thermal imager after soaking the power supply in an enclosure (to minimize the effect of airflow) for 1 hour.

Critical Components	Temperature (°C)		
	40VDC	**100VDC**	**500VDC**
INN3996CQ (IC200)	67.9	65.7	64.7
LQ10N200CQ (D100)	46.5	54.1	54.2
Transformer Winding (T200)	55.1	55.5	52.9
Transformer Core (T200)	52.2	53.2	53.2
Primary Snubber Resistor (R200)	58.9	62.2	61.8
Primary Snubber Diode (D200)	60.7	67	67.5
Output Capacitor (C101)	39.9	41.6	39.2
Bias Capacitor (C206)	37.3	39.3	36.9

Table 9 – Thermal Data at 25 °C at Different Input Voltages.

Figure 24 – Thermal Scan at 500 VDC Input, 1 A Load.

Figure 25 – Thermal Scan at 100 VDC Input, 1 A Load.

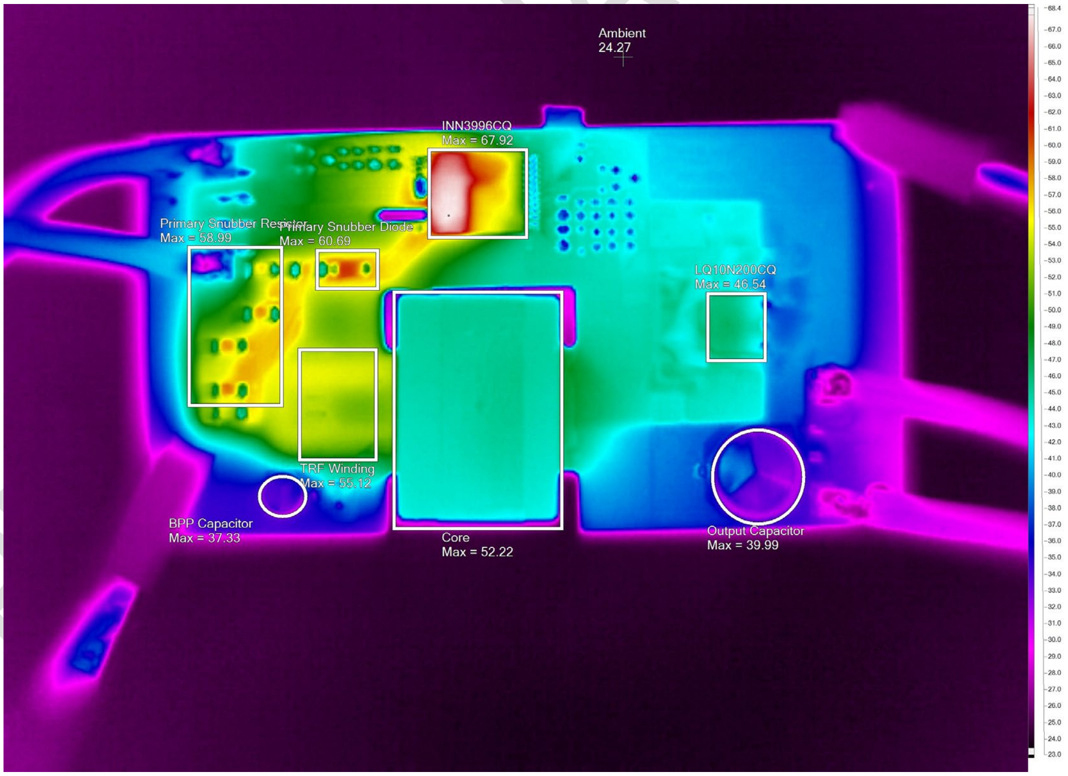


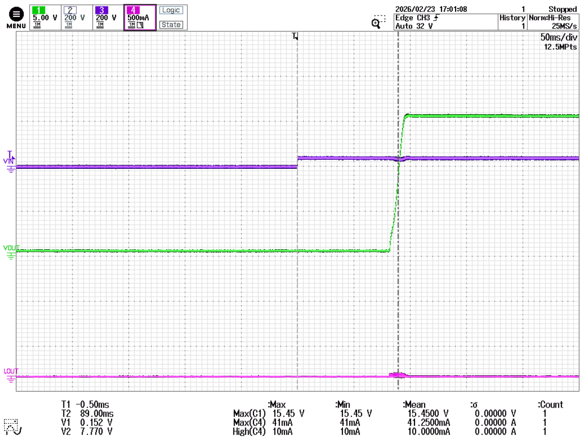
Figure 26 – Thermal Scan at 40 VDC Input, 0.67 A Load.

11 Waveforms

11.1 Start-Up Waveforms

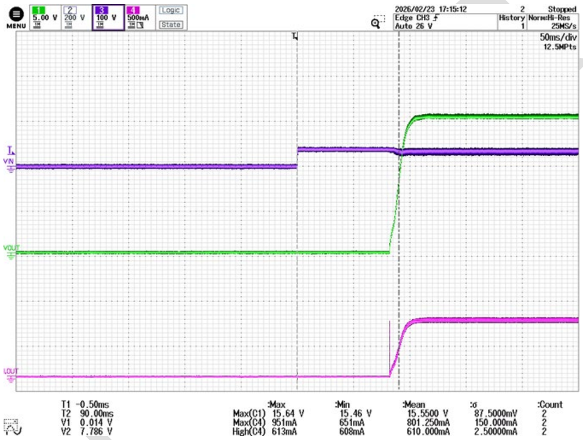
The following measurements were taken by connecting the unit to a fully charged DC-link capacitor at different input voltages. A constant resistance load configuration was used for all start-up tests.

11.1.1 Output Voltage and Current at 25 °C Ambient



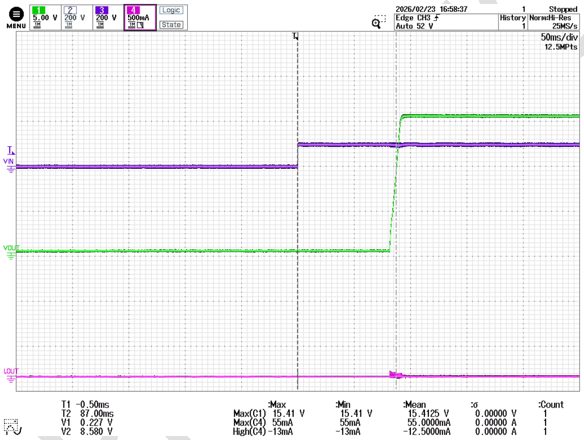
```
T1  -0.50ms                    :Max      :Min      :Mean        :σ          :Count
T2  89.00ms       Max(C1)  15.45 V   15.45 V   15.4500 V    0.00000 V    1
V1  0.152 V       Max(C4)  41mA      41mA      41.2500mA    0.00000 A    1
V2  7.770 V       High(C4) 10mA      10mA      10.0000mA    0.00000 A    1
```

Figure 27 – Output Voltage and Current.
40 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH1: V_{OUT}, 5 V / div.
CH4: I_{OUT}, 500 mA / div.
Time: 50 ms / div.



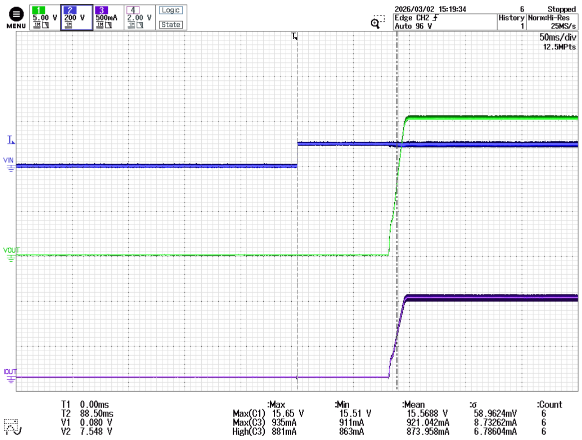
```
T1  -0.50ms                    :Max      :Min      :Mean        :σ           :Count
T2  90.00ms       Max(C1)  15.64 V   15.46 V   15.5500 V    87.5000mV    2
V1  0.014 V       Max(C4)  951mA     651mA     801.250mA    150.000mA    2
V2  7.786 V       High(C4) 613mA     608mA     610.000mA    2.50000mA    2
```

Figure 28 – Output Voltage and Current.
40 VDC, 22.5 Ω Load.
CH3: V_{IN}, 200 V / div.
CH1: V_{OUT}, 5 V / div.
CH4: I_{OUT}, 500 mA / div.
Time: 50 ms / div.



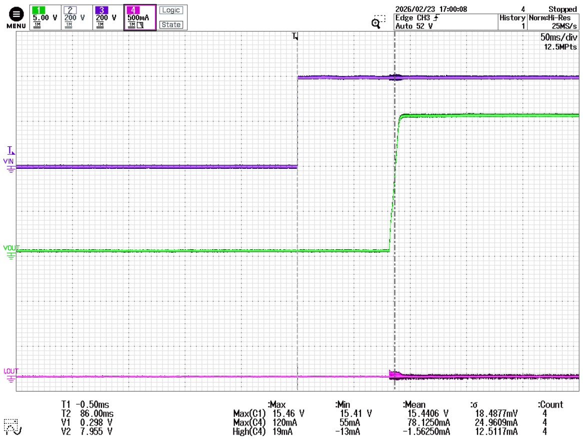
```
T1  -0.50ms                    :Max      :Min      :Mean        :σ          :Count
T2  87.00ms       Max(C1)  15.41 V   15.41 V   15.4125 V    0.00000 V    1
V1  0.227 V       Max(C4)  55mA      55mA      55.0000mA    0.00000 A    1
V2  8.580 V       High(C4) -13mA     -13mA     -12.5000mA   0.00000 A    1
```

Figure 29 – Output Voltage and Current.
100 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH1: V_{OUT}, 5 V / div.
CH4: I_{OUT}, 500 mA / div.
Time: 50 ms / div.



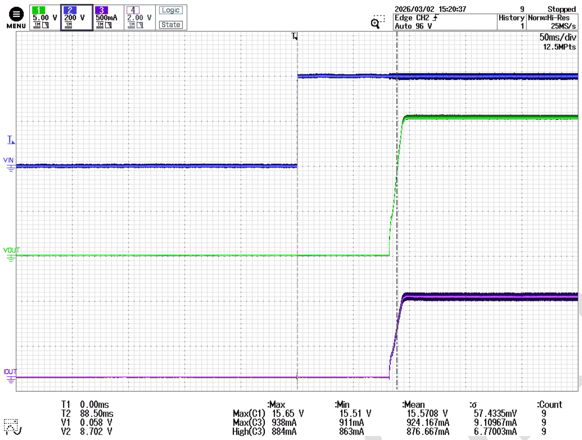
```
T1  0.00ms                     :Max      :Min      :Mean        :σ           :Count
T2  88.50ms       Max(C1)  15.65 V   15.51 V   15.5688 V    58.9624mV    6
V1  0.080 V       Max(C3)  935mA     911mA     921.042mA    8.73262mA    6
V2  7.548 V       High(C3) 881mA     863mA     873.958mA    6.78604mA    6
```

Figure 30 – Output Voltage and Current.
100 VDC, 15 Ω Load.
CH2: V_{IN}, 200 V / div.
CH1: V_{OUT}, 5 V / div.
CH3: I_{OUT}, 500 mA / div.
Time: 50 ms / div.



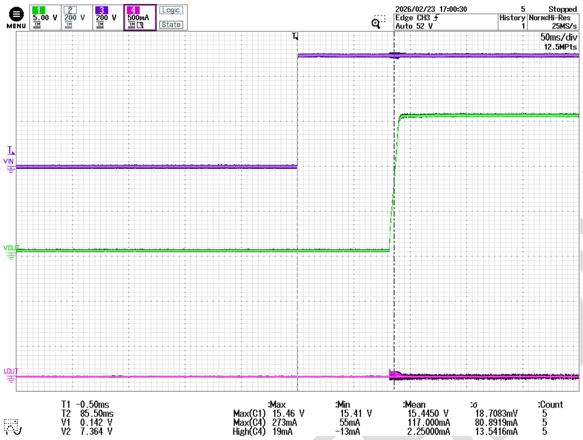
```
T1  -0.50ms              :Max        :Min       :Mean         :σ           :Count
T2  86.00ms   Max(C1)  15.46 V     15.41 V    15.4406 V     18.4877mV     4
V1  0.298 V   Max(C4)  120mA       55mA       78.1250mA     24.9609mA     4
V2  7.955 V   High(C4) 19mA        -13mA      -1.56250mA    12.5117mA     4
```

Figure 31 – Output Voltage and Current.
400 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH1: V_{OUT}, 5 V / div.
CH4: I_{OUT}, 500 mA / div.
Time: 50 ms / div.



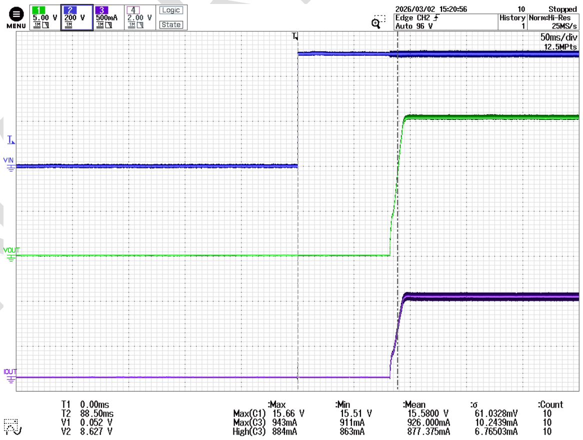
```
T1  0.00ms               :Max        :Min       :Mean         :σ           :Count
T2  88.50ms   Max(C1)  15.65 V     15.51 V    15.5708 V     57.4335mV     9
V1  0.058 V   Max(C3)  938mA       911mA      924.167mA     9.10967mA     9
V2  8.702 V   High(C3) 884mA       863mA      876.667mA     6.77003mA     9
```

Figure 32 – Output Voltage and Current.
400 VDC, 15 Ω Load.
CH2: V_{IN}, 200 V / div.
CH1: V_{OUT}, 5 V / div.
CH3: I_{OUT}, 500 mA / div.
Time: 50 ms / div.



```
T1  -0.50ms              :Max        :Min       :Mean         :σ           :Count
T2  85.50ms   Max(C1)  15.46 V     15.41 V    15.4450 V     18.7083mV     5
V1  0.142 V   Max(C4)  273mA       55mA       117.000mA     80.8919mA     5
V2  7.364 V   High(C4) 19mA        -13mA      2.25000mA     13.5416mA     5
```

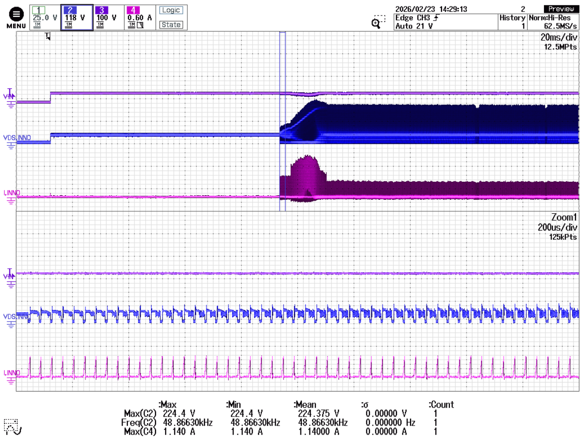
Figure 33 – Output Voltage and Current.
500 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH1: V_{OUT}, 5 V / div.
CH4: I_{OUT}, 500 mA / div.
Time: 50 ms / div.



```
T1  0.00ms               :Max        :Min       :Mean         :σ           :Count
T2  88.50ms   Max(C1)  15.66 V     15.51 V    15.5800 V     61.0328mV     10
V1  0.052 V   Max(C3)  943mA       911mA      926.000mA     10.2439mA     10
V2  8.627 V   High(C3) 884mA       863mA      877.375mA     6.76503mA     10
```

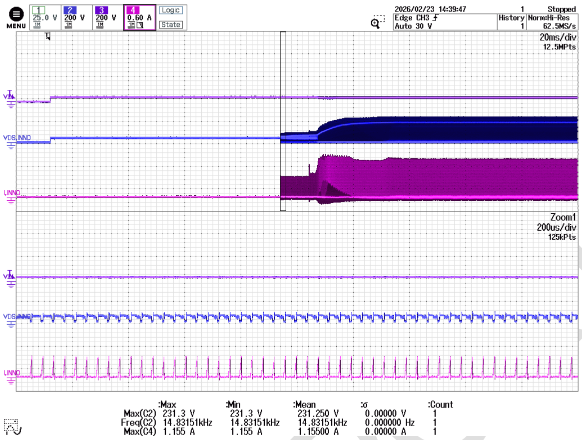
Figure 34 – Output Voltage and Current.
500 VDC, 15 Ω Load.
CH2: V_{IN}, 200 V / div.
CH1: V_{OUT}, 5 V / div.
CH3: I_{OUT}, 500 mA / div.
Time: 50 ms / div.

11.1.2 InnoSwitch3-AQ Drain Voltage and Current at 25 °C Ambient



```
        :Max         :Min         :Mean        :σ            :Count
Max(C2)  224.4 V      224.4 V      224.375 V    0.00000 V     1
Freq(C2) 48.86630kHz  48.86630kHz  48.86630kHz  0.000000 Hz   1
Max(C4)  1.140 A      1.140 A      1.14000 A    0.00000 A     1
```

Figure 35 – INN3996CQ Drain Voltage and Current.
40 VDC, No Load.
CH3: V_{IN}, 100 V / div.
CH2: $V_{DS,INNO}$, 118 V / div.
CH4: $I_{DS,INNO}$, 600 mA / div.
Time: 20 ms / div.

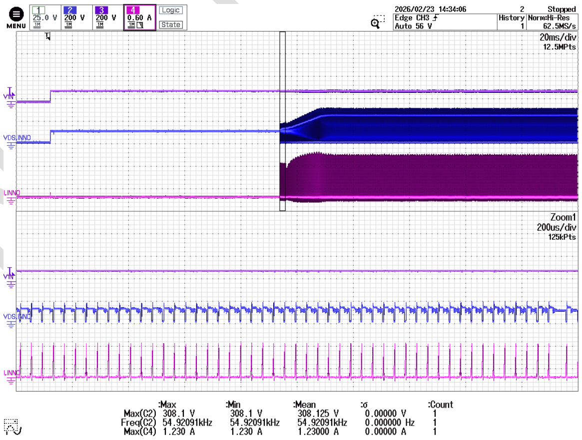


```
        :Max         :Min         :Mean        :σ            :Count
Max(C2)  231.3 V      231.3 V      231.250 V    0.00000 V     1
Freq(C2) 14.83151kHz  14.83151kHz  14.83151kHz  0.000000 Hz   1
Max(C4)  1.155 A      1.155 A      1.15500 A    0.00000 A     1
```

Figure 36 – INN3996CQ Drain Voltage and Current.
40 VDC, 22.5 Ω Load.
CH3: V_{IN}, 100 V / div.
CH2: $V_{DS,INNO}$, 200 V / div.
CH4: $I_{DS,INNO}$, 600 mA / div.
Time: 20 ms / div.

```
        :Max         :Min         :Mean        :σ            :Count
Max(C2)  286.3 V      286.3 V      286.250 V    0.00000 V     1
Freq(C2) 13.55748kHz  13.55748kHz  13.55748kHz  0.000000 Hz   1
Max(C4)  1.183 A      1.183 A      1.18250 A    0.00000 A     1
```

Figure 37 – INN3996CQ Drain Voltage and Current.
100 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH2: $V_{DS,INNO}$, 200 V / div.
CH4: $I_{DS,INNO}$, 600 mA / div.
Time: 20 ms / div.



```
        :Max         :Min         :Mean        :σ            :Count
Max(C2)  308.1 V      308.1 V      308.125 V    0.00000 V     1
Freq(C2) 54.92091kHz  54.92091kHz  54.92091kHz  0.000000 Hz   1
Max(C4)  1.230 A      1.230 A      1.23000 A    0.00000 A     1
```

Figure 38 – INN3996CQ Drain Voltage and Current.
100 VDC, 15 Ω Load.
CH3: V_{IN}, 200 V / div.
CH2: $V_{DS,INNO}$, 200 V / div.
CH4: $I_{DS,INNO}$, 600 mA / div.
Time: 20 ms / div.

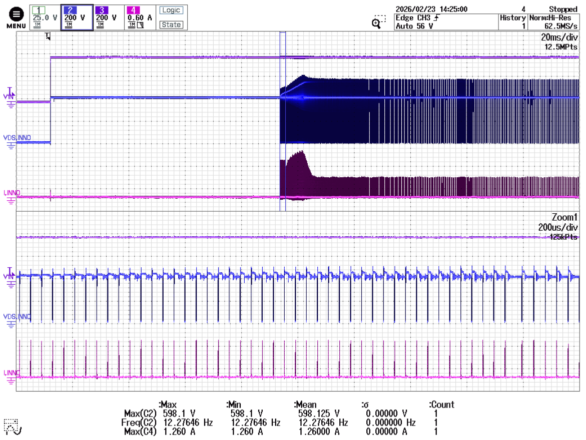


Figure 39 – INN3996CQ Drain Voltage and Current.
400 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH2: $V_{DS,INNO}$, 5 V / div.
CH4: $I_{DS,INNO}$, 600 mA / div.
Time: 20 ms / div.

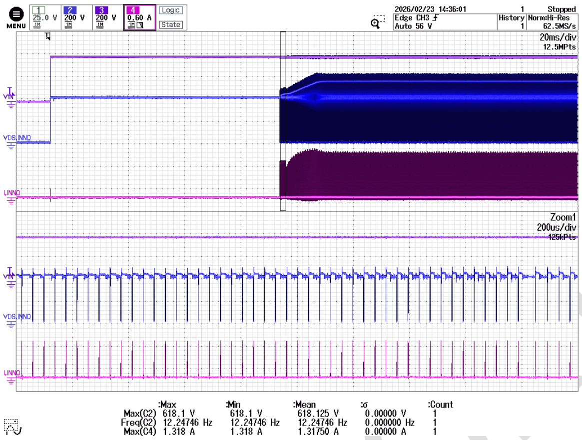


Figure 40 – INN3996CQ Drain Voltage and Current.
400 VDC, 15 Ω Load.
CH3: V_{IN}, 200 V / div.
CH2: $V_{DS,INNO}$, 5 V / div.
CH4: $I_{DS,INNO}$, 600 mA / div.
Time: 20 ms / div.

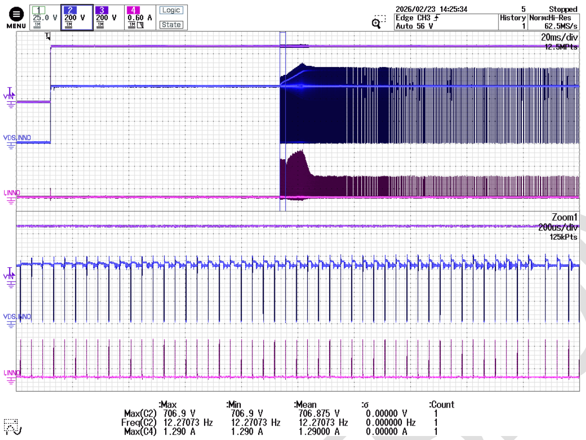


Figure 41 – INN3996CQ Drain Voltage and Current.
500 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH2: $V_{DS,INNO}$, 200 V / div.
CH4: $I_{DS,INNO}$, 600 mA / div.
Time: 20 ms / div.

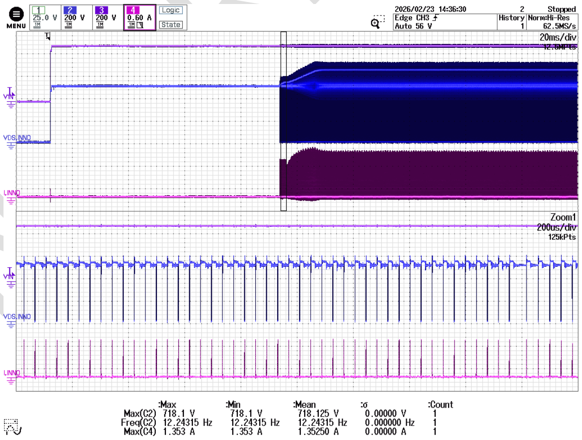
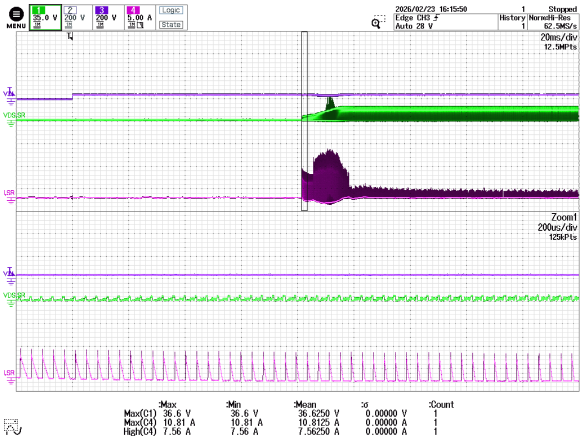


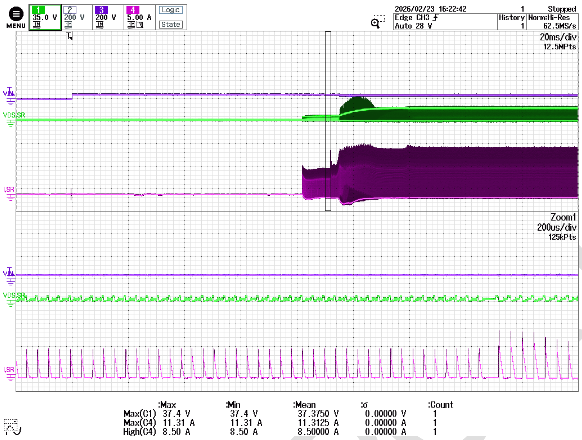
Figure 42 – INN3996CQ Drain Voltage and Current.
500 VDC, 15 Ω Load.
CH3: V_{IN}, 200 V / div.
CH2: $V_{DS,INNO}$, 200 V / div.
CH4: $I_{DS,INNO}$, 600 mA / div.
Time: 20 ms / div.

11.1.3 Q-Speed Diode Voltage and Current at 25 °C Ambient



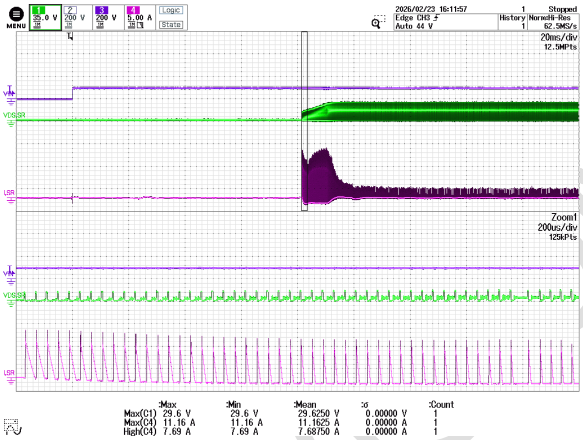
```
           :Max        :Min       :Mean        :σ           :Count
Max(C1)  36.6 V       36.6 V     36.6250 V    0.00000 V     1
Max(C4)  10.81 A      10.81 A    10.8125 A    0.00000 A     1
High(C4) 7.56 A       7.56 A     7.56250 A    0.00000 A     1
```

Figure 43 – Q-Speed Diode Voltage and Current.
40 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH1: $V_{KA,QSP}$, 35 V / div.
CH4: $I_{KA,QSP}$, 5 A / div.
Time: 20 ms / div.



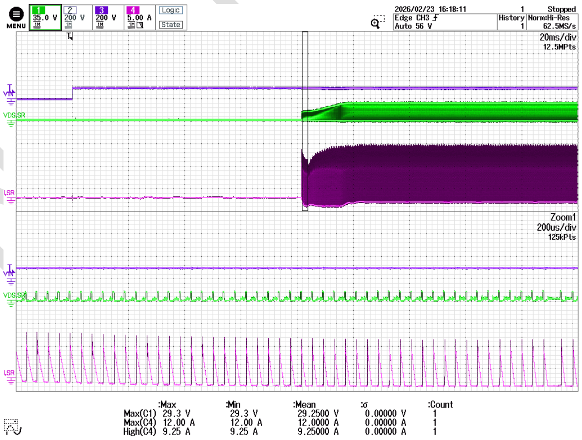
```
           :Max        :Min       :Mean        :σ           :Count
Max(C1)  37.4 V       37.4 V     37.3750 V    0.00000 V     1
Max(C4)  11.31 A      11.31 A    11.3125 A    0.00000 A     1
High(C4) 8.50 A       8.50 A     8.50000 A    0.00000 A     1
```

Figure 44 – Q-Speed Diode Voltage and Current.
40 VDC, 22.5 Ω Load.
CH3: V_{IN}, 200 V / div.
CH1: $V_{KA,QSP}$, 35 V / div.
CH4: $I_{KA,QSP}$, 5 A / div.
Time: 20 ms / div.



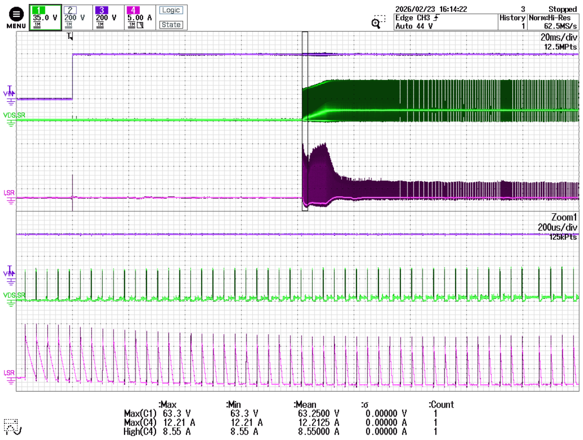
```
           :Max        :Min       :Mean        :σ           :Count
Max(C1)  29.6 V       29.6 V     29.6250 V    0.00000 V     1
Max(C4)  11.16 A      11.16 A    11.1625 A    0.00000 A     1
High(C4) 7.69 A       7.69 A     7.68750 A    0.00000 A     1
```

Figure 45 – Q-Speed Diode Voltage and Current.
100 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH1: $V_{KA,QSP}$, 35 V / div.
CH4: $I_{KA,QSP}$, 5 A / div.
Time: 20 ms / div.



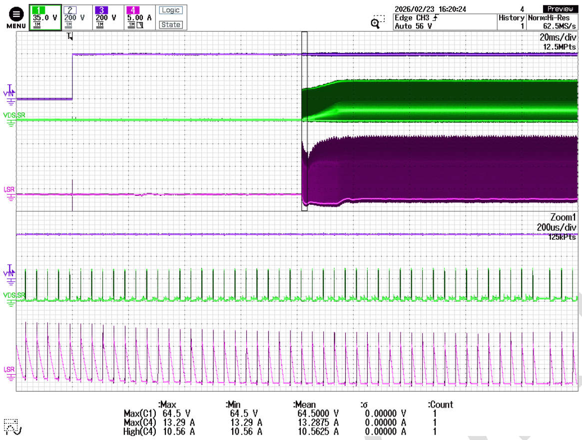
```
           :Max        :Min       :Mean        :σ           :Count
Max(C1)  29.3 V       29.3 V     29.2500 V    0.00000 V     1
Max(C4)  12.00 A      12.00 A    12.0000 A    0.00000 A     1
High(C4) 9.25 A       9.25 A     9.25000 A    0.00000 A     1
```

Figure 46 – Q-Speed Diode Voltage and Current.
100 VDC, 15 Ω Load.
CH3: V_{IN}, 200 V / div.
CH1: $V_{KA,QSP}$, 35 V / div.
CH4: $I_{KA,QSP}$, 5 A / div.
Time: 20 ms / div.



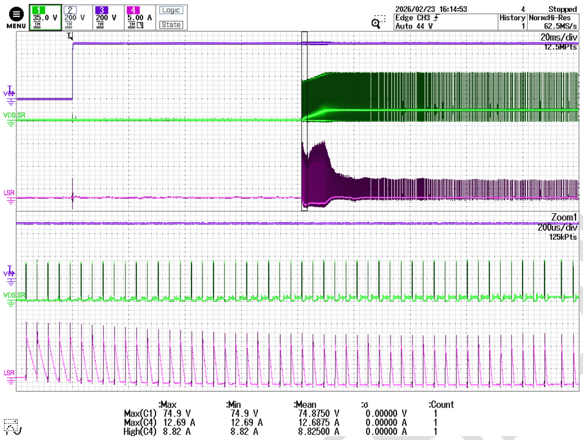
	:Max	:Min	:Mean	:σ	:Count
Max(C1)	63.3 V	63.3 V	63.2500 V	0.00000 V	1
Max(C4)	12.21 A	12.21 A	12.2125 A	0.00000 A	1
High(C4)	8.55 A	8.55 A	8.55000 A	0.00000 A	1

Figure 47 – Q-Speed Diode Voltage and Current.
400 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH1: $V_{KA,QSP}$, 35 V / div.
CH4: $I_{KA,QSP}$, 5 A / div.
Time: 20 ms / div.



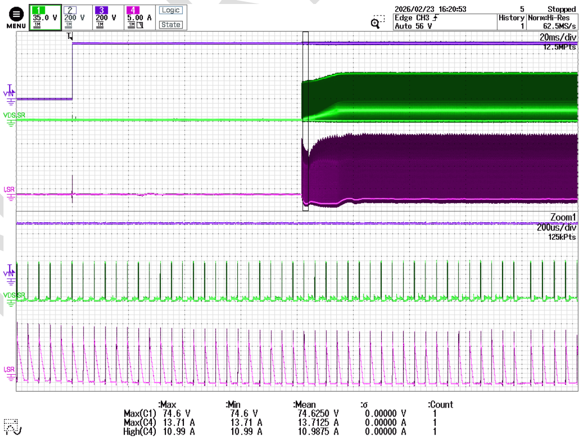
	:Max	:Min	:Mean	:σ	:Count
Max(C1)	64.5 V	64.5 V	64.5000 V	0.00000 V	1
Max(C4)	13.29 A	13.29 A	13.2875 A	0.00000 A	1
High(C4)	10.56 A	10.56 A	10.5625 A	0.00000 A	1

Figure 48 – Q-Speed Diode Voltage and Current.
400 VDC, 15 Ω Load.
CH3: V_{IN}, 200 V / div.
CH1: $V_{KA,QSP}$, 35 V / div.
CH4: $I_{KA,QSP}$, 5 A / div.
Time: 20 ms / div.



	:Max	:Min	:Mean	:σ	:Count
Max(C1)	74.9 V	74.9 V	74.8750 V	0.00000 V	1
Max(C4)	12.69 A	12.69 A	12.6875 A	0.00000 A	1
High(C4)	8.82 A	8.82 A	8.82500 A	0.00000 A	1

Figure 49 – Q-Speed Diode Voltage and Current.
500 VDC, No Load.
CH3: V_{IN}, 200 V / div.
CH1: $V_{KA,QSP}$, 35 V / div.
CH4: $I_{KA,QSP}$, 5 A / div.
Time: 20 ms / div.



	:Max	:Min	:Mean	:σ	:Count
Max(C1)	74.6 V	74.6 V	74.6250 V	0.00000 V	1
Max(C4)	13.71 A	13.71 A	13.7125 A	0.00000 A	1
High(C4)	10.99 A	10.99 A	10.9875 A	0.00000 A	1

Figure 50 – Q-Speed Diode Voltage and Current.
500 VDC, 15 Ω Load.
CH3: V_{IN}, 200 V / div.
CH1: $V_{KA,QSP}$, 35 V / div.
CH4: $I_{KA,QSP}$, 5 A / div.
Time: 20 ms / div.

11.2 Steady-State Waveforms

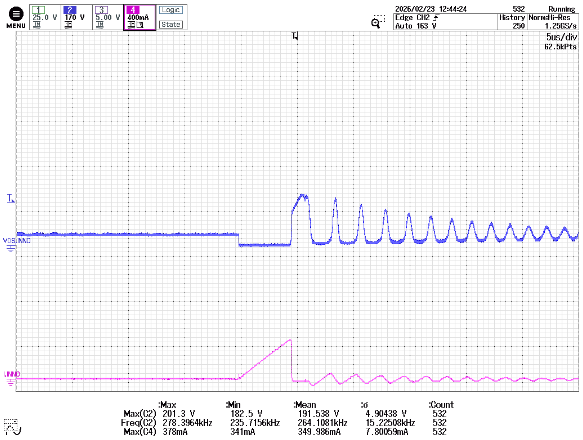
11.2.1 Switching Waveforms at 25 °C Ambient

11.2.1.1 Normal Operation Component Stress

Steady-State Switching Waveforms 25 °C Ambient							
Input	**Load**	**INN3996CQ**			**LQ10N200CQ**		
V_{IN} (VDC)	**I_{OUT} (A)**	**I_D (A)**	**V_{DS} (V)**	**V_{STRESS} (%)**	**I_D (A)**	**V_{DS} (V)**	**V_{STRESS} (%)**
40	0	0.38	201	22.4	1.84	21.4	10.7
	0.67	1.1	243	27.0	9.20	21.3	10.7
100	0	0.4	262	29.2	2.10	29.0	14.5
	1	1.18	312	34.7	10.1	28.0	14.0
400	0	0.52	564	62.7	3.34	63.6	31.8
	1	1.25	613	68.2	11.4	63.5	31.8
500	0	0.54	666	74.1	3.73	74.6	37.3
	1	1.27	715	79.5	11.8	74.3	37.2

Table 10 – Summary of Voltage Stress on Critical Components at 25 °C Ambient.

11.2.1.1.1 InnoSwitch3-AQ Drain Voltage and Current at 25 °C Ambient

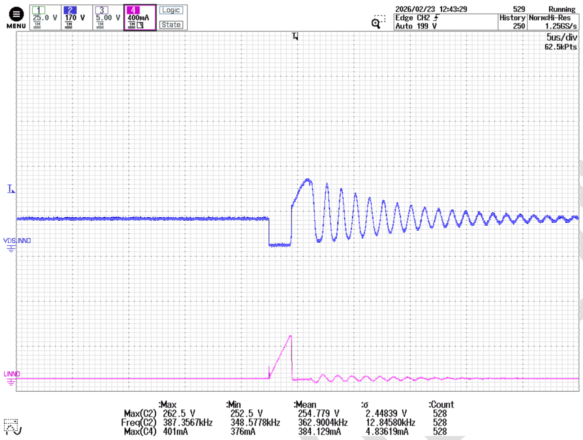


```
         :Max         :Min         :Mean        :σ            :Count
Max(C2)  201.3 V      182.5 V      191.538 V    4.90438 V     532
Freq(C2) 278.3964kHz  235.7156kHz  264.1081kHz  15.22508kHz   532
Max(C4)  378mA        341mA        349.986mA    7.80059mA     532
```

Figure 51 – INN3996CQ Drain Voltage and Current.
40 VDC, No Load.
CH2: $V_{DS,INNO}$, 170 V / div.
CH4: $I_{DS,INNO}$, 400 mA / div.
Time: 5 µs / div

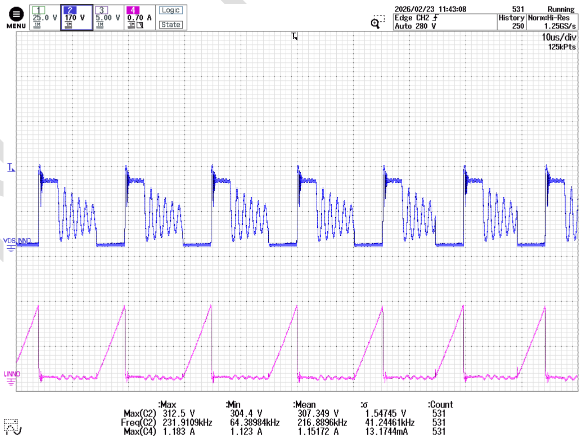
```
         :Max         :Min         :Mean        :σ            :Count
Max(C2)  243.1 V      236.3 V      240.334 V    1.39307 V     520
Freq(C2) 52.76711kHz  48.11579kHz  50.48408kHz  1.168157kHz   520
Max(C4)  1.098 A      1.043 A      1.07020 A    13.1173mA     520
```

Figure 52 – INN3996CQ Drain Voltage and Current.
40 VDC, 0.67A Load.
CH2: $V_{DS,INNO}$, 170 V / div.
CH4: $I_{DS,INNO}$, 700 mA / div.
Time: 10 µs / div



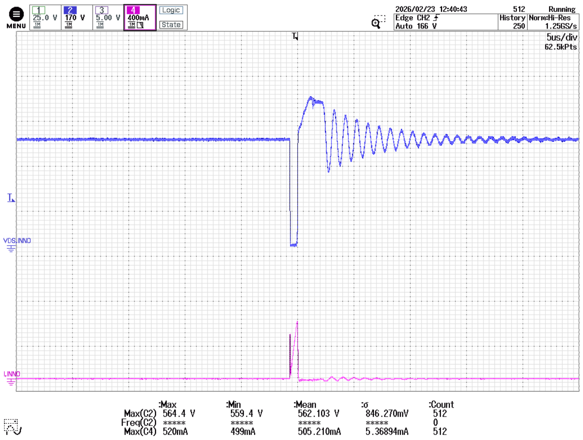
```
         :Max         :Min         :Mean        :σ            :Count
Max(C2)  262.5 V      252.5 V      254.779 V    2.44839 V     528
Freq(C2) 387.3567kHz  348.5778kHz  362.9004kHz  12.84580kHz   528
Max(C4)  401mA        376mA        384.129mA    4.83619mA     528
```

Figure 53 – INN3996CQ Drain Voltage and Current.
100 VDC, No Load.
CH2: $V_{DS,INNO}$, 170 V / div.
CH4: $I_{DS,INNO}$, 400 mA / div.
Time: 5 µs / div



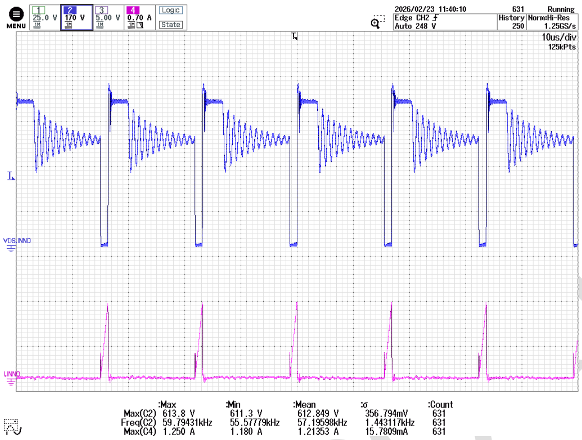
```
         :Max         :Min         :Mean        :σ            :Count
Max(C2)  312.5 V      304.4 V      307.349 V    1.54745 V     531
Freq(C2) 231.9109kHz  64.38984kHz  216.8896kHz  41.24461kHz   531
Max(C4)  1.183 A      1.123 A      1.15172 A    13.1744mA     531
```

Figure 54 – INN3996CQ Drain Voltage and Current.
100 VDC, 1A Load.
CH2: $V_{DS,INNO}$, 170 V / div.
CH4: $I_{DS,INNO}$, 700 mA / div.
Time: 10 µs / div



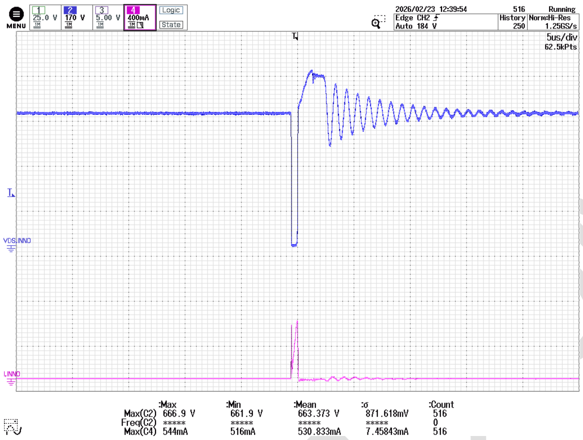
```
        :Max        :Min        :Mean         :σ            :Count
Max(C2) 564.4 V     559.4 V     562.103 V     846.270mV     512
Freq(C2) *****      *****       *****         *****         0
Max(C4) 520mA       499mA       505.210mA     5.36894mA     512
```

Figure 55 – INN3996CQ Drain Voltage and Current.
400 VDC, No Load.
CH2: $V_{DS,INNO}$, 170 V / div.
CH4: $I_{DS,INNO}$, 400 mA / div.
Time: 5 µs / div



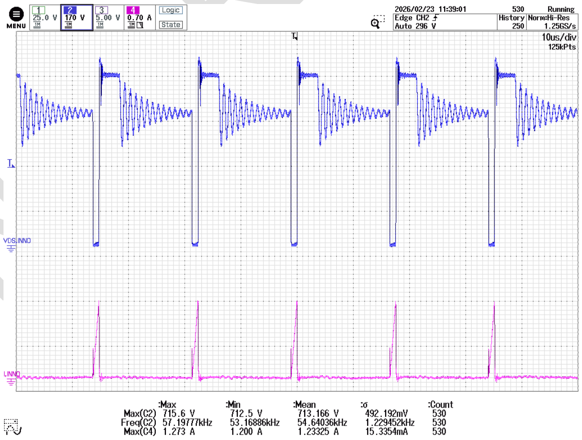
```
        :Max          :Min          :Mean         :σ             :Count
Max(C2) 613.8 V       611.3 V       612.849 V     356.794mV      631
Freq(C2) 59.79431kHz  55.57779kHz   57.19598kHz   1.443117kHz    631
Max(C4) 1.250 A       1.180 A       1.21353 A     15.7809mA      631
```

Figure 56 – INN3996CQ Drain Voltage and Current.
400 VDC, 1A Load.
CH2: $V_{DS,INNO}$, 170 V / div.
CH4: $I_{DS,INNO}$, 700 mA / div.
Time: 10 us / div



```
        :Max        :Min        :Mean         :σ            :Count
Max(C2) 666.9 V     661.9 V     663.373 V     871.618mV     516
Freq(C2) *****      *****       *****         *****         0
Max(C4) 544mA       516mA       530.833mA     7.45843mA     516
```

Figure 57 – INN3996CQ Drain Voltage and Current.
500 VDC, No Load.
CH2: $V_{DS,INNO}$, 170 V / div.
CH4: $I_{DS,INNO}$, 400 mA / div.
Time: 5 µs / div



```
        :Max          :Min          :Mean         :σ             :Count
Max(C2) 715.6 V       712.5 V       713.166 V     492.192mV      530
Freq(C2) 57.19777kHz  53.16886kHz   54.64036kHz   1.229452kHz    530
Max(C4) 1.273 A       1.200 A       1.23325 A     15.3354mA      530
```

Figure 58 – INN3996CQ Drain Voltage and Current.
500 VDC, 1A Load.
CH2: $V_{DS,INNO}$, 170 V / div.
CH4: $I_{DS,INNO}$, 700 mA / div.
Time: 10 µs / div

11.2.1.1.2 Q-Speed Diode Voltage and Current at 25 °C Ambient

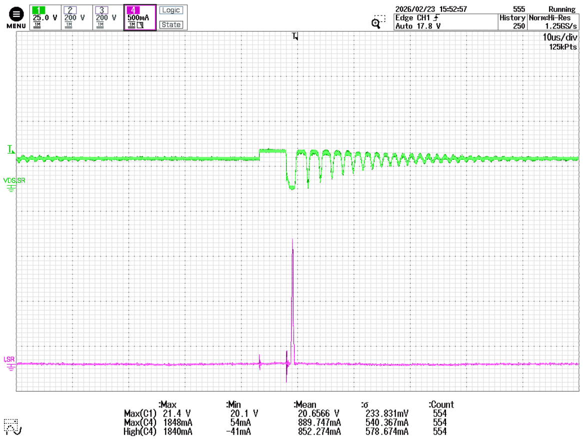


Figure 59 – Q-Speed Diode Voltage and Current.
40 VDC, No Load.
CH1: $V_{KA,QSP}$, 25 V / div.
CH4: $I_{KA,QSP}$, 0.5 A / div.
Time: 5 µs / div

Figure 60 – Q-Speed Diode Voltage and Current.
40 VDC, 0.67A Load.
CH1: $V_{KA,QSP}$, 25 V / div.
CH4: $I_{DS,INNO}$, 5 A / div.
Time: 10 µs / div

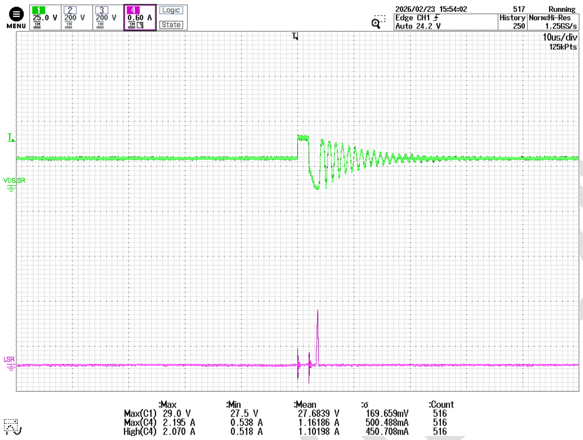
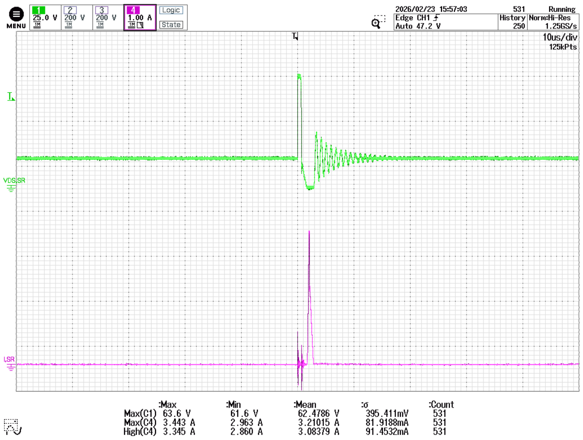


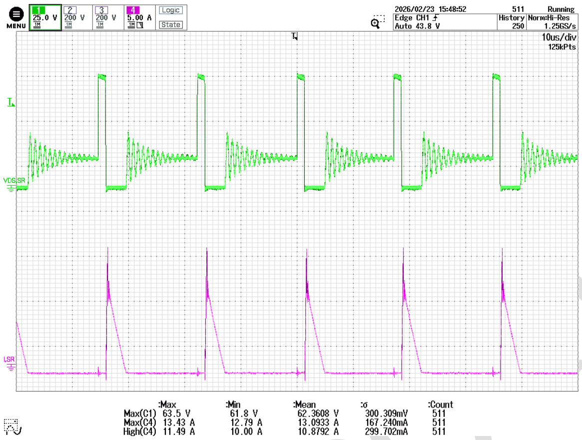
Figure 61 – Q-Speed Diode Voltage and Current.
100 VDC, No Load.
CH1: $V_{KA,QSP}$, 25 V / div.
CH4: $I_{KA,QSP}$, 0.6 A / div.
Time: 5 µs / div

Figure 62 – Q-Speed Diode Voltage and Current.
100 VDC, 1A Load.
CH1: $V_{KA,QSP}$, 25 V / div.
CH4: $I_{DS,INNO}$, 5 A / div.
Time: 10 µs / div



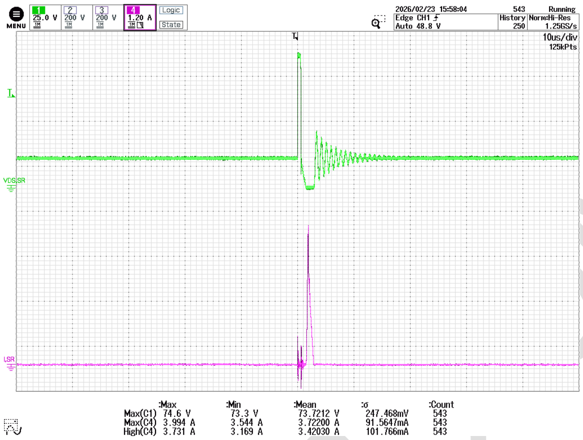
```
          :Max       :Min       :Mean        :σ           :Count
Max(C1)  63.6 V     61.6 V     62.4786 V    395.411mV     531
Max(C4)  3.443 A    2.963 A    3.21015 A    81.9188mA     531
High(C4) 3.345 A    2.860 A    3.08379 A    91.4532mA     531
```

Figure 63 – Q-Speed Diode Voltage and Current.
400 VDC, No Load.
CH1: $V_{KA,QSP}$, 25 V / div.
CH4: $I_{KA,QSP}$, 1 A / div.
Time: 5 µs / div



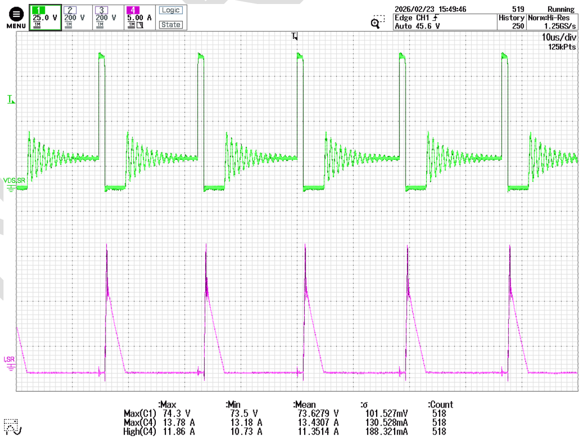
```
          :Max       :Min       :Mean        :σ           :Count
Max(C1)  63.5 V     61.8 V     62.3608 V    300.309mV     511
Max(C4)  13.43 A    12.79 A    13.0933 A    167.240mA     511
High(C4) 11.49 A    10.00 A    10.8792 A    299.702mA     511
```

Figure 64 – Q-Speed Diode Voltage and Current.
400 VDC, 1A Load.
CH1: $V_{KA,QSP}$, 25 V / div.
CH4: $I_{DS,INNO}$, 5 A / div.
Time: 10 µs / div



```
          :Max       :Min       :Mean        :σ           :Count
Max(C1)  74.6 V     73.3 V     73.7212 V    247.468mV     543
Max(C4)  3.994 A    3.544 A    3.72200 A    91.5647mA     543
High(C4) 3.731 A    3.169 A    3.42030 A    101.766mA     543
```

Figure 65 – Q-Speed Diode Voltage and Current.
500 VDC, No Load.
CH1: $V_{KA,QSP}$, 25 V / div.
CH4: $I_{KA,QSP}$, 1.2 A / div.
Time: 5 µs / div

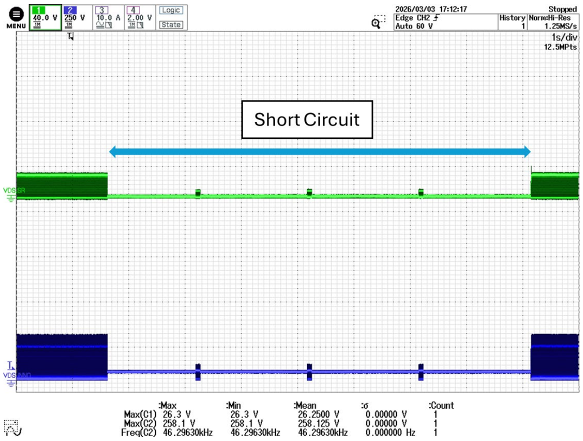


```
          :Max       :Min       :Mean        :σ           :Count
Max(C1)  74.3 V     73.5 V     73.6279 V    101.527mV     518
Max(C4)  13.78 A    13.18 A    13.4307 A    130.528mA     518
High(C4) 11.86 A    10.73 A    11.3514 A    188.321mA     518
```

Figure 66 – Q-Speed Diode Voltage and Current.
500 VDC, 1A Load.
CH1: $V_{KA,QSP}$, 25 V / div.
CH4: $I_{DS,INNO}$, 5 A / div.
Time: 10 µs / div

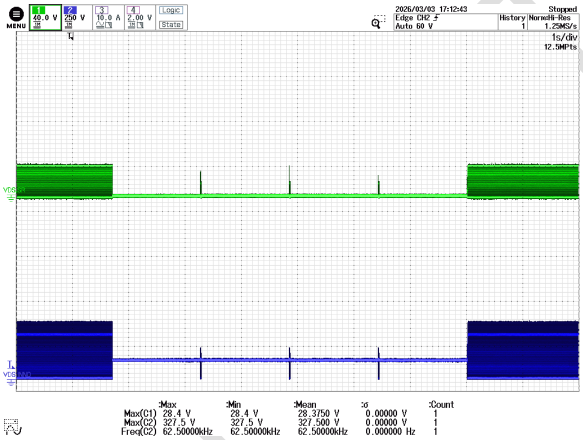
11.2.1.1.3 Short-Circuit Response at 25 °C Ambient

The unit was tested by applying an output short-circuit during normal working conditions and then removing the short-circuit to determine whether the unit would recover and operate normally. During a short-circuit, the expected response is for the unit to enter auto-restart (AR) mode and attempt to recover every 1.7 to 2.11 seconds. Full load configuration is at 15 Ω constant resistance from 100 V – 500 V and 22.5 Ω constant resistance for 40 V.



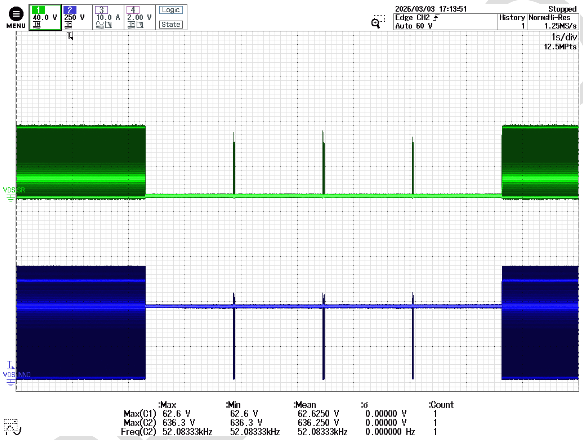
```
           :Max          :Min          :Mean         :σ             :Count
Max(C1)   26.3 V        26.3 V        26.2500 V     0.00000 V      1
Max(C2)   258.1 V       258.1 V       258.125 V     0.00000 V      1
Freq(C2)  46.29630kHz   46.29630kHz   46.29630kHz   0.000000 Hz    1
```

Figure 67 – INN3996CQ and Q-Speed Diode Voltage
40 VDC, 22.5 Ω-Short 22.5 Ω.
25 °C Ambient
CH1: $V_{KA,QSP}$, 40 V / div.
CH2: $V_{DS,INNO}$, 250 V / div.
Time: 1 s / div



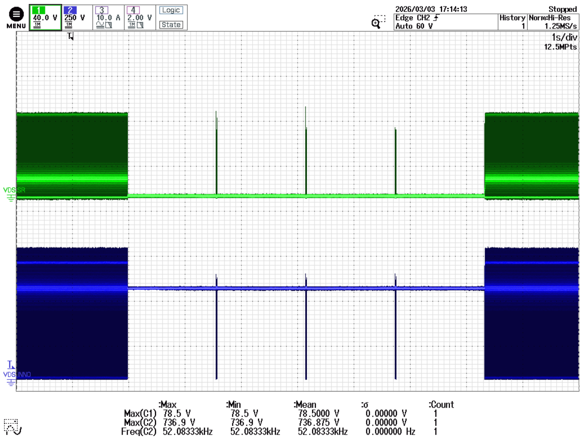
```
           :Max          :Min          :Mean         :σ             :Count
Max(C1)   28.4 V        28.4 V        28.3750 V     0.00000 V      1
Max(C2)   327.5 V       327.5 V       327.500 V     0.00000 V      1
Freq(C2)  62.50000kHz   62.50000kHz   62.50000kHz   0.000000 Hz    1
```

Figure 68 – INN3996CQ and Q-Speed Diode Voltage
100 VDC, 15 Ω-Short 15 Ω.
25 °C Ambient
CH1: $V_{KA,QSP}$, 40 V / div.
CH2: $V_{DS,INNO}$, 250 V / div.
Time: 1 s / div



```
           :Max          :Min          :Mean         :σ             :Count
Max(C1)   62.6 V        62.6 V        62.6250 V     0.00000 V      1
Max(C2)   636.3 V       636.3 V       636.250 V     0.00000 V      1
Freq(C2)  52.08333kHz   52.08333kHz   52.08333kHz   0.000000 Hz    1
```

Figure 69 – INN3996CQ and Q-Speed Diode Voltage
400 VDC, 15 Ω-Short 15 Ω.
25 °C Ambient
CH1: $V_{KA,QSP}$, 40 V / div.
CH2: $V_{DS,INNO}$, 250 V / div.
Time: 1 s / div



```
           :Max          :Min          :Mean         :σ             :Count
Max(C1)   78.5 V        78.5 V        78.5000 V     0.00000 V      1
Max(C2)   736.9 V       736.9 V       736.875 V     0.00000 V      1
Freq(C2)  52.08333kHz   52.08333kHz   52.08333kHz   0.000000 Hz    1
```

Figure 70 – INN3996CQ and Q-Speed Diode Voltage
500 VDC, 15 Ω-Short 15 Ω.
25 °C Ambient
CH1: $V_{KA,QSP}$, 40 V / div.
CH2: $V_{DS,INNO}$, 250 V / div.
Time: 1 s / div

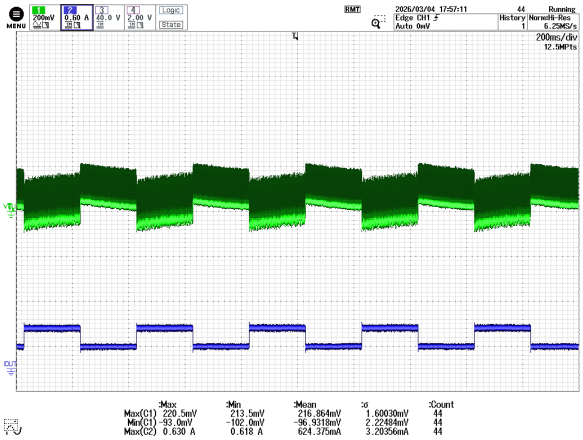
11.3 Load Transient Response

Output voltage waveforms were captured under dynamic loading from 0% to 50%, 50% to 100%, and 10% to 90%. The time duration for the load at each state was set to 500 ms with a load slew rate of 400 mA / µs. The test was performed at 25 °C ambient.

Dynamic Load Setting	V_{IN} (VDC)	$V_{OUT(MAX)}$ (V)	$V_{OUT(MIN)}$ (V)
0% - 50% - 0% **(0 A – 0.5 A – 0 A)**	40	0.169	0.161
	100	0.194	0.176
	400	0.205	0.166
	500	0.211	0.163
50% - 100% - 50% **(0.5 A – 1 A – 0.5 A)**	40	0.221	0.093
	100	0.225	0.074
	400	0.274	0.096
	500	0.279	0.100
10% - 90% - 10% **(0.1 A – 0.9 A – 0.1 A)**	40	0.223	0.137
	100	0.251	0.145
	400	0.303	0.174
	500	0.302	0.207

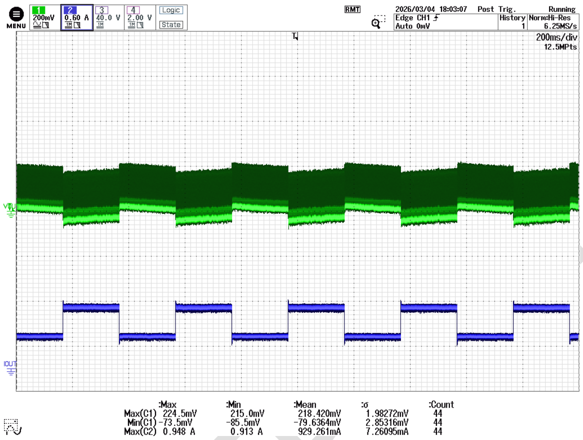
Table 11 – Load Transient Response.

11.3.1 Output Voltage Ripple with 0% - 50% - 0% Transient Load at 25 °C Ambient



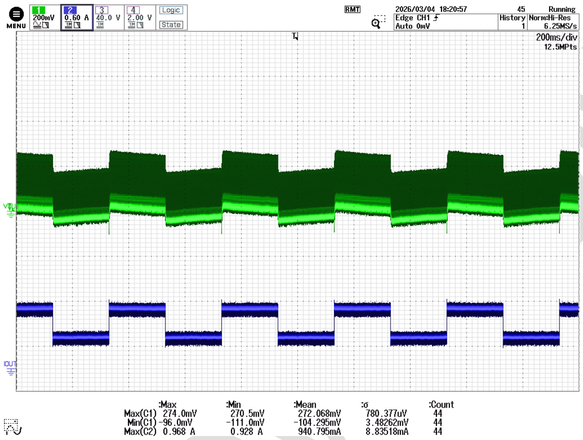
	:Max	:Min	:Mean	:σ	:Count
Max(C1)	220.5mV	213.5mV	216.864mV	1.60030mV	44
Min(C1)	-93.0mV	-102.0mV	-96.9318mV	2.22484mV	44
Max(C2)	0.630 A	0.618 A	624.375mA	3.20356mA	44

Figure 71 – Output Voltage and Current.
40 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.



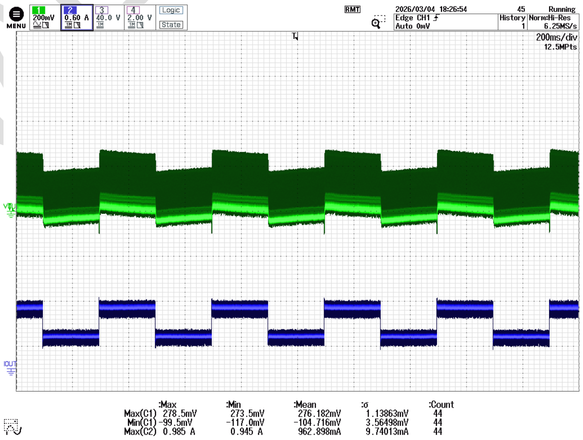
	:Max	:Min	:Mean	:σ	:Count
Max(C1)	224.5mV	215.0mV	218.420mV	1.98272mV	44
Min(C1)	-73.5mV	-85.5mV	-79.6364mV	2.85316mV	44
Max(C2)	0.948 A	0.913 A	929.261mA	7.26095mA	44

Figure 72 – Output Voltage and Current.
100 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.



	:Max	:Min	:Mean	:σ	:Count
Max(C1)	274.0mV	270.5mV	272.068mV	780.377uV	44
Min(C1)	-96.0mV	-111.0mV	-104.295mV	3.48262mV	44
Max(C2)	0.968 A	0.928 A	940.795mA	8.83518mA	44

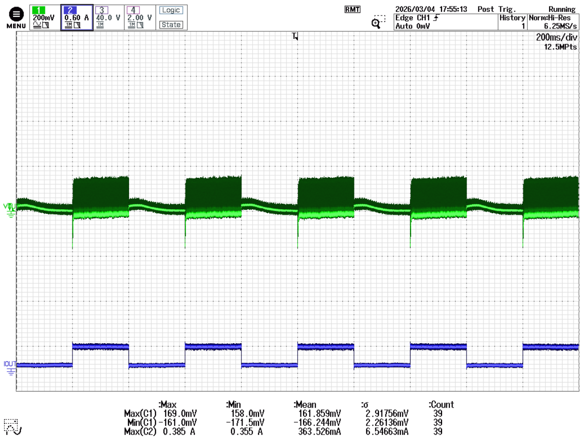
Figure 73 – Output Voltage and Current.
400 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.



	:Max	:Min	:Mean	:σ	:Count
Max(C1)	278.5mV	273.5mV	276.182mV	1.13863mV	44
Min(C1)	-99.5mV	-117.0mV	-104.716mV	3.56498mV	44
Max(C2)	0.985 A	0.945 A	962.898mA	9.74013mA	44

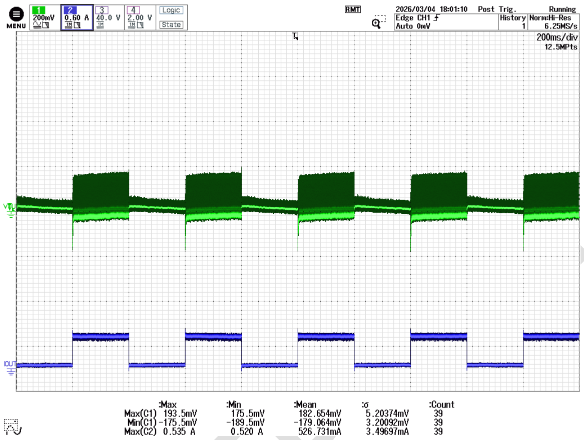
Figure 74 – Output Voltage and Current.
500 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.

11.3.2 Output Voltage Ripple with 50% - 100% - 50% Transient Load at 25 °C Ambient



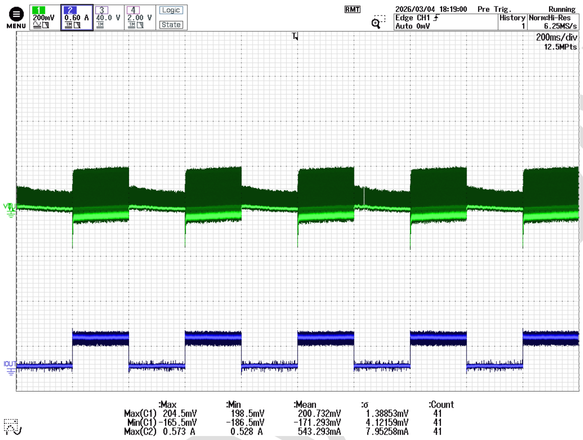
```
          :Max       :Min        :Mean        :σ           :Count
Max(C1)  169.0mV    158.0mV     161.859mV    2.91756mV    39
Min(C1) -161.0mV   -171.5mV    -166.244mV    2.26136mV    39
Max(C2)  0.385 A    0.355 A     363.526mA    6.54663mA    39
```

Figure 75 – Output Voltage and Current.
40 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.



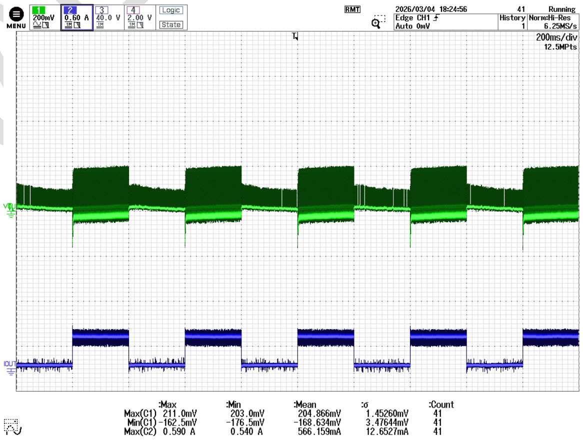
```
          :Max       :Min        :Mean        :σ           :Count
Max(C1)  193.5mV    175.5mV     182.654mV    5.20374mV    39
Min(C1) -175.5mV   -189.5mV    -179.064mV    3.20092mV    39
Max(C2)  0.535 A    0.520 A     526.731mA    3.49697mA    39
```

Figure 76 – Output Voltage and Current.
100 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.



```
          :Max       :Min        :Mean        :σ           :Count
Max(C1)  204.5mV    198.5mV     200.732mV    1.38853mV    41
Min(C1) -165.5mV   -186.5mV    -171.293mV    4.12159mV    41
Max(C2)  0.573 A    0.528 A     543.293mA    7.95258mA    41
```

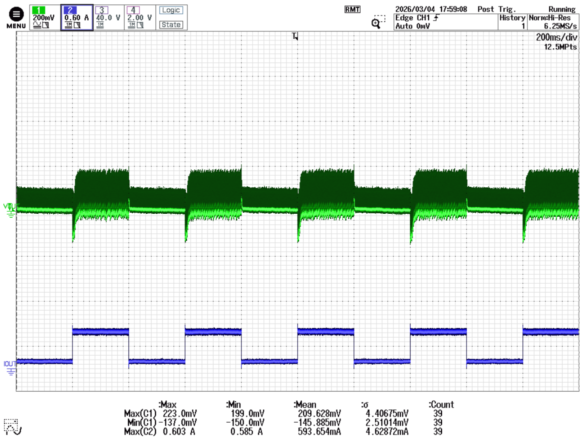
Figure 77 – Output Voltage and Current.
400 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.



```
          :Max       :Min        :Mean        :σ           :Count
Max(C1)  211.0mV    203.0mV     204.866mV    1.45260mV    41
Min(C1) -162.5mV   -176.5mV    -168.634mV    3.47644mV    41
Max(C2)  0.590 A    0.540 A     566.159mA    12.6527mA    41
```

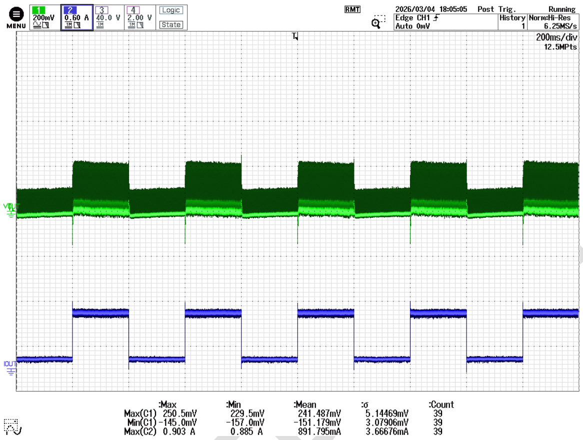
Figure 78 – Output Voltage and Current.
500 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.

11.3.3 Output Voltage Ripple with 10% - 90% - 10% Transient Load at 25 °C Ambient



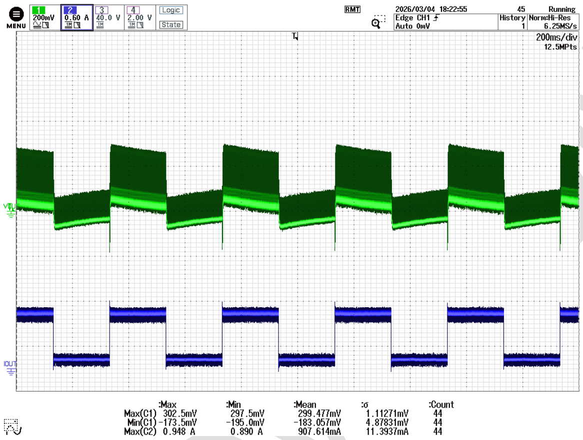
```
          :Max        :Min       :Mean        :σ          :Count
Max(C1)  223.0mV     199.0mV    209.628mV    4.40675mV    39
Min(C1) -137.0mV    -150.0mV   -145.885mV    2.51014mV    39
Max(C2)  0.603 A     0.585 A    593.654mA    4.62872mA    39
```

Figure 79 – Output Voltage and Current.
40 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.



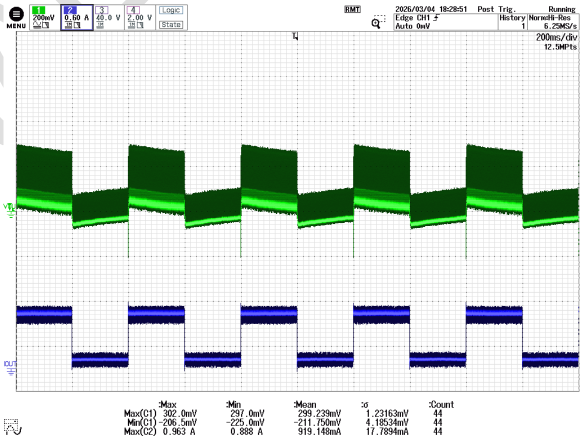
```
          :Max        :Min       :Mean        :σ          :Count
Max(C1)  250.5mV     229.5mV    241.487mV    5.14469mV    39
Min(C1) -145.0mV    -157.0mV   -151.179mV    3.07906mV    39
Max(C2)  0.903 A     0.885 A    891.795mA    3.66676mA    39
```

Figure 80 – Output Voltage and Current.
100 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.



```
          :Max        :Min       :Mean        :σ          :Count
Max(C1)  302.5mV     297.5mV    299.477mV    1.11271mV    44
Min(C1) -173.5mV    -195.0mV   -183.057mV    4.87831mV    44
Max(C2)  0.948 A     0.890 A    907.614mA    11.3937mA    44
```

Figure 81 – Output Voltage and Current.
400 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.



```
          :Max        :Min       :Mean        :σ          :Count
Max(C1)  302.0mV     297.0mV    299.239mV    1.23163mV    44
Min(C1) -206.5mV    -225.0mV   -211.750mV    4.18534mV    44
Max(C2)  0.963 A     0.888 A    919.148mA    17.7894mA    44
```

Figure 82 – Output Voltage and Current.
500 VDC, 5 A - 10 A – 5 A Transient Load,
25 °C Ambient
CH3: V_{OUT}, 200 mV / div.
CH1: I_{OUT}, 0.6 A / div.
Time: 200 ms / div.

11.4 Output Ripple Measurements

11.4.1 Ripple Measurement Technique

A modified oscilloscope test probe was used for output voltage ripple measurements to eliminate spurious signals due to pick-up. Figure 83 and Figure 84 below provide details of the probe modification.

A CT2708 probe adapter was affixed with a 1 µF / 50 V ceramic capacitor parallel to the probe tip and GND terminal. A twisted pair of wires kept as short as possible, were soldered directly between the probe and the output terminals.

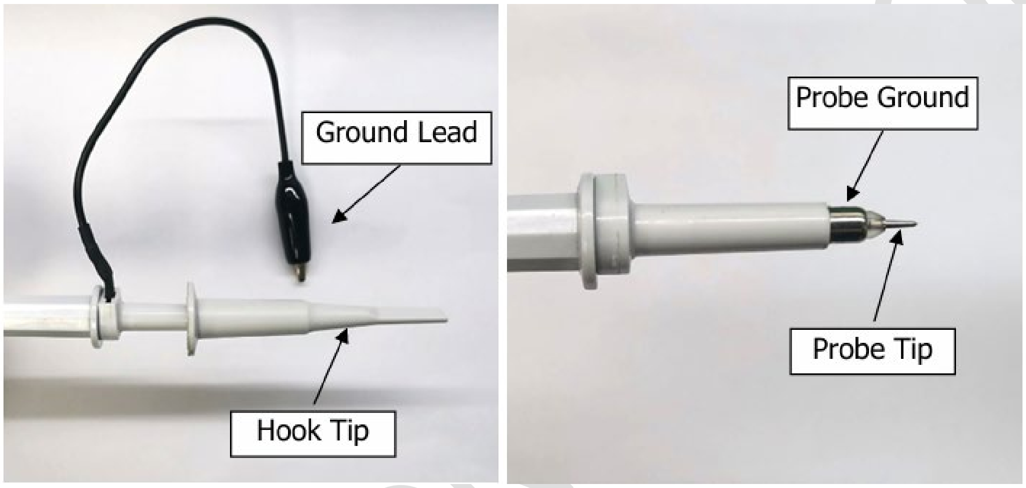


Figure 83 – Oscilloscope Probe Prepared for Ripple Measurement. (Hook Tip and Ground Lead Removed.)

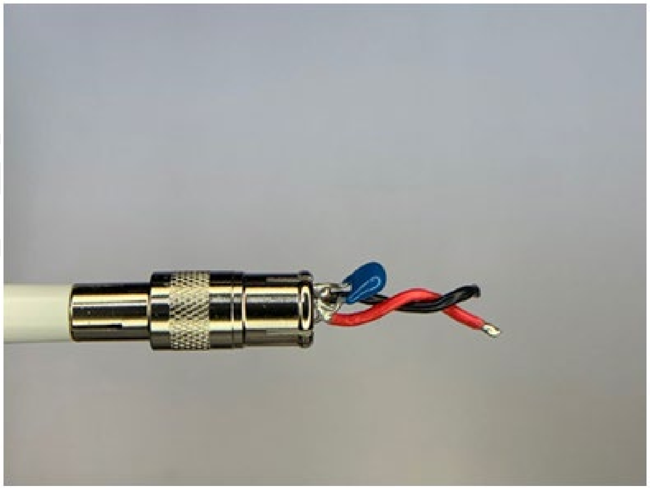


Figure 84 – Oscilloscope Probe with Cal Test CT2708 BNC Adapter. (Modified with Wires for Ripple Measurement and a Parallel Decoupling Capacitor Added.)

11.4.2 Output Voltage Ripple Waveforms at 25 °C Ambient

The output voltage ripple waveform was recorded at the output terminals at full load using the ripple measurement probe with a decoupling capacitor.

	:Max	:Min	:Mean	:σ	:Count
Max(C1)	222.0mV	206.5mV	210.359mV	2.74213mV	96
Min(C1)	-35.5mV	-41.0mV	-37.9479mV	1.14900mV	96
P-P(C1)	259.5mV	242.5mV	248.307mV	2.84803mV	96

Figure 85 – Output Voltage Ripple.
40 VDC, 0.67 A, 25 °C Ambient
CH1: V_{OUT}, 150 mV / div.
Time: 10 ms / div.

	:Max	:Min	:Mean	:σ	:Count
Max(C1)	224.0mV	216.5mV	219.755mV	1.20760mV	96
Min(C1)	-44.0mV	-49.0mV	-46.6771mV	1.09444mV	96
P-P(C1)	270.0mV	264.0mV	266.432mV	1.26372mV	96

Figure 86 – Output Voltage Ripple.
100 VDC, 1 A, 25 °C Ambient
CH1: V_{OUT}, 150 mV / div.
Time: 10 ms / div.

	:Max	:Min	:Mean	:σ	:Count
Max(C1)	249.0mV	244.0mV	246.349mV	910.356uV	96
Min(C1)	-47.0mV	-50.5mV	-48.2969mV	755.460uV	96
P-P(C1)	298.0mV	292.0mV	294.646mV	1.03561mV	96

Figure 87 – Output Voltage Ripple.
400 VDC, 0.67 A, 25 °C Ambient
CH1: V_{OUT}, 150 mV / div.
Time: 10 ms / div.

	:Max	:Min	:Mean	:σ	:Count
Max(C1)	255.5mV	250.5mV	252.547mV	858.621uV	95
Min(C1)	-53.5mV	-58.0mV	-55.6947mV	895.294uV	95
P-P(C1)	312.0mV	305.5mV	308.242mV	1.08303mV	95

Figure 88 – Output Voltage Ripple.
500 VDC, 1 A, 25 °C Ambient
CH1: V_{OUT}, 150 mV / div.
Time: 10 ms / div.

11.4.3 Output Ripple vs. Load at 25 °C Ambient

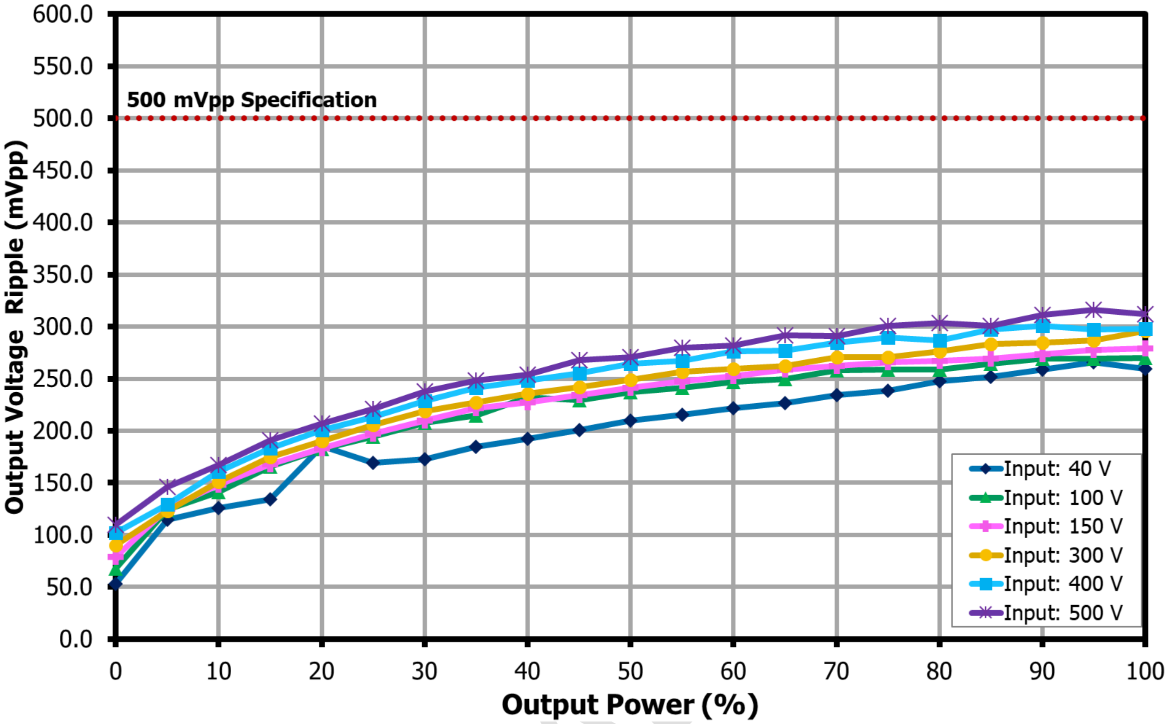


Figure 89 – Output Ripple Voltage Across Full Load Range (25 °C Ambient).

12 Maximum Output Power Derating

The unit under test was placed inside a thermal chamber. The chamber was pre-heated to 105 °C and stabilized for 30 minutes before the unit under test was turned on. Maximum output power at each given input voltage was determined by finding the maximum loading condition at which the unit started up (did not enter auto-restart (AR)) or trigger any overtemperature protection. Case temperatures for critical components were also considered when determining the maximum output power capability for the power supply.

12.1 Continuous Output Power

The unit was allowed to stabilize for 30 minutes for each change in input voltage and loading condition during the start of each test sequence.

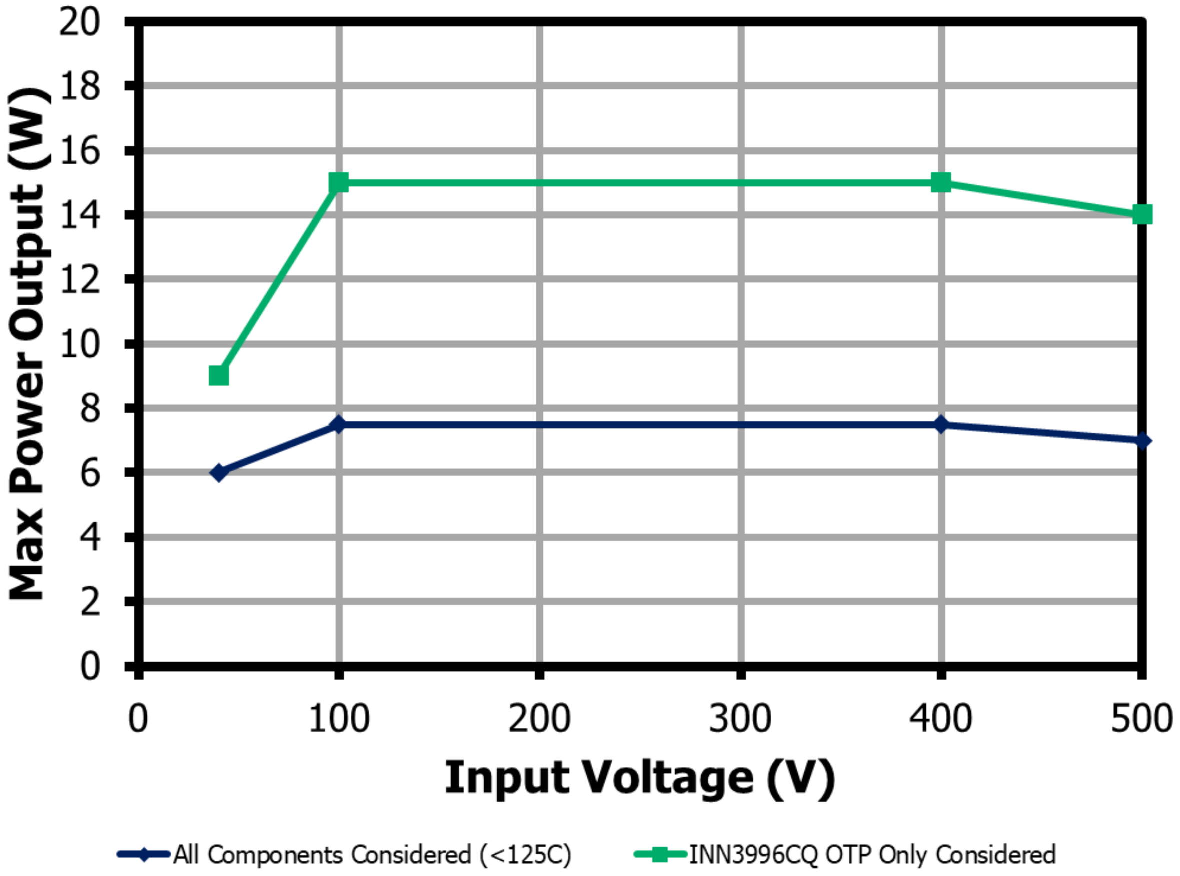


Figure 90 – Maximum Continuous Output Power Curve at 105 °C Ambient.

Input Voltage	Maximum Output Power	Limiting Factor	Value
500 VDC	7 W	Primary snubber diode case temperature	> 125 °C
400 VDC	7.5 W	Primary snubber diode case temperature	> 125 °C
100 VDC	7.5 W	Primary snubber diode case temperature	> 125 °C
40 VDC	6 W	Primary snubber diode case temperature	> 125 °C

Table 12 – Maximum Continuous Output Power Capability Limiting Factor at 105 °C Ambient (All Components Considered).

Input Voltage	Maximum Output Power	Limiting Factor	Value
500 VDC	14 W	INN3996CQ OTP	> 125 °C
400 VDC	15 W	INN3996CQ OTP	> 125 °C
100 VDC	15 W	INN3996CQ OTP	> 125 °C
40 VDC	9 W	INN3996CQ OTP	> 125 °C

Table 13 – Maximum Continuous Output Power Capability Limiting Factor at 105 °C Ambient (INN3996CQ OTP Only Considered).

13 Revision History

Date	Author	Revision	Description & Changes	Reviewed
28-May-26	JDL	1	First release (Provisional)	Apps & Mktg

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

For patent information, Life support policy, trademark information and to access a list of Power Integrations worldwide Sales and engineering support locations and services, please use the links below.

https://www.power.com/company/sales/sales-offices