EVM User's Guide: UCG28824EVM-124

Using the UCG28824EVM-124 45W High-Density GaN Integrated Quasi-Resonant Flyback Converter

Description

The UCG28824EVM-124 is a 45W 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 to be an end product. The UCG28824EVM-124 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 of $5V_{DC}$ to $24V_{DC}$. The EVM is designed to deliver 3.00A of maximum output current upto $15V_{DC}$ and 45W of maximum output power for the output voltage in the range of $15V_{DC}$ to $24V_{DC}$. The main device used in this design is the UCG28824 with integrated 750V GaN FET and controller in 5mm × 5mm package.

Get Started

1. Read and study this user's guide completely before evaluating.
2. Order the UCG28824EVM-124 for evaluation if step 1 met.
3. Setup and test the UCG28824EVM-124 per user's guide instructions.

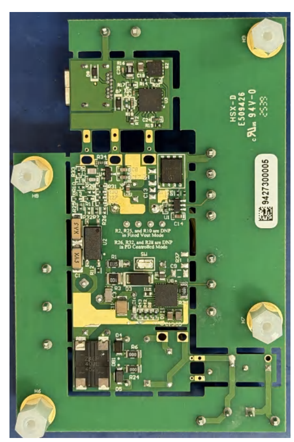
Features

- 93-95% efficiency under full-load operation over entire input voltage range
- $2W/cm^3$ (5.4cm × 2.67cm × 1.6cm) 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

UCG28824EVM-124 (Top View)



UCG28824EVM-124 (Bottom View)

1 Evaluation Module Overview

1.1 Introduction

The UCG28824EVM-124 facilitates the evaluation of UCG28824, 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 of 5V to 24V. This user guide provides a high-voltage safety overview, recommended test setup, efficiency results, waveforms, and conducted EMI performance.

1.2 Kit Contents

- 45W 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/2.25A, 15V/3.00A, 9V/3.00A, and 5V/3.00A	45W
	Fixed output voltage	5V - 15V/3A and 15V-24V/45W	

1.4 Device Information

The UCG28824 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 45W. This device gives benefit of GaN integration to achieve high power density designs with high switching frequency up to 500kHz. The UCG28824 features industry's first 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 UCG28824 supports continuous conduction mode (CCM) operation for up to 10msec for transient output power conditions of up to 90W (two times the 45W 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 UCG28824 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

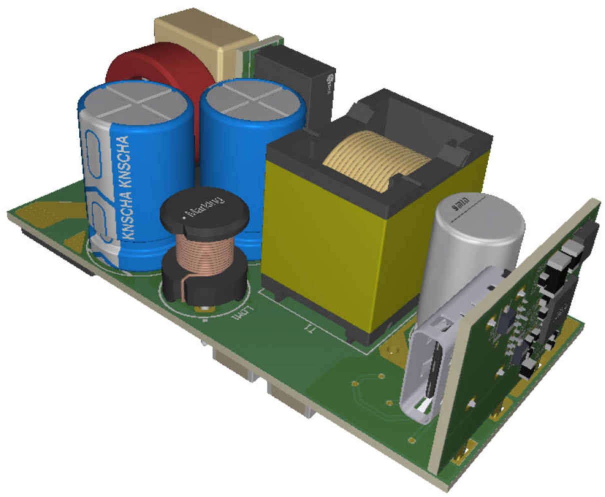


Figure 2-1. High Power-Density Configuration

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

UCG28824EVM-124 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 on "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. To obtain the full load current 3.00A from 5V, 9V, and 15V, a standard USB-C cable can be used. To obtain 3.25A at 20V output, an "E-marker" USB-C® cable must be used.

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

UCG28824EVM-124 can be reconfigured to produce fixed out voltage in the range 5V-24V when evaluating with a non-USB-C PD load. The corresponding test setup diagram is shown in section on"Section 3.2.2". UCG28824EVM-124 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 on "Section 4.1". In fixed output voltage control mode, the converter can deliver 3A rated current at 5V-15V output and 45W rated power at 15V-24V output.

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		8/32		mW
P_{180mW}	Input power at 180mW load	V_{IN} = 230V_{RMS}, V_{OUT} = 5V, P_{OUT} = 180mW, USB-C PD controller enabled		260		mW
P_{300mW}	Input power at 300mW load	V_{IN} = 230V_{RMS}, V_{OUT} = 5V, P_{OUT} = 300mW, USB-C PD controller enabled		390		
OUTPUT CHARACTERISTICS						
V_{OUT}	Output voltage	I_{OUT} = 0 to 1.875A, fixed V_{OUT} controller enabled		24		V
		I_{OUT} = 0 to 2.25A, 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		1.875		A
		V_{OUT} = 20V		2.250		A
		V_{OUT} = 5V/9V/12V/15V		3.000		A
V_{OUT_pp}	Output voltage ripple at V_{IN} = 115V/230V	V_{OUT} = 24V, I_{OUT} = 0 to 1.875A		45		mVpp
		V_{OUT} = 20V, I_{OUT} = 0 to 2.25A		98		mVpp
		V_{OUT} = 15V, I_{OUT} = 0 to 3A		89		mVpp
		V_{OUT} = 12V, I_{OUT} = 0 to 3A		108		mVpp
		V_{OUT} = 9V, I_{OUT} = 0 to 3A		136		mVpp
		V_{OUT} = 5V, I_{OUT} = 0 to 3A		115		mVpp
V_{OUT_Δ}	V_{OUT} deviation due to load step Up / Down (I_{OUT} step change between 0 and 100% load at 100Hz rate)	V_{OUT} = 24V		-260/120		mV
		V_{OUT} = 20V		-440/330		mV
		V_{OUT} = 15V		-510/360		mV
		V_{OUT} = 12V		-410/120		mV
		V_{OUT} = 9V		-450/380		mV
		V_{OUT} = 5V		-440/460		mV
P_{OPP}	Over power protection threshold	V_{IN} = 90 to 264V_{RMS}		100		W
SYSTEMS CHARACTERISTICS						

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

PARAMETER		TEST CONDITIONS	MIN	NOM	MAX	UNIT
η	Full load efficiency at V_{IN} = 115V/230V	V_{OUT} = 24V, I_{OUT} = 1.875A		94.50/95.17		%
		V_{OUT} = 20V, I_{OUT} = 2.25A		94.44/94.96		%
		V_{OUT} = 15V, I_{OUT} = 3A		94.16/94.56		%
		V_{OUT} = 12V, I_{OUT} = 3A		93.81/94.31		%
		V_{OUT} = 9V, I_{OUT} = 3A		93.66/93.56		%
		V_{OUT} = 5V, I_{OUT} = 3A		92.36/91.62		%
η	4-point average efficiency at V_{IN} = 115V/230V(1)	V_{OUT} = 24V (CoC Tier 2, 87.7%)		94.41/94.01		%
		V_{OUT} = 20V (CoC Tier 2, 87.7%)		94.49/94.29		%
		V_{OUT} = 15V (CoC Tier 2, 87.7%)		94.33/94.06		%
		V_{OUT} = 12V (CoC Tier 2, 86.8%)		94.12/93.19		%
		V_{OUT} = 9V (CoC Tier 2, 85.4%)		93.86/92.86		%
		V_{OUT} = 5V (CoC Tier 2, 81.8%)		92.57/91.03		%
η	Efficiency at 10% load at V_{IN} = 115V/230V	V_{OUT} = 24V (CoC Tier 2, 77.8%)		92.24/90.10		%
		V_{OUT} = 20V (CoC Tier 2, 77.8%)		93.64/92.48		%
		V_{OUT} = 15V (CoC Tier 2, 77.8%)		94.15/92.88		%
		V_{OUT} = 12V (CoC Tier 2, 77.1%)		92.97/90.10		%
		V_{OUT} = 9V (CoC Tier 2, 75.9%)		93.67/91.30		%
		V_{OUT} = 5V (CoC Tier 2, 72.5%)		92.25/88.73		
T_{AMB}	Operating ambient temperature	V_{IN} = 90 to 264V_{RMS}, I_{OUT} = 0 to 3.00A (5V/9V/15V), 2.25A (20V) , or 1.875A (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 UCG28824EVM-124

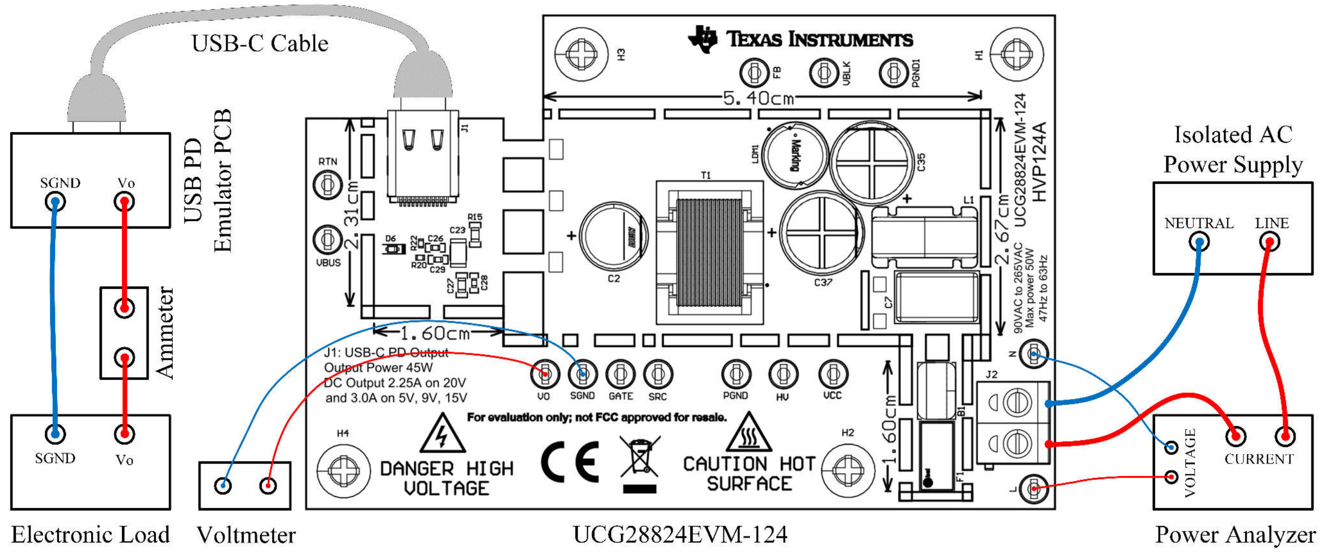


Figure 3-1. Test Setup Diagram of UCG28824EVM-124 Using a USB-C PD Load

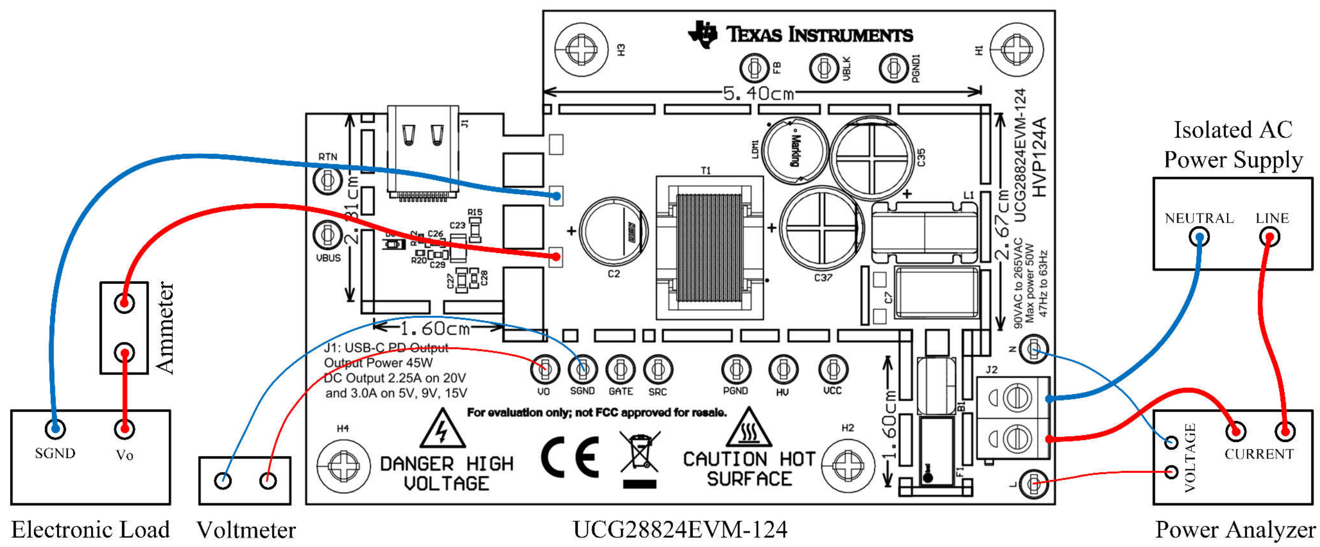
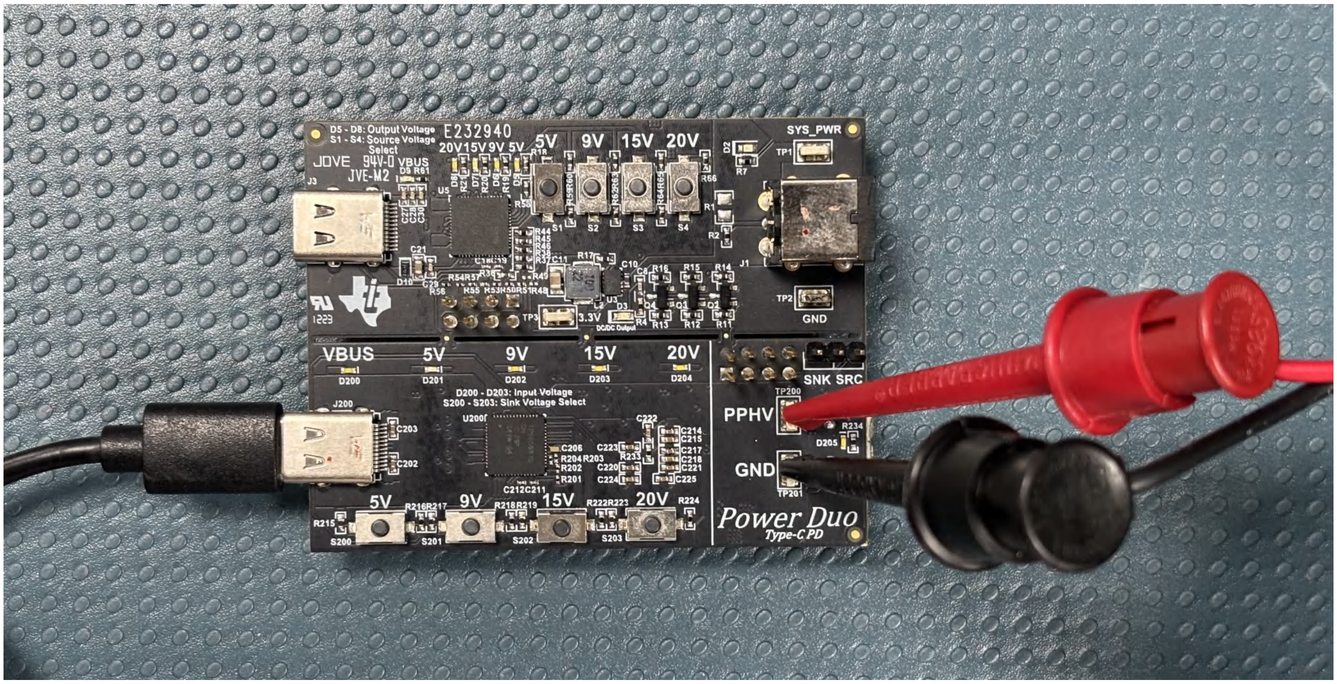


Figure 3-2. Test Setup Diagram of UCG28824EVM-124 Using a Non-USB-C PD Load

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
L	Test point for AC input - Line
N	Test point for AC input - Neutral
PGND, PGND1	Test points for primary ground
VBLK	Test point for bulk capacitor voltage
FB	Test point for FB pin
VCC	Test point for VCC pin
HV	Test point for HV pin
SRC	Test point for SR FET source
GATE	Test point for SR FET gate
SGND	Test point for secondary ground
VO	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 24-Vout

V_{IN} (VRMS)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{out} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	4.94	23.99	0.188	4.50	10	90.99%	93.85%
90	12.04	23.99	0.470	11.28	25	93.65%	
90	23.93	23.99	0.939	22.53	50	94.15%	
90	35.90	23.99	1.406	33.73	75	93.96%	
90	48.03	23.99	1.875	44.98	100	93.65%	
115	5.08	24.05	0.195	4.69	10	92.24%	94.41%
115	12.16	24.05	0.475	11.42	25	93.95%	
115	23.97	24.05	0.943	22.68	50	94.63%	
115	35.84	24.05	1.409	33.89	75	94.54%	
115	47.79	24.05	1.878	45.17	100	94.50%	
230	5.23	24.06	0.196	4.72	10	90.10%	94.01%
230	12.44	24.05	0.475	11.42	25	91.82%	
230	24.08	24.05	0.943	22.68	50	94.17%	
230	35.72	24.04	1.410	33.90	75	94.89%	
230	47.44	24.04	1.878	45.15	100	95.17%	
264	5.14	23.99	0.188	4.51	10	87.70%	93.46%
264	12.41	23.99	0.470	11.28	25	90.86%	
264	24.07	23.99	0.938	22.50	50	93.48%	
264	35.68	23.99	1.406	33.70	75	94.47%	
264	47.32	23.99	1.875	44.96	100	95.02%	
CoC Tier 2, 4-pt average							87.70%
CoC Tier 2, 10%-load							77.83%

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	4.98	19.94	0.225	4.65	10	93.50%	94.00%
90	12.12	19.94	0.564	11.41	25	94.15%	
90	24.02	19.93	1.126	22.61	50	94.14%	
90	35.98	19.94	1.688	33.83	75	94.02%	
90	48.06	19.94	2.250	45.03	100	93.71%	
115	4.97	19.95	0.225	4.66	10	93.64%	94.49%
115	12.11	19.95	0.564	11.42	25	94.27%	
115	23.90	19.94	1.126	22.62	50	94.63%	
115	35.76	19.94	1.688	33.83	75	94.60%	
115	47.68	19.94	2.250	45.03	100	94.44%	
230	5.04	19.95	0.225	4.66	10	92.48%	94.29%
230	12.27	19.95	0.564	11.42	25	93.09%	
230	24.00	19.95	1.127	22.65	50	94.36%	
230	35.71	19.95	1.688	33.84	75	94.76%	
230	47.42	19.94	2.250	45.03	100	94.96%	
264	5.08	19.95	0.225	4.66	10	91.71%	93.83%
264	12.35	19.95	0.564	11.42	25	92.47%	
264	24.16	19.95	1.126	22.63	50	93.69%	
264	35.86	19.95	1.688	33.84	75	94.38%	
264	47.55	19.95	2.250	45.06	100	94.76%	
CoC Tier 2, 4-pt average							87.70%
CoC Tier 2, 10%-load							77.83%

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	4.98	15.00	0.300	4.61	10	93.78%	93.71%
90	12.12	15.00	0.750	11.36	25	94.17%	
90	24.02	15.00	1.501	22.62	50	94.03%	
90	35.98	15.00	2.250	33.86	75	93.58%	
90	48.06	15.00	3.000	45.11	100	93.06%	
115	4.91	15.00	0.301	4.62	10	94.15%	94.33%
115	12.05	15.00	0.750	11.36	25	94.29%	
115	23.93	15.00	1.500	22.61	50	94.47%	
115	35.86	15.00	2.250	33.86	75	94.40%	
115	47.90	15.00	3.000	45.11	100	94.16%	
230	4.98	15.01	0.301	4.63	10	92.88%	94.06%
230	12.21	15.01	0.751	11.38	25	93.20%	
230	24.05	15.00	1.501	22.62	50	94.06%	
230	35.86	15.00	2.250	33.86	75	94.42%	
230	47.70	15.00	3.000	45.11	100	94.56%	
264	5.02	15.01	0.301	4.63	10	92.06%	93.66%
264	12.30	15.01	0.750	11.37	25	92.40%	
264	24.14	15.00	1.501	22.62	50	93.70%	
264	36.01	15.00	2.250	33.86	75	94.02%	
264	47.73	15.00	3.001	45.12	100	94.53%	
CoC Tier 2, 4-pt average							87.70%
CoC Tier 2, 10%-load							77.83%

3.3.4 Efficiency Result of 4-Point Average at 12-Vout

V_{IN} (VRMS)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{out} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	3.96	12.10	0.305	3.69	10	93.25%	93.41%
90	9.72	12.10	0.755	9.13	25	94.00%	
90	19.41	12.10	1.504	18.19	50	93.76%	
90	29.17	12.10	2.252	27.25	75	93.40%	
90	39.25	12.10	3.001	36.31	100	92.50%	
115	3.97	12.10	0.305	3.69	10	92.97%	94.12%
115	9.71	12.10	0.755	9.13	25	94.08%	
115	19.30	12.10	1.504	18.20	50	94.31%	
115	28.92	12.10	2.253	27.26	75	94.28%	
115	38.72	12.10	3.002	36.33	100	93.81%	
230	4.10	12.10	0.305	3.69	10	90.10%	93.19%
230	10.00	12.10	0.755	9.13	25	91.36%	
230	19.53	12.10	1.504	18.19	50	93.12%	
230	29.00	12.10	2.253	27.26	75	93.98%	
230	38.51	12.10	3.002	36.32	100	94.31%	
264	4.14	12.10	0.306	3.70	10	89.32%	92.53%
264	10.12	12.10	0.755	9.13	25	90.26%	
264	19.70	12.09	1.504	18.19	50	92.34%	
264	29.14	12.10	2.252	27.24	75	93.46%	
264	8.62	12.10	3.002	36.32	100	94.05%	
CoC Tier 2, 4-pt average							86.83%
CoC Tier 2, 10%-load							77.11%

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	2.95	9.01	0.301	2.76	10	93.68%	93.37%
90	7.27	9.01	0.750	6.81	25	93.68%	
90	14.49	9.01	1.500	13.57	50	93.61%	
90	21.76	9.01	2.250	20.32	75	93.39%	
90	29.15	9.00	3.000	27.05	100	92.81%	
115	2.95	9.01	0.301	2.76	10	93.67%	93.86%
115	7.25	9.01	0.751	6.82	25	93.97%	
115	14.44	9.01	1.501	13.57	50	93.99%	
115	21.66	9.01	2.250	20.32	75	93.82%	
115	28.92	9.01	3.001	27.09	100	93.66%	
230	3.03	9.01	0.301	2.76	10	91.30%	92.86%
230	7.40	9.01	0.750	6.81	25	92.04%	
230	14.66	9.01	1.501	13.57	50	92.59%	
230	21.77	9.00	2.250	20.30	75	93.24%	
230	28.92	9.00	3.001	27.06	100	93.56%	
264	3.07	9.01	0.301	2.76	10	90.10%	92.25%
264	7.47	9.01	0.751	6.82	25	91.28%	
264	14.78	9.01	1.500	13.57	50	91.77%	
264	21.89	9.01	2.250	20.32	75	92.83%	
264	29.06	9.00	3.001	27.06	100	93.11%	
CoC Tier 2, 4-pt average							85.42%
CoC Tier 2, 10%-load							75.86%

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	1.65	4.98	0.301	1.52	10	92.43%	92.30%
90	4.05	4.98	0.750	3.75	25	92.60%	
90	8.08	4.97	1.500	7.48	50	92.56%	
90	12.15	4.97	2.250	11.20	75	92.21%	
90	16.24	4.97	3.000	14.92	100	91.84%	
115	1.65	4.98	0.301	1.52	10	92.25%	92.57%
115	4.05	4.97	0.750	3.75	25	92.62%	
115	8.07	4.97	1.501	7.49	50	92.73%	
115	12.10	4.97	2.250	11.20	75	92.56%	
115	16.16	4.97	3.000	14.92	100	92.36%	
230	1.71	4.98	0.301	1.52	10	88.73%	91.03%
230	4.16	4.97	0.751	3.76	25	90.45%	
230	8.24	4.97	1.500	7.48	50	90.72%	
230	12.27	4.97	2.251	11.21	75	91.34%	
230	16.28	4.97	3.000	14.92	100	91.62%	
264	1.75	4.98	0.301	1.52	10	87.07%	90.11%
264	4.21	4.98	0.751	3.76	25	89.31%	
264	8.34	4.97	1.501	7.49	50	89.78%	
264	12.42	4.97	2.250	11.21	75	90.25%	
264	16.39	4.97	3.000	14.93	100	91.10%	
CoC Tier 2, 4-pt average							81.84%
CoC Tier 2, 10%-load							72.48%

3.3.7 Efficiency Typical Results

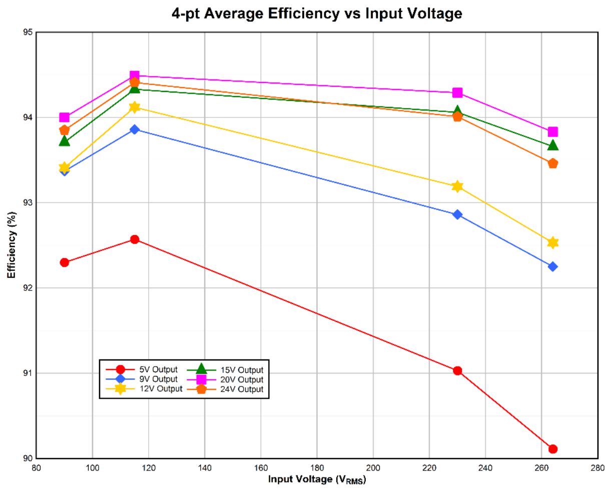


Figure 3-4. 4pt-Average Efficiency versus Input Voltage

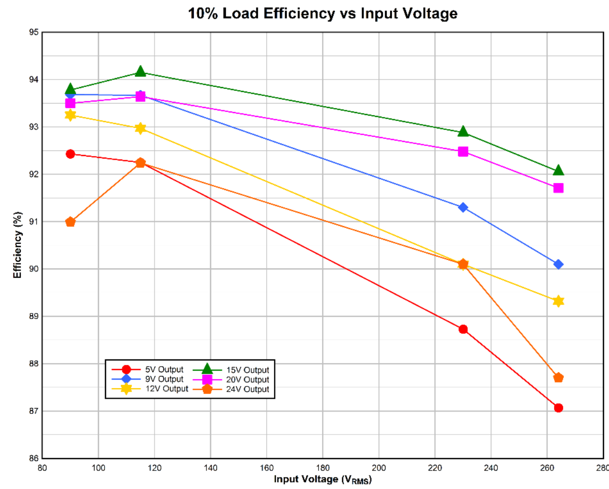


Figure 3-5. Efficiency of 10%-Load vs. Input Voltage

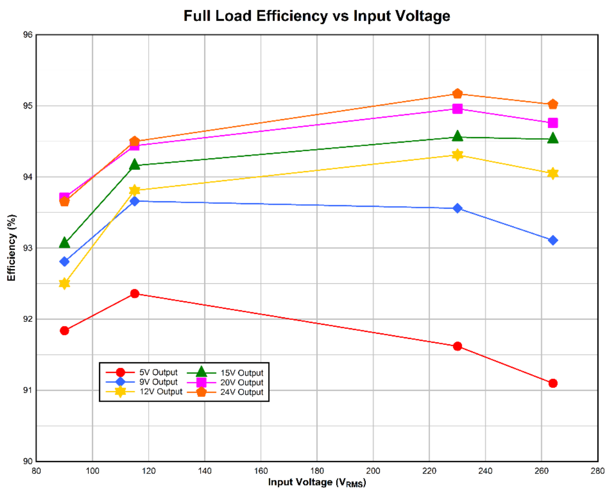


Figure 3-6. Full-load Efficiency versus Input Voltage

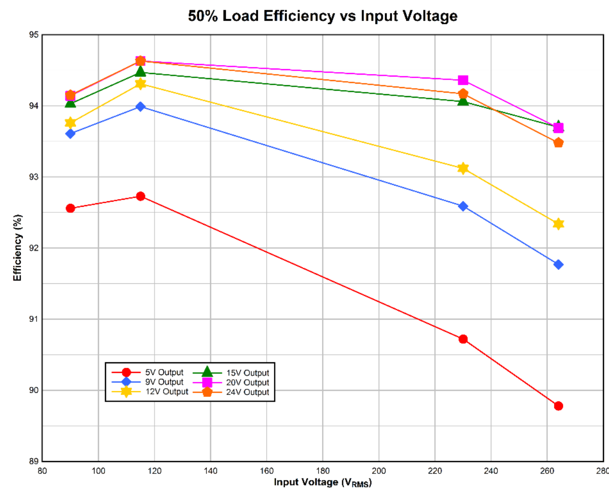


Figure 3-7. Efficiency of 50%-load versus Input Voltage

3.3.8 Output Characteristics

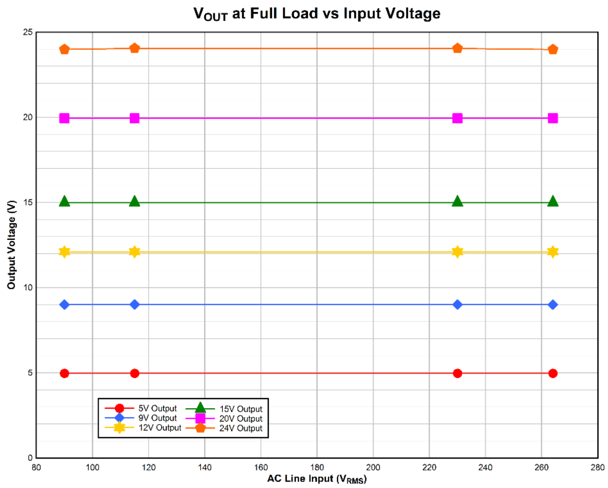


Figure 3-8. V_{OUT} at Full-Load versus Input Voltage

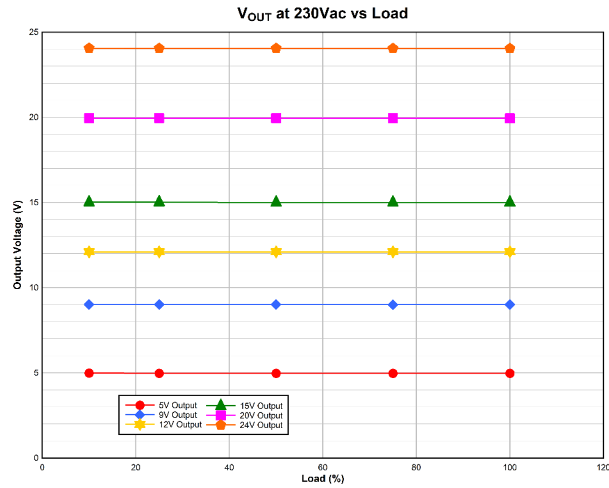


Figure 3-9. V_{OUT} versus Output Current

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.

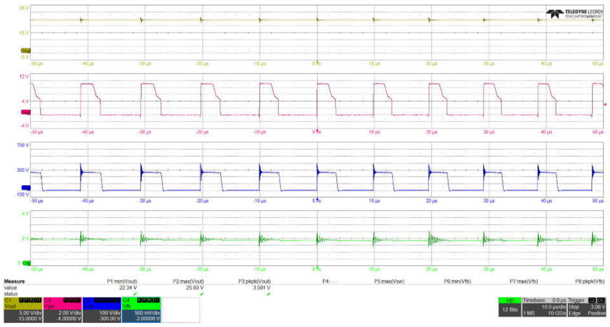


Figure 3-10. Vin = 90Vac, Vout = 24V

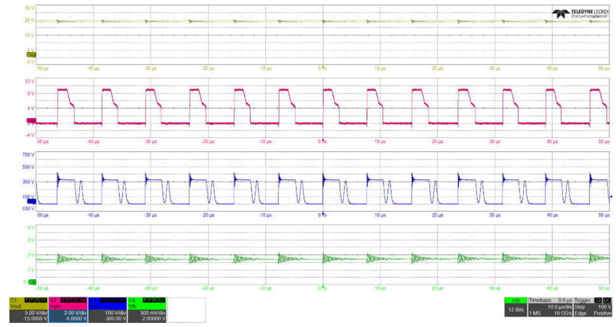


Figure 3-11. Vin = 115Vac, Vout = 24V

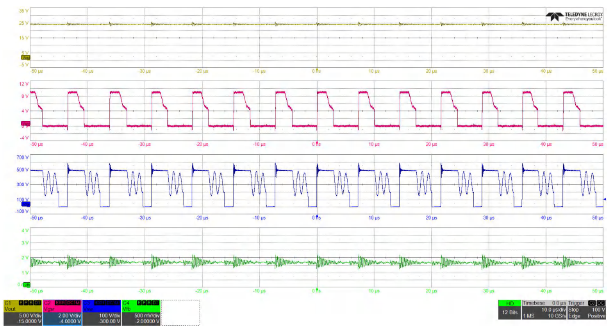


Figure 3-12. Vin = 230Vac, Vout = 24V

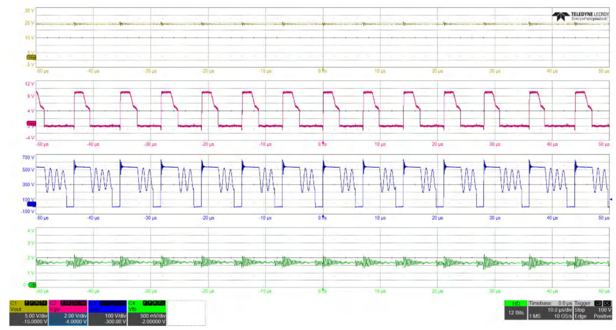


Figure 3-13. Vin = 264Vac, Vout = 24V

Figure 3-14. Vin = 90Vac, Vout = 20V

Figure 3-15. Vin = 115Vac, Vout = 20V

Figure 3-16. Vin = 230Vac, Vout = 20V

Figure 3-17. Vin = 264Vac, Vout = 20V

Figure 3-18. Vin = 90Vac, Vout = 15V

Figure 3-19. Vin = 115Vac, Vout = 15V

Figure 3-20. Vin = 230Vac, Vout = 15V

Figure 3-21. Vin = 264Vac, Vout = 15V

Figure 3-22. Vin = 90Vac, Vout = 12V

Figure 3-23. Vin = 115Vac, Vout = 12V

Figure 3-24. Vin = 230Vac, Vout = 12V

Figure 3-25. Vin = 264Vac, Vout = 12V

Figure 3-26. Vin = 90Vac, Vout = 9V

Figure 3-27. Vin = 115Vac, Vout = 9V

Figure 3-28. Vin = 230Vac, Vout = 9V

Figure 3-29. Vin = 264Vac, Vout = 9V

Figure 3-30. Vin = 90Vac, Vout = 5V

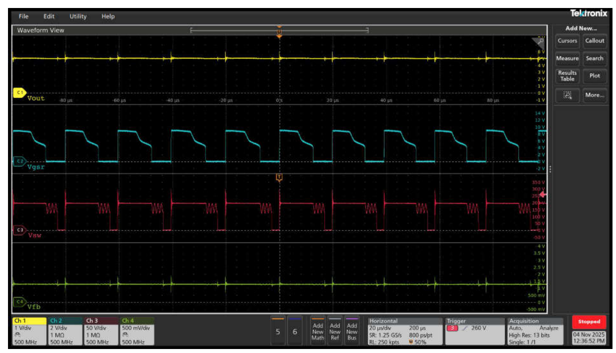


Figure 3-31. Vin = 115Vac, Vout = 5V

Figure 3-32. Vin = 230Vac, Vout = 5V

Figure 3-33. Vin = 264Vac, Vout = 5V

3.3.10 Switching Frequency versus Load

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

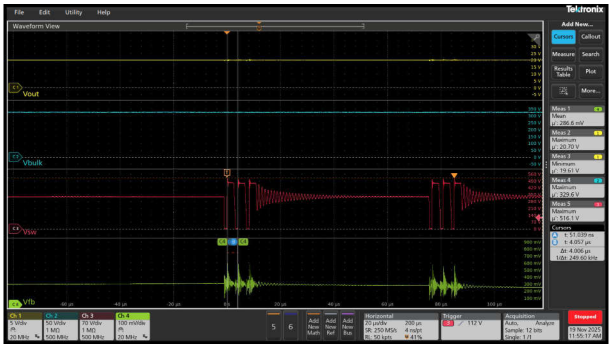


Figure 3-34. 230Vac/1W (250khz Burst Frequency/ Vfb - 0.29V)

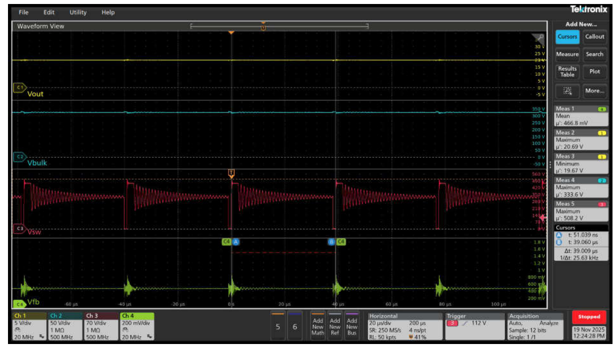


Figure 3-35. 230Vac/4.3W (25kHz Switching Frequency/ Frequency - Foldback Mode/ Vfb - 0.47V)

Figure 3-36. 230Vac/12W (68kHz Frequency/ Vfb - 0.76V)

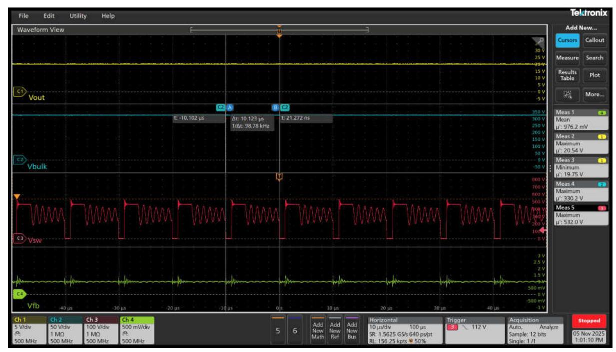


Figure 3-37. 230Vac/18W (99kHz Frequency/ Vfb - 0.98V)

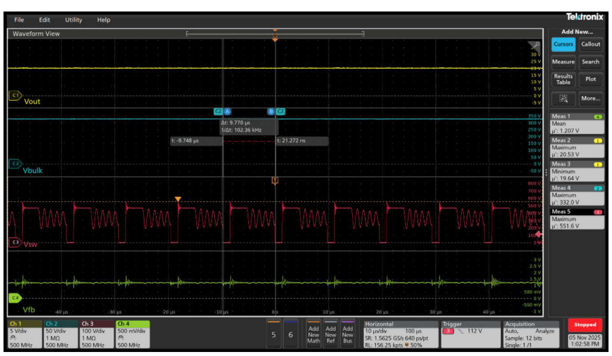


Figure 3-38. 230Vac/30W (102kHz Frequency/ Vfb - 1.21V)

Figure 3-39. 230Vac/45W (128kHz Frequency/ Vfb - 1.26V)

3.3.11 Output Ripple Voltage

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

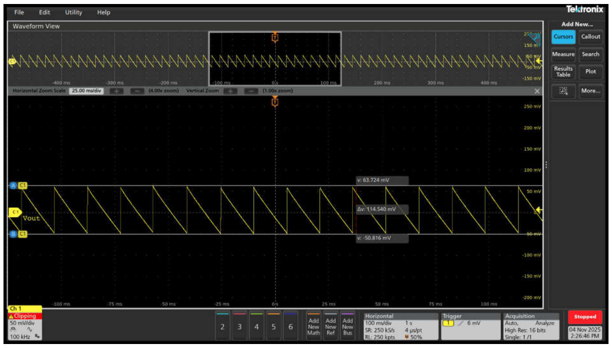


Figure 3-40. Typical Ripple Voltage of V_{OUT} = 5V at No Load (115mVpp)

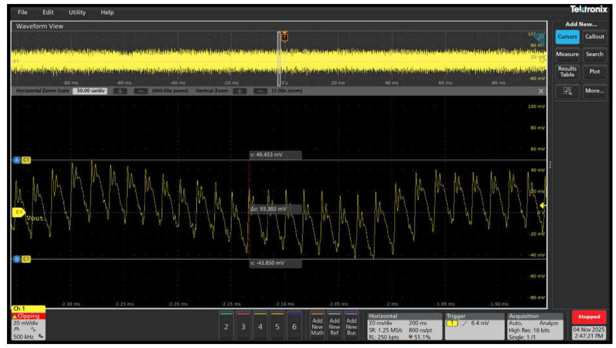


Figure 3-41. Typical Ripple Voltage of V_{OUT} = 5V at Full Load (93mVpp)

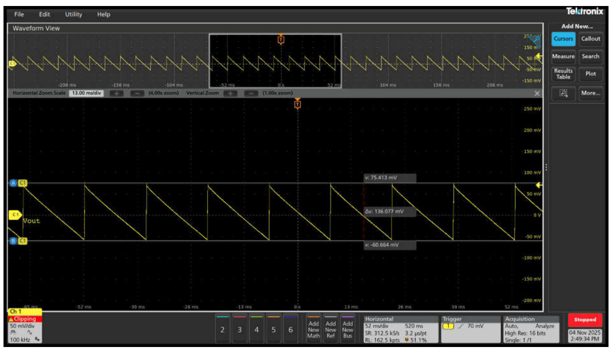


Figure 3-42. Typical Ripple Voltage of V_{OUT} = 9V at No Load (136mVpp)

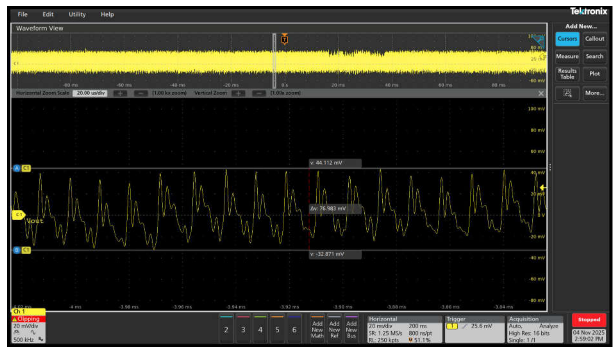


Figure 3-43. Typical Ripple Voltage of V_{OUT} = 9V at Full Load (77mVpp)

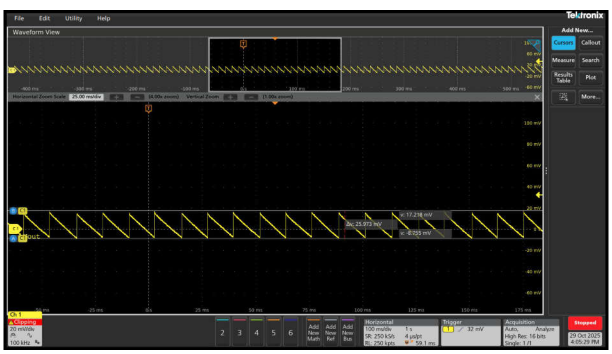


Figure 3-44. Typical Ripple Voltage of V_{OUT} = 12V at No Load (26mVpp)

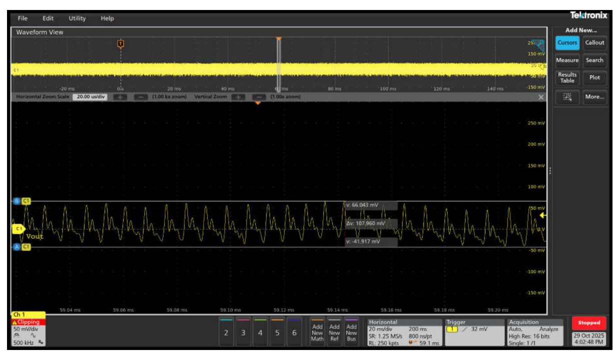


Figure 3-45. Typical Ripple Voltage of V_{OUT} = 12V at Full Load (108mVpp)

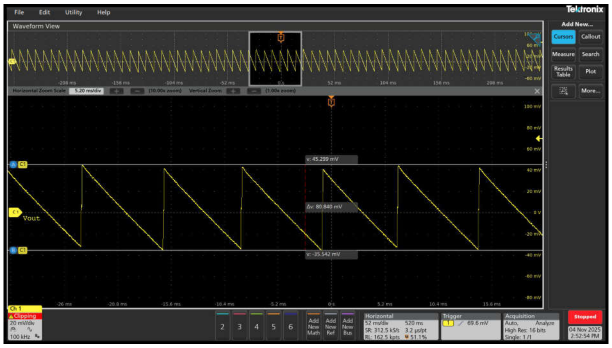


Figure 3-46. Typical Ripple Voltage of V_{OUT} = 15V at No Load (89mVpp)

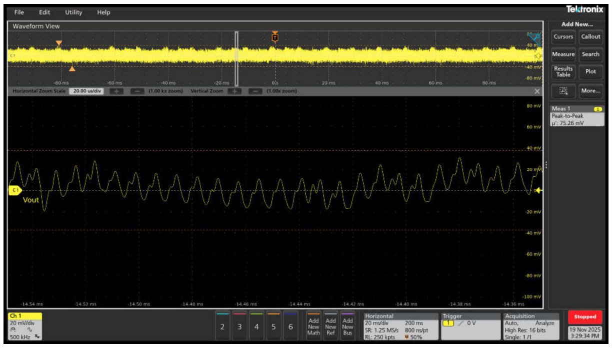


Figure 3-47. Typical Ripple Voltage of V_{OUT} = 15V at Full Load (75mVpp)

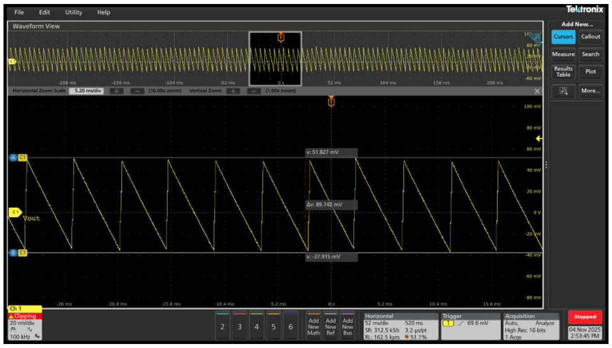


Figure 3-48. Typical Ripple Voltage of V_{OUT} = 20V at No Load (90mVpp)

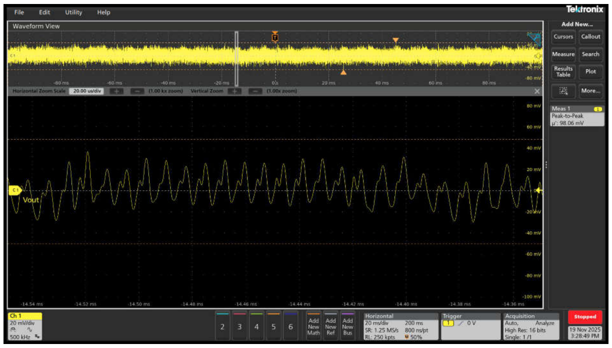


Figure 3-49. Typical Ripple Voltage of V_{OUT} = 20V at Full Load (98mVpp)

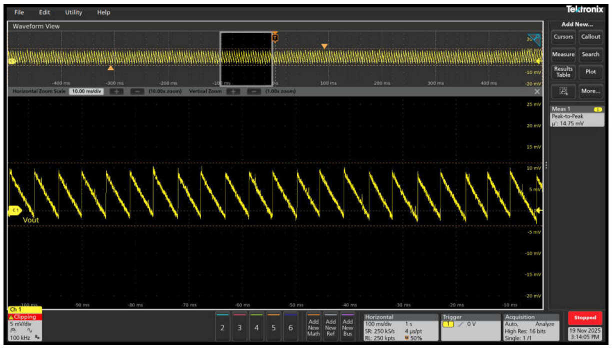


Figure 3-50. Typical Ripple Voltage of V_{OUT} = 24V at No Load (15mVpp)

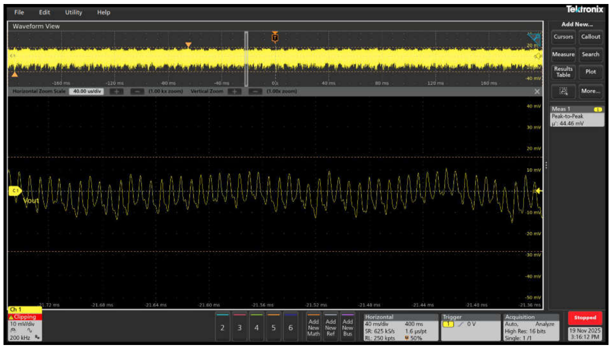


Figure 3-51. Typical Ripple Voltage of V_{OUT} = 24V at Full Load (45mVpp)

3.3.12 Load Transient Response

This section presents the switching waveforms under load transient condition. Here, the load current step change is between 0% and 100%, at 100Hz rate at 2.5A/µs.

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

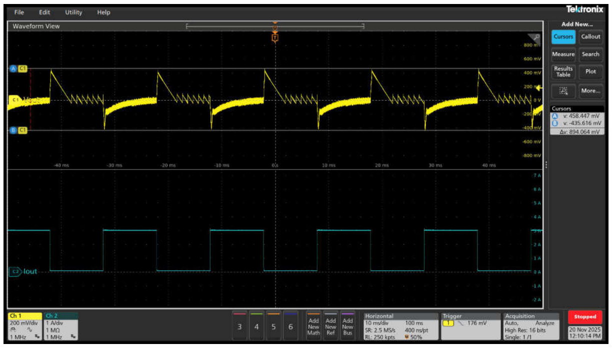


Figure 3-52. Load Transient Response at V_{OUT} = 5V Overshoot / Undershoot = 460mV / -440mV

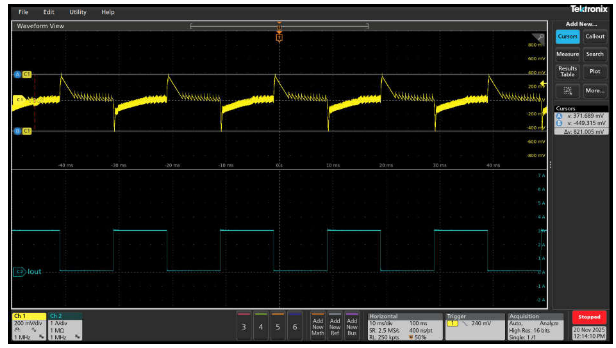


Figure 3-53. Transient Response at V_{OUT} = 9V Overshoot / Undershoot = 380mV / -450mV

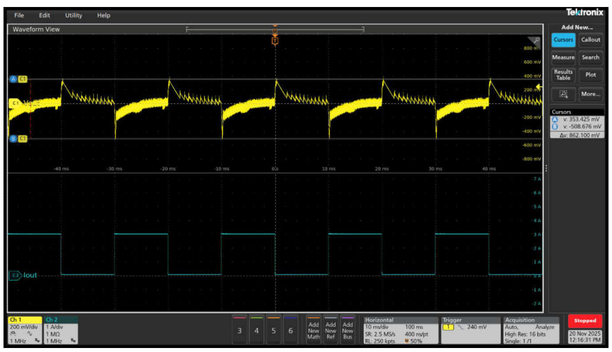


Figure 3-54. Transient Response at V_{OUT} = 15V Overshoot / Undershoot = 360mV / -510mV

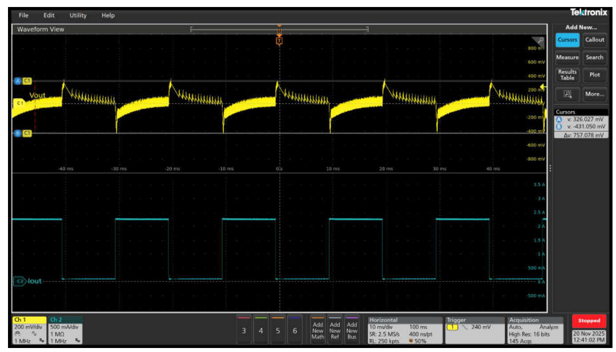


Figure 3-55. Transient Response at V_{OUT} = 20V Overshoot / Undershoot = 330mV / -440mV

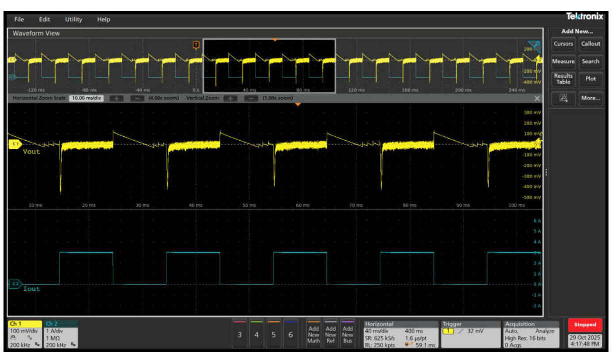


Figure 3-56. Transient Response at V_{OUT} = 12V Overshoot / Undershoot = 120mV / -410mV

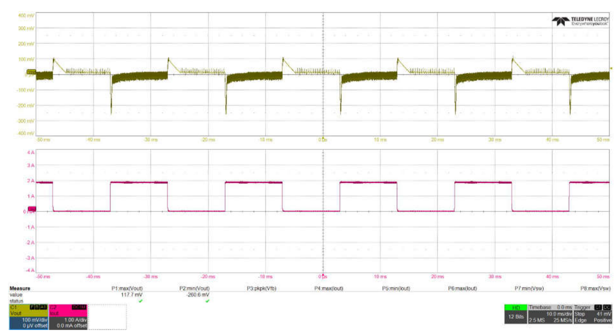


Figure 3-57. Transient Response at V_{OUT} = 24V Overshoot / Undershoot = 120mV / -260mV

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 19.2V when peak short term overload of 5.1A is applied for 1ms. The output voltage drops to 19.3V when peak short term overload of 4.5A is applied for 2ms. The results are checked at 90Vac. Ch1 - Output Voltage, Ch2 - Output Current, Ch3 - Switch Node Voltage, Ch4 - Feedback Pin Voltage.

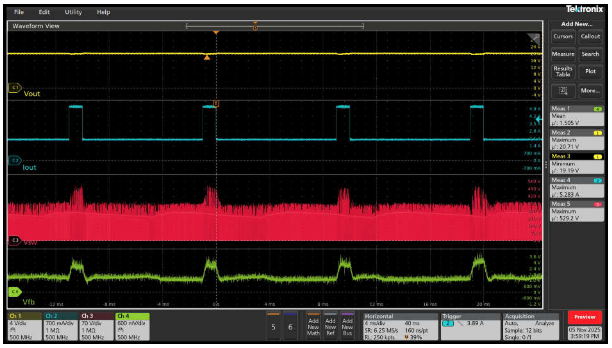


Figure 3-60. VIN=90Vac (2.25x Rated Current for 1ms, 0.9x Rated Current for 9ms)

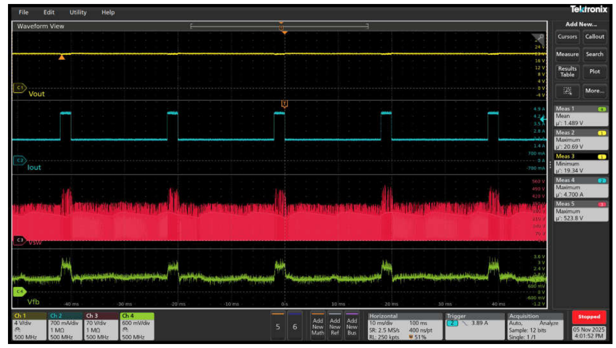


Figure 3-61. VIN=90Vac (2x Rated Current for 2ms, 0.9x Rated Current for 18ms)

3.3.15 CCM operation

This section presents the switching waveforms under the CCM operation at 90Vac with 4.5A 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 CISPR32 Class B Conducted EMI Test Result

Please note 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.

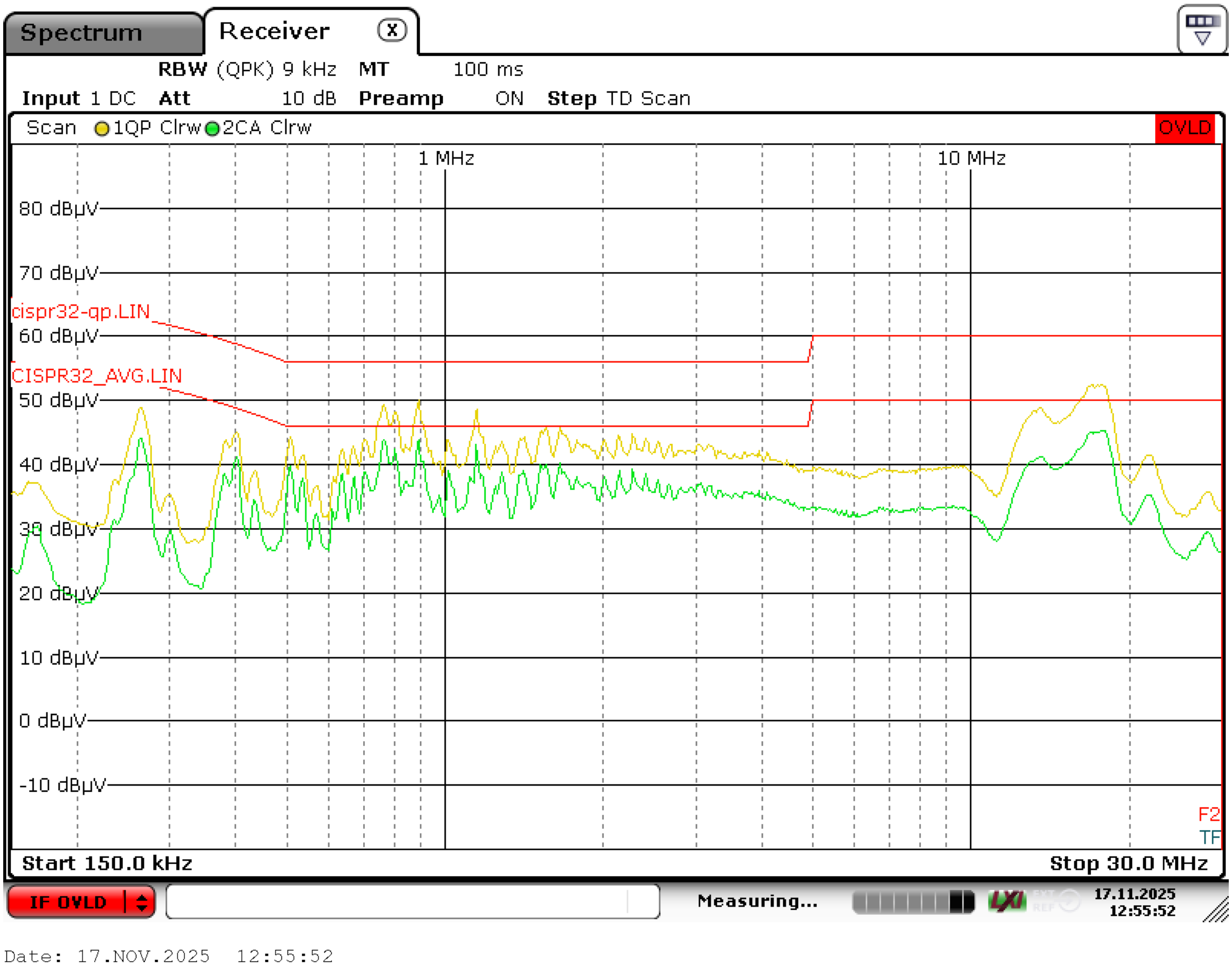


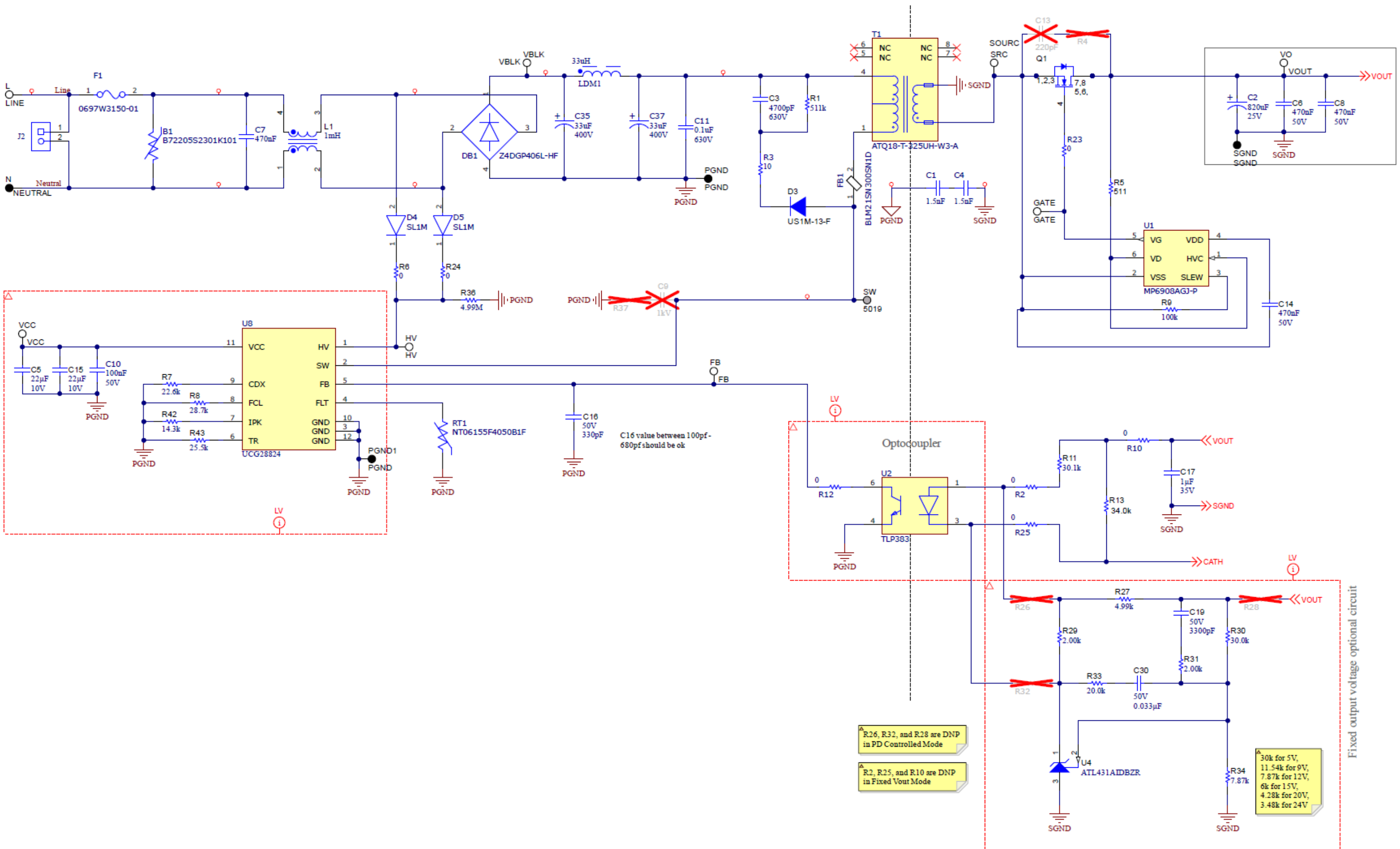
Figure 3-64. VIN = 230V_{RMS}, VOUT = 20V, Load = 3.25A (SGND is Not Connected to LISN Ground)

4 Hardware Design Files

4.1 Schematics

The schematic of the UCG28824EVM-124 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 zero ohm 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 the formula...

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



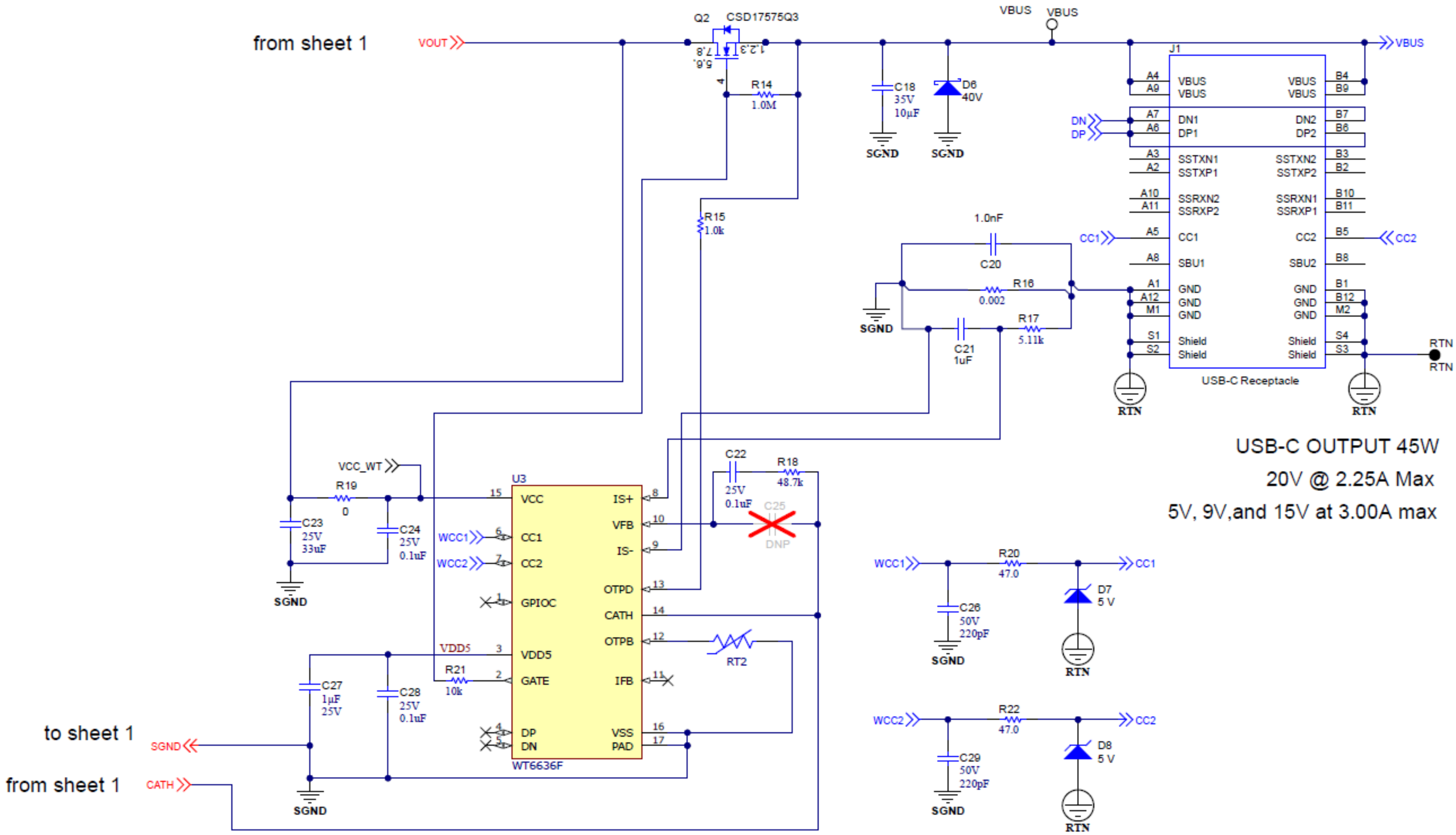


Figure 4-1. UCG28824EVM-124 Circuit Schematic

4.2 PCB Layouts

UCG28824EVM-124 uses two layers PCB. The screenshots of the layout of each layer are shown below.

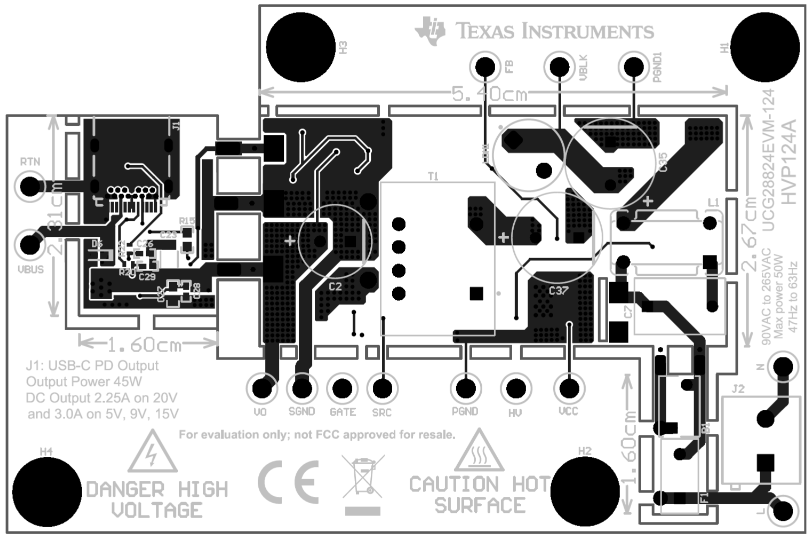


Figure 4-2. Top Layer

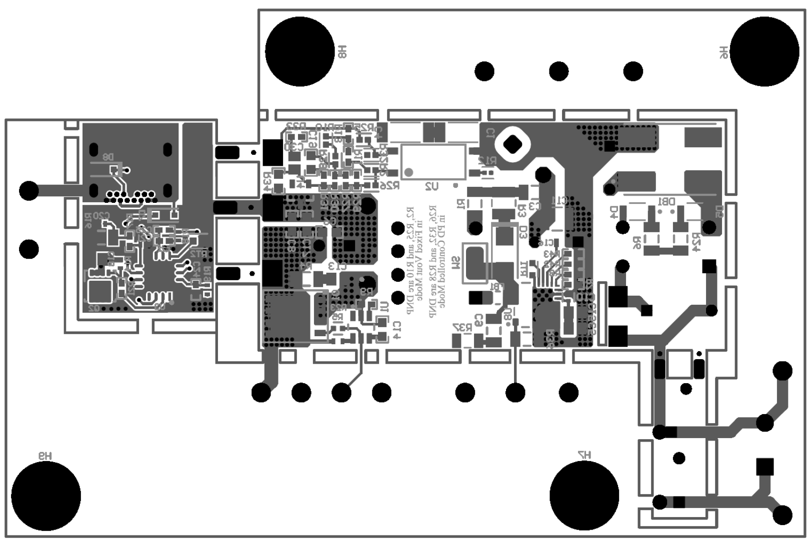


Figure 4-3. Bottom Layer

4.3 Transformer Details

This design uses ATQ18-T-325UH-W3-A transformer from 3L Coils and the specifications are mentioned below.

4.3.1 ATQ18-T-325UH-W3-A

The details of the ATQ18-T-325UH-W3-A are given below.

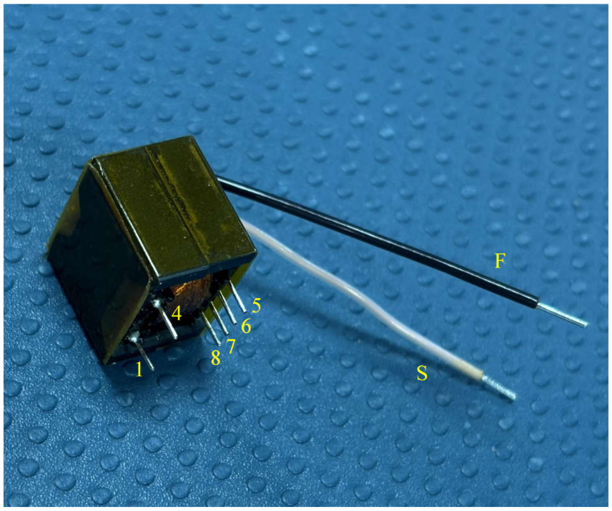


Figure 4-4. Picture of the Transformer

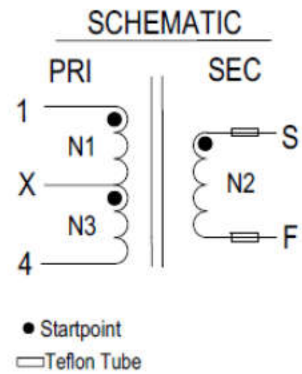


Figure 4-5. Schematic of the Transformer

Table 4-1. Transformer Specifications at 25°C

PARAMETER	TYPICAL VALUE	PINS/LEADS	TEST CONDITIONS
Inductance (µH)	325, ± 10%	1 – 4	Open all other pins, 100kHz / 0.25Vac
Leakage Inductance (µH)	6.73	1 – 4	Short S - F, 100kHz / 0.25Vac
D.C. resistance (Ω)	0.255	1 – 4	
D.C. resistance (Ω)	0.017 Max.	S – F	
Dielectric (VAC, 60Hz)	3000Vac	1– S	3mA, 50Hz, 3s
Turns-ratios	7:1	(1-4):(S-F)	

4.4 Bill of Materials

This section presents the bill of materials for UCG28824EVM-124.

Table 4-2. Bill of Materials

Designator	Value	Quantity	Description	Part Number	Manufacturer
B1	470V	1	470 V 800 A Varistor Through Hole Disc 5mm	B72205S2301K101	EPCOS
C1, C4	1.5nF	2	1500 pF ±10% 250VAC Ceramic Capacitor X7R 1808 (4520 Metric)	1808YA250152KJTSYX	Knowles
C2	820uF	1	820uF 25V ±20% Plugin,D8xL14mm Aluminum Electrolytic Capacitors	NPXD1401E821MF	Ymin
C3	4.7nF	1	CAP, CERM, 4700 pF, 630V,+/- 5%, C0G/NP0, 1206	CGA5F4C0G2J472J085AA	TDK
C5, C15	22uF	2	CAP, CERM, 22uF, 10 V, +/- 20%, X7R, 0805	GRM21BZ71A226ME15L	Murata
C6, C8, C14	470nF	3	CAP, CERM, 0.47uF, 50V, +/- 10%, X7R, 0603	C1608X7R1H474K080AC	TDK
C7	470nF	1	470nF ±10% 310Vac X2 Plugin, P=7.5mm Safety Capacitors	MPX474K31B9KN20600	KNSCHA
C10	100nF	1	CAP, CERM, 100nF 50V X7R ±10% 0402	GRT155R71H104KE01D	Murata
C11	100nF	1	CAP, CERM, 0.1uF, 630V, +/- 10%, X7R, 1210	C1210C104KBRACTU	KEMET
C16	330pF	1	CAP, CERM, 330pF, 50V, +/- 5%, C0G/NP0, 0603	885012006060	Wurth Elektronik
C17	1uF	1	CAP, CERM, 1 uF, 35 V, +/- 10%, X7R, 0603	CGA3E1X7R1V105K080AC	TDK
C18	10uF	1	CAP, CERM, 10 µF, 35 V,+/- 10%, X5R, 0805	GMK212BBJ106KG-T	Taiyo Yuden
C19	3.3nF	1	CAP, CERM, 3300 pF, 50 V, +/- 5%, C0G/NP0, 0603	GRM1885C1H332JA01D	Murata
C20	1nF	1	CAP, CERM, 1000 pF, 50 V, +/- 10%, X7R, 0402	885012205061	Wurth Elektronik
C21	1uF	1	CAP, CERM, 1 uF, 6.3 V, +/- 20%, X7R, 0402	GRM155R70J105MA12D	Murata
C22	100nF	1	CAP, CERM, 0.1 uF, 25 V, +/- 10%, X7R, 0402	GRM155R71E104KE14D	Murata
C23	33uF	1	CAP, CERM, 33 uF, 25 V, +/- 20%, X5R, 1206	C3216X5R1E336M160AC	TDK
C24, C28	100nF	2	CAP, CERM, 0.1 uF, 25 V, +/- 10%, X7R, 0402	GRM155R71E104KE14D	Murata
C26, C29	220pF	2	CAP, CERM, 220 pF, 50 V, +/- 10%, X7R, 0402	GRM155R71H221KA01D	Murata
C27	1uF	1	CAP, CERM, 1 uF, 25 V, +/- 10%, X7R, 0603	GCM188R71E105KA64D	Murata
C30	33nF	1	CAP, CERM, 0.033 µF, 50 V,+/- 5%, C0G/NP0, 0805	CGA4J2C0G1H333J125AA	TDK

Table 4-2. Bill of Materials (continued)

Designator	Value	Quantity	Description	Part Number	Manufacturer
C35, C37	33uF	2	33uF 400V 500mΩ@100kHz 370mA@100kHz ±20% Plugin,D10xL15mm Aluminum Electrolytic Capacitors	87EC0493	KNSCHA
D3	1000V	1	Diode, Ultrafast, 1000 V, 1 A, SMA	US1M-13-F	Diodes Inc.
D4, D5	800V	2	Diode 800 V 1A Surface Mount SOD-123FL	SL1K	Diotec
D6	40V	1	Diode, Schottky, 40 V, 0.2 A, SOD-523	RB521SM-40T2R	ROHM
D7, D8	5.1V	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	Z4DGP406L-HF	Comchip
F1	3.15A	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, L, SRC, VBLK, VBUS, VCC, VO		9	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
H6, H7, H8, H9		4	Standoff, Hex, 0.5	1902C	Keystone
J1	USB-C Receptacle	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.
L1	1mH	1	Coupled inductor, 1 mH, 2 A, 0.045 ohm, TH	744821201	Wurth Elektronik
LDM1	33uH	1	WE-TI Radial Leaded Wire Wound Inductor, size 8095, 33uH, 2.5A, 0.066Ohm	7447720330	Wurth Elektronik
N, PGND, PGND1, RTN, SGND		5	Test Point, Multipurpose, Black, TH	5011	Keystone
Q1	150V	1	MOSFET, N-CH, 150 V, 87 A, PG-TDSON-8	BSC093N15NS5ATMA1	Infineon Technologies
Q2	30V	1	MOSFET, N-CH, 30 V, 60 A, DQG0008A (VSON-CLIP-8)	CSD17575Q3	Texas Instruments
R1	511k	1	RES, 511 k, 1%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW1206511KFKEA	Vishay/Dale
R2, R10, R12, R23, R25	0	5	RES Thick Film, 0, 0.2W, 0402	CRCW04020000Z0EDHP	Vishay
R3	10	1	10 ±5% 0.5W 1210 Thick Film Chip Resistor AEC-Q200 compliant	RMCF1210JT10R0	Stackpole Electronics
R5	511	1	RES, 511, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW0402511RFKED	Vishay Dale

Table 4-2. Bill of Materials (continued)

Designator	Value	Quantity	Description	Part Number	Manufacturer
R6, R24	0	2	RES, 0, 5%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW12060000Z0EA	Vishay/Dale
R7	22.6	1	RES, 22.6 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040222K6FKED	Vishay Dale
R8	28.7	1	RES, 28.7 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040228K7FKED	Vishay Dale
R9	100k	1	RES, 100 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW0402100KFKED	Vishay / Dale
R11	30.1k	1	RES, 30.1 k, 1%, 0.063 W, 0402	CRCW040230K1FKED	Vishay Dale
R13	34k	1	RES, 34.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040234K0FKED	Vishay Dale
R14	1Meg	1	RES, 1.0 M, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04021M00JNED	Vishay Dale
R15	1k	1	RES, 1.0 k, 5%, 0.25 W, AEC-Q200 Grade 0, 0603	ESR03EZPJ102	ROHM
R16	0.002	1	RES, 0.002, 1%, 1 W, 1206	CSNL1206FT2L00	Stackpole Electronics Inc
R17	5.11k	1	RES, 5.11 k, 1%, 0.063 W, 0402	CRCW04025K11FKED	Vishay Dale
R18	48.7k	1	RES, 48.7 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040248K7FKED	Vishay Dale
R19	0	1	RES, 0, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04020000Z0ED	Vishay / Dale
R20, R22	47	2	RES, 47.0, 1%, 0.063 W, 0402	RK73H1ETTP47R0F	KOA Speer
R21	10k	1	RES, 10 k, 5%, 0.063 W, 0402	CRCW040210K0JNED	Vishay / Dale
R27	4.99k	1	RES, 4.99 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04024K99FKED	Vishay Dale
R29, R31	2.00k	2	RES, 2.00 k, 0.1%, 0.063 W, 0402	RG1005P-202-B-T5	Susumu
R30	30k	1	RES, 30.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040230K0FKED	Vishay
R33	20.0k	1	RES, 20.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040220K0FKED	Vishay / Dale
R34	7.87k	1	RES, 7.87 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06037K87FKEA	Vishay / Dale
R36	4.99k	1	RES, 4.99 M, 1%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW12064M99FKEA	Vishay/Dale
R42	14.3k	1	RES, 14.3 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040214K3FKED	Vishay / Dale
R43	25.5k	1	RES, 25.5 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040225K5FKED	Vishay / Dale
RT1	150k	1	NTC Thermistor 150k 0603 (1608 Metric)	NT06155F4050B1F	Eaton
RT2	220k	1	Thermistor NTC, 220k ohm, 5%, 0603	ERT-J1VT224J	Panasonic
SW		1	Test Point, Miniature, SMT	5019	Keystone
T1		1	Flyback Transformer	ATQ18-T-325UH-W3-A	3L Coil

Table 4-2. Bill of Materials (continued)

Designator	Value	Quantity	Description	Part Number	Manufacturer
U1		1	FAST TURN-OFF INTELLIGENT RECTIF	MP6908GJ-Z	Monolithic Power Systems Inc.
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	2.5V Low Iq Adjustable Precision Shunt Regulator, DBZ0003A (SOT-23-3)	ATL431AIDBZR	Texas Instruments
U8		1	Self-Biased High Frequency QR Flyback Converter With Integrated GaN	UCG28824-1REZR	Texas Instruments

5 Additional Information

Trademarks

USB-C® is a registered 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

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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/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.

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