User's Guide

Using the UCC28782EVM-030 65-W USB-C PD High-Density Active-Clamp Flyback Converter

1 Using the UCC28782EVM-030 65-W USB-C PD High-Density Active-Clamp Flyback Converter

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Trademarks

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2 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 their 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 may 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 suitable qualified, you should immediately stop from further use of the HV EVM.

1. Work Area Safety
   a. Keep work area clean and orderly.
   b. Qualified observer(s) must be present anytime circuits are energized.
   c. Effective barriers and signage must be present in the area where the TI HV EVM and its interface electronics are energized, indicating operation of accessible high voltages may 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, it is always a good engineering practice to assume that the entire EVM may have fully accessible and active high voltages.
   a. De-energize the TI HV EVM and all its 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 its electrical circuits, as they could 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.

3 Description

The UCC28782EVM-030 is a 65-W USB-C PD evaluation module (EVM) for evaluating an off-line active-clamp flyback adapter for notebook charging 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 UCC28782EVM-030 converts input voltage of 90 V_{RMS} to 264 V_{RMS} down to USB-C PD selectable output voltage 20 V_{DC}, with a max 3.25 A, and to 5 V_{DC}, 9 V_{DC}, and 15 V_{DC}, with a max 3.00-A output current rating and a 160-ms limit for over-power capability. The main devices used in this design are active clamp flyback controller, UCC28782, and integrated GaN half-bridge, LMG2610. Please read this user's guide thoroughly before applying power to this board.

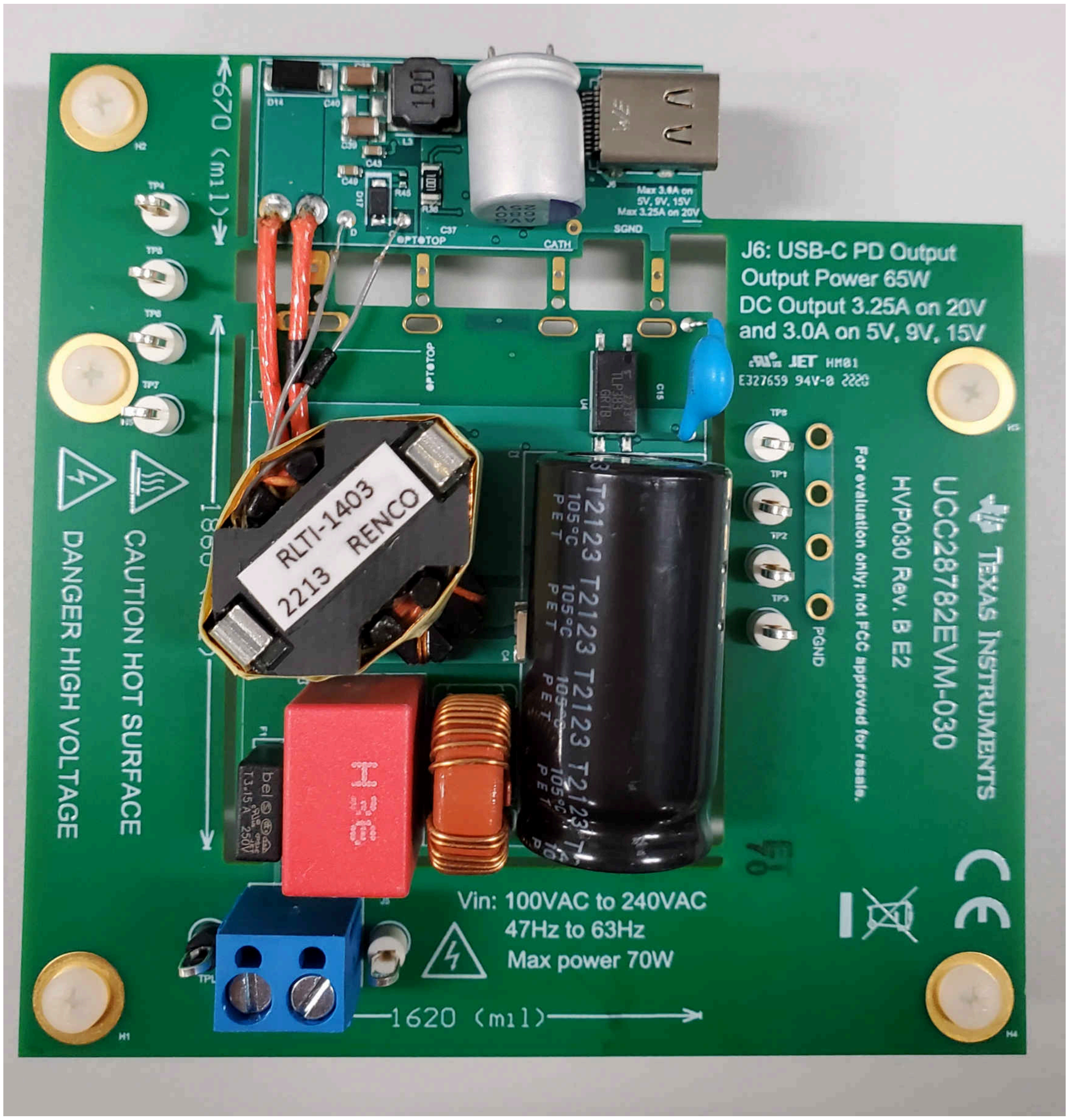

Figure 3-1. UCC28782EVM-030 top View

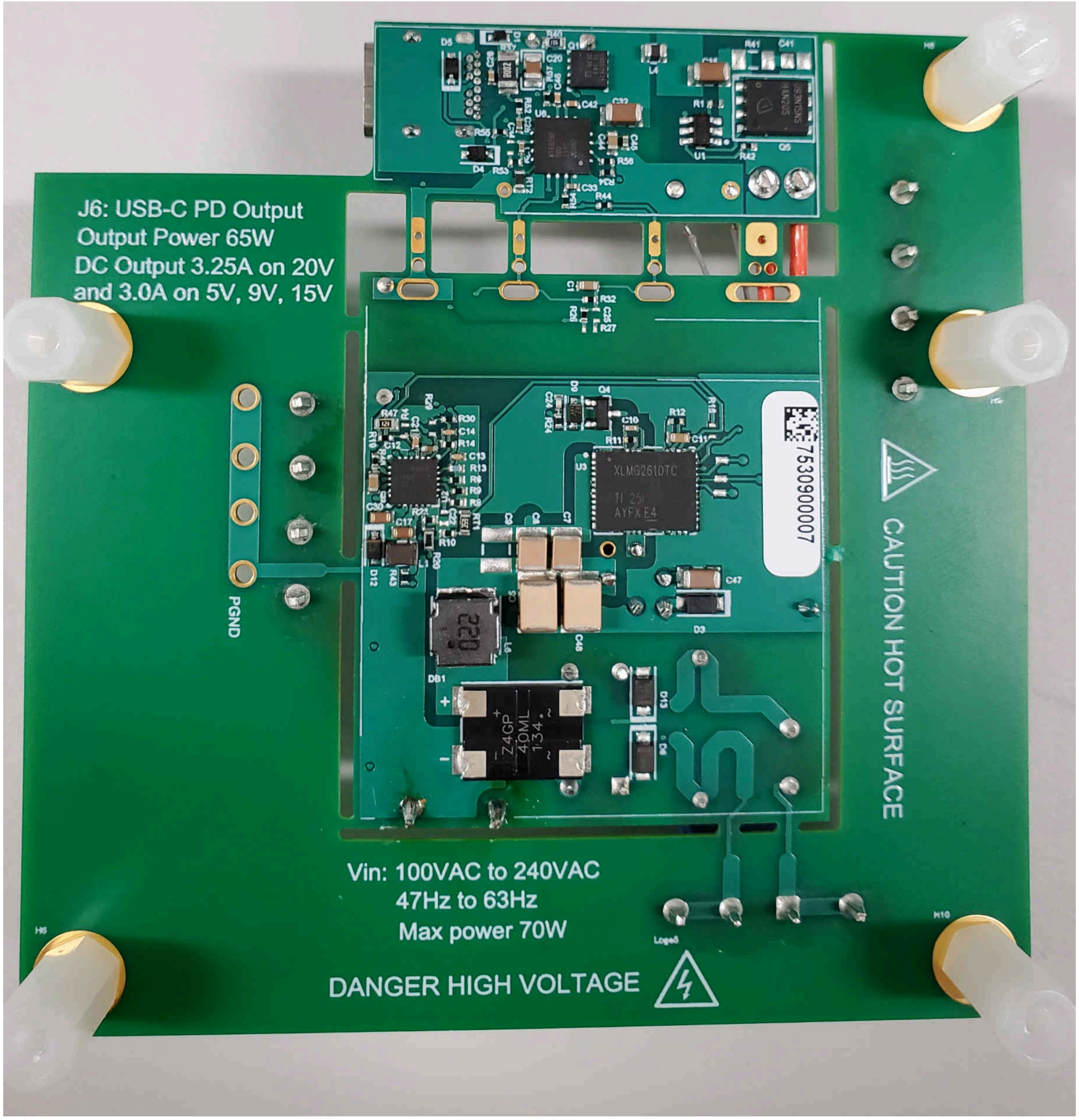

Figure 3-2. UCC28782EVM-030 bottom View

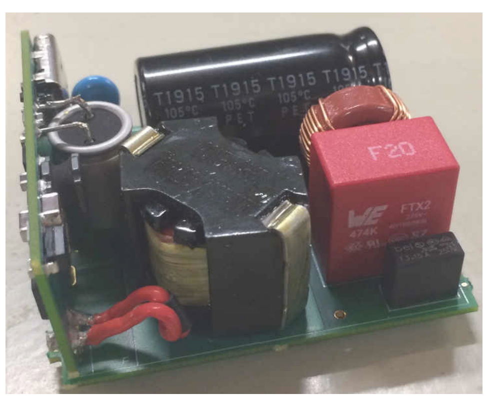

Figure 3-3. High-Density Configuration

4 Electrical Performance Specifications

Table 4-1. UCC28782EVM-030 Electrical Performance Specifications(2)

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} = 115/230 V_{RMS}, I_{OUT} = 0 A		48/58		mW
$P_{0.25W}$	Input power at 0.25W load	V_{IN} = 115/230 V_{RMS}, P_{OUT} = 250 mW		345/385		mW
OUTPUT CHARACTERISTICS						
V_{OUT}	Output voltage (USB-C PD) V_{IN} = 90 to 264 V_{RMS}	I_{OUT} = 0 to 3.25 A		19.950		V
		I_{OUT} = 0 to 3.00 A		15.060		
				9.050		
				5.050		
I_{OUT}	Full load rated output current V_{IN} = 90 to 264 V_{RMS}	V_{OUT} = 20.0 V		3.250		A
		V_{OUT} = 5.0, 9.0, or 15.0 V		3.000		
V_{OUT_pp}	Output ripple voltage V_{IN} = 115 V / 230 V_{RMS}	V_{OUT} = 20.0 V, I_{OUT} = 0 to 3.25 A		150		mVpp
		V_{OUT} = 15.0 V, I_{OUT} = 0 to 3.00 A		150		
		V_{OUT} = 9.0 V, I_{OUT} = 0 to 3.00 A		150		
		V_{OUT} = 5.0 V, I_{OUT} = 0 to 3.00 A		150		
V_{OUT_Δ}	Output voltage deviation due to load step Up / Down (I_{OUT} step change between 0 and 100% load at 100 Hz rate)	V_{OUT} = 20.0 V		-604 / 340		mVpp
		V_{OUT} = 15.0 V		-584 / 360		
		V_{OUT} = 9.0 V		-404 / 304		
		V_{OUT} = 5.0 V		-404 / 304		
P_{OUT_opp}	Over-power protection threshold	V_{IN} = 90 to 264 V_{RMS}		70		W
SYSTEMS CHARACTERISTICS						
η	Full-load efficiency (V_{IN}= 115/230V_{RMS})	V_{OUT} = 20 V, I_{OUT} = 3.25A		94.6 / 94.4		%
		V_{OUT} = 15 V, I_{OUT} = 3.00A		94.8 / 94.6		
		V_{OUT} = 9 V, I_{OUT} = 3.00A		94.2 / 93.8		
		V_{OUT} = 5 V, I_{OUT} = 3.00A		92.9/ 88.1		
η	4-point average efficiency(1) V_{IN}= 115/230 V_{RMS}	V_{OUT} = 20 V (CoC Tier 2, 89.0%)		94.2 / 93.1		%
		V_{OUT} = 15 V (CoC Tier 2, 88.9%)		93.9 / 91.8		
		V_{OUT} = 9 V (CoC Tier 2, 87.3%)		92.0 / 89.3		
		V_{OUT} = 5 V (CoC Tier 2, 81.8%)		89.3 / 83.6		
η	Efficiency at 10% Load V_{IN}= 115/230 V_{RMS}	V_{OUT} = 20 V (CoC Tier 2, 79.0%)		90.8 / 85.0		%
		V_{OUT} = 15 V (CoC Tier 2, 78.9%)		89.3 / 84.1		
		V_{OUT} = 9 V (CoC Tier 2, 77.3%)		88.3 / 82.2		
		V_{OUT} = 5 V (CoC Tier 2, 72.5%)		87.4 /81.0		
T_{AMB}	Ambient operating temperature range	V_{IN} = 90 to 264 V_{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.
(2) The performance listed in this table is achieved using secondary resonance and based on the test results from a single board.

5 Schematic Diagram

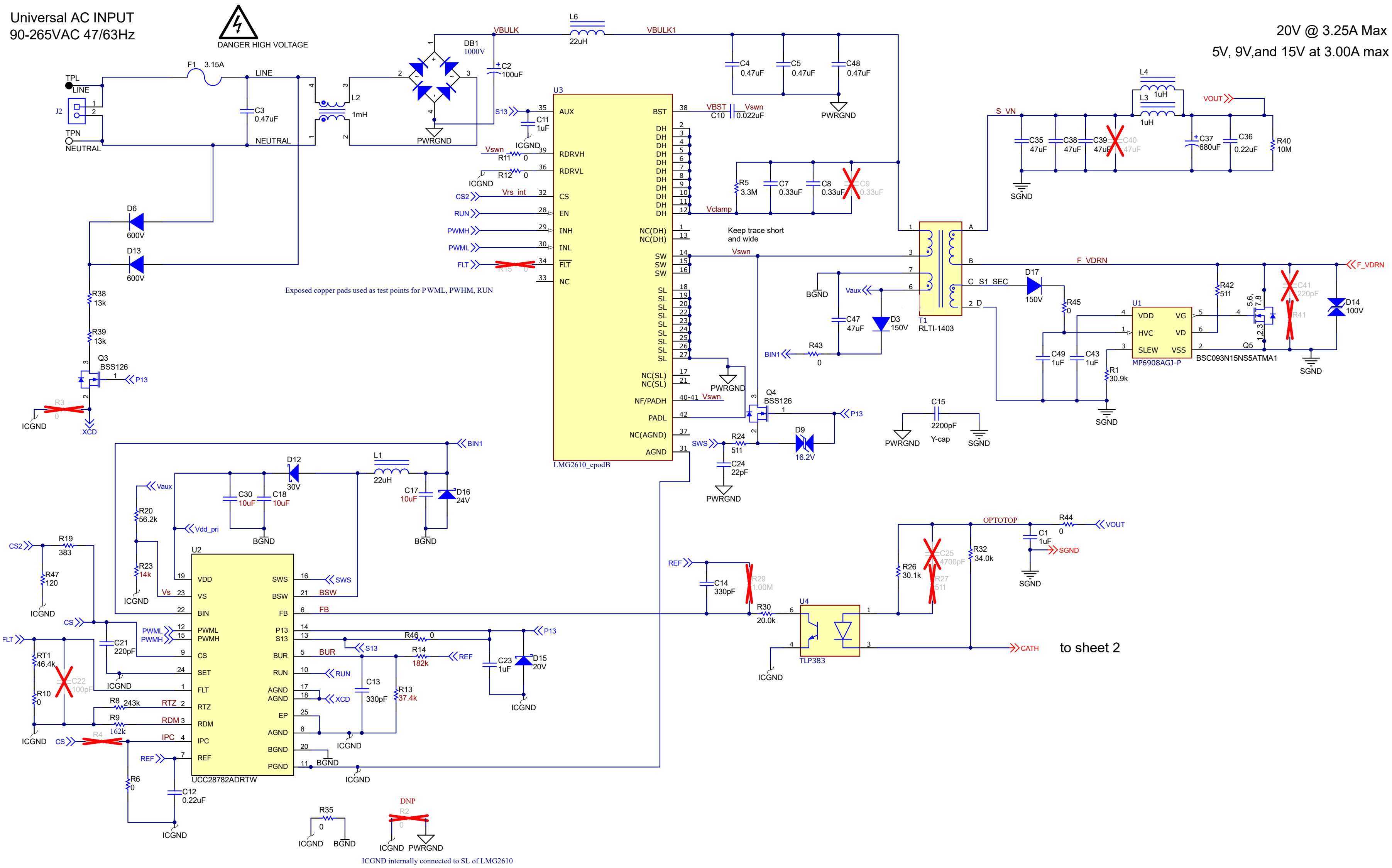

Figure 5-1. UCC28782EVM-030 Schematic Diagram (1 of 2), Updated October 2022 with LMG2610 integrated GaN half-bridge.

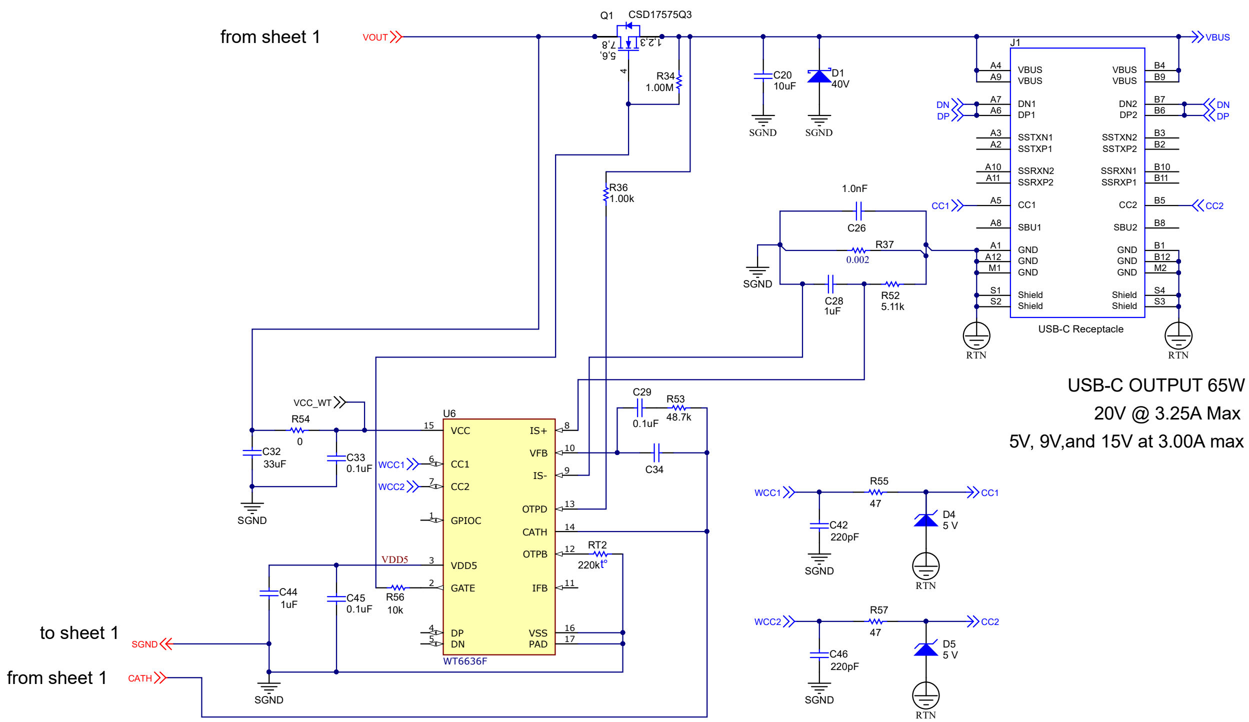

Figure 5-2. UCC28782EVM-030 Schematic Diagram (2 of 2)

6 Description

6.1 Typical Application

- USB-C PD Power Adapters
- USB-C PPS 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

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

UCC28782EVM-030 comes populated with USB-C PD controller (WT6636F) and requires external connection through an on-board USB-C connector to a USB-C PD load so to adjust the board output to obtain 5-V, 9-V, 15-V or 20-V. A USB-C PD communicating load is required in order to make the board evaluation. An example of such a load is PM110, USB Power Delivery Tester, and PassMark Software. Without such a communication load, the board output USB-C connector (J1) does not provide output voltage. Besides, to get full load current 3.00-A from 5-V, 9-V and 15-V, a USB-C cable without E-mark may be used, but to get 3.25-A at 20-V output, an E-mark USB-C cable has to be used. In case the EVM is desired to test on a load without USB-C PD communication, the next section describes how to modify the board to make test.

6.3 Using the EVM on a Load without USB-C PD Communication

Normally, a USB-C PD communicated load is required in order to make evaluation. Without such a USB-C PD communication-based load, the board does not provide output voltage on USB-C (J1) connector. In such a case, the board output voltage can be obtained from C37 but only 5-V and up to 3.00-A can be obtained.

7 Test Setup

7.1 Test Setup Requirements

Safety: This evaluation module is not encapsulated and there are accessible voltages that are greater than 50 V_{DC}.

Isolation Input Transformer: A suitably rated 1:1 isolation transformer shall be used on the input(s) to this EVM and be constructed in a manner in which the primary winding(s) are separated from the secondary winding(s) by reinforced insulation, double insulation, or a screen connected to the protective conductor terminal.

WARNING

- If you are not trained in the proper safety of handling and testing power electronics please do not test this evaluation module.
- While the EVM is energized, never touch the EVM or its electrical circuits, as they could be at high voltages capable of causing electrical shock hazard.
- Caution Hot surface. Contact may 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 264 V_{RMS} and capable of handling 100 W power level. **Warning: Do not apply DC voltage to this board when making test, or damage may happen**. If DC voltage source has to be used, the XCD pins need to be grounded by adding R3 = 0 Ω and removing Q3.

Voltmeter: Digital voltage meter

Power Analyzer: Capable of measuring 1 mW to 100 W of input power and capable of handling 264-V_{RMS} input voltage. Some power analyzers may require a precision shunt resistor for measuring input current to measure input power of 5 W 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, 500 MHz bandwidth.
- Probes capable of handling 600 V.

Output Load: Resistive or electronic load capable of handling 100 W at 20 V.

Recommended Wire Gauge: Insulated 22 AWG to 18 AWG.

WARNING

Caution: Do not leave EVM powered when unattended.

!! Do not apply DC voltage source to this board or damage may happen !! (See above setup of Voltage Source)

7.2 Test Setup Diagram

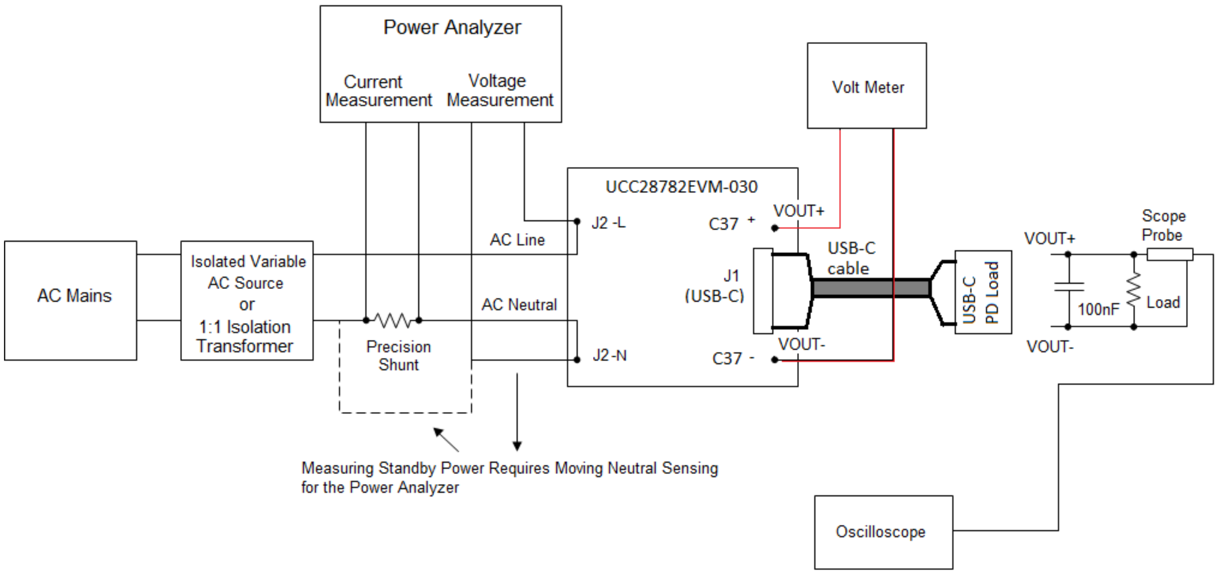

Figure 7-1. UCC28782EVM-030 Test Setup Diagram

7.3 Test Points

Table 7-1. Input / Output Terminals and Test Point Functions

Terminals and TEST POINTS		NAME	DESCRIPTION
J1	Location J1 Terminal	J1	USB-C
J2-L	Location J2 Terminal	L	AC voltage input - Line
J2-N		N	AC voltage input - Neutral
TPL	Input test points	TPL	AC input monitor - Line
TPN	Input test points	TPL	AC input monitor -Neutral
TP1 to TP4	Floating test points	TP1, TP2, TP3, TP4	Floating, need to solder connections, leave them floating if not used
TP5 to TP8	Floating test points	TP5, TP6, TP7, TP8	Floating, need to solder connections, leave them floating if not used

8 Performance Data and Typical Characteristic Curves

8.1 Efficiency Result of 4-Point Average on 20-Vout

V_{IN} (VRMS)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT}(%)	EFFICIENCY	EFFICIENCY 4pt-AVERAGE	Average Switching Frequency @ Full Load
90.06	70.10	20.03	3.25	100%	93.2%		150 kHz
89.9	51.8200	20.02	2.442	75%	94.3%		
90.0	34.64	20.01	1.631	50%	94.2%		
90.0	17.66	19.99	0.822	25%	93.0%		
90.1	7.32	19.98	0.335	10%	91.6%		
115.08	68.80	20.03	3.25	100%	94.6%	94.25%	160 kHz
115.0	51.49	20.02	2.443	75%	95.0%		
115.0	34.66	20.00	1.632	50%	94.2%		
115.1	17.62	19.98	0.822	25%	93.2%		
115.1	7.35	19.97	0.334	10%	90.8%		
230.2	68.90	20.00	3.250	100%	94.4%	93.09%	220 kHz
230.2	51.73	20.02	2.442	75%	94.5%		
230.2	35.07	20.00	1.631	50%	93.0%		
230.2	18.17	19.98	0.823	25%	90.5%		
230.2	7.86	19.97	0.334	10%	85.0%		
265.24	69.20	20.04	3.25	100%	94.1%		230 kHz
265.2	51.93	20.02	2.443	75%	94.2%		
265.2	35.30	19.99	1.630	50%	92.3%		
265.23	18.49	19.98	0.823	25%	88.9%		
265.2	8.14	19.97	0.336	10%	82.4%		
CoC Tier 2, 4pt-average						89.0%	
CoC Tier 2, 10%-load						79.0%	

8.2 Efficiency Result of 4-Point Average at 15-Vout

$V_{IN\ (VRMS)}$	$P_{IN\ (W)}$	$V_{OUT\ (V)}$	$I_{OUT\ (A)}$	$P_{OUT(\%)}$	EFFICIENCY	EFFICIENCY 4pt-AVERAGE	Average Switching Frequency @ Full Load
89.94	48.05	15.04	3.00	100%	94.0%		155 kHz
90.0	35.8700	15.02	2.254	75%	94.4%		
90.0	24.22	15.01	1.508	50%	93.4%		
90.0	12.36	14.99	0.759	25%	92.1%		
90.1	5.14	14.98	0.310	10%	90.4%		
114.99	47.61	15.04	3.00	100%	94.8%	93.93%	176 kHz
115.0	35.73	15.02	2.255	75%	94.8%		
115.0	24.11	15.01	1.506	50%	93.7%		
115.1	12.33	14.99	0.760	25%	92.4%		
115.1	5.20	14.98	0.310	10%	89.3%		
230.2	47.7	15.0	3.0	100%	94.6%	91.76%	192 kHz
230.2	36.44	15.02	2.255	75%	92.9%		
230.2	24.60	15.00	1.506	50%	91.9%		
230.2	12.99	14.99	0.760	25%	87.6%		
230.2	5.51	14.98	0.309	10%	84.1%		
265.2	47.9	15.0	3.0	100%	94.3%		190 kHz
265.2	36.70	15.02	2.255	75%	92.3%		
265.2	24.88	15.00	1.509	50%	91.0%		
265.2	13.35	14.99	0.760	25%	85.4%		
265.2	5.68	14.98	0.310	10%	81.7%		
CoC Tier 2, 4pt-average						88.9%	
CoC Tier 2, 10%-load						78.9%	

8.3 Efficiency Result of 4-Point Average at 9-Vout

$V_{IN\ (VRMS)}$	$P_{IN\ (W)}$	$V_{OUT\ (V)}$	$I_{OUT\ (A)}$	$P_{OUT(\%)}$	EFFICIENCY	EFFICIENCY 4pt-AVERAGE	Average Switching Frequency @ Full Load
90.0	28.9900	9.04	3.005	100%	93.7%		133 kHz
90.0	22.21	9.02	2.258	75%	91.7%		
90.0	15.84	9.00	1.510	50%	85.8%		
90.0	7.54	8.99	0.762	25%	90.81%		
90.0	3.14	8.98	0.313	10%	89.3%		
115.0	28.8100	9.03	3.003	100%	94.2%	91.95%	140 kHz
115.0	21.97	9.02	2.258	75%	92.7%		
115.1	14.99	9.00	1.509	50%	90.6%		
115.1	7.58	8.98	0.762	25%	90.3%		
115.1	3.17	8.97	0.313	10%	88.6%		
230.2	28.9300	9.04	3.005	100%	93.8%	89.28%	132 kHz
230.2	22.44	9.02	2.257	75%	90.7%		
230.2	15.34	9.00	1.510	50%	88.6%		
230.2	8.15	8.98	0.762	25%	84.0%		
230.2	3.39	8.97	0.313	10%	82.8%		
265.2	29.0700	9.03	3.005	100%	93.4%		129 kHz
265.2	22.7000	9.02	2.258	75%	89.7%		
265.2	15.51	9.00	1.510	50%	87.6%		
265.2	8.41	8.98	0.762	25%	81.4%		
265.2	3.50	8.97	0.313	10%	80.47%		
CoC Tier 2, 4pt-average						87.3%	
CoC Tier 2, 10%-load						77.3%	

8.4 Efficiency Result of 4-Point Average at 5-Vout

$V_{IN\ (VRMS)}$	$P_{IN\ (W)}$	$V_{OUT\ (V)}$	$I_{OUT\ (A)}$	$P_{OUT(\%)}$	EFFICIENCY	EFFICIENCY 4pt-AVERAGE	Average Switching Frequency @ Full Load
90.0	16.2	5.01	2.99	100%	92.5%		95 kHz
90.0	12.60	4.99	2.246	75%	89.0%		
90.0	8.47	4.97	1.498	50%	88.0%		
90.1	4.25	4.96	0.751	25%	87.6%		
90.1	1.69	4.95	0.302	10%	88.4%		
115.05	16.13	5.01	2.99	100%	92.9%	89.27%	96 kHz
115.1	12.59	4.99	2.246	75%	89.0%		
115.1	8.50	4.97	1.499	50%	87.7%		
115.1	4.26	4.95	0.751	25%	87.4%		
115.1	1.71	4.94	0.301	10%	87.4%		
230.19	17.02	5.01	2.99	100%	88.1%	83.63%	82 kHz
230.2	13.40	4.99	2.246	75%	83.6%		
230.2	9.11	4.97	1.498	50%	81.8%		
230.2	4.59	4.95	0.751	25%	81.1%		
230.2	1.85	4.94	0.303	10%	81.0%		
265.23	17.40	5.01	2.99	100%	86.1%		79 kHz
265.2	13.7700	4.99	2.246	75%	81.4%		
265.2	9.45	4.97	1.498	50%	78.8%		
265.2	4.73	4.95	0.751	25%	78.7%		
265.2	1.91	4.94	0.301	10%	77.9%		
CoC Tier 2, 4pt-average						81.8%	
CoC Tier 2, 10%-load						72.5%	

8.5 Efficiency Typical Results

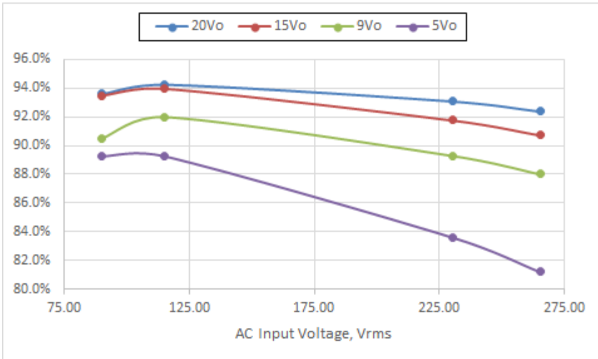

Figure 8-1. 4pt-Average Efficiency vs. Input Voltage

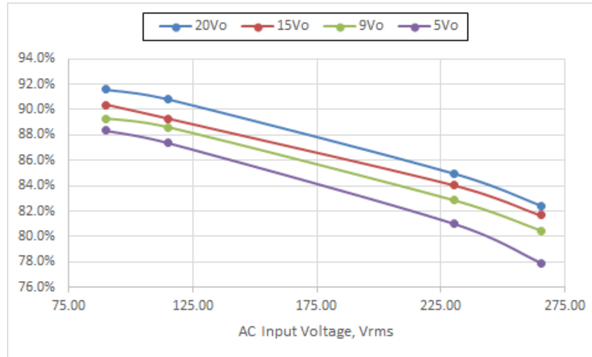

Figure 8-2. Efficiency of 10%-Load vs. Input Voltage

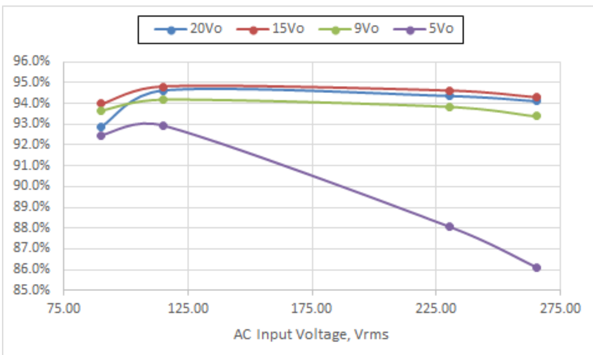

Figure 8-3. Full-load Efficiency vs. Input Voltage

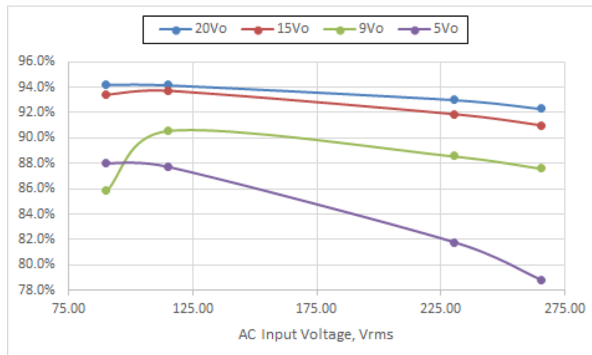

Figure 8-4. Efficiency of 50%-load vs. Input Voltage

8.6 Output Characteristics

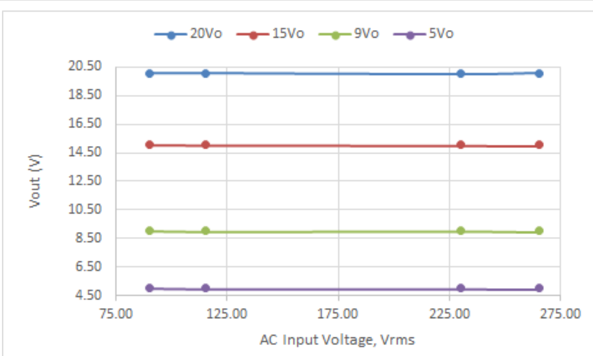

Figure 8-5. V_{OUT} at Full-Load vs. Input Voltge

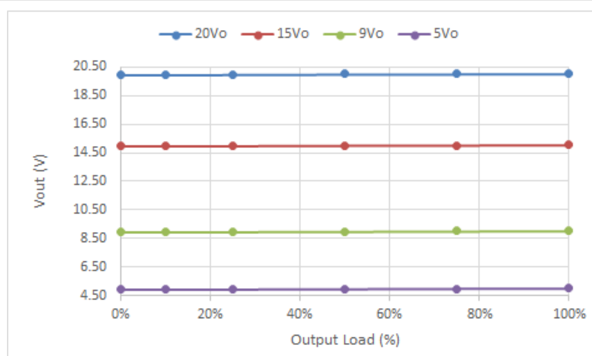

Figure 8-6. V_{OUT} vs. Output Current

8.7 Switching Frequency

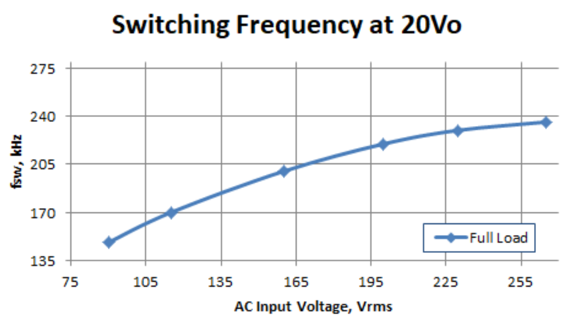

Figure 8-7. Average Switching Frequency vs. Input at 20-Vo Full Load

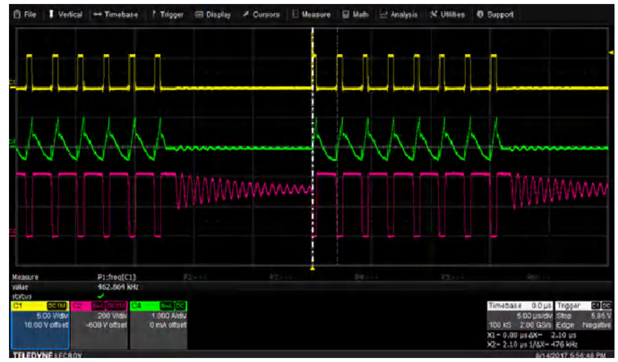

Figure 8-8. Maximum switching frequency about 240 kHz (Yellow = PWML, Green = Transformer Primary Winding Current, Red = Switch Node Voltage

8.8 Key Switching Waveforms and Operation Mode Load Current

This section shows typical operation modes in Table 8-1 along with typical load currents in this design and with Vin = 115Vac and Vo = 20V as an example.

- AAM: Adaptive Amplitude Modulation
- ABM: Adaptive Burst Mode
- LPM: Low Power Mode
- SBP1: First Standby Power Mode
- SBP2: Second Standby Power Mode

Table 8-1. Operation Mode and Load Current at 20-V Output and 115Vac Input

Mode	AAM	ABM	LPM	SBP1	SBP2	Survival
Burst Frequency, f_{BUR}	Not Applicable	> 25kHz (2 to 9 pulses)	about 25kHz (2 pulses)	8.5kHz to 25kHz (2 pulses)	< 8.5kHz (2 pulses)	about 8 pulses
Typical Load Current	1.8 A to 3.25 A	0.5 A to 1.8 A	0.2 A to 0.5 A	0.1 A to 0.2 A	< 0.1 A	Not Applicable

Figure 8-9. Typcial Waveform in AAM Operation Yellow = PWML, Red = PWMH, Green = Transformer Primary Winding Current (0.2 V/A), Blue = Switch Node Voltage

Figure 8-10. Typical Waveform in ABM Operation Yellow = PWML, Red = PWMH, Green = Transformer Primary Winding Current (0.2 V/A), Blue = Switch Node Voltage

Figure 8-11. Typical Waveform in ABM Operation Yellow = PWML, Red = Vgs of SR MOSFET, Green = Transformer Primary Winding Current (0.2 V/A), Blue = Switch Node Voltage

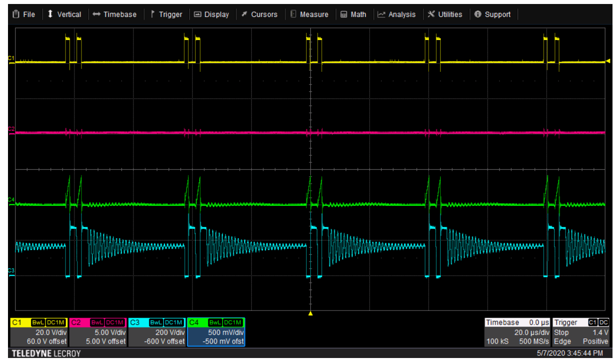

Figure 8-12. Typical Waveform in LPM Operation Yellow = PWML, Red = PWMH, Green = Transformer Primary Winding Current (0.2 V/A), Blue = Switch Node Voltage

Figure 8-13. Typical Waveform in SBP1 Operation Yellow = PWML, Red = PWMH, Green = Transformer Primary Winding Current (0.2 V/A), Blue = Switch Node Voltage

Figure 8-14. Typical Waveform in SBP2 Operation Yellow = PWML, Red = PWMH, Green = Transformer Primary Winding Current (0.2 V/A), Blue = Switch Node Voltage

8.9 Start Up

Yellow = PWML, Red = Switch Node Voltage, Blue = Output Voltage, Green = Transformer Primary Winding Current.

Figure 8-15. 115 V_{AC} and Full Load Startup

Figure 8-16. 230 V_{AC} and Full Load Startup

8.10 Output Voltage Adjustment by USB-C PD

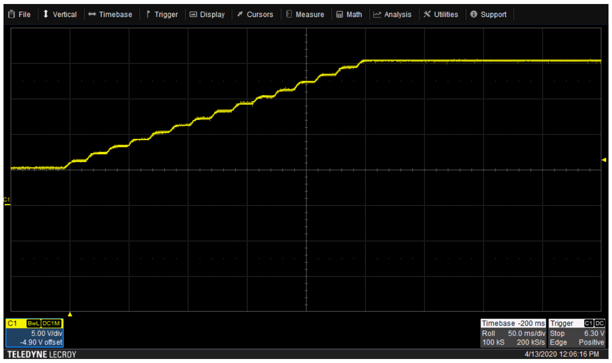

Figure 8-17. USB-C PD Output Change from 5 V to 20 V

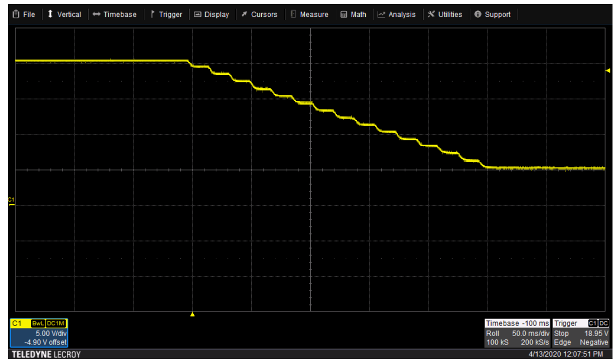

Figure 8-18. USB-C PD Output Change from 20 V to 5 V

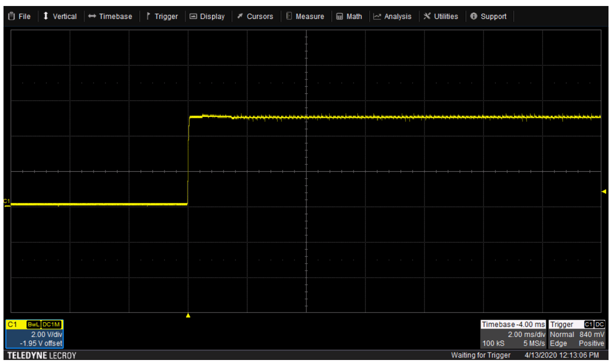

Figure 8-19. 5-V Output Power On

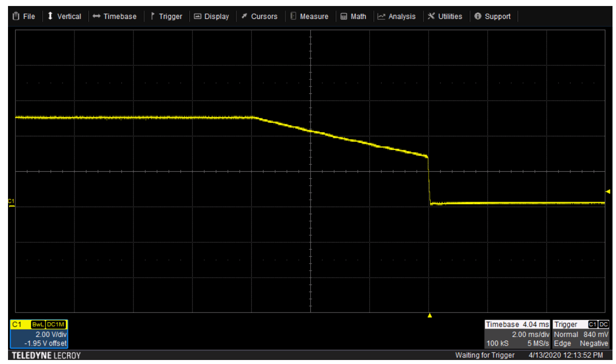

Figure 8-20. 5-V Output Power Off

8.11 Line Transient Response

Yellow = VOUT, Red = Line voltage.

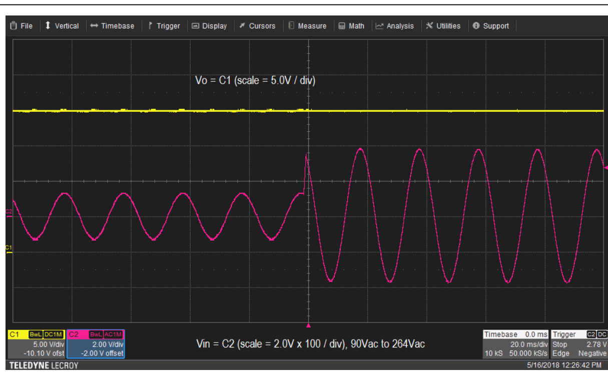

Figure 8-21. Output Voltage Response to Line Transient with Full Load.

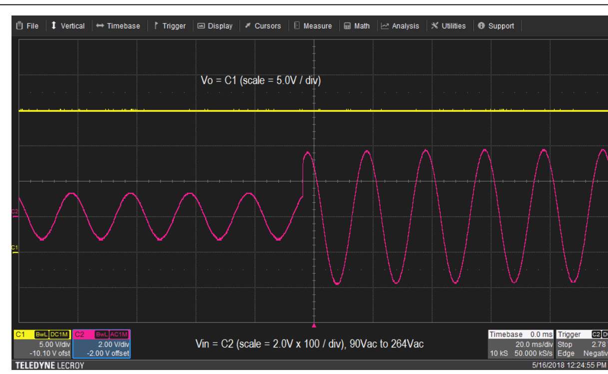

Figure 8-22. Output Voltage Response to Line Transient with No Load.

8.12 Output Ripple Voltage

Blue = Output Voltage Ripple, Oscilloscope Channel Bandwidth = 20 MHz, Voltage span between two dashed lines is 150 mV. The ripples are with the 50% load condition unless specified in the associated figures.

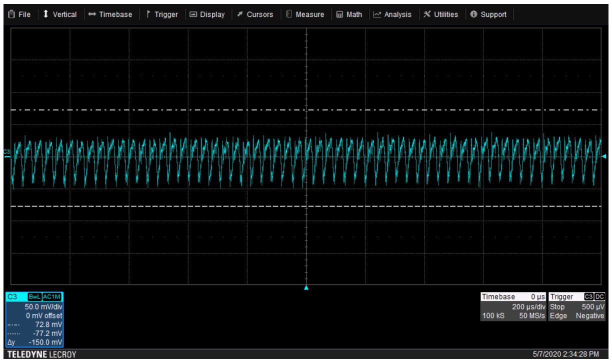

Figure 8-23. Typical Ripple Voltage of V_{OUT} = 20 V

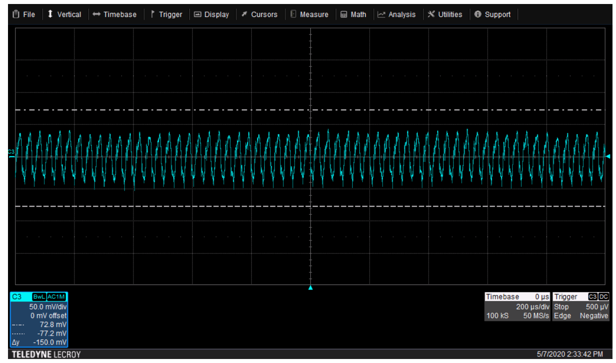

Figure 8-24. Typical Ripple Voltage of V_{OUT} = 15 V

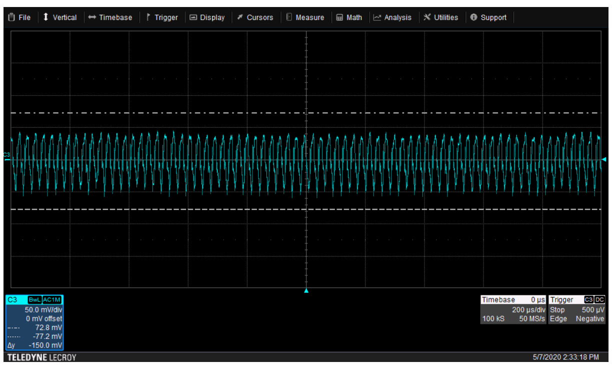

Figure 8-25. Typical Ripple Voltage of V_{OUT} = 9 V

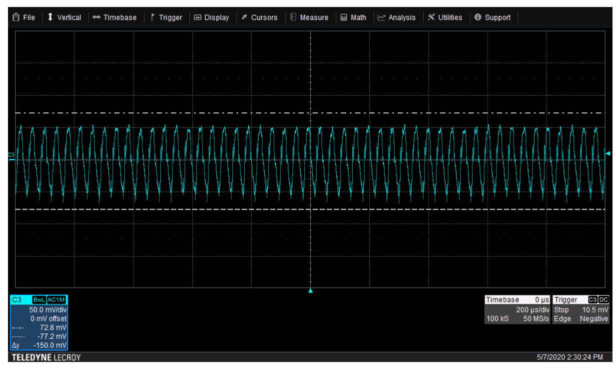

Figure 8-26. Typical Ripple Voltage of V_{OUT} = 5 V

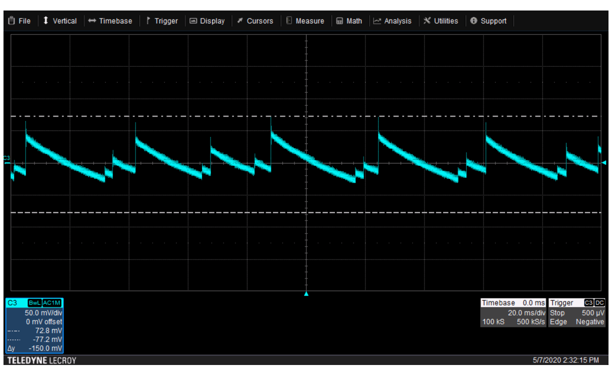

Figure 8-27. Typical Ripple Voltage of V_{OUT} = 5 V at No Load

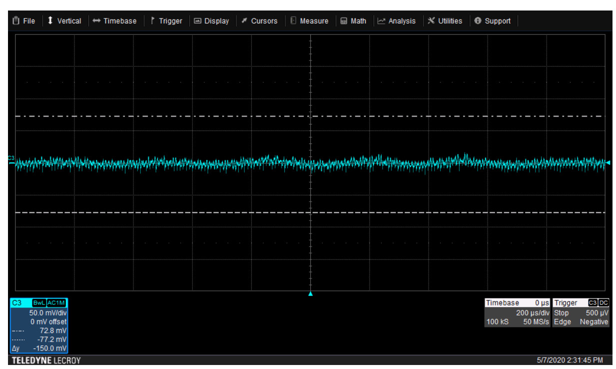

Figure 8-28. Typical Ripple Voltage of V_{OUT} = 5 V at Full Load

8.13 Boost Function for VDD Bias

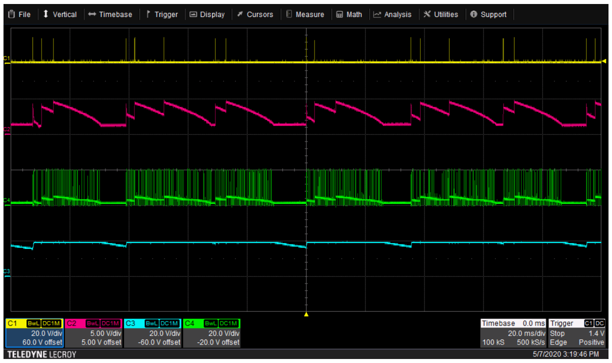

Figure 8-29. Boost Operation at 5 V_{OUT} and No Load (Yellow = PWML, Red = BIN, Green = BSW, Blue = VDD)

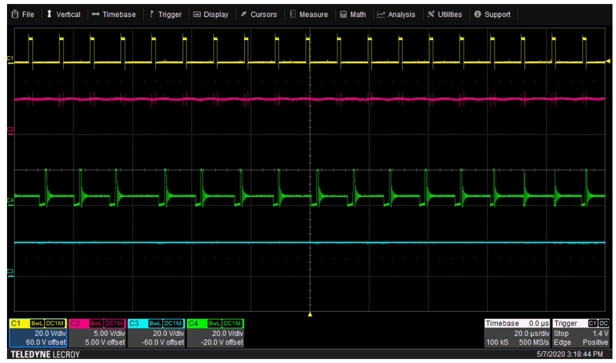

Figure 8-30. Boost Operation at 5 V_{OUT} and Full Load (Yellow = PWML, Red = BIN, Green = BSW, Blue = VDD)

8.14 X-Capacitor Discharge

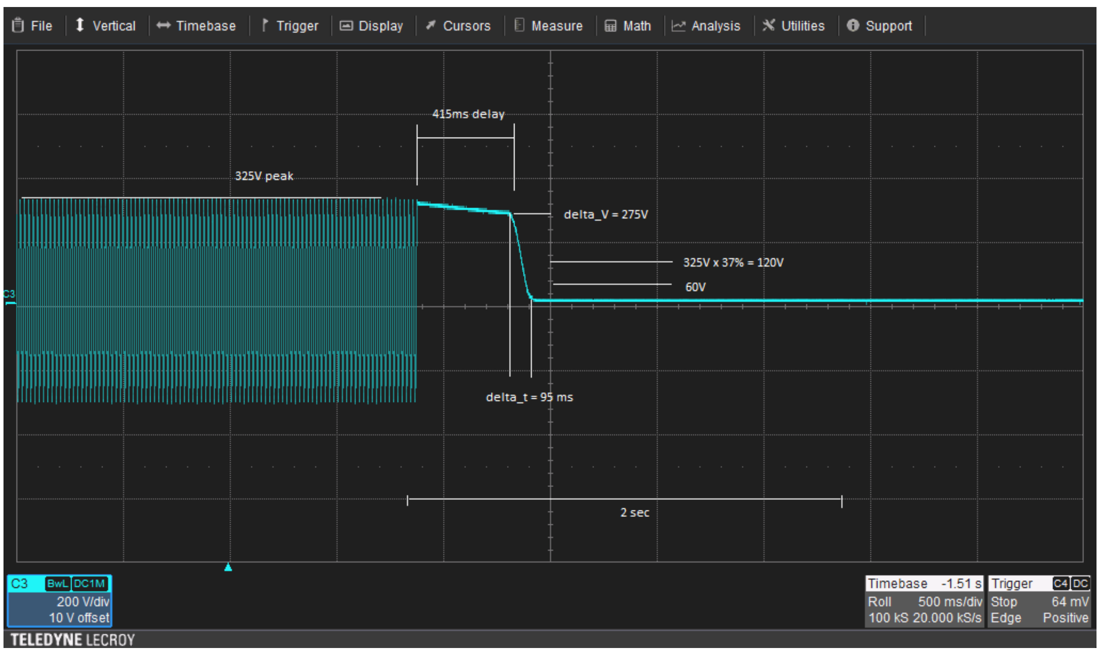

Figure 8-31. Typical X-Capacitor Discharge

8.15 USB-C PD Over Current Limit

Figure 8-32 shows the converter USB-C PD Over Current Limit with respect to input voltage. Figure 8-33 shows the converter auto-retry to resume operation after over current.

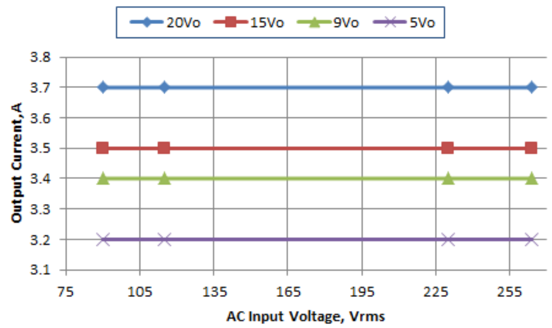

Figure 8-32. USB-PD Current Limit vs. Input Voltage

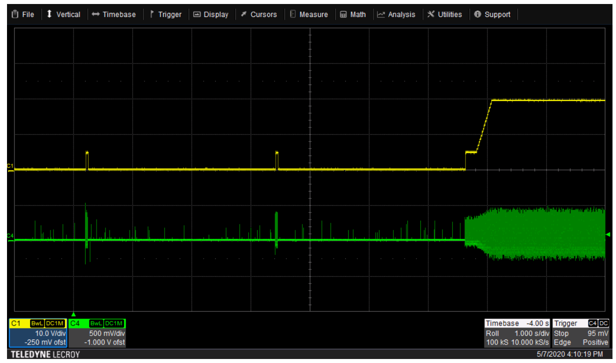

Figure 8-33. USB-C PD Over Current Limit Retry and Resume (Yellow = V_{OUT}, Green = Transformer Primary Current, 0.2 V/A)

8.16 Load Transient Response

Figure 8-34 to Figure 8-37 show output voltage V_{OUT} deviation when load current step change is between 0 and 100%, at 100-Hz rate.

Blue = V_{OUT}, Green = Load Current.

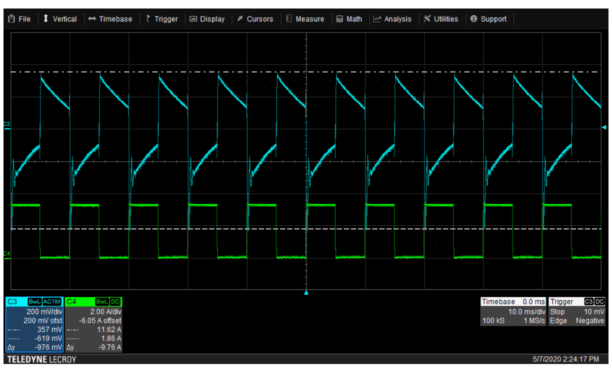

Figure 8-34. Load Transient Response at V_{OUT} = 20 V Overshoot / Undershoot = 357 mV / -619 mV

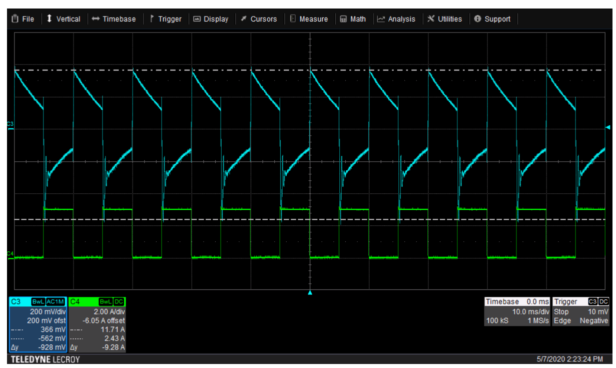

Figure 8-35. Transient Response at V_{OUT} = 15 V Overshoot / Undershoot = 366 mV / -562 mV

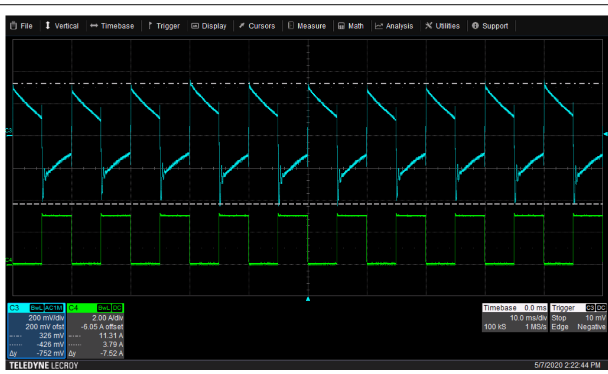

Figure 8-36. Transient Response at V_{OUT} = 9 V Overshoot / Undershoot = 326 mV / -426 mV

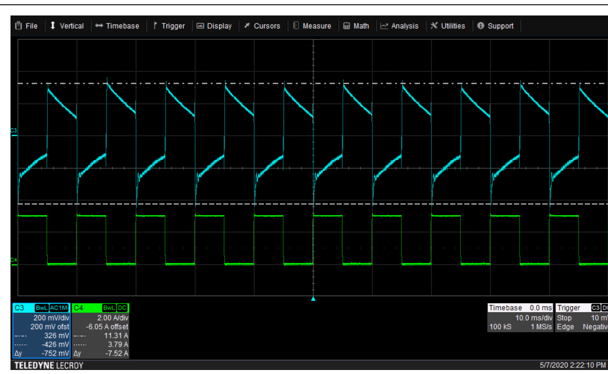

Figure 8-37. Transient Response at V_{OUT} = 5 V Overshoot / Undershoot = 326 mV / -426 mV

8.17 EN55022 Class B Conducted EMI Test Result

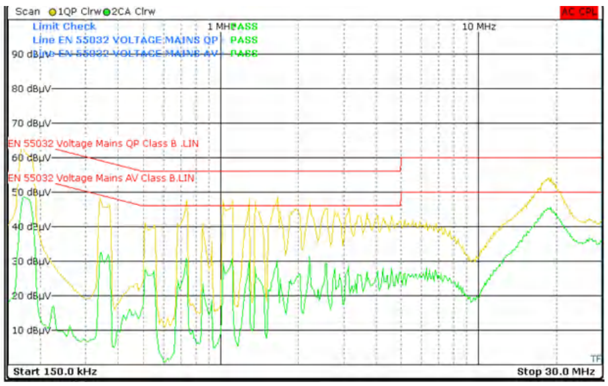

Figure 8-38. VIN = 115 V_{RMS}, VOUT = 20 V, Load = 3.25 A (Output Not Grounded to LISN Ground, Ref Fig 54 and 55)

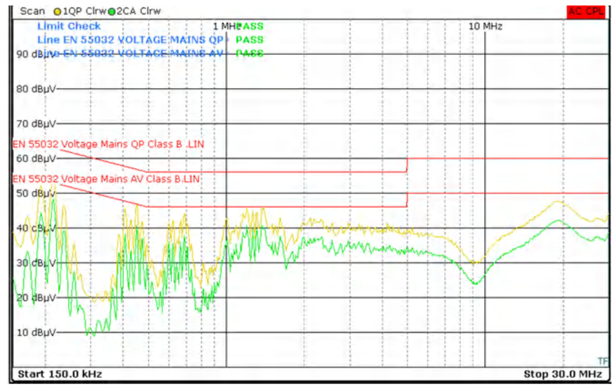

Figure 8-39. VIN = 230 V_{RMS}, VOUT = 20 V, Load = 3.25 A (Output Not Grounded to LISN Ground, Ref Fig 54 and 55)

Note

Please note this was evaluated on an EMI station for pre-qualification purpose only. It is recommended that all final designs be verified by an agency-qualified EMI test house.

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

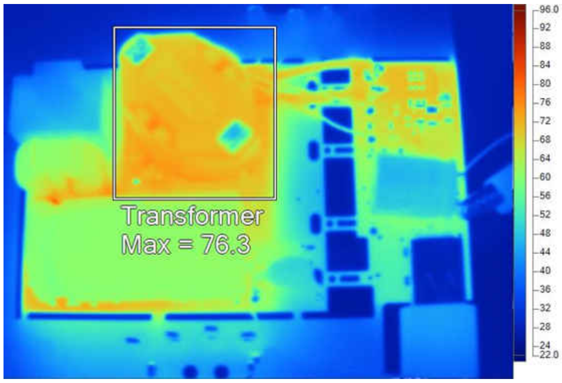

Figure 8-40. V_{IN} = 90 V_{AC}, Top Side

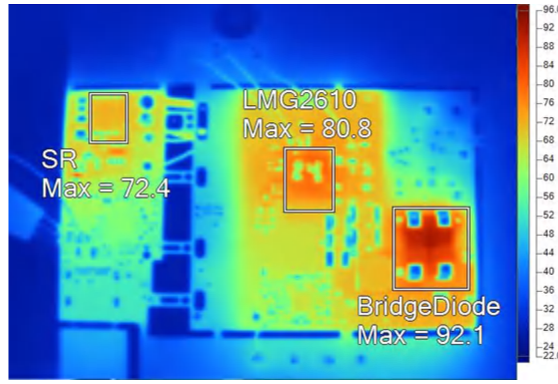

Figure 8-41. V_{IN} = 90 V_{AC}, Bottom Side

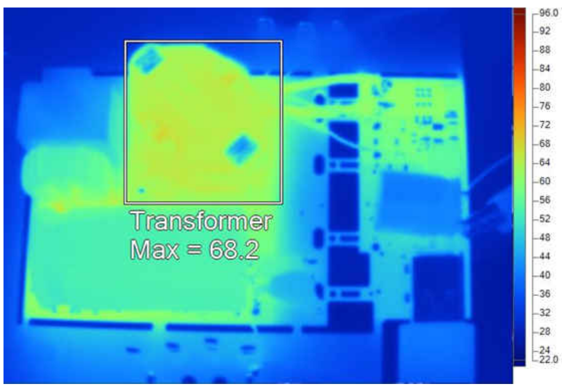

Figure 8-42. V_{IN} = 115 V_{AC}, Top Side

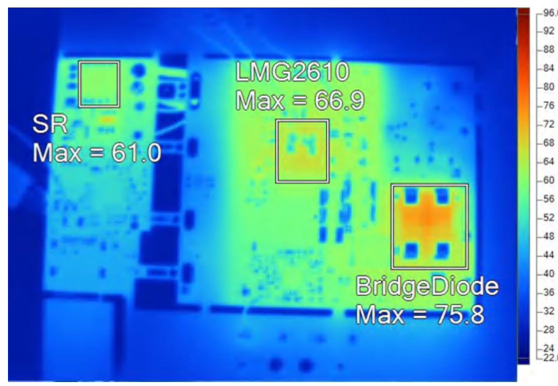

Figure 8-43. V_{IN} = 115 V_{AC}, Bottom Side

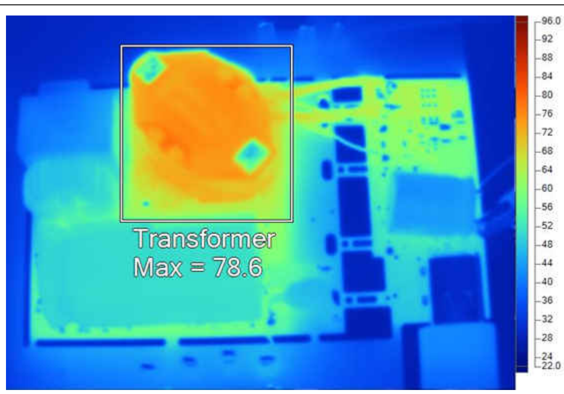

Figure 8-44. V_{IN} = 230 V_{AC}, Top Side

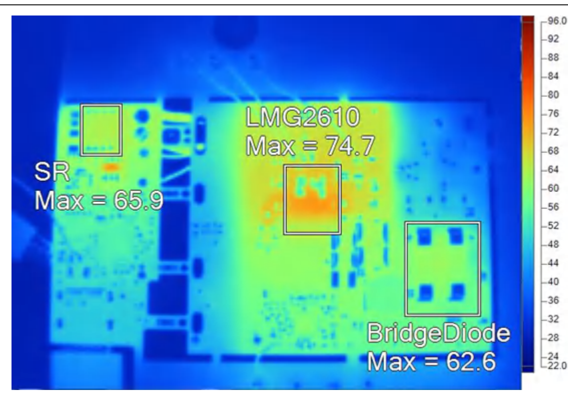

Figure 8-45. V_{IN} = 230 V_{AC}, Bottom Side

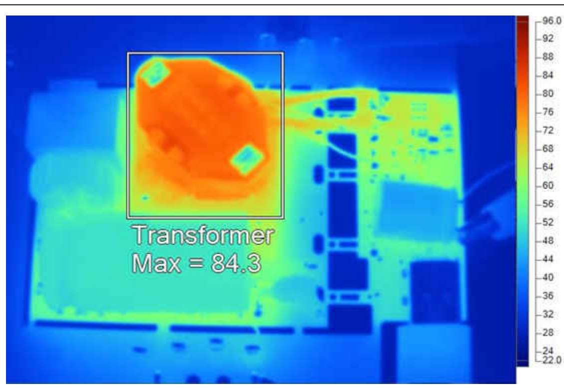

Figure 8-46. V_{IN} = 265 V_{AC}, Top Side

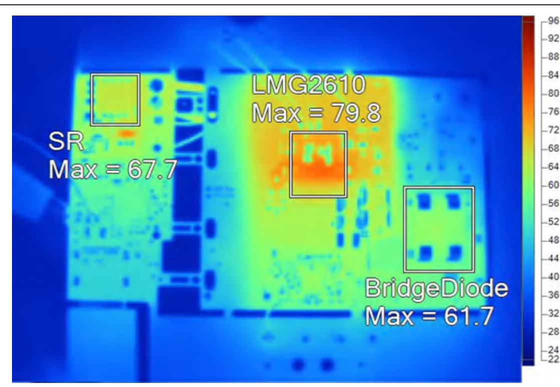

Figure 8-47. V_{IN} = 265 V_{AC}, Bottom Side

9 Transformer Details

Renco Electronics transformer part number RLTI-1403 is used on this design and wound on an RM8 core set.

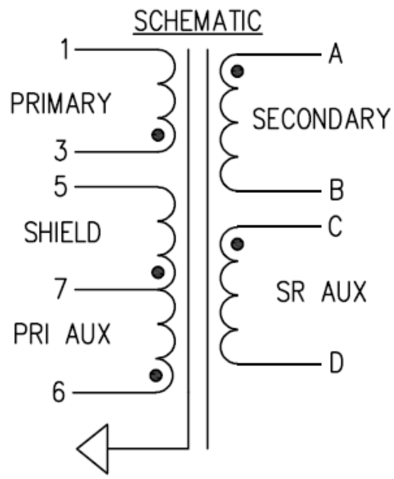

Figure 9-1. Transformer Schematic Diagram

Table 9-1. Transformer Specifications at 25°C

PARAMETER	VALUE	PINS/LEADS	TEST CONDITIONS
Inductance (µH)	110, ± 5%	1 – 3	Open all other pins, 100kHz, 0.1V
Leakage Inductance (µH)	2.5 Max.	1 – 3	Short A - B, 100kHz, 0.1V
D.C. resistance (Ω)	0.1, ±15%	1 – 3	
D.C. resistance (Ω)	0.007 Max.	A – B	
D.C. resistance (Ω)	0.02, ±15%	6 – 7	
D.C. resistance (Ω)	0.12, ±15%	C – D	
Dielectric (VAC, 60Hz)	3000	1, 6 – A	1 mA, 60 Hz, 1 s
Turns-ratios	1 : 0.2 : 0.2 : 0.32	(1-3):(A-B):(6-7):(C-D)	1.0V @ 10kHz to 1 - 3

10 EVM Assembly and Layout

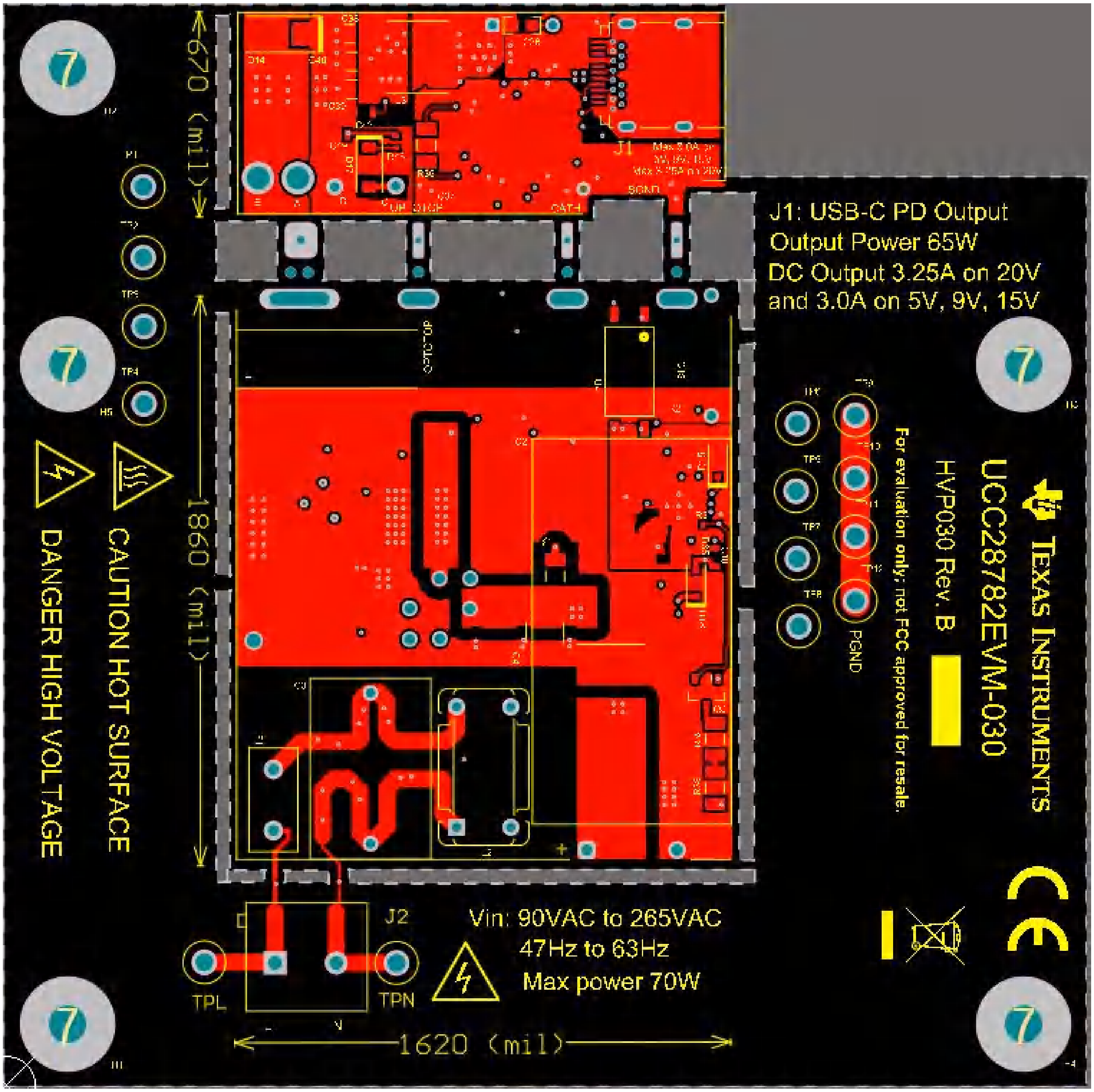

Figure 10-1. EVM Assembly (Top View)

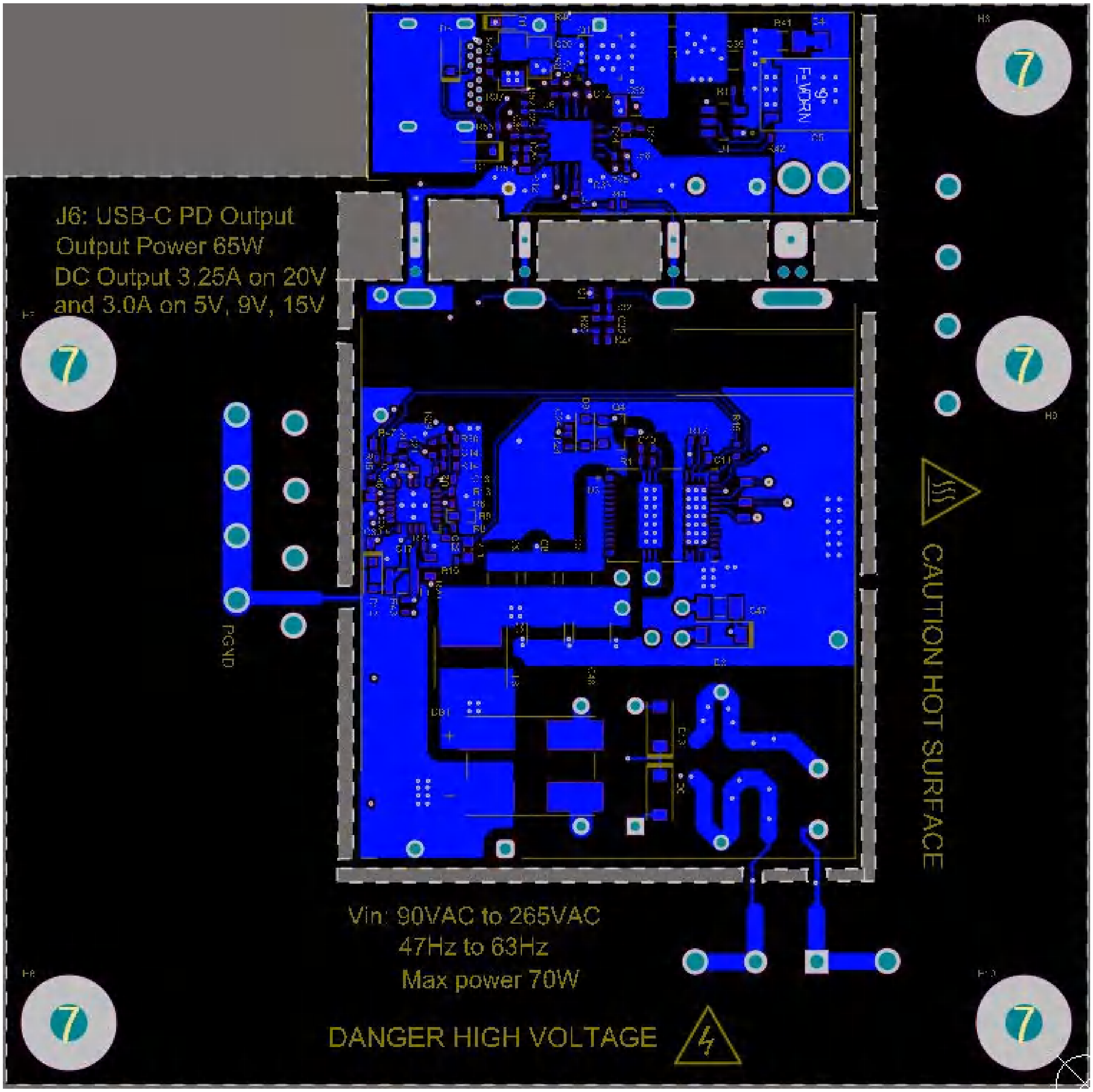

Figure 10-2. EVM Assembly (Bottom View)

11 List of Materials

UCC28782EVM-030 list of materials for the schematic diagrams shown in Figure 5-1 and in Figure 5-2.

Table 11-1. UCC28782EVM-030 List of Materials

Designator	Quantity	PartNumber	Manufacturer	Description
C1, C11, C23, C43	4	C1608X7R1E105K080AB	TDK	CAP, CERM, 1 µF, 25 V, +/- 10%, X7R, 0603
C2	1	400BXW100MEFR16X30	Rubycon	CAP, AL, 100 µF, 400 V, +/- 20%, TH
C3	1	890324024005	Wurth Elektronik	CAP, Film, 0.47 µF, 275 V, +/- 10%, TH
C4, C5, C48	3	1812Y5000474KXTWS2	Knowles Syfer	CAP, CERM, 0.47 µF, 500 V,+/- 20%, X7R, 1812
C7, C8	2	C1210C334KARACAUTO	Kemet	CAP, CERM, 0.33 µF, 250 V, +/- 10%, X7R, 1210
C10	1	GRM155R71H223KA12D	MuRata	CAP, CERM, 0.022 uF, 50 V, +/- 10%, X7R, 0402
C12	1	GRM155R71C224KA12D	MuRata	CAP, CERM, 0.22 µF, 16 V, +/- 10%, X7R, 0402
C13, C14	2	GRM155R71H331KA01D	MuRata	CAP, CERM, 330 pF, 50 V, +/- 10%, X7R, 0402
C15	1	DE1E3RA222MN4AN01F	MuRata	CAP, CERM, 2200 pF, 250 V,+/- 20%, E, Dia 9mm
C17, C18, C30	3	GRM188R6YA106MA73D	Murata	CAP, CERM, 10 µF, 35 V, +/- 10%, X5R, 0603
C20	1	GRM21BR6YA106KE43L	MuRata	CAP, CERM, 10 µF, 35 V,+/- 10%, X5R, 0805
C21, C42, C46	3	GRM155R71H221KA01D	MuRata	CAP, CERM, 220 pF, 50 V, +/- 10%, X7R, 0402
C24	1	GRM1555C1H220JA01D	MuRata	CAP, CERM, 22 pF, 50 V, +/- 5%, C0G/NP0, 0402
C26	1	885012205061	Wurth Elektronik	CAP, CERM, 1000 pF, 50 V, +/- 10%, X7R, 0402
C28	1	GRM155R70J105MA12D	MuRata	CAP, CERM, 1 µF, 6.3 V, +/- 20%, X7R, 0402
C29, C33, C45	3	GRM155R71E104KE14D	MuRata	CAP, CERM, 0.1 µF, 25 V, +/- 10%, X7R, 0402
C32	1	C3216X5R1E336M160AC	TDK	CAP, CERM, 33 µF, 25 V, +/- 20%, X5R, 1206
C34	1	DNP		DNP
C35, C38, C39, C47	4	C3216X5R1E476M160AC	TDK	CAP, CERM, 47 µF, 25 V, +/- 20%, X5R, 1206
C36	1	CGA3E3X7R1H224K080AB	TDK	CAP, CERM, 0.22 µF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603
C37	1	687AVG025MGBJ	Illinois Capacitor	CAP, Aluminum Polymer, 680 µF, 25 V,+/- 20%, 0.29256 ohm, TH
C44	1	GCM188R71E105KA64D	MuRata	CAP, CERM, 1 µF, 25 V,+/- 10%, X7R, 0603
C49	1	UMK107AB7105KA-T	Taiyo Yuden	CAP, CERM, 1 µF, 50 V, +/- 10%, X7R, 0603
D1	1	RB521SM-40T2R	Rohm	Diode, Schottky, 40 V, 0.2 A, SOD-523
D3, D17	2	SS115LW RVG	Taiwan Semiconductor	Diode, Schottky, 150 V, 1 A, SOD-123
D4, D5	2	PESD5V0L1BA,115	NXP Semiconductor	TVS, 5 V, bidirectional, SOD-323
D6, D13	2	ES1JFL	ON Semiconductor	Diode, Switching, 600 V, 1 A, SOD-123
D9	1	DF2B18FU,H3F	Toshiba	Diode, TVS, Bi, 16.2 V, SOD-323
D12	1	CUS08F30,H3F	Toshiba	Diode, Schottky, 30 V, 0.8 A, SOD-323
D14	1	SMAJ100CA	Littelfuse	Diode, TVS, Bi, 100 V, SMA
D15	1	MM3Z20VST1G	On Semi	Diode, Zener, 20 V, 300mW, SOD-323
D16	1	CDSOD323-T24SC	Bourns Inc	Diode, TVS, 24 V, Clamping 9A, SOD-323

Table 11-1. UCC28782EVM-030 List of Materials (continued)

Designator	Quantity	PartNumber	Manufacturer	Description
DB1	1	Z4DGP410L-HF	Comchip Technology	Diode, P-N-Bridge, 1000 V, 4 A, Z4-D
F1	1	RST 3.15-BULK	Bel-Fuse	Fuse, 3.15 A, 250VAC/VDC, TH
H1, H2, H3, H4, H5	5	NSP-4-4-01	Essentra Components	MACHINE SCREW PAN PHILLIPS 4-40
H6, H7, H8, H9, H10	5	1902C	Keystone	Standoff, Hex, 0.5"L #4-40 Nylon
J1	1	632723300011	Wurth Elektronik	Connector, Receptacle, USB Type C, R/A
J2	1	ED120/2DS	On-Shore Technology	Terminal Block, 5.08 mm, 2x1, Brass, TH
L1	1	BRC2518T220K	Taiyo Yuden	Inductor, Wirewound, 22 uH, 0.49 A, 0.56 ohm, SMD
L2	1	744821201	Wurth Elektronik	Coupled inductor, 1 mH, 2 A, 0.045 ohm, TH
L3	1	SRN6045TA-1R0Y	Bourns	Inductor, Shielded, Ferrite, 1 µH, 8 A, 0.012 ohm, AEC-Q200 Grade 1, SMD
L4	1	LBR2012T1R0M	Taiyo Yuden	Inductor, Wirewound, Ceramic, 1 µH, 0.09 ohm, SMD
L6	1	74404064220	Wurth	Inductor, Shielded, Ferrite, 22 µH, 1.8 A, 0.089 ohm, SMD
Q1	1	CSD17575Q3	Texas Instruments	MOSFET, N-CH, 30 V, 60 A, DQG0008A (VSON-CLIP-8)
Q3, Q4	2	BSS126H6327XTSA2	Infineon Technologies	MOSFET, N-CH, 600 V, 0.021 A, AEC-Q101, SOT-23
Q5	1	BSC093N15NS5ATMA1	Infineon Technologies	MOSFET, N-CH, 150 V, 87 A, PG-TDSON-8
R1	1	CRCW040230K9FKED	Vishay-Dale	RES, 30.9 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402
R5	1	CRCW12063M30JNEA	Vishay-Dale	RES, 3.3 M, 5%, 0.25 W, AEC-Q200 Grade 0, 1206
R6, R10, R35, R43, R44, R45, R54	7	CRCW04020000Z0ED	Vishay-Dale	RES, 0, 5%, 0.063 W, AEC-Q200 Grade 0, 0402
R8	1	CRCW0402243KFKED	Vishay-Dale	RES, 243 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402
R9	1	CRCW0402162KFKED	Vishay-Dale	RES, 162 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402
R11, R12, R46	3	CRCW04020000Z0EDHP	Vishay-Dale	RES, 0, 0%, 0.2 W, AEC-Q200 Grade 0, 0402
R13	1	CRCW040237K4FKED	Vishay-Dale	RES, 37.4 k, 1%, 0.063 W, 0402
R14	1	RC0402FR-07182KL	Yageo America	RES, 182 k, 1%, 0.0625 W, 0402
R19	1	CRCW0402383RFKED	Vishay-Dale	RES, 383, 1%, 0.063 W, AEC-Q200 Grade 0, 0402
R20	1	CRCW060356K2FKEA	Vishay-Dale	RES, 56.2 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603
R23	1	ERA-2AEB1402X	Panasonic	RES, 14 k, 1%, 0.063 W, 0402
R24, R42	2	CRCW0402511RFKED	Vishay-Dale	RES, 511, 1%, 0.063 W, AEC-Q200 Grade 0, 0402
R26	1	CRCW040230K1FKED	Vishay-Dale	RES, 30.1 k, 1%, 0.063 W, 0402
R30	1	CRCW040220K0FKED	Vishay-Dale	RES, 20.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402
R32	1	CRCW040234K0FKED	Vishay-Dale	RES, 34.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402
R34	1	RMCF0402FT1M00	Stackpole Electronics Inc	RES, 1.00 M, 1%, 0.063 W, AEC-Q200 Grade 0, 0402
R36	1	RC1206FR-071KL	Yageo America	RES, 1.00 k, 1%, 0.25 W, 1206

Table 11-1. UCC28782EVM-030 List of Materials (continued)

Designator	Quantity	PartNumber	Manufacturer	Description
R37	1	CSNL1206FT2L00	Stackpole Electronics Inc	RES, 0.002, 1%, 1 W, 1206
R38, R39	2	ERA-8AEB133V	Vishay-Dale	RES, 13k, 5%, 0.25 W, AEC-Q200 Grade 0, 1206
R40	1	CRCW060310M0JNEA	Vishay-Dale	RES, 10 M, 5%, 0.1 W, AEC-Q200 Grade 0, 0603
R47	1	RT0603BRD07120RL	Yageo America	RES, 120, 0.1%, 0.1 W, 0603
R52	1	CRCW04025K11FKED	Vishay-Dale	RES, 5.11 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402
R53	1	CRCW040248K7FKED	Vishay-Dale	RES, 48.7 k, 1%, 0.063 W, 0402
R55, R57	2	CRCW040247R0JNED	Vishay-Dale	RES, 47, 5%, 0.063 W, 0402
R56	1	CRCW040210K0JNED	Vishay-Dale	RES, 10 k, 5%, 0.063 W, AEC-Q200 Grade 0, 0402
RT1	1	CRCW060346K4FKEA	Vishay-Dale	RES, 46.4 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603
RT2	1	NCP18WM224J03RB	MuRata	Thermistor NTC, 220k ohm, 5%, 0603
T1	1	RLTI-1403	Renco Electronics	ACF FLYBACK TRANSFORMER
TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TPN	9	5012	Keystone	Test Point, Multipurpose, White, TH
TP9, TP10, TP11, TP12, TPL	5	5011	Keystone Electronics, Keystone	Test Point, Multipurpose, Black, TH
U1	1	MP6908AGJ-P	Monolithic Power Systems	FAST TURN-OFF INTELLIGENT RECTIF
U2	1	UCC28782ADRTWR	Texas Instruments	UCC28782ADRTW, RTW0024B (WQFN-24)
U3	1	LMG2610	Texas Instruments	Integrated 650-V GaN Half-Bridge for Active Clamp Flyback Converters
U4	1	TLP383(GR-TPL,E	Toshiba	Optoisolator Transistor Output 5000Vrms 1 Channel 6-SO
U6	1	WT6636F	Weltrend	USB PD/QC4/QC4+ Controller

12 Revision History

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

Changes from Revision B (August 2020) to Revision C (October 2022) **Page**

Changes from Revision A (June 2020) to Revision B (August 2020) **Page**

STANDARD TERMS FOR EVALUATION MODULES

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

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

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

2 *Limited Warranty and Related Remedies/Disclaimers*:

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

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

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

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

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

NOTE:

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

3 *Regulatory Notices:*

3.1 *United States*

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

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

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

CAUTION

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

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

FCC Interference Statement for Class A EVM devices

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

FCC Interference Statement for Class B EVM devices

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

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

3.2 *Canada*

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

Concerning EVMs Including Radio Transmitters:

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

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

Concernant les EVMs avec appareils radio:

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

Concerning EVMs Including Detachable Antennas:

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

Concernant les EVMs avec antennes détachables

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

3.3 *Japan*

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

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。

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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。

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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。http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

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.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265