EVM User's Guide: UCG28836EVM-150

UCG28836 Evaluation Module

Description

The UCG28836EVM-150 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 UCG28836EVM-150 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 UCG28836 with integrated 750V GaN FET and controller in 5mm × 5mm package.

Get Started

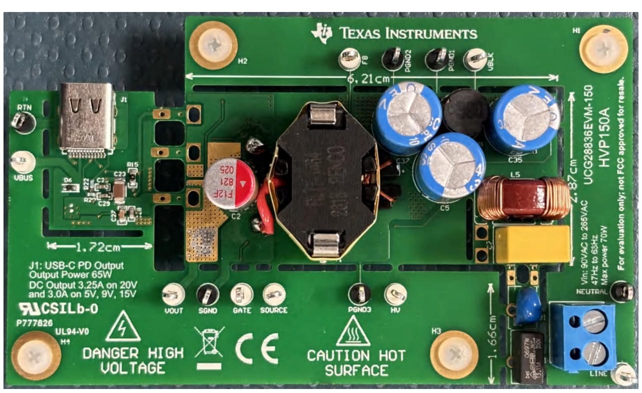
1. Read and study this EVM user's guide completely before evaluating.
2. After completing step one, order the UCG28836EVM-150 for evaluation.
3. Setup and test the UCG28836EVM-150 per EVM user's guide instructions.

Features

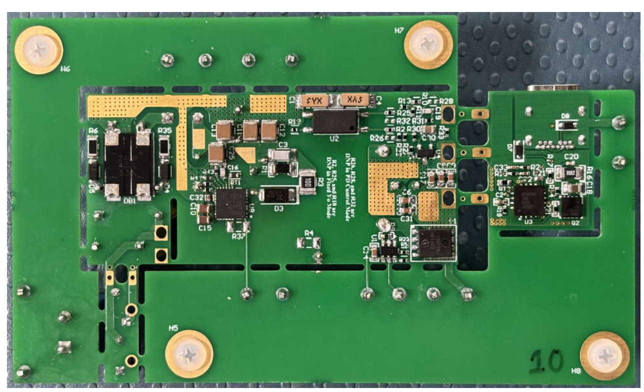
- From 93% to 95% efficiency under full-load operation over entire input voltage range
- 6.21cm × 2.87cm × 1.8cm box volume in high power - density configuration
- $2W/cm^3$ power density enabled by 140kHz maximum switching frequency
- Self-bias and auxless-sense, integrated current sense, integrated 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



UCG28836EVM-150 (Top View)



UCG28836EVM-150 (Bottom View)

1 Evaluation Module Overview

1.1 Introduction

The UCG28836EVM-150 facilitates the evaluation of UCG28836, 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 EVM user's 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 UCG28836 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 UCG28836 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 UCG28836 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 UCG28836 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

WARNING

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

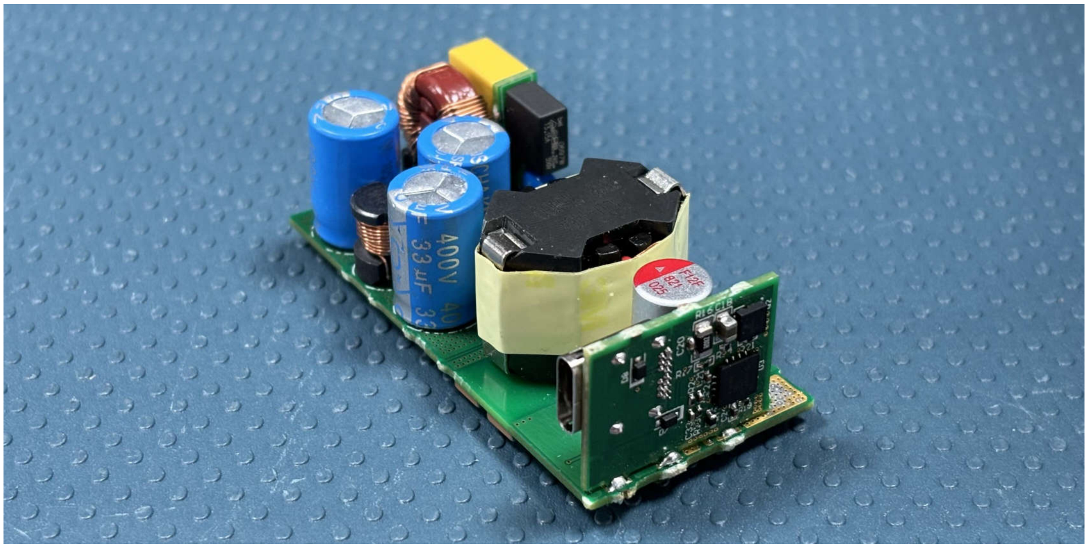


Figure 2-1. High Power-Density Configuration (6.21cm × 2.87cm × 1.8cm)

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

UCG28836EVM-150 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 (J1) 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

UCG28836EVM-150 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. UCG28836EVM-150 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. UCC28836EVM-150 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		18/31		mW
P_{180mW}	Input power at 180mW load	V_{IN} = 230V_{RMS}, V_{OUT} = 5V, P_{OUT} = 180mW, USB-C PD controller enabled		233		mW
P_{300mW}	Input power at 300mW load	V_{IN} = 230V_{RMS}, V_{OUT} = 5V, P_{OUT} = 300mW, USB-C PD controller enabled		370		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		112		mVpp
		V_{OUT} = 20V, I_{OUT} = 0 to 3.25A		108		mVpp
		V_{OUT} = 15V, I_{OUT} = 0 to 3A		103		mVpp
		V_{OUT} = 12V, I_{OUT} = 0 to 3A		137		mVpp
		V_{OUT} = 9V, I_{OUT} = 0 to 3A		102		mVpp
		V_{OUT} = 5V, I_{OUT} = 0 to 3A		104		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		-481/198		mV
		V_{OUT} = 20V		-566/225		mV
		V_{OUT} = 15V		-523/312		mV
		V_{OUT} = 12V		-463/225		mV
		V_{OUT} = 9V		-488/351		mV
		V_{OUT} = 5V		-458/390		mV
P_{OPP}	Over power protection threshold	V_{IN} = 90 to 264V_{RMS}		100		W

Table 3-1. UCC28836EVM-150 Electrical Performance Specifications (continued)

PARAMETER		TEST CONDITIONS	MIN	NOM	MAX	UNIT
SYSTEMS CHARACTERISTICS						
η	Full load efficiency at V_{IN} = 115V/230V	V_{OUT} = 24V, I_{OUT} = 2.71A		94.25/94.72		%
		V_{OUT} = 20V, I_{OUT} = 3.25A		94.00/94.38		%
		V_{OUT} = 15V, I_{OUT} = 3A		94.10/94.15		%
		V_{OUT} = 12V, I_{OUT} = 3A		94.17/93.97		%
		V_{OUT} = 9V, I_{OUT} = 3A		93.88/93.26		%
		V_{OUT} = 5V, I_{OUT} = 3A		93.05/91.51		%
η	4-point average efficiency at V_{IN} = 115V/230V(1)	V_{OUT} = 24V (CoC Tier 2, 89.0%)		94.39/94.28		%
		V_{OUT} = 20V (CoC Tier 2, 89.0%)		94.18/94.03		%
		V_{OUT} = 15V (CoC Tier 2, 88.9%)		94.18/93.71		%
		V_{OUT} = 12V (CoC Tier 2, 88.3%)		94.23/93.58		%
		V_{OUT} = 9V (CoC Tier 2, 87.3%)		93.74/92.68		%
		V_{OUT} = 5V (CoC Tier 2, 81.8%)		92.59/90.23		%
η	Efficiency at 10% load at V_{IN} = 115V/230V	V_{OUT} = 24V (CoC Tier 2, 79.0%)		92.32/91.72		%
		V_{OUT} = 20V (CoC Tier 2, 79.0%)		92.57/91.79		%
		V_{OUT} = 15V (CoC Tier 2, 78.9%)		92.73/90.77		%
		V_{OUT} = 12V (CoC Tier 2, 78.3%)		93.92/90.58		%
		V_{OUT} = 9V (CoC Tier 2, 77.3%)		92.89/88.47		%
		V_{OUT} = 5V (CoC Tier 2, 72.5%)		91.83/86.56		
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 $50V_{DC}$.

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 $264V_{RMS}$ 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 $264V_{RMS}$ 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.

3.2.2 Test Setup Diagram of UCG28836EVM-150

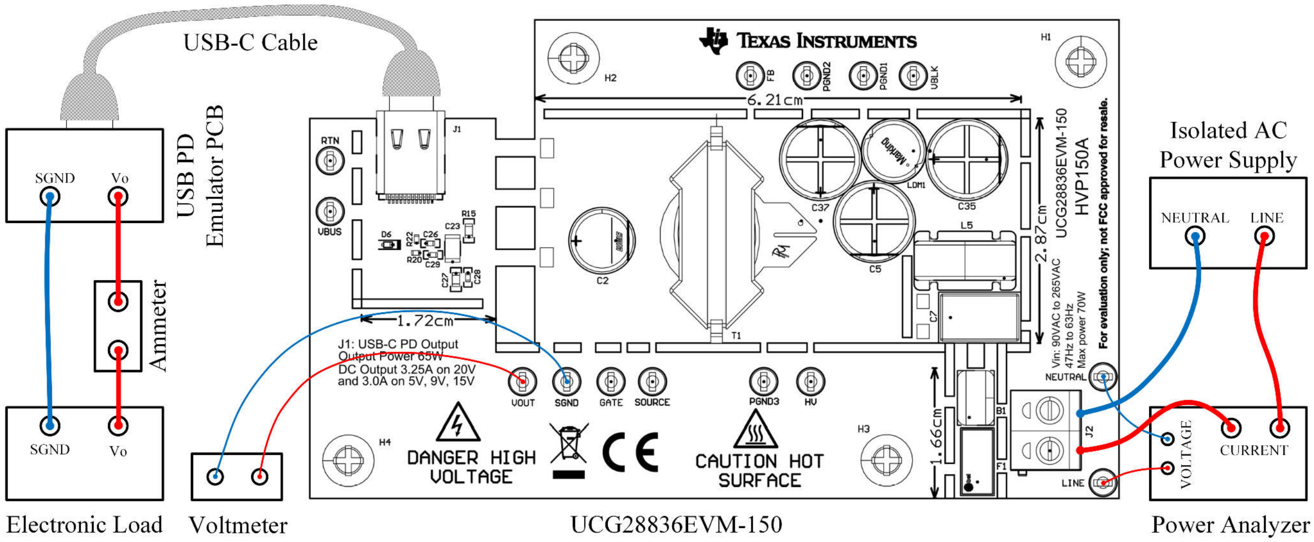


Figure 3-1. Test Setup Diagram of UCG28836EVM-150 Using a USB-C PD Load

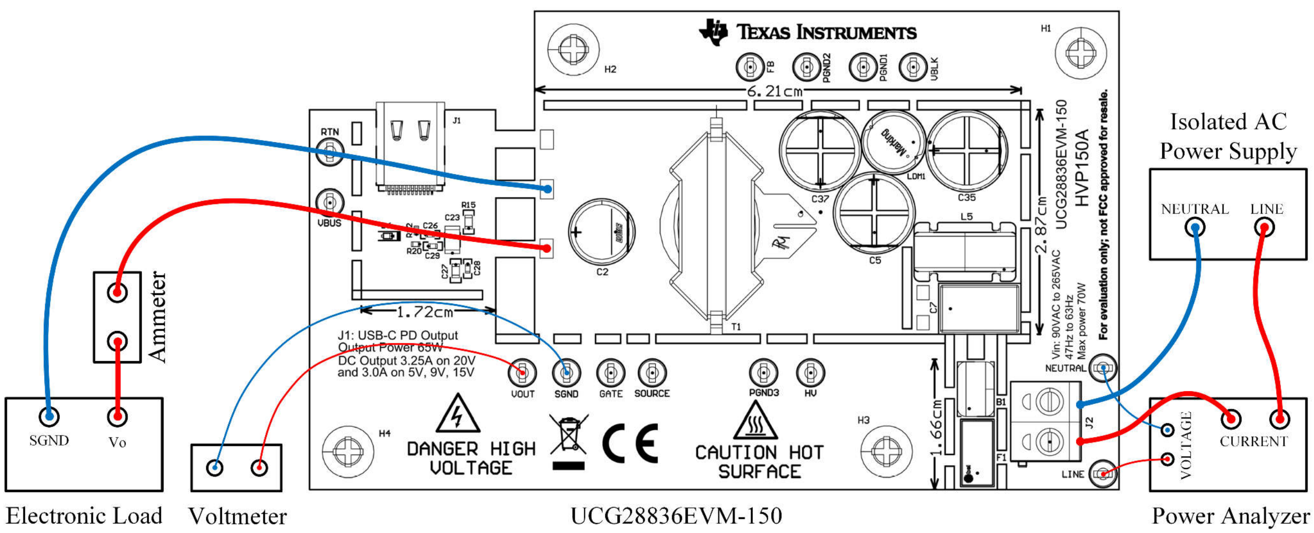
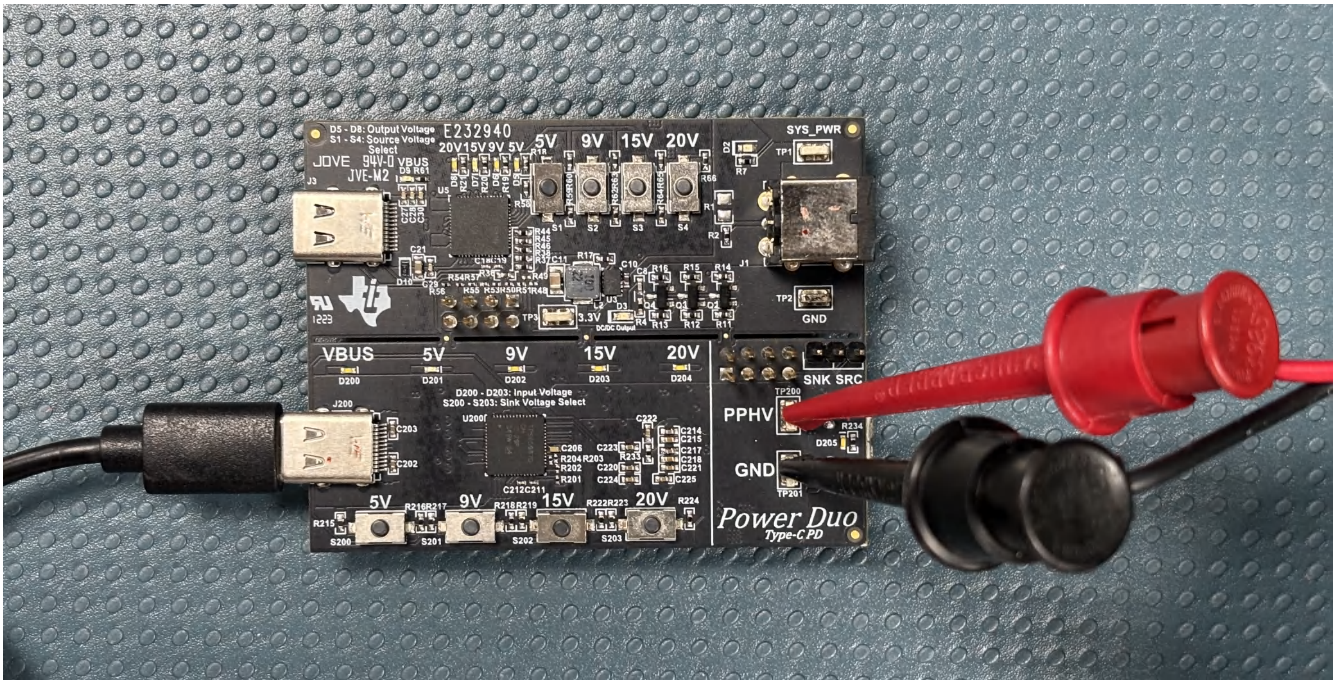


Figure 3-2. Test Setup Diagram of UCG28836EVM-150 Using a Non-USB-C PD Load

The efficiency results for 25%-100% load are taken with the above configurations. For standby and 10% load the voltage measurement is done at the source/load to record efficiency numbers.



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	7.06	24.14	0.271	6.54	10	92.66	93.70
90	17.36	24.14	0.677	16.34	25	94.12	
90	34.77	24.13	1.354	32.67	50	93.98	
90	52.29	24.13	2.032	49.03	75	93.77	
90	70.30	24.12	2.709	65.34	100	92.95	
115	7.09	24.14	0.271	6.54	10	92.32	94.39
115	17.33	24.14	0.677	16.34	25	94.31	
115	34.56	24.13	1.354	32.67	50	94.54	
115	51.90	24.13	2.032	49.03	75	94.47	
115	69.36	24.13	2.709	65.37	100	94.25	
230	7.13	24.14	0.271	6.54	10	91.72	94.28
230	17.49	24.14	0.677	16.34	25	93.45	
230	34.64	24.13	1.354	32.67	50	94.33	
230	51.81	24.13	2.032	49.03	75	94.64	
230	69.01	24.13	2.709	65.37	100	94.72	
264	7.20	24.14	0.271	6.54	10	90.88	93.95
264	17.59	24.13	0.677	16.34	25	92.90	
264	34.75	24.13	1.354	32.67	50	94.01	
264	51.94	24.13	2.032	49.03	75	94.40	
264	69.15	24.12	2.709	65.34	100	94.50	
CoC Tier 2, 4-pt average							89.00%
CoC Tier 2, 10%-load							79.00%

3.3.2 Efficiency Result of 4-Point Average on $20V_{OUT}$

V_{IN} (VRMS)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{OUT} (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	7.16	19.98	0.334	6.68	10	93.25	93.51
90	17.42	19.97	0.820	16.39	25	94.05	
90	34.75	19.98	1.632	32.61	50	93.85	
90	52.21	19.98	2.445	48.86	75	93.59	
90	70.32	19.99	3.256	65.09	100	92.56	
115	7.20	19.98	0.333	6.66	10	92.57	94.18
115	17.40	19.98	0.820	16.39	25	94.19	
115	34.58	19.98	1.632	32.61	50	94.30	
115	51.85	19.98	2.445	48.86	75	94.24	
115	69.24	19.99	3.256	65.09	100	94.00	
230	7.25	19.97	0.333	6.66	10	91.79	94.03
230	17.57	19.97	0.820	16.39	25	93.25	
230	34.66	19.98	1.633	32.63	50	94.13	
230	51.78	19.98	2.445	48.85	75	94.35	
230	68.95	19.98	3.256	65.08	100	94.38	
264	7.33	19.98	0.333	6.66	10	90.83	93.58
264	17.71	19.97	0.821	16.41	25	92.65	
264	34.85	19.98	1.632	32.61	50	93.55	
264	51.97	19.98	2.444	48.84	75	93.98	
264	69.12	19.98	3.255	65.06	100	94.12	
CoC Tier 2, 4-pt average							89.00
CoC Tier 2, 10%-load							79.00

3.3.3 Efficiency Result of 4-Point Average at 15V_{OUT}

V_{IN} (VRMS)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{OUT} (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	4.95	15.02	0.307	4.61	10	93.22	93.82
90	12.07	15.02	0.757	11.37	25	94.19	
90	24.08	15.02	1.506	22.62	50	93.92	
90	36.15	15.02	2.256	33.89	75	93.74	
90	48.33	15.02	3.005	45.15	100	93.43	
115	4.98	15.02	0.307	4.61	10	92.73	94.18
115	12.08	15.02	0.756	11.36	25	93.98	
115	23.95	15.02	1.506	22.62	50	94.43	
115	35.98	15.02	2.256	33.89	75	94.20	
115	47.98	15.02	3.005	45.15	100	94.09	
230	5.08	15.02	0.307	4.61	10	90.77	93.71
230	12.22	15.01	0.756	11.35	25	92.86	
230	24.13	15.01	1.506	22.61	50	93.72	
230	36.00	15.02	2.256	33.88	75	94.10	
230	47.94	15.02	3.005	45.14	100	94.15	
264	5.15	15.01	0.307	4.61	10	89.49	93.11
264	12.34	15.01	0.756	11.35	25	92.01	
264	24.30	15.02	1.506	22.62	50	93.09	
264	36.20	15.02	2.256	33.88	75	93.58	
264	48.14	15.02	3.005	45.14	100	93.77	
CoC Tier 2, 4-pt average							88.85
CoC Tier 2, 10%-load							78.85

3.3.4 Efficiency Result of 4-Point Average at $12V_{out}$

V_{IN} (VRMS)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{OUT} (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	3.84	12.05	0.301	3.63	10	94.38	93.90
90	9.59	12.05	0.749	9.03	25	94.07	
90	19.20	12.05	1.501	18.09	50	94.19	
90	28.91	12.05	2.249	27.10	75	93.75	
90	38.64	12.05	3.001	36.16	100	93.58	
115	3.86	12.05	0.301	3.63	10	93.92	94.23
115	9.62	12.05	0.749	9.03	25	93.83	
115	19.13	12.05	1.501	18.09	50	94.52	
115	28.74	12.05	2.251	27.12	75	94.39	
115	38.41	12.05	3.002	36.17	100	94.17	
230	4.01	12.06	0.301	3.63	10	90.58	93.58
230	9.75	12.05	0.751	9.05	25	92.83	
230	19.33	12.05	1.502	18.10	50	93.63	
230	28.89	12.05	2.251	27.12	75	93.89	
230	38.49	12.05	3.002	36.17	100	93.97	
264	4.07	12.06	0.301	3.63	10	89.17	92.89
264	9.85	12.05	0.751	9.05	25	91.88	
264	19.47	12.05	1.501	18.09	50	92.88	
264	29.08	12.05	2.251	27.12	75	93.28	
264	38.68	12.05	3.002	36.17	100	93.52	
CoC Tier 2, 4-pt average							88.30
CoC Tier 2, 10%-load							78.30

3.3.5 Efficiency Result of 4-Point Average at 9V_{OUT}

V_{IN} (VRMS)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{OUT} (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	2.94	8.99	0.306	2.75	10	93.40	93.54
90	7.25	8.98	0.755	6.78	25	93.48	
90	14.40	8.98	1.505	13.52	50	93.86	
90	21.64	8.99	2.255	20.26	75	93.63	
90	28.97	8.99	3.004	27.00	100	93.20	
115	2.96	8.99	0.306	2.75	10	92.89	93.74
115	7.29	8.99	0.756	6.79	25	93.15	
115	14.40	8.99	1.505	13.52	50	93.88	
115	21.55	8.99	2.255	20.26	75	94.04	
115	28.77	8.99	3.005	27.01	100	93.88	
230	3.10	8.98	0.306	2.74	10	88.47	92.68
230	7.38	8.98	0.755	6.78	25	91.79	
230	14.59	8.98	1.505	13.51	50	92.64	
230	21.76	8.98	2.254	20.24	75	93.02	
230	28.94	8.99	3.004	26.99	100	93.26	
264	3.15	8.98	0.306	2.74	10	87.13	91.96
264	7.46	8.98	0.755	6.78	25	90.84	
264	14.70	8.98	1.505	13.51	50	91.92	
264	21.91	8.98	2.255	20.26	75	92.44	
264	29.14	8.99	3.004	27.00	100	92.65	
CoC Tier 2, 4-pt average							87.30
CoC Tier 2, 10%-load							77.30

3.3.6 Efficiency Result of 4-Point Average at $5V_{OUT}$

V_{IN} (VRMS)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{OUT} (%)	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	1.61	4.96	0.300	1.49	10	92.57	92.81
90	4.01	4.96	0.749	3.72	25	92.57	
90	8.00	4.96	1.499	7.44	50	92.94	
90	12.01	4.96	2.249	11.16	75	92.98	
90	16.06	4.97	2.998	14.89	100	92.74	
115	1.62	4.96	0.300	1.49	10	91.83	92.59
115	4.05	4.96	0.749	3.72	25	91.82	
115	8.04	4.96	1.499	7.44	50	92.50	
115	12.00	4.96	2.249	11.16	75	93.00	
115	16.01	4.97	2.998	14.89	100	93.05	
230	1.72	4.96	0.300	1.49	10	86.56	90.23
230	4.25	4.96	0.749	3.72	25	87.53	
230	8.21	4.97	1.499	7.44	50	90.67	
230	12.25	4.97	2.249	11.17	75	91.22	
230	16.28	4.97	2.999	14.90	100	91.51	
264	1.76	4.97	0.300	1.49	10	84.74	89.14
264	4.33	4.96	0.749	3.72	25	85.96	
264	8.31	4.97	1.500	7.45	50	89.65	
264	12.38	4.97	2.249	11.17	75	90.26	
264	16.43	4.97	2.999	14.90	100	90.69	
CoC Tier 2, 4-pt average							81.84
CoC Tier 2, 10%-load							72.48

3.3.7 Efficiency Typical Results

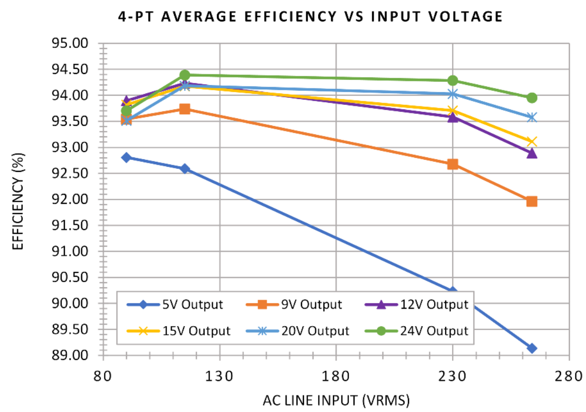


Figure 3-4. 4pt-Average Efficiency vs Input Voltage

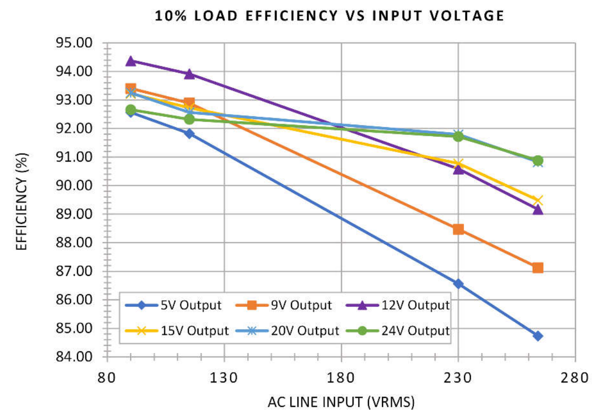


Figure 3-5. 10%-Load Efficiency vs Input Voltage

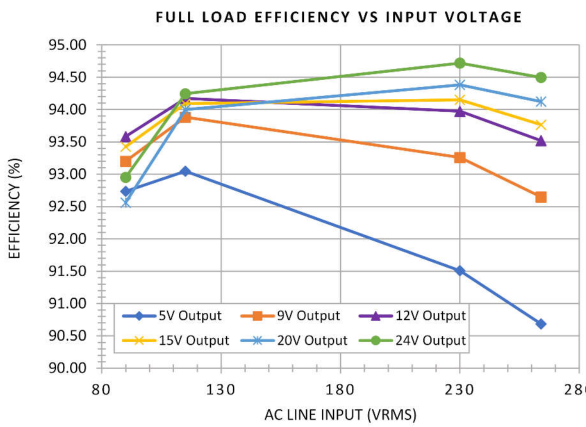


Figure 3-6. Full-load Efficiency vs Input Voltage

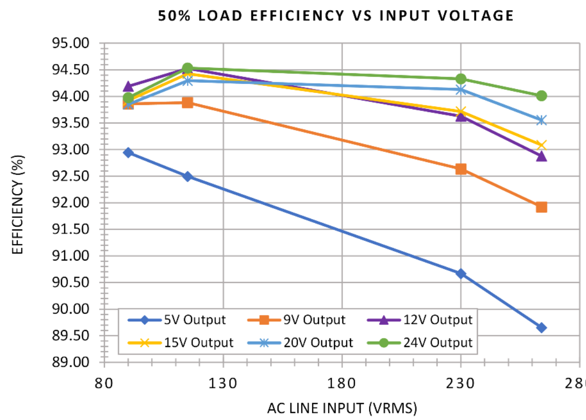


Figure 3-7. 50%-load Efficiency vs Input Voltage

3.3.8 Output Characteristics

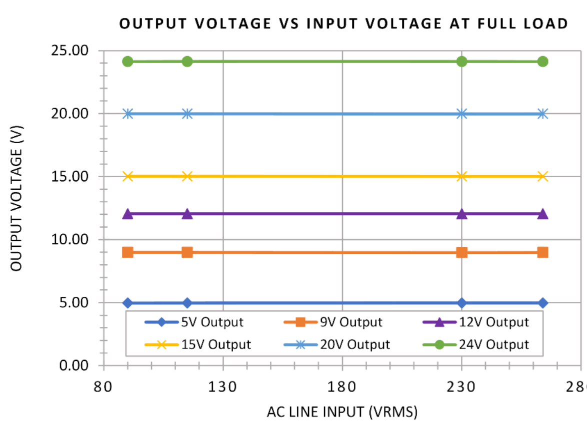


Figure 3-8. V_{OUT} vs Input Voltage at Full-Load

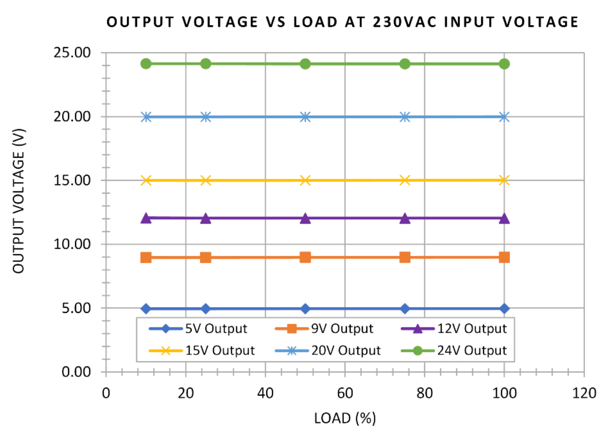


Figure 3-9. V_{OUT} vs Load at 230Vac Input Voltage

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} = 90Vac, V_{out} = 24V

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

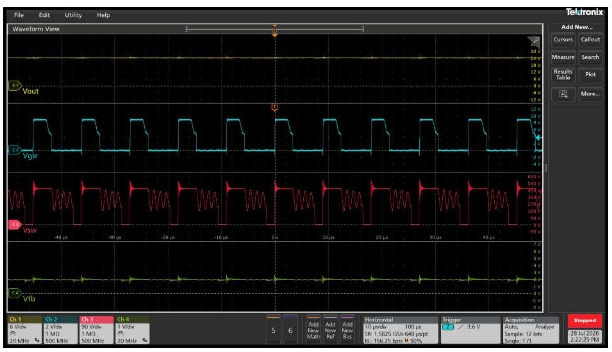


Figure 3-12. V_{in} = 230Vac, V_{out} = 24V

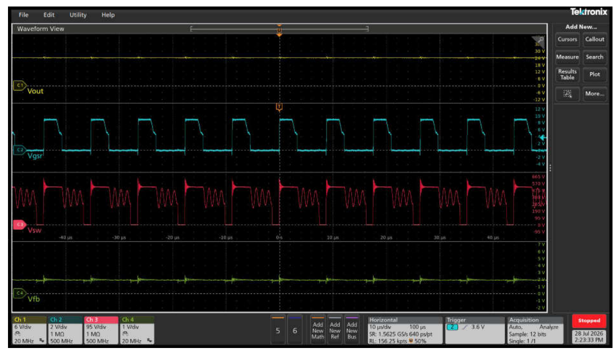


Figure 3-13. V_{in} = 264Vac, V_{out} = 24V

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

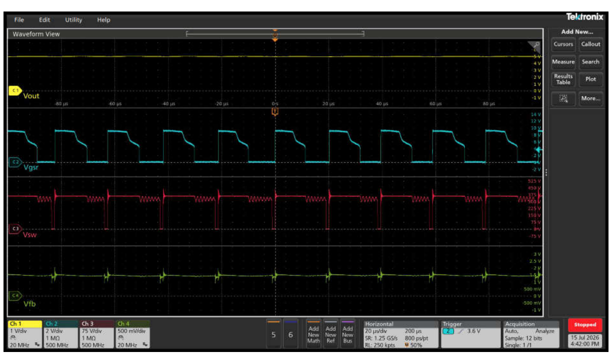


Figure 3-32. V_{in} = 230Vac, V_{out} = 5V

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

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

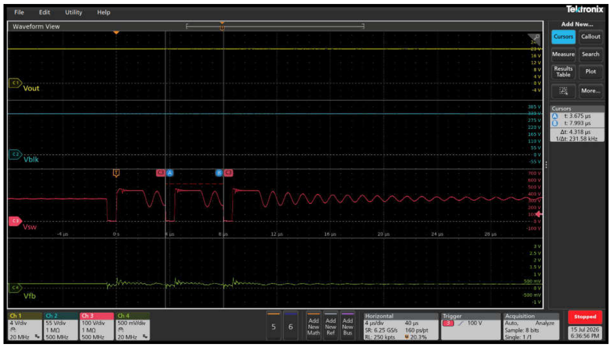


Figure 3-34. 230Vac/0.4W (231khz Burst Frequency/ Vfb - 0.26V)

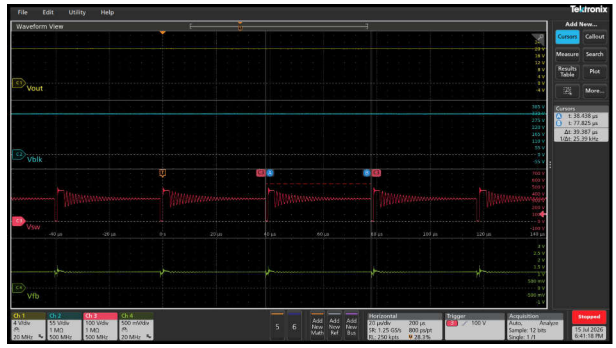


Figure 3-35. 230Vac/4.4W (25kHz Frequency-Foldback / Vfb - 1.15V)

Figure 3-36. 230Vac/10W (39kHz Frequency-Foldback/ Vfb - 1.35V)

Figure 3-37. 230Vac/16W (52kHz Frequency-Foldback/ Vfb - 1.46V)

Figure 3-38. 230Vac/40W (87kHz 6th Valley Switching/ Vfb - 1.73V)

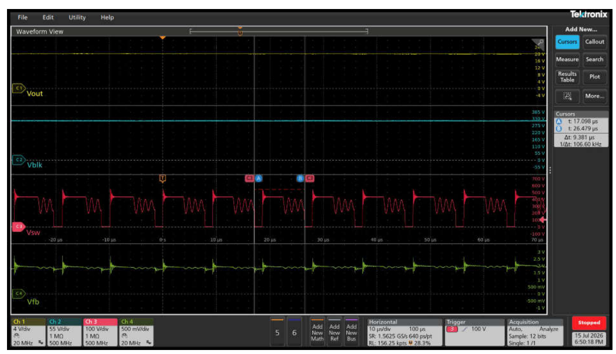


Figure 3-39. 230Vac/65W (106kHz 3rd Valley Switching/Vfb - 1.93V)

3.3.11 Output Ripple Voltage

This section shows the output voltage ripple waveforms at 230Vac input. Ch1 - Output Voltage Ripple, Oscilloscope Channel Bandwidth = 20MHz.

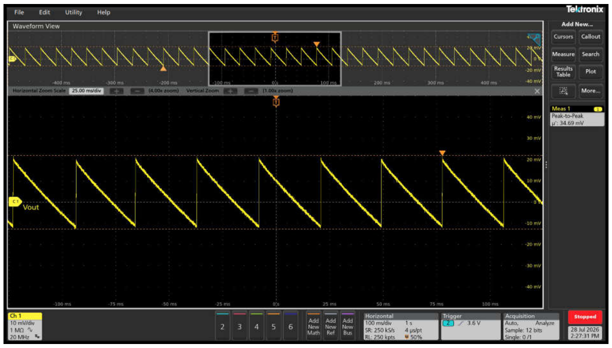


Figure 3-40. Typical Ripple Voltage of V_{OUT} = 24V at No Load (35mVpp)

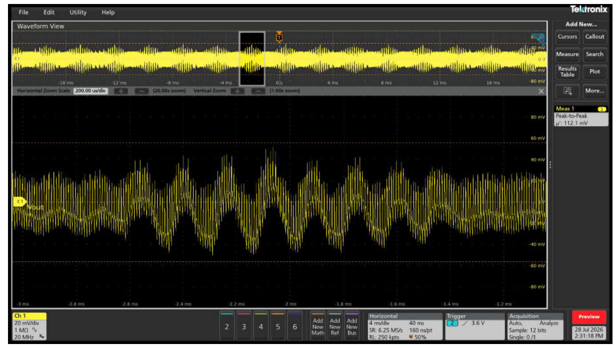


Figure 3-41. Typical Ripple Voltage of V_{OUT} = 24V at Full Load (112mVpp)

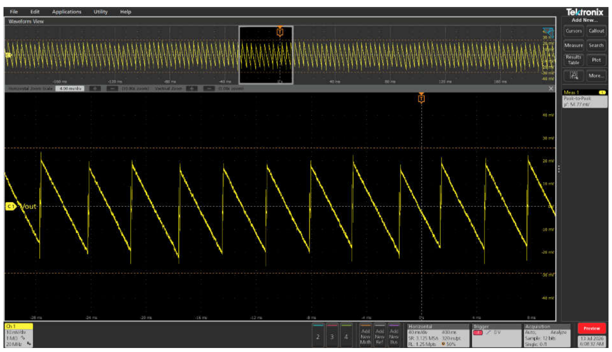


Figure 3-42. Typical Ripple Voltage of V_{OUT} = 20V at No Load (55mVpp)

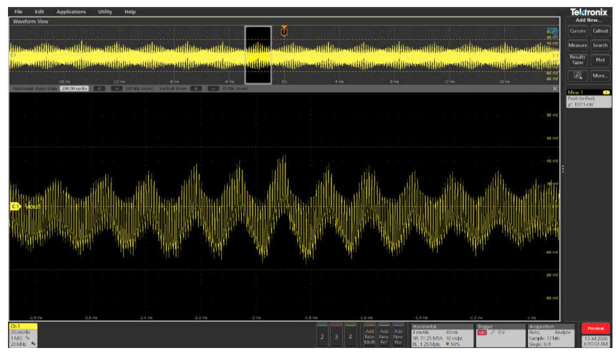


Figure 3-43. Typical Ripple Voltage of V_{OUT} = 20V at Full Load (108mVpp)

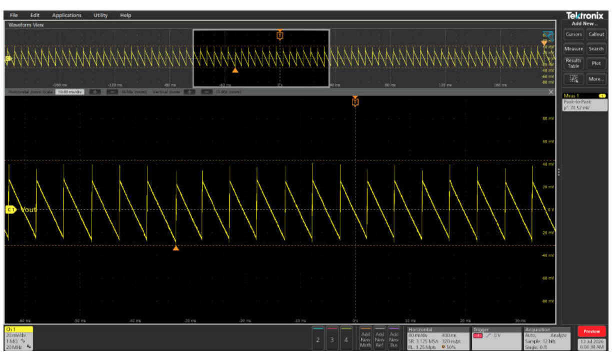


Figure 3-44. Typical Ripple Voltage of V_{OUT} = 15V at No Load (75mVpp)

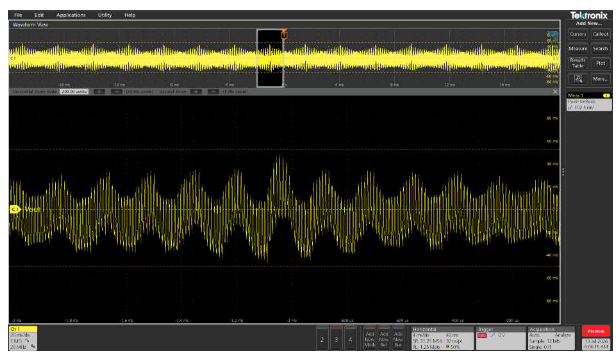


Figure 3-45. Typical Ripple Voltage of V_{OUT} = 15V at Full Load (103mVpp)

Figure 3-46. Typical Ripple Voltage of V_{OUT} = 12V at No Load (38mVpp)

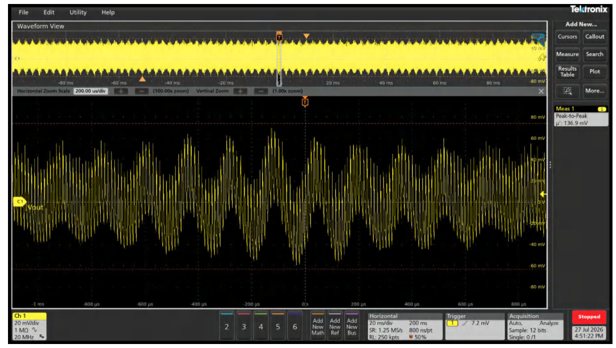


Figure 3-47. Typical Ripple Voltage of V_{OUT} = 12V at Full Load (137mVpp)

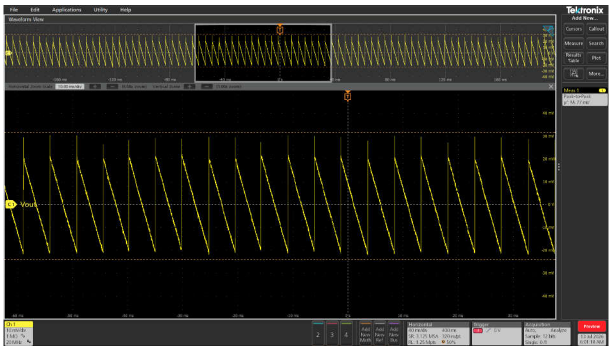


Figure 3-48. Typical Ripple Voltage of V_{OUT} = 9V at No Load (56mVpp)

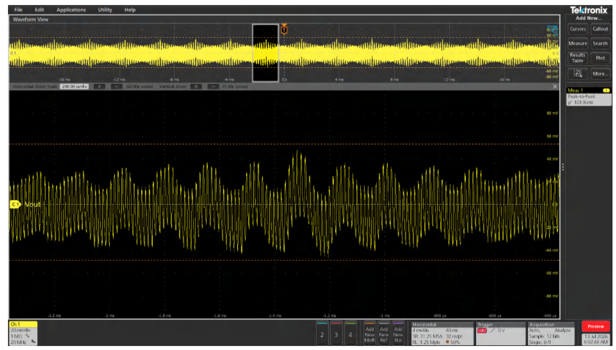


Figure 3-49. Typical Ripple Voltage of V_{OUT} = 9V at Full Load (102mVpp)

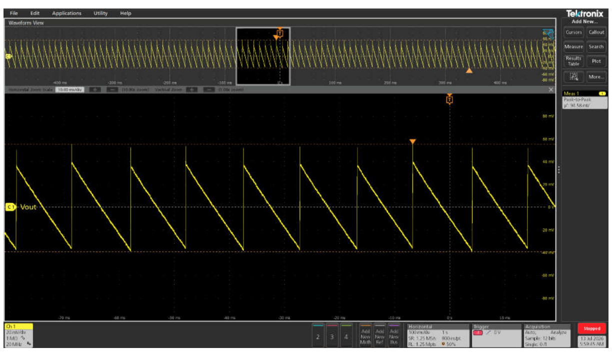


Figure 3-50. Typical Ripple Voltage of V_{OUT} = 5V at No Load (95mVpp)

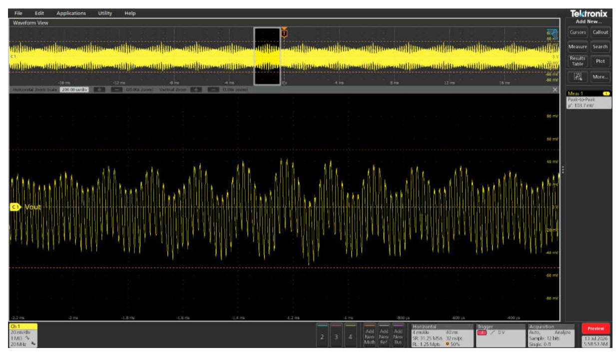


Figure 3-51. Typical Ripple Voltage of V_{OUT} = 5V at Full Load (104mVpp)

3.3.12 Load Transient Response

This section presents the switching waveforms under load transient condition at 230Vac input. Here, the load current step change is between 2% and 100%, at 25Hz rate at 2.5A/µs.

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

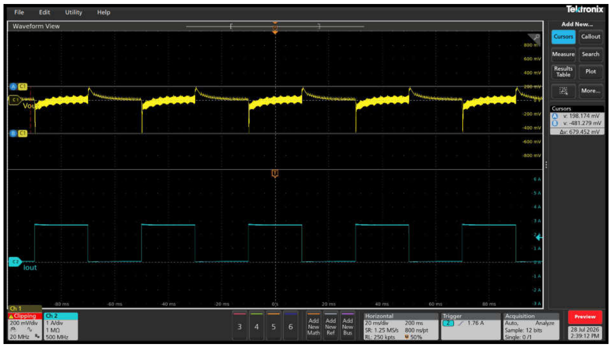


Figure 3-52. Load Transient Response at V_{OUT} = 24V Overshoot / Undershoot = 198mV / –481mV

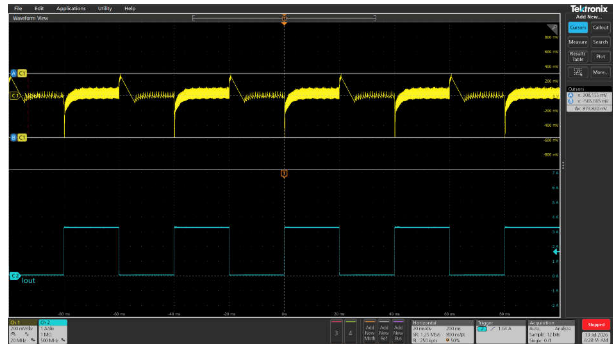


Figure 3-53. Transient Response at V_{OUT} = 20V Overshoot / Undershoot = 308mV / –566mV

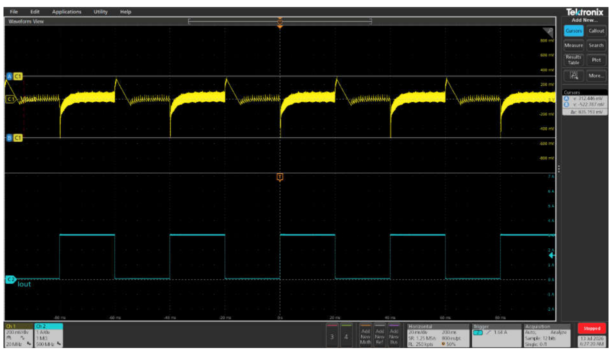


Figure 3-54. Transient Response at V_{OUT} = 15V Overshoot / Undershoot = 312mV / –523mV

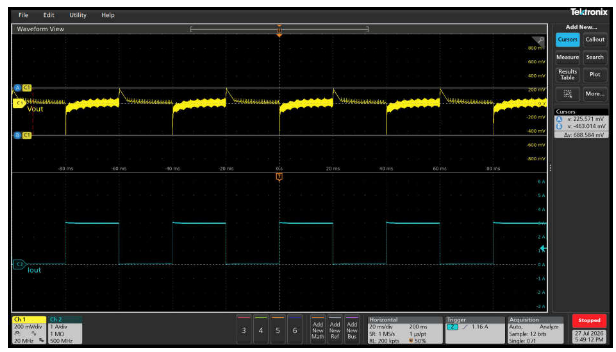


Figure 3-55. Transient Response at V_{OUT} = 12V Overshoot / Undershoot = 225mV / –463mV

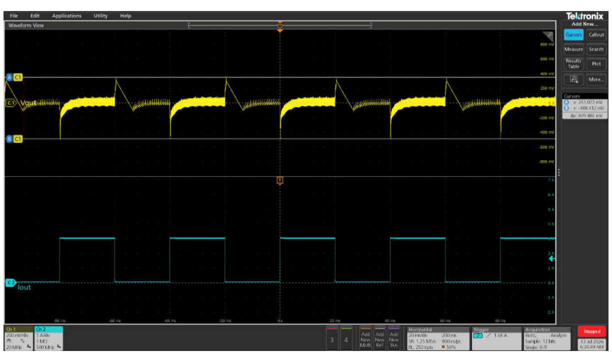


Figure 3-56. Transient Response at V_{OUT} = 9V Overshoot / Undershoot = 351mV / –488mV

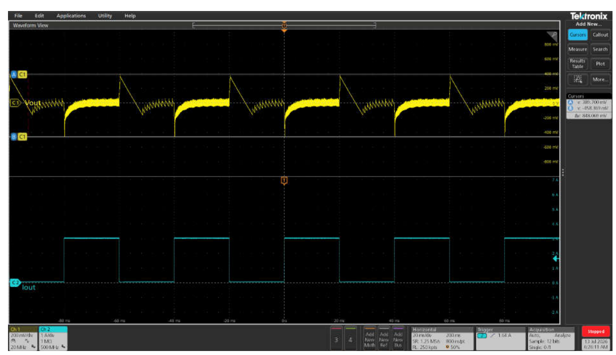


Figure 3-57. Transient Response at V_{OUT} = 5V Overshoot / Undershoot = 390mV / –458mV

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 at 20V output. 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

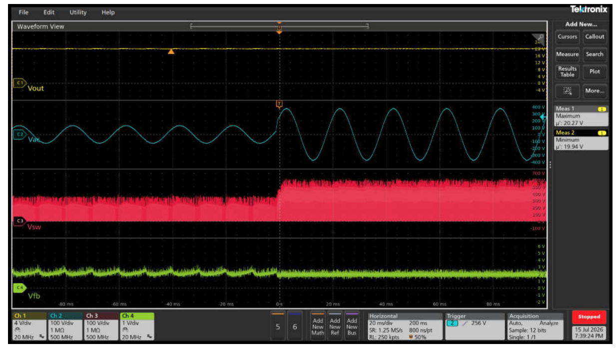


Figure 3-59. Line Transient from 90Vac to 264Vac at 20V/Full Load

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 18.2V when peak short term overload of 7.3A is applied for 1ms. The output voltage drops to 18.6V 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.

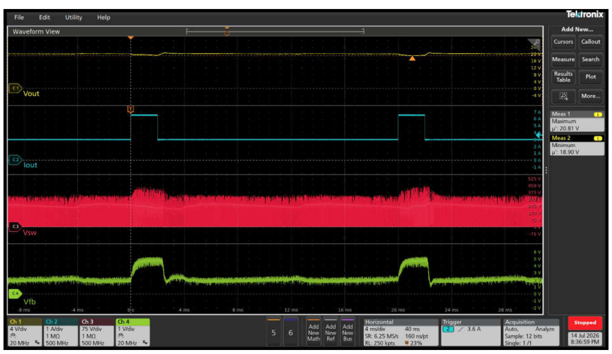


Figure 3-62. VIN=90Vac (2× Rated Current for 2ms, 0.9× Rated Current for 18ms)

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

3.3.16 Start-Up Performance

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

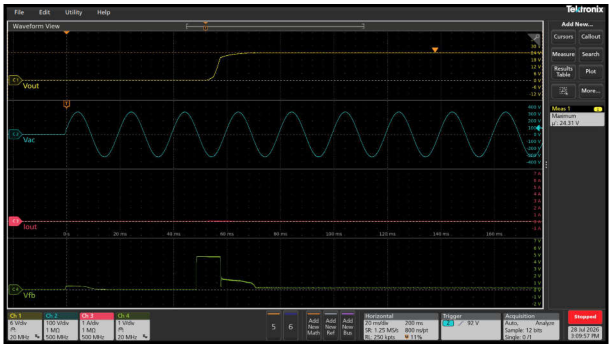


Figure 3-64. Start-Up Response at 24V and 0A

Figure 3-65. Start-Up Response at 24V and 2.71A

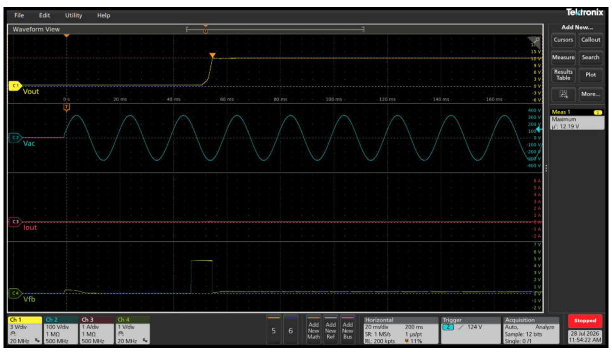


Figure 3-66. Start-Up Response at 12V and 0A

Figure 3-67. Start-Up Response at 12V and 3A

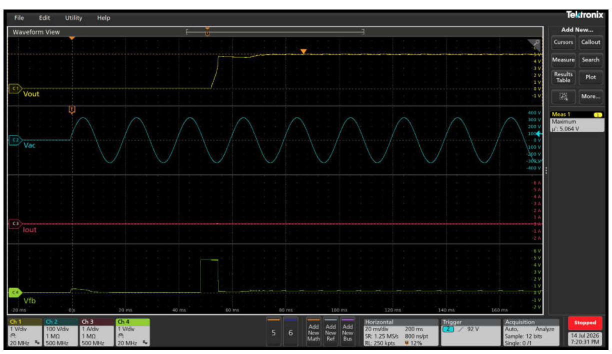


Figure 3-68. Start-Up Response at 5V and 0A

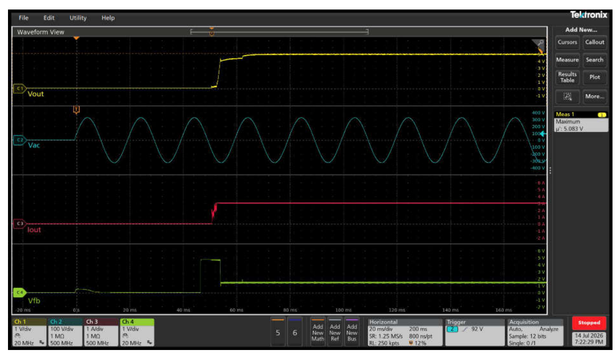


Figure 3-69. Start-Up Response at 5V and 3A

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

This section presents the thermal images of the EVM while operating at full load at both at 24V and 20V output voltages and at different line voltages. The data was taken after a thermal soak of 15 minutes.

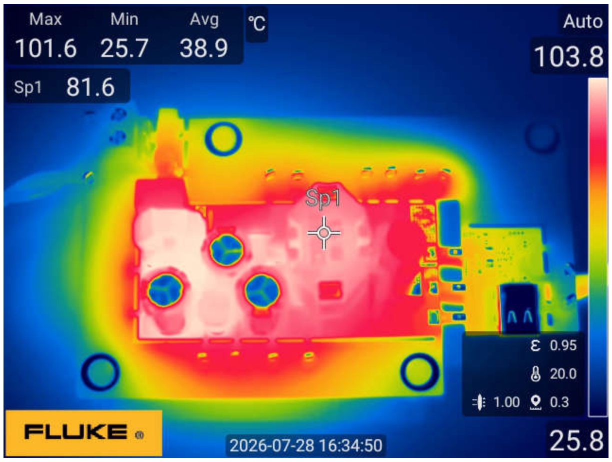


Figure 3-70. Top Side at 90Vac-to-24V/2.71A

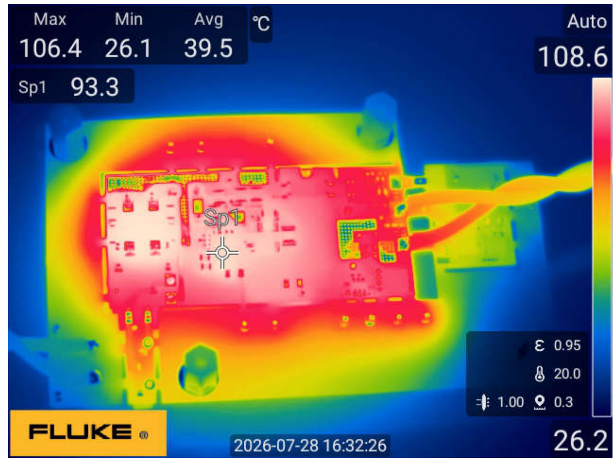


Figure 3-71. Bottom Side at 90Vac-to-24V/2.71A

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

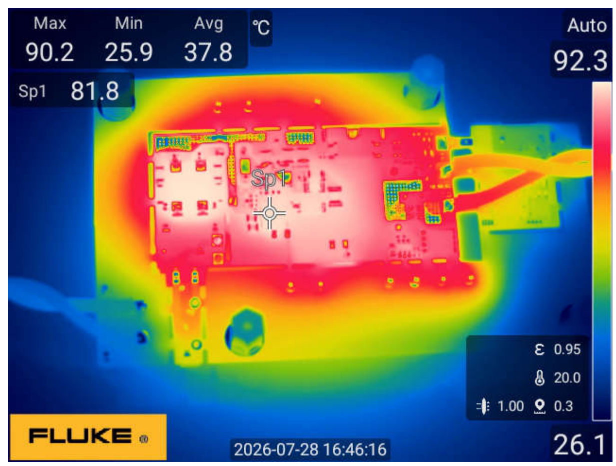


Figure 3-73. Bottom Side at 115Vac-to-24V/2.71A

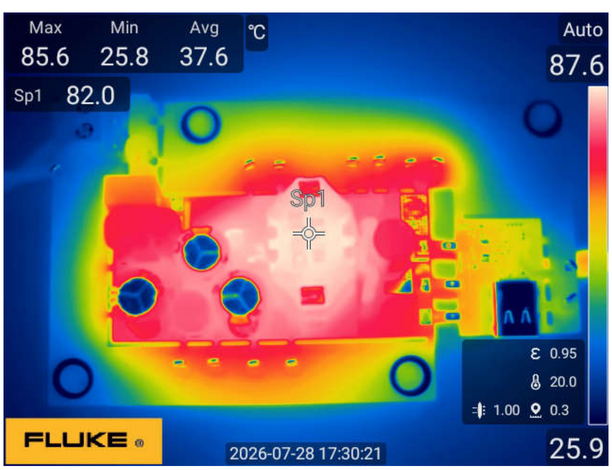


Figure 3-74. Top Side at 230Vac-to-24V/2.71A

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

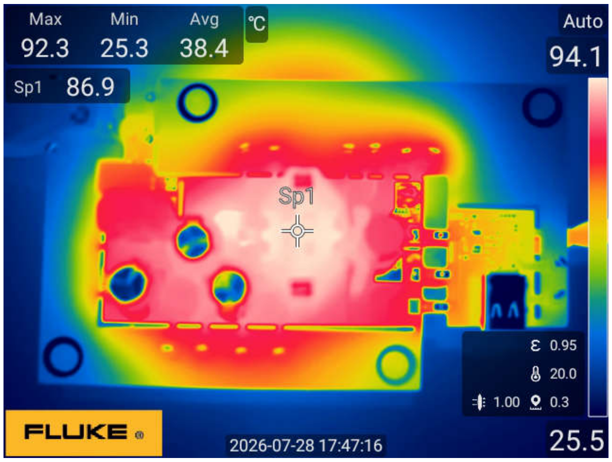


Figure 3-76. Top Side at 264Vac-to-24V/2.71A

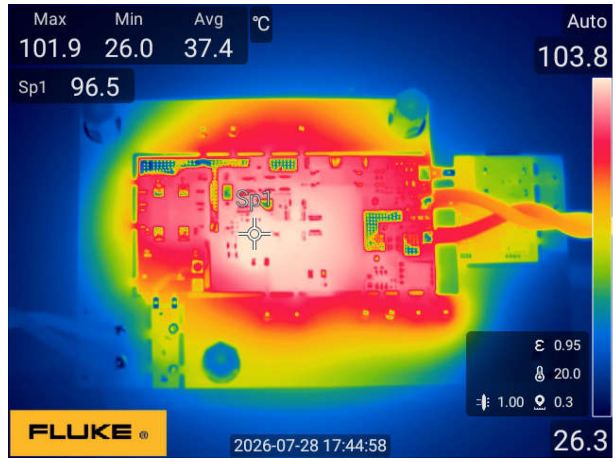


Figure 3-77. Bottom Side at 264Vac-to-24V/2.71A

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

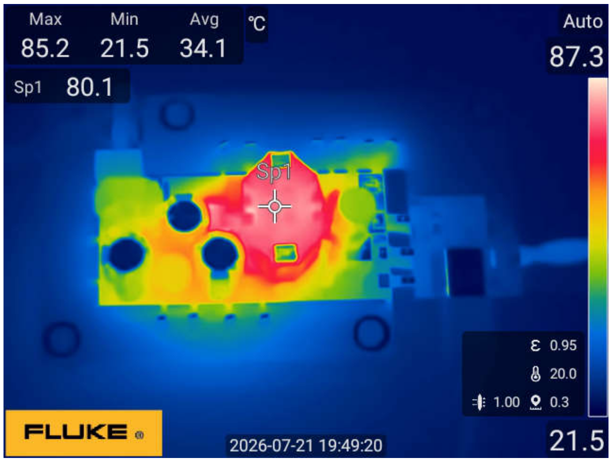


Figure 3-82. Top Side at 230Vac-to-20V/3.25A

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. The following EMI results are captured with SGND not connected to LISN ground.

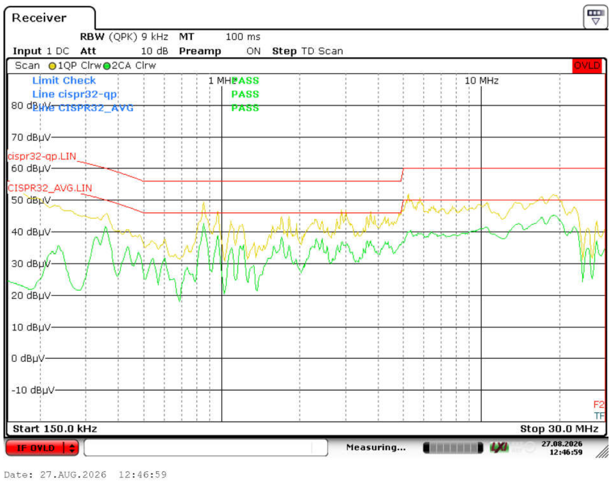


Figure 3-86. Line at V_{IN} = 230VRMS, V_{OUT} = 20V, I_{OUT} = 3.25A

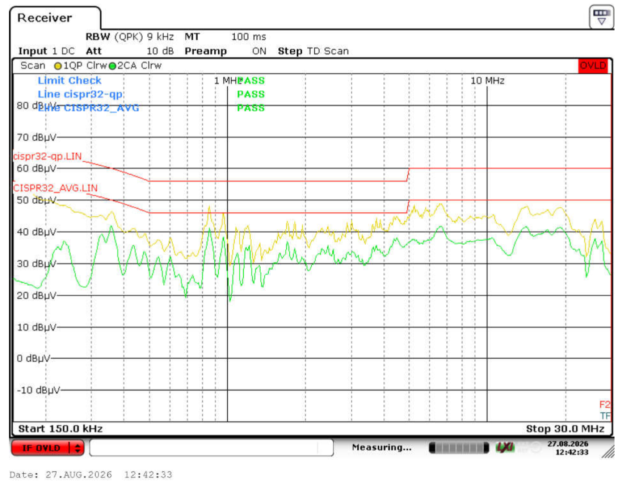


Figure 3-87. Neutral at V_{IN} = 230VRMS, V_{OUT} = 20V, I_{OUT} = 3.25A

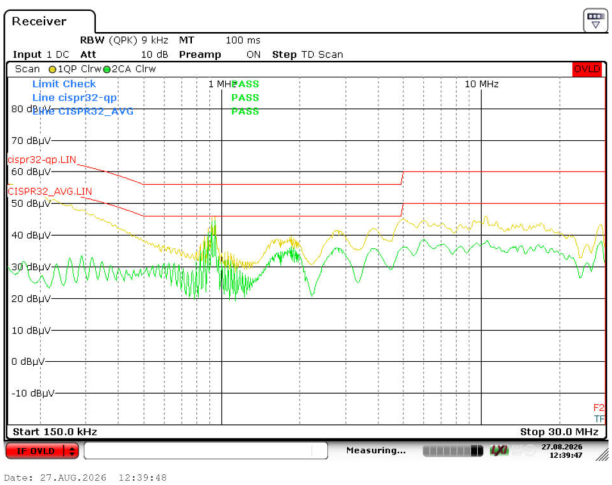


Figure 3-88. Line at V_{IN} = 230VRMS, V_{OUT} = 20V, I_{OUT} = 0.325A

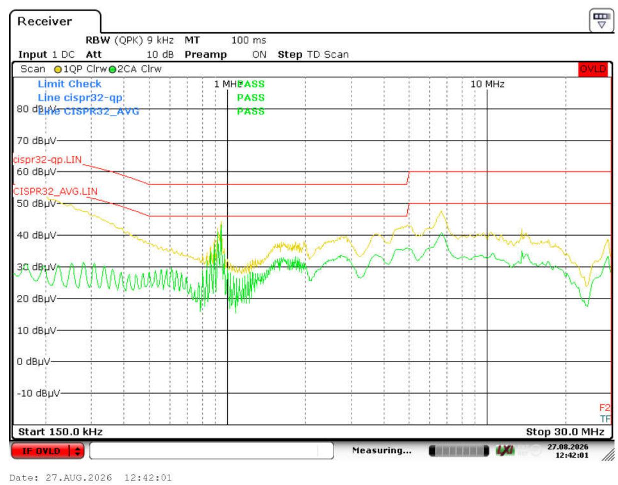


Figure 3-89. Neutral at V_{IN} = 230VRMS, V_{OUT} = 20V, I_{OUT} = 0.325A

4 Hardware Design Files

4.1 Schematics

The schematic of the UCG28836EVM-150 is shown below. This EVM is configured with USB-PD controller enabled for USB-PD load. It can be reconfigured for fixed output voltage. For this, 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 0Ω resistors R26, R32, and R28. The output voltage can then be set by adjusting R34 using:

$$R34 = R30 \times 2.5V/(Vout - 2.5V) \tag{1}$$

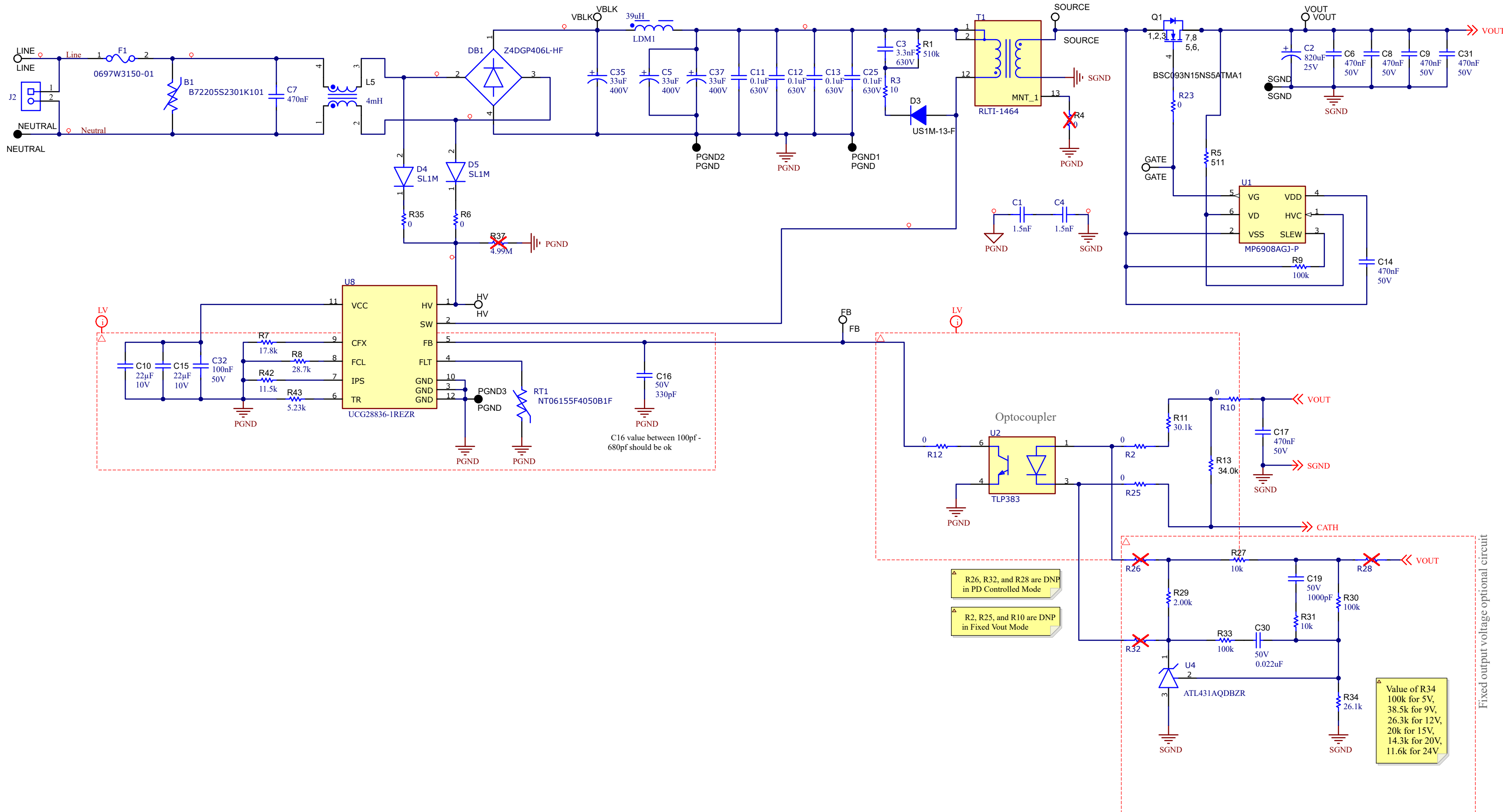


Figure 4-1. UCG28836EVM-150 Power Circuit Schematic

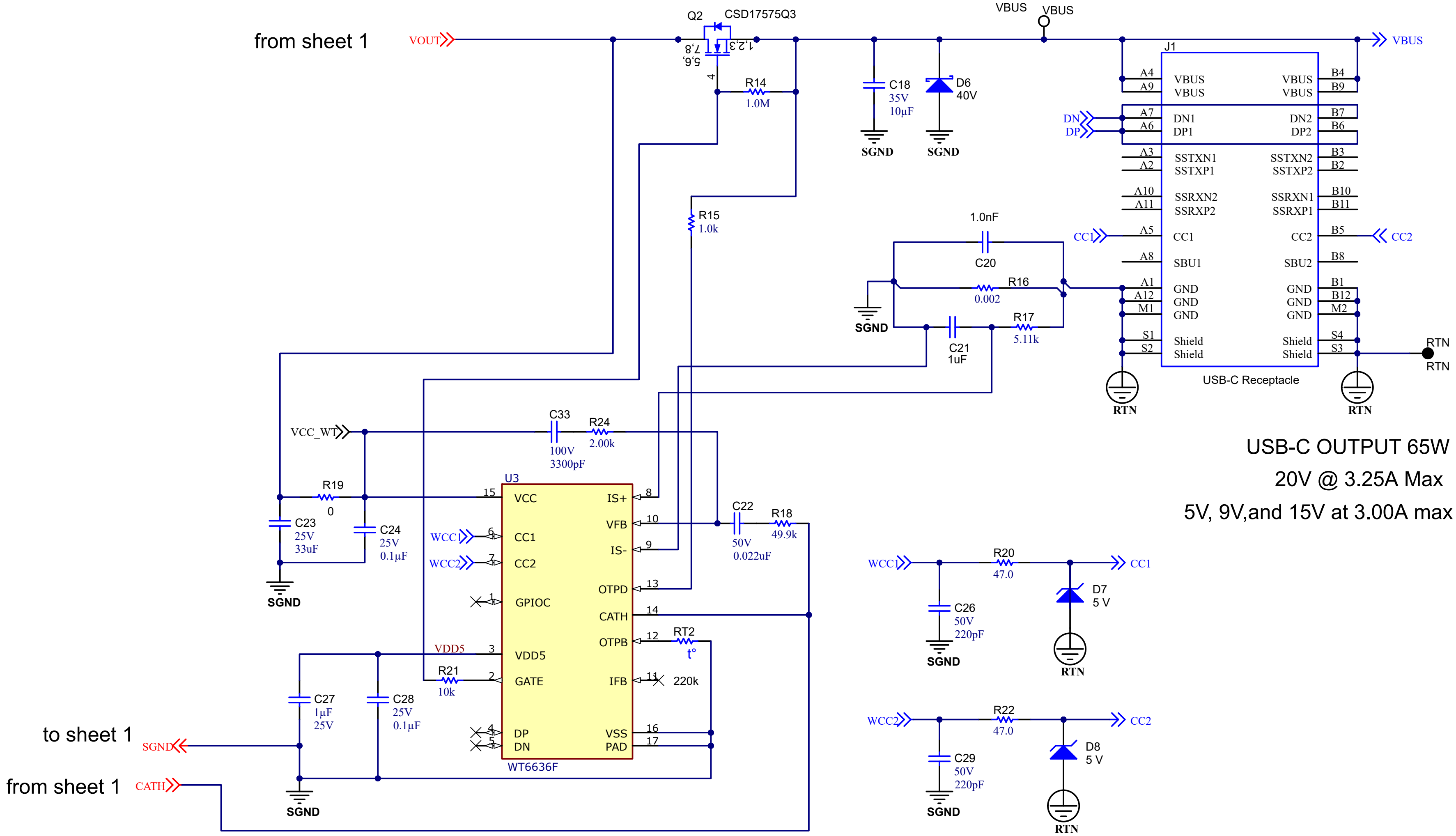


Figure 4-2. UCG28836EVM-150 PD Controller Circuit Schematic

4.2 PCB Layouts

UCG28836EVM-150 uses two layers PCB. The screenshots of the layout of each layer are shown below.

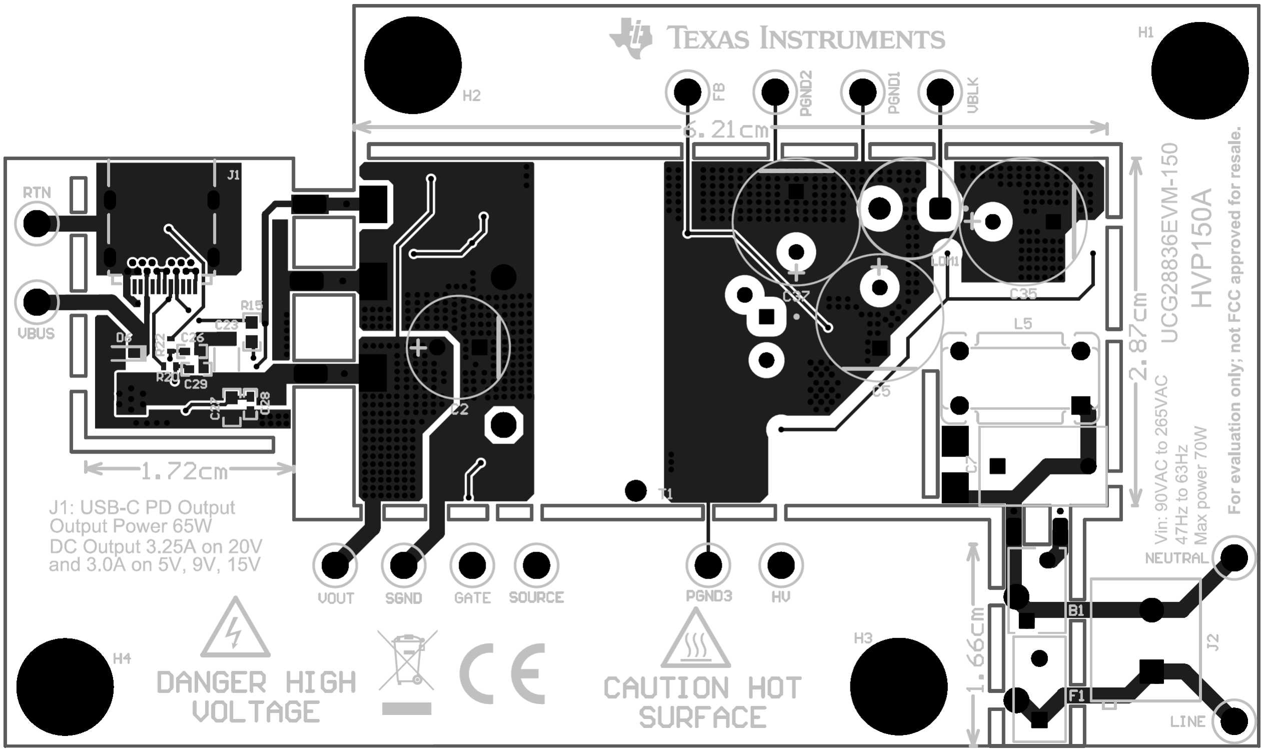


Figure 4-3. Top Layer

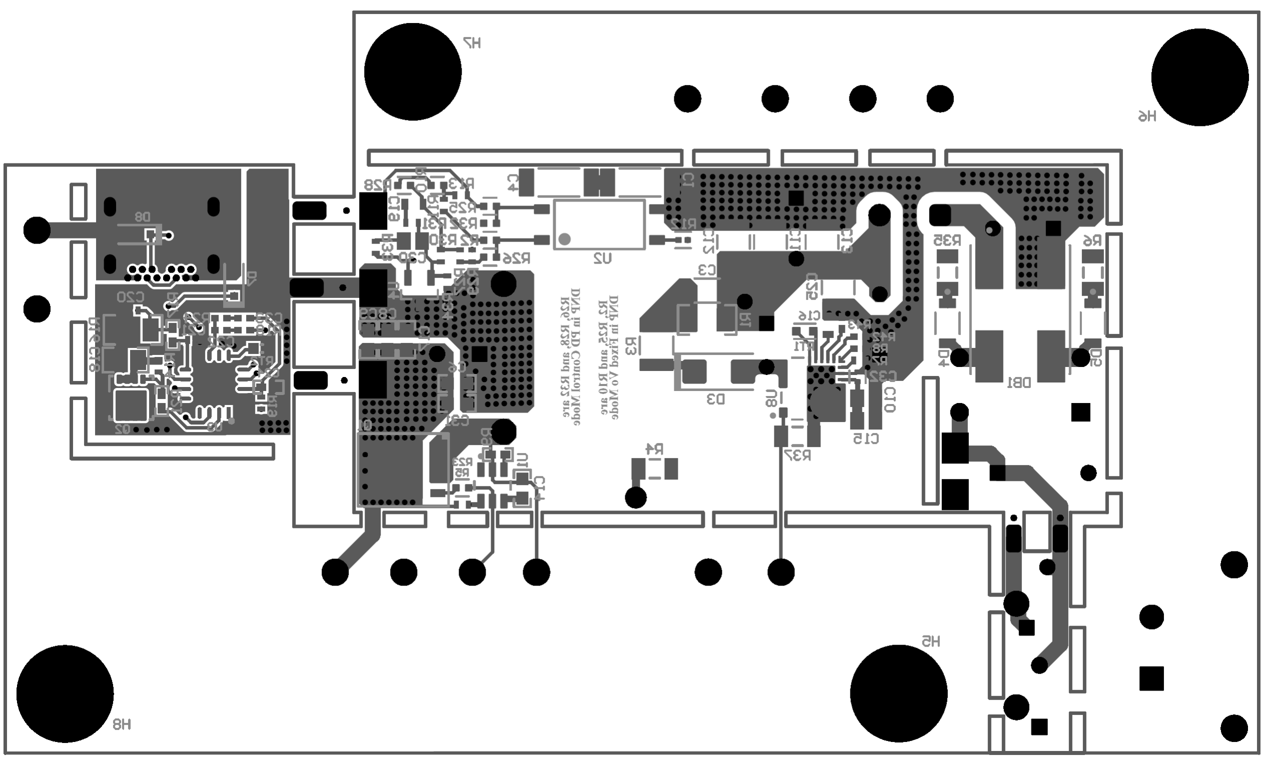


Figure 4-4. Bottom Layer

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.

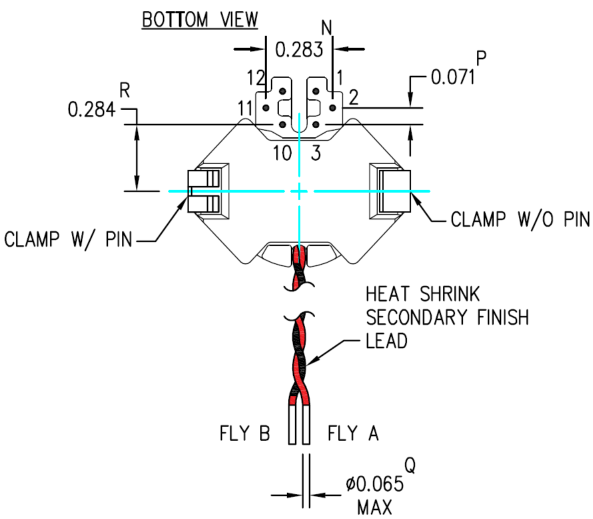


Figure 4-5. RLTI-1464 Pin Configuration

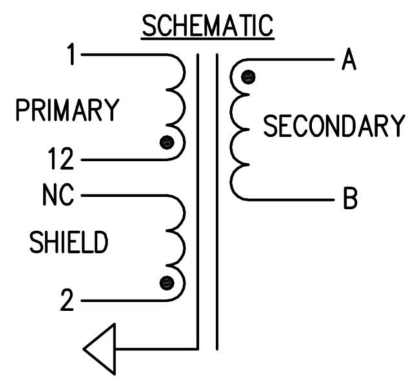


Figure 4-6. RLTI-1464 Schematic

Table 4-1. Transformer Specifications at 25°C

PARAMETER	TYPICAL VALUE	PINS/LEADS	TEST CONDITIONS
Inductance (µH)	325, ±5%	1 – 12	Open all other pins, 100kHz / 0.1Vac
Leakage Inductance (µH)	3.5 Max.	1 – 12	Short A - B, 100kHz / 0.1Vac
D.C. resistance (Ω)	0.220, ±15%	1 – 12	
D.C. resistance (Ω)	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 UCG28836EVM-150.

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	TDK
C1, C4	2	1500 pF ±10% 250VAC Ceramic Capacitor X7R 1808 (4520 Metric)	1808YA250152KJTSYX	Knowles
C2	1	820uF 25V Aluminum - Polymer Capacitors, Radial Can, 22mOhm	RPF0816821M025K	KYOCERA AVX
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 Aluminum Electrolytic Capacitors	87EC0493	KNSCHA
C6, C8, C9, C14, C17, C31	6	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, C13, C25	4	Cap Ceramic 0.1uF 630V X7R 10% Pad SMD 1210 125C Low ESR Medical T/R	C1210C104KBRACTU	Yageo Group
C16	1	CAP, CERM, 330 pF, 50 V, +/- 5%, C0G/NP0, 0603	885012006060	Wurth Elektronik
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	CGA2B3X7R1E104K050BB	TDK
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, 5.6 V, 400 mW, SOD-323F	D3Z5V6BF-7	Diodes Inc.
DB1	1	Bridge Rectifier Single Phase Standard 600 V Surface Mount Z4-D	Z4DGP406L-HF	Comchip
F1	1	Fuse Subminiature Slow Blow Acting 3.15A 350V Radial 8.35 X 4 X 7.8mm Thermoplastic Box	0697W3150-01	Bel Fuse

Table 4-2. Bill of Materials (continued)

Designator	Quantity	Description	Part Number	Manufacturer
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, 4 mH, 1.5 A, 0.14 ohm, TH	744821240	Wurth Elektronik
LDM1	1	WE-TI Radial Leaded Wire Wound Inductor, size 8095, 39uH, 2.2A, 0.1Ohm	7447720390	Wurth 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)	CSD17575Q3T	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
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

Table 4-2. Bill of Materials (continued)

Designator	Quantity	Description	Part Number	Manufacturer
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	ERJ-2RKF1152X	Panasonic
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, 1%, 0603	ERT-J1VT224FM	Panasonic
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
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	UCG28836-1REZR	Texas Instruments

5 Additional Information

Trademarks

USB-C™ is a trademark of USB Implementers Forum.
All trademarks are the property of their respective owners.

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an “EVM” or “EVMs”) to the User (“User”) in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.

   1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM (“Software”) shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software

   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

   2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits 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 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 DEGREDATION 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/lsds/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.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。 技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・インスツルメンツ株式会社

東京都新宿区西新宿６丁目２４番１号

西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/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.

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.

6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT, REGARDLESS OF WHEN MADE, CONCEIVED OR ACQUIRED.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVMS , REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, , EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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