

# EVM User's Guide: UCG28846DREVM-151

## UCG28846DREVM-151 Evaluation Module



### Description

The UCG28846DREVM-151 is a 65W USB-C PD evaluation module (EVM) for evaluating an off-line GaN integrated quasi-resonant flyback converter for AC/DC adapters, chargers, USB wall outlets, and other applications. The EVM meets CoC Tier 2 and DoE Level 6 efficiency requirements. The EVM is intended for evaluation purposes and is not intended as a product. The UCG28846DREVM-151 converts input voltage of  $90V_{RMS}$  to  $264V_{RMS}$  down to a selectable USB-C PD output voltage of  $5V_{DC}$ ,  $9V_{DC}$ ,  $15V_{DC}$ , or  $20V_{DC}$ . This EVM can also be configured to produce a fixed output voltage in the range from  $5V_{DC}$  to  $24V_{DC}$ . The EVM is designed to deliver 3.00A of maximum output current up to  $15V_{DC}$  and 65W of maximum output power for the output voltage above  $15V_{DC}$  up to  $24V_{DC}$ . The main device used in this design is the UCG28846 with integrated 750V GaN FET and controller in  $3.9mm \times 9.9mm$  package.

### Get Started

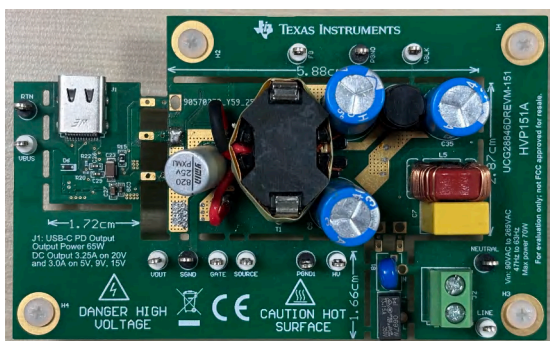
1. Read and study this user's guide completely before evaluating.
2. After completing step one, order the [UCG28846DREVM-151](#) for evaluation.
3. Setup and test the [UCG28846DREVM-151](#) per user's guide instructions.

### Features

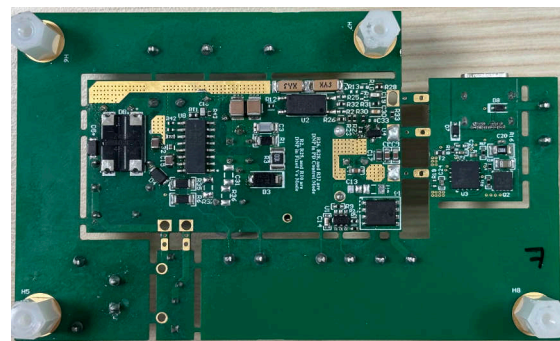
- From 93% to 95% efficiency under full-load operation over entire input voltage range
- $6.06cm \times 2.87cm \times 1.8cm$  box volume in [high power - density configuration](#)
- $2.1W/cm^3$  power density enabled by 140kHz maximum switching frequency
- Self-bias and auxless-sense, integrated current sense, integrated HV start-up and integrated X-cap discharge enable lowest BOM cost by integration
- Comprehensive protection features including OVP, OTP, short circuit, overcurrent, and brown-in/out protections
- USB-C output enables full system-level evaluation for end-equipments like adapters, notebook chargers, and USB wall outlets

### Applications

- USB-C PD power adapters
- AC-to-DC or DC-to-DC auxiliary power supplies
- High-density AC-to-DC converters, adapters for notebook computers, tablet computers, TV, and set-top box
- USB-C PPS power adapters



UCG28846DREVM-151 (Top View)



UCG28846DREVM-151 (Bottom View)

# 1 Evaluation Module Overview

## 1.1 Introduction

The UCG28846DREVM-151 facilitates the evaluation of UCG28846, integrated GaN FET with controller, within an AC-DC QR flyback power converter. The EVM is designed for a universal AC input range of 90VAC-264VAC and follows the USB PD 3.0 output protocol of 20V/15V/9V/5V. The EVM can also be configured to produce a fixed output voltage in the range from 5V to 24V. This user guide provides a high-voltage safety overview, recommended test setup, efficiency results, waveforms, and thermal performance.

## 1.2 Kit Contents

- 65W USB-C QR flyback evaluation module
- Quick start guide
- High-voltage notice

## 1.3 Specification

Input	Controller Configuration	Output	Maximum Output Power
90VAC-264VAC 47-63Hz	USB-C PD	20V/3.25A, 15V/3.00A, 9V/3.00A, and 5V/3.00A	65W
	Fixed output voltage	5V to 15V/3A and >15V to 24V/65W	

## 1.4 Device Information

The UCG28846 is a high frequency, quasi-resonant (QR) AC/DC flyback converter with integrated 750V primary-side GaN FET designed for use in power supplies up to 65W. This device gives benefit of GaN integration to achieve high power density designs with high switching frequency up to 500kHz.

The UCG28846 features auxless flyback architecture with self-bias to give a compact and low cost power supply design without the need for an auxiliary winding in the transformer. The self-bias feature reduces losses to improve efficiency in wide output voltage applications like USB-PD chargers by eliminating the need for a low dropout regulator (LDO) and associated losses to generate the device bias.

The UCG28846 supports continuous conduction mode (CCM) operation for up to 10msec for transient output power conditions of up to 130W (two times the 65W nominal output power) in low-line input conditions without the need for a transformer designed for such transient load conditions, saving space and cost. This device also includes frequency foldback and burst modes for higher efficiency operation during light load and no-load conditions, respectively. The X-cap discharge circuit discharges the X-capacitor in the input EMI filter to 0V within less than 1sec to prevent the user from an electric shock at the time of unplugging the power supply from the wall socket.

The UCG28846 overcomes the system design limitations of integrated converters by offering resistor programmable options for maximum flexibility to user to optimize performance at the desired operating point. The device also includes many in-built protections to output over-voltage, over-current, overload, short-circuit and over-temperature conditions with auto-restart and latch response for a robust power supply design preventing any damage during such fault conditions.

## 1.5 General Texas Instruments High Voltage Evaluation (TI HV EVM) User Safety Guidelines



Always follow TI's setup and application instructions, including use of all interface components within the recommended electrical rated voltage and power limits. Always use electrical safety precautions to help ensure your personal safety and those working around you. Contact TI's Product Information Center <http://support/ti.com> for further information.

**Save all warnings and instructions for future reference.**

### WARNING

Failure to follow warnings and instructions can result in personal injury, property damage or death due to electrical shock and burn hazards.

The term TI HV EVM refers to an electronic device typically provided as an open framed, unenclosed printed circuit board assembly. It is *intended strictly for use in development laboratory environments, solely for qualified professional users having training, expertise and knowledge of electrical safety risks in development and application of high voltage electrical circuits. Any other use and/or application are strictly prohibited by Texas Instruments.* If you are not qualified, then you should immediately stop from further use of the HV EVM.

1. Work Area Safety
  - a. Keep work area clean and orderly.
  - b. Qualified observers must be present anytime circuits are energized.
  - c. Effective barriers and signage must be present in the area where the TI HV EVM and the interface electronics are energized, indicating operation of accessible high voltages can be present, for the purpose of protecting inadvertent access.
  - d. All interface circuits, power supplies, evaluation modules, instruments, meters, scopes and other related apparatus used in a development environment exceeding 50Vrms/75VDC must be electrically located within a protected Emergency Power Off EPO protected power strip.
  - e. Use stable and nonconductive work surface.
  - f. Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.
2. Electrical Safety: As a precautionary measure, a good engineering practice is to assume that the entire EVM can have fully accessible and active high voltages.
  - a. De-energize the TI HV EVM at all the inputs, outputs and electrical loads before performing any electrical or other diagnostic measurements. Revalidate that TI HV EVM power has been safely de-energized.
  - b. With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment connection, and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
  - c. After EVM readiness is complete, energize the EVM as intended.

### WARNING

While the EVM is energized, never touch the EVM or the electrical circuits, as the EVM or the electrical circuits can be at high voltages capable of causing electrical shock hazard.

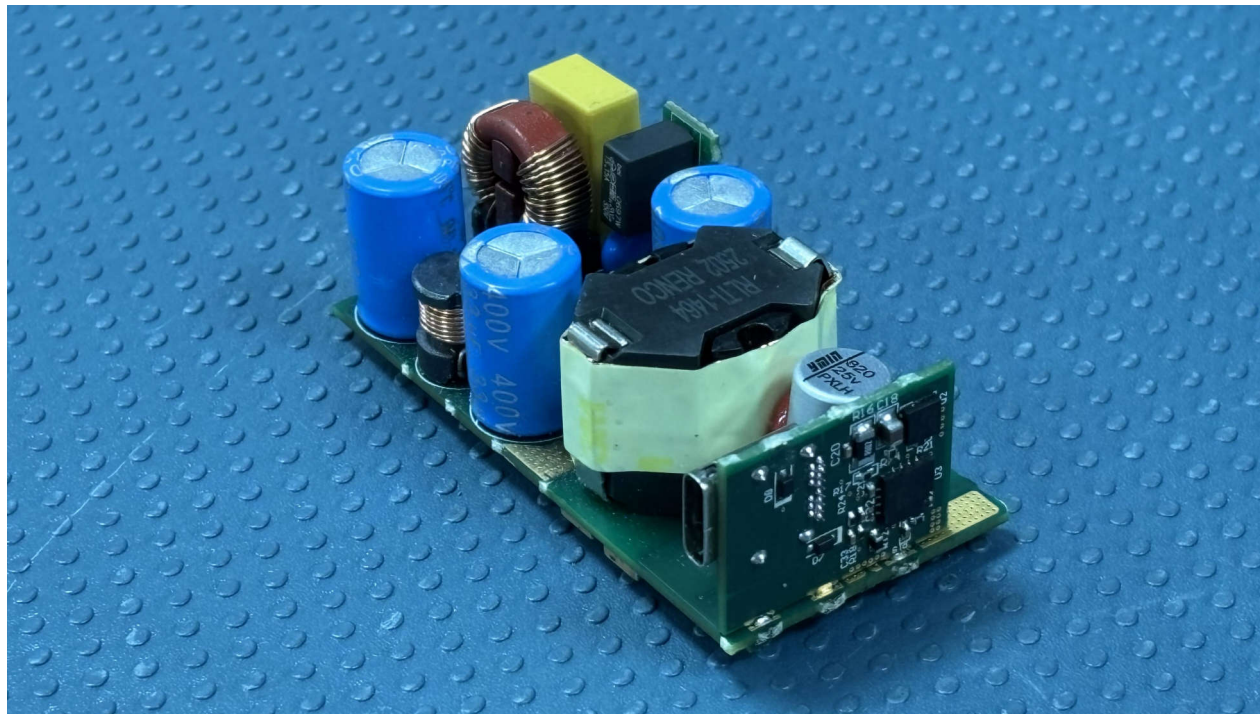
3. Personal Safety
  - a. Wear personal protective equipment (for example, latex gloves or safety glasses with side shields) or protect EVM in an adequate lucent plastic box with interlocks to protect from accidental touch.

### Limitation for safe use:

EVMs are not to be used as all or part of a production unit.

## 2 Hardware

### 2.1 Additional Image



**Figure 2-1. High Power-Density Configuration (6.06cm × 2.87cm × 1.8cm)**

#### **2.1.1 Using the EVM on a Load with USB-C PD Communication**

UCG28846DREVM-151 comes populated with a USB-C PD controller along with an on-board USB-C connector to allow evaluation with a USB-C PD load which can be connected through a USB-C cable. The corresponding test setup diagram is shown in [Section 3.2.2](#). USB-C PD controller can adjust the board output to obtain 5V, 9V, 15V, or 20V. A USB-C PD communicating load is required for evaluation of this EVM. An example of such a load is USB-C-PD-DUO-EVM. Without such a communication load, the board output USB-C connector (J2) does not provide a variable output voltage. Use a standard USB-C cable to obtain the full load current 3.00A from 5V, 9V, and 15V. Use an *E-marker* USB-C® cable to obtain 3.25A at 20V output

#### **2.1.2 Using the EVM on a Load Without USB-C PD Communication**

UCG28846DREVM-151 can be reconfigured to produce fixed out voltage in the range from 5V to 24V when evaluating with a non-USB-C PD load. The corresponding test setup diagram is shown in [Section 3.2.2](#). UCG28846DREVM-151 comes with USB-C PD control mode as default controller configuration for using USB-C PD load. For testing with non-USB-C PD load, the controller circuit must be reconfigured to enable the fixed output voltage mode. The controller reconfiguration guidelines can be found in [Section 4.1](#). In fixed output voltage control mode, the converter can deliver 3A rated current at an output from 5V to 15V and 65W rated power at an output above 15V up to 24V.

### 3 Implementation Results

#### 3.1 Electrical Performance Specifications

**Table 3-1. UCC28824EVM-124 Electrical Performance Specifications**

PARAMETER		TEST CONDITIONS	MIN	NOM	MAX	UNIT
INPUT CHARACTERISTICS						
$V_{IN}$	Input line voltage (RMS)		90	115/230	264	V
$f_{LINE}$	Input line frequency		47	50/60	63	Hz
$P_{STBY}$	Input power at no-load	$V_{IN} = 115/230V_{RMS}$ , $V_{OUT} = 5V$ , and $I_{OUT} = 0A$ , USB-C PD controller enabled		17/34		mW
$P_{180mW}$	Input power at 180mW load	$V_{IN} = 230V_{RMS}$ , $V_{OUT} = 5V$ , $P_{OUT} = 180mW$ , USB-C PD controller enabled		244		mW
$P_{300mW}$	Input power at 300mW load	$V_{IN} = 230V_{RMS}$ , $V_{OUT} = 5V$ , $P_{OUT} = 300mW$ , USB-C PD controller enabled		380		mW
OUTPUT CHARACTERISTICS						
$V_{OUT}$	Output voltage	$I_{OUT} = 0$ to 2.71A, fixed $V_{OUT}$ controller enabled		24		V
		$I_{OUT} = 0$ to 3.25A, USB-C PD controller enabled		20		V
		$I_{OUT} = 0$ to 3A, USB-C PD controller enabled		15		V
		$I_{OUT} = 0$ to 3A, fixed $V_{OUT}$ controller enabled		12		V
		$I_{OUT} = 0$ to 3A, USB-C PD controller enabled		9		V
		$I_{OUT} = 0$ to 3A, USB-C PD controller enabled		5		V
$I_{OUT}$	Full load rated output current	$V_{OUT} = 24V$		2.71		A
		$V_{OUT} = 20V$		3.25		A
		$V_{OUT} = 5V/9V/12V/15V$		3.00		A
$V_{OUT\_pp}$	Output voltage ripple at $V_{IN} = 115V/230V$	$V_{OUT} = 24V$ , $I_{OUT} = 0$ to 2.71A		50		mVpp
		$V_{OUT} = 20V$ , $I_{OUT} = 0$ to 3.25A		86		mVpp
		$V_{OUT} = 15V$ , $I_{OUT} = 0$ to 3A		98		mVpp
		$V_{OUT} = 12V$ , $I_{OUT} = 0$ to 3A		117		mVpp
		$V_{OUT} = 9V$ , $I_{OUT} = 0$ to 3A		100		mVpp
		$V_{OUT} = 5V$ , $I_{OUT} = 0$ to 3A		91		mVpp
$V_{OUT\_Δ}$	$V_{OUT}$ deviation due to load step Up / Down ( $I_{OUT}$ step change between 2% and 100% load at 25Hz rate)	$V_{OUT} = 24V$		-472/205		mV
		$V_{OUT} = 20V$		-504/289		mV
		$V_{OUT} = 15V$		-477/294		mV
		$V_{OUT} = 12V$		-454/221		mV
		$V_{OUT} = 9V$		-449/299		mV
		$V_{OUT} = 5V$		-395/307		mV
$P_{OPP}$	Over power protection threshold	$V_{IN} = 90$ to $264V_{RMS}$		100		W

**Table 3-1. UCC28824EVM-124 Electrical Performance Specifications (continued)**

PARAMETER		TEST CONDITIONS	MIN	NOM	MAX	UNIT
SYSTEMS CHARACTERISTICS						
$\eta$	Full load efficiency at $V_{IN} = 115V/230V$	$V_{OUT} = 24V, I_{OUT} = 2.71A$		94.06/94.59		%
		$V_{OUT} = 20V, I_{OUT} = 3.25A$		94.01/94.70		%
		$V_{OUT} = 15V, I_{OUT} = 3A$		94.10/94.40		%
		$V_{OUT} = 12V, I_{OUT} = 3A$		94.15/94.03		%
		$V_{OUT} = 9V, I_{OUT} = 3A$		93.96/93.54		%
		$V_{OUT} = 5V, I_{OUT} = 3A$		93.19/91.93		%
$\eta$	4-point average efficiency at $V_{IN} = 115V/230V$ <sup>(1)</sup>	$V_{OUT} = 24V$ (CoC Tier 2, 89.0%)		94.20/94.14		%
		$V_{OUT} = 20V$ (CoC Tier 2, 89.0%)		94.19/94.35		%
		$V_{OUT} = 15V$ (CoC Tier 2, 88.9%)		94.24/94.03		%
		$V_{OUT} = 12V$ (CoC Tier 2, 88.3%)		94.20/93.67		%
		$V_{OUT} = 9V$ (CoC Tier 2, 87.3%)		93.85/93.07		%
		$V_{OUT} = 5V$ (CoC Tier 2, 81.8%)		92.92/90.90		%
$\eta$	Efficiency at 10% load at $V_{IN} = 115V/230V$	$V_{OUT} = 24V$ (CoC Tier 2, 79.0%)		92.41/92.13		%
		$V_{OUT} = 20V$ (CoC Tier 2, 79.0%)		93.09/92.36		%
		$V_{OUT} = 15V$ (CoC Tier 2, 78.9%)		93.24/91.38		%
		$V_{OUT} = 12V$ (CoC Tier 2, 78.3%)		93.27/90.21		%
		$V_{OUT} = 9V$ (CoC Tier 2, 77.3%)		92.72/88.48		%
		$V_{OUT} = 5V$ (CoC Tier 2, 72.5%)		91.96/86.40		%
$T_{AMB}$	Operating ambient temperature	$V_{IN} = 90$ to $264V_{RMS}$ , $I_{OUT} = 0$ to $3.00A$ (5V/9V/15V), $3.25A$ (20V), or $2.71A$ (24V)		25		°C

(1) Average efficiency of four load points,  $I_{OUT} = 100\%$ ,  $75\%$ ,  $50\%$  and  $25\%$  of rated full-load current for each respective output voltage.

## 3.2 Test Setup

### 3.2.1 Test Setup Requirements

**Safety:** This evaluation module is not encapsulated and there are accessible voltages that are greater than 50V<sub>DC</sub>.

**Isolation Input Transformer:** An appropriately rated 1:1 isolation transformer shall be used on the inputs to this EVM and be constructed in a manner in which the primary winding are separated from the secondary windings by reinforced insulation, double insulation, or a screen connected to the protective conductor terminal.



#### WARNING

- If the user is not trained in the proper safety of handling and testing power electronics, then please do not test this evaluation module.
- While the EVM is energized, never touch the EVM or the electrical circuits, as the EVM or the electrical circuits can be at high voltages capable of causing electrical shock hazard.
- Caution: Hot surface. Contact can cause burns. Do not touch!
- Read this user's guide thoroughly before making test.

**Voltage Source:** Isolated AC source or variable AC transformer rated for atleast 264V<sub>RMS</sub> and capable of handling 100W power level.

**Voltmeter:** Digital voltage meter

**Power Analyzer:** Capable of measuring 1mW to 100W of input power and capable of handling 264V<sub>RMS</sub> input voltage. Some power analyzers require a precision shunt resistor for measuring input current to measure input power of 5W or less. Please read the power analyzer's user manual for proper measurement setups for full power and for stand-by power.

**Oscilloscope:**

- 4 Channel, 500MHz bandwidth.
- Probes capable of handling 600V.

**Output Load:** Resistive or electronic load capable of handling 130W at 20V.

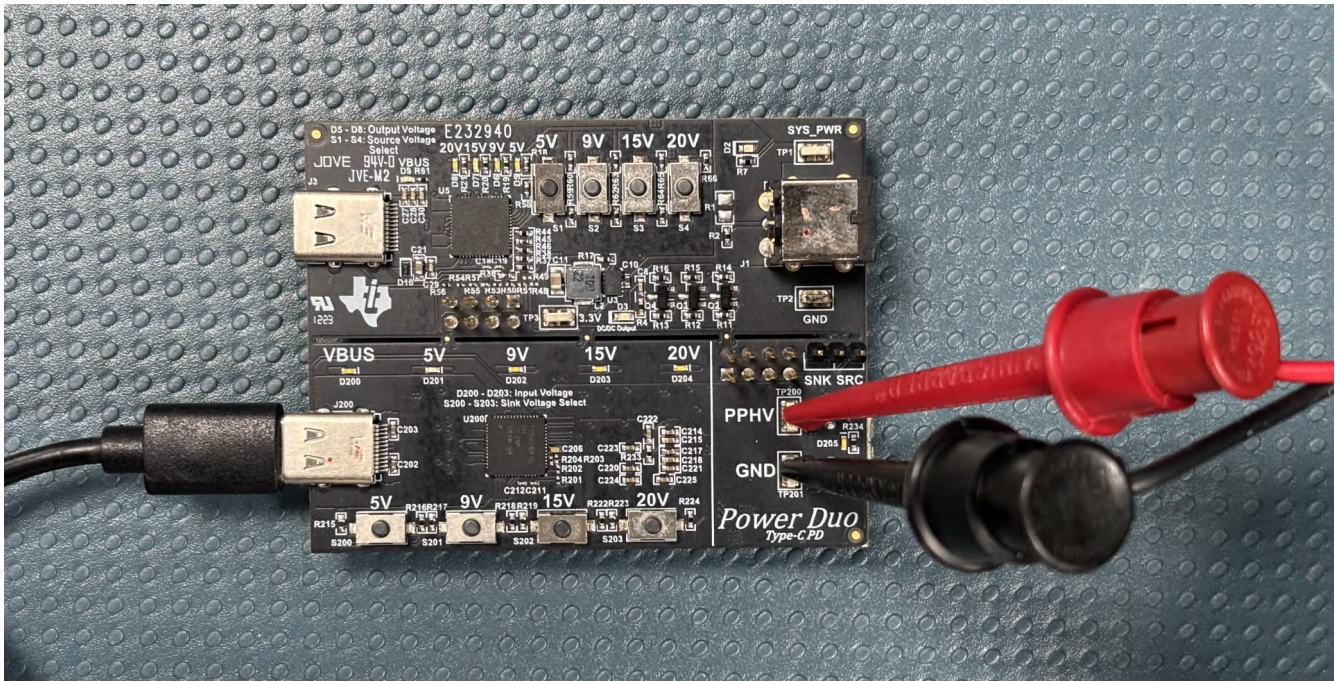
**Recommended Wire Gauge:** Insulated 22AWG to 18AWG.



#### WARNING

Caution: Do not leave EVM powered when unattended.





- A. The following USB emulator "USB-C-DUO EVM" is used for this evaluation. Any other PD3.0 compliant USB-C PD emulator can also be used for the evaluation of this EVM. Note that the USB-C PD emulators consumes few mA of current which needs to be considered for efficiency calculation.

**Figure 3-3. USB-C Emulator**

**3.2.3 Test Points**

**Table 3-2. Input/Output Terminals and Test Point Functions**

TERMINALS and TEST POINTS	DESCRIPTION
J1	USB-C terminal
J2	AC voltage input terminal
LINE	Test point for AC input - Line
NEUTRAL	Test point for AC input - Neutral
PGND1, PGND2, and PGND3	Test points for primary ground
VBLK	Test point for bulk capacitor voltage
FB	Test point for FB pin
HV	Test point for HV pin
SOURCE	Test point for SR FET source
GATE	Test point for SR FET gate
SGND	Test point for secondary ground
VOUT	Test point for converter output voltage
VBUS	Test point for bus voltage at output side
RTN	Test point for return line at output side

### 3.3 Performance Data and Typical Characteristic Curves

#### 3.3.1 Efficiency Result of 4-Point Average at $24V_{out}$

$V_{IN}$ (VRMS)	$P_{IN}$ (W)	$V_{OUT}$ (V)	$I_{OUT}$ (A)	$P_{OUT}$ (W)	$P_{OUT}$ (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	7.14	23.98	0.275	6.59	10	92.37%	93.46%
90	17.42	23.97	0.680	16.30	25	93.58%	
90	34.64	23.97	1.355	32.48	50	93.75%	
90	52.03	23.97	2.032	48.71	75	93.62%	
90	69.85	23.96	2.708	64.88	100	92.89%	
115	7.18	23.97	0.277	6.64	10	92.41%	94.20%
115	17.39	23.97	0.683	16.37	25	94.17%	
115	34.44	23.96	1.356	32.49	50	94.35%	
115	51.70	23.96	2.033	48.71	75	94.22%	
115	68.98	23.95	2.709	64.88	100	94.06%	
230	7.23	23.96	0.278	6.66	10	92.13%	94.14%
230	17.50	23.96	0.682	16.34	25	93.35%	
230	34.50	23.96	1.356	32.49	50	94.17%	
230	51.53	23.95	2.032	48.67	75	94.44%	
230	68.62	23.95	2.710	64.90	100	94.59%	
264	7.31	23.96	0.277	6.64	10	90.77%	93.78%
264	17.65	23.96	0.683	16.36	25	92.72%	
264	34.67	23.96	1.358	32.54	50	93.85%	
264	51.71	23.95	2.033	48.69	75	94.16%	
264	68.75	23.95	2.709	64.88	100	94.38%	
CoC Tier 2, 4pt average							89.00%
CoC Tier 2, 10%-load							79.00%

**3.3.2 Efficiency Result of 4-Point Average on 20V<sub>OUT</sub>**

V <sub>IN</sub> (VRMS)	P <sub>IN</sub> (W)	V <sub>OUT</sub> (V)	I <sub>OUT</sub> (A)	P <sub>OUT</sub> (W)	P <sub>OUT</sub> (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	7.29	20.00	0.331	6.79	10	93.07%	93.46%
90	17.59	20.00	0.818	16.53	25	93.99%	
90	34.96	20.00	1.628	32.73	50	93.63%	
90	52.33	20.00	2.440	48.96	75	93.56%	
90	70.34	19.99	3.253	65.19	100	92.68%	
115	7.31	19.99	0.332	6.81	10	93.09%	94.19%
115	17.53	20.00	0.818	16.52	25	94.28%	
115	34.66	19.99	1.628	32.72	50	94.39%	
115	52.05	19.99	2.441	48.97	75	94.08%	
115	69.36	19.99	3.253	65.20	100	94.01%	
230	7.33	20.01	0.330	6.77	10	92.36%	94.35%
230	17.62	20.01	0.817	16.51	25	93.71%	
230	34.67	20.01	1.627	32.72	50	94.37%	
230	51.75	20.00	2.439	48.96	75	94.61%	
230	68.83	20.00	3.251	65.18	100	94.70%	
264	7.43	19.99	0.331	6.79	10	91.33%	93.92%
264	17.78	20.00	0.819	16.54	25	93.05%	
264	34.86	20.00	1.628	32.72	50	93.85%	
264	51.94	20.00	2.441	48.98	75	94.30%	
264	69.01	20.00	3.252	65.20	100	94.47%	
CoC Tier 2, 4pt average							89.00%
CoC Tier 2, 10%-load							79.00%

### 3.3.3 Efficiency Result of 4-Point Average at 15V<sub>OUT</sub>

V <sub>IN</sub> (VRMS)	P <sub>IN</sub> (W)	V <sub>OUT</sub> (V)	I <sub>OUT</sub> (A)	P <sub>OUT</sub> (W)	P <sub>OUT</sub> (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	5.02	15.02	0.305	4.69	10	93.42%	93.70%
90	12.17	15.02	0.755	11.45	25	94.09%	
90	24.17	15.02	1.503	22.68	50	93.85%	
90	36.26	15.02	2.252	33.93	75	93.57%	
90	48.46	15.02	3.003	45.21	100	93.31%	
115	5.04	15.01	0.306	4.70	10	93.24%	94.24%
115	12.15	15.01	0.755	11.44	25	94.16%	
115	24.02	15.01	1.504	22.69	50	94.45%	
115	36.00	15.01	2.253	33.93	75	94.24%	
115	48.03	15.01	3.003	45.19	100	94.09%	
230	5.13	15.02	0.305	4.69	10	91.38%	94.03%
230	12.25	15.02	0.755	11.45	25	93.43%	
230	24.14	15.02	1.503	22.69	50	93.97%	
230	36.00	15.02	2.253	33.95	75	94.31%	
230	47.88	15.02	3.002	45.20	100	94.40%	
264	5.19	15.02	0.305	4.69	10	90.23%	93.48%
264	12.37	15.02	0.755	11.45	25	92.53%	
264	24.29	15.02	1.504	22.69	50	93.44%	
264	36.17	15.02	2.253	33.95	75	93.86%	
264	48.05	15.02	3.003	45.21	100	94.09%	
CoC Tier 2, 4pt average							88.85%
CoC Tier 2, 10%-load							78.85%

### 3.3.4 Efficiency Result of 4-Point Average at 12V<sub>out</sub>

V <sub>IN</sub> (VRMS)	P <sub>IN</sub> (W)	V <sub>OUT</sub> (V)	I <sub>OUT</sub> (A)	P <sub>OUT</sub> (W)	P <sub>OUT</sub> (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	3.89	11.98	0.305	3.65	10	93.91%	93.74%
90	9.60	11.98	0.754	9.03	25	94.09%	
90	19.15	11.98	1.503	18.00	50	94.01%	
90	28.85	11.98	2.252	26.97	75	93.48%	
90	38.49	11.97	3.002	35.94	100	93.38%	
115	3.92	11.98	0.305	3.65	10	93.27%	94.20%
115	9.62	11.98	0.755	9.04	25	94.01%	
115	19.09	11.97	1.504	18.01	50	94.36%	
115	28.62	11.97	2.253	26.98	75	94.26%	
115	38.18	11.97	3.003	35.95	100	94.15%	
230	4.05	11.98	0.305	3.65	10	90.21%	93.67%
230	9.73	11.98	0.756	9.05	25	93.07%	
230	19.23	11.97	1.504	18.01	50	93.66%	
230	28.73	11.97	2.254	26.98	75	93.93%	
230	38.23	11.97	3.003	35.94	100	94.03%	
264	4.12	11.98	0.305	3.65	10	88.72%	93.09%
264	9.82	11.97	0.756	9.05	25	92.23%	
264	19.35	11.97	1.504	18.01	50	93.05%	
264	28.87	11.97	2.254	26.98	75	93.44%	
264	38.38	11.97	3.003	35.94	100	93.63%	
CoC Tier 2, 4pt average							88.30%
CoC Tier 2, 10%-load							78.30%

### 3.3.5 Efficiency Result of 4-Point Average at 9V<sub>OUT</sub>

V <sub>IN</sub> (VRMS)	P <sub>IN</sub> (W)	V <sub>OUT</sub> (V)	I <sub>OUT</sub> (A)	P <sub>OUT</sub> (W)	P <sub>OUT</sub> (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	3.00	9.02	0.305	2.80	10	93.33%	93.52%
90	7.32	9.02	0.754	6.85	25	93.62%	
90	14.52	9.02	1.504	13.62	50	93.79%	
90	21.80	9.02	2.253	20.38	75	93.50%	
90	29.13	9.03	3.002	27.14	100	93.18%	
115	3.03	9.02	0.306	2.81	10	92.72%	93.85%
115	7.35	9.02	0.755	6.86	25	93.33%	
115	14.48	9.02	1.504	13.61	50	94.02%	
115	21.66	9.02	2.254	20.38	75	94.08%	
115	28.90	9.02	3.004	27.15	100	93.96%	
230	3.16	9.02	0.304	2.79	10	88.48%	93.07%
230	7.42	9.02	0.754	6.85	25	92.41%	
230	14.63	9.02	1.503	13.61	50	93.03%	
230	21.83	9.02	2.252	20.37	75	93.31%	
230	29.02	9.03	3.002	27.15	100	93.54%	
264	3.22	9.02	0.304	2.79	10	86.84%	92.36%
264	7.50	9.03	0.754	6.86	25	91.43%	
264	14.76	9.03	1.503	13.62	50	92.28%	
264	21.97	9.03	2.252	20.37	75	92.74%	
264	29.19	9.02	3.003	27.15	100	93.01%	
CoC Tier 2, 4pt average							87.30%
CoC Tier 2, 10%-load							77.30%

### 3.3.6 Efficiency Result of 4-Point Average at 5V<sub>OUT</sub>

V <sub>IN</sub> (VRMS)	P <sub>IN</sub> (W)	V <sub>OUT</sub> (V)	I <sub>OUT</sub> (A)	P <sub>OUT</sub> (W)	P <sub>OUT</sub> (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	1.64	4.99	0.304	1.52	10	92.34%	92.96%
90	4.05	4.99	0.754	3.76	25	92.87%	
90	8.04	4.99	1.503	7.49	50	93.16%	
90	12.08	4.99	2.253	11.23	75	93.01%	
90	16.14	4.99	3.003	14.98	100	92.77%	
115	1.65	4.98	0.305	1.52	10	91.96%	92.92%
115	4.08	4.98	0.755	3.76	25	92.31%	
115	8.07	4.99	1.504	7.50	50	92.93%	
115	12.05	4.99	2.253	11.24	75	93.24%	
115	16.07	4.99	3.003	14.98	100	93.19%	
230	1.76	4.98	0.305	1.52	10	86.40%	90.90%
230	4.24	4.98	0.755	3.76	25	88.85%	
230	8.22	4.99	1.504	7.50	50	91.18%	
230	12.26	4.99	2.254	11.24	75	91.64%	
230	16.29	4.99	3.003	14.98	100	91.93%	
264	1.80	4.98	0.305	1.52	10	84.58%	89.82%
264	4.31	4.98	0.755	3.76	25	87.27%	
264	8.32	4.99	1.504	7.50	50	90.10%	
264	12.38	4.99	2.254	11.24	75	90.77%	
264	16.43	4.99	3.003	14.97	100	91.15%	
CoC Tier 2, 4pt average							81.84%
CoC Tier 2, 10%-load							72.48%

### 3.3.7 Efficiency Typical Results

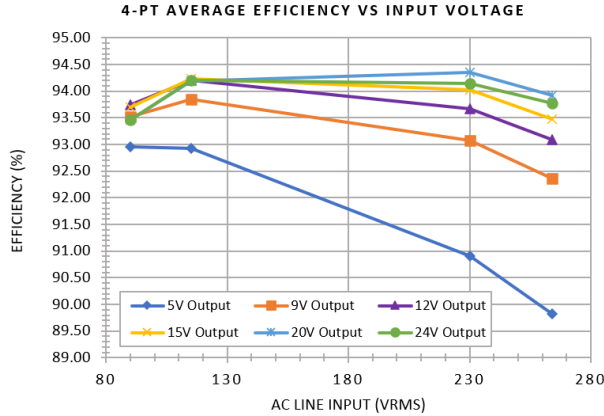


Figure 3-4. 4pt-Average Efficiency vs. Input Voltage

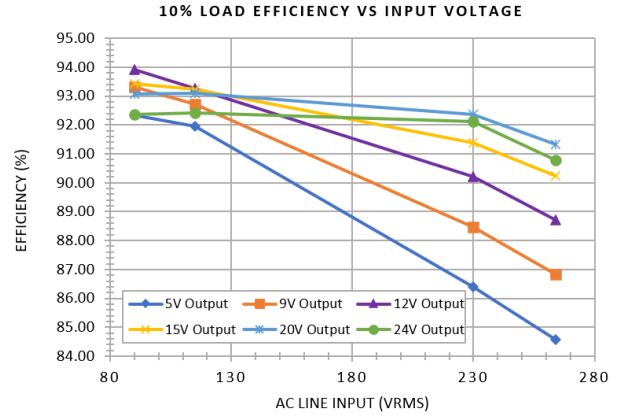


Figure 3-5. 10%-Load Efficiency vs. Input Voltage

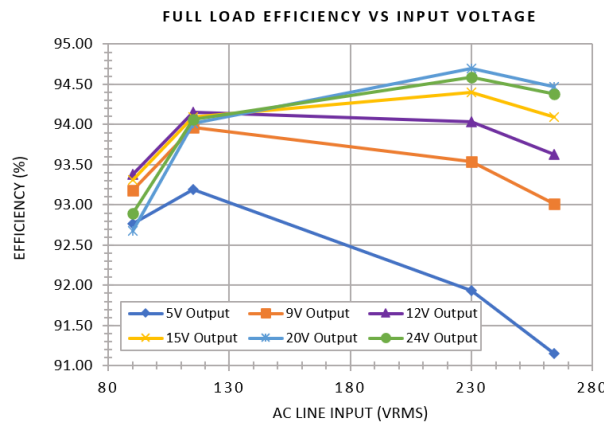


Figure 3-6. Full-load Efficiency vs. Input Voltage

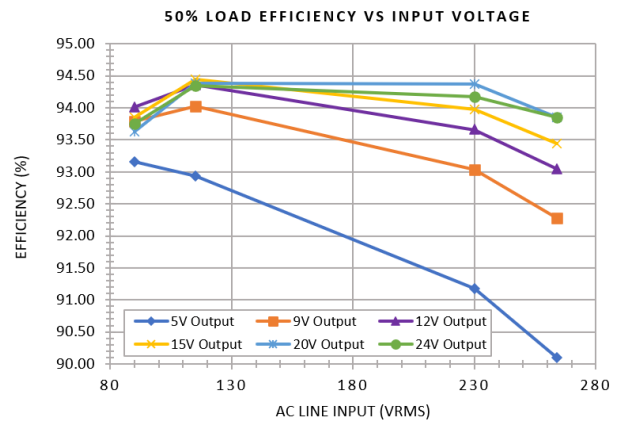


Figure 3-7. 50%-load Efficiency vs. Input Voltage

### 3.3.8 Output Characteristics

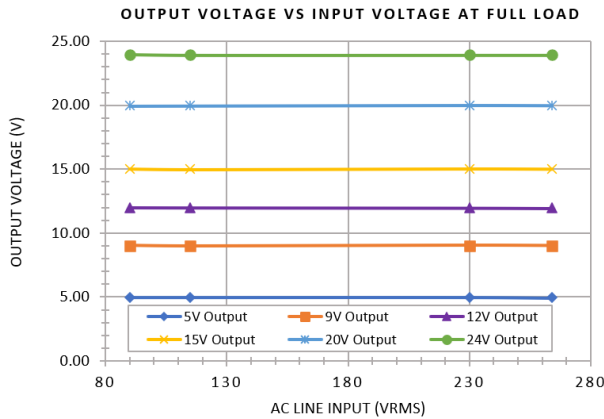


Figure 3-8.  $V_{OUT}$  vs. Input Voltage at Full-Load

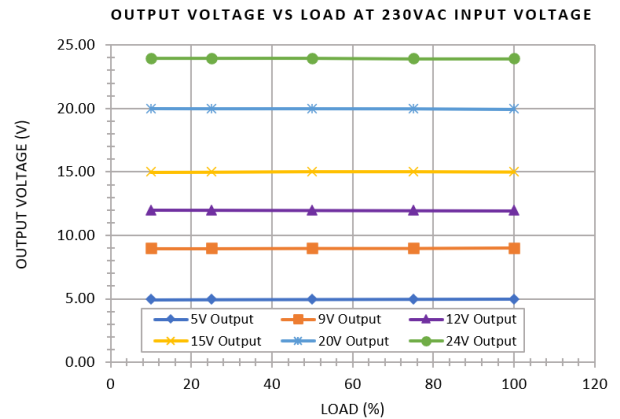


Figure 3-9.  $V_{OUT}$  vs. Load at 230Vac Input Voltage

### 3.3.9 Key Switching Waveforms

This section shows typical switching waveforms at full load. Ch1 - Output Voltage, Ch2 - SR Gate Voltage, Ch3 - Switch Node voltage, and Ch4 - FB pin Voltage.

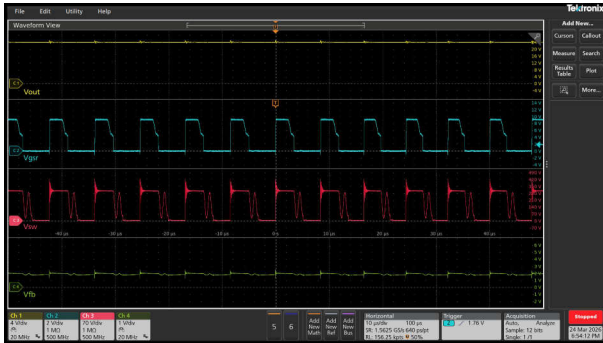


Figure 3-10.  $V_{in} = 90\text{Vac}$ ,  $V_{out} = 24\text{V}$



Figure 3-11.  $V_{in} = 115\text{Vac}$ ,  $V_{out} = 24\text{V}$



Figure 3-12.  $V_{in} = 230\text{Vac}$ ,  $V_{out} = 24\text{V}$



Figure 3-13.  $V_{in} = 264\text{Vac}$ ,  $V_{out} = 24\text{V}$



Figure 3-14.  $V_{in} = 90\text{Vac}$ ,  $V_{out} = 20\text{V}$



Figure 3-15.  $V_{in} = 115\text{Vac}$ ,  $V_{out} = 20\text{V}$



Figure 3-16.  $V_{in} = 230\text{Vac}$ ,  $V_{out} = 20\text{V}$



Figure 3-17.  $V_{in} = 264\text{Vac}$ ,  $V_{out} = 20\text{V}$


**Figure 3-18.  $V_{in} = 90\text{Vac}$ ,  $V_{out} = 15\text{V}$** 

**Figure 3-19.  $V_{in} = 115\text{Vac}$ ,  $V_{out} = 15\text{V}$** 

**Figure 3-20.  $V_{in} = 230\text{Vac}$ ,  $V_{out} = 15\text{V}$** 

**Figure 3-21.  $V_{in} = 264\text{Vac}$ ,  $V_{out} = 15\text{V}$** 

**Figure 3-22.  $V_{in} = 90\text{Vac}$ ,  $V_{out} = 12\text{V}$** 

**Figure 3-23.  $V_{in} = 115\text{Vac}$ ,  $V_{out} = 12\text{V}$** 

**Figure 3-24.  $V_{in} = 230\text{Vac}$ ,  $V_{out} = 12\text{V}$** 

**Figure 3-25.  $V_{in} = 264\text{Vac}$ ,  $V_{out} = 12\text{V}$**



Figure 3-26.  $V_{in} = 90\text{Vac}$ ,  $V_{out} = 9\text{V}$



Figure 3-27.  $V_{in} = 115\text{Vac}$ ,  $V_{out} = 9\text{V}$



Figure 3-28.  $V_{in} = 230\text{Vac}$ ,  $V_{out} = 9\text{V}$



Figure 3-29.  $V_{in} = 264\text{Vac}$ ,  $V_{out} = 9\text{V}$



Figure 3-30.  $V_{in} = 90\text{Vac}$ ,  $V_{out} = 5\text{V}$



Figure 3-31.  $V_{in} = 115\text{Vac}$ ,  $V_{out} = 5\text{V}$

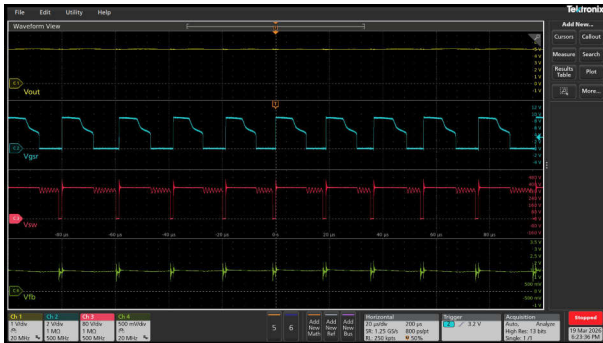


Figure 3-32.  $V_{in} = 230\text{Vac}$ ,  $V_{out} = 5\text{V}$

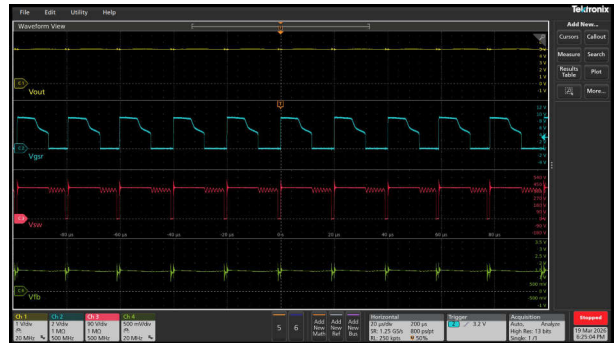


Figure 3-33.  $V_{in} = 264\text{Vac}$ ,  $V_{out} = 5\text{V}$

### 3.3.10 Switching Frequency versus Load

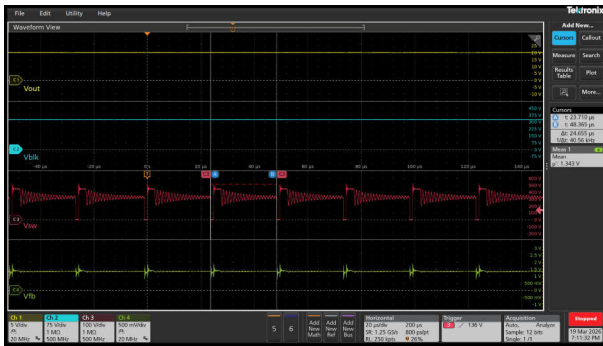
This section shows typical switching waveforms at different load conditions at 230Vac input and 20V output. Ch1 - Output Voltage, Ch2 - Bulk Capacitor Voltage, Ch3 - Switch Node Voltage, and Ch4 - FB pin Voltage



**Figure 3-34. 230Vac/0.4W (25kHz Burst Frequency/ Vfb - 0.27V)**



**Figure 3-35. 230Vac/3W (25kHz Frequency-Foldback / Vfb - 0.98V)**



**Figure 3-36. 230Vac/10W (40kHz Frequency-Foldback/ Vfb - 1.34V)**



**Figure 3-37. 230Vac/16W (53kHz Frequency-Foldback/ Vfb - 1.45V)**



**Figure 3-38. 230Vac/40W (91kHz 6<sup>th</sup> Valley Switching/ Vfb - 1.71V)**



**Figure 3-39. 230Vac/65W (115kHz 3<sup>rd</sup> Valley Switching/Vfb - 1.93V)**

### 3.3.11 Output Ripple Voltage

This section shows the output voltage ripple waveforms. Ch1 - Output Voltage Ripple, Oscilloscope Channel Bandwidth = 20MHz.

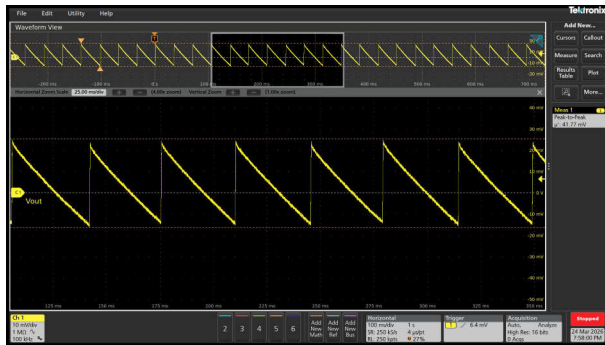


Figure 3-40. Typical Ripple Voltage of  $V_{OUT} = 24V$  at No Load (42mVpp)



Figure 3-41. Typical Ripple Voltage of  $V_{OUT} = 24V$  at Full Load (50mVpp)

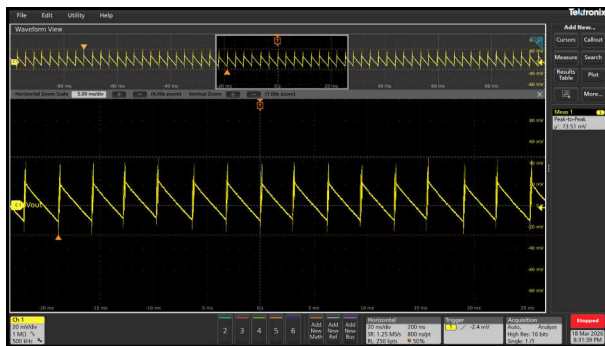


Figure 3-42. Typical Ripple Voltage of  $V_{OUT} = 20V$  at No Load (74mVpp)

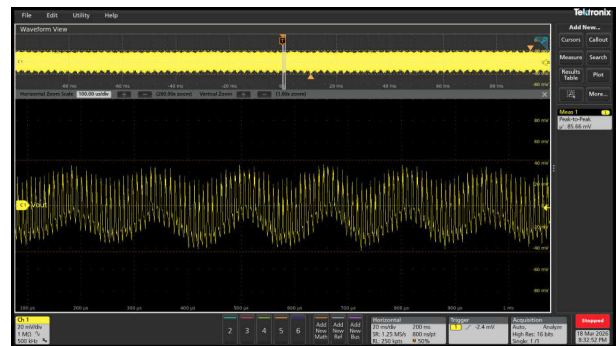


Figure 3-43. Typical Ripple Voltage of  $V_{OUT} = 20V$  at Full Load (86mVpp)

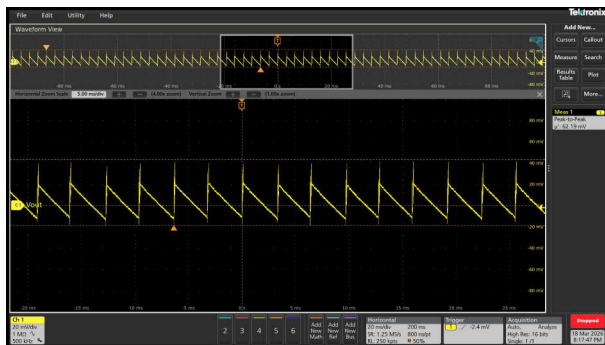


Figure 3-44. Typical Ripple Voltage of  $V_{OUT} = 15V$  at No Load (62mVpp)

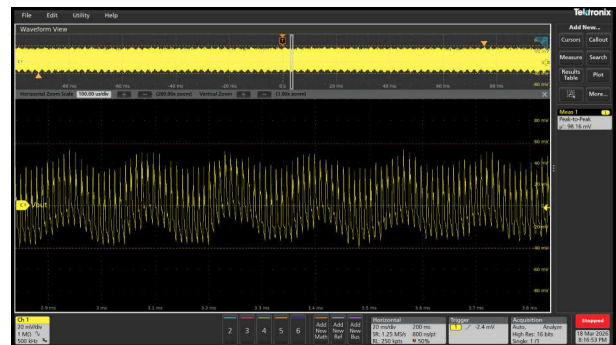


Figure 3-45. Typical Ripple Voltage of  $V_{OUT} = 15V$  at Full Load (98mVpp)

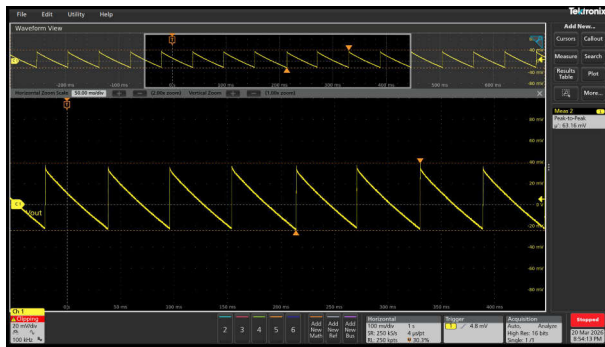


Figure 3-46. Typical Ripple Voltage of  $V_{OUT} = 12V$  at No Load (63mVpp)

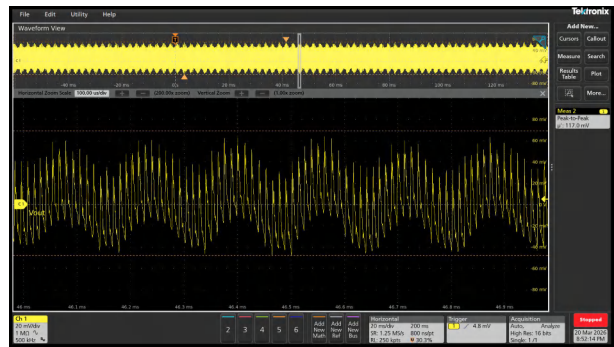


Figure 3-47. Typical Ripple Voltage of  $V_{OUT} = 12V$  at Full Load (117mVpp)

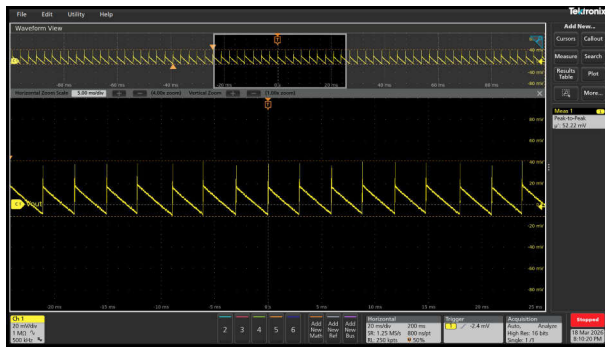


Figure 3-48. Typical Ripple Voltage of  $V_{OUT} = 9V$  at No Load (52mVpp)



Figure 3-49. Typical Ripple Voltage of  $V_{OUT} = 9V$  at Full Load (100mVpp)

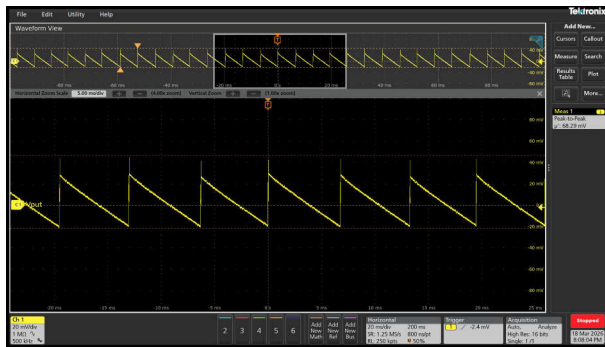


Figure 3-50. Typical Ripple Voltage of  $V_{OUT} = 5V$  at No Load (68mVpp)

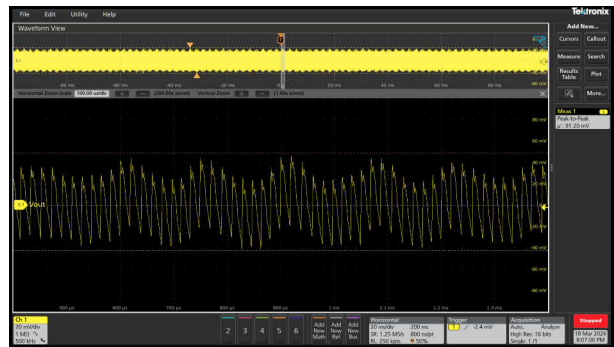
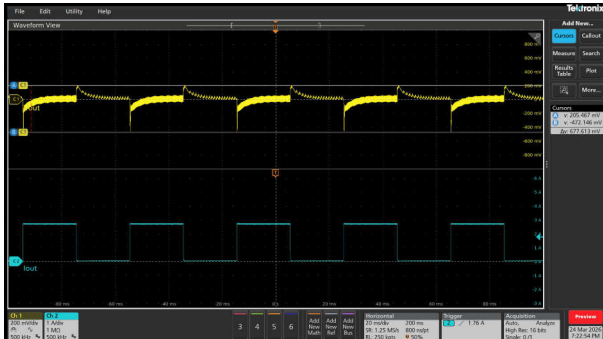


Figure 3-51. Typical Ripple Voltage of  $V_{OUT} = 5V$  at Full Load (91mVpp)

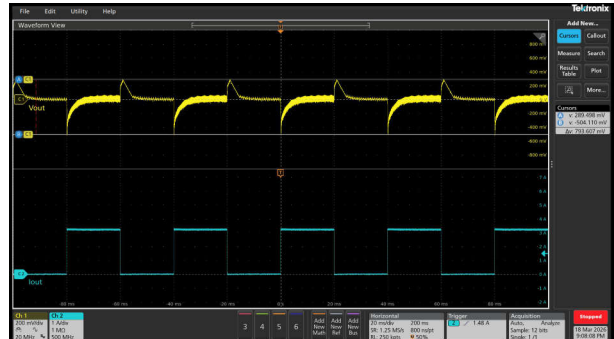
### 3.3.12 Load Transient Response

This section presents the switching waveforms under load transient condition. Here, the load current step change is between 2% and 100%, at 25Hz rate at 2.5A/ $\mu$ s.

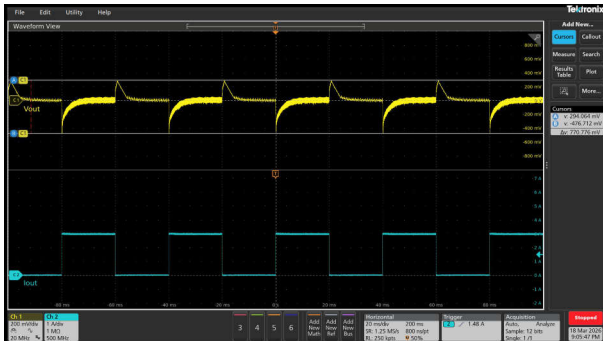
Ch1 – Output Voltage (AC Coupled), Ch2 – Output Current.



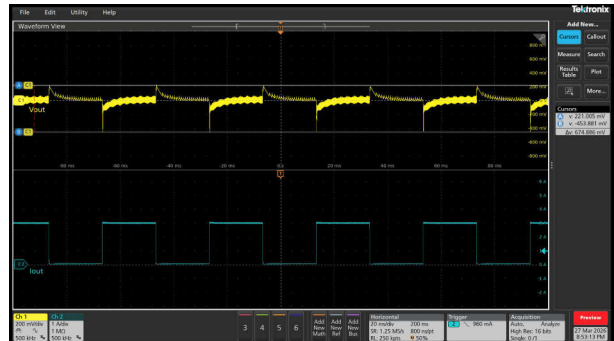
**Figure 3-52. Load Transient Response at  $V_{OUT} = 24V$   
Overshoot / Undershoot = 205mV / -472mV**



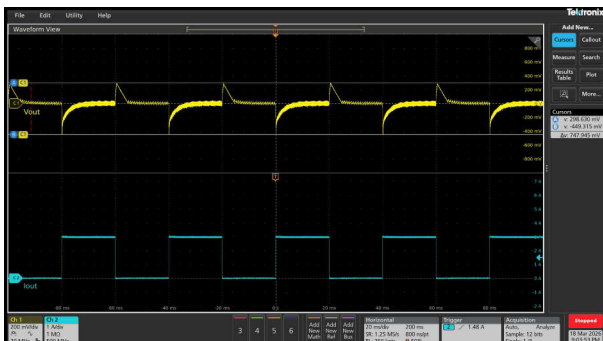
**Figure 3-53. Transient Response at  $V_{OUT} = 20V$   
Overshoot / Undershoot = 289mV / -504mV**



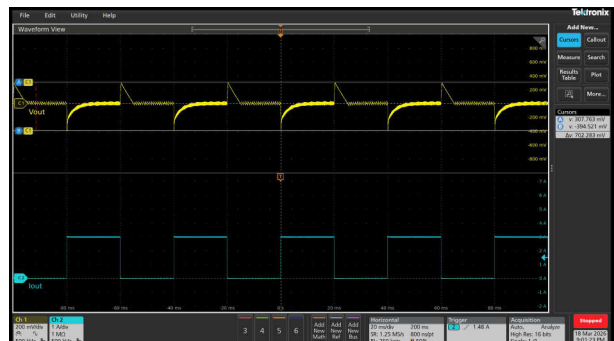
**Figure 3-54. Transient Response at  $V_{OUT} = 15V$   
Overshoot / Undershoot = 294mV / -477mV**



**Figure 3-55. Transient Response at  $V_{OUT} = 12V$   
Overshoot / Undershoot = 221mV / -454mV**



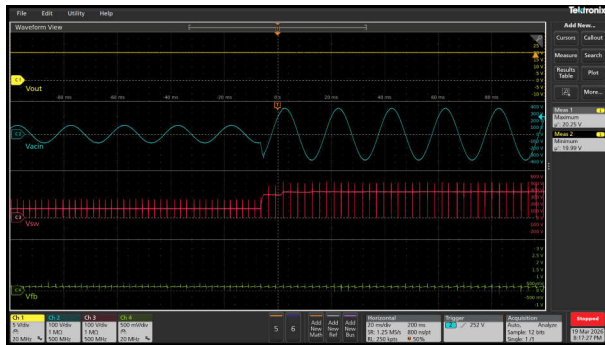
**Figure 3-56. Transient Response at  $V_{OUT} = 9V$   
Overshoot / Undershoot = 299mV / -449mV**



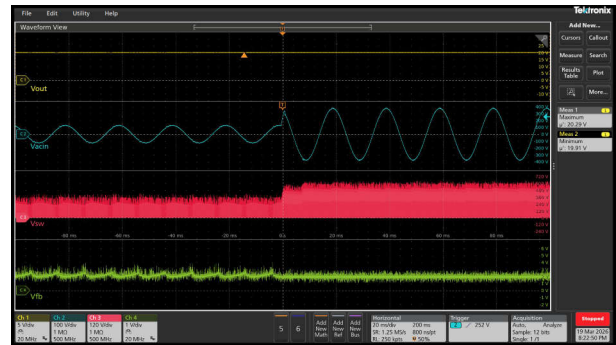
**Figure 3-57. Transient Response at  $V_{OUT} = 5V$   
Overshoot / Undershoot = 307mV / -395mV**

### 3.3.13 Line Transient Response

This section presents the switching waveforms under line transient from 90Vac to 264Vac at no load and full load. Ch1 - Output Voltage, Ch2 - AC Input Voltage, Ch3 - Switch Node Voltage, Ch4 - FB Pin Voltage



**Figure 3-58. Line Transient From 90Vac to 264Vac at 20V/No Load**



**Figure 3-59. Line Transient From 90Vac to 264Vac at 20V/Full Load**

### 3.3.14 Short Term Overload Operation

The EVM is capable of supporting short term overload without damage, safety issues or triggering protection. The output voltage drops to 17.9V when peak short term overload of 7.3A is applied for 1ms. The output voltage drops to 18.1V when peak short term overload of 6.5A is applied for 2ms. The results are checked at 90Vac. Ch1 - Output Voltage, Ch2 - Output Current, Ch3 - Switch Node Voltage, Ch4 - Feedback Pin Voltage.



Figure 3-60. VIN=90Vac (2.25x Rated Current for 1ms, 0.9x Rated Current for 9ms)



Figure 3-61. VIN=90Vac (2x Rated Current for 2ms, 0.9x Rated Current for 18ms)

### 3.3.15 CCM operation

This section presents the switching waveforms under the CCM operation at 90Vac with 6.5A load. A zoomed version of the waveforms is also presented here. Ch1 - Output Voltage, Ch2 - Output Current, Ch3 - Switch Node Voltage, Ch4 - Feedback Pin Voltage.

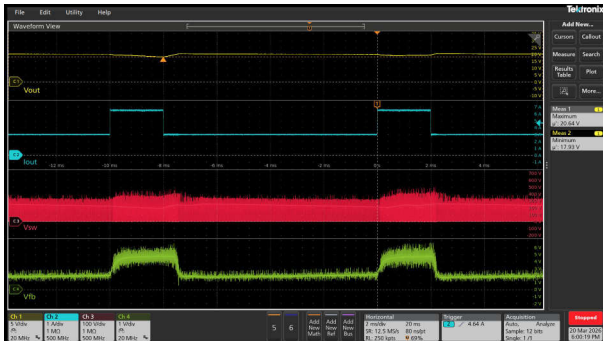


Figure 3-62. VIN=90Vac (2x Rated Current for 2ms, 0.9x Rated Current for 18ms)



Figure 3-63. VIN=90Vac (2x Rated Current for 2ms, 0.9x Rated Current for 18ms) - Zoomed

### 3.3.16 Startup Performance

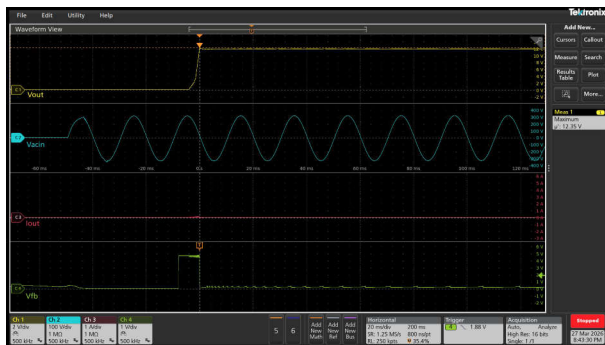
This section presents the startup performance of the converter at 230Vac input. The startup responses at 24V and 12V are captured with the fixed  $V_{OUT}$  control mode. The startup response at 5V is captured with PD control mode. Ch1 - Output Voltage, Ch2 - Input Voltage, Ch3 - Output Current, Ch4 - Feedback Pin Voltage.



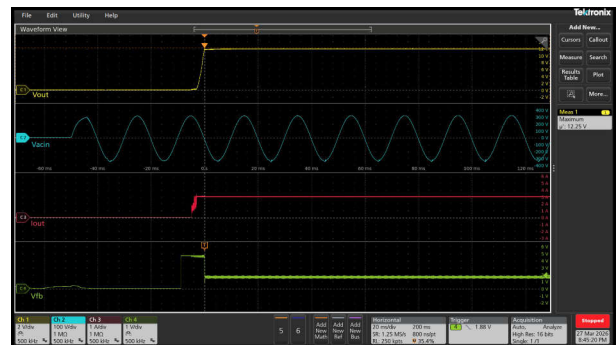
**Figure 3-64. Startup Response at 24V and 0A (Overshoot = 230mV)**



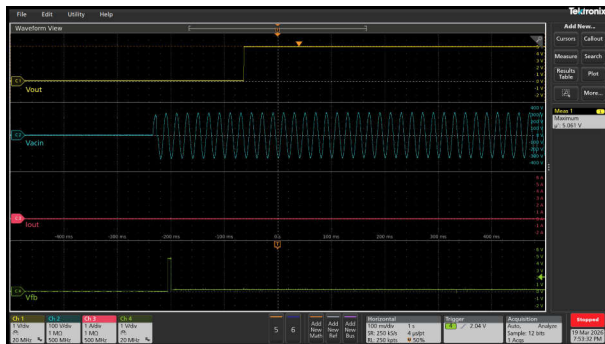
**Figure 3-65. Startup Response at 24V and 2.71A (Overshoot = 270mV)**



**Figure 3-66. Startup Response at 12V and 0A (Overshoot = 350mV)**



**Figure 3-67. Startup Response at 12V and 3A (Overshoot = 250mV)**



**Figure 3-68. Startup Response at 5V and 0A (Overshoot = 61mV)**



**Figure 3-69. Startup Response at 5V and 3A (Overshoot = 59mV)**

### 3.3.17 Thermal Images at Full Load (20V/3.25A and 24V/2.71A)

This section presents the thermal images of the EVM while operating at full load at both at 20V and 24V output voltages and at different line voltages. The data was taken after a thermal soak of 30 minutes.



Figure 3-70. Top Side at 90Vac-to-24V/2.71A

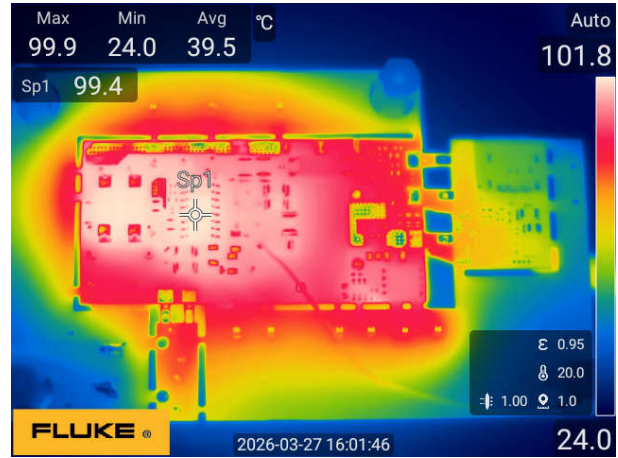


Figure 3-71. Bottom Side at 90Vac-to-24V/2.71A

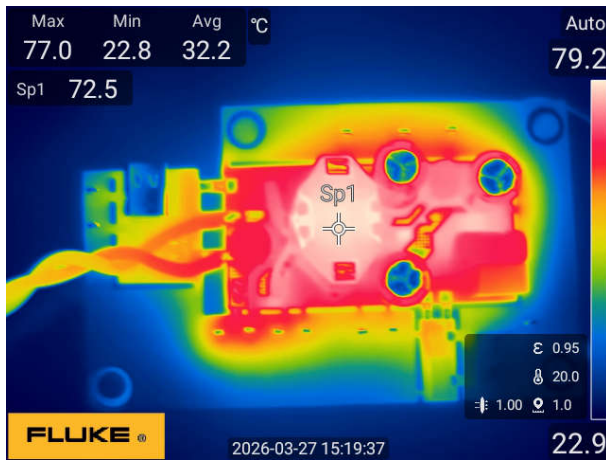


Figure 3-72. Top Side at 115Vac-to-24V/2.71A



Figure 3-73. Bottom Side at 115Vac-to-24V/2.71A



Figure 3-74. Top Side at 230Vac-to-24V/2.71A



Figure 3-75. Bottom Side at 230Vac-to-24V/2.71A

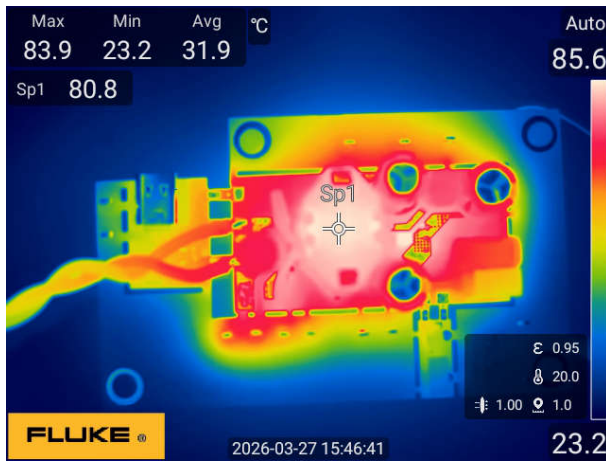


Figure 3-76. Top Side at 264Vac-to-24V/2.71A

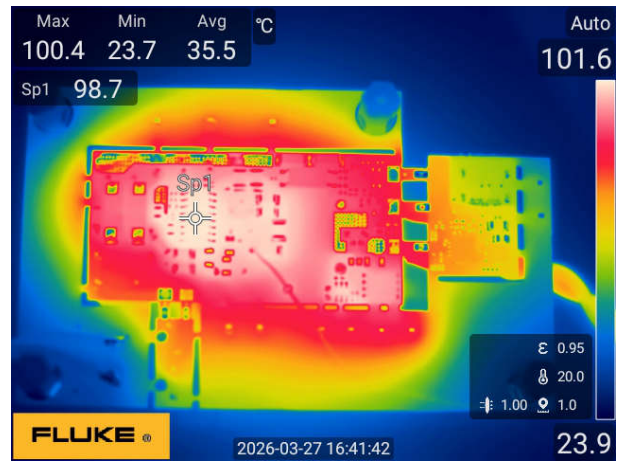


Figure 3-77. Bottom Side at 264Vac-to-24V/2.71A



Figure 3-78. Top Side at 90Vac-to-20V/3.25A

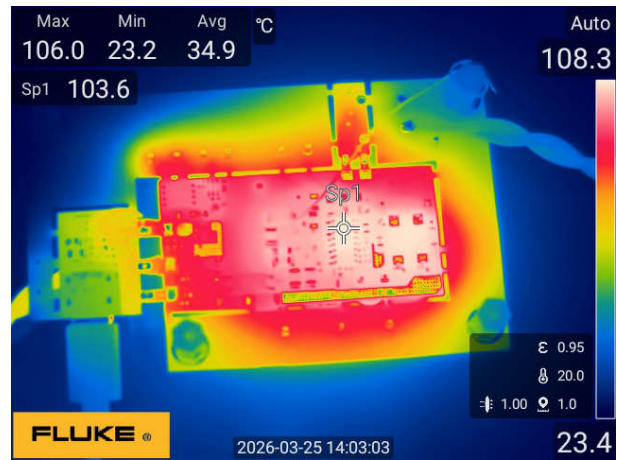


Figure 3-79. Bottom Side at 90Vac-to-20V/3.25A

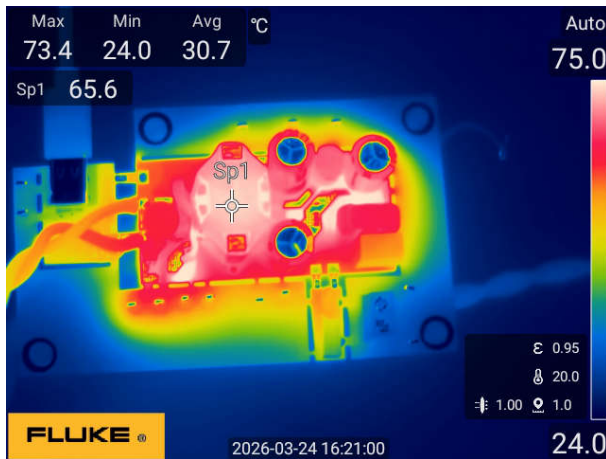


Figure 3-80. Top Side at 115Vac-to-20V/3.25A

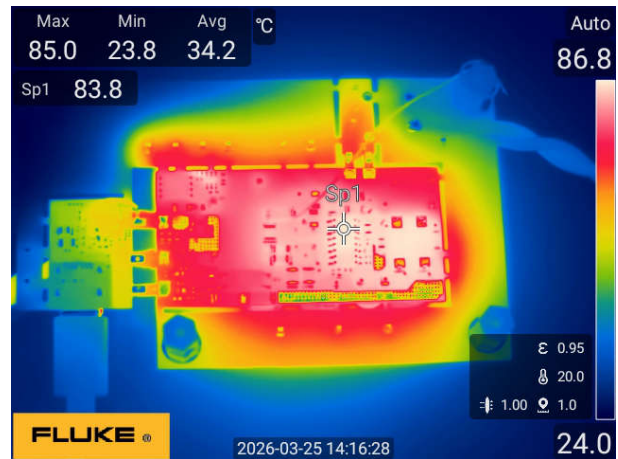


Figure 3-81. Bottom Side at 115Vac-to-20V/3.25A



Figure 3-82. Top Side at 230Vac-to-20V/3.25A

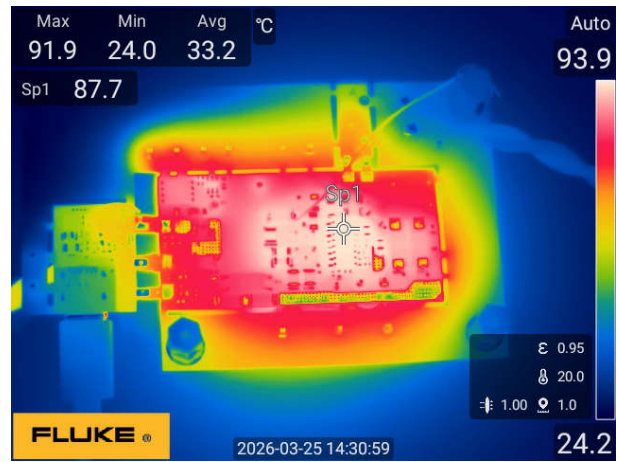


Figure 3-83. Bottom Side at 230Vac-to-20V/3.25A



Figure 3-84. Top Side at 264Vac-to-20V/3.25A

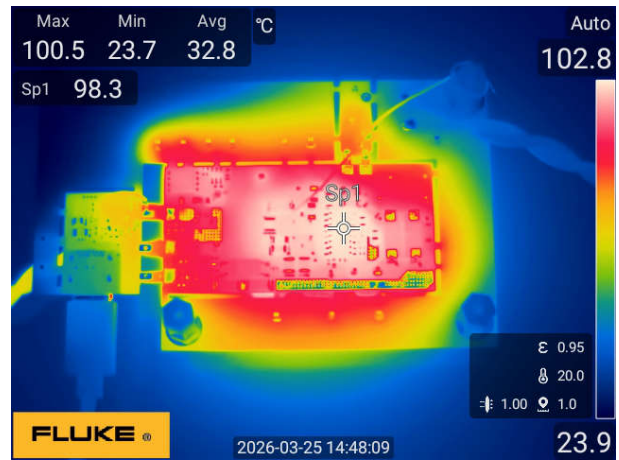


Figure 3-85. Bottom Side at 264Vac-to-20V/3.25A

### 3.3.18 CISPR32 Class B Conducted EMI Test Result

Please note that this was evaluated on an EMI station for pre-qualification purpose only. TI recommends that all final designs be verified by an agency-qualified EMI test house. Following EMI results are captured with SGND not connected to LISN ground.

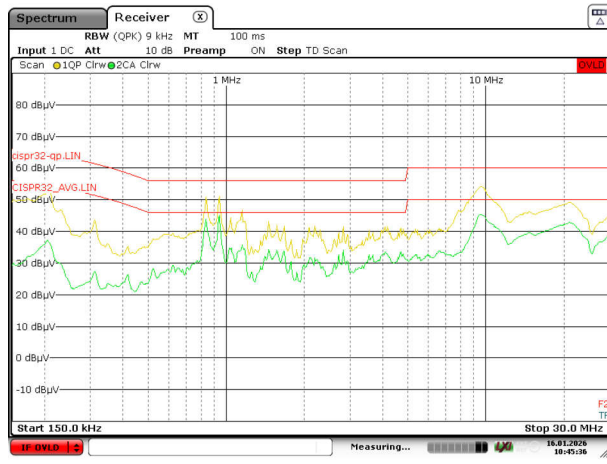


Figure 3-86. Line at  $V_{IN} = 230V_{RMS}$ ,  $V_{OUT} = 20V$ ,  $I_{OUT} = 3.25A$

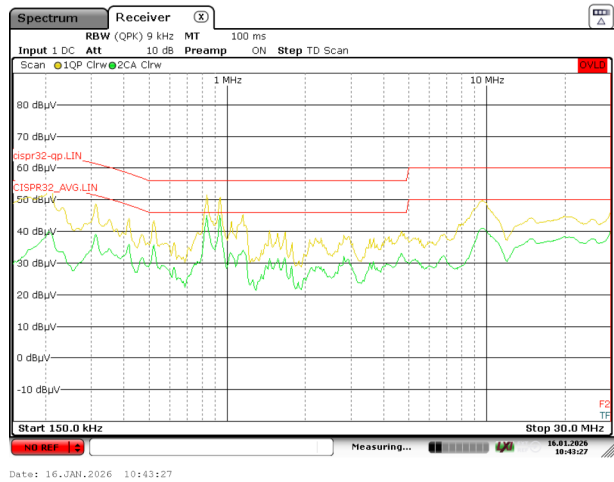


Figure 3-87. Neutral at  $V_{IN} = 230V_{RMS}$ ,  $V_{OUT} = 20V$ ,  $I_{OUT} = 3.25A$

## 4 Hardware Design Files

### 4.1 Schematics

The schematic of the UCG28846DREVM-151 is shown below. This EVM is configured with USB-PD controller enabled for evaluation using a USB-PD load. This EVM also can be reconfigured to produce fixed output voltage for testing with a non-USB-PD load. For enabling the fixed output voltage controller the USB-C PD controller is disabled first by unmounting the 0Ω resistors R2, R25, R10, and R19. Then the fixed output voltage controller is enabled by mounting the zero ohm resistors R26, R32, and R28. The output voltage can then be set by adjusting R34 using:

$$R34 = R30 \times 2.5V / (V_{out} - 2.5V)$$

(1)

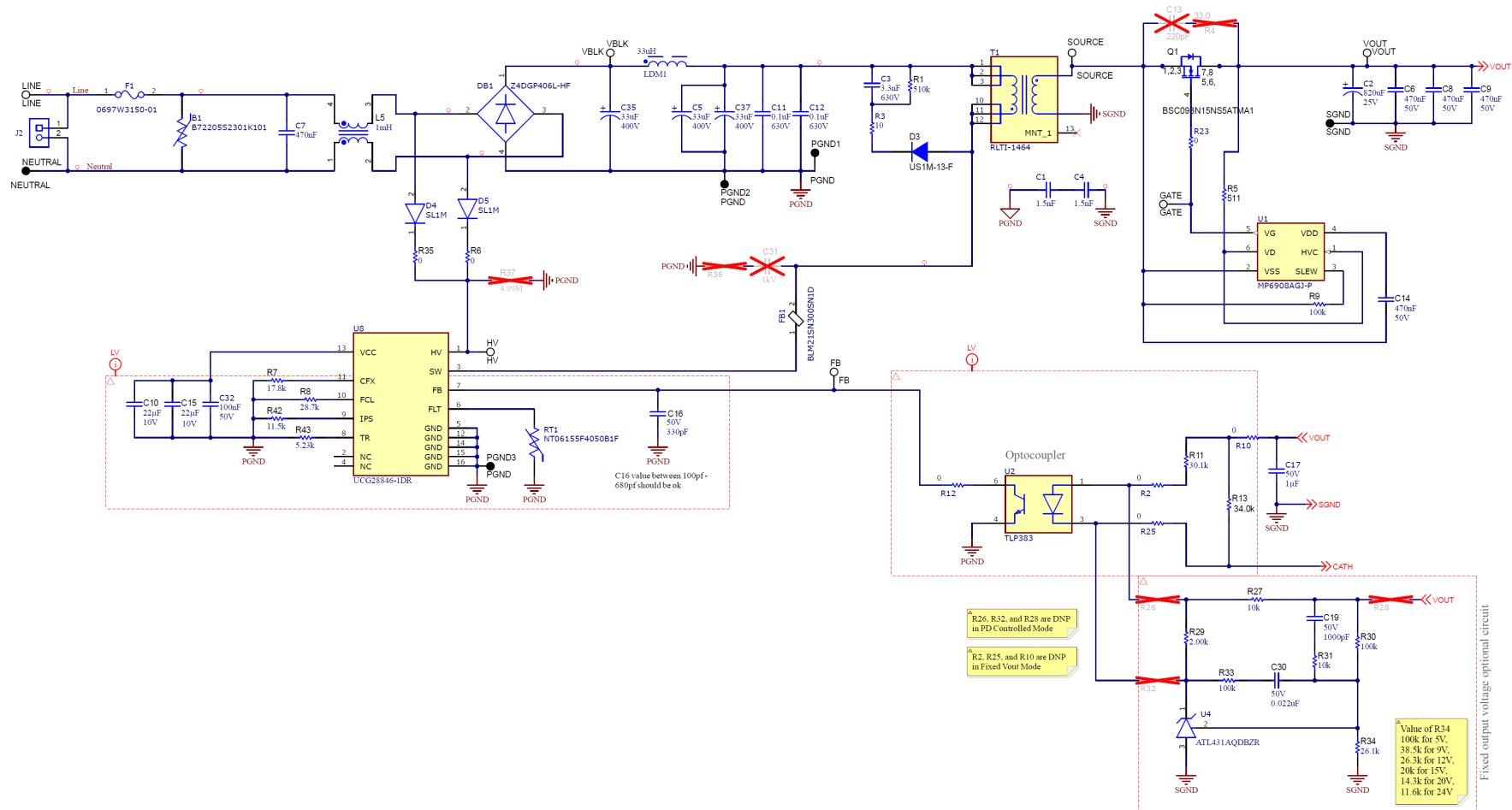


Figure 4-1. UCG28846DREVM-151 Power Circuit Schematic

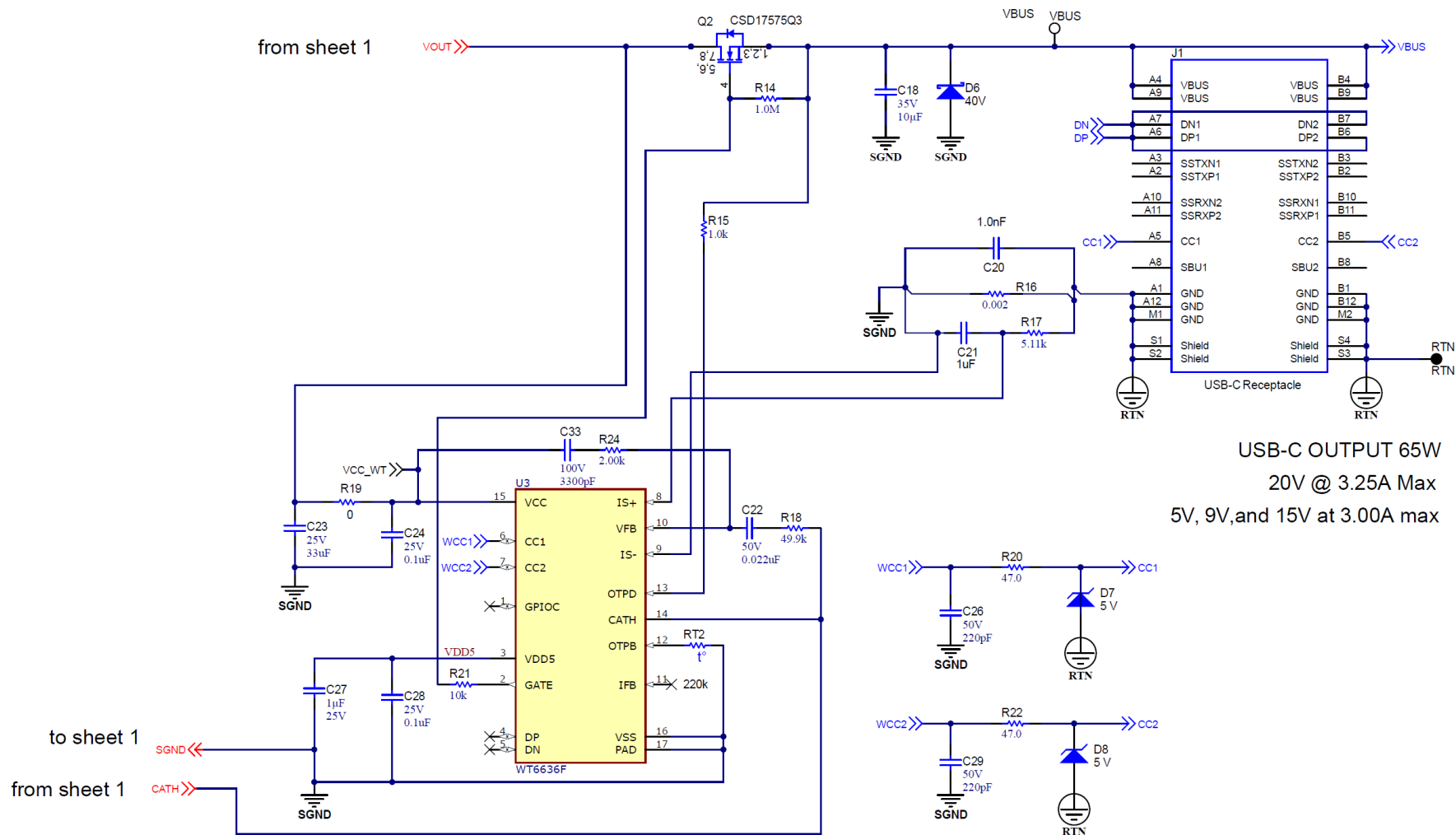


Figure 4-2. UCG28846DREVM-151 PD Controller Circuit Schematic

## 4.2 PCB Layouts

UCG28846DREVM-151 uses two layers PCB. The screenshots of the layout of each layer are shown below.

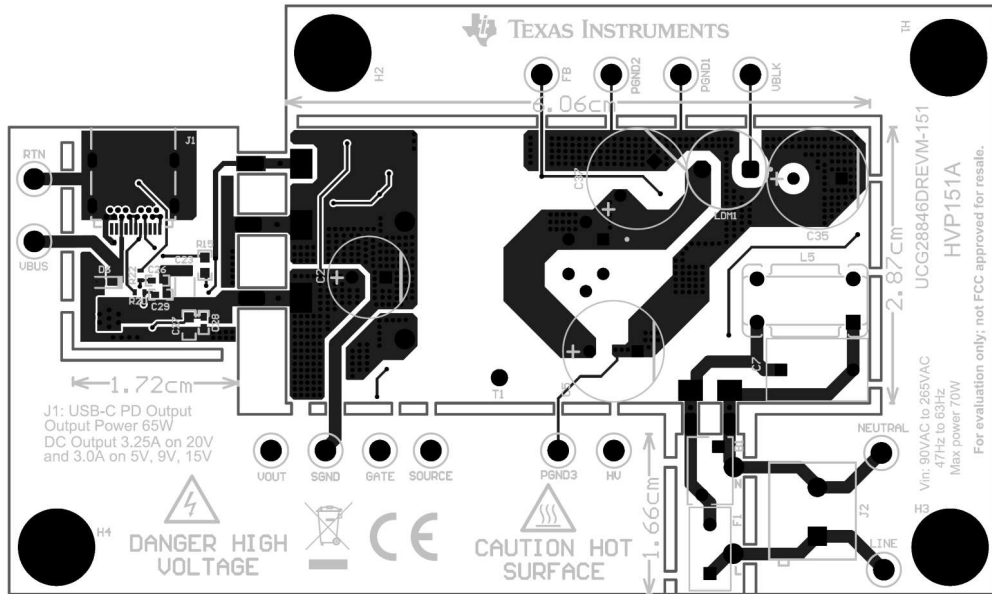


Figure 4-3. Top Layer

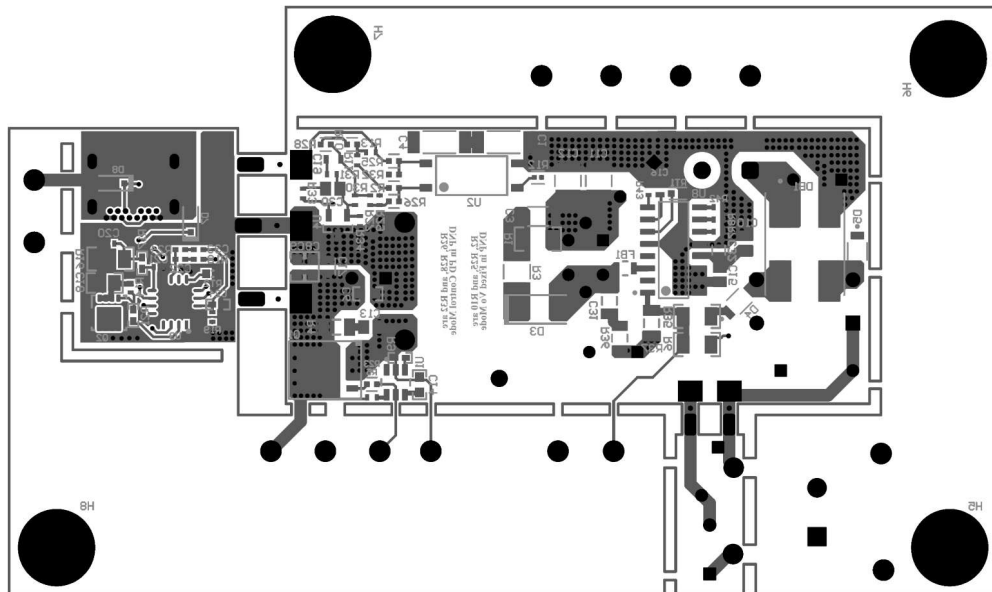


Figure 4-4. Bottom Layer

### 4.3 Transformer Details

This design uses RLTI-1464 transformer from Renco Electronics. This transformer has good balance between leakage inductance and interturn capacitance. The details of the RLTI-1464 transformer are given below.

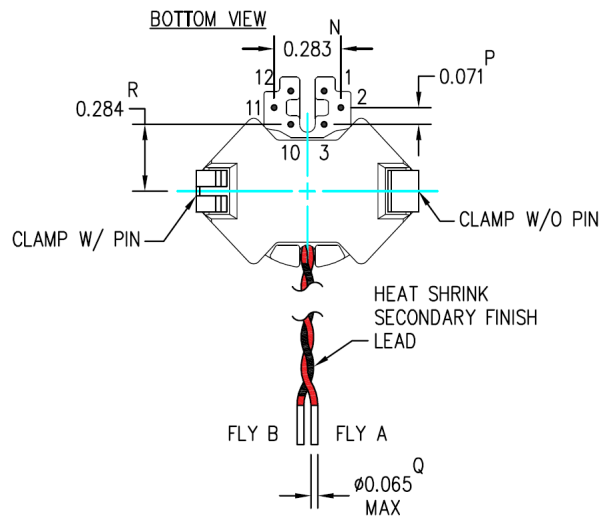


Figure 4-5. RLTI-1464 Pin Configuration

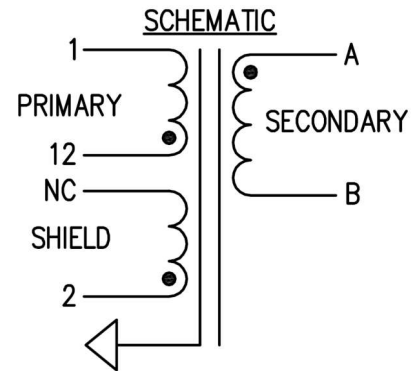


Figure 4-6. RLTI-1464 Schematic

Table 4-1. Transformer Specifications at 25°C

PARAMETER	TYPICAL VALUE	PINS/LEADS	TEST CONDITIONS
Inductance ( $\mu\text{H}$ )	325, $\pm 5\%$	1 – 12	Open all other pins, 100kHz / 0.1Vac
Leakage Inductance ( $\mu\text{H}$ )	3.5 Max.	1 – 12	Short A - B, 100kHz / 0.1Vac
D.C. resistance ( $\Omega$ )	0.220, $\pm 15\%$	1 – 12	
D.C. resistance ( $\Omega$ )	0.007 Max.	A – B	
Dielectric (VAC, 60Hz)	3000Vac	1– A	1mA, 60Hz, 1s
Turns-ratio	6:1	(1-12):(A-B)	Apply: 1.0V/10kHz to (12 - 1) Vout: (A-B) 0.167V

## 4.4 Bill of Materials

This section presents the bill of materials for UCG28846DREVM-151.

**Table 4-2. Bill of Materials**

Designator	Quantity	Description	Part Number	Manufacturer
B1	1	470 V 800 A Varistor 1 Circuit Through Hole Disc 5mm	B72205S2301K101	EPCOS
C1, C4	2	1500 pF ±10% 250VAC Ceramic Capacitor X7R 1808 (4520 Metric)	1808YA250152KJTSYX	Knowles Syfer
C2	1	820uF 25V ±20% Plugin,D8xL14mm Aluminum Electrolytic Capacitors - Leaded ROHS	NPXD1401E821MF	Ymin
C3	1	Cap Ceramic 3.3nF 630V C0G 5% Pad SMD 1206 +125°C Automotive T/R	CGA5L4C0G2J332J160AA	TDK
C5, C35, C37	3	33uF 400V 500mΩ@100kHz 370mA@100kHz ±20% Plugin,D10xL15mm Aluminum Electrolytic Capacitors - Leaded ROHS	87EC0493	KNSCHA
C6, C8, C9, C14	4	CAP, CERM, 0.47 uF, 50 V, +/- 10%, X7R, 0603	C1608X7R1H474K080AC	TDK
C7	1	470nF ±10% X2 Plugin,P=7.5mm Suppression Capacitors ROHS	MPX474K31B9KN20600	KNSCHA
C10, C15	2	CAP, CERM, 22 uF, 10 V, +/- 20%, X7R, 0805	GRM21BZ71A226ME15L	Murata
C11, C12	2	Cap Ceramic 0.1uF 630V X7R 10% Pad SMD 1210 125C Low ESR Medical T/R	C1210C104KBRACU	KEMET
C16	1	CAP, CERM, 330 pF, 50 V, +/- 5%, C0G/NP0, 0603	885012006060	Wurth Elektronik
C17	1	1µF ±10% 50V Ceramic Capacitor X7R 0603 (1608 Metric)	CC0603KRX7R9BB105	Yageo Group
C18	1	CAP, CERM, 10 µF, 35 V,+/- 10%, X5R, 0805	GMK212BBJ106KG-T	TAIYO YUDEN
C19	1	CAP, CERM, 1000 pF, 50 V, +/- 5%, C0G/NP0, 0603	C0603C102J5GAC	Kemet
C20	1	CAP, CERM, 1000 pF, 50 V, +/- 10%, X7R, 0402	885012205061	Wurth Elektronik
C21	1	CAP, CERM, 1 uF, 6.3 V, +/- 20%, X7R, 0402	GRM155R70J105MA12D	Murata
C22	1	CAP, CERM, 0.022 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402	CGA2B3X7R1H223K050BB	TDK
C23	1	CAP, CERM, 33 uF, 25 V, +/- 20%, X5R, 1206	C3216X5R1E336M160AC	TDK
C24, C28	2	CAP, CERM, 0.1 uF, 25 V, +/- 10%, X7R, 0402	GRM155R71E104KE14D	Murata
C26, C29	2	CAP, CERM, 220 pF, 50 V, +/- 10%, X7R, 0402	GRM155R71H221KA01D	Murata
C27	1	CAP, CERM, 1 uF, 25 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	GCM188R71E105KA64D	Murata
C30	1	CAP, CERM, 0.022 uF, 50 V, +/- 1%, C0G/NP0, 0805	C0805C223F5GACTU	KEMET
C32	1	Multi-Layer Ceramic Capacitor 100nF 50V X7R ±10% 0402 Paper T/R	GRT155R71H104KE01D	Murata
C33	1	CAP, CERM, 3300 pF, 100 V, +/- 10%, X7R, 0402	GRM155R72A332KA01D	Murata
D3	1	Diode, Ultrafast, 1000 V, 1 A, SMA	US1M-13-F	Diodes Inc.
D4, D5	2	Diode 800 V 1A Surface Mount SOD-123FL	SL1K	Diotec
D6	1	Diode, Schottky, 40 V, 0.2 A, SOD-523	RB521SM-40T2R	ROHM
D7, D8	2	Diode, Zener, 5.1 V, 400 mW, SOD-323F	D3Z5V1BF-7	Diodes Inc.
DB1	1	Bridge Rectifier Single Phase Standard 600 V Surface Mount Z4-D	Z4DGP406L-HF	Comchip

**Table 4-2. Bill of Materials (continued)**

Designator	Quantity	Description	Part Number	Manufacturer
F1	1	Fuse Subminiature Slow Blow Acting 3.15A 350V Radial 8.35 X 4 X 7.8mm Thermoplastic Box	0697W3150-01	Bel Fuse
FB1	1	30 Ohms @ 100MHz 1 Power Line Ferrite Bead 0805 (2012 Metric) 8.5A 4mOhm	BLM21SN300SN1D	Murata
FB, GATE, HV, LINE, SOURCE, VBLK, VBUS, VOUT	8	Test Point, Multipurpose, White, TH	5012	Keystone
H1, H2, H3, H4	4	#4-40 Pan Head Machine Screw Phillips Drive Nylon	NY PMS 440 0038 PH	Building Fasteners
H5, H6, H7, H8	4	Standoff, Hex, 0.5"L #4-40 Nylon	1902C	Keystone
J1	1	Connector, Receptacle, USB Type C, R/A	632723300011	Würth Elektronik
J2	1	Terminal Block, 5.08 mm, 2x1, Brass, TH	ED120/2DS	On Shore Technology Inc.
L5	1	Coupled inductor, 1 mH, 2 A, 0.045 ohm, TH	744821201	Würth Elektronik
LDM1	1	WE-TI Radial Leaded Wire Wound Inductor, size 8095, 33uH, 2.5A, 0.066Ohm	7447720330	Würth Elektronik
NEUTRAL, PGND1, PGND2, PGND3, RTN, SGND	6	Test Point, Multipurpose, Black, TH	5011	Keystone
Q1	1	MOSFET, N-CH, 150 V, 87 A, PG-TDSON-8	BSC093N15NS5ATMA1	Infineon Technologies
Q2	1	MOSFET, N-CH, 30 V, 60 A, DQG0008A (VSON-CLIP-8)	CSD17575Q3	Texas Instruments
R1	1	RES, 510 k, 5%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW1206510KJNEA	Vishay/Dale
R2, R10, R12, R23, R25	5	RES Thick Film, 0Ω, 0.2W, 0402	CRCW04020000Z0EDHP	Vishay
R3	1	10Ω ±5% 0.5W 1210 Thick Film Chip Resistor AEC-Q200 compliant	RMCF1210JT10R0	Stackpole Electronics
R5	1	RES, 511, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW0402511RFKED	Vishay/Dale
R6, R35	2	RES, 0, 5%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW12060000Z0EA	Vishay/Dale
R7	1	RES, 17.8 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040217K8FKED	Vishay / Dale
R8	1	RES, 28.7 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040228K7FKED	Vishay/Dale
R9, R30, R33	3	RES, 100 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW0402100KFKED	Vishay / Dale
R11	1	RES, 30.1 k, 1%, 0.063 W, 0402	CRCW040230K1FKED	Vishay / Dale
R13	1	RES, 34.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040234K0FKED	Vishay / Dale
R14	1	RES, 1.0 M, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04021M00JNED	Vishay / Dale
R15	1	RES, 1.0 k, 5%, 0.25 W, AEC-Q200 Grade 0, 0603	ESR03EZPJ102	ROHM
R16	1	RES, 0.002, 1%, 1 W, 1206	CSNL1206FT2L00	Stackpole Electronics Inc
R17	1	RES, 5.11 k, 1%, 0.063 W, 0402	CRCW04025K11FKED	Vishay / Dale

**Table 4-2. Bill of Materials (continued)**

Designator	Quantity	Description	Part Number	Manufacturer
R18	1	RES, 49.9 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040249K9FKED	Vishay / Dale
R19	1	RES, 0, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04020000Z0ED	Vishay / Dale
R20, R22	2	RES, 47.0, 1%, 0.063 W, 0402	RK73H1ETTP47R0F	KOA Speer
R21, R27, R31	3	RES, 10 k, 5%, 0.063 W, 0402	CRCW040210K0JNED	Vishay / Dale
R24	1	RES, 2.00 k, 0.1%, 0.063 W, 0402	RG1005P-202-B-T5	Susumu
R29	1	RES, 2.00 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04022K00FKED	Vishay / Dale
R34	1	RES, 26.1 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040226K1FKED	Vishay / Dale
R42	1	RES, 11.5 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040211K5FKED	Vishay / Dale
R43	1	RES, 5.23 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04025K23FKED	Vishay / Dale
RT1	1	NTC Thermistor 150k 0603 (1608 Metric)	NT06155F4050B1F	Eaton
RT2	1	Thermistor NTC, 220k ohm, 5%, 0603	NCP18WM224J03RB	Murata
T1	1	Flyback Transformer	RLTI-1464	RENCO
U1	1	FAST TURN-OFF INTELLIGENT RECTIF	MP6908GJ-Z	Monolithic Power Systems
U2	1	Optoisolator Transistor Output 5000Vrms 1 Channel 6-SO	TLP383(GR-TPL,E	Toshiba Semiconductor and Storage
U3	1	USB PD/QC4/QC4+ Controller	WT6636F	Weltrend
U4	1	V-Ref Adjustable/Precision 2.5V to 36V 100mA 3-Pin SOT-23 T/R	ATL431AQDBZR	Texas Instruments
U8	1	Self-Biased High Frequency QR Flyback Converter With Integrated GaN	UCG28846-1DR	Texas Instruments

## 5 Additional Information

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**User shall operate the Evaluation Kit within TI's recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI's recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI's instructions for electrical ratings of interface circuits such as input, output and electrical loads.**

**NOTE:**

**EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGRADATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.**

### 3 Regulatory Notices:

#### 3.1 United States

##### 3.1.1 Notice applicable to EVMs not FCC-Approved:

**FCC NOTICE:** This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

##### 3.1.2 For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:

#### **CAUTION**

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

#### **FCC Interference Statement for Class A EVM devices**

*NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.*

#### **FCC Interference Statement for Class B EVM devices**

*NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:*

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

#### 3.2 Canada

##### 3.2.1 For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247

#### **Concerning EVMs Including Radio Transmitters:**

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

#### **Concernant les EVMs avec appareils radio:**

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

#### **Concerning EVMs Including Detachable Antennas:**

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

### Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

#### 3.3 Japan

3.3.1 *Notice for EVMs delivered in Japan:* Please see [http://www.tij.co.jp/lstds/ti\\_ja/general/eStore/notice\\_01.page](http://www.tij.co.jp/lstds/ti_ja/general/eStore/notice_01.page) 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

<https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html>

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see [http://www.tij.co.jp/lstds/ti\\_ja/general/eStore/notice\\_02.page](http://www.tij.co.jp/lstds/ti_ja/general/eStore/notice_02.page)

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。 <https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html>

#### 3.4 European Union

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive):*

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

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4. *EVM Use Restrictions and Warnings:*
    - 4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.
    - 4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.
    - 4.3 *Safety-Related Warnings and Restrictions:*
      - 4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.
      - 4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.
    - 4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.
  5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.
  6. *Disclaimers:*
    - 6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY EPIDEMIC FAILURE WARRANTY OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.
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