EVM User's Guide: UCG28826EVM-093

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

Description

The UCG28826EVM-093 is a 65W USB-C PD 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 $20V_{DC}$, with a max 3.25A, and to $5V_{DC}$, $9V_{DC}$, and $15V_{DC}$, with a max 3.00A output current rating. The main device used in this design is the UCG28826 with integrated 650V GaN FET and controller in 5mm x 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 and 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)

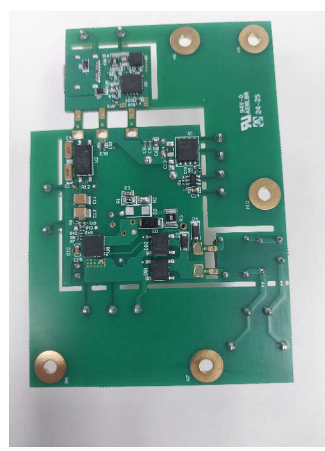


Figure 1-2. UCG28826EVM-093 (Bottom view)

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

Input	Output	Max Output Power
90VAC-264VAC 47-63Hz	20V/3.25A, 15V/3.00A, 9V/3.00A, 5V/3.00A	65W

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 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 4msec for transient output power conditions of up to 130W (two times the 65W nominal output power) in low-line input conditions without the need for a transformer designed for such transient load conditions, saving space and cost. This device also includes frequency foldback and burst nodes 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 UCG28826 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 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 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 Images

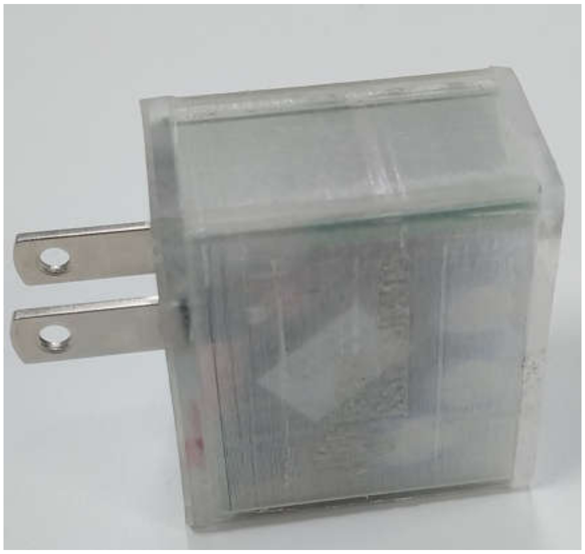


Figure 2-1. Adapter Configuration

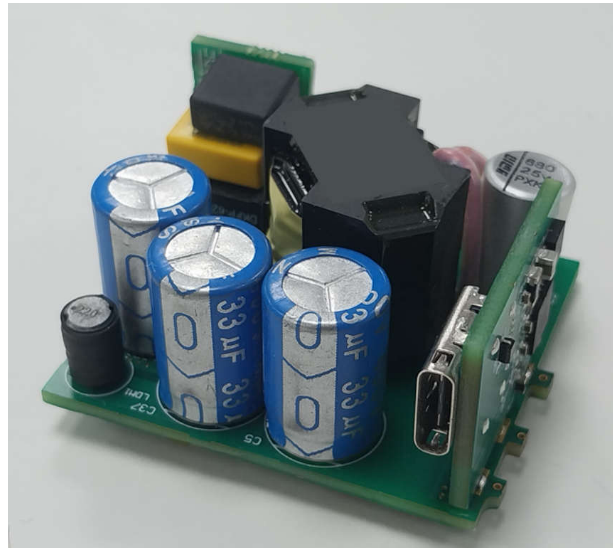


Figure 2-2. High-Density Configuration

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

UCG28826EVM-093 comes populated with a USB-C PD controller and requires external connection through an on-board USB-C connector to a USB-C PD load to adjust the board output to obtain 5V, 9V, 15V or 20V. A USB-C PD communicating load is required for board evaluation. 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

Normally, a USB-C PD communicated load is required to make evaluation. Without a USB-C PD communication-based load, the board does not provide output voltage on USB-C (J2) connector. In such a case, the board output voltage can be obtained from C2, but the output will be limited to 5V and up to 3.00A.

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}, I_{OUT} = 0A		10/26		mW
$P_{0.18W}$	Input power at 0.18W load	V_{IN} = 230V_{RMS}, P_{OUT} = 180mW		270		mW
$P_{0.3W}$	Input power at 0.3W load	V_{IN} = 230V_{RMS}, P_{OUT} = 300mW		400		mW
OUTPUT CHARACTERISTICS						
V_{OUT}	Output voltage (USB-C PD) V_{IN} = 90 to 264V_{RMS}	I_{OUT} = 0 to 3.25A		19.950		V
		I_{OUT} = 0 to 3.00A		15.050		
				9.050		
				5.050		
I_{OUT}	Full load rated output current V_{IN} = 90 to 264V_{RMS}	V_{OUT} = 20.0V		3.250		A
		V_{OUT} = 5.0, 9.0, or 15.0V		3.000		
V_{OUT_pp}	Output ripple voltage[2] V_{IN} = 115V / 230V_{RMS}	V_{OUT} = 20.0V, I_{OUT} = 0 to 3.25A (Including switching noise)		420		mV pp
		V_{OUT} = 15.0V, I_{OUT} = 0 to 3.00A (Including switching noise)		380		
		V_{OUT} = 9.0V, I_{OUT} = 0 to 3.00A (Including switching noise)		280		
		V_{OUT} = 5.0V, I_{OUT} = 0 to 3.00A (Including switching noise)		200		
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} = 20.0V		-660 / 500		mV pp
		V_{OUT} = 15.0V		-520 / 480		
		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}		80		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} = 20V, I_{OUT} = 3.25A		94.08/ 94.63		%
		V_{OUT} = 15V, I_{OUT} = 3.00A		93.88 / 94.31		
		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} = 20V (CoC Tier 2, 89.0%)		94.14 / 93.85		%
		V_{OUT} = 15V (CoC Tier 2, 88.9%)		94.15 / 92.95		
		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} = 20V (CoC Tier 2, 79.0%)		92.04 / 89.39		%
		V_{OUT} = 15V (CoC Tier 2, 78.9%)		92.4 / 89.71		
		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.

(2) The voltage ripple numbers mentioned above include switching noise. Without this it is less than 150mVpp. Please refer section on "Section 3.3.9".

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 may 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

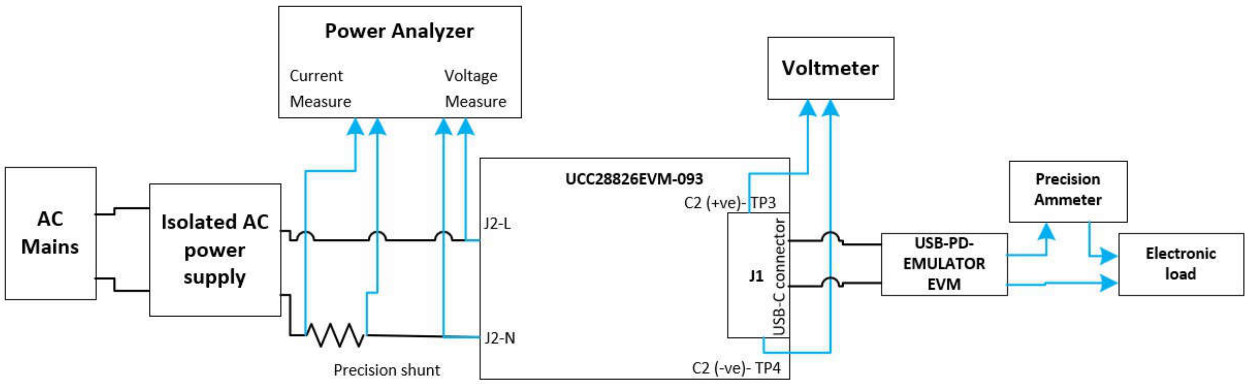


Figure 3-1. UCG28826EVM-093 Test Setup Diagram

The efficiency results for 25%-100% load are taken with the above configuration. For standby and 10% load the voltmeter is moved outside of the shunt to record efficiency numbers.

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 efficency calculation.

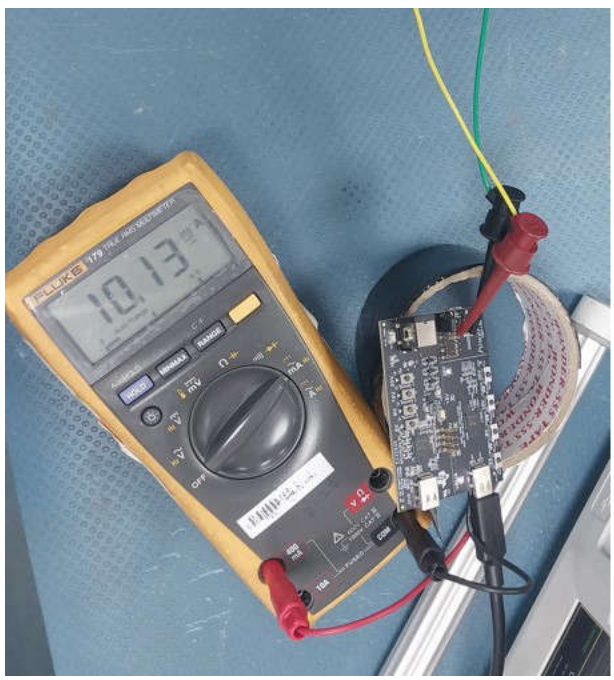


Figure 3-2. USB-C Emulator

3.2.3 Test Points

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

Terminals and TEST POINTS		NAME	DESCRIPTION
J1	J1 Terminal	J1	USB-C
J2-L	J2 Terminal	L	AC voltage input - Line
J2-N		N	AC voltage input - Neutral
TPL	Input test points	TPL1	AC input monitor - Line
TPN	Input test points	TPN1	AC input monitor - Neutral
TP1	Bulk voltage	VBULK	Bulk voltage measurement point
TP5 , TP9	Power / Primary GND	PGND	Ground
TP6	Drain	VSW	Switch node voltage
TP8	Feedback	FB	Feedback pin voltage
TP2	Source	SRC	Source of SR FET
TP3	Drain	VOUT	Drain of SR FET
TP7	SR Gate	GATE	SR FET gate voltage pin
TP10	Output bus voltage	VBUS	Bus voltage at output side
TP11	Output return line	RTN	Return line atoutput side

3.3 Performance Data and Typical Characteristic Curves

3.3.1 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%

3.3.2 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%

3.3.3 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%

3.3.4 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%

Note

Please refer "Section 6" section for more efficiency results with a different power analyzer. This was done as the above readings showed some slight offset in the measured input current and hence low line efficiency numbers are marginally low.

3.3.5 Efficiency Typical Results

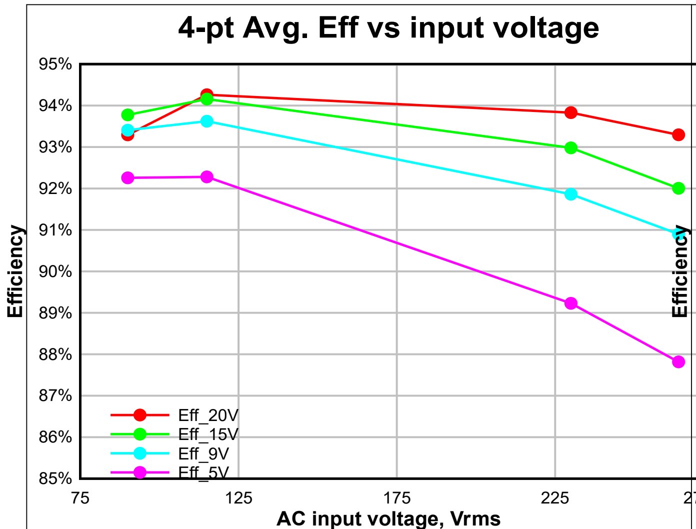


Figure 3-3. 4pt-Average Efficiency vs. Input Voltage

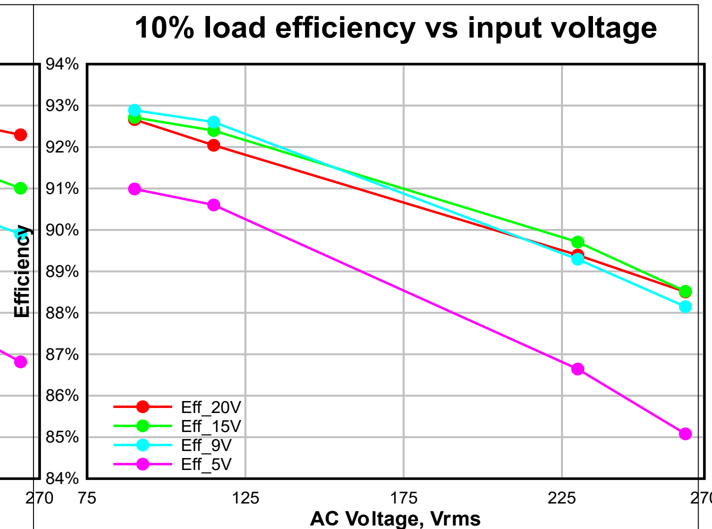


Figure 3-4. Efficiency of 10%-Load vs. Input Voltage

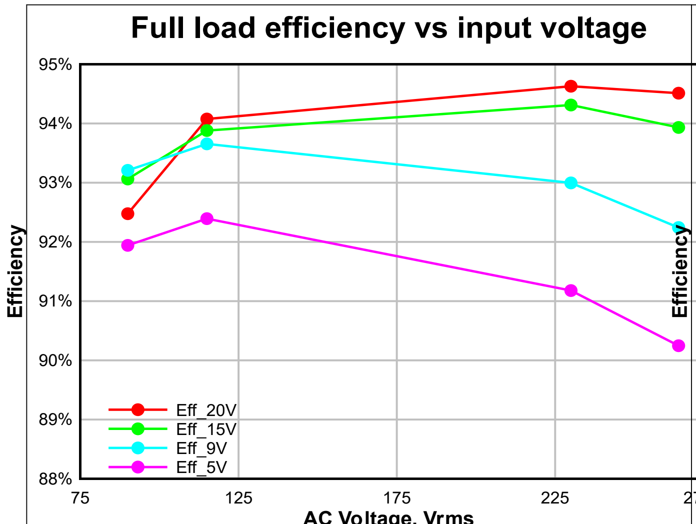


Figure 3-5. Full-load Efficiency vs. Input Voltage

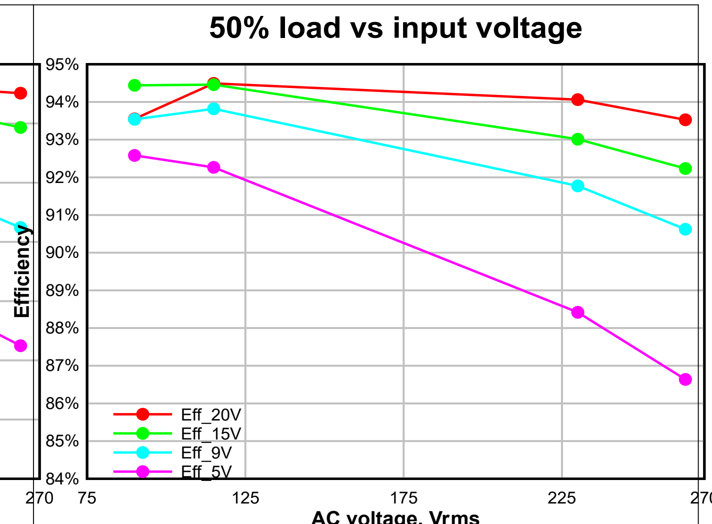


Figure 3-6. Efficiency of 50%-load vs. Input Voltage

3.3.6 Output Characteristics

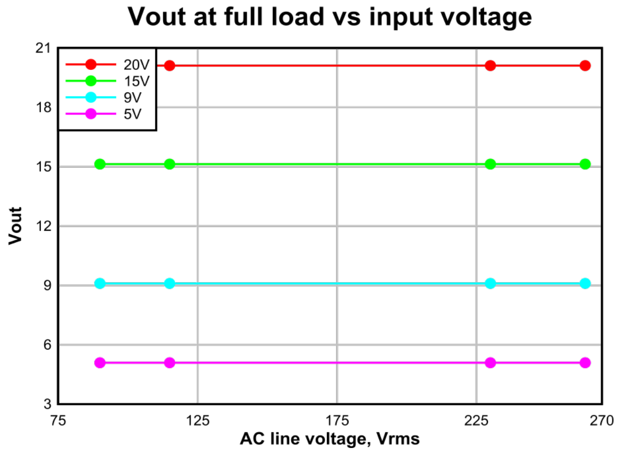


Figure 3-7. V_{OUT} at Full-Load vs Input Voltage

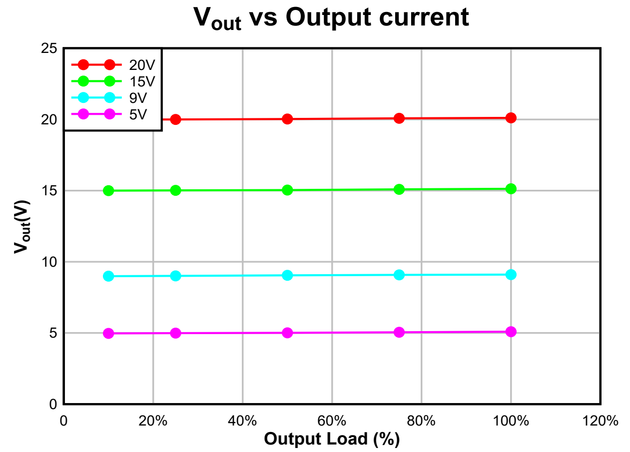


Figure 3-8. V_{OUT} vs Output Current

3.3.7 Key Switching Waveforms

This section (Figure 3-9 to Figure 3-24) shows typical switching waveforms at full load. YELLOW = Switch Node, BLUE = Output Voltage, BROWN - SR Gate voltage, RED - FB

Figure 3-9. Vin = 90Vac, Vout = 20V

Figure 3-10. Vin = 115Vac, Vout = 20V

Figure 3-11. Vin = 230Vac, Vout = 20V

Figure 3-12. Vin = 264Vac, Vout = 20V

Figure 3-13. Vin = 90Vac, Vout = 15V

Figure 3-14. Vin = 115Vac, Vout = 15V

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

Figure 3-16. Vin = 264Vac, Vout = 15V

Figure 3-17. Vin = 90Vac, Vout = 9V

Figure 3-18. Vin = 115Vac, Vout = 9V

Figure 3-19. Vin = 230Vac, Vout = 9V

Figure 3-20. Vin = 264Vac, Vout = 9V

Figure 3-21. Vin = 90Vac, Vout = 5V

Figure 3-22. Vin = 115Vac, Vout = 5V

Figure 3-23. Vin = 230Vac, Vout = 5V

Figure 3-24. Vin = 264Vac, Vout = 5V

3.3.8 Switching Frequency vs Load

This section shows typical switching waveforms at different load conditions. YELLOW = Switch Node, GREEN= Vbulk, PINK - Vfb

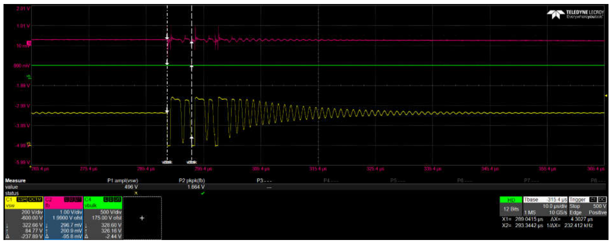


Figure 3-25. 230Vac/0.6W (240khz burst frequency/ Vfb - 0.3V)

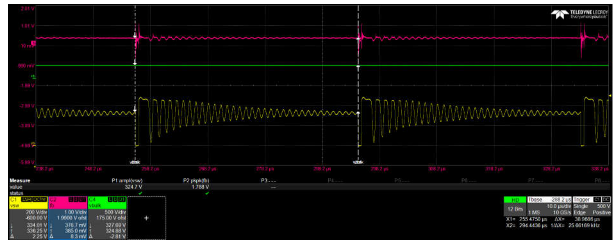


Figure 3-26. 230Vac/1.2W (25kHz frequency - foldback / Vfb - 0.35V)

Figure 3-27. 230Vac/5.3W (87kHz frequency/ Vfb - 0.7V)

Figure 3-28. 230Vac/17W (113kHz frequency/ Vfb - 1.1V)

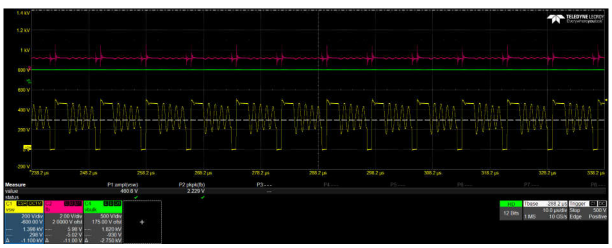


Figure 3-29. 230Vac/25W (125kHz frequency/ Vfb - 1.2V)

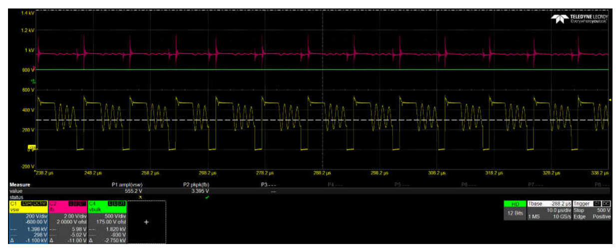


Figure 3-30. 230Vac/45W (130kHz frequency/ Vfb - 1.7V)

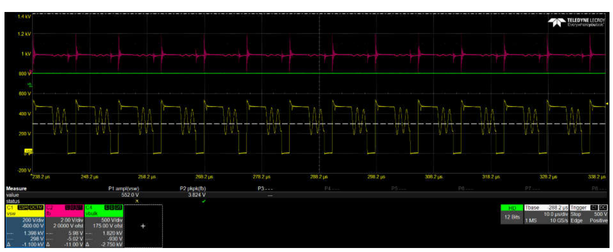


Figure 3-31. 230Vac/65W (140kHz frequency/ Vfb - 1.9V)

3.3.9 Output Ripple Voltage

Figure 3-32 to Figure 3-40 shows the output voltage ripple. Blue = Output Voltage Ripple, Oscilloscope Channel Bandwidth = 20MHz. The ripples are with the 100% load condition unless specified in the associated figures.

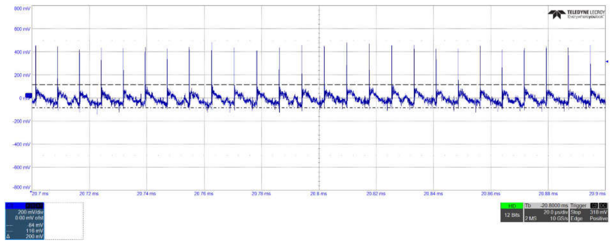


Figure 3-32. Typical Ripple Voltage of V_{OUT} = 20V (420mVpp)

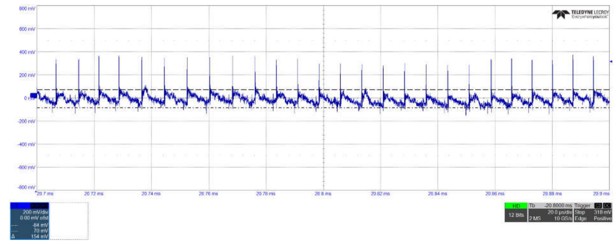


Figure 3-33. Typical Ripple Voltage of V_{OUT} = 15V (380mVpp)

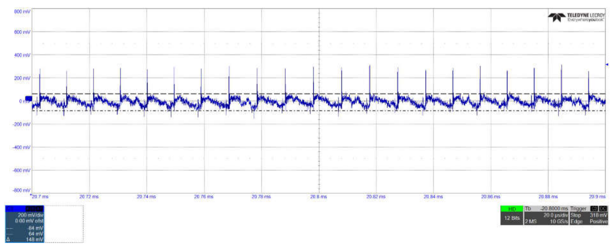


Figure 3-34. Typical Ripple Voltage of V_{OUT} = 9V (280mVpp)

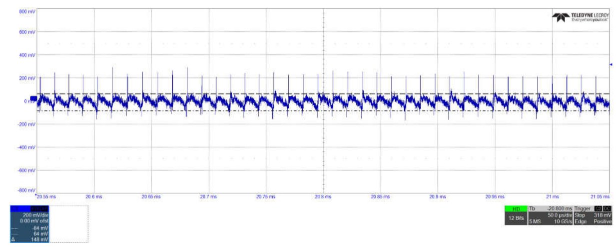


Figure 3-35. Typical Ripple Voltage of V_{OUT} = 5V (200mVpp)

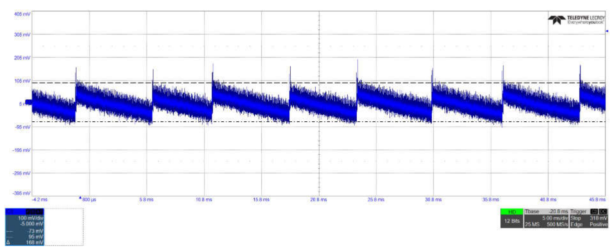


Figure 3-36. Typical Ripple Voltage of V_{OUT} = 5V at No Load (168mVpp)

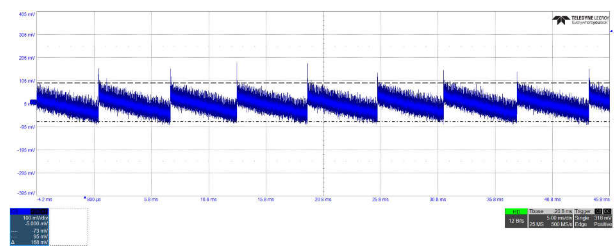


Figure 3-37. Typical Ripple Voltage of V_{OUT} = 5V at No Load (168mVpp)

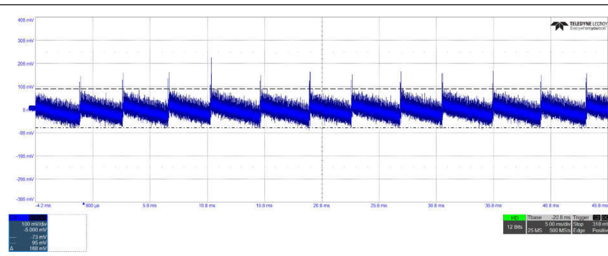


Figure 3-38. Typical Ripple Voltage of V_{OUT} = 15V at No Load (168mVpp)

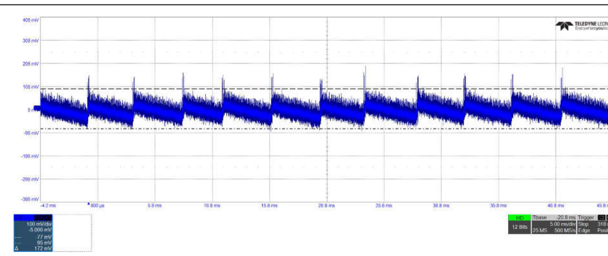


Figure 3-39. Typical Ripple Voltage of V_{OUT} = 20V at No Load (168mVpp)

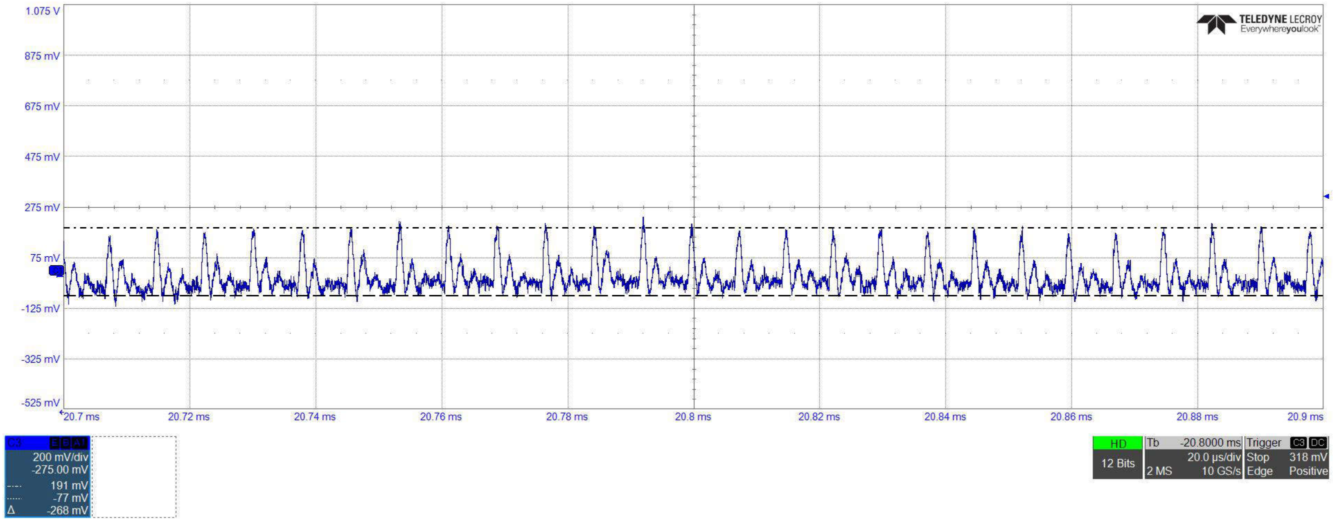


Figure 3-40. Typical Ripple Voltage of V_{OUT} = 20V at Full Load (260mVpp)

3.3.10 Load Transient Response

Figure 3-41 to Figure 3-44 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.

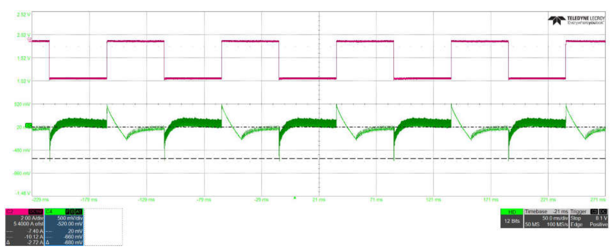


Figure 3-41. Load Transient Response at V_{OUT} = 20V Overshoot / Undershoot = 495mV / -680mV

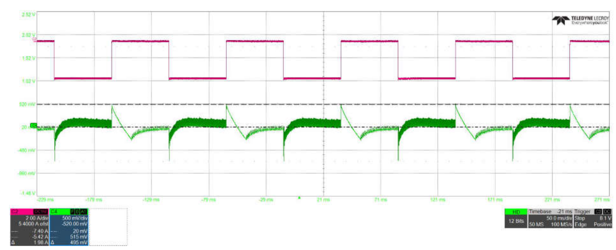


Figure 3-42. Transient Response at V_{OUT} = 15V Overshoot / Undershoot = 485mV / -630mV

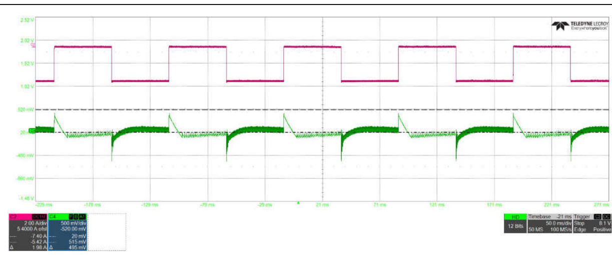


Figure 3-43. Transient Response at V_{OUT} = 9V Overshoot / Undershoot = 460mV / -500mV

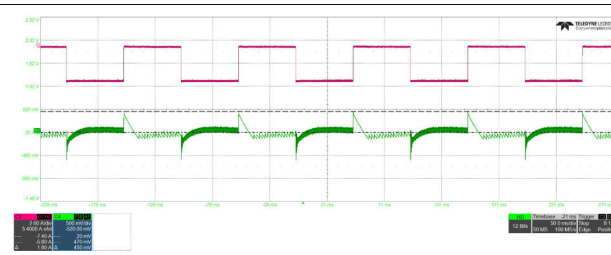


Figure 3-44. Transient Response at V_{OUT} = 5V Overshoot / Undershoot = 440mV / -480mV

3.3.11 Line transient Response

Figure 3-45 and Figure 3-46shows 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

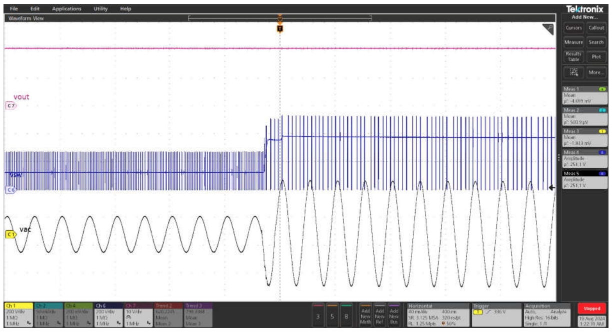


Figure 3-45. Line transient from 90Vac to 265Vac at 20V/No load

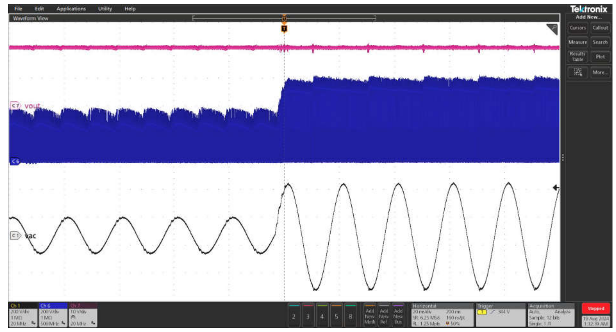


Figure 3-46. Line transient from 90Vac to 265Vac at 20V/Full load

3.3.12 Surge Test

Figure 3-47 and Figure 3-48 shows response when 2KV and 1KV surge is applied to the EVM with one positive impulse and a phase angle of 90 degrees

YELLOW - Bulk voltage, PURPLE - Switching Node Voltage

Figure 3-47. 2KV Surge at 230Vac input

Figure 3-48. 1KV Surge at 230Vac input

3.3.13 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 18V when peak short term overload of 6.5A is applied for 2ms (Figure 3-50) and also when 7.32A is applied for 1ms (Figure 3-49). The results are checked at 230Vac and 100Vac.

VSW = PINK, Load Current = GREEN, VOUT = BLUE, FB = YELLOW

The output votage drops to approximatly 18.2V

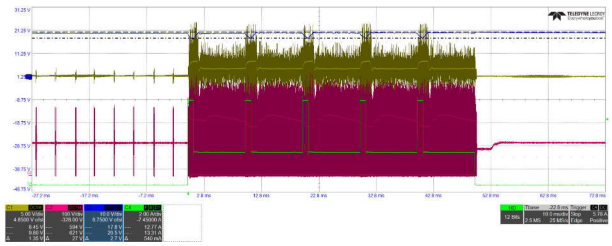


Figure 3-49. VIN=100Vac (2.25x rated current for 1ms, 0.9x rated current for 9ms)

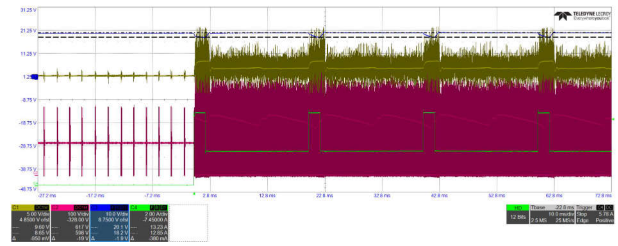


Figure 3-50. VIN=100Vac (2x rated current for 2ms, 0.9x rated current for 18ms)

3.3.14 CCM operation

VSW = PINK, Load Current = GREEN, VOUT = BLUE, FB = YELLOW

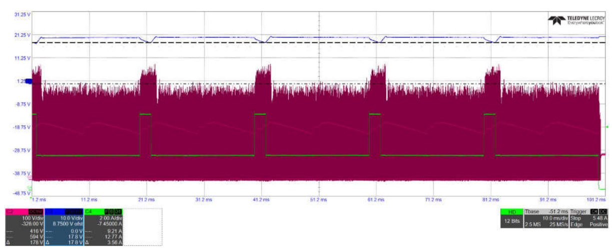


Figure 3-51. VIN=90Vac (2x rated current for 2ms, 0.9x rated current for 18ms)

Figure 3-52. VIN=90Vac (2x rated current for 2ms, 0.9x rated current for 18ms) - Zoomed

3.3.15 EN55022 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 3-54 shows scan with existing EVM components. However, Figure 3-53 shows scan taken with the an additional DM choke of 22uH placed before L5 in the schematic. Final EMI analysis will be available in the final release of this EVM.

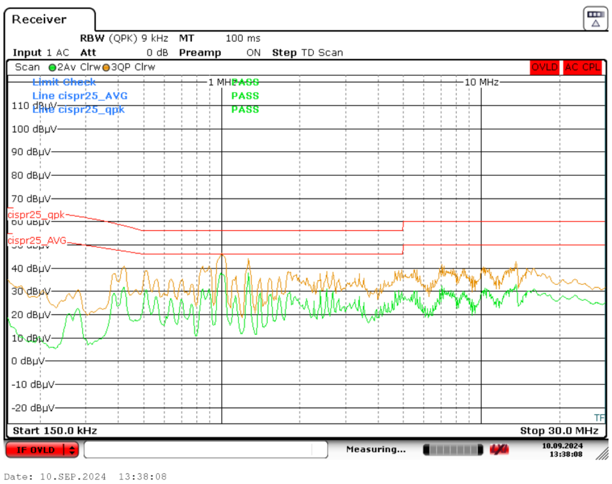


Figure 3-53. VIN = 230V$_{RMS}$, VOUT = 20V, Load = 3.25A (Output Not Grounded to LISN Ground) - With DM choke modification

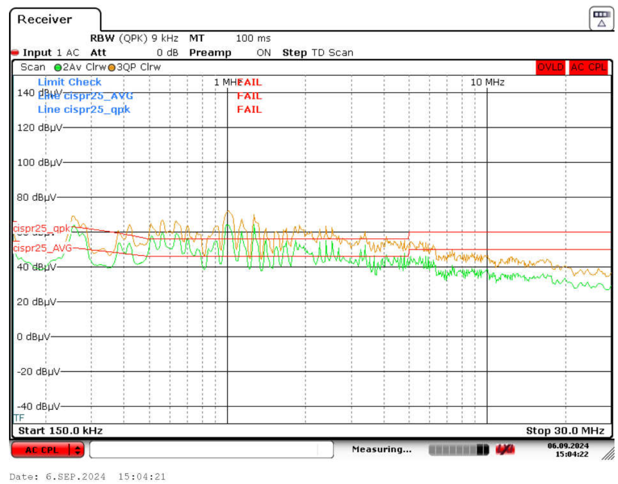


Figure 3-54. VIN = 230V$_{RMS}$, VOUT = 20V, Load = 3.25A (Output Not Grounded to LISN Ground) - Orginal EVM

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

Figure 3-55 to Figure 3-62 shows the thermal images at full load for different line voltage

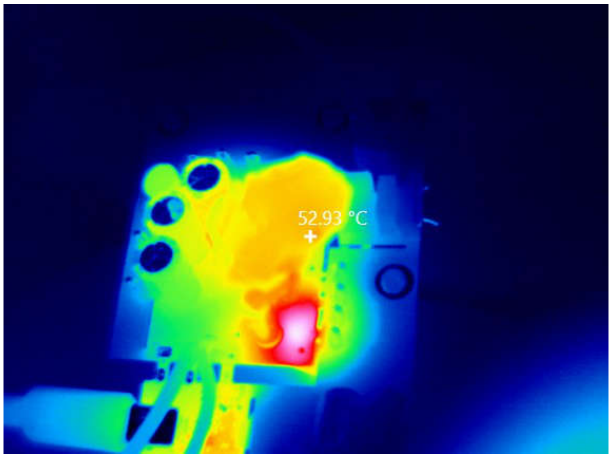


Figure 3-55. V_{IN} = 90V_{AC}, Top Side

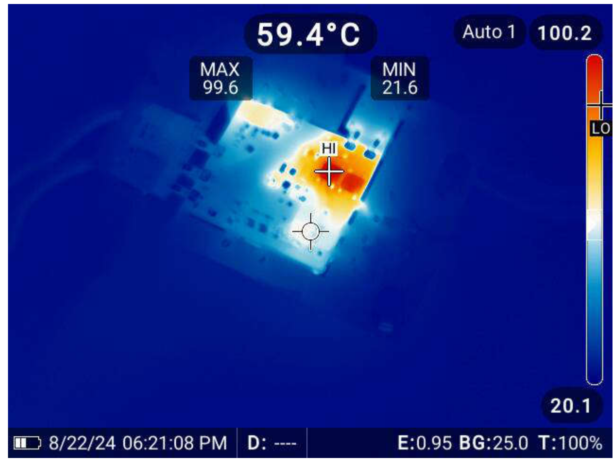


Figure 3-56. V_{IN} = 90V_{AC}, Bottom Side

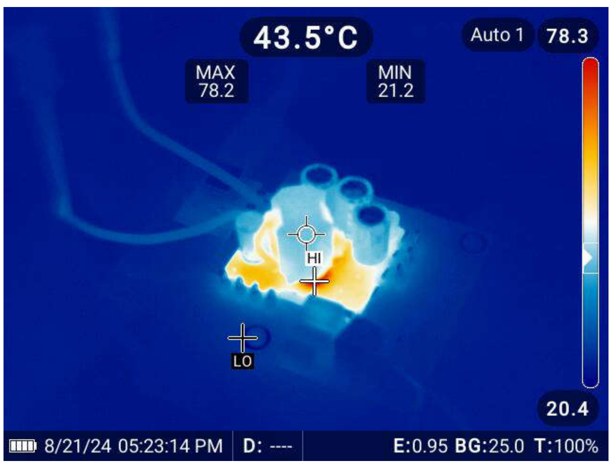


Figure 3-57. V_{IN} = 115V_{AC}, Top Side

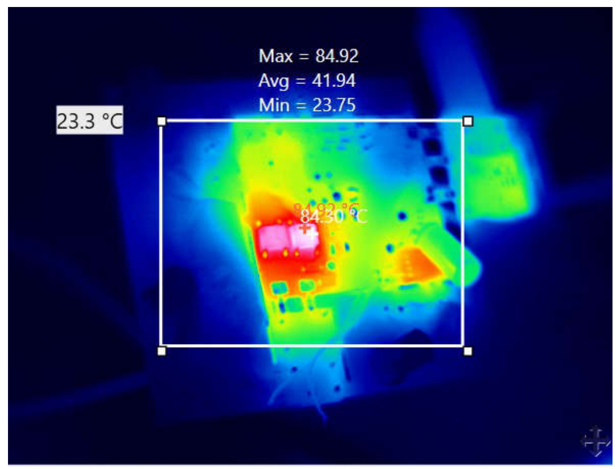


Figure 3-58. V_{IN} = 115V_{AC}, Bottom Side

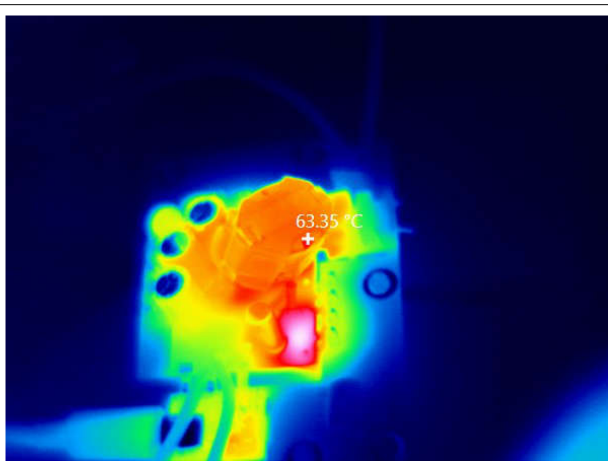


Figure 3-59. V_{IN} = 230V_{AC}, Top Side

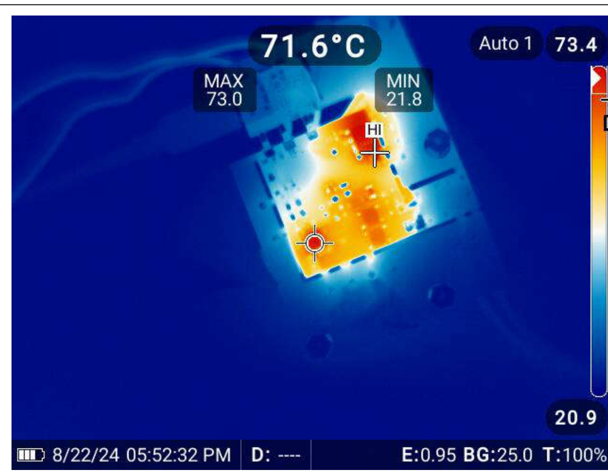


Figure 3-60. V_{IN} = 230V_{AC}, Bottom Side

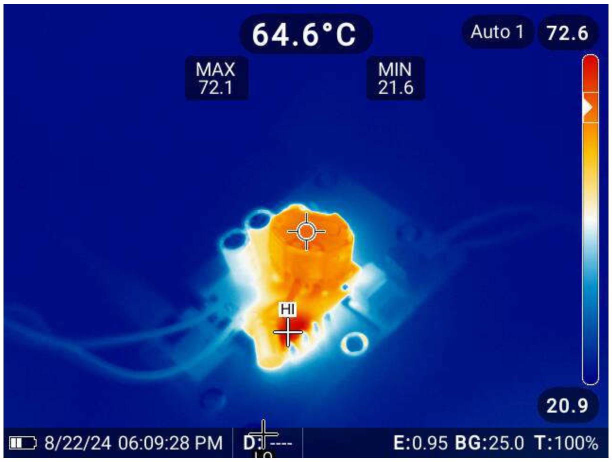


Figure 3-61. V_{IN} = 265V_{AC}, Top Side

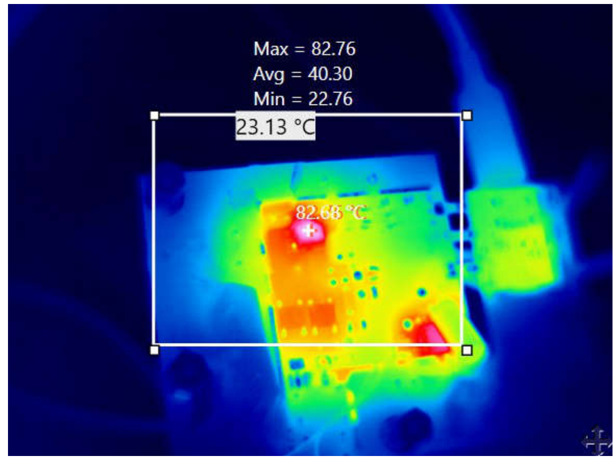
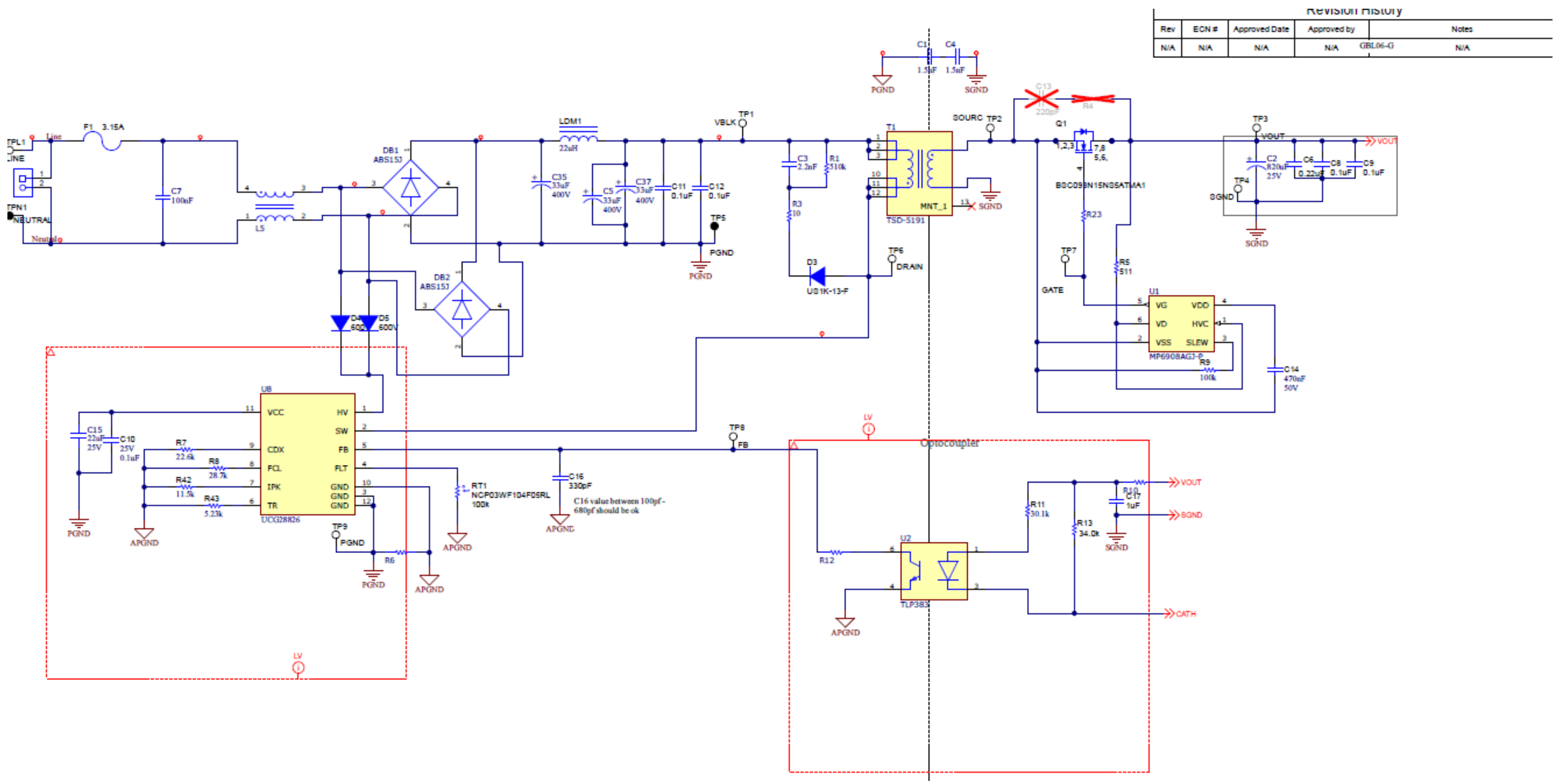


Figure 3-62. V_{IN} = 265V_{AC}, Bottom Side

4 Hardware Design Files

4.1 Schematics



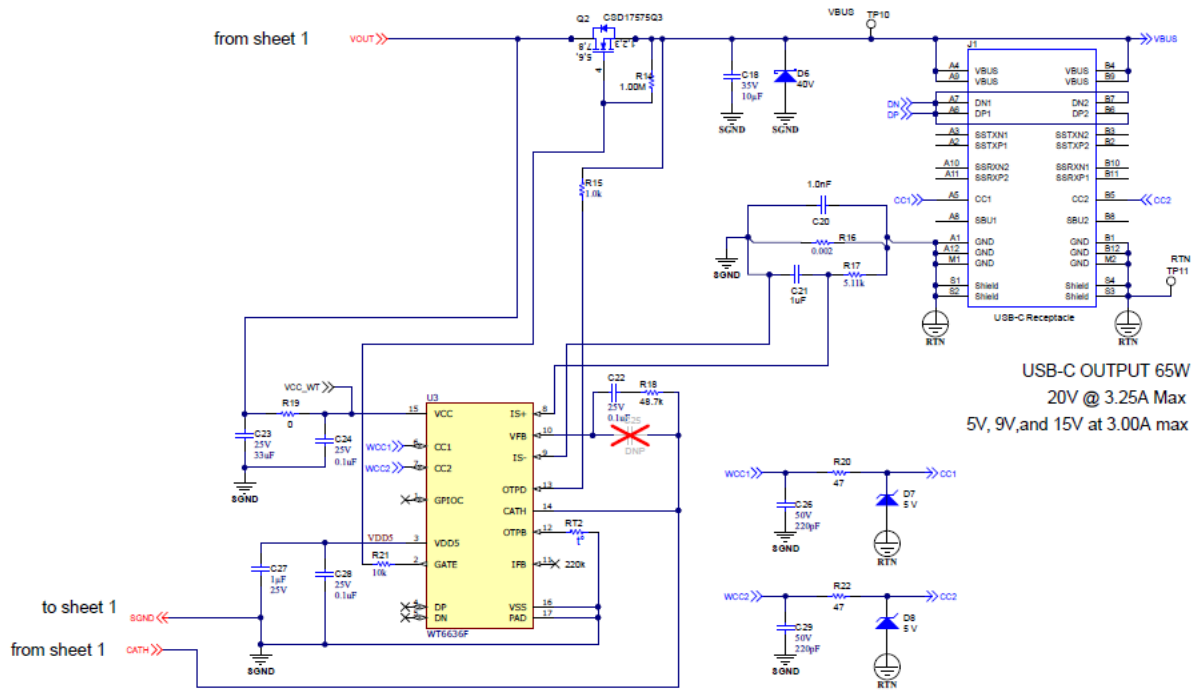


Figure 4-1. UCG28826EVM-093 Schematic Diagram

4.2 PCB Layouts

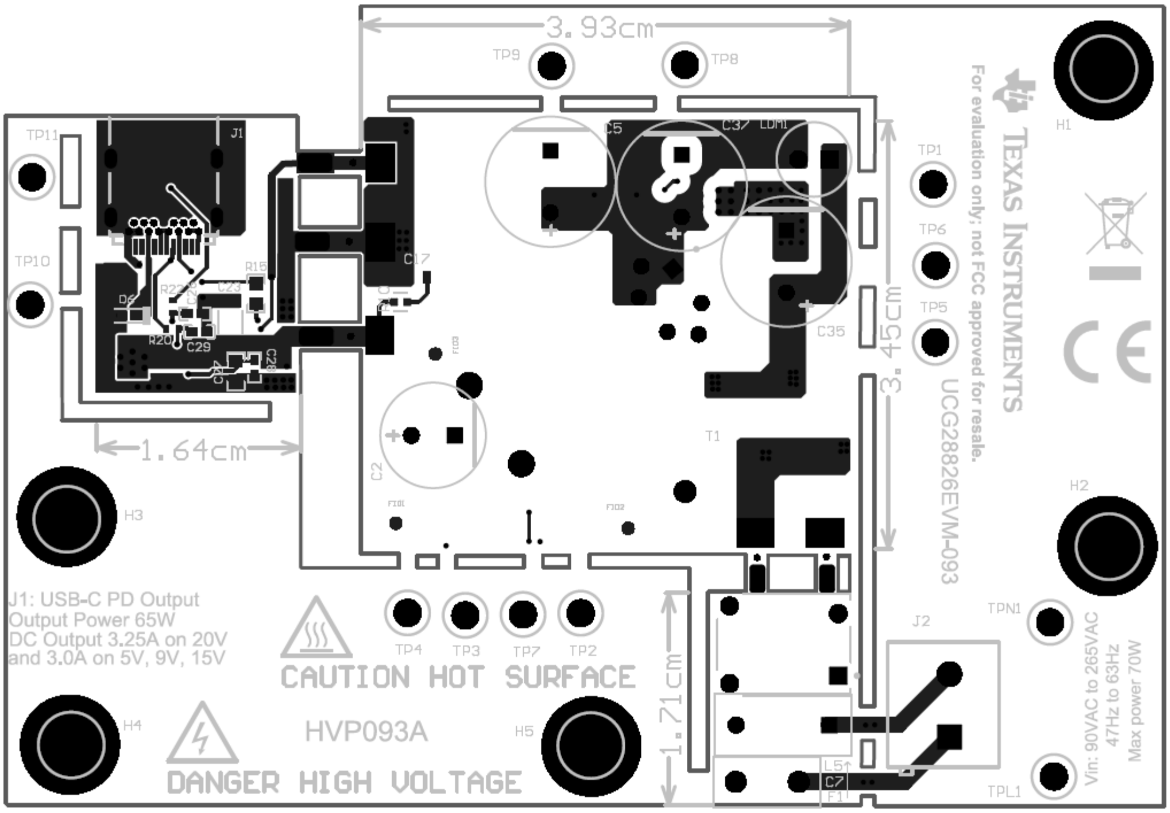


Figure 4-2. EVM Assembly (Top View)

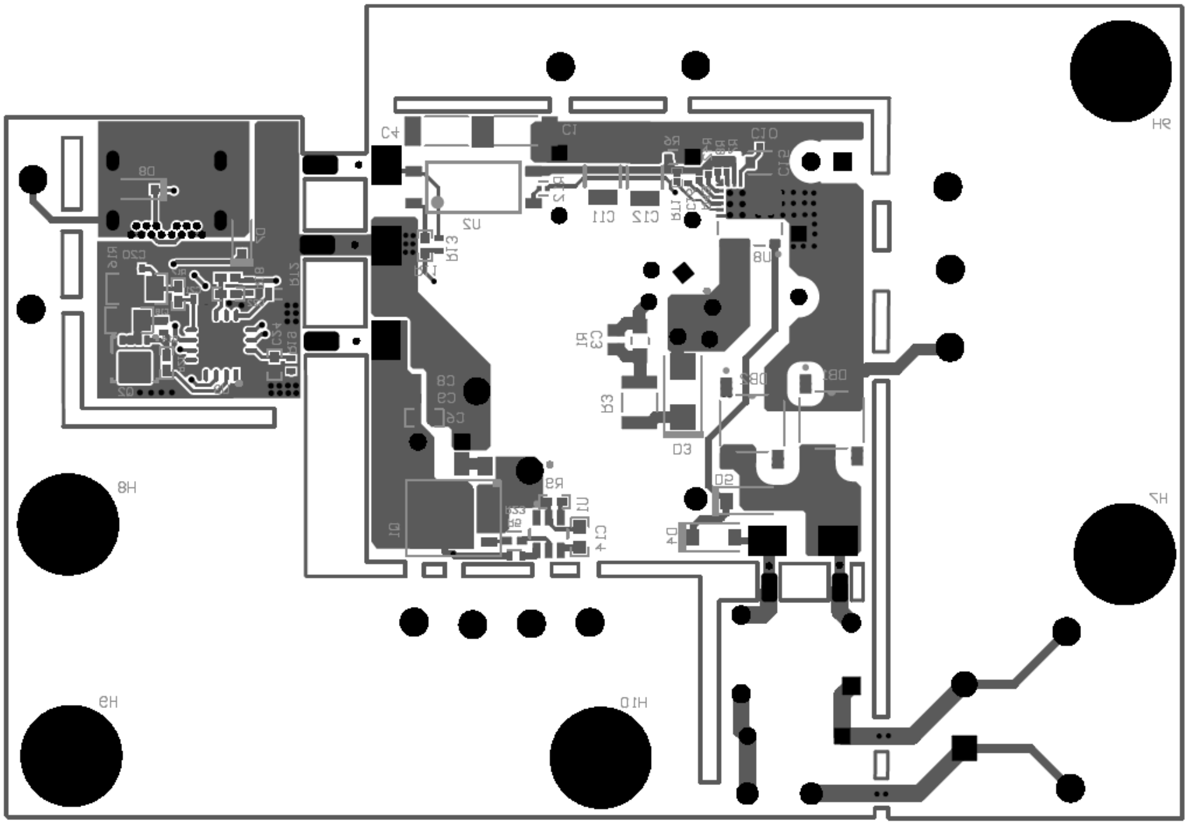


Figure 4-3. EVM Assembly (Bottom View)

4.3 Transformer Details

This design uses three different transformer variants from Renco, Wurth Electronik and Premier Magnetics and the specifications are mentioned below. Also variants are wound on the same RM8 core set and are compatible with EVM.

4.3.1 RLTI-1464 (RENCO)

This transformer is most optimal and recommended for this design to meet the efficiency specifications. This achievs good balance between leakage energy (thereby enabling efficiency) and interwinding capacitance (helps with the thermal performance of UCG28826).

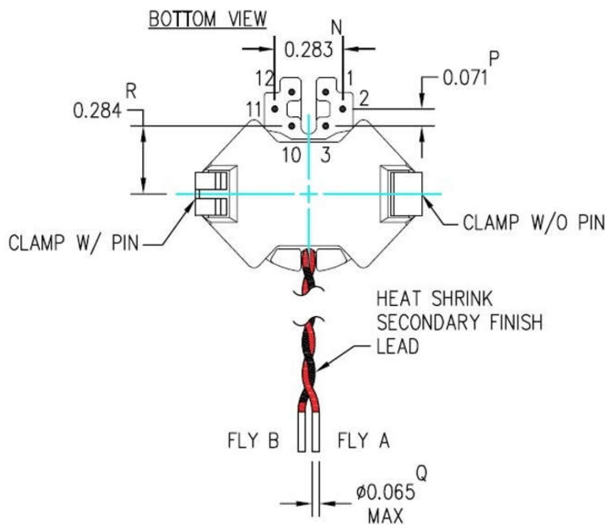


Figure 4-4. RLTI-1464 pin configuration

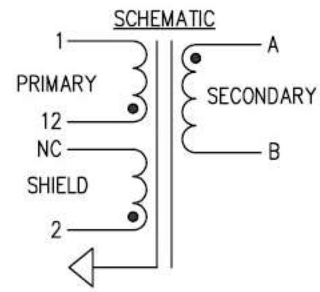


Figure 4-5. RLTI-1464 Schematic

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

4.3.2 750847341Rev02 (WURTH)

This 750847341Rev02 comes with a turns ratio of 7:1 and hence it is slightly less efficient than RLTI1464. The drawback of 750847341Rev02 is more leakage which slightly lowers efficiency. Interwinding capacitance is similar in performance to RLTI-1464 and also improves the thermal performance of UCG28826. The terminals 3 and 4 of the 750847341Rev02 needs to be shorted externally before these are inserted in to the EVM. There is another optimized variant from Wurth 750847341Rev03 which has a turns ratio of 6:1 with all other specifications remaining the same as the Rev02 variant. If using 750847341Rev02 variant, ensure C3 is 4.7nF capacitor like GRM21AR72H472KW10D, D3 is a slow diode like SL1K and R1 is close to 200kΩ like ERJ-P06J204V. R43 which is the turns ratio setting resistor needs to be changed to 25.5kΩ.

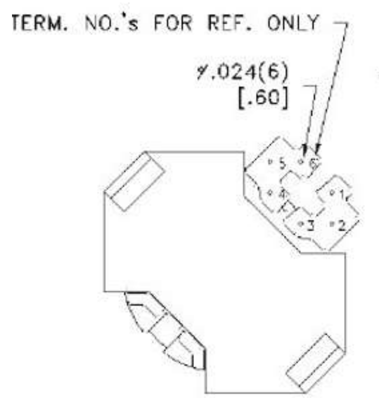


Figure 4-6. 750847341Rev02 pin configuration

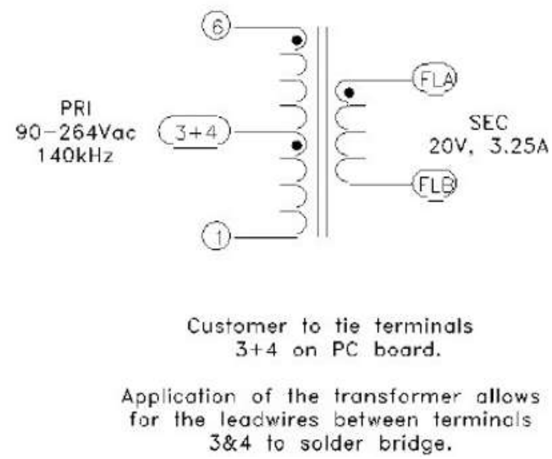


Figure 4-7. 750847341Rev02 schematic

Table 4-2. Transformer Specifications at 25°C

PARAMETER	VALUE	PINS/LEADS	TEST CONDITIONS
Inductance (µH)	200µH ±10%	6:1	Open all other pins, 100kHz / 0.1Vac
Leakage Inductance (µH)	6uH	6:1	tie(3+4,FLA+FLB),100kHz, 100mV,
D.C. resistance (Ω)	0.23	6:1	tie(3+4), @20ºC
D.C. resistance (Ω)	0.03	FLA:FLB	@20ºC
Dielectric (VAC, 60Hz)	3000Vac	1– FLA	tie(3+4), 3000VAC, 1 second , 1mA 60Hz
Turns-ratios	7:1	(6-1):(FLA-FLB), tie(3+4)	APPLY: 1.0V @ 10kHz to (6 - 1) Vout: (FLA-FLB) 0.142V

4.3.3 TSD-5191 (Premier Magnetics)

This transformer comes with a turns ratio of 7:1. Although this transformer has the advantage of lowest leakage amongst all variants the major drawback of this transformer is higher interwinding capacitance which heats up the UCG28826 controller. The

Snubber components used can be the same as RLTI-1464. R43 which is the turns ratio setting resistor needs to be changed to 25.5kΩ.

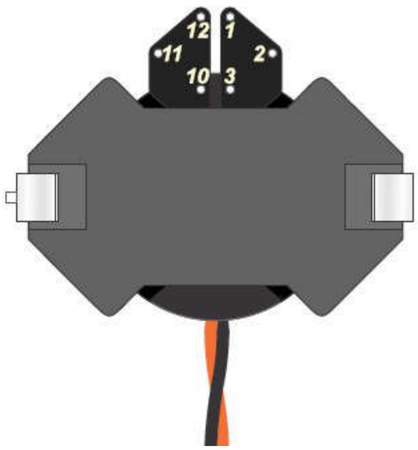


Figure 4-8. TSD-5191 Pin Configuration

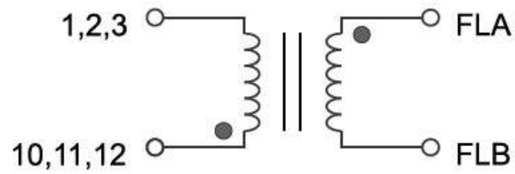


Figure 4-9. TSD-5191 Schematic

Table 4-3. Transformer Specifications at 25°C

PARAMETER	VALUE	PINS/LEADS	TEST CONDITIONS
Inductance (µH)	200µH ±5%	(10,11,12) - (1,2,3)	Open all other pins, 100kHz / 0.1Vac
Leakage Inductance (µH)	3µH	(10,11,12) - (1,2,3)	Short FLA - FLB, 100kHz / 0.1Vac
Dielectric (VAC, 60Hz)	4000Vac	(10,11,12):FLA	60Hz, 3mA, 1s ramp, 1s dwell
Turns-ratios	7:1	(10,11,12)-(1,2,3): (FLA:FLB)	APPLY: 1.0V @ 10 kHz to (10,11,12)-(1,2,3) Vout: (FLA-FLB) 0.142V

4.3.4 Transformer Summary

Table 4-4. Transformer Specifications Summary

Transformer type	Turns ratio	Leakage	Interwinding Cap
TSD-5191	7:1	1.7uH	240pF
750847341Rev02	7:1	4.9uH	75pF
RLTI-1464	6:1	2.7uH	85pF

Table 4-5. BOM Summary

Transformer type	BOM Modifications
TSD-5191	D3 - US1k-13-F , R3 -10ohms, R2 – 0hms, R1 – 511k, C3 – 1nF, R43 - 25.5k
750847341Rev02	D3 - SL1K/SE20AFJ-M3/6A (trr- 1us); R3 -10ohms, R2 – 0hms, R1 – 150k, C3 – 4.7nF, R43 - 25.5k
RLTI-1464	D3 - US1k-13-F; R3 -10ohms, R2 – 0hms, R1 – 510k, C3 – 2.2nF, R43 - 5.23k

4.4 Bill of Materials

Table 4-6 lists the bill of materials for UCG28826EVM-093.

Table 4-6. Bill of Materials

Designator	Value	Quantity	Description	Part Number	Manufacturer
C1, C4	1.5nF	2	1500 pF ±10% 250VAC Ceramic Capacitor X7R 1808 (4520 Metric)	1808YA250152KJTSYX	Knowles Syfer
C2	820uF	1	820uF 25V ±20% Plugin,D8xL14mm Aluminum Electrolytic Capacitors	NPXD1401E821MF	Ymin
C3	2.2nF	1	2200 pF ±10% 500V Ceramic Capacitor X7R 0805 (2012 Metric)	C0805C222KCRAC7800	KEMET
C5, C35, C37	33uF	3	33uF 400V 500mΩ@100kHz 370mA@100kHz ±20% Plugin,D10xL15mm Aluminum Electrolytic Capacitors	87EC0493	KNSCHA
C6	0.22uF	1	CAP, CERM, 0.22 µF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	CGA3E3X7R1H224K080AB	TDK
C7	100nF	1	Suppression Capacitors P=7.5mm 100nF ±10% X2 310VAC	MPX104K31B3KN20600	KNSCHA
C8, C9	0.1uF	2	CAP, CERM, 0.1 µF, 25 V, +/- 10%, X7R, 0402	GRM155R71E104KE14D	MuRata
C10	0.1uF	1	CAP, CERM, 0.1 uF, 25 V, +/- 10%, X5R, 0201	GRM033R61E104KE14J	MuRata
C11, C12	0.1uF	2	CAP, CERM, 0.1 uF, 630 V, +/- 10%, X7R, 1210	C1210C104KBRAC7800	Kemet
C14	0.47uF	1	CAP, CERM, 0.47 uF, 50 V, +/- 10%, X7R, 0603	C1608X7R1H474K080AC	TDK
C15	22uF	1	22 µF ±20% 25V Ceramic Capacitor X5S 0603 (1608 Metric)	GRM188C61E226ME01J	MuRata
C16	8330pF	1	CAP, CERM, 330 pF, 50 V, +/- 10%, X7R, 0402	GRM155R71H331KA01D	MuRata
C17	1uF	1	CAP, CERM, 1 µF, 25 V, +/- 10%, X7R, 0603	C1608X7R1E105K080AB	TDK
C18	10uF	1	CAP, CERM, 10 µF, 35 V,+/- 10%, X5R, 0805	GMK212BBJ106KG-T	Taiyo Yuden
C20	1000pF	1	CAP, CERM, 1000 pF, 50 V, +/- 10%, X7R, 0402	885012205061	Wurth Elektronik
C21	1uF	1	CAP, CERM, 1 µF, 6.3 V, +/- 20%, X7R, 0402	GRM155R70J105MA12D	MuRata
C22, C24, C28	0.1uF	3	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
C26, C29	220pF	1	CAP, CERM, 220 pF, 50 V, +/- 10%, X7R, 0402	GRM155R71H221KA01D	MuRata
C27	1uF	1	CAP, CERM, 1 uF, 25 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	GCM188R71E105KA64D	MuRata
D3	800V	1	Diode, Fast Rectifier, 800 V, 1 A, SMA	US1K-13-F	Diodes Inc.

Table 4-6. Bill of Materials (continued)

Designator	Value	Quantity	Description	Part Number	Manufacturer
D4, D5	600V	2	Diode, Switching, 600 V, 1 A, SOD-123	ES1JFL	ON Semiconductor
D6	40V	1	Diode, Schottky, 40 V, 0.2 A, SOD-523	RB521SM-40T2R	Rohm
D7, D8	5V	2	TVS, 5 V, bidirectional, SOD-323	PESD5V0L1BA,115	NXP Semiconductor
DB1, DB2		2	Diode Rectifier Bridge Quad 600V 1.5A 4-Pin ABS T/R	ABS15J	Taiwan Semiconductor
F1	3.15A	1	Fuse, 3.15 A, 250VAC/VDC, TH	RST 3.15-BULK	Bel-Fuse
FID1, FID2, FID3			Fiducial mark. There is nothing to buy or mount.	N/A	N/A
H1, H2, H3, H4. H5		5	MACHINE SCREW PAN PHILLIPS 4-40	NSP-4-4-01	Essentra Components
H6, H7, H8, H9, H10		5	Standoff, Hex, 0.5"L #4-40 Nylon	1902C	Keystone
J1	USB-C Receptacle	1	Connector, Receptacle, USB Type C, R/A	632723300011	Wurth Elektronik
J2		1	Terminal Block, 5.08 mm, 2x1, Brass, TH	ED120/2DS	On-Shore Technology
L5		1	2 Line Common Mode Choke Through Hole 2A DCR 50mOhm	DKFP-6248-02D5	Schurter
LDM1	22uH	1	Inductor, Unshielded Drum Core, Ferrite, 22 uH, 1.7 A, 0.102 ohm, TH	7447462220	Wurth Elektronik
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	510k	1	510 kOhms ±5% 0.5W, 1/2W Chip Resistor 0805 (2012 Metric) Automotive AEC-Q200, Pulse Withstanding Thick Film	ERJ-P06J514V	Panasonic Electronic Components
R3	10	1	10Ω ±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
R6, R12	0	2	0Ω ±0 0.05W 0201 Thick Film Chip Resistor AEC-Q200 compliant	RMCF0201ZT0R00	Stackpole Electronics
R7	22.6k	1	RES, 22.6 k, 1%, 0.05 W, 0201	RC0201FR-0722K6L	Yageo America
R8	28.7k	1	RES, 28.7 k, 1%, 0.05 W, 0201	CRCW020128K7FKED	Vishay-Dale
R9	100k	1	RES, 100 k, 1%, 0.1 W, 0402	ERJ-2RKF1003X	Panasonic
R10	0	1	RES Thick Film, 0Ω, 0.2W, 0402	CRCW04020000Z0EDHP	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	1.0Meg	1	RES, 1.00 M, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	RMCF0402FT1M00	Stackpole Electronics Inc
R15	1k	1	RES, 1.0 k, 5%, 0.25 W, AEC-Q200 Grade 0, 0603	ESR03EZPJ102	Rohm

Table 4-6. Bill of Materials (continued)

Designator	Value	Quantity	Description	Part Number	Manufacturer
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	4.87k	1	RES, 48.7 k, 1%, 0.063 W, 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, 5%, 0.063 W, 0402	CRCW040247R0JNED	Vishay-Dale
R21	10k	1	RES, 10 k, 5%, 0.063 W, 0402	CRCW040210K0JNED	Vishay-Dale
R23	0uΩ	1	0 Ohms Jumper 0.1W, 1/10W Chip Resistor 0402 (1005 Metric) - Thick Film	CR0402-10W-000T	Venkel
R42	11.5k	1	RES, 11.5 k, 1%, 0.05 W, 0201	RC0201FR-0711K5L	Yageo America
R43	5.23k	1	RES, 5.23 k, 1%, 0.05 W, 0201	RC0201FR-075K23L	Yageo America
RT1	100k	1	Thermistor NTC, 100k ohm, 1%, 0201	NCP03WF104F05RL	MuRata
RT2	220k	1	Thermistor NTC, 220k ohm, 5%, 0603	NCP18WM224J03RB	MuRata
T1		1	Flyback Transformer	TSD-5191 RLTI-1464/1454 750847341	Premier Magnetics RENCO Wurth Elektronik
TP1		1	Test Point, Multipurpose, White, TH	5012	Keystone
TP2		1	Test Point, Multipurpose, White, TH	5012	Keystone
TP3		1	Test Point, Multipurpose, White, TH	5012	Keystone
TP4		1	Test Point, Multipurpose, White, TH	5012	Keystone
TP5		1	Test Point, Multipurpose, Black, TH	5011	Keystone
TP6		1	Test Point, Multipurpose, White, TH	5012	Keystone
TP7		1	Test Point, Multipurpose, White, TH	5012	Keystone
TP8		1	Test Point, Multipurpose, White, TH	5012	Keystone
TP9		1	Test Point, Multipurpose, White, TH	5012	Keystone
TP10		1	Test Point, Multipurpose, White, TH	5012	Keystone
TP11		1	Test Point, Multipurpose, White, TH	5012	Keystone
TPL1		1	Test Point, Multipurpose, White, TH	5012	Keystone
TPN1		1	Test Point, Multipurpose, Black, TH	5011	Keystone
U1		1	FAST TURN-OFF INTELLIGENT RECTIFIER	MP6908AGJ-P	Monolithic Power Systems
U2		1	Optoisolator Transistor Output 5000Vrms 1 Channel 6-SO	TLP383(GR-TPL,E	Toshiba
U3		1	USB PD/QC4/QC4+ Controller	WT6636F	Weltrend
U8		1	UCG28826 - Flyback controller	UCG28826	Texas Instruments

5 Appendix - Efficiency

In this section, the input current into the EVM was measured using a precision ammeter in order remove the unertainities with the current measurement offset in the power analyzer which can arise due to improper calibration of the equipment.

SYSTEMS CHARACTERISTICS				
η	Full-load efficiency (V_{IN}= 115/230V_{RMS})	V_{OUT} = 20V, I_{OUT} = 3.25A	94.08/ 94.63	%
		V_{OUT} = 15V, I_{OUT} = 3.00A	93.88 / 94.31	
		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} = 20V (CoC Tier 2, 89.0%)	94.14 / 93.85	%
		V_{OUT} = 15V (CoC Tier 2, 88.9%)	94.15 / 92.95	
		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}= 115/230V_{RMS}	V_{OUT} = 20V (CoC Tier 2, 79.0%)	92.04 / 89.39	%
		V_{OUT} = 15 V (CoC Tier 2, 78.9%)	92.4 / 89.71	
		V_{OUT} = 9V (CoC Tier 2, 77.3%)	92.6 / 89.29	
		V_{OUT} = 5V (CoC Tier 2, 72.5%)	90.6 /86.64	

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

V_{IN} (VRMS)	P_{IN} (W)	I_{IN}(IRMS)	PF	P_{OUT} (W)	P_EMULATOR (W)	P_{out} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
89.88	70.8	1.665	0.473	65.64	0.204	100%	93.1%	
89.91	52.64	1.333	0.439	49.214	0.2	75%	93.87%	
89.94	34.82	0.914	0.424	32.777	0.2	50%	94.7%	94.04%
89.98	17.62	0.574	0.341	16.46	0.2	25%	94.57%	
90.03	7.36	0.221	0.37	6.6193	0.2	10%	92.68%	
114.91	69.73	1.38	0.44	65.65	0.203	100%	94.45%	
114.94	52.05	1.226	0.369	449.235	0.203	75%	94.97%	
114.96	34.65	0.815	0.37	32.778	0.2	50%	95.18%	94.86%
115	17.58	0.421	0.363	16.474	0.2	25%	94.82%	
115.04	7.39	0.176	0.365	6.62	0.199	10%	92.28%	
229.98	69.01	0.886	0.339	65.662	0.2	100%	95.43%	
230.01	51.90	0.674	0.335	49.235.	0.2	75%	95.24%	
230.01	34.84	0.46	0.329	32.778	0.2	50%	94.65%	94.51%
230.02	17.98	0.236	0.331	16.471	0.2	25%	92.7%	
230.08	7.62	0.109	0.304	6.6214	0.199	10%	89.52%	
264	69.11	0.781	0.335	65.684	0.2	100%	95.33%	
264	52.1	0.596	0.331	49235	0.2	75%	94.89%	
264	35.06	0.411	0.323	32.678	0.2	50%	94.04%	93.86%
264.02	18.29	0.215	0.322	16.475	0.2	25%	91.17%	
264.1	7.62	0.096	0.3	6.62	0.199	10%	89.54%	
CoC Tier 2, 4-pt average								89.0%
CoC Tier 2, 10%-load								79.0%

5.2 Efficiency Result of 4-Point Average on 15V_{OUT}

V_{IN} (VRMS)	P_{IN} (W)	I_{IN}(IRMS)	PF	P_{OUT} (W)	P_EMULATOR (W)	P_{out} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
89.92	48.79	1.252	0.433	45.525	0.15	100%	93.61%	94.25%
89.95	36.35	0.95	0.425	34.088	0.148	75%	94.18%	
89.97	24.17	0.691	0.389	22.735	0.148	50%	94.67%	
89.99	12.2	0.397	0.342	11.384	0.15	25%	94.54%	
90.03	5.08	0.157	0.36	4.5789	0.148	10%	92.99%	
114.94	48.24	1.161	0.362	45.525	0.148	100%	94.68%	94.69%
114.95	36.1	0.85	0.37	34.105	0.15	75%	94.88%	
114.98	24.07	0.569	0.368	22.737	0.15	50%	95.09%	
115	12.25	0.281	0.379	11.382	0.15	25%	94.11%	
115.04	5.08	0.122	0.362	4.5776	0.149	10%	93.02%	
230	48.1	0.626	0.334	45.527	0.148	100%	94.95%	93.63%
230	36.19	0.477	0.33	34.088	0.148	75%	94.59%	
230	24.39	0.33	0.321	22.742	0.148	50%	93.86%	
230.02	12.65	0.172	0.32	11.382	0.148	25%	91.13%	
230.09	5.19	0.075	0.298	4.5757	0.15	10%	91.1%	
264	48.26	0.554	0.33	45.52	0.15	100%	94.62%	92.71%
264	36.43	0.426	0.324	34.101	0.148	75%	94.02%	
264.02	24.64	0.297	0.314	22.735	0.148	50%	92.88%	
264.04	12.91	0.157	0.311	11.383	0.148	25%	89.33%	
264.08	5.3	0.07	0.287	4.5779	0.148	10%	89.14%	
CoC Tier 2, 4-pt average								88.9%
CoC Tier 2, 10%-load								78.

5.3 Efficiency Result of 4-Point Average on $9V_{OUT}$

V_{IN} (VRMS)	P_{IN} (W)	I_{IN}(IRMS)	PF	P_{OUT} (W)	P_EMULATOR (W)	P_{out} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
89.96	29.21	0.784	0.414	27.316	0.087	100%	93.8%	93.87%
89.98	21.86	0.635	0.383	20.424	0.087	75%	93.85%	
89.99	14.56	0.475	0.341	13.607	0.087	50%	94.06%	
90.0	7.35	0.222	0.368	6.8052	0.088	25%	93.78%	
90.03	3.04	0.095	0.356	2.7394	0.087	10%	92.93%	
114.98	29.08	0.683	0.37	27.307	0.087	100%	94.2%	94.12%
114.99	21.72	0.514	0.368	20.432	0.088	75%	94.47%	
115.0	14.53	0.35	0.361	13.601	0.087	50%	94.23%	
115.01	7.37	0.176	0.364	6.8077	0.088	25%	93.57%	
115.03	3.03	0.077	0.342	2.7368	0.088	10%	93.32%	
230.06	29.33	0.391	0.326	27.319	0.087	100%	93.43%	92.12%
230.06	22.04	0.3	0.319	20.42	0.089	75%	93.03%	
230.06	14.93	0.199	0.326	13.604	0.088	50%	91.71%	
230.06	7.63	0.109	0.304	6.8056	0.088	25%	90.32%	
230.08	3.14	0.049	0.279	2.739	0.087	10%	90.01%	
264.07	29.52	0.35	0.319	27.309	0.087	100%	92.8%	91.01%
264.07	22.25	0.27	0.312	20.42	0.087	75%	92.16%	
264.05	15.13	0.181	0.317	13.606	0.087	50%	90.49%	
264.05	7.78	0.098	0.301	6.803	0.087	25%	88.59%	
264.07	3.18	0.045	0.267	2.739	0.087	10%	88.9%	
CoC Tier 2, 4-pt average								87.3%
CoC Tier 2, 10%-load								77.3%

5.4 Efficiency Result of 4-Point Average on 5V_{OUT}

V_{IN} (VRMS)	P_{IN} (W)	I_{IN}(IRMS)	PF	P_{OUT} (W)	P_EMULATOR (W)	P_{out} %	EFFICIENCY	4-PT AVERAGE EFFICIENCY
89.99	16.52	0.542	0.339	15.242	0.048	100%	92.55%	92.79%
90	12.27	0.399	0.342	11.382	0.049	75%	93.13%	
90	8.21	0.246	0.371	7.5643	0.049	50%	92.76%	
90.02	4.13	0.13	0.353	3.7775	0.049	25%	92.72%	
90.03	1.71	0.057	0.334	1.5192	0.049	10%	91.57%	
115	16.48	0.395	0.363	15.243	0.048	100%	92.81%	92.71%
115	12.32	0.282	0.38	11.395	0.048	75%	92.9%	
115.01	8.2	0.194	0.368	7.5648	0.048	50%	92.79%	
115.01	4.14	0.102	0.353	3.7773	0.048	25%	92.32%	
115.03	1.74	0.047	0.322	1.5204	0.048	10%	90.23%	
230.04	16.68	0.22	0.33	15.242	0.049	100%	91.67%	89.64%
230.05	12.67	0.172	0.32	11.395	0.049	75%	90.32%	
230.06	8.59	0.121	0.308	7.5737	0.048	50%	88.78%	
230.06	4.36	0.065	0.292	3.7791	0.048	25%	87.79%	
230.08	1.805	0.031	0.256	1.5205	0.049	10%	86.99%	
264.04	16.91	0.2	0.32	15.258	0.048	100%	90.52%	88.45%
264.05	12.82	0.156	0.311	11.397	0.049	75%	89.26%	
264.07	8.75	0.111	0.299	7.5673	0.048	50%	87.04%	
264.07	4.4	0.059	0.281	3.777	0.048	25%	87%	
264.09	1.83	0.028	0.243	1.5192	0.048	10%	85.86%	
CoC Tier 2, 4-pt average								81.8%
CoC Tier 2, 10%-load								72.5%

5.5 Efficiency Typical Results

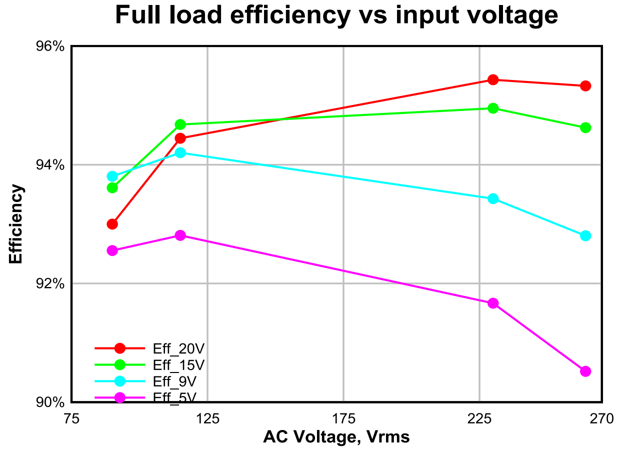


Figure 5-1. Full-Load Efficiency vs. Input Voltage

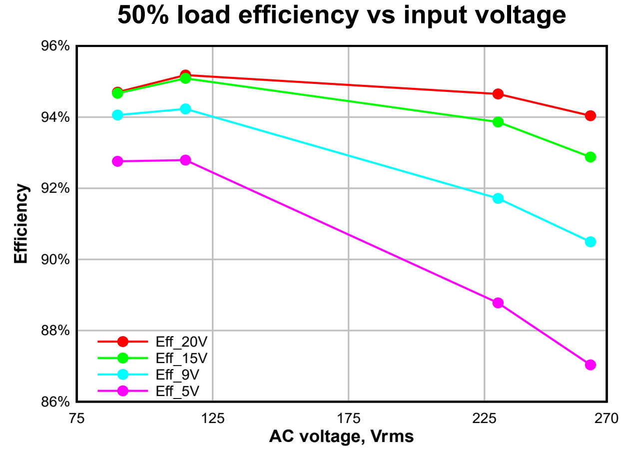


Figure 5-2. Efficiency of 50%-Load vs Input Voltage

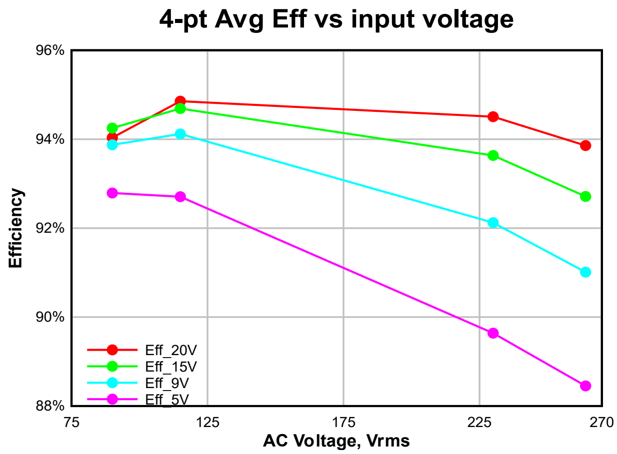


Figure 5-3. 4pt-Average Efficiency vs. Input Voltage

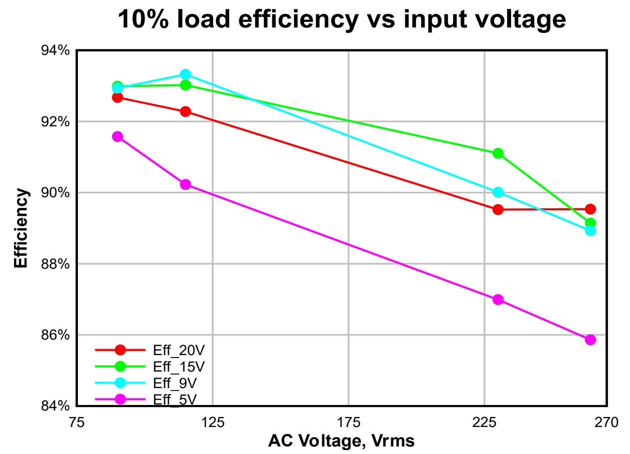


Figure 5-4. Efficiency of 10%-Load vs. Input Voltage

6 Additional Information

Trademarks

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