EVM User's Guide: UCG28826EVM-093

Using the UCG28826EVM-093 65W High-Density GaN Integrated Quasi-Resonant Flyback Converter

TEXAS INSTRUMENTS

Description

The UCG28826EVM-093 is a 65W evaluation module (EVM) for evaluating an off-line GaN integrated quasi-resonant flyback adapter 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 UCG28826EVM-093 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 up to 15V_{DC} and 65W 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 UCG28826 with integrated 650V GaN FET and controller in 5mm × 5mm package.

Get Started

1. Read and study this user's guide completely before evaluating
2. Order the UCG28826EVM-093 for evaluation if step 1 met
3. Setup and test the UCG28826EVM-093 per user's guide instructions

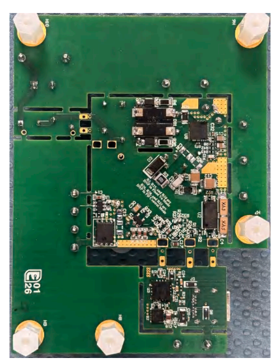
Features

- 93-95% efficiency under full-load operation over entire input voltage range
- 2.8W/cm^3 (3.9cm x 3.43cm x 1.71cm) power density enabled by 140kHz maximum switching frequency
- Self-bias and auxless-sense, integrated current sense, integrated HV startup and integrated X-cap discharge enable lowest BOM cost by integration
- Comprehensive protection features including OVP, OTP, short circuit, overcurrent protection and brown-in/out protection
- USB-C output enables full system-level evaluation for end-equipments like adapters, notebook chargers, 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

Figure 1-1. UCG28826EVM-093 (Top View)



UCG28826EVM-093 (Bottom View)

1 Evaluation Module Overview

1.1 Introduction

The UCG28826EVM-093 facilitates the evaluation of UCG28826, 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. This user guide provides a high-voltage safety overview, recommended test setup, resulting efficiency results, thermals, waveforms, and conducted EMI performance.

1.2 Kit Contents

- 65W USB-C QR Flyback Evaluation Module
- Quick Start Guide
- High Voltage Notice

1.3 Specification

<table>
<tr><th>Input</th><th>Controller Configuration</th><th>Output</th><th>Max Output Power</th></tr>
<tr><td rowspan="2">90VAC-264VAC
47-63Hz</td><td>USB-C PD</td><td>20V/3.25A, 15V/3.00A, 9V/3.00A, 5V/3.00A</td><td rowspan="2">65W</td></tr>
<tr><td>Fixed output voltage</td><td>5V to 15V/3A and >15V to 24V/65W</td></tr>
</table>

1.4 Device Information

The UCG28826 is a high frequency, quasi-resonant (QR) AC/DC flyback converter with integrated 650V primary-side GaN FET suitable for use in power supplies up to 65W without PFC and 120W with a PFC front-end. This device gives the benefit of GaN integration to achieve high power density designs with high switching frequency, up to 500kHz. The UCG28826 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 its associated losses to generate the device bias. The UCG28826 supports continuous conduction mode (CCM) operation for upto 4ms for transient output power of up to 130W (two times the 65W nominal output power) at low-line input 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 1s to prevent the user from an electric shock at the time of unplugging the power supply from the wall socket. The UCG28826 overcomes the system design limitations of integrated converters by offering resistor programmable options for maximum flexibility to the user to optimize performance at the desired operating point. The device also includes many in-built protections such as 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 maintain 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. The EVM 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 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 and 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 Lucite 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 Using the EVM on a Load with USB-C PD Communication

UCG28826EVM-093 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.

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

UCG28826EVM-093 can be reconfigured to produce fixed output voltage in the range 5V-24V when evaluating with a non-USB-C PD load. The corresponding test setup diagram is shown in Section 3.2.2 . UCG28826EVM-093 comes with USB-C PD control mode as default controller configuration. 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 5V-15V output and 45W rated power at 15V-24V output.

3 Implementation Results

3.1 Electrical Performance Specifications

Table 3-1. UCC28826EVM-093 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		10/26		mW
$P_{0.18W}$	Input power at 0.18W load	V_{IN} = 230V_{RMS}, V_{OUT} = 5V, P_{OUT} = 180mW, USB-C PD controller enabled		270		mW
$P_{0.3W}$	Input power at 0.3W load	V_{IN} = 230V_{RMS}, V_{OUT} = 5V, P_{OUT} = 300mW, USB-C PD controller enabled		400		mW
OUTPUT CHARACTERISTICS						
V_{OUT}	Output voltage V_{IN} = 90 to 264V_{RMS}	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		
		I_{OUT} = 0 to 3.00A, USB- PD controller enabled		15		
		I_{OUT} = 0 to 3.00A, fixed V_{OUT} controller enabled		12		
		I_{OUT} = 0 to 3.00A, USB- PD controller enabled		9		
		I_{OUT} = 0 to 3.00A, USB- PD controller enabled		5		
I_{OUT}	Full load rated output current V_{IN} = 90 to 264V_{RMS}	V_{OUT} = 24.0V		2.71		A
		V_{OUT} = 20.0V		3.250		
		V_{OUT} = 5.0, 9.0, 12.0 or 15.0V		3.000		
V_{OUT_pp}	Output ripple voltage at V_{IN} = 115V / 230V_{RMS}	V_{OUT} = 24.0V, I_{OUT} = 0 to 2.71A		58.62		mV pp
		V_{OUT} = 20.0V, I_{OUT} = 0 to 3.25A		90.48		
		V_{OUT} = 15.0V, I_{OUT} = 0 to 3.00A		114		
		V_{OUT} = 12.0V, I_{OUT} = 0 to 3.00A		99.97		
		V_{OUT} = 9.0V, I_{OUT} = 0 to 3.00A		87.22		
		V_{OUT} = 5.0V, I_{OUT} = 0 to 3.00A		87.92		
V_{OUT_Δ}	Output voltage deviation due to load step Up / Down (I_{OUT} step change between 0 and 100% load at 100Hz rate)	V_{OUT} = 24.0V		-463/251		mV pp
		V_{OUT} = 20.0V		-660 / 500		
		V_{OUT} = 15.0V		-520 / 480		
		V_{OUT} = 12.0V		-462/261		
		V_{OUT} = 9.0V		-490 / 460		
		V_{OUT} = 5.0V		-480 / 450		
P_{OUT_opp}	Over-power protection threshold	V_{IN} = 90 to 264V_{RMS}		100		W

Table 3-1. UCC28826EVM-093 Electrical Performance Specifications (continued)

PARAMETER		TEST CONDITIONS	MIN	NOM	MAX	UNIT
SYSTEMS CHARACTERISTICS						
η	Full-load efficiency (V_{IN}= 115/230V_{RMS})	V_{OUT} = 24V, I_{OUT} = 2.71A		94.23/94.40		%
		V_{OUT} = 20V, I_{OUT} = 3.25A		94.08/ 94.63		
		V_{OUT} = 15V, I_{OUT} = 3.00A		93.88 / 94.31		
		V_{OUT} = 12V, I_{OUT} = 3.00A		94.24/93.06		
		V_{OUT} = 9V, I_{OUT} = 3.00A		93.66/ 93		
		V_{OUT} = 5V, I_{OUT} = 3.00A		92.8 / 91.67		
η	4-point average efficiency(1) V_{IN}= 115/230V_{RMS}	V_{OUT} = 24V (CoC Tier 2, 89.0%)		93.67/92.00		%
		V_{OUT} = 20V (CoC Tier 2, 89.0%)		94.14 / 93.85		
		V_{OUT} = 15V (CoC Tier 2, 88.9%)		94.15 / 92.95		
		V_{OUT} = 12V (CoC Tier 2, 88.3%)		93.88/91.18		
		V_{OUT} = 9V (CoC Tier 2, 87.3%)		93.6 / 91.64		
		V_{OUT} = 5V (CoC Tier 2, 81.8%)		92.28 / 89.23		
η	Efficiency at 10% Load V_{IN}= 115/230 V_{RMS}	V_{OUT} = 24V (CoC Tier 2, 79.0%)		91.87/87.66		%
		V_{OUT} = 20V (CoC Tier 2, 79.0%)		92.04 / 89.39		
		V_{OUT} = 15V (CoC Tier 2, 78.9%)		92.4 / 89.71		
		V_{OUT} = 12V (CoC Tier 2, 78.3%)		93.47/89.37		
		V_{OUT} = 9V (CoC Tier 2, 77.3%)		92.6 / 89.29		
		V_{OUT} = 5V (CoC Tier 2, 72.5%)		90.6 /86.64		
T_{AMB}	Ambient operating temperature range	V_{IN} = 90 to 264V_{RMS}, I_{OUT} = 0 to 3.00A (5V/9V/15V), or 3.25A (20V)		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. Also the 4 point efficiency numbers are measured with MP6951 for better 9V & 5V performance. MP6908 and MP6951 are pin to pin and can be swapped on the EVM.

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 capable of $264V_{RMS}$ 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 can 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

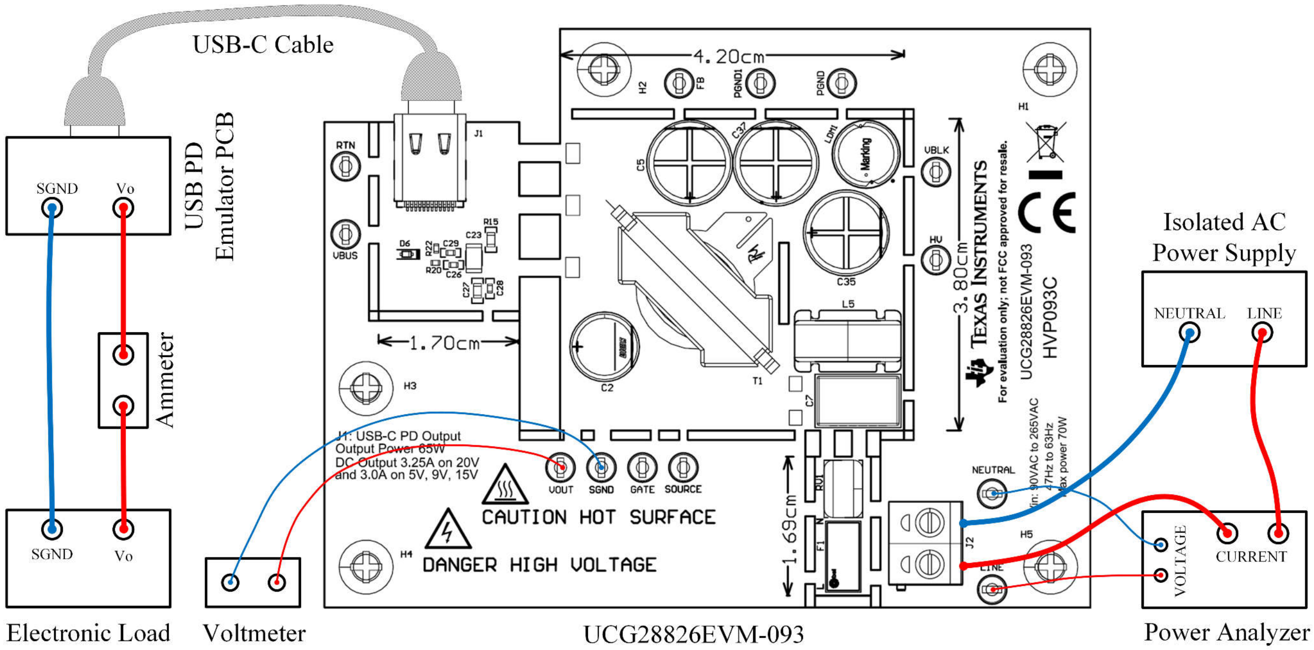


Figure 3-1. Test Setup Diagram of UCG28826EVM-093 Using a USB-C PD Load

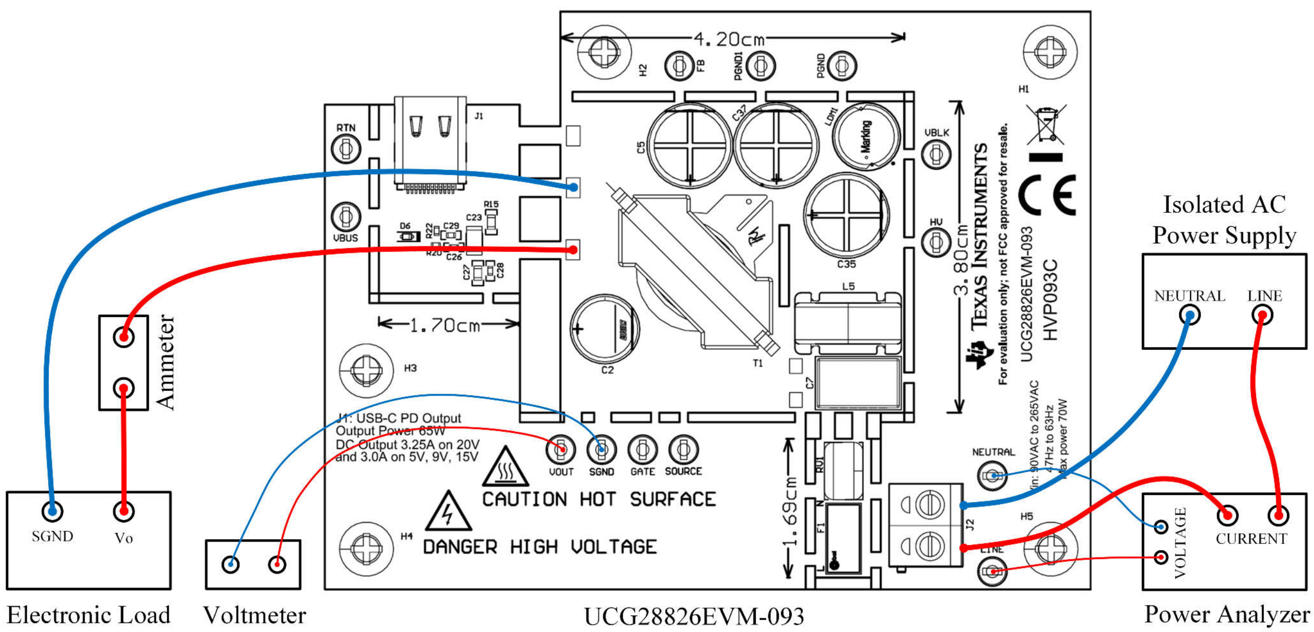
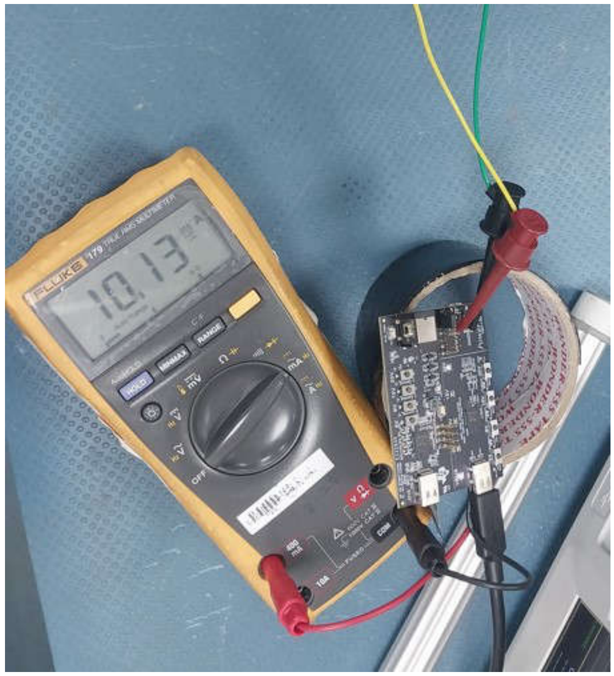


Figure 3-2. Test Setup Diagram of UCG28826EVM-093 Using a Non-USB-C PD Load

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 evaluation purpose. It is important to note that this EVM consumes close to 10mA of current and this 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
PGND, PGND1	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} (V_{RMS})	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{OUT} %	EFFICIENCY %	4-PT AVERAGE EFFICIENCY
90	69.78	24.02	2.708	65.05	100%	93.22%	93.38%
90	51.99	24.02	2.031	48.78	75%	93.84%	
90	34.64	24.03	1.354	32.54	50%	93.93%	
90	17.39	24.04	0.676	16.25	25%	93.46%	
90	7.05	24.05	0.271	6.52	10%	92.45%	
115	69.03	24.02	2.708	65.05	100%	94.23%	93.67%
115	51.72	24.02	2.031	48.78	75%	94.33%	
115	34.45	24.02	1.353	32.50	50%	94.33%	
115	17.36	24.04	0.676	16.25	25%	93.60%	
115	7.09	24.05	0.271	6.52	10%	91.87%	
230	68.80	24	2.706	64.94	100%	94.40%	92.00%
230	51.80	24	2.03	48.72	75%	94.05%	
230	34.90	24.02	1.353	32.50	50%	93.11%	
230	17.92	24,03	0.677	16.27	25%	90.76%	
230	7.43	24.04	0.271	6.51	10%	87.66%	
264	69.00	24	2.707	64.97	100%	94.16%	91.08%
264	52.10	24	2.03	48.72	75%	93.52%	
264	35.19	24.01	1.353	32.49	50%	92.30%	
264	18.18	24.03	0.676	16.24	25%	89.35%	
264	7.54	24.04	0.27	6.49	10%	86.05%	
CoC Tier 2, 4-pt average							89%
CoC Tier 2, 10%-load							79%

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_EMULATOR (W)	P_{out} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
89.88	71.2	20.09	3.264	65.64	0.204	100%	92.48%	93.29%
89.91	52.94	20.08	2.451	49.214	0.2	75%	93.34%	
89.94	35.25	20.03	1.636	32.777	0.2	50%	93.55%	
89.98	17.76	20	0.823	16.46	0.2	25%	93.81%	
90.03	7.359	19.99	0.331	6.6193	0.2	10%	92.66%	
114.91	70	20.09	3.265	65.65	0.203	100%	94.08%	94.26%
114.94	52.5	20.08	2.452	449.235	0.203	75%	94.17%	
114.96	34.9	20.03	1.636	32.778	0.2	50%	94.49%	
115	17.68	20	0.824	16.474	0.2	25%	94.31%	
115.04	7.409	19.99	0.331	6.62	0.199	10%	92.04%	
229.98	69.6	20.08	3.265	65.662	0.2	100%	94.63%	93.83%
230.01	52.27	20.07	2.452	49.235.	0.2	75%	94.58%	
230.01	35.06	20.02	1.636	32.778	0.2	50%	94.06%	
230.02	18.11	19.99	0.824	16.471	0.2	25%	92.05%	
230.08	7.63	19.98	0.331	6.6214	0.199	10%	89.39%	
264	69.71	20.08	3.266	65.684	0.2	100%	94.51%	93.29%
264	52.44	20.06	2.452	49235	0.2	75%	94.27%	
264	35.25	20.03	1.636	32.678	0.2	50%	93.53%	
264.02	18.35	20	0.824	16.475	0.2	25%	90.87%	
264.1	7.705	19.98	0.331	6.62	0.199	10%	88.5%	
CoC Tier 2, 4-pt average								89.0%
CoC Tier 2, 10%-load								79.0%

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_EMULATOR (W)	P_{out} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
89.92	49.08	15.11	3.009	45.525	0.15	100%	93.06%	93.77%
89.95	36.55	15.09	2.259	34.088	0.148	75%	93.67%	
89.97	24.23	15.04	1.512	22.735	0.148	50%	94.44%	
89.99	12.28	15.02	0.758	11.384	0.15	25%	93.93%	
90.03	5.098	15.00	0.305	4.5789	0.148	10%	92.71%	
114.94	48.65	15.12	3.009	45.525	0.148	100%	93.88%	94.16%
114.95	36.32	15.09	2.26	34.105	0.15	75%	94.32%	
114.98	24.23	15.05	1.512	22.737	0.15	50%	94.46%	
115	12.272	15.02	0.758	11.382	0.15	25%	93.97%	
115.04	5.115	15.00	0.305	4.5776	0.149	10%	92.4%	
230	48.43	15.13	3.009	45.527	0.148	100%	94.31%	92.98%
230	36.44	15.08	2.26	34.088	0.148	75%	93.95%	
230	24.61	15.03	1.512	22.742	0.148	50%	93.01%	
230.02	12.72	15.01	0.758	11.382	0.148	25%	90.64%	
230.09	5.268	15.00	0.305	4.5757	0.15	10%	89.71%	
264	48.62	15.11	3.009	45.52	0.15	100%	93.93%	92%
264	36.66	15.08	2.259	34.101	0.148	75%	93.42%	
264.02	24.81	15.04	1.512	22.735	0.148	50%	92.23%	
264.04	13.04	15.02	0.759	11.383	0.148	25%	88.43%	
264.08	5.339	15.00	0.305	4.5779	0.148	10%	88.52%	
CoC Tier 2, 4-pt average								88.9%
CoC Tier 2, 10%-load								78.9%

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

V_{IN} (V_{RMS})	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{OUT} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
90	38.46	12.01	3.000	36.03	100%	93.66%	93.68%
90	28.85	12.01	2.250	27.03	75%	93.69%	
90	19.18	12.02	1.500	18.02	50%	93.97%	
90	9.61	12.02	0.750	9.01	25%	93.82%	
90	3.87	12.02	0.300	3.61	10%	93.23%	
115	38.23	12.01	3.001	36.03	100%	94.24%	93.88%
115	28.67	12.01	2.250	27.02	75%	94.26%	
115	19.14	12.01	1.500	18.02	50%	94.12%	
115	9.66	12.02	0.750	9.01	25%	93.30%	
115	3.86	12.02	0.300	3.61	10%	93.47%	
230	38.70	12.00	3.001	36.02	100%	93.06%	91.18%
230	29.22	12.01	2.250	27.02	75%	92.45%	
230	19.65	12.01	1.500	18.02	50%	91.69%	
230	10.09	12.02	0.750	9.01	25%	89.35%	
230	4.03	12.02	0.300	3.61	10%	89.37%	
264	39.07	12.00	3.001	36.01	100%	92.16%	89.83%
264	29.61	12.00	2.250	27.00	75%	91.20%	
264	19.94	12.01	1.500	18.01	50%	90.31%	
264	10.28	12.01	0.750	9.01	25%	87.64%	
264	4.12	12.02	0.301	3.62	10%	87.83%	
CoC Tier 2, 4-pt average							88.3%
CoC Tier 2, 10%-load							78.3%

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_EMULATOR (W)	P_{out} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
89.96	29.4	9.1	3.002	27.316	0.087	100%	93.21%	93.41%
89.98	21.98	9.08	2.249	20.424	0.087	75%	93.32%	
89.99	14.64	9.05	1.504	13.607	0.087	50%	93.54%	
90.0	7.368	9.01	0.755	6.8052	0.088	25%	93.56%	
90.03	3.043	8.99	0.305	2.7394	0.087	10%	92.89%	
114.98	29.25	9.09	3.001	27.307	0.087	100%	93.66%	93.62%
114.99	21.85	9.07	2.25	20.432	0.088	75%	93.92%	
115.0	14.59	9.05	1.503	13.601	0.087	50%	93.82%	
115.01	7.407	9.01	0.756	6.8077	0.088	25%	93.10%	
115.03	3.051	9.00	0.304	2.7368	0.088	10%	92.6%	
230.06	29.47	9.1	3.002	27.319	0.087	100%	93.0%	91.86%
230.06	22.13	9.08	2.249	20.42	0.089	75%	92.67%	
230.06	14.92	9.05	1.503	13.604	0.088	50%	91.77%	
230.06	7.66	9.01	0.755	6.8056	0.088	25%	90.0%	
230.08	3.165	8.99	0.305	2.739	0.087	10%	89.29%	
264.07	29.7	9.09	3.001	27.309	0.087	100%	92.24%	90.9%
264.07	22.34	9.06	2.249	20.42	0.087	75%	91.8%	
264.05	15.11	9.03	1.503	13.606	0.087	50%	90.62%	
264.05	7.747	9.01	0.755	6.803	0.087	25%	88.94%	
264.07	3.206	9.00	0.305	2.739	0.087	10%	88.15%	
CoC Tier 2, 4-pt average								87.3%
CoC Tier 2, 10%-load								77.3%

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_EMULATOR (W)	P_{out} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
89.99	16.63	5.09	2.994	15.242	0.048	100%	91.94%	92.26%
90	12.38	5.05	2.254	11.382	0.049	75%	92.33%	
90	8.223	5.01	1.51	7.5643	0.049	50%	92.58%	
90.02	4.151	4.99	0.757	3.7775	0.049	25%	92.17%	
90.03	1.723	4.97	0.306	1.5192	0.049	10%	90.99%	
115	16.55	5.09	2.995	15.243	0.048	100%	92.39%	92.28%
115	12.349	5.05	2.256	11.395	0.048	75%	92.66%	
115.01	8.251	5.01	1.51	7.5648	0.048	50%	92.26%	
115.01	4.167	4.99	0.757	3.7773	0.048	25%	91.18%	
115.03	1.731	4.97	0.306	1.5204	0.048	10%	90.6%	
230.04	16.77	5.08	2.994	15.242	0.049	100%	91.18%	89.23%
230.05	12.72	5.04	2.256	11.395	0.049	75%	89.97%	
230.06	8.62	5.01	1.512	7.5737	0.048	50%	88.42%	
230.06	4.381	4.99	0.757	3.7791	0.048	25%	87.35%	
230.08	1.811	4.97	0.306	1.5205	0.049	10%	86.64%	
264.04	16.96	5.08	2.998	15.258	0.048	100%	90.25%	87.82%
264.05	12.91	5.03	2.257	11.397	0.049	75%	88.66%	
264.07	8.79	5.01	1.51	7.5673	0.048	50%	86.64%	
264.07	4.462	4.99	0.757	3.777	0.048	25%	85.72%	
264.09	1.842	4.97	0.306	1.5192	0.048	10%	85.08%	
CoC Tier 2, 4-pt average								81.8%
CoC Tier 2, 10%-load								72.5%

3.3.7 Efficiency Typical Results

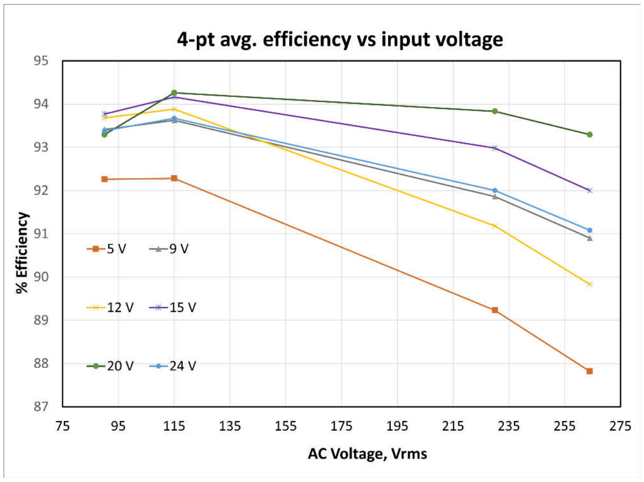


Figure 3-4. 4pt-Average Efficiency vs. Input Voltage

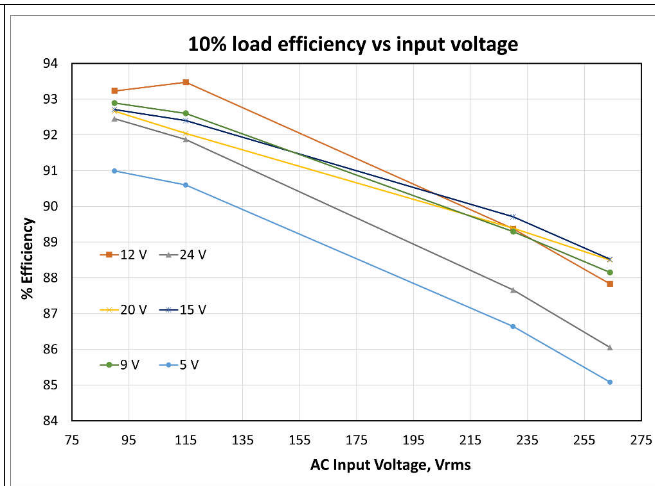


Figure 3-5. Efficiency of 10%-Load vs. Input Voltage

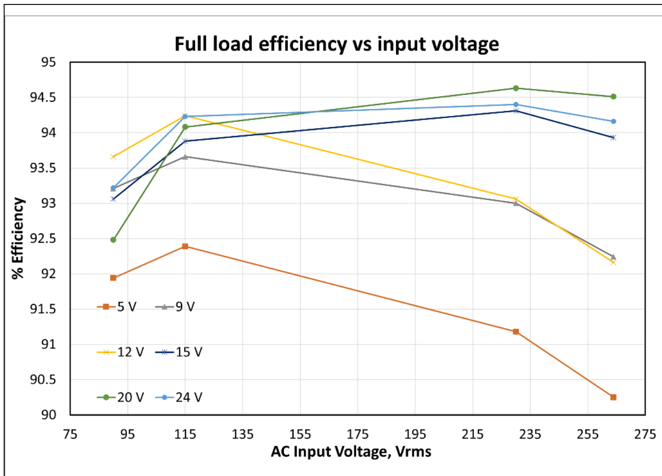


Figure 3-6. Full-load Efficiency vs. Input Voltage

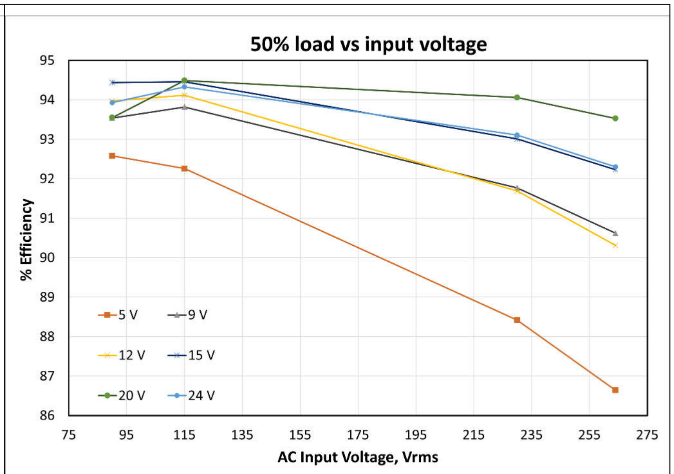


Figure 3-7. Efficiency of 50%-load vs. Input Voltage

3.3.8 Output Characteristics

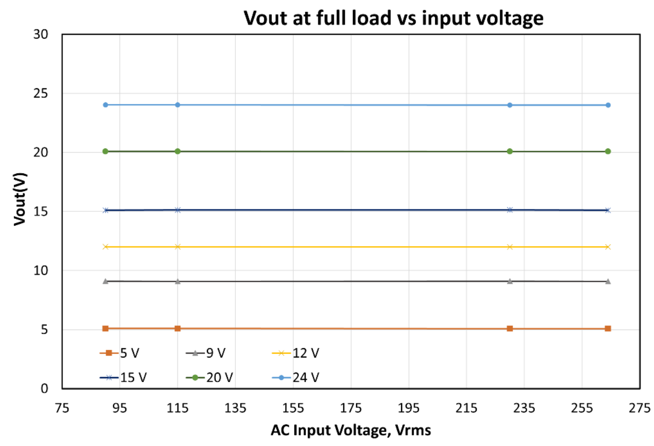


Figure 3-8. V_{OUT} at Full-Load vs Input Voltage

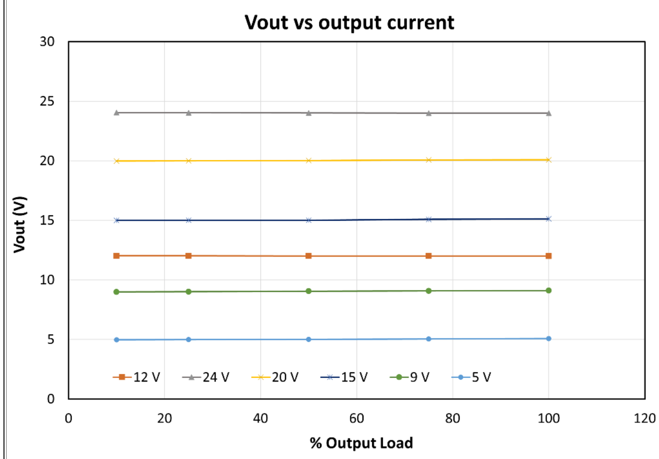


Figure 3-9. V_{OUT} vs Output Current

3.3.9 Startup Waveforms

This section shows the waveforms at no load and full load startup for 12V and 24V output. YELLOW = Output Voltage, BLUE = Vbulk, RED = Switch Node Voltage, GREEN = FB Pin Voltage

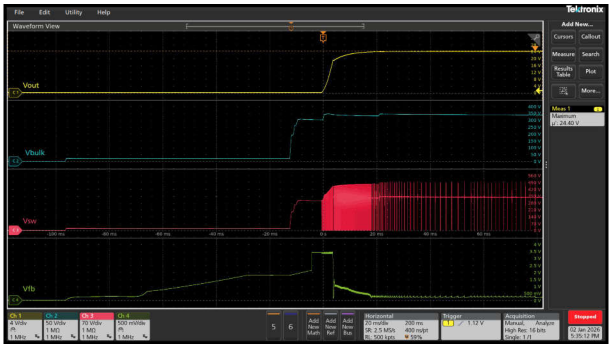


Figure 3-10. Startup waveform for 24V output at no load

Figure 3-11. Startup waveform for 24V output at full load

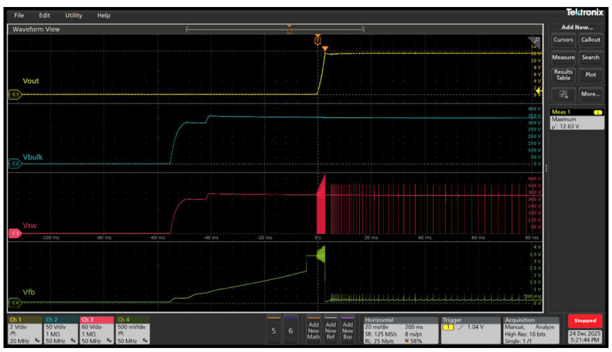


Figure 3-12. Startup waveform for 12V output at no load

Figure 3-13. Startup waveform for 12V output at full load

3.3.10 Key Switching Waveforms

This section shows typical switching waveforms at full load for 5V, 9V, 15V and 20V output.

YELLOW = Switch Node, BLUE = Output Voltage, BROWN = SR Gate voltage, RED = FB Pin Voltage

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 = 9V

Figure 3-23. Vin = 115Vac, Vout = 9V

Figure 3-24. Vin = 230Vac, Vout = 9V

Figure 3-25. Vin = 264Vac, Vout = 9V

Figure 3-26. Vin = 90Vac, Vout = 5V

Figure 3-27. Vin = 115Vac, Vout = 5V

Figure 3-28. Vin = 230Vac, Vout = 5V

Figure 3-29. Vin = 264Vac, Vout = 5V

This section shows typical switching waveforms at full load for 24V and 12 V output.

YELLOW = Output Voltage, BLUE = SR Gate Voltage, RED = SR Gate voltage, GREEN = FB Pin Voltage

Figure 3-30. Vin = 90Vac, Vout = 24V

Figure 3-31. Vin = 115Vac, Vout = 24V

Figure 3-32. Vin = 230Vac, Vout = 24V

Figure 3-33. Vin = 264Vac, Vout = 24V

Figure 3-34. Vin = 90Vac, Vout = 12V

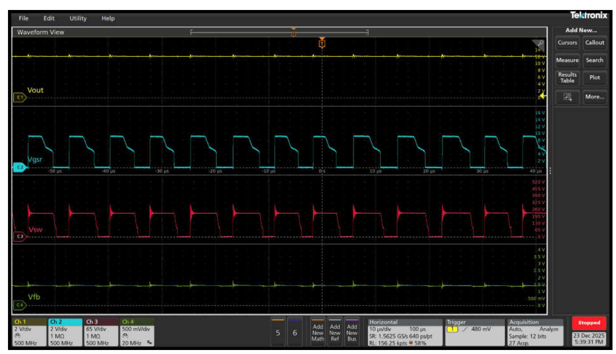


Figure 3-35. Vin = 115Vac, Vout = 12V

Figure 3-36. Vin = 230Vac, Vout = 12V

Figure 3-37. Vin = 264Vac, Vout = 12V

3.3.11 Switching Frequency vs Load

This section shows typical switching waveforms at different load conditions. YELLOW = Output Voltage, BLUE = Vbulk, RED = Switch Node Voltage, GREEN = FB Pin Voltage

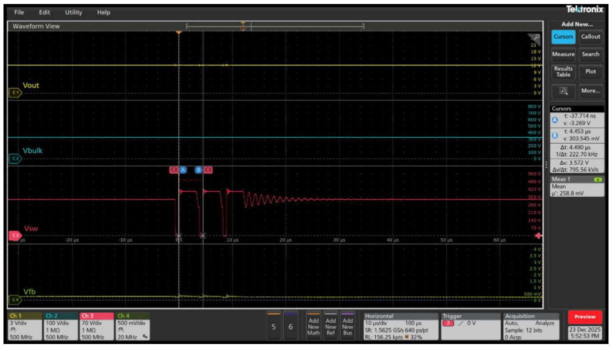


Figure 3-38. 230Vac/0.6W (222khz burst frequency/ Vfb - 0.258V)

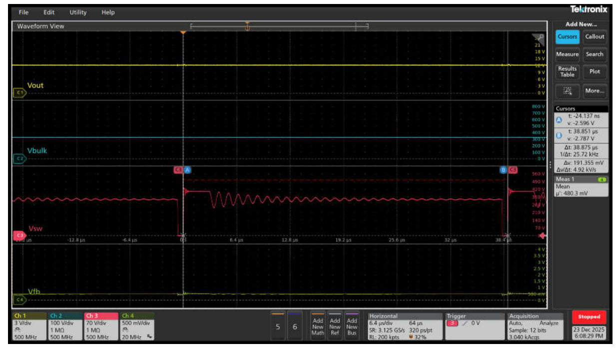


Figure 3-39. 230Vac/2.94W (25kHz frequency - foldback / Vfb - 0.48V)

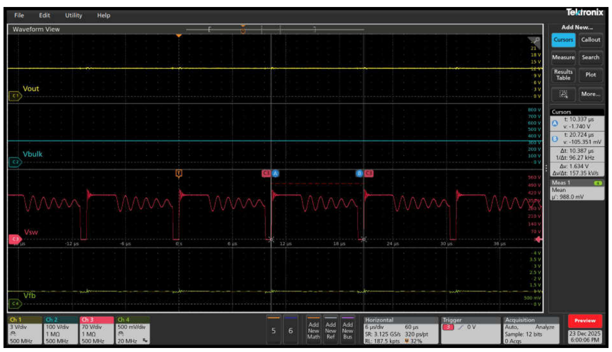


Figure 3-40. 230Vac/12W (96kHz frequency/ Vfb - 0.988V)

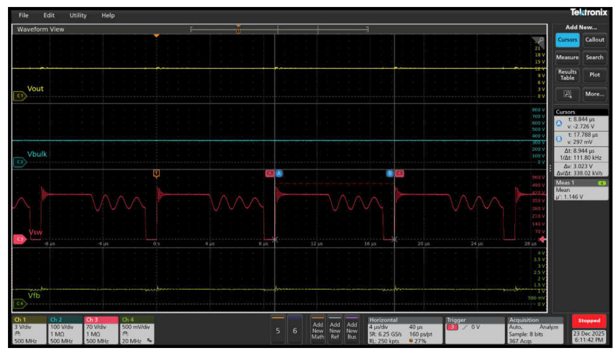


Figure 3-41. 230Vac/20.4W (111kHz frequency/ Vfb - 1.146V)

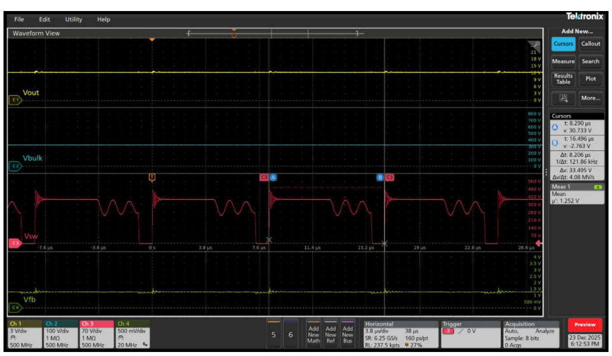


Figure 3-42. 230Vac/27.6W (121kHz frequency/ Vfb - 1.252V)

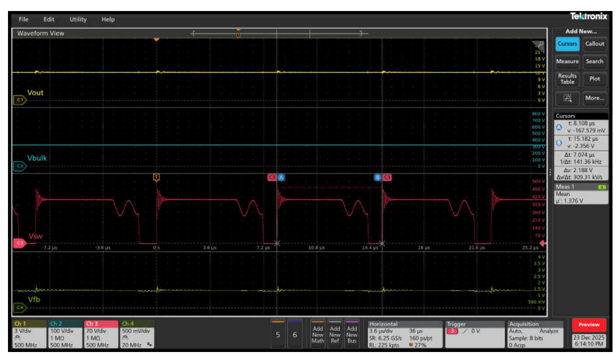


Figure 3-43. 230Vac/36W (141kHz frequency/ Vfb - 1.376V)

3.3.12 Output Ripple Voltage

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

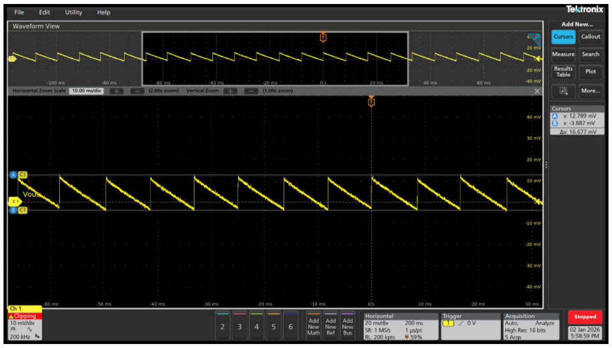


Figure 3-44. Typical Ripple Voltage of V_{OUT} = 24V at no load (16.67mVpp)

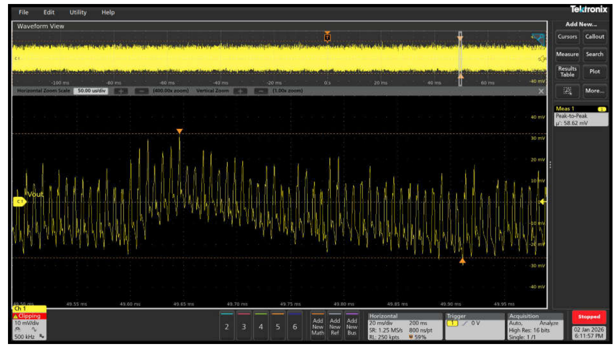


Figure 3-45. Typical Ripple Voltage of V_{OUT} = 20V at full load (58.62mVpp)

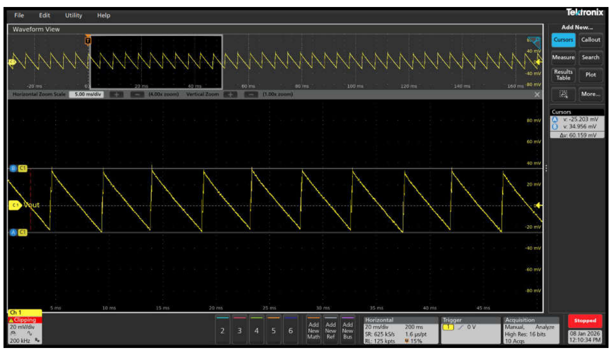


Figure 3-46. Typical Ripple Voltage of V_{OUT} = 20V at no load (60.16mVpp)

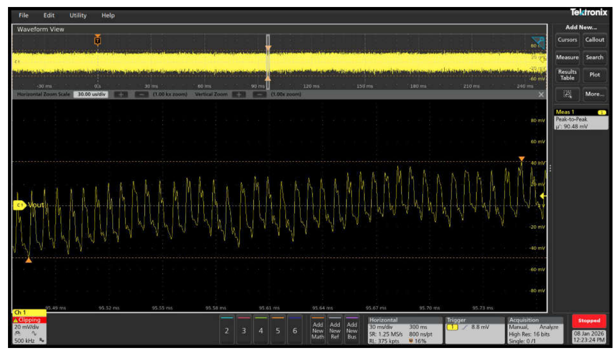


Figure 3-47. Typical Ripple Voltage of V_{OUT} = 20V at full load (90.48mVpp)

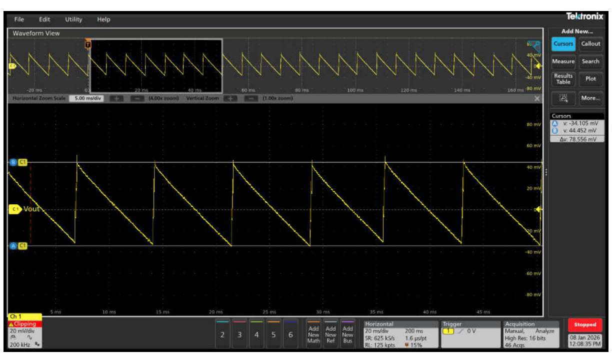


Figure 3-48. Typical Ripple Voltage of V_{OUT} = 15V at no load (78.56mVpp)

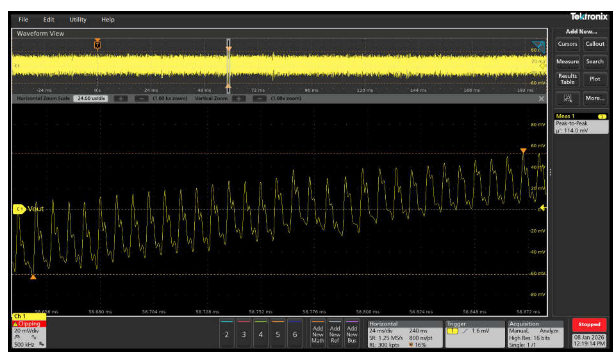


Figure 3-49. Typical Ripple Voltage of V_{OUT} = 15V at full load (114mVpp)

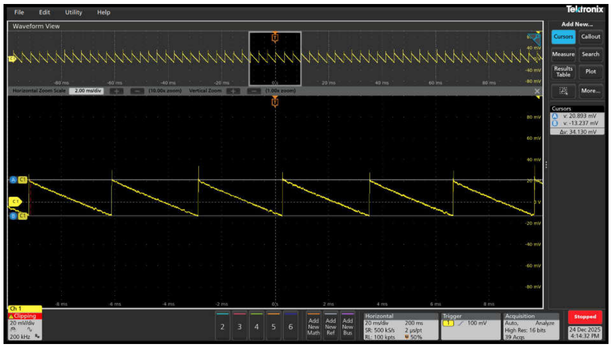


Figure 3-50. Typical Ripple Voltage of V_{OUT} = 12V at no load (34.13mVpp)

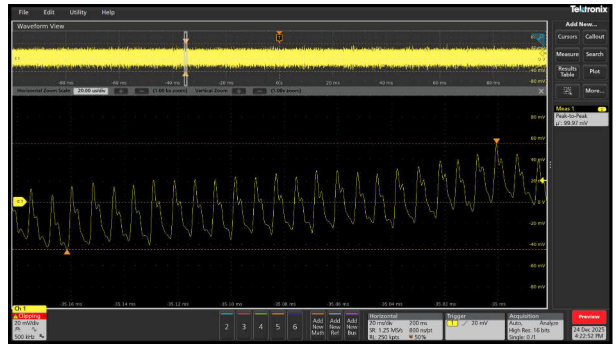


Figure 3-51. Typical Ripple Voltage of V_{OUT} = 12V at full load (99.97mVpp)

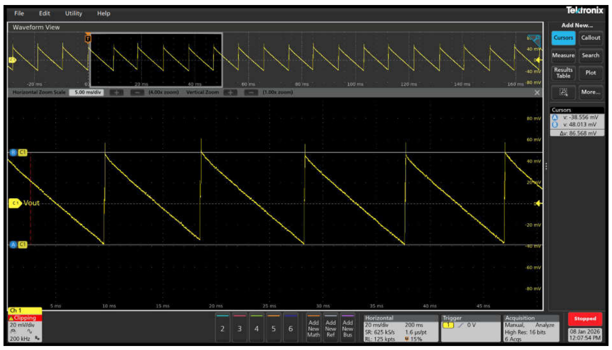


Figure 3-52. Typical Ripple Voltage of V_{OUT} = 9V at noload (86.57mVpp)

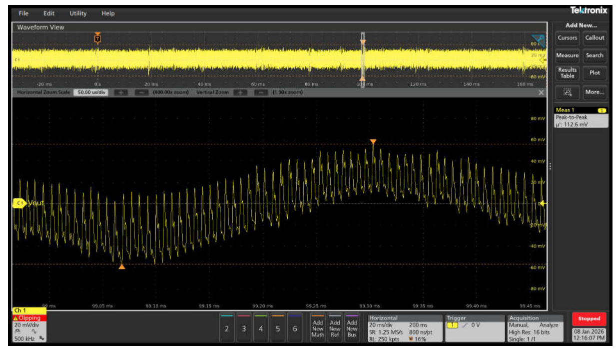


Figure 3-53. Typical Ripple Voltage of V_{OUT} = 9V at full load (112.6mVpp)

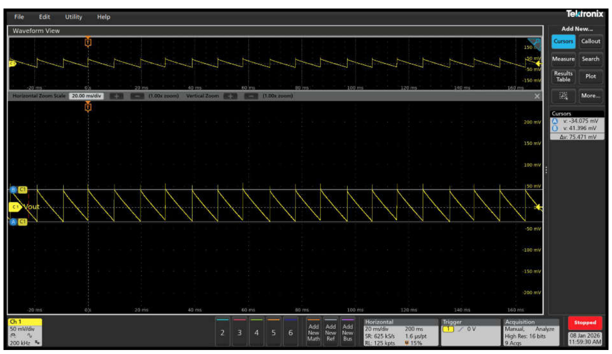


Figure 3-54. Typical Ripple Voltage of V_{OUT} = 5V at no load (75.47mVpp)

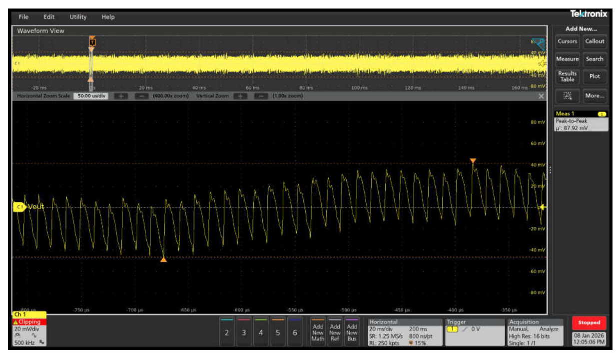


Figure 3-55. Typical Ripple Voltage of V_{OUT} = 5V at full load (87.92mVpp)

3.3.13 Load Transient Response

The scope captures below show output voltage V_{OUT} deviation when load current step change is between 0 and 100%, at 100Hz rate at 2.5A/us. Note, the step load current is inverted in the capture.

GREEN (AC coupled)= V_{OUT}, PINK= Load Current.

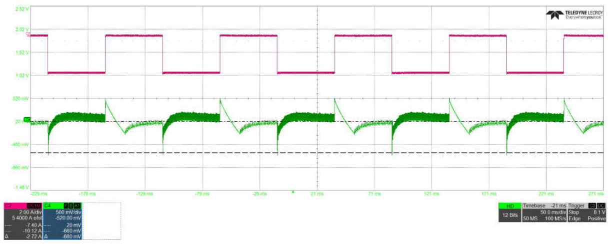


Figure 3-56. Load Transient Response at V_{OUT} = 20V Overshoot / Undershoot = 495mV / -680mV

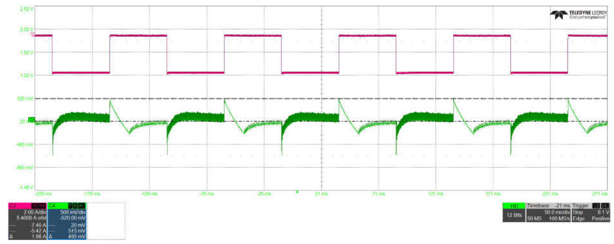


Figure 3-57. Transient Response at V_{OUT} = 15V Overshoot / Undershoot = 485mV / -630mV

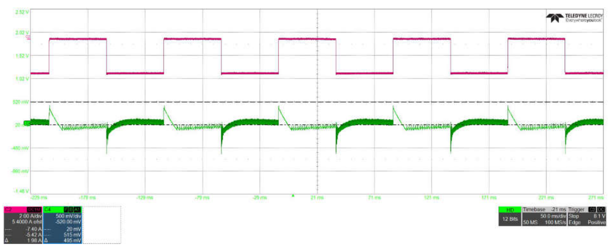


Figure 3-58. Transient Response at V_{OUT} = 9V Overshoot / Undershoot = 460mV / -500mV

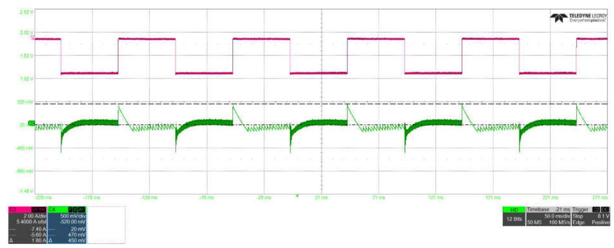


Figure 3-59. Transient Response at V_{OUT} = 5V Overshoot / Undershoot = 440mV / -480mV

The scope captures below show output voltage V_{OUT} deviation when load current step change is between 0 and 100%, at 100Hz rate at 2.5A/us. The step load current is not inverted in the captures below.

YELLOW(AC coupled)= V_{OUT}, BLUE= Load Current.

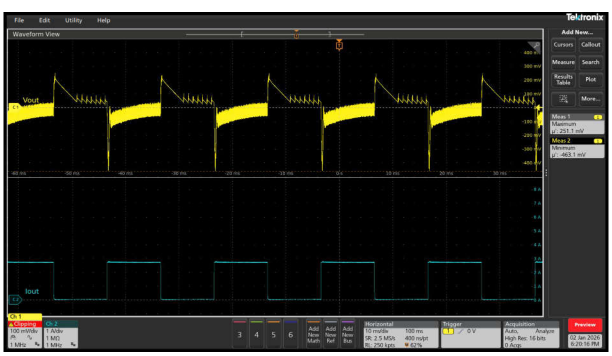


Figure 3-60. Transient Response at V_{OUT} = 24V Overshoot / Undershoot = 251.1mV / -463.1mV

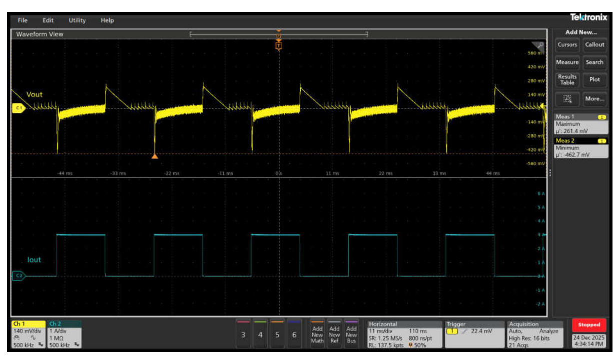


Figure 3-61. Transient Response at V_{OUT} = 12V Overshoot / Undershoot = 261.4mV / -462.7mV

3.3.14 Line Transient Response

This section shows output voltage when line transient is applied from 90Vac to 264Vac at no load and full load. RED = Output Voltage, BLACK = AC Input, BLUE = Switch Node

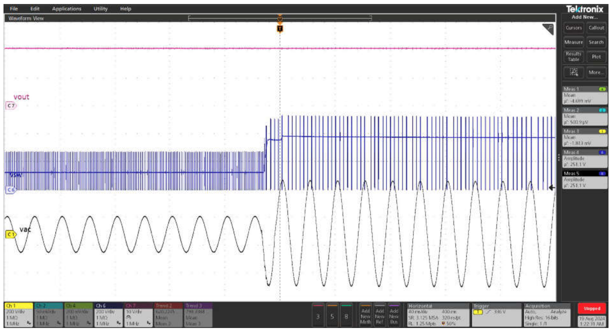


Figure 3-62. Line Transient From 90Vac to 264Vac at 20V/No Load

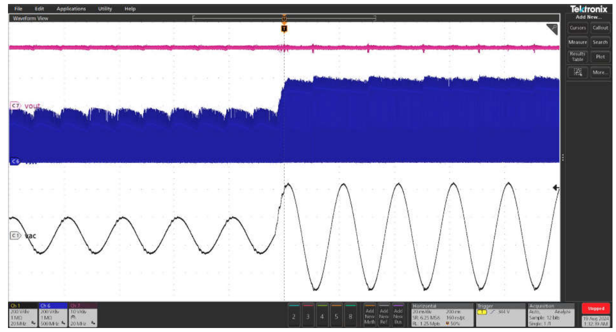


Figure 3-63. Line Transient From 90Vac to 264Vac at 20V/Full Load

3.3.15 Surge Test

The section below shows the response when a 2KV and a 1KV surge is applied to the EVM with one positive impulse and a phase angle of 90 degrees. YELLOW = Bulk voltage, PURPLE = Switch Node Voltage

Figure 3-64. 2KV Surge at 230Vac input

Figure 3-65. 1KV Surge at 230Vac input

3.3.16 Short Term Overload Operation

The EVM is capable of supporting short term overload without damage, safety issues or triggering protection. The output voltage drops to 17.8V when peak short term overload of 6.5A is applied for 2ms and to 18.2V when 7.32A is applied for 1ms . The results are checked at 100Vac. PINK = Switch Node Voltage, GREEN = Load Current, BLUE = Output Voltage, YELLOW = FB Pin Voltage

The output voltage drops to approximately 17.8V

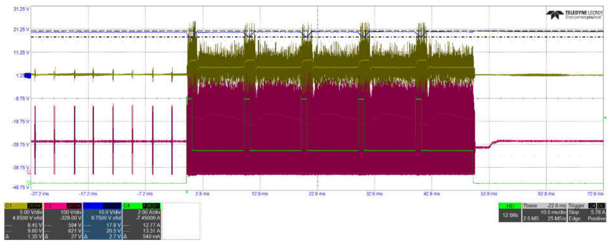


Figure 3-66. VIN=100Vac (2.25x rated current for 1ms, 0.9x rated current for 9ms)

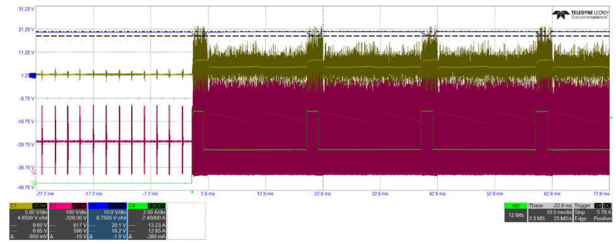


Figure 3-67. VIN=100Vac (2x rated current for 2ms, 0.9x rated current for 18ms)

3.3.17 CCM operation

This section shows CCM operation at 90Vac with 6.5A load, which is 2x the rated current of 3.25A at 20V output. PINK = Switch Node Voltage, GREEN = Load Current, BLUE = Output Voltage

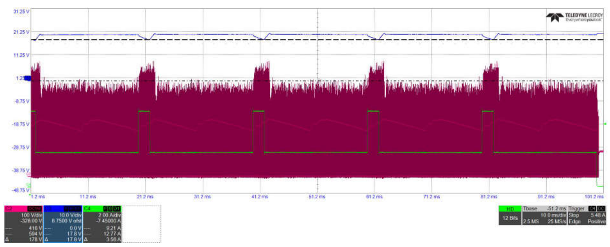


Figure 3-68. VIN=90Vac (2x rated current for 2ms, 0.9x rated current for 18ms)

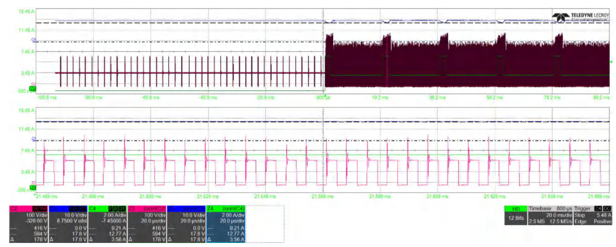


Figure 3-69. VIN=90Vac (2x rated current for 2ms, 0.9x rated current for 18ms) - Zoomed

3.3.18 Thermal Images at Full Load (20V and 3.25A)

The thermal images below show the maximum temperature at full load for different line voltages.

Figure 3-70. V_{IN} = $90V_{AC}$, Top Side

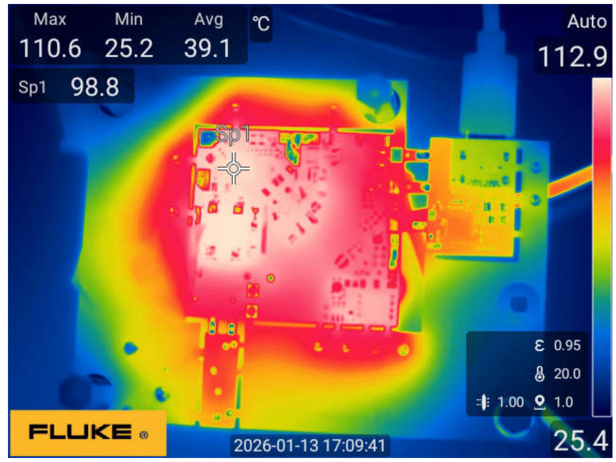


Figure 3-71. V_{IN} = $90V_{AC}$, Bottom Side

Figure 3-72. V_{IN} = $115V_{AC}$, Top Side

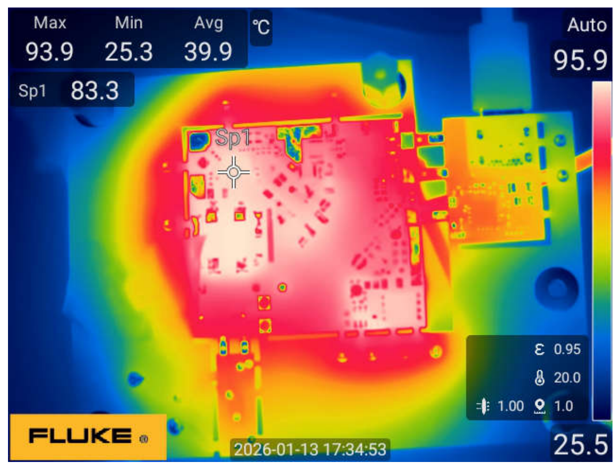


Figure 3-73. V_{IN} = $115V_{AC}$, Bottom Side

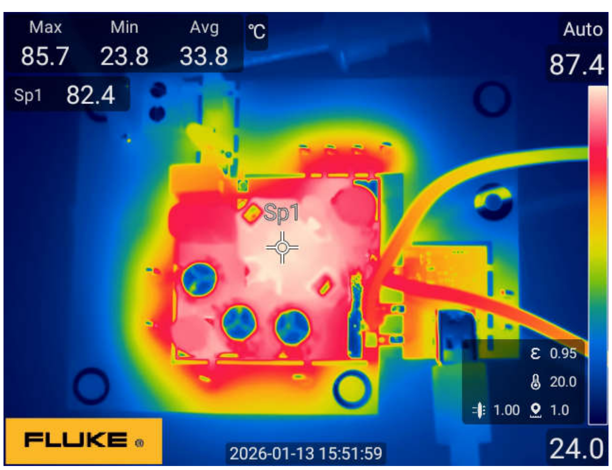


Figure 3-74. V_{IN} = $230V_{AC}$, Top Side

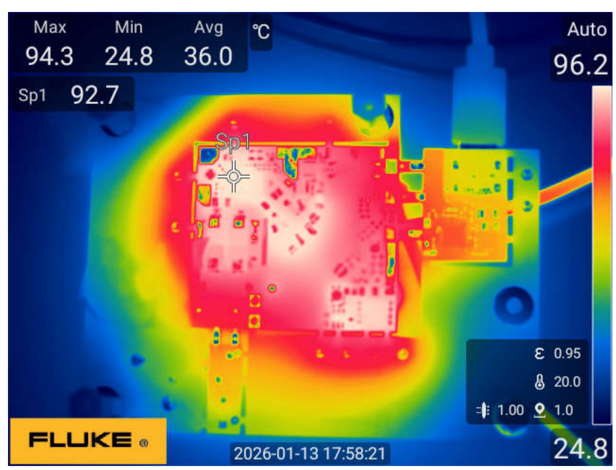


Figure 3-75. V_{IN} = $230V_{AC}$, Bottom Side

Figure 3-76. V_{IN} = $264V_{AC}$, Top Side

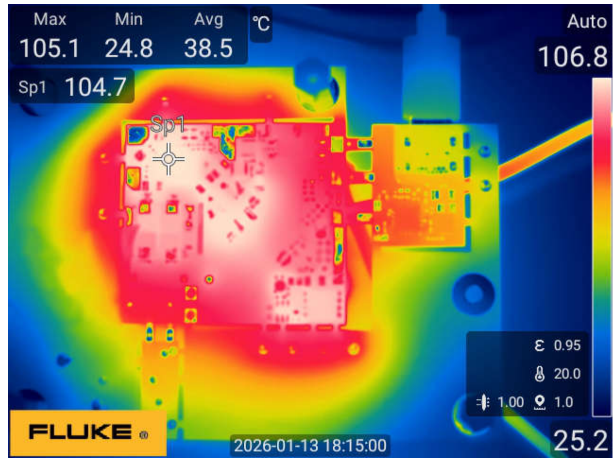


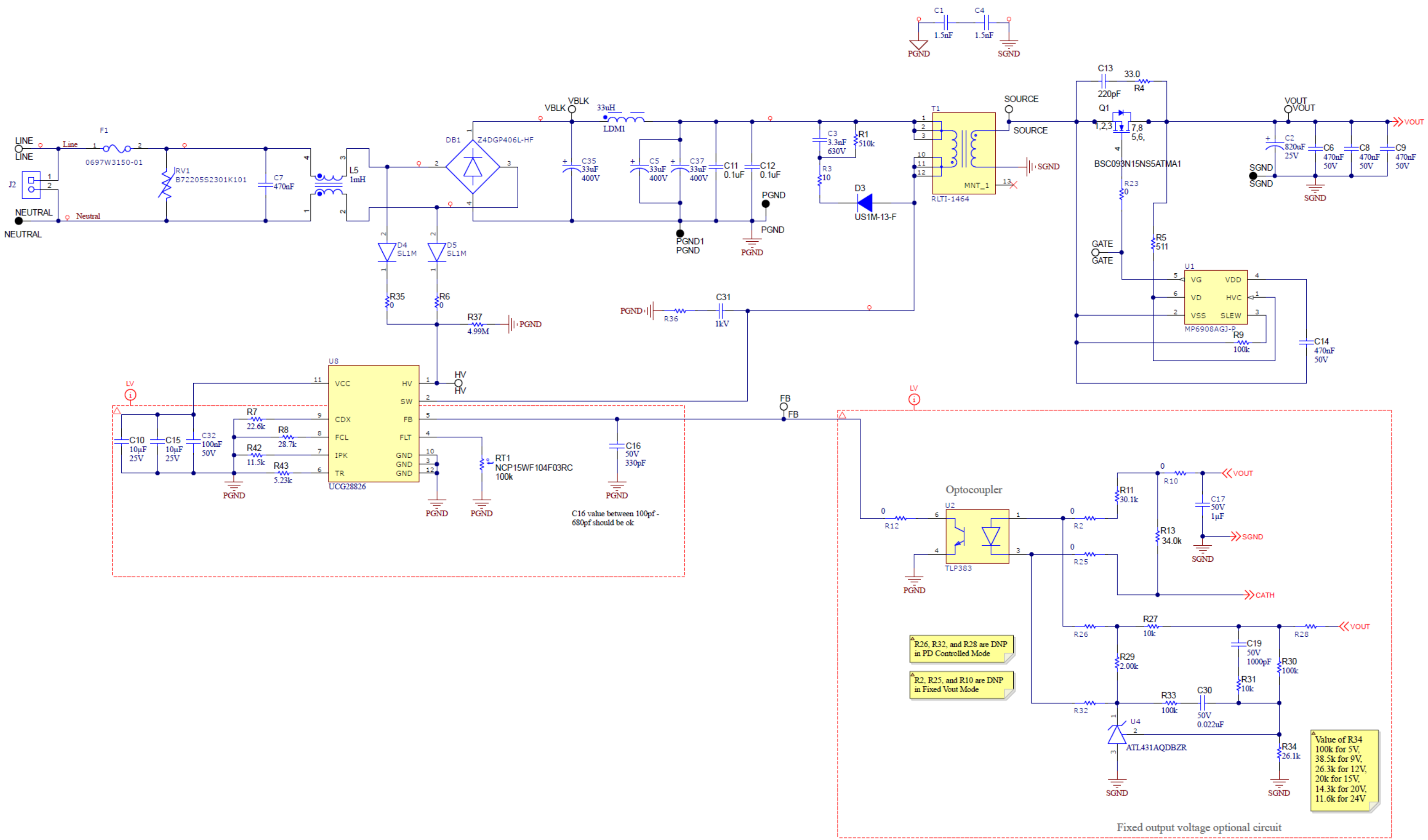
Figure 3-77. V_{IN} = $264V_{AC}$, Bottom Side

4 Hardware Design Files

4.1 Schematics

The schematic of the UCG28826EVM-093 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:

$$R34 = R30 \times \frac{2.5V}{(Vout - 2.5V)}$$



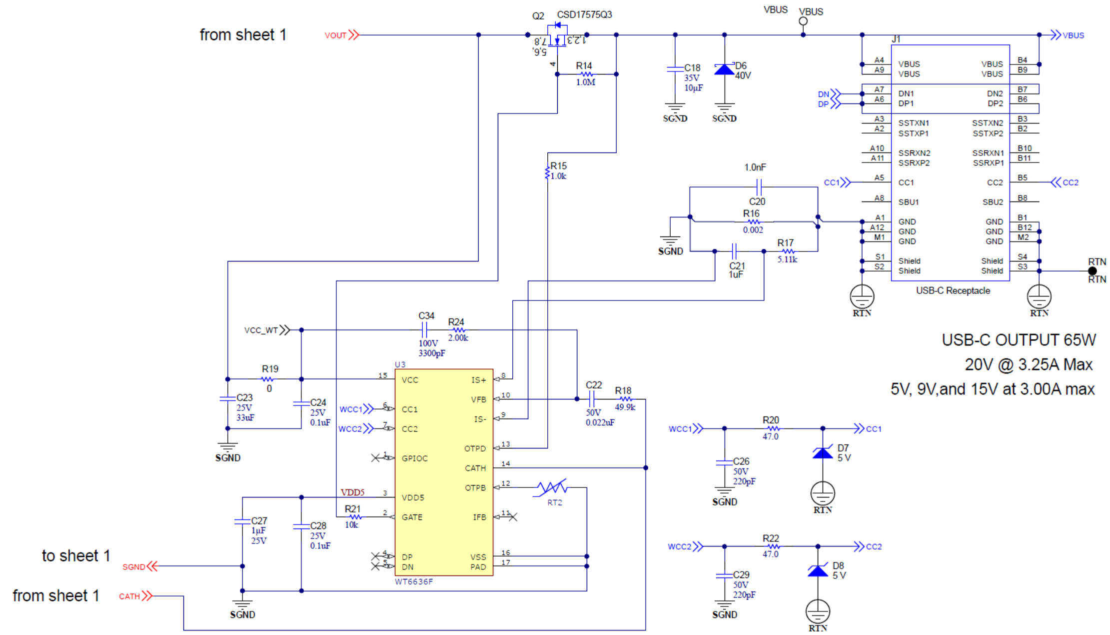


Figure 4-1. UCG28826EVM-093 Schematic Diagram

4.2 PCB Layouts

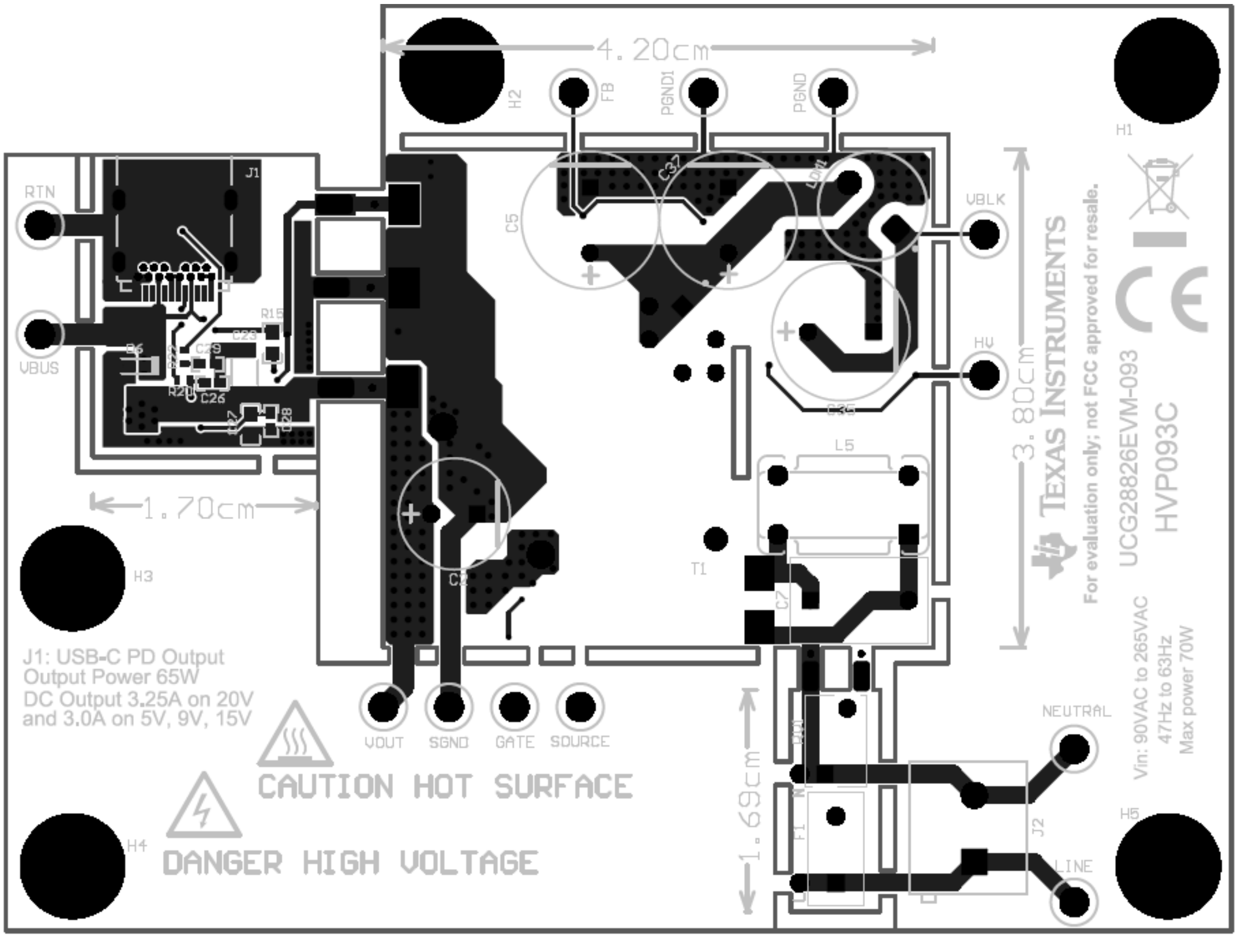


Figure 4-2. EVM Assembly (Top View)

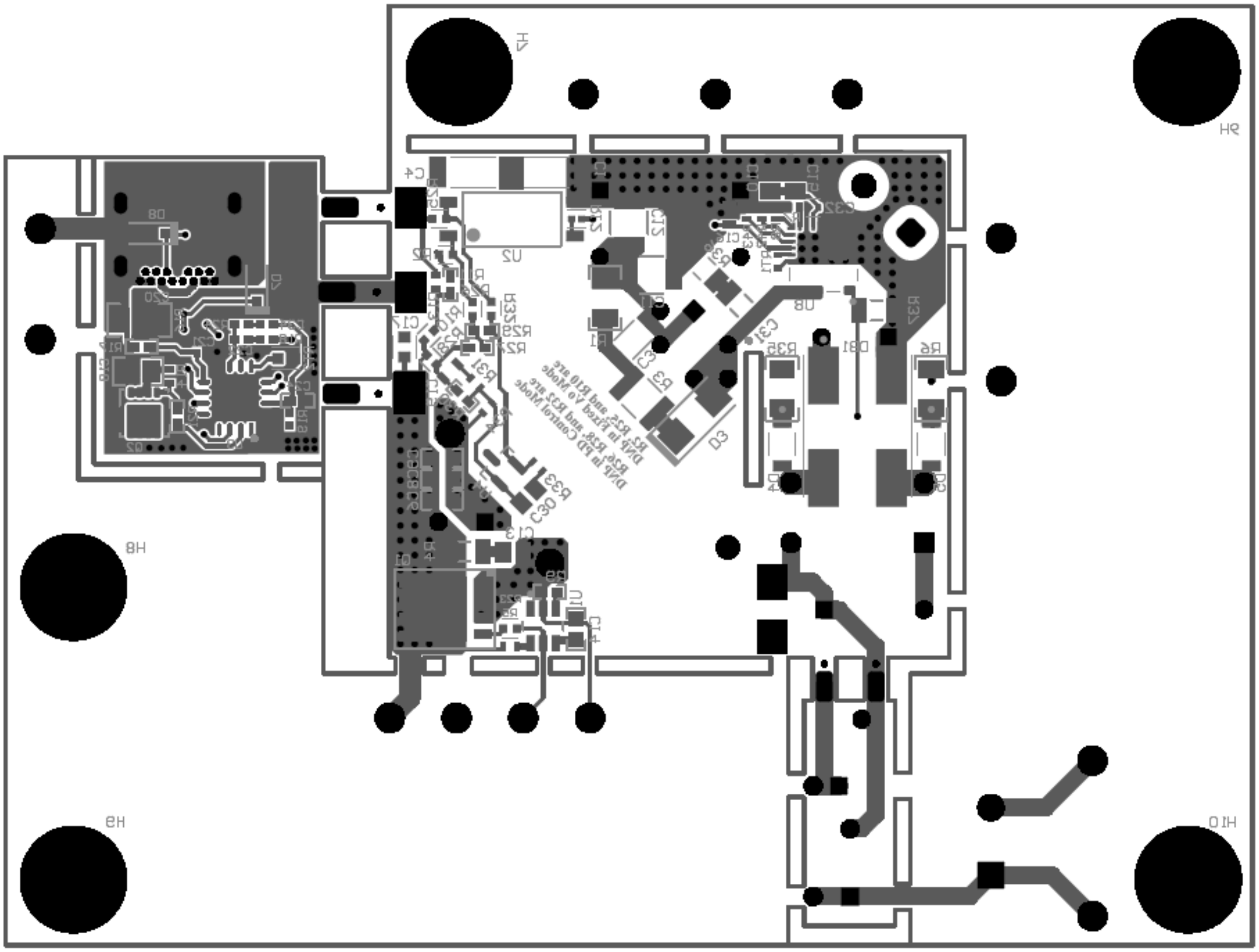


Figure 4-3. EVM Assembly (Bottom View)

4.3 Transformer Details

This design uses transformer from Renco and the specifications are mentioned below.

4.3.1 RLTI-1464 (RENCO)

This transformer is an excellent choice and recommended for this design to meet the efficiency specifications. This achieves good balance between leakage energy (thereby enabling efficiency) and inter-winding capacitance (helps with the thermal performance of UCG28826).

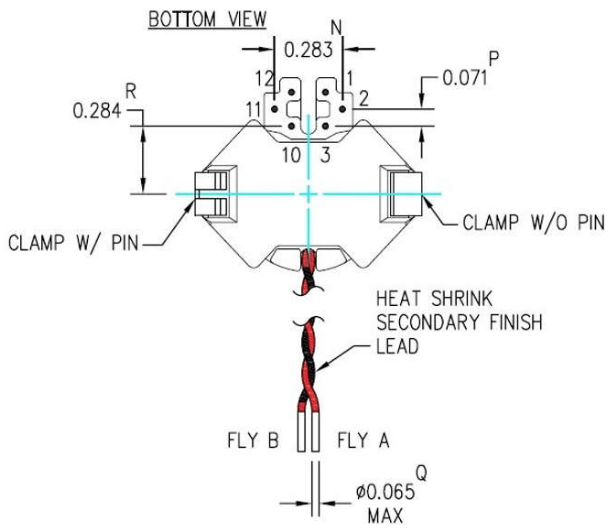


Figure 4-4. RLTI-1464 pin configuration

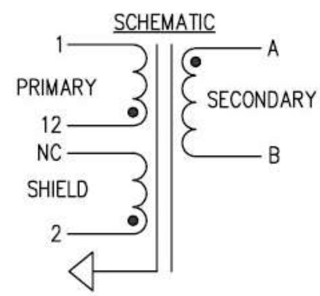


Figure 4-5. RLTI-1464 Schematic

Table 4-1. Transformer Specifications at 25°C

PARAMETER	VALUE	PINS/LEADS	TEST CONDITIONS
Inductance (µH)	200, ± 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-ratios	6:1	(1-12):(A-B)	APPLY: 1.0V @ 10kHz to (12 - 1) Vout: (A-B) 0.167V

4.4 Bill of Materials

The table below lists the bill of materials for UCG28826EVM-093.

Table 4-2. Bill of Materials

Designator	Value	Quantity	Description	Part Number	Manufacturer
C1, C4	1500pF	2	1500 pF ±10% 250VAC Ceramic Capacitor X7R 1808 (4520 Metric)	1808YA250152KJTSYX	Knowles Syfer
C2	820µF	1	820 µF 25 V Aluminum - Polymer Capacitors Radial, Can 22mOhm 5000 Hrs @ 105°C	RPF0816821M025K	KYOCERA AVX
C3	3.3nF	1	Cap Ceramic 3.3nF 630V C0G 5% Pad SMD 1206 +125°C Automotive T/R	CGA5L4C0G2J332J160AA	TDK
C5, C35, C37	33µF	3	33uF 400V 500mΩ@100kHz 370mA@100kHz ±20% Plugin,D10xL15mm Aluminum Electrolytic Capacitors - Leaded ROHS	87EC0493	KNSCHA
C6, C8, C9, C14	0.47µF	4	CAP, CERM, 0.47 uF, 50 V, +/- 20%, X7R, AEC-Q200 Grade 1, 0603	CGA3E3X7R1H474M080AE	TDK
C7	470nF	1	470nF ±10% X2 Plugin,P=7.5mm Suppression Capacitors ROHS	MPX474K31B9KN20600	KNSCHA
C10, C15	10µF	2	CAP, CERM, 10 uF, 25 V, +/- 10%, X7R, 0805	GRM21BZ71E106KE15L	Murata
C11, C12	0.1µF	2	CAP, CERM, 0.1 uF, 630 V, +/- 10%, X7R, 1210	C1210C104KBRAC7800	KEMET
C16	330pF	1	CAP, CERM, 330 pF, 50 V, +/- 5%, C0G/NP0, 0603	885012006060	Wurth Elektronik
C17	1µF	1	1µF ±10% 50V Ceramic Capacitor X7R 0603 (1608 Metric)	CC0603KRX7R9BB105	Yageo Group
C18	10µF	1	CAP, CERM, 10 µF, 35 V,+/- 10%, X5R, 0805	GMK212BBJ106KG-T	TAIYO YUDEN
C19	1000pF	1	CAP, CERM, 1000 pF, 50 V, +/- 5%, C0G/NP0, 0603	C0603C102J5GAC	Kemet
C20	1000pF	1	CAP, CERM, 1000 pF, 50 V, +/- 10%, X7R, 0402	885012205061	Wurth Elektronik
C21	1µF	1	CAP, CERM, 1 uF, 6.3 V, +/- 20%, X7R, 0402	GRM155R70J105MA12D	Murata
C22	0.022µF	1	CAP, CERM, 0.022 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402	CGA2B3X7R1H223K050BB	TDK
C23	33µF	1	CAP, CERM, 33 uF, 25 V, +/- 20%, X5R, 1206	C3216X5R1E336M160AC	TDK
C24, C28	0.1µF	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	1µF	1	CAP, CERM, 1 uF, 25 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	GCM188R71E105KA64D	Murata
C30	0.022µF	1	CAP, CERM, 0.022 uF, 50 V, +/- 1%, C0G/NP0, 0805	C0805C223F5GACTU	KEMET
C32	100nF	1	Multi-Layer Ceramic Capacitor 100nF 50V X7R ±10% 0402 Paper T/R	GRT155R71H104KE01D	Murata
C34	3300µF	1	CAP, CERM, 3300 pF, 100 V, +/- 10%, X7R, 0402	GRM155R72A332KA01D	Murata
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	5.6V	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

Table 4-2. Bill of Materials (continued)

Designator	Value	Quantity	Description	Part Number	Manufacturer
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
FB, GATE, HV, LINE, SOURCE, VBLK, VBUS, VOUT		8	Test Point, Multipurpose, White, TH	5012	Keystone
H1, H2, H3, H4, H5		5	#4-40 Pan Head Machine Screw Phillips Drive Nylon	NY PMS 440 0038 PH	Building Fasteners
H6, H7, H8, H9, H10		5	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	1mH	1	Coupled inductor, 1 mH, 2 A, 0.045 ohm, TH	744821201	Wurth Elektronik
LDM1	33µH	1	WE-TI Radial Leaded Wire Wound Inductor, size 8095, 33uH, 2.5A, 0.066Ohm	7447720330	Wurth Elektronik
NEUTRAL, 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	BSC093N15NS5ATMA 1	Infineon Technologies
Q2	30V	1	MOSFET, N-CH, 30 V, 60 A, DQG0008A (VSON-CLIP-8)	CSD17575Q3	Texas Instruments
R1	510kΩ	1	RES, 510 k, 5%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW1206510KJNEA	Vishay/Dale
R2, R10, R12, R23, R25	0Ω	5	RES Thick Film, 0Ω, 0.2W, 0402	CRCW04020000Z0ED HP	Vishay
R3	10Ω	1	10Ω ±5% 0.5W 1210 Thick Film Chip Resistor AEC-Q200 compliant	RMCF1210JT10R0	Stackpole Electronics
R5	511Ω	1	RES, 511, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW0402511RFKED	Vishay/Dale
R6, R35	0Ω	2	RES, 0, 5%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW12060000Z0EA	Vishay/Dale
R7	22.6kΩ	1	RES, 22.6 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040222K6FKED	Vishay/Dale
R8	28.7kΩ	1	RES, 28.7 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040228K7FKED	Vishay/Dale
R9, R30	100kΩ	2	RES, 100 k, 1%, 0.1 W, 0402	ERJ-2RKF1003X	Panasonic
R11	30.1kΩ	1	RES, 30.1 k, 1%, 0.063 W, 0402	CRCW040230K1FKED	Vishay/Dale
R13	34kΩ	1	RES, 34.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040234K0FKED	Vishay/Dale
R14	1MΩ	1	RES, 1.0 M, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04021M00JNED	Vishay/Dale
R15	1kΩ	1	RES, 1.0 k, 5%, 0.25 W, AEC-Q200 Grade 0, 0603	ESR03EZPJ102	ROHM
R16	0.002Ω	1	RES, 0.002, 1%, 1 W, AEC-Q200 Grade 0, 1206	PMR18EZPFV2L00	ROHM
R17	5.11kΩ	1	RES, 5.11 k, 1%, 0.063 W, 0402	CRCW04025K11FKED	Vishay/Dale
R18	49.9kΩ	1	RES, 49.9 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040249K9FKED	Vishay/Dale
R19	0Ω	1	RES, 0, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04020000Z0ED	Vishay / Dale
R20, R22	47Ω	2	RES, 47.0, 1%, 0.063 W, 0402	RK73H1ETTP47R0F	KOA Speer
R21, R27, R31	10kΩ	3	RES, 10 k, 5%, 0.063 W, 0402	CRCW040210K0JNED	Vishay / Dale

Table 4-2. Bill of Materials (continued)

Designator	Value	Quantity	Description	Part Number	Manufacturer
R24	2kΩ	1	RES, 2.00 k, 0.1%, 0.063 W, 0402	RG1005P-202-B-T5	Susumu
R29	2kΩ	1	RES, 2.00 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04022K00FKED	Vishay / Dale
R33	100kΩ	1	RES, 100 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW0402100KFKED	Vishay / Dale
R34	26.1kΩ	1	RES, 26.1 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040226K1FKED	Vishay / Dale
R37	4.99MΩ	1	RES, 4.99 M, 1%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW12064M99FKEA	Vishay/Dale
R42	11.5kΩ	1	RES, 11.5 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040211K5FKED	Vishay / Dale
R43	5.23kΩ	1	RES, 5.23 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04025K23FKED	Vishay / Dale
RT1	100kΩ	1	Thermistor NTC, 100k ohm, 1%, 0402	NCP15WF104F03RC	Murata
RT2	220kΩ	1	Thermistor NTC 220K Ohm 5% 2-Pin 0603 Surface Mount Solder Pad 4450K Reel	ERT-J1VT224J	Panasonic
RV1		1	470 V 800 A Varistor 1 Circuit Through Hole Disc 5mm	B72205S2301K101	EPCOS
T1		1	Flyback Transformer	RLTI-1464	RENCO
U1		1	FAST TURN-OFF INTELLIGENT RECTIF	MP6908GJ-Z	Monolithic Power Systems
U2		1	Optoisolator Transistor Output 5000Vrms 1 Channel 6-SO	TLP383(GR-TPL,E	Toshiba Semiconductor and Storage
U3		1	USB PD/QC4/QC4+ Controller	WT6636F	Weltrend
U4		1	V-Ref Adjustable/Precision 2.5V to 36V 100mA 3-Pin SOT-23 T/R	ATL431AQDBZR	Texas Instruments
U8		1	Self-Biased High Frequency QR Flyback Converter With Integrated GaN	UCG28826-1REZR	Texas Instruments

5 Additional Information

Trademarks

All trademarks are the property of their respective owners.

6 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision B (May 2025) to Revision C (November 2025) **Page**

- Updated Table 3-1 5
- Updated images in the Section 3.2.2 section........ 8
- Updated Table 3-2 10

Changes from Revision A (February 2025) to Revision B (May 2025) **Page**

- Updated image in the *Test Setup Diagram* section........ 8
- Updated input voltage range for figure comment in the *Line Transient Response* section........ 27
- Updated images in the *Thermal Images at Full Load (20V and 3.25A)* section........ 29
- Updated images in the *Hardware Design Files* section........ 31
- Updated details for transformer design in the *Transformer Details* section........ 35
- Updated table per current BOM in the *Bill of Materials* section........ 36

Changes from Revision * (October 2024) to Revision A (February 2025)	**Page**
• Updated images in the *Thermal Images at Full Load (20V and 3.25A)* section	29

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   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.

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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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