Using the UCC28780EVM-002 45-W 20-V High Density GaN Active-Clamp Flyback Converter

User's Guide

Literature Number: SLUUBO8A
October 2018–Revised February 2018

General Texas Instruments High Voltage Evaluation (TI HV EVM) User Safety Guidelines

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.

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
    1. Keep work area clean and orderly.
    2. Qualified observer(s) must be present anytime circuits are energized.
    3. 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.
    4. 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.
    5. Use stable and nonconductive work surface.
    6. 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.
    1. 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.
    2. 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.
    3. 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
    1. 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.

Using the UCC28780EVM-002 45-W 20-V High Density GaN Active-Clamp Flyback Converter

1 Description

The UCC28780EVM-002 is a 45-W 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. It is intended for evaluation purposes and is not intended to be an end product. The UCC28780EVM-002 converts input voltage of 90-V_{RMS} to 264-V_{RMS} down to 20-V_{DC}, with a 2.25-A nominal output current rating and a 160-ms limit for over-power capability. The main devices used in this design are active clamp flyback controller UCC28780, SR controller UCC24612, and GaN MOSFET Power IC NV6117 and NV6115. Please read this user's guide thoroughly before applying power to this board.

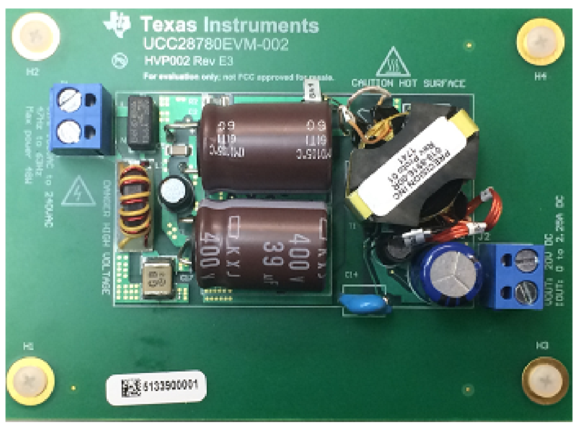

Figure 1. UCC28780EVM-002 Top View

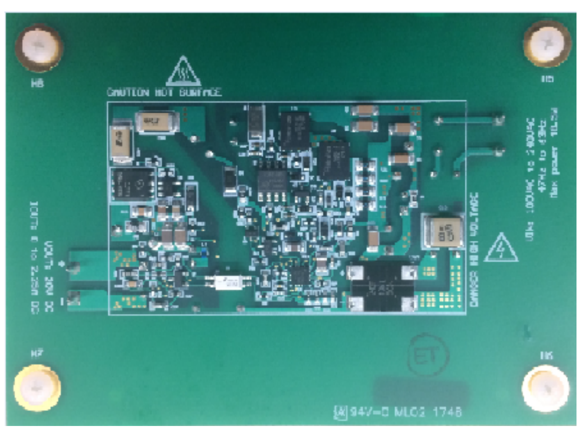

Figure 2. UCC28780EVM-002 Bottom View

2 Electrical Performance Specifications

Table 1. UCC28780EVM-002 Electrical Performance Specifications[1]

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 V_{RMS}, I_{OUT} = 0 A		41.1		mW
P_{STBY}	Input power at no-load	V_{IN} = 230 V_{RMS}, I_{OUT} = 0 A		52.8		mW
$P_{0.25W}$	Input power at 0.25W load	V_{IN} = 115 V_{RMS}, P_{OUT} = 250.6 mW		383.8		mW
$P_{0.25W}$	Input power at 0.25W load	V_{IN} = 230 V_{RMS}, P_{OUT} = 250.6 mW		435.0		mW
OUTPUT CHARACTERISTICS						
V_{OUT}	Output voltage	V_{IN} = 115 V_{RMS}, I_{OUT} = 2.249 A		19.853		V
		V_{IN} = 230V_{RMS}, I_{OUT} = 2.249 A		19.852		
V_{OUT}	Output voltage	V_{IN} = 115 V_{RMS}, I_{OUT} = 0 A		19.943		V
		V_{IN} = 230V_{RMS}, I_{OUT} = 0 A		19.948		
I_{OUT}	Full load rated output current	V_{IN} = 90 to 264 V_{RMS}		2.25		A
V_{OUT_pp}	Output ripple voltage	V_{IN} = 115 V / 230 V_{RMS}, I_{OUT} = 0 to 2.25		80		mVpp
V_{OUT_pp}	Output ripple voltage	V_{IN} = 115 V / 230 V_{RMS}, I_{OUT} = 2.25 A		45		mVpp
V_{OUT_pp}	Output ripple voltage	V_{IN} = 115 V / 230 V_{RMS}, I_{OUT} = 0 A		50		mVpp
P_{OUT_opp}	Over-power protection power limit	V_{IN} = 90 to 264 V_{RMS}		55		W
t_{OPP}	Over-power protection duration	V_{IN} = 90 to 264 V_{RMS}, P_{OUT} = P_{OUT_opp}		160		ms
V_{OUT_Δ}	Output voltage deviation due to load step up	I_{OUT} step between 0 A and 2.25A		< 5		%
SYSTEMS CHARACTERISTICS						
η	Full-load efficiency	V_{IN} = 115 V_{RMS}, I_{OUT} = 2.25A		94.59		%
		V_{IN} = 230 V_{RMS}, I_{OUT} = 2.25A		94.74		%
		V_{IN} = 90V RMS, I_{OUT} = 2.25A		93.98		%
η	4-point average efficiency[2]	V_{IN} = 115 V_{RMS}		93.88		%
		V_{IN} = 230 V_{RMS}		92.47		%
η	Efficiency at 10% Load	V_{IN} = 115 V_{RMS}, I_{OUT} = 10% rated current		88.69		%
		V_{IN} = 230 V_{RMS}, I_{OUT} = 10% rated current		85.86		%
T_{AMB}	Ambient operating temperature range	V_{IN} = 90 to 264 V_{RMS}, I_{OUT} = 0 to 2.25A		25		°C

(1) The performance listed in this table is achieved using secondary resonance and based on the test results from a single board.
(2) Average efficiency of four load points, I_{OUT} = 25%, 50%, 75% and 100% nom.

3 Schematic Diagram

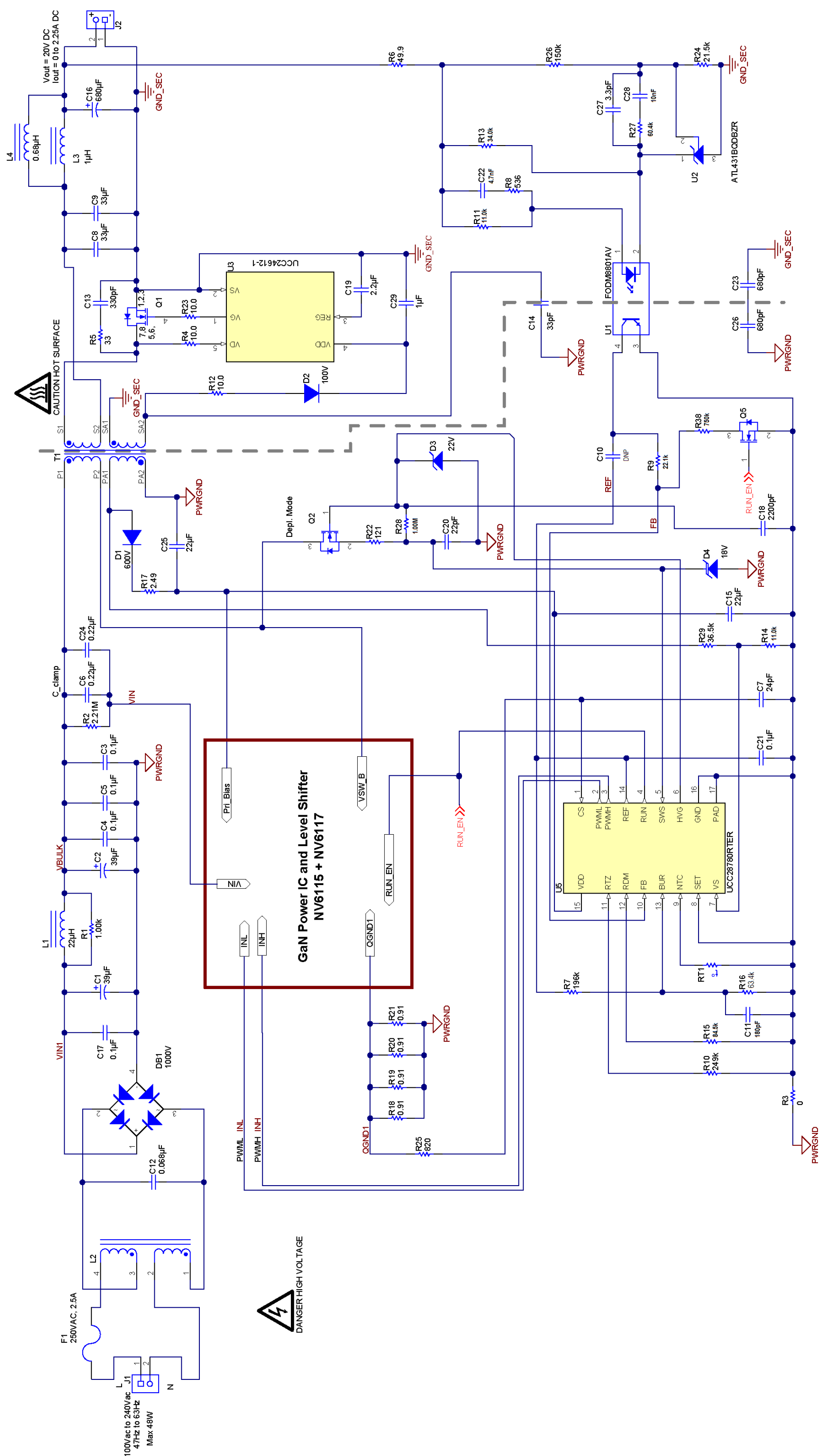

Figure 3. UCC28780EVM-002 Schematic Diagram (1 of 2)

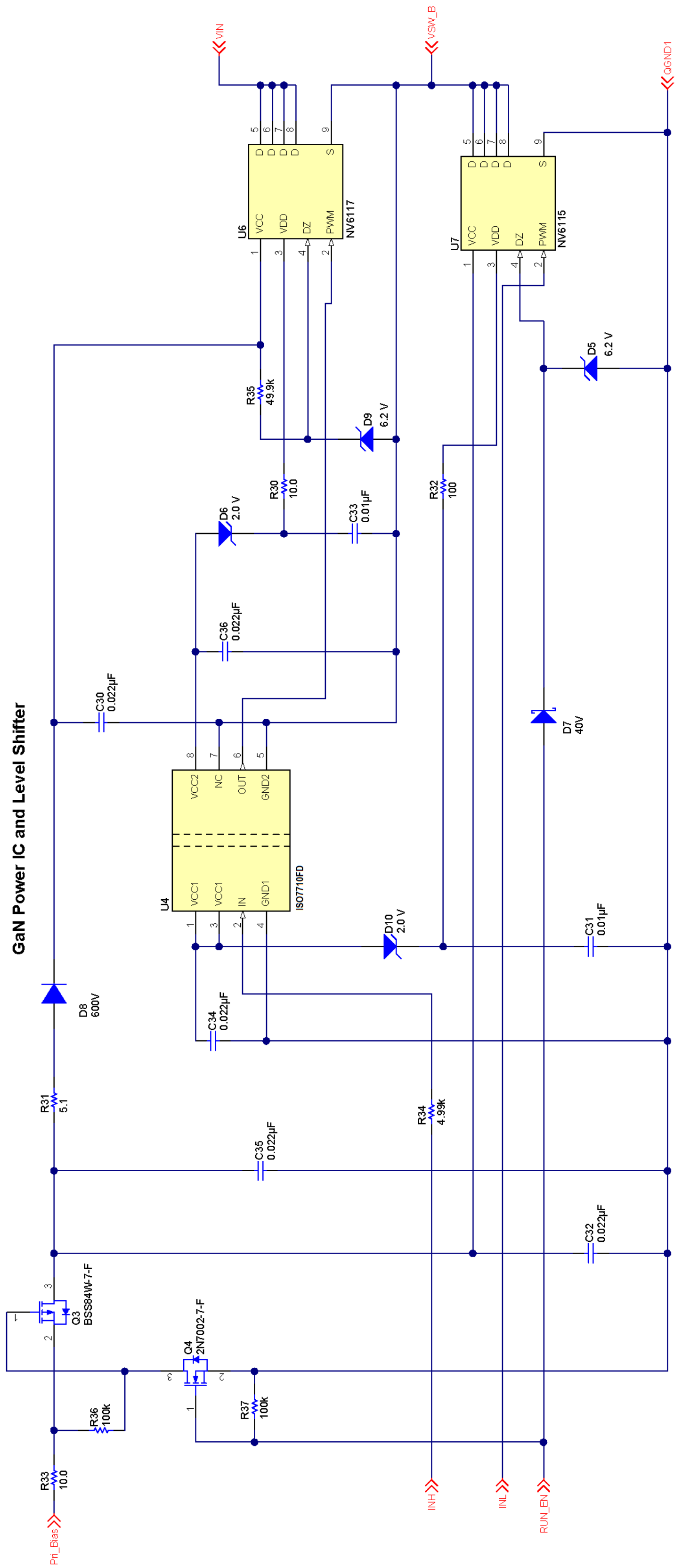

Figure 4. UCC28780EVM-002 Schematic Diagram (2 of 2)

4 Test Setup

4.1 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.

Read this user's guide thoroughly before making test.

Voltage Source: Isolated AC source or variable AC transformer capable of 264 V_{RMS} cable of handling 100 W

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

4.2 Test Setup Diagram

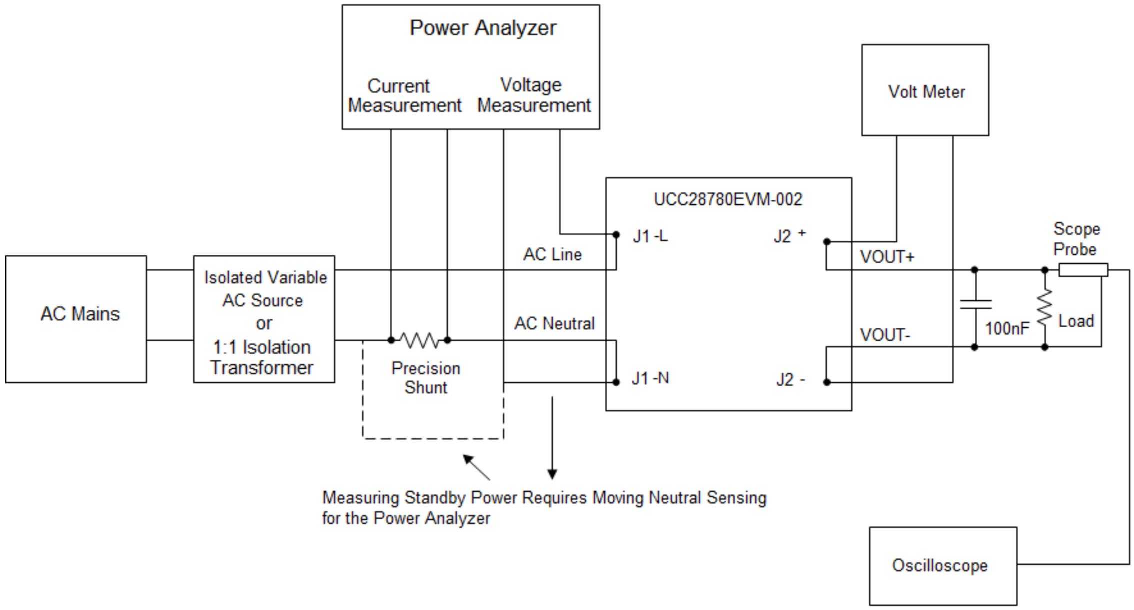

Figure 5. UCC28780EVM-002 Test Setup Diagram

4.3 Design Notes

In Table 6, a component list shows critical components to achieve stable ABM operation with secondary resonance which provides better efficiency and output voltage ripple performance. Details on secondary resonance can be found in the UCC28780 datasheet.

4.4 Test Points

Table 2. Test Point Functions

TEST POINTS		NAME	DESCRIPTION
J1-L	Location J1 Terminal	L	AC line voltage input
J1-N		N	AC neutral input
J2+	Location J2 Terminal	VOUT +	Output supply
J2-		VOUT –	Output return

5 Performance Data and Typical Characteristic Curves

5.1 Efficiency Typical Result of 4-Point Average

Table 3. Efficiency Test Data

V_{IN} RMS	P_{IN}	V_{OUT}	I_{OUT}	P_{OUT}(%)	EFFICIENCY	EFFICIENCY 4pt-AVERAGE	Switching Frequency @ Full Load
90	47.50	19.852	2.249	100%	93.98%	93.58%	194 kHz
90	35.70	19.855	1.693	75%	94.17%		
90	23.67	19.859	1.117	50%	93.71%		
90	12.27	19.861	0.571	25%	92.44%		
115	47.20	19.855	2.249	100%	94.59%	93.88%	242 kHz
115	35.50	19.859	1.693	75%	94.71%		
115	23.68	19.862	1.117	50%	93.68%		
115	12.26	19.861	0.571	25%	92.52%		
230	47.12	19.852	2.249	100%	94.74%	92.47%	300 kHz
230	35.79	19.855	1.694	75%	93.94%		
230	24.19	19.859	1.117	50%	91.71%		
230	12.67	19.861	0.571	25%	89.48%		
264	47.24	19.853	2.249	100%	94.50%	92.03%	303 kHz
264	35.91	19.855	1.693	75%	93.63%		
264	24.28	19.860	1.117	50%	91.33%		
264	12.79	19.860	0.571	25%	88.64%		

5.2 Efficiency Typical Results

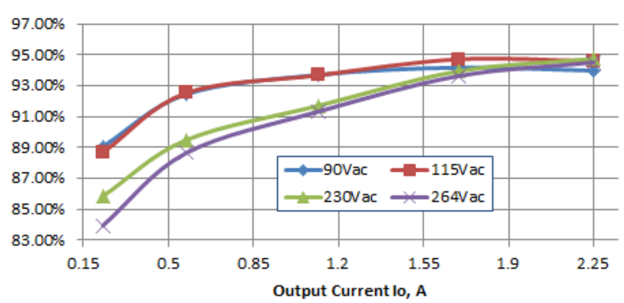

Figure 6. Efficiency Over Load

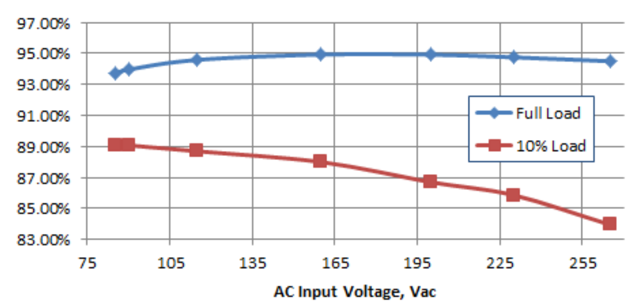

Figure 7. Efficiency Over Input Voltage

5.3 VI Characteristics

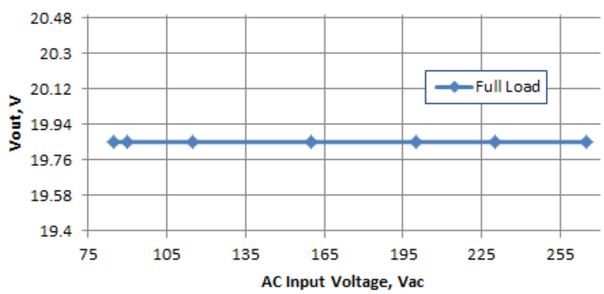

Figure 8. V_{OUT} Over Input Voltge

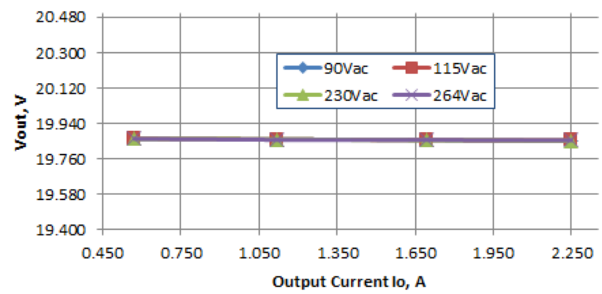

Figure 9. V_{OUT} Over Output Current

5.4 Switching Frequency

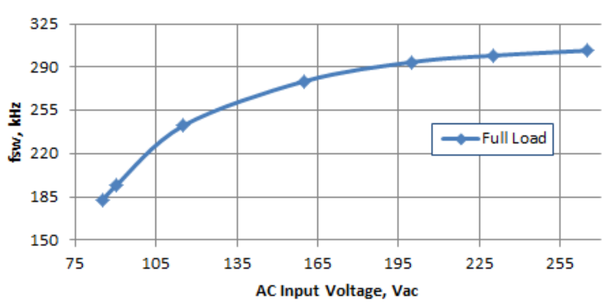

Figure 10. Switching Frequency Over Input at Full Load

Figure 11. Maximum switching frequency about 500kHz at high line and entering ABM

CH1 = PWML, CH4 = Transformer Primary Winding Current, CH3 = Switch Node Voltage

5.5 Key Switching Waveforms and Operation Mode Load Current

This section shows typical operation modes in Table 4 along with typical load currents in this design and with Vin = 115Vac as an example.

- AAM: Adaptive Amplitude Modulation
- ABM: Adaptive Burst Mode
- LPM: Lower Power Mode
- SBP: Standby Power Mode

Table 4. Operation Mode and Load Current

Mode	AAM	AAM to ABM	ABM End	LPM	SBP
Typical Load Current	1.50 A to 2.25 A	1.30 A to 1.60 A	0.15 A to 0.18 A	0.05 A to 0.15 A	< 0.08 A
Typical Load %	67% to 100%	58% to 71%	6.7% to 8%	2.2% to 6.7%	< 3.5%

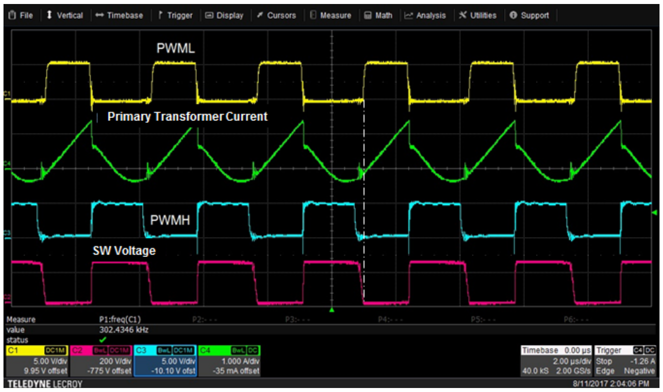

Figure 12. AAM Mode at Heavy Loads (CH1 = PWML, CH4 = Transformer Primary Winding Current, CH2 = Switch Node Voltage, CH3 = PWMH)

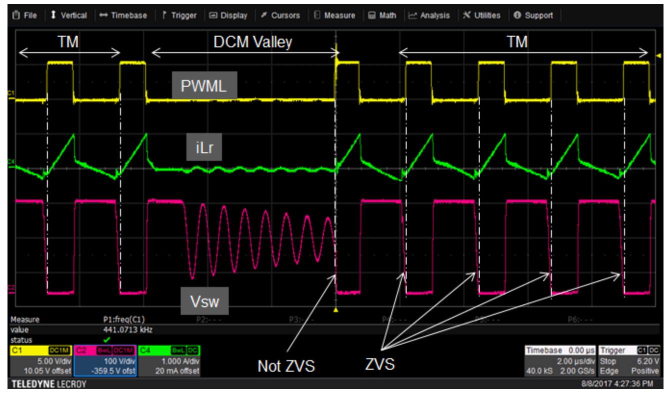

Figure 13. ABM Mode at Medium Loads (CH1 = PWML, CH4 = Transformer Primary Winding Current, CH2 = Switch Node Voltage)

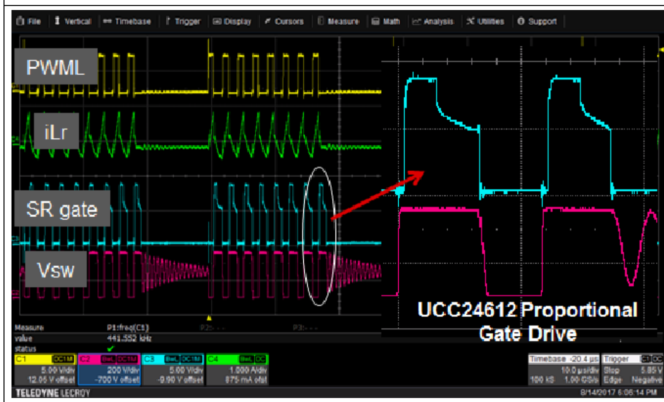

Figure 14. ABM Mode and SR (CH1 = PWML, CH4 = Transformer Primary Winding Current, CH2 = Switch Node Voltage, CH3 = SR Vgs)

Figure 15. Recovery after OPP with 3 Stages of Peak Current (CH1 = PWML, CH4 = Transformer Primary Winding Current, CH2 = Switch Node Voltage)

Figure 16. LPM Mode Operation (when a burst packet contains 2 pulses and the interval between 2 packets is around 40µs, and peak current starts to reduce. CH3 = PWML, CH4 = Transformer primary winding current.)

Figure 17. SBP Mode Operation (when a burst packet contains 2 pulses and the interval between 2 packets is > 40 µs. CH3 = PWML, CH4 = Transformer primary winding current.)

5.6 Start Up

CH1 = PWML, CH2 = Switch Node Voltage, CH3 = Output Voltage, CH4 = Transformer Primary Current.

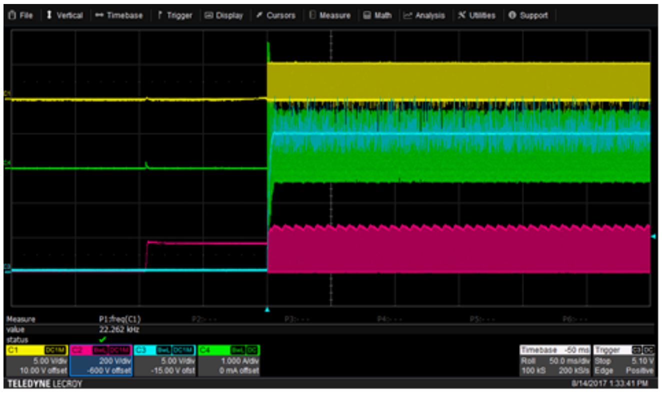

Figure 18. 115 V_{AC} and Full Load Startup

Figure 19. 230 V_{AC} and Full Load Startup

5.7 Line Transient Response

CH1 = Vout, CH2 = Line voltage.

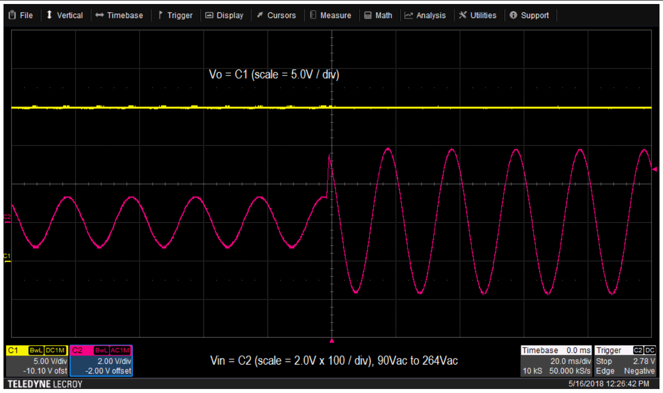

Figure 20. Output Voltage Response to Line Transient with Full Load.

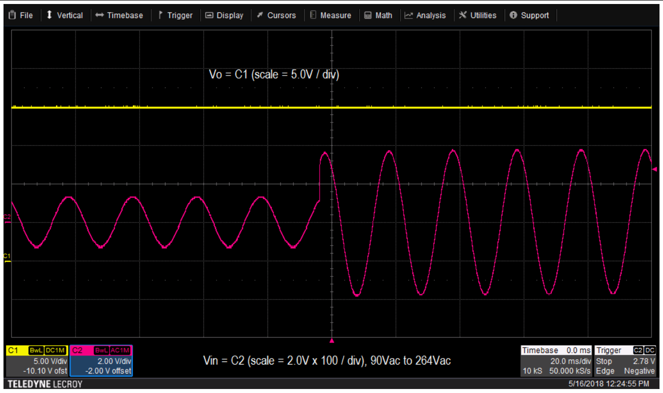

Figure 21. Output Voltage Response to Line Transient with No Load.

5.8 Output Ripple Voltage

CH3 = Output Voltage Ripple

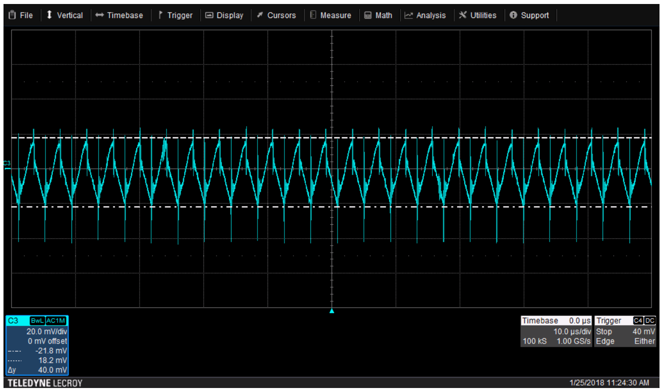

Figure 22. Ripple Voltage = 40.0mV, V_{IN} = 115 V_{RMS}, I_{OUT} = 2.25 A

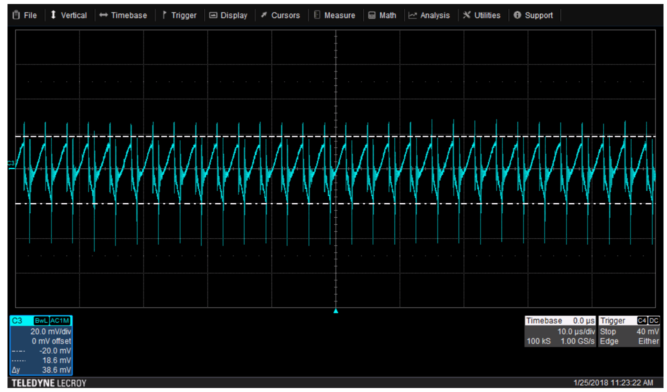

Figure 23. Ripple Voltage = 38.6mV, V_{IN} = 230 V_{RMS}, I_{OUT} = 2.25 A

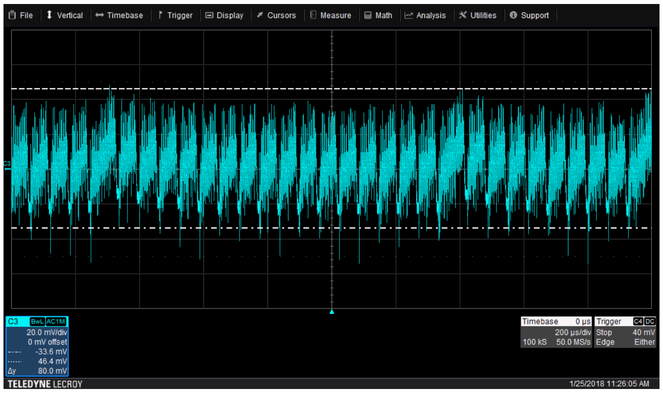

Figure 24. Ripple Voltage < 80 mV, V_{IN} = 115V_{RMS}, I_{OUT} = 1.125 A

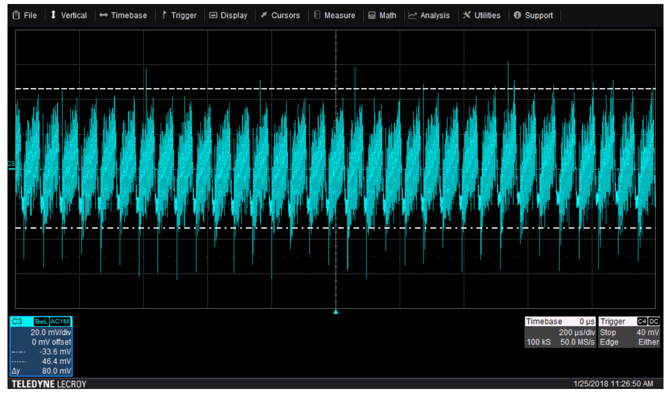

Figure 25. Ripple Voltage < 80mV, V_{IN} = 230V_{RMS}, I_{OUT} = 1.125 A

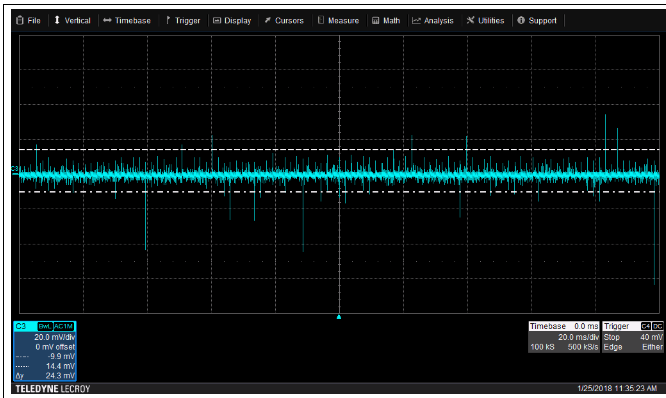

Figure 26. Ripple Voltage = 24.3 mV, V_{IN} = 115V_{RMS}, I_{OUT} = 0 A

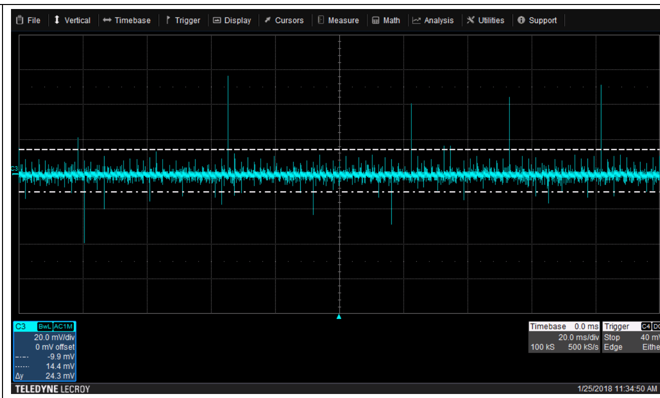

Figure 27. Ripple Voltage = 24.3mV, V_{IN} = 230V_{RMS}, I_{OUT} = 0 A

5.9 Over Power Protection

Figure 28 shows the converter Over Power Protection (OPP) with respect to input voltage. Figure 29 shows the converter auto-retry to resume operation after OPP.

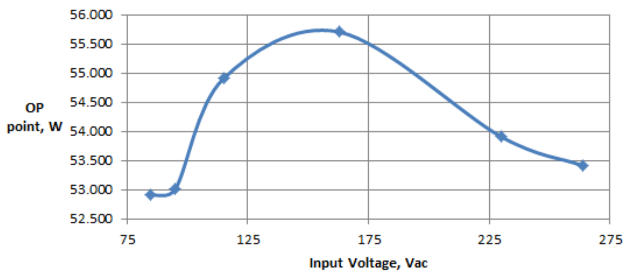

Figure 28. OPP with Respect to Input Voltage

Figure 29. OPP Auto Retry (CH1 = PWML, CH2 = Switch Node Voltage, CH3 = Transformer Primary Current)

5.10 Load Transient Response

Figure 30 and Figure 31 show output voltage Vout deviation < 5% for 0 and 2.25A load step change. CH3 = Vout, CH4 = Load Current.

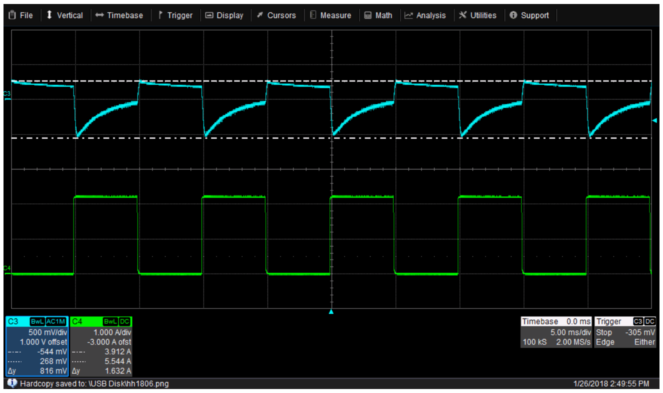

Figure 30. Vout Load Transient Response at V_{IN} = 115 V_{RMS}

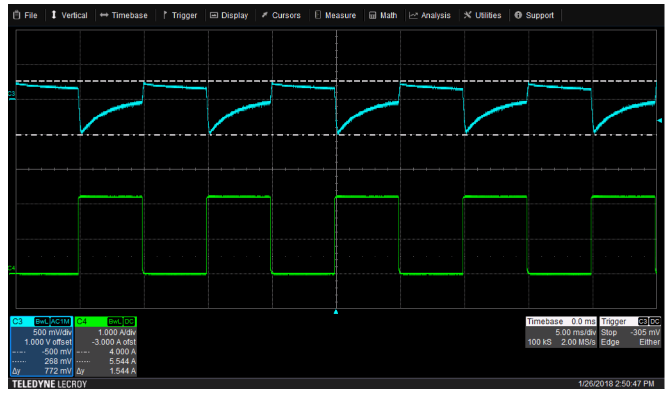

Figure 31. Vout Load Transient Response at V_{IN} = 230 V_{RMS}

Figure 32 and Figure 33 show the switching node voltage response for 0 and 2.25A load step change. CH2 = PWML, CH3 = Switch Node Voltage, CH4 = Load Current.

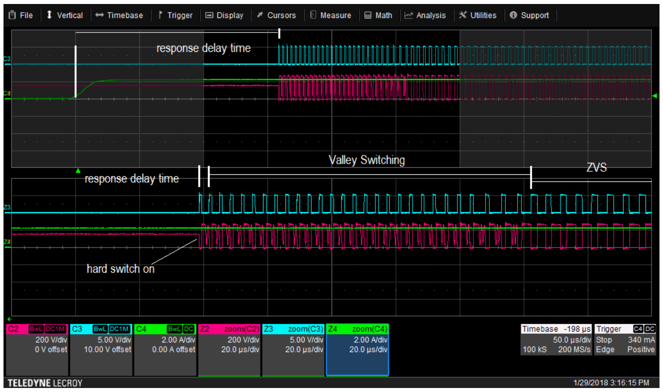

Figure 32. Load Step-Up (0A to 2.25A) Switching Response

Figure 33. Load Step-Down (2.25A to 0A) Switching Response

5.11 Conducted EMI Output Not Grounded to LISN ground

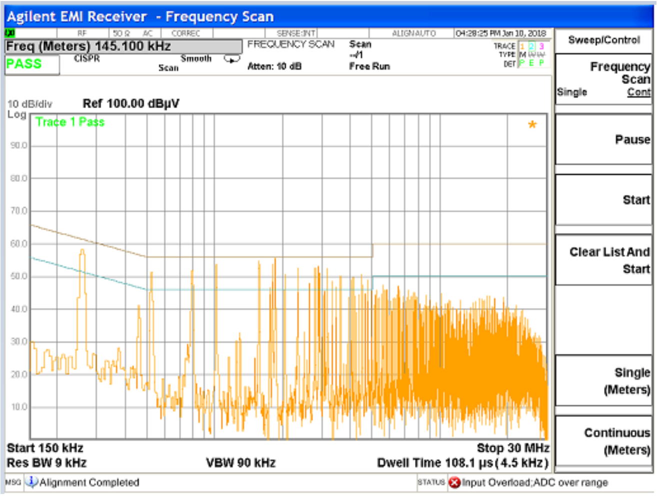

Figure 34. VIN = 115 V_{RMS}, Load = 9.3 Ω

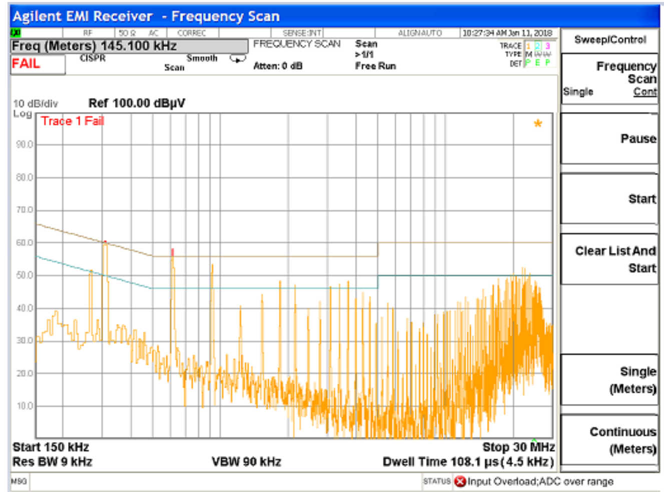

Figure 35. VIN = 230 V_{RMS}, Load = 9.3 Ω

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.

5.12 Thermal Images at Full Load (2.25 A)

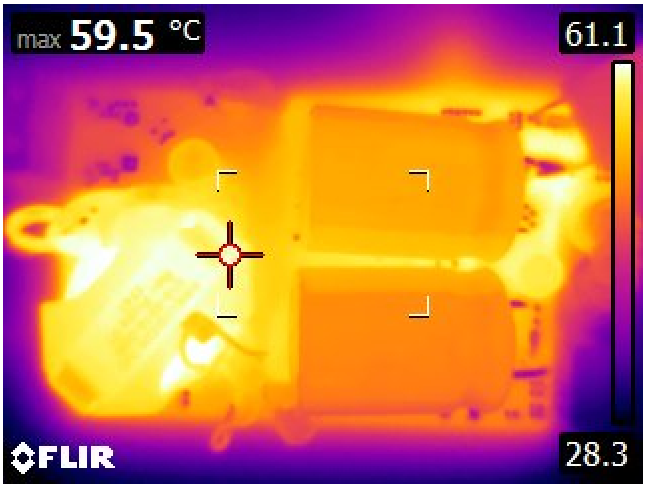

Figure 36. V_{IN} = 90 V_{AC}, Top Side (Transformer: 60 °C)

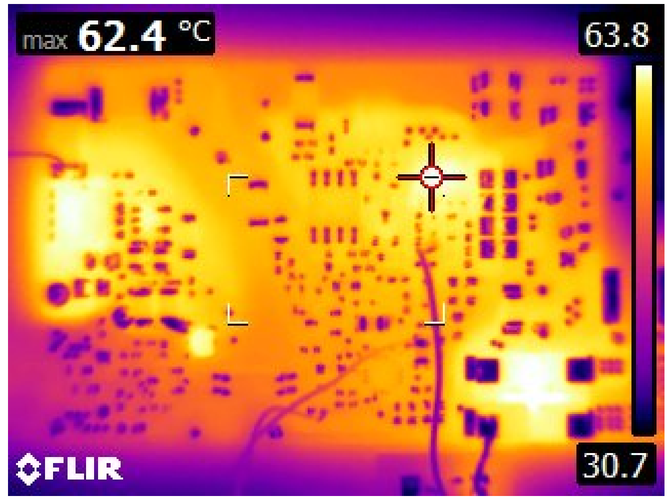

Figure 37. V_{IN} = 90 V_{AC}, Bottom Side (Q1: 64 °C; U7: 63 °C; DB1: 64 °C)

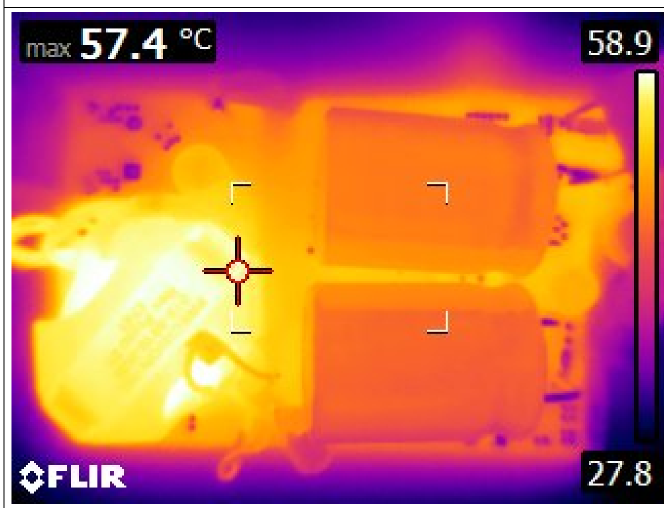

Figure 38. V_{IN} = 115 V_{AC}, Top Side (Transformer: 59 °C)

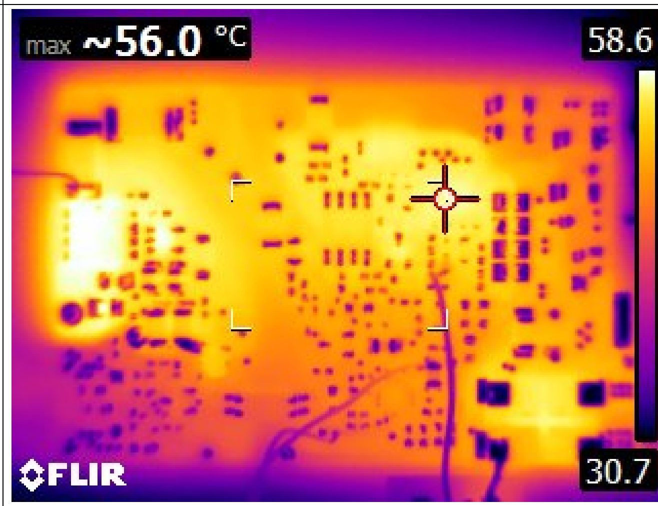

Figure 39. V_{IN} = 115 V_{AC}, Bottom Side (Q1: 59 °C; U7: 56 °C)

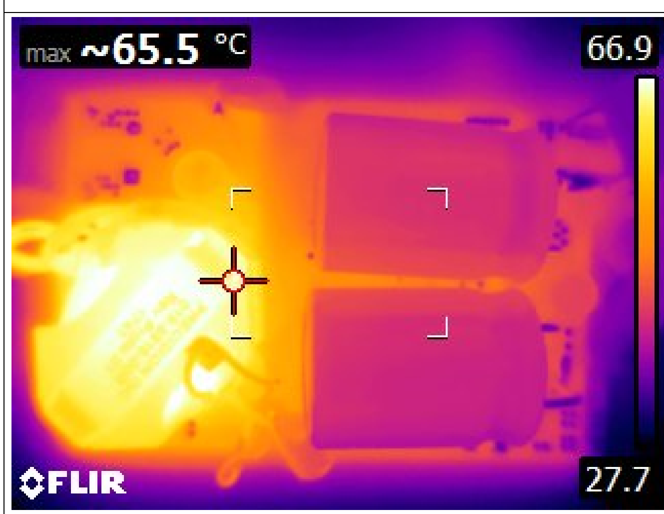

Figure 40. V_{IN} = 230 V_{AC}, Top Side (Transformer: 66 °C)

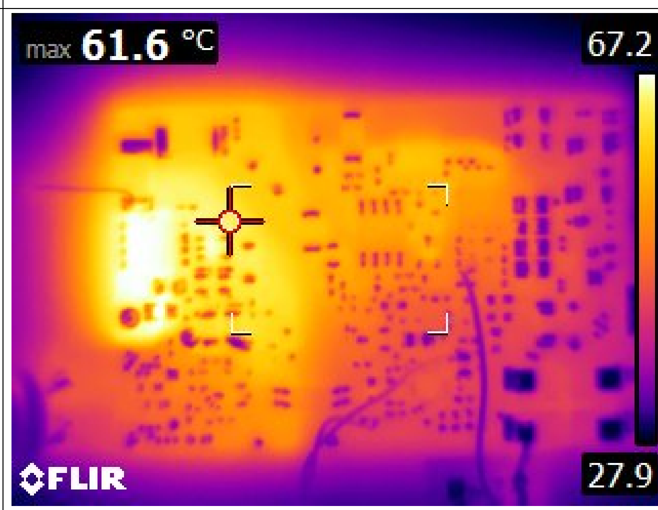

Figure 41. V_{IN} = 230 V_{AC}, Bottom Side (Q1: 76 °C)

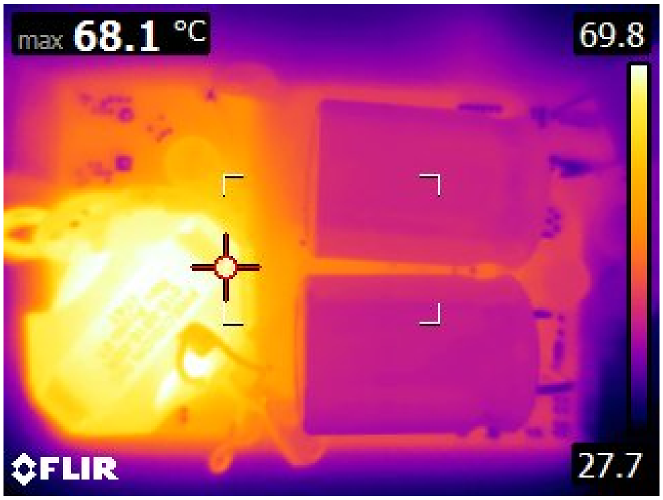

Figure 42. V_{IN} = 265 V_{AC}, Top Side (Transformer: 69 °C)

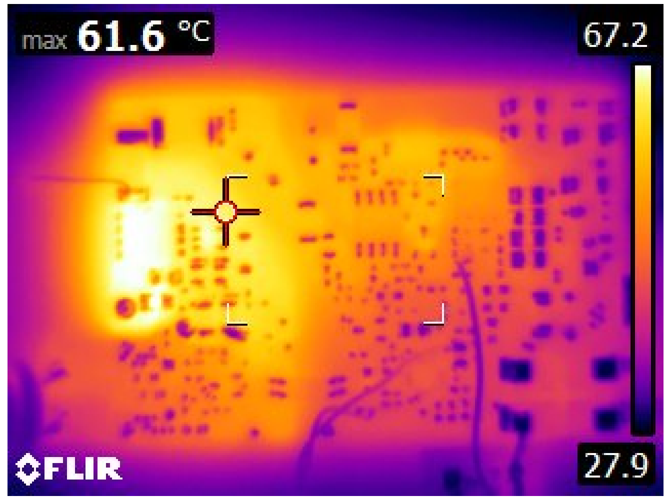

Figure 43. V_{IN} = 265 V_{AC}, Bottom Side (Q1: 79 °C)

6 Transformer Details

Precision Inc transformer part number 019-8916-00R is used on this design and wound on a low profile RM8/ILP core set (11.6 mm height).

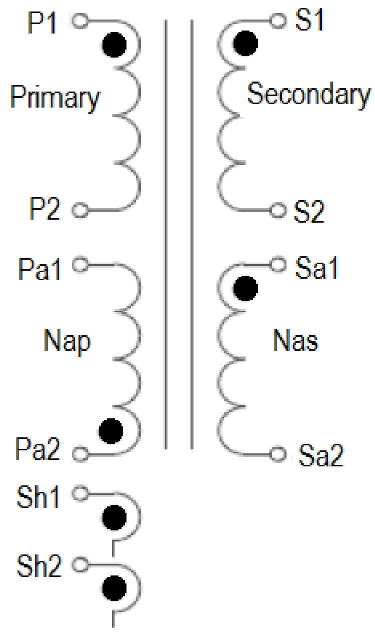

Figure 44. Transformer Schematic Diagram

Sh1 and Sh2 are the terminals for EMI shields. Their optimal connections are to be determined and their current connections are to pin P1.

Table 5. Transformer Specifications at 25°C

PARAMETER	VALUE	PINS/LEADS	TEST CONDITIONS
Inductance (µH)	104 to 127	P1 – P2	Open all other pins
Leakage Inductance (µH)	2.5 Max.	P1 – P2	Tie S1 - S2, 0.1 V, 200 kHz
D.C. resistance (Ω)	0.147 Max.	P1 – P2	
D.C. resistance (Ω)	0.014 Max.	S1 – S2	
D.C. resistance (Ω)	0.16 Max.	Pa1 – Pa2	
D.C. resistance (Ω)	0.168 Max.	Sa1 – Sa2	
Dielectric (VAC)	1500	P1 – S1	1 mA, 60 Hz, 1 s
Dielectric (VAC)	500	P1, S1 to Core	1 mA, 60 Hz, 1 s
Turns ratio	1:0.19:0.14:0.1	(P1-P2):(S1-S2):(Pa1-Pa2):(Sa1-Sa2)	

7 EVM Assembly and Layout

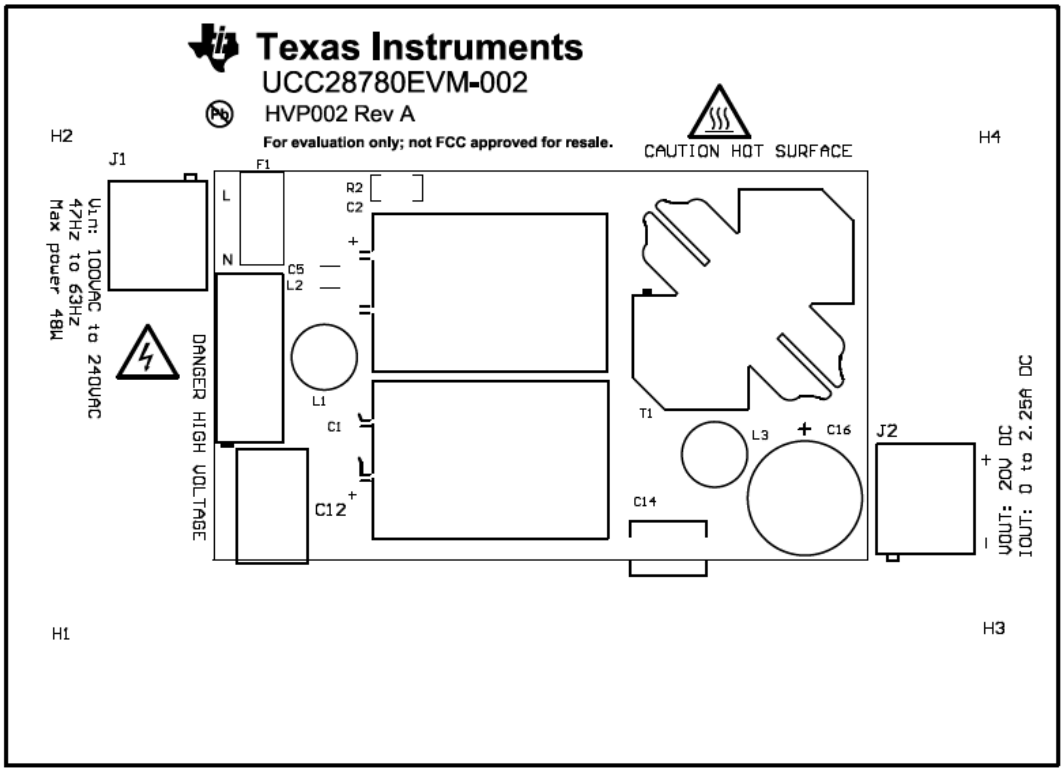

Figure 45. EVM Assembly (Top View)

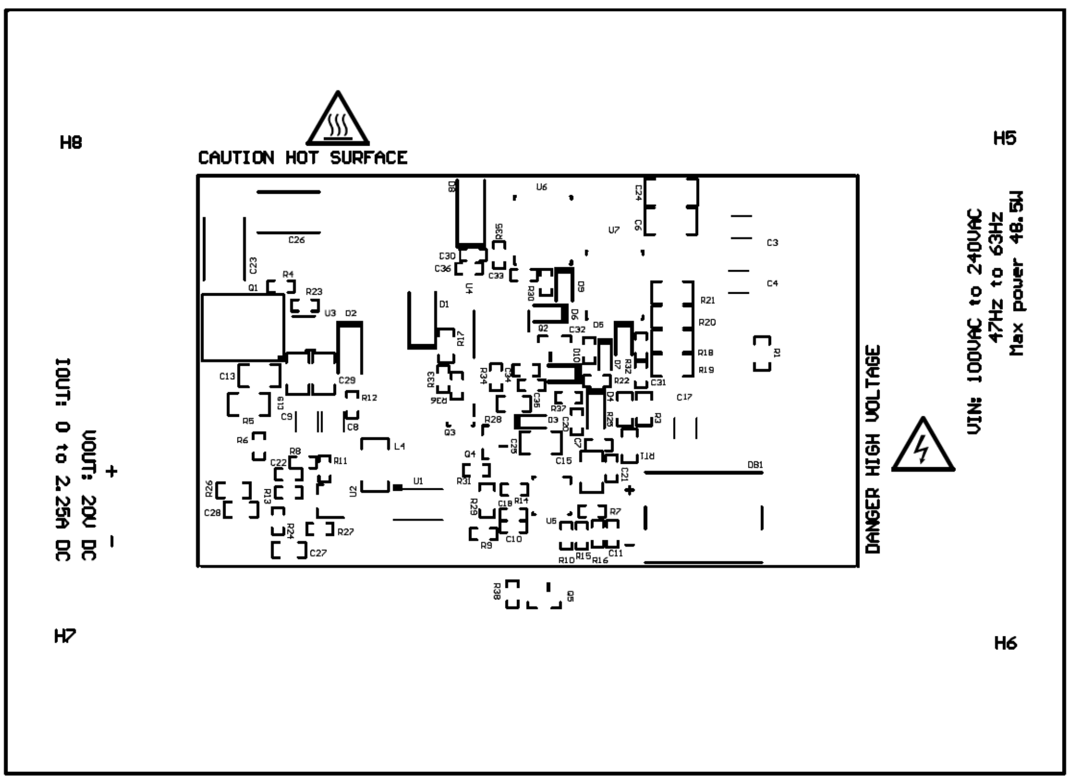

Figure 46. EVM Assembly (Bottom View)

8 List of Materials

UCC28780EVM-002 (secondary resonance approach as default) list of materials for the schematic diagrams shown in Figure 3 and in Figure 4. At bottom of the table, a component change list shows how to modify the design to obtain the primary resonance.

Table 6. UCC28780EVM-002 List of Materials

Quantity	Designator	Description	PartNumber	Manufacturer
2	C1, C2	Capacitor, aluminum, 39 µF, 400 V, ±20%, AEC-Q200 Grade 2, TH	EKXJ401ELL390MU20S	Chemi-Con
4	C3, C4, C5, C17	Capacitor, ceramic, 0.1 µF, 450 V, ±10%, X7T, 1206_190	C3216X7T2W104K160AA	TDK
2	C6, C24	Capacitor, ceramic, 0.22 µF, 250 V, ±10%, X7T, AEC-Q200 Grade 1, 1206	CGA5L3X7T2E224K160AE	TDK
1	C7	Capacitor, ceramic, 24 pF, 50 V, ±5%, C0G/NP0, 0402	GRM1555C1H240JA01D	MuRata
2	C8, C9	Capacitor, ceramic, 33 µF, 25 V, 20%, JB, 1206	C3216JB1E336M160AC	MuRata
1	C10	Do Not Populate		
1	C11	Capacitor, ceramic, 180 pF, 50 V, 1%, C0G/NP0, 0402	04025A181FAT2A	AVX
1	C12	CAP, Film, 0.068 µF, X2 275 VAC, +/- 10%, TH	890324022017CS	Wurth Elektronik
1	C13	Capacitor, ceramic, 330 PF, 250 V, C0G/NP0, 0805	GRM21A5C2E331JW01D	MuRata
1	C14	Capacitor, ceramic, 33 pF, X1/Y2 250 VAC, ±5%, SL, D7xT5mm	DE21XKY330JN3AM02F	TDK
2	C15, C25	Capacitor, ceramic, 22 µF, 35 V, ±20%, X5R, 0805	C2012X5R1V226M125AC	TDK
1	C16	Capacitor, AL Poly, 680 µF, 25V, ±20%, TH	687AVG025MGBJ	Illinois Capacitor
1	C18	Capacitor, ceramic, 2200 pF, 50 V, ±10%, X7R, 0402	CGA2B2X7R1H222K050BA	TDK
1	C19	Capacitor, ceramic, 2.2 µF, 50 V, ±10%, X7R, 0805	C2012X7R1H225K125AC	TDK
1	20	Capacitor, ceramic, 22 pF, 50 V, ±5%, C0G/NP0, 0402	GRM1555C1H220JA01D	MuRata
1	C21	Capacitor, ceramic, 0.1 µF, 25 V, ±10%, X7R, 0402	GRM155R71E104KE14D	MuRata
1	C22	Capacitor, ceramic, 0.022 µF, 50V, ±5%, X7R, 0402	CGA2B2X7R1H472K050BA	TDK
5	C30, C32, C34, C35, C36	Capacitor, ceramic, 0.047 µF, 50V, 10%, X7R, 0402	GRM155R71H223KA12D	MuRata
2	C23, C26	Capacitor, ceramic, 680 pF, X1 250 VAC/Y2 250 VAC, +/- 10%, X7R, 2211	GA352QR7GF681KW01L	MuRata
1	C27	Capacitor, ceramic, 3.3 pF, 50 V, ±8%, C0G/NP0, 0603	06035A3R3CAT2A	AVX
1	C28	Capacitor, ceramic, 10 nF, 50 V, ±5%, C0G/NP0, 0603	CGA3E2C0G1H103J080AA	TDK
1	C29	Capacitor, ceramic, 1 µF, 50 V, ±10%, X7R, AEC-Q200 Grade 1, 0805	CGA4J3X7R1H105K125AB	TDK
2	C31, C33	Capacitor, ceramic, 0.01 µF, 50 V, ±10%, X7R, 0402	GRM155R71H103KA88D	MuRata
1	D1	Diode, superfast rectifier, 600 V, 1 A, 3.5x1.6mm	CSFMT108-HF	Comchip Technology
1	D2	Diode, ultrafast, 100 V, 0.15 A, SOD-123	1N4148W-7-F	Diodes Inc.
1	D3	Diode, Zener, 22 V, 300 mW, SOD-523	BZT52C22T-7	Diodes Inc.
1	D4	Diode, TVS, Uni, 18V, SOD-323	CDSOD323-T18	Bourns
2	D5, D9	Diode, Zener, 6.2 V, 150 mW, SOD-523F	CZRU52C6V2	Comchip Technology
2	D6, D10	Diode, Zener, 2 V, 150 mW, SOD-523F	CZRU52C2	Comchip Technology
1	D7	Diode, Schottky, 40 V, 0.03 A, SOD-523	SDM03U40-7	Diodes Inc.

Table 6. UCC28780EVM-002 List of Materials (continued)

Quantity	Designator	Description	PartNumber	Manufacturer
1	D8	Diode, Ultrafast, 600 V, 1 A, AEC-Q101, SMAF	ES1JAF	Fairchild Semi
1	DB1	Diode, P-N-bridge, 1000 V, 4 A, Z4-D	Z4DGP410L-HF	Comchip Technology
1	F1	Fuse, 2.5 A, 250 VAC/VDC, TH	RST 2.5-Bulk	Bel-Fuse
1	L1	Inductor, unshielded Drum Core, Ferrite, 22 µH, 1.7 A, 0.102 Ω, TH	7447462220	Wurth Elektronik
1	L2	Coupled inductor, 0.014 Ω, TH	019-8917-00R	Precision Incorporated
1	L3	Inductor, Unshielded Drum Core, Ferrite, 1 µH, 8 A, 0.006 ohm, TH	7447462010	Wurth Elektronik
1	L4	Inductor, Multilayer, Ferrite, 0.68 µH, 0.19 A, 0.67 ohm, 1206	LQH31MNR68K03L	MuRata
1	Q1	MOSFET, N-Channel, 150 V, 87 A, PG-TDSON-8	BSC160N15NS5ATMA1	Infineon Technologies
1	Q2	MOSFET, N-Channel, 600 V, 0.021 A, AEC-Q101, SOT-23	BSS126H6327XTSA2	Infineon Technologies
1	Q3	MOSFET, P-CH, -50 V, -0.13 A, SOT-323	BSS84W-7-F	Diodes Inc.
2	Q4, Q5	MOSFET, N-CH, 60 V, 0.17 A, SOT-23	2N7002-7-F	Diodes Inc.
1	R1	Resistor, 1.00 k, 1%, 0.1 W, 0603	ERJ-3EKF1001V	Panasonic
1	R2	Resistor, 2.21 MΩ, 1%, 0.25 W, 1206	CRCW12062M21FKEA	Vishay-Dale
1	R3	Resistor, 0 Ω, 5%, 0.1 W, 0603	CRCW06030000Z0EA	Vishay-Dale
3	R4, R12, R23	Resistor, 10.0 Ω, 1%, 0.063 W, 0402	ERJ-2RKF10R0X	Panasonic
1	R5	Resistor, 33 Ω, 5%, 0.125 W, 0805	CRCW080533R0JNEA	Vishay-Dale
1	R6	Resistor, 49.9 Ω, 1%, 0.1 W, 0402	ERJ-2RKF49R9X	Panasonic
1	R7	Resistor, 196 kΩ, 1%, 0.063 W, 0402	CRCW0402196KFKED	Vishay-Dale
1	R8	Resistor, 536, 1%, 0.063 W, 0402	RC0402FR-07536RL	Yageo
1	R9	Resistor, 22.1kΩ, 1%, 0.063 W, 0402	CRCW040222K1FKED	Vishay-Dale
1	R10	Resistor, 249 kΩ, 1%, 0.063 W, 0402	CRCW0402249KFKED	Vishay-Dale
2	R11, R14	Resistor, 11.0 k, 1%, 0.063 W, 0402	CRCW040211K0FKED	Vishay-Dale
1	R13	Resistor, 34.0 k, 1%, 0.063 W, 0402	CRCW040234K0FKED	Vishay-Dale
1	R15	Resistor, 95.3 k, 1%, 0.063 W, 0402	RC0402FR-0795K3L	Yageo
1	R16	Resistor, 63.4 kΩ, 1%, 0.063 W, 0402	CRCW040263K4FKED	Vishay-Dale
1	R17	Resistor, 2.49, 1%, 0.1 W, 0603	RC0603FR-072R49L	Yageo
4	R18, R19, R20, R21	Resistor, 0.91 Ω, 1%, 0.125 W, 0805	RL0805FR-070R91L	Yageo
1	R22	Resistor, 121 Ω, 1%, 0.063 W, 0402	CRCW0402121RFKED	Vishay-Dale
1	R24	Resistor, 21.5 kΩ, 1%, 0.063 W, 0402	CRCW040221K5FKED	Vishay-Dale
1	R25	Resistor, 820 Ω, 1%, 0.1 W, 0603	RC0603FR-07820RL	Yageo America
1	R26	Resistor, 150 kΩ, 1%, 0.1 W, 0603	RC0603FR-07150KL	Yageo America
1	R27	Resistor, 60.4 kΩ, 1%, 0.063 W, 0402	CRCW040260K4FKED	Vishay-Dale
1	R28	Resistor, 1.00 MΩ, 1%, 0.1 W, 0603	CRCW06031M00FKEA	Vishay-Dale
1	R29	Resistor, 36.5 kΩ, 1%, 0.125 W, 0805	CRCW080536K5FKEA	Vishay-Dale
2	R30, R33	Resistor, 10.0, 1%, 0.063 W, 0402	RC0402FR-0710RL	Yageo
1	R31	Resistor, 5.1, 5%, 0.063 W, 0402	RC0402JR-075R1L	Yageo
1	R32	Resistor, 100, 5%, 0.1 W, 0402	'ERJ-2GEJ101X	Panasonic
1	R34	Resistor, 4.99 kΩ, 1%, 0.063 W, 0402	RC0402FR-074K99L	Yageo
1	R35	Resistor, 49.9 kΩ, 1%, 0.063 W, 0402	RC0402FR-0749K9L	Yageo
2	R36, R37	Resistor, 100 kΩ, 5%, 0.1 W, 0402	ERJ-2GEJ104X	Panasonic
1	R38	Resistor, 750 kΩ, 1%, 0.1 W, 0402	CRCW0402750KFKED	Vishay-Dale
1	RT1	Thermistor NTC, 47 kΩ, 5%, 0603	NCP18WB473J03RB	MuRata

Table 6. UCC28780EVM-002 List of Materials (continued)

Quantity	Designator	Description	PartNumber	Manufacturer
1	T1	Transformer, 115 µH, TH	019-8916-00R	Precision Incorporated
1	U1	Optocoupler, 3.75 kV, 80-160% CTR, SMT	FODM8801AV	Fairchild Semi
1	U2	Adjustable Precision Shunt Regulator, SOT23-3	ATL431BQDBZR	Texas Instruments
1	U3	UCC24612-1DBV, DBV0005A (SOT-23-5)	UCC24612-1DBVR	Texas Instruments
1	U4	High Speed, Digital Isolator, SOIC-8	ISO7710FD	Texas Instruments
1	U5	Active-Clamp Flyback Controller, RTE0016C (QFN-16)	UCC28780RTER	Texas Instruments
1	U6	650V AllGaN Power IC with iDrive, PQFN-8	NV6117	Navitas Semi
1	U7	650V AllGaN Power IC with iDrive, PQFN-8	NV6115	Navitas Semi

Revision History

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

Changes from Original (October 2017) to A Revision **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.

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。

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

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

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

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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
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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.

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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.

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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.

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