User's Guide

Using the UCC28781EVM-053 60-W, 15-V ZVS-Flyback Converter

ABSTRACT

This user's guide provides direction on how to operate and evaluate the UCC28781EVM-053 for various performance metrics. The UCC28781EVM-053 implements a typical application for a high-voltage, wide-Vin, single output ZVSF power converter operating from 50 V to 500 V DC input to produce a 15-V output rail for up to 4 A of load current. The EVM includes a means to operate from the standard world-wide AC input range of 90 V_{RMS} to 264 V_{RMS}, as well.

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Trademarks

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1 Introduction

The UCC28781EVM-053 is a 60-W, 15-V evaluation module (EVM) for evaluating a high-voltage DC-input zero-voltage-switching flyback (ZVSF) converter for use as a bias supply in traction inverters and other applications. It is intended for evaluation purposes and is not intended to be an end product. The EVM converts a DC input voltage range of 50 V to 500V down to an isolated output of 15 V. Output current is rated for a maximum of 4 A for input voltages between 250 V and 500 V, and derated to a maximum of 2 A for input voltages between 50 V and 250 V. An over-power capability of up to approximately 133% of rated power is limited to a 160-ms duration.

Alternatively, the EVM may be powered from an ***isolated*** AC source with voltages between 90-V_{RMS} to 264-V_{RMS} by connecting the rectified-AC section to the DC input as presented later in this user guide.

2 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.

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 of EVM

The UCC28781EVM-053 consists of a 4-layer printed circuit board (pcb) with through-hole components on the top side and surface-mount components on the bottom side. The actual conversion circuitry is contained within the break-away slots. Terminal blocks on the EVM for input and output connection are positioned outside the break-away slots to avoid being included in any power-density assessment. A jumper for enabling and disabling the X-capacitor discharge feature is also positioned outside the slots, since it is provided for evaluation purposes only.

Control circuit reworks per Figure 5-2 are added to the bottom side, but not shown in the Bottom View, below. Also on the bottom side are resistors R33, R34, and R35 applied across the bulk capacitor C2 to provide rapid bleed-down of high voltage upon removal of AC input power, if the Rectified-AC Output was left unconnected to a load. Not normally used in a real design, their power loss is subtracted from measured input power.

The main devices used in this design are zero-voltage-switching flyback controller UCC28781-Q1 and isolated driver UCC5304. Please read this user's guide thoroughly before applying power to this board.

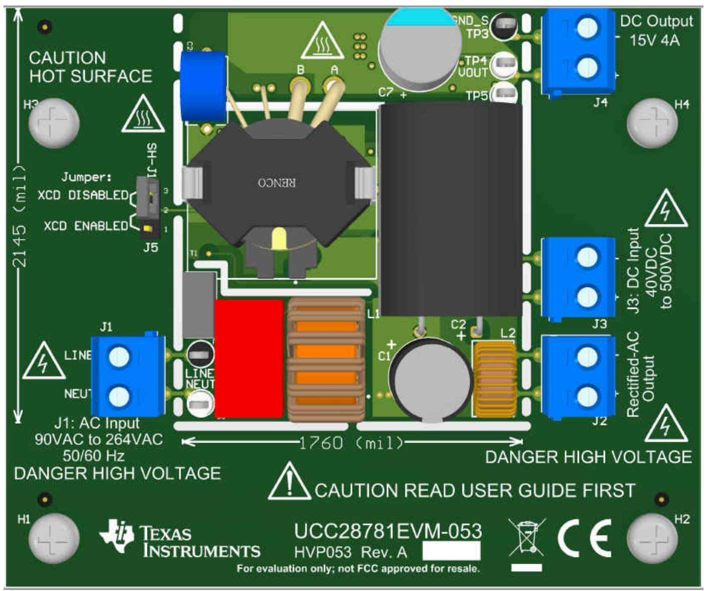

Figure 3-1. UCC28781EVM-053 Top View

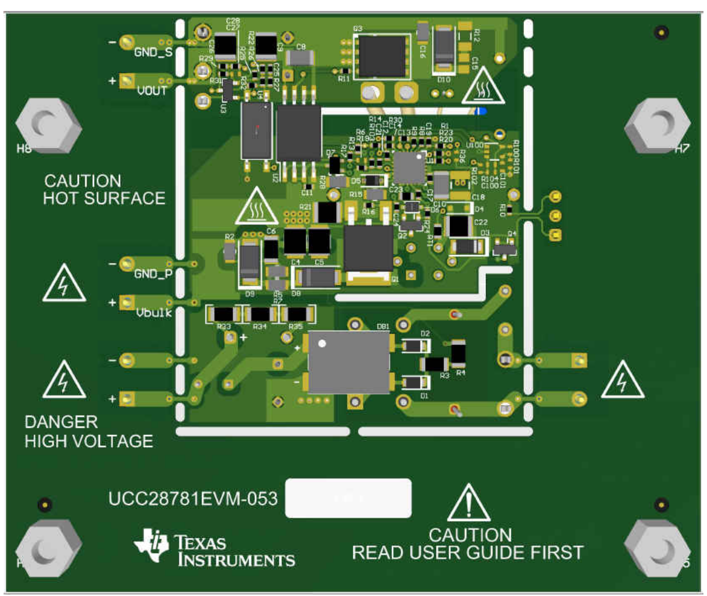

Figure 3-2. UCC28781EVM-053 Bottom View

4 Electrical Performance Specifications

Table 4-1. DC Input, Primary Switch = Si MOSFET[1]

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT CHARACTERISTICS						
V_{IN}	Input line voltage (DC)		50	400	500	V
P_{STBY} [5]	Input power at no-load, V_O = 15 V	V_{IN} = 500 V_{DC}, I_O = 0 A		47		mW
		V_{IN} = 250 V_{DC}, I_O = 0 A		36		mW
OUTPUT CHARACTERISTICS						
V_O	Output voltage	V_{IN} = 250 to 500 V_{DC}, I_O = 4.0 A to 0 A V_{IN} = 40 to 250 V_{DC}, I_O = 2.0 A to 0 A	14.7	15	15.3	V
$I_{O(FL\_HI)}$	Full-load rated output current, high input range	V_{IN} = 250 to 500 V_{DC}			4	A
$I_{O(FL\_LO)}$	Full-load rated output current, low input range	V_{IN} = 40 to 250 V_{DC}			2	A
V_{O_pp}	Output ripple voltage, peak to peak, high input range	V_{IN} = 250 to 500 V_{DC}, I_O = 0 A to 4 A		350	500	mVpp
	Output ripple voltage, peak to peak, low input range	V_{IN} = 40 to 250 V_{DC}, I_O = 0 A to 2 A		200	300	
$P_{O(OPP)}$ [4]	Over-power protection threshold	V_{IN} = 40 to 500 V_{DC}			70	W
t_{OPP} [4]	Over-power protection duration	V_{IN} = 40 to 500 V_{DC}, P_O > $P_{O(OPP)}$		160		ms
ΔV_O	Output voltage transient deviation at load-step	I_O steps between 0 A and $I_{O(FL\_HI)}$ at 100 Hz			±1000	mVpp
SYSTEM CHARACTERISTICS						
η_{FL}	Full-load efficiency[2]	V_{IN} = 500 V_{DC}, I_O = 4 A		0.932		
		V_{IN} = 250 V_{DC}, I_O = 2 A		0.937		
η_{avg}	4-point average efficiency[2] [3]	V_{IN} = 500 V_{DC}, $I_{O(FL\_HI)}$ range		0.905		
		V_{IN} = 250 V_{DC}, $I_{O(FL\_LO)}$ range		0.919		
$\eta_{10\%}$	Efficiency at 10% load[2]	V_{IN} = 500 V_{DC}, I_O = 10% of $I_{O(FL\_HI)}$		0.808		
		V_{IN} = 250 V_{DC}, I_O = 10% of $I_{O(FL\_LO)}$		0.835		
T_{AMB}	Ambient operating temperature range	V_{IN} = 90 to 264 V_{DC}, V_O = 20 V, I_O = 0 to 3.25 A		25		°C

(1) The performance listed in this table is based on the test results from a single board, using either DC input or AC input for their respective results.
(2) Power losses from external input and output cables are not included in efficiency results.
(3) Average efficiency of four load points: I_O = 100%, 75%, 50%, and 25% of $I_{O(FL)}$.
(4) OPP function not available in UCC28781A.
(5) Input stand-by power measured with XCD function disabled.

Table 4-2. AC Input, Primary Switch = Si MOSFET[(1)]

PARAMETER		TEST CONDITIONS	MIN	NOM	MAX	UNIT
INPUT CHARACTERISTICS						
V_{IN}	Input AC-line voltage (RMS)		90	115 / 230	264	V
f_{LINE}	Input AC-line frequency		47	50 / 60	63	Hz
P_{STBY} [(5)] [(6)]	Input power at no-load, V_O = 15 V	V_{IN} = 230 V_{RMS}, I_O = 0 A		42		mW
		V_{IN} = 115 V_{RMS}, I_O = 0 A		36		
OUTPUT CHARACTERISTICS						
V_O	Output voltage	V_{IN} = 180 to 264 V_{RMS}, I_O = 0 to $I_{O(FL\_HI)}$	14.7	15	15.3	V
		V_{IN} = 90 to 180 V_{RMS}, I_O = 0 to $I_{O(FL\_LO)}$				
$I_{O(FL\_HI)}$	Full-load rated output current, high input range	V_{IN} = 180 to 264 V_{RMS}			4	A
$I_{O(FL\_LO)}$	Full-load rated output current, low input range	V_{IN} = 90 to 180 V_{RMS}			2	A
$P_{O(OPP)}$ [(4)]	Over-power protection threshold	V_{IN} = 90 to 264 V_{RMS}			70	W
t_{OPP} [(4)]	Over-power protection duration	V_{IN} = 90 to 264 V_{RMS}, P_O > $P_{O(OPP)}$		160		ms
ΔV_O	Output voltage transient deviation at load-step	I_O steps between 0 A and $I_{O(FL\_HI)}$ at 100 Hz			±1000	mVpp
SYSTEMS CHARACTERISTICS[(6)]						
η_{FL}	Full-load efficiency[(2)]	V_{IN} = 230 V_{RMS}, I_O = $I_{O(FL\_HI)}$		0.9336		
		V_{IN} = 115 V_{RMS}, I_O = $I_{O(FL\_LO)}$		0.9271		
η_{avg}	4-point average efficiency[(2)] [(3)]	V_{IN} = 230 V_{RMS}, $I_{O(FL\_HI)}$ range		0.9213		
		V_{IN} = 115 V_{RMS}, $I_{O(FL\_LO)}$ range		0.9150		
$\eta_{10\%}$	Efficiency at 10% load[(2)]	V_{IN} = 230 V_{RMS}, I_O = 10% of $I_{O(FL\_HI)}$		0.8684		
		V_{IN} = 115 V_{RMS}, I_O = 10% of $I_{O(FL\_LO)}$		0.8480		
T_{AMB}	Ambient operating temperature range	V_{IN} = 90 to 264 V_{RMS}, I_O = 0 to $I_{O(FL)}$		25		°C

(1) The performance listed in this table is based on the test results from a single board, using either DC input or AC input for their respective results.
(2) Power losses from external input and output cables are not included in efficiency results.
(3) Average efficiency of four load points: I_O = 100%, 75%, 50%, and 25% of $I_{O(FL)}$.
(4) OPP function not available in UCC28781A.
(5) Input stand-by power measured with XCD function disabled.
(6) Excludes power loss from bulk voltage bleeder resistors R33, R34, and R35 across bulk capacitor C2.

5 Schematic Diagram

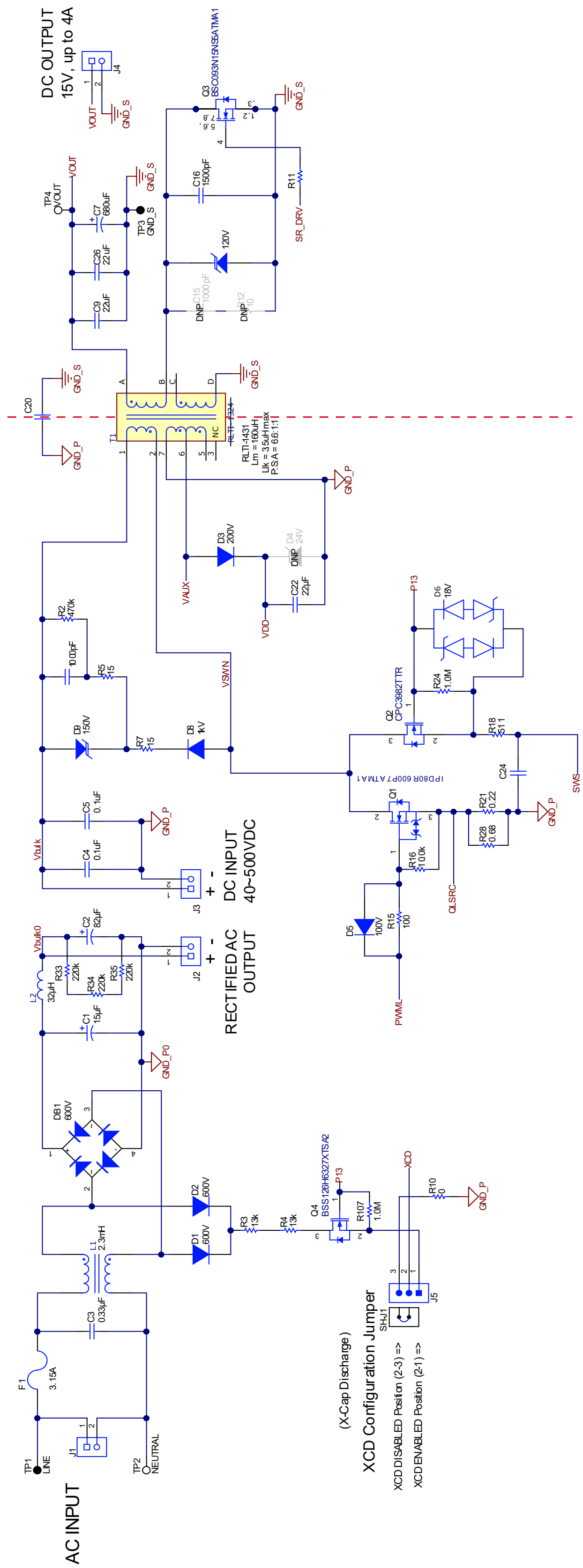

Figure 5-1. UCC28781EVM-053 Schematic Diagram (1 of 3) - Conversion Section

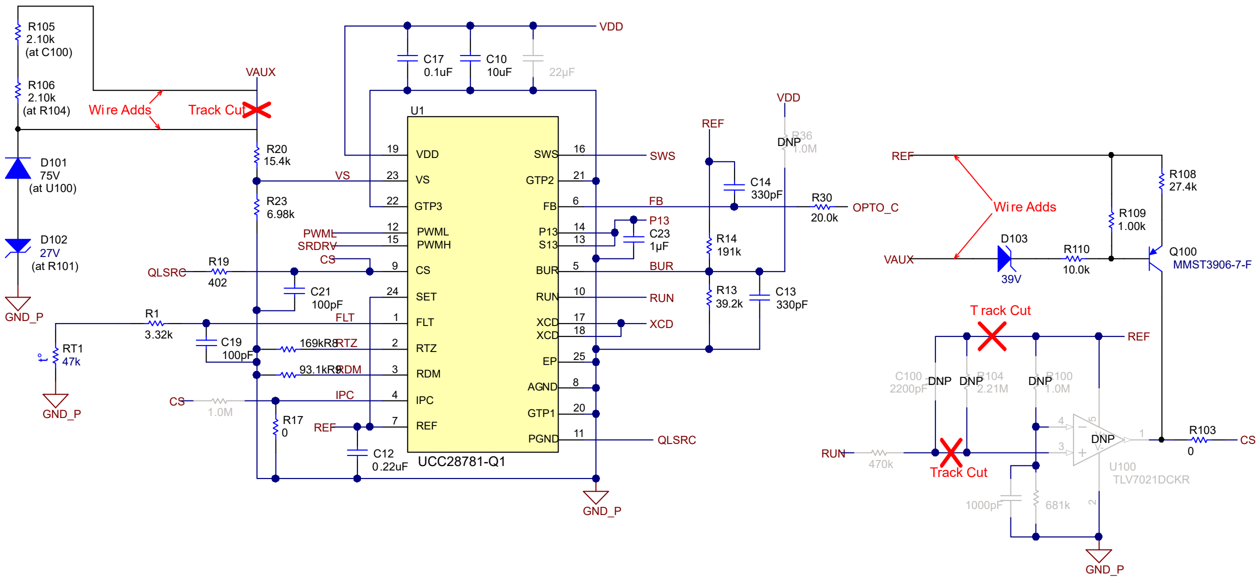

Figure 5-2. UCC28781EVM-053 Schematic Diagram (2 of 3) - Controller Section

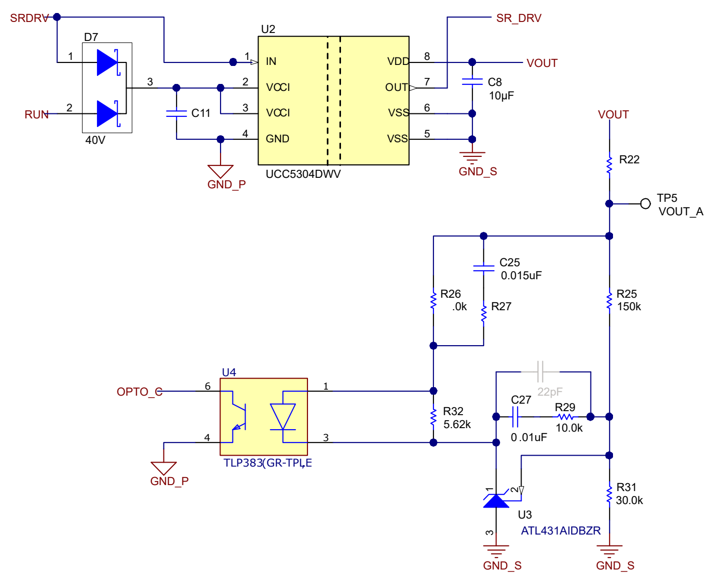

Figure 5-3. UCC28781EVM-053 Schematic Diagram (3 of 3) - Feedback Section

6 Description of Test Set-ups

6.1 Typical Applications

- High-voltage automotive traction inverter bias supply
- High-voltage automotive redundant supply
- High-density AC-to-DC or DC-to-DC auxiliary power supplies

6.2 Using the EVM with a DC Voltage Source

The UCC28781EVM-053 may be powered directly from an isolated high-voltage DC source ranging from 500 V down to < 50 V. In general, input voltage must be > 100 V to start and may be reduced to < 50 V after start-up. Output current should be limited to 2 A or less when starting with input voltage < 250 V.

Full-rated output power (60 W) may be obtained for input voltages in the [250-V to 500-V] range. Output power rating is reduced (30 W) for input voltages in the [50-V to 250-V] range due to the high rms level of primary current at low input voltages.

The isolated DC source should be connected to the EVM at J3 (DC INPUT terminal block) using a low-impedance cable such as suitably-insulated 18AWG twisted-pair wire less than 1 meter in length. The EVM has very little on-board bulk-voltage by-pass capacitance at the DC input, so an additional high-voltage capacitor may be added externally to J3 to augment the DC bulk voltage for certain performance tests.

When the DC input is used, the AC section of the EVM should remain completely unused, without any connections to terminal blocks J1 and J2. Also, the XCD Jumper should be installed in the "XCD Disabled" position at J5.

At light loads, the DC input current consists of pulses at the burst mode frequency, which digital multimeters (DMMs) cannot properly average and measure. For accurate input current measuremetns at light loads, a high-voltage 2-μF film capacitor should be applied across the DC input terminal block. Also, a 10-W, 100-Ω resistor should be inserted in series with the DC input as shown in Figure 7-1 to form an R-C filter which smooths the pulsing input currents.

The output of the EVM (15 V) is taken from terminal block J4 which should be connected to a passive load (high-power resistor or resistor bank) or an active electronic load. An active load usually affords great flexibility in loading methods and perturbations.

6.3 Using the EVM with an AC Voltage Source

The UCC28781EVM-053 may also be powered from an isolated high-voltage AC source ranging from 264 V_{RMS} down to 90 V_{RMS} with line frequency ranging from 50 Hz to 60 Hz. In general, input voltage must be > 90 V_{RMS} to start and output current should be limited to 2 A or less when starting with input voltage < 180 V_{RMS}.

Full-rated output power (60 W) may be obtained for input voltages in the 180-V_{RMS} to 264-V_{RMS} range. Output power rating is reduced (30 W) for input voltages in the 90-V_{RMS} to 180-V_{RMS} range due to the high rms level of primary current at low input voltages.

The isolated AC source should be connected to the EVM at J1 (AC INPUT terminal block) using a low-impedance cable such as suitably-insulated 18AWG twisted-pair wire less than 1 meter in length. The EVM provides the traditional full-wave rectified and filtered bulk-voltage section to enable evaluation of ZVSF performance when powered by an AC line. The output of the AC section is connected to the DC input by jumpering terminal block J2 to block J3 with short insulated jumper wires, observing the proper polarities. See connections per Figure 7-2.

When using an AC line input, the X-Cap Discharge (XCD) feature of the UCC28781-Q1 may be evaluated by installing the XCD Jumper into the "XCD ENABLED" position at J5. Remember to reposition the XCD Jumper into the "XCD DISABLED" position any time the AC input is not being used to avoid the risk of component damage from DC operation.

The output of the EVM (15 V) is taken from terminal block J4 which should be connected to a passive load (high-power resistor or resistor bank) or an active electronic load. An active load usually affords great flexibility in loading methods and perturbations.

7 Test Set-ups

7.1 Test Set-up Requirements

7.1.1 Test Set-up Requirements for DC Input

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: Line-Isolated DC source capable of handling 100-W power level.

Output Meters: Digital voltage meter, digital current meter

Input Meters: Digital voltage meter, digital current meter

Oscilloscope:

- 4-Channel, 500 MHz bandwidth.
- Probes capable of handling 600 V.

Output Load: Resistive or electronic load capable of handling 100 W at 15 V.

Recommended Wire Gauge: Insulated 18AWG.

Set up the test configuration for DC input as shown in Figure 7-1.

WARNING

Caution: Do not leave EVM powered when unattended.

7.1.2 Test Set-up Requirements for AC Input

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 the X-capacitor discharge function is enabled, or damage may happen.** If a DC voltage source must be used, the XCD Jumper at J5 must be set to "XCD DISABLED" position.

Output Meters: Digital voltage meter, digital current meter

Input Power Analyzer: Capable of measuring 10 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 15 V.

Recommended Wire Gauge: Insulated 18AWG.

Set up the test configuration for AC input as shown in Figure 7-2.

WARNING

Caution: Do not leave EVM powered when unattended.

!! Do not apply DC voltage source to the AC input of this board or damage may happen! (See above set-up of Voltage Source)

7.2 Test Set-up Diagrams

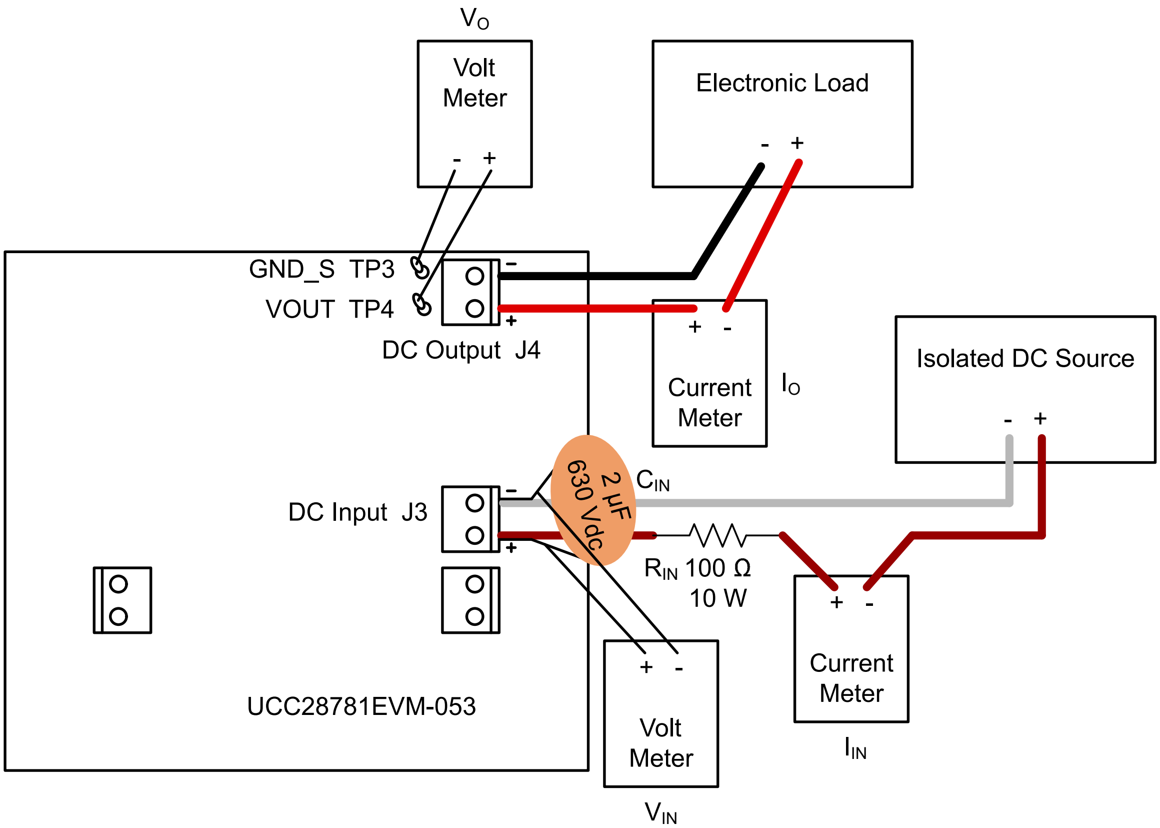

Figure 7-1. UCC28781EVM-053 Test Set-up Diagram for DC Input

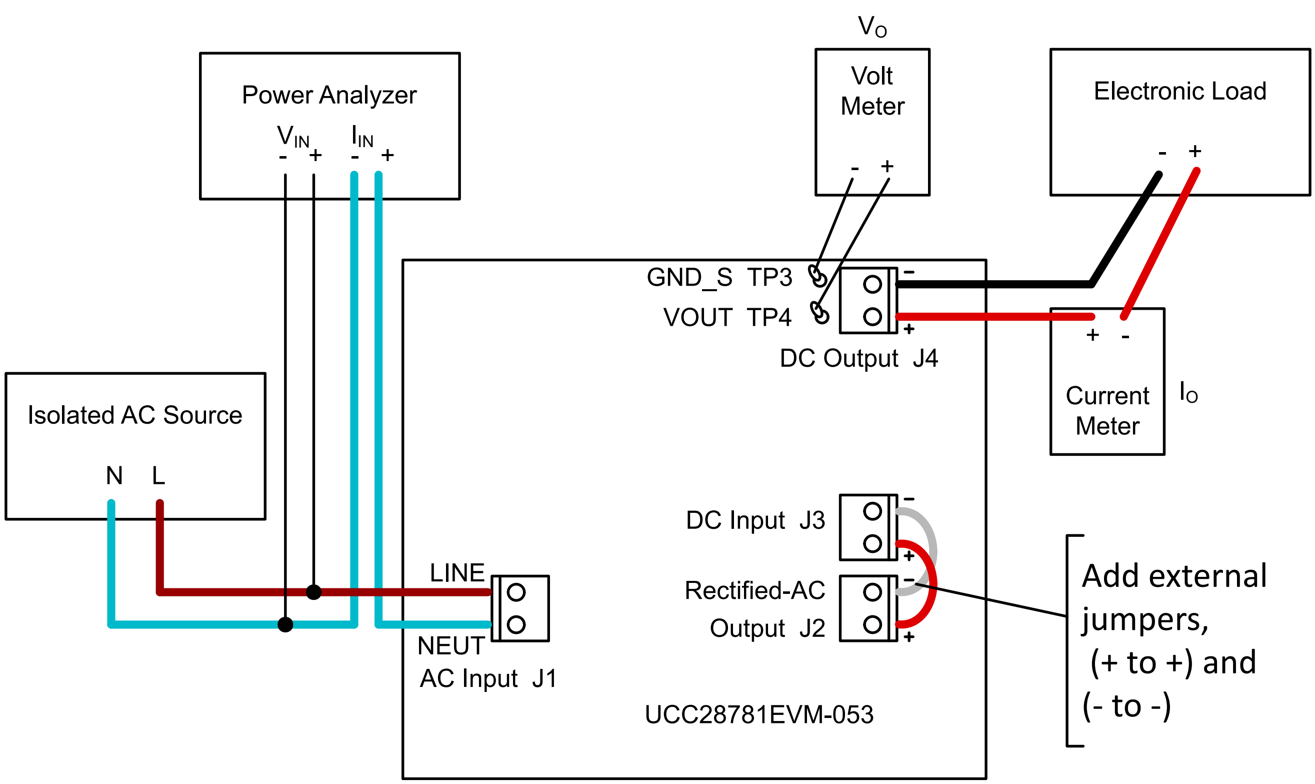

Figure 7-2. UCC28781EVM-053 Test Set-up Diagram for AC Input

7.3 Terminals and Test Points

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

Terminals and TEST POINTS		NAME	DESCRIPTION
J1-1	Terminal Block J1	LINE	Primary-side AC-input "Line" or Line-1.
J1-2		NEUT	Primary-side AC-input "Neutral" or Line-2.
J2-1	Terminal Block J2	Vbulk0	Primary-side rectified and filtered positive voltage output "Vbulk0" (+) derived from AC source.
J2-2		GND_P0	Primary-side rectified and filtered negative voltage output "GND_P0" (-) derived from AC source.
J3-1	Terminal Block J3	Vbulk	Primary-side positive voltage input "Vbulk" (+) derived from DC source.
J3-2		GND_P	Primary-side negative voltage input "GND_P" (-) derived from DC source.
J4-1	Terminal Block J4	VOUT	Secondary-side DC voltage output "VOUT" (+) positive connection.
J4-2		GND_S	Secondary-side DC voltage output "GND_S" (-) negative connection.
J5-1	3-Pin Header J5	AC-Sense	Primary-side sense and discharge path from X-capacitor.
J5-2		XCD	Primary-side connection to XCD pins of UCC28781-Q1 controller.
J5-3		GND_P	Primary-side ground reference, used to disable XCD function.
TP1	Input test point near J1-1	LINE	Primary-side AC input monitor point - Line (or Line 1).
TP2	Input test point near J1-2	NEUT	Primary-side AC input monitor point - Neutral (or Line 2).
TP3	Output test point near J4-2	GND_S	Secondary-side DC output monitor "GND_S" (-) ground reference.
TP4	Output test point near J4-1	VOUT	Secondary-side DC output monitor "VOUT" (+) positive reference.
TP5	Output test point near J4-1	VOUT_A	Secondary-side DC insertion point "VOUT_A" for small-signal loop-stability analysis.

8 Performance Data and Typical Characteristic Curves

8.1 Efficiency Results of EVM with DC Input

Table 8-1. Efficiency Test Data of 15-V Output with DC Input

V_{IN} (V_{DC})	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	I_{OUT}(%)	Efficiency at I_{OUT}	Efficiency 4pt-Average	Average Switching Frequency at Full Load
500 I_{FL_HI} range	63.990	14.090	4.001	100%	0.9322	0.9050	170 kHz
	48.464	14.915	3.002	75%	0.9239		
	32.991	14.919	2.003	50%	0.9058		
	17.462	14.925	1.004	25%	0.8581		
	7.484	14.930	0.405	10%	0.8082		
375 I_{FL_HI} range	63.454	14.911	4.001	100%	0.9402	0.9234	165 kHz
	47.820	14.917	3.003	75%	0.9368		
	32.377	14.921	2.003	50%	0.9231		
	16.762	14.928	1.003	25%	0.8936		
	6.999	14.933	0.405	10%	0.8634		
250 I_{FL_HI} range	63.01	14.910	4.002	100%	0.9470	0.9354	154 kHz
	47.36	14.920	3.002	75%	0.9458		
	31.89	14.925	2.002	50%	0.9370		
	16.44	14.928	1.004	25%	0.9118		
	6.95	14.934	0.405	10%	0.8711		
250 I_{FL_LO} range	31.89	14.925	2.002	50%	0.9370	0.9185	221 kHz
	24.11	14.928	1.500	75%	0.9287		
	16.44	14.928	1.004	25%	0.9118		
	8.34	14.938	0.501	25%	0.8965		
	3.65	14.940	0.204	10%	0.8354		
150 I_{FL_LO} range	31.62	14.927	2.002	100%	0.9452	0.9315	190 kHz
	23.79	14.930	1.500	75%	0.9414		
	16.14	14.931	1.004	50%	0.9291		
	8.23	14.934	0.502	25%	0.9105		
	3.47	14.938	0.200	10%	0.8624		
50 I_{FL_LO} range	32.28	14.925	2.002	100%	0.9257	0.9271	86.2 kHz
	23.94	14.930	1.500	75%	0.9357		
	15.98	14.933	1.004	50%	0.9384		
	8.25	14.935	0.502	25%	0.9085		
	3.51	14.939	0.204	10%	0.8685		
For reference only: CoC Tier 2, 4pt-average efficiency ≥ 0.890 for 15 V, 60 W (at 230V_{RMS})							
For reference only: CoC Tier 2, 10%-load efficiency ≥ 0.790 for 15 V, 60 W (at 230V_{RMS})							

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

Table 8-2. Efficiency Test Data on 15-V Output with AC Input

V_{IN} (V_{RMS})	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	I_{OUT}(%)	Efficiency at I_{OUT}	Efficiency 4pt-Average	Average Switching Frequency at Full Load
265 I_{FL_HI} range	64.24	14.914	4.001	100%	0.9319	0.9150	164 kHz
	48.46	19.919	3.002	75%	0.9282		
	32.86	14.922	2.002	50%	0.9150		
	17.13	14.020	1.003	25%	0.8849		
	7.31	14.934	0.404	10%	0.8501		
230 I_{FL_HI} range	64.06	14.911	4.001	100%	0.9336	0.9213	161 kHz
	48.23	14.918	3.002	75%	0.9316		
	32.59	14.923	2.002	50%	0.9212		
	16.83	14.934	1.003	25%	0.8987		
	7.12	14.934	0.405	10%	0.8684		
115 I_{FL_LO} range	32.27	14.926	2.002	100%	0.9271	0.9150	198 kHz
	24.20	14.931	1.501	75%	0.9241		
	16.43	14.932	1.003	50%	0.9135		
	8.42	14.936	0.502	25%	0.8953		
	3.63	14.938	0.204	10%	0.8480		
90 I_{FL_LO} range	32.48	14.927	2.003	100%	0.9212	0.9121	162 kHz
	24.34	14.929	1.501	75%	0.9218		
	16.50	14.932	1.005	50%	0.9105		
	8.41	14.935	0.503	25%	0.8949		
	3.63	14.939	0.205	10%	0.8518		
For reference: CoC Tier 2, 4pt-average efficiency ≥ 0.890 for 15 V, 60 W (at 230V_{RMS})							
For reference: CoC Tier 2, 10%-load efficiency ≥ 0.790 for 15 V, 60 W (at 230V_{RMS})							

8.3 Efficiency Typical Results Graphs with DC Inputs

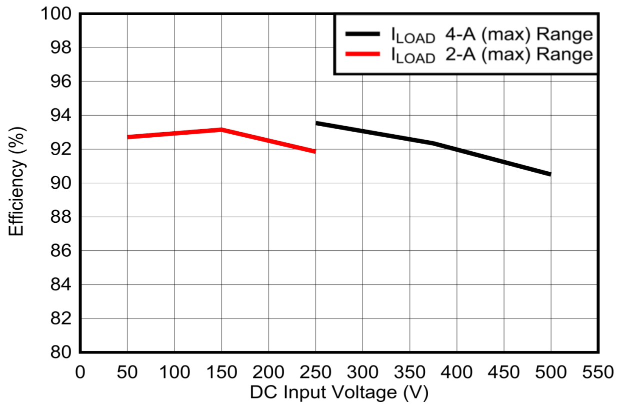

Figure 8-1. 4pt-Average Efficiency vs. Input Voltage

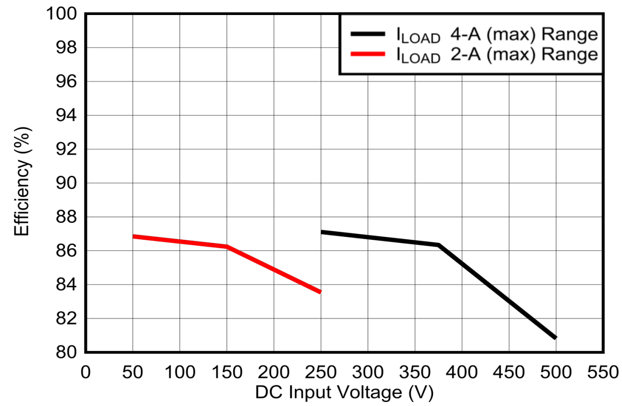

Figure 8-2. Efficiency of 10%-Load vs. Input Voltage

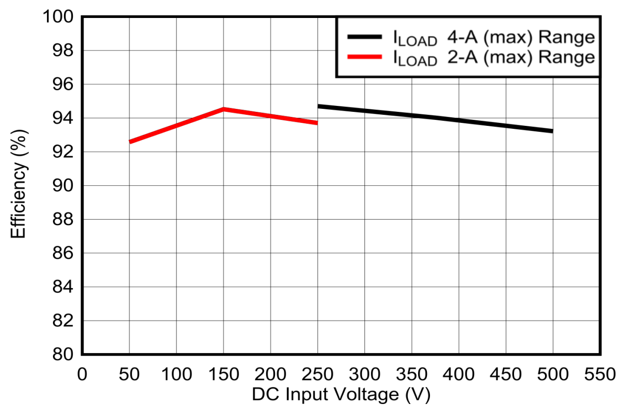

Figure 8-3. Full-load Efficiency vs. Input Voltage

8.4 Switching Frequency

In the following waveforms, Ch2 (blue) = V_{DS} of SR-Mosfet at 10 V/div, 20 V/div, and 50 V/div, respectively (all AC-coupled), Ch4 (green) = Transformer Primary Winding Current at 1 A/div. Sweep speeds are 10 µs/div, 10 µs/div and 1 µs/div, respectively.

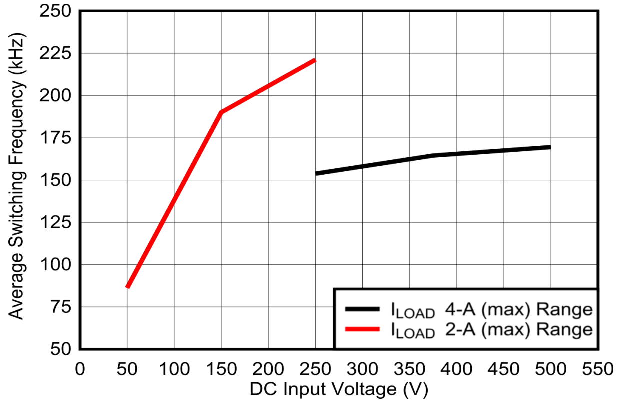

Figure 8-4. Average Switching Frequency at Full-Load vs. DC Input Voltage

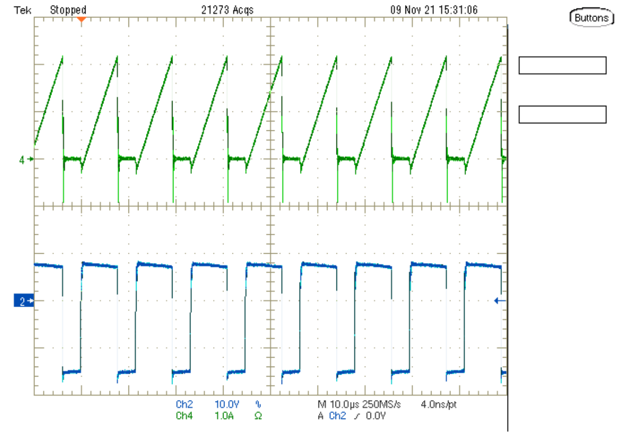

Figure 8-5. Minimum switching frequency in AAM = 86.2 kHz at 50 V_{DC} input, 100% load

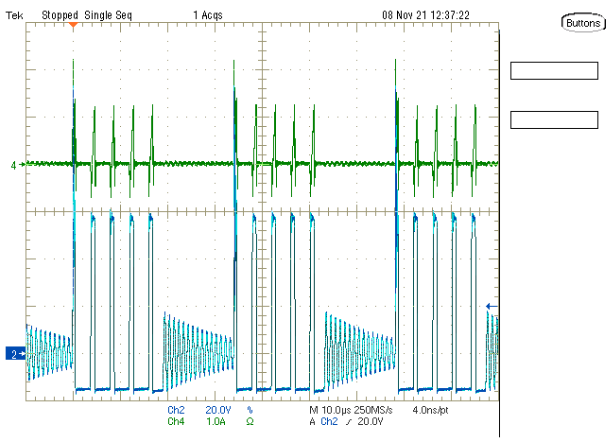

Figure 8-6. Maximum switching frequency in ABM = 261.8 kHz at 375 V_{DC} input, 25% load

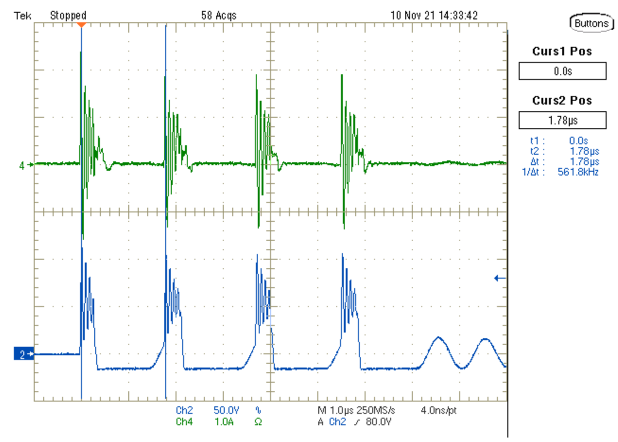

Figure 8-7. Maximum switching frequency in SBP2 = 561.8 kHz at 264 V_{AC} input, 1% load

8.5 Key Switching Waveforms and Operating Mode Load Current

This section shows a table of typical load-current ranges within each operating mode in this design, at Vin = 250 V_{DC} and I_{FL_HI} range as an example. Following the table are typical waveforms seen while in each of the operating modes of Table 8-3. Hysteresis between modes results in differences between the modes' current ranges when load is decreasing compared to when load is increasing.

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

Table 8-3. Operating Modes and Load Currents at 250-V Output in I_{FL_HI} Range

Mode:	AAM	ABM	LPM	SBP1	SBP2
Typical Load Current (Decreasing)	4.0 A to 1.30 A	1.30 A to 0.41 A	0.41 A to 0.22 A	0.22 A to 0.09 A	0.09 A to 0 A
Typical Load Current (Increasing)	1.8 A to 4.0 A	0.53 A to 1.8 A	0.23 A to 0.53 A	0.14 A to 0.23 A	0 A to 0.14 A

Table 8-3. Operating Modes and Load Currents at 250-V Output in I_{FL_HI} Range (continued)

Mode:	AAM	ABM	LPM	SBP1	SBP2
Burst Frequency, f_{BUR}	Not Applicable	> 25 kHz (2 to 9 pulses)	about 25 kHz (2 pulses)	8.5 kHz to 25 kHz (2 pulses)	< 8.5 kHz (2 pulses)

In the following waveforms, Ch2 (blue) = V_{DS} of SR-Mosfet at 20 V/div (AC-coupled), Ch4 (green) = Transformer Primary Winding Current at 1 A/div.

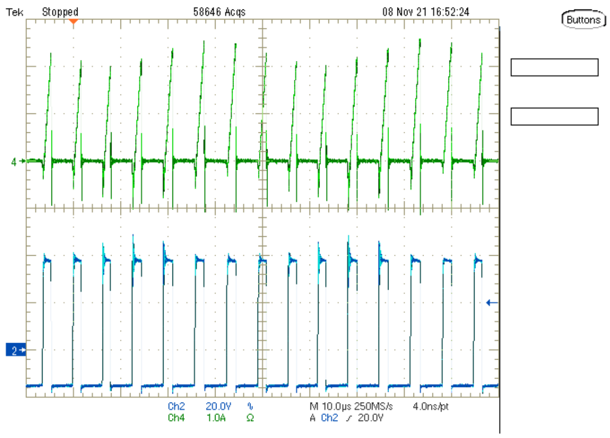

Figure 8-8. Typcial Waveform in AAM Operation (Sweep = 10 µs/div)

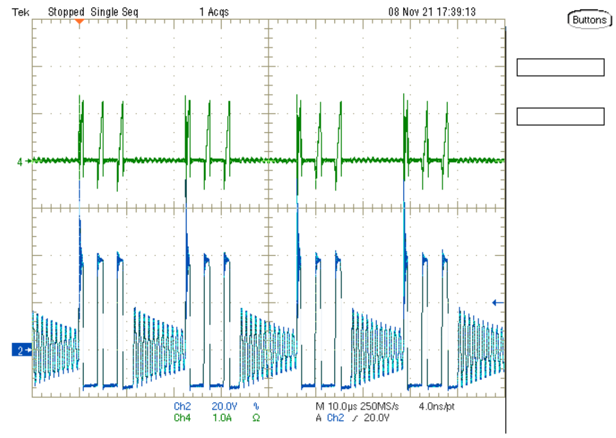

Figure 8-9. Typical Waveform in ABM Operation (Sweep = 10 µs/div)

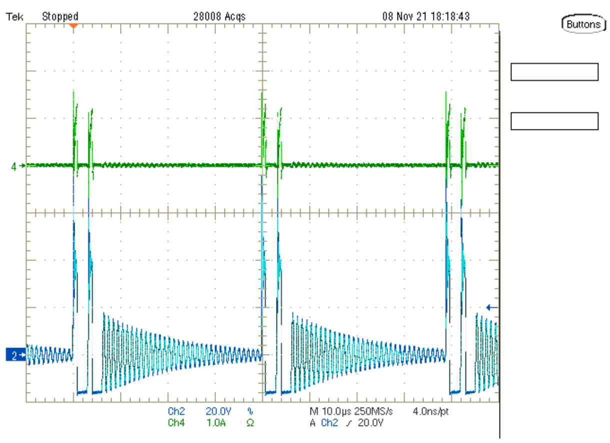

Figure 8-10. Typical Waveform in LPM Operation (Sweep = 10 µs/div)

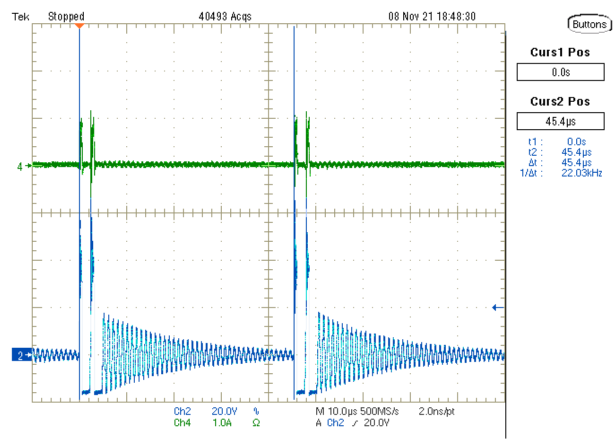

Figure 8-11. Typical Waveform in SBP1 Operation (Sweep = 10 µs/div)

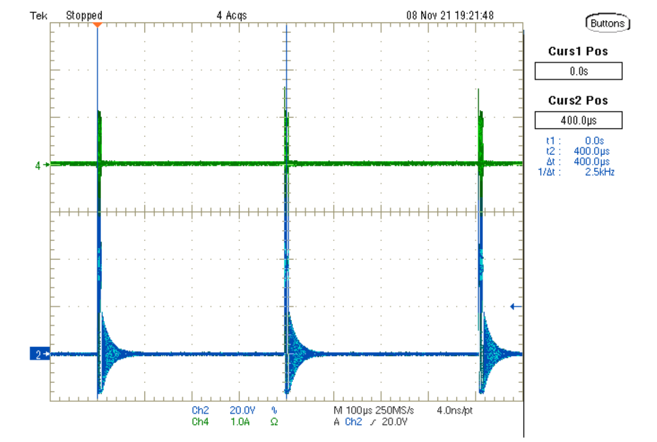

Figure 8-12. Typical Waveform in SBP2 Operation (Sweep = 100 μs/div)

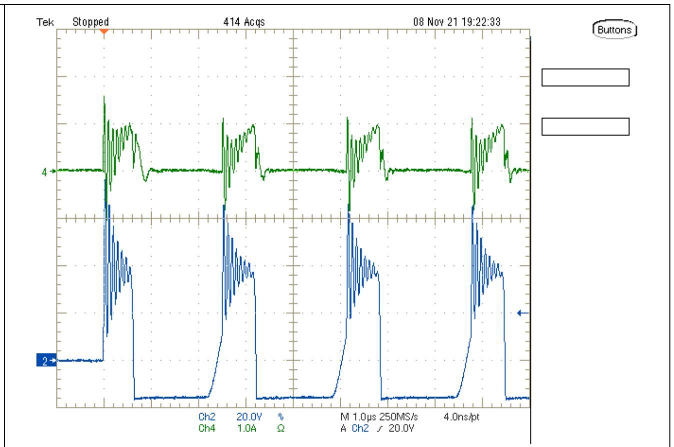

Figure 8-13. Typical Waveform in SBP2 Operation, Burst Detail (Sweep = 1 μs/div)

8.6 Thermal Images at Full Load (15 V, 4.0 A) with DC and AC Inputs

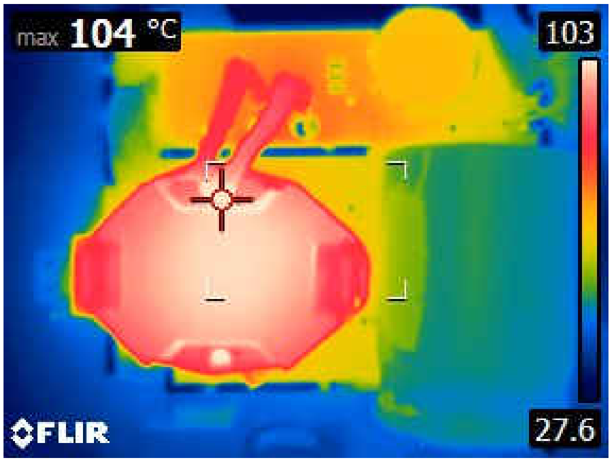

Figure 8-14. V_{IN} = 500 V_{DC}, Transformer Windings: 104°C

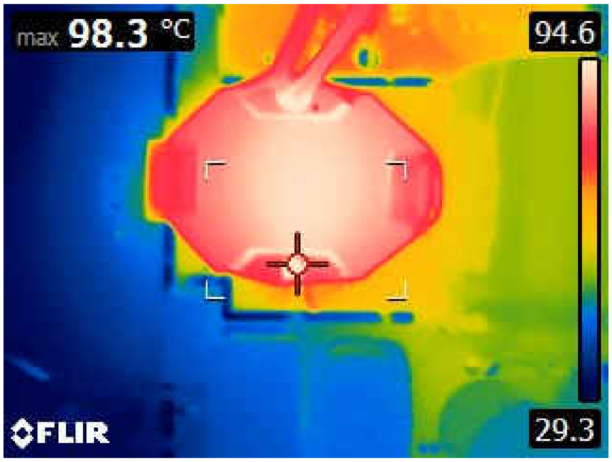

Figure 8-15. V_{IN} = 264 V_{AC}, Transformer Windings: 98.3°C

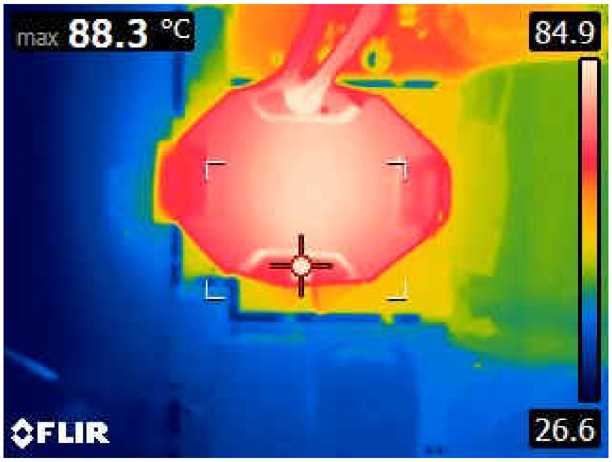

Figure 8-16. V_{IN} = 250 V_{DC}, Transformer Windings: 88.3°C

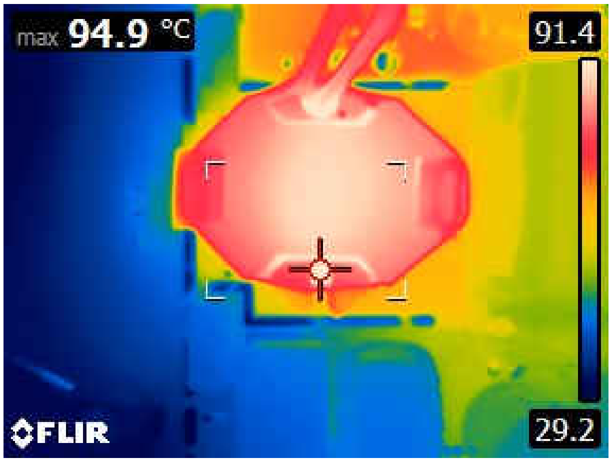

Figure 8-17. V_{IN} = 230 V_{AC}, Transformer Windings: 94.9°C

9 Transformer Details

The transformer (part number RLTI-1431) used on this design is wound on an RM8 core set. It is custom-designed for this EVM by Renco Electronics, Inc.

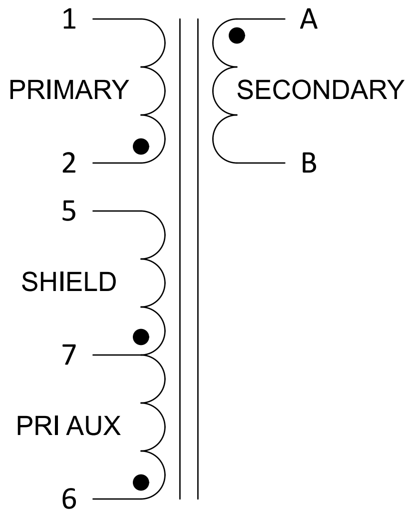

Figure 9-1. Transformer Schematic Diagram

Table 9-1. Transformer Specifications at 25°C

PARAMETER	VALUE	PINS/LEADS	TEST CONDITIONS
Magnetizing Inductance (μH)	160, ± 5%	2 – 1	Open all other pins, 150 kHz, 0.1 V
Leakage Inductance (μH)	3.5 Max.	2 – 1	Short A - B, 150 kHz, 0.1 V
D.C. Resistance (Ω)	0.24, ±15%	2 – 1	
D.C. Resistance (Ω)	0.007 Max.	A – B	
D.C. Resistance (Ω)	0.36, ±15%	6 – 7	
D.C. Resistance (Ω)	3.5, ±15%	7 – 5	
Dielectric (VAC, 60Hz)	3000	1,6 – A	1 s, 1 mA Max.
Turns-Ratios	1 : 0.151 : 0.151	(2-1):(A-B):(6-7)	1.0 V @ 10 kHz to 2 - 1

10 EVM Assembly and Layout

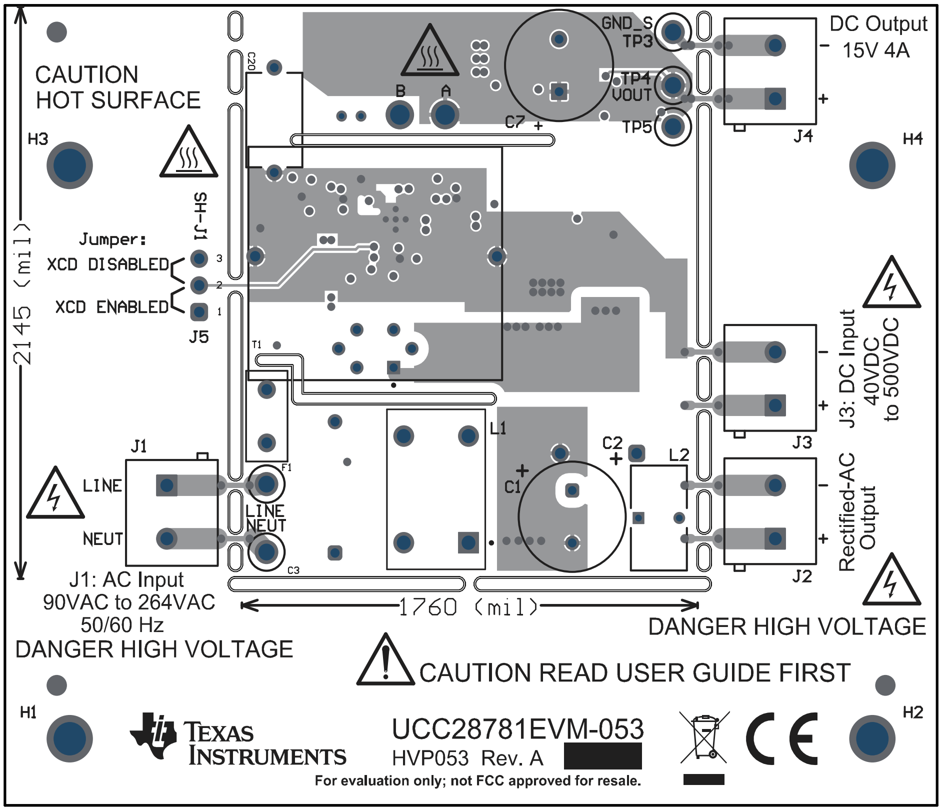

Figure 10-1. EVM Assembly (Top View)

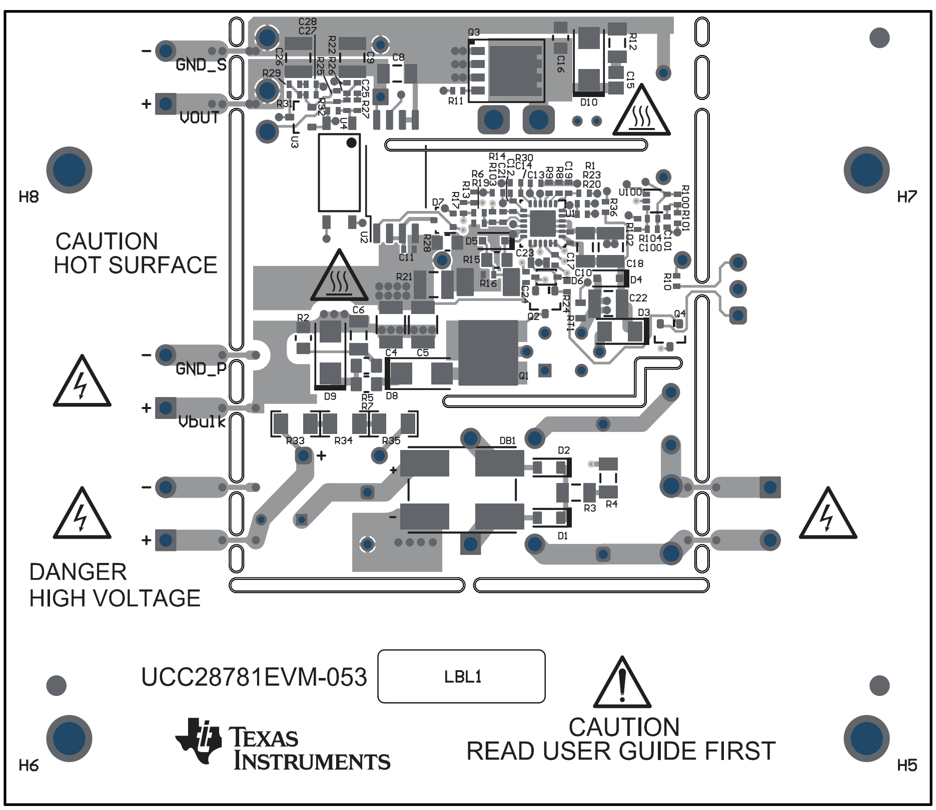

Figure 10-2. EVM Assembly (Bottom View)

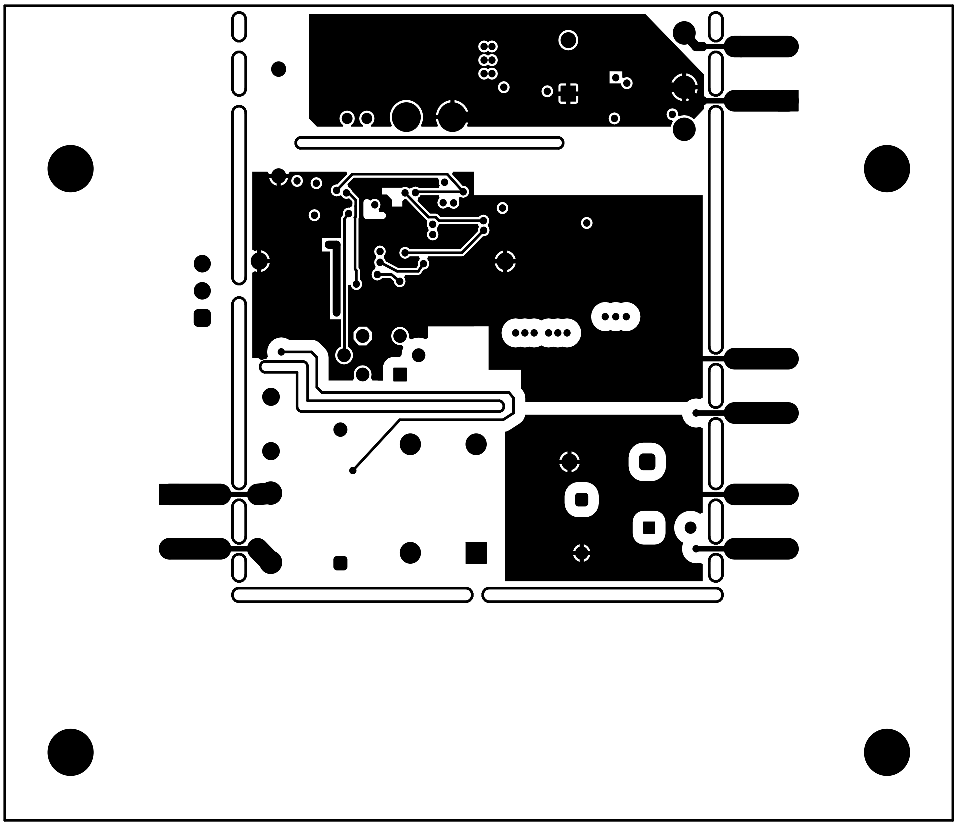

Figure 10-3. EVM Inner Signal Layer 1 (Top View)

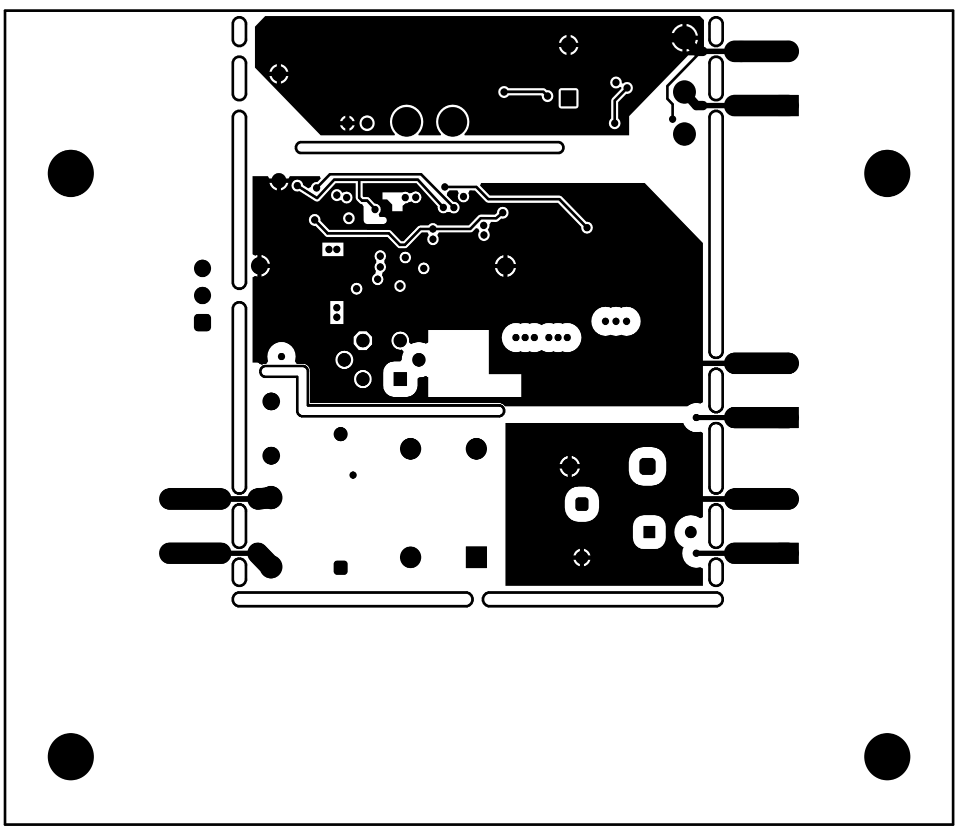

Figure 10-4. EVM Inner Signal Layer 2 (Top View)

11 List of Materials

UCC28781EVM-053 list of materials for the schematic diagrams shown in Section 5.

Table 11-1. UCC28781EVM-053 List of Materials

Designator	Quantity	Description	PartNumber	Manufacturer
C1	1	CAP, AL, 15 µF, 400 V, +/- 20%, AEC-Q200 Grade 2, TH	UVC2G150MPD	Nichicon
C2	1	CAP, AL, 82 µF, 400 V, +/- 20%, TH	400BXW82MEFR18X25	Rubycon
C3	1	CAP, Film, 0.33 µF, X2 275 VAC, +/- 10%, TH	890324024003	Wurth Elektronik
C4, C5	2	CAP, CERM, 0.1 uF, 630 V, +/- 10%, X7R, 1210	C1210C104KBRAC7800	Kemet
C6	1	CAP, CERM, 1000 pF, 630 V, +/- 10%, X7R, 1206	GRM31BR72J102KW01L	MuRata
C7	1	CAP, Aluminum Polymer, 680 uF, 20 V, +/- 20%, 0.012 ohm, TH	APSG200ELL681MJB5S	Chemi-Con
C8	1	CAP, CERM, 10 µF, 25 V,+/- 5%, X7R, AEC-Q200 Grade 1, 1206	C1206C106J3RACAUTO	Kemet
C9, C26	2	CAP, CERM, 22 uF, 25 V, +/- 10%, X7R, 1210	GRM32ER71E226KE15L	MuRata
C10	1	CAP, CERM, 10 uF, 50 V, +/- 10%, X5R, 1206	C3216X5R1H106K160AB	TDK
C11, C17	2	CAP, CERM, 0.1 uF, 50 V, +/- 20%, X7R, 0402	GRM155R71H104ME14D	MuRata
C12	1	CAP, CERM, 0.22 uF, 16 V, +/- 10%, X7R, 0402	GRM155R71C224KA12D	MuRata
C13, C14	2	CAP, CERM, 330 pF, 50 V, +/- 10%, X7R, 0402	GRM155R71H331KA01D	MuRata
C16	1	CAP, CERM, 1500 pF, 250 V, +/- 10%, X7R, 0805	GRM21AR72E152KW01D	MuRata
C19, C21	2	CAP, CERM, 100 pF, 50 V, +/- 5%, C0G/NP0, 0402	GRM1555C1H101JA01D	MuRata
C20	1	CAP, CERM, 2200 pF, X1 400 VAC/Y1 400 VAC, +/- 20%, Y5V, D9xL13mm	C921U222MVVDBA7317	Kemet
C22	1	CAP, CERM, 22 µF, 35 V,+/- 20%, X5R, 1210	GMK325BJ226MM-P	Taiyo Yuden
C23	1	CAP, CERM, 1 uF, 35 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	CGA3E1X7R1V105K080AC	TDK
C24	1	CAP, CERM, 22 pF, 50 V, +/- 5%, C0G/NP0, AEC-Q200 Grade 1, 0402	GCM1555C1H220JA16D	MuRata
C25	1	CAP, CERM, 0.015 uF, 50 V, +/- 10%, X7R, 0402	GRM155R71H153KA12D	MuRata
C27	1	CAP, CERM, 0.01 uF, 50 V, +/- 10%, X7R, 0402	GRM155R71H103KA88D	MuRata
C15	0	Not used, 0805		
C18	0	Not used, 1210		
C28, C100, C101	0	Not used, 0402		
D1, D2	2	Diode, Standard Recovery Rectifier, 600 V, 0.2 A, 2x1.4mm	RFU02VSM6STR	Rohm
D3	1	Diode, Superfast Rectifier, 200 V, 1 A, 3.5x1.6mm	CSFMT104-HF	Comchip Technology
D5	1	Diode, Ultrafast, 100 V, 0.25 A, SOD-323	BAS316,115	Nexperia
D6	1	Diode, TVS, Bi, 18 V, SOD-323	CDSOD323-T18C	Bourns Inc.
D7	1	Diode, Schottky, 40 V, 0.2 A, SOT-323	BAS40W-05-7-F	Diodes Inc.
D8	1	Diode, Standard Recovery Rectifier, 1000 V, 1 A, AEC-Q101, SMA	MRA4007T3G	ON Semiconductor
D9	1	Diode, TVS, Uni, 150 V, 243 Vc, 400 W, 1.6 A, SMA	SMAJ150A	Littelfuse
D10	1	Diode, TVS, Uni, 120 V, 193 Vc, 400 W, 2.1 A, SMA	SMAJ120A	Littelfuse
D101	1	Diode, Ultrafast, 100 V, 0.3 A, SOD-523	1N4148XHE3	MCC
D102	1	Diode, Zener, 27V, 400mW, SOD-323	PDZ27B, 115	Nexperian
D103	1	Diode, Zener, 39V, 200mW, SOD-523	BZT52C39T-TP	MCC
D4	0	Not used, SOD-323		
DB1	1	Diode, P-N-Bridge, 600 V, 4 A, Z4-D	Z4DGP406L-HF	Comchip Technology
F1	1	Fuse, 3.15 A, 250VAC/VDC, TH	39213150000	Littelfuse
J1, J2, J3, J4	4	Terminal Block, 5.08 mm, 2x1, Brass, TH	ED120/2DS	On-Shore Technology

Table 11-1. UCC28781EVM-053 List of Materials (continued)

Designator	Quantity	Description	PartNumber	Manufacturer
J5	1	Header, 100mil, 3x1, Gold, TH	TSW-103-07-G-S	Samtec
L1	1	Common Mode Choke, 2.3mH 35%, 0.6x0.38x0.75 IN	RLTI-1387	Renco
L2	1	WE-FI Leaded Toroidal Line Choke	7447052	Wurth
Q1	1	MOSFET, N-CH, 800 V, 8 A, DPAK	IPD80R600P7ATMA1	Infineon Technologies
Q2	1	MOSFET, N-CH, Depletion Mode, 800 V, SOT-23	CPC3982TTR	IXYS
Q3	1	MOSFET, N-CH, 150 V, 87 A, PG-TDSON-8	BSC093N15NS5ATMA1	Infineon Technologies
Q4	1	MOSFET, N-CH, Depletion Mode, 100 V, 0.17 A, AEC-Q101, SOT-23	BSS126H6327XTSA2	Infineon Technologies
Q100	1	BJT, PNP, 40 V, 200mA, SOT-323	MMBT3906W_R1_00001	Panjit
R1	1	RES, 3.32 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	'CRCW04023K32FKED	Vishay-Dale
R2	1	RES, 470 k, 5%, 0.125 W, AEC-Q200 Grade 0, 0805	CRCW0805470KJNEA	Vishay-Dale
R3, R4	2	RES, 13 k, 5%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW120613K0JNEA	Vishay-Dale
R5, R7	2	RES, 15, 5%, 0.125 W, AEC-Q200 Grade 0, 0805	CRCW080515R0JNEA	Vishay-Dale
R8	1	RES, 169 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW0402169KFKED	Vishay-Dale
R9	1	RES, 93.1 k, 1%, 0.063 W, 0402	RC0402FR-0793K1L	Yageo America
R10, R17	2	RES, 0, 0%, 0.2 W, AEC-Q200 Grade 0, 0402	CRCW04020000Z0EDHP	Vishay-Dale
R11	1	RES, 10, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040210R0JNED	Vishay-Dale
R13	1	RES, 39.2 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040239K2FKED	Vishay-Dale
R14	1	RES, 191 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW0402191KFKED	Vishay-Dale
R15	1	RES, 100, 5%, 0.125 W, AEC-Q200 Grade 0, 0805	CRCW0805100RJNEA	Vishay-Dale
R16, R29, R110	3	RES, 10.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040210K0FKED	Vishay-Dale
R18, R27	2	RES, 511, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW0402511RFKED	Vishay-Dale
R19	1	RES, 402, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW0402402RFKED	Vishay-Dale
R20	1	RES, 15.4 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040215K4FKED	Vishay-Dale
R21	1	RES, 0.22, 1%, 0.5 W, 1210	MCR25JZHFLR220	Rohm
R22, R103	2	RES, 0, 5%, 0.063 W, 0402	RC0402JR-070RL	Yageo America
R23	1	RES, 6.98 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04026K98FKED	Vishay-Dale
R24	1	RES, 1.0 M, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04021M00JNED	Vishay-Dale
R25	1	RES, 150 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0402	ERJ-2RKF1503X	Panasonic
R26	1	RES, 15.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040215K0FKED	Vishay-Dale
R28	1	RES, 0.68, 1%, 0.125 W, AEC-Q200 Grade 0, 0805	ERJ-6RQFR68V	Panasonic
R30	1	RES, 20.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040220K0FKED	Vishay-Dale
R31	1	RES, 30.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040230K0FKED	Vishay-Dale
R32	1	'RES, 5.62 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04025K62FKED	Vishay-Dale
R33, R34, R35	3	RES, 220 k, 5%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW1206220KJNEA	Vishay-Dale
R105, R106	2	RES, 2.1 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04022K10FNED	Vishay-Dale
R107	1	RES, 1.0 M, 5%, 0.100 W, AEC-Q200 Grade 0, 0603	CRCW06031M00JKED	Vishay-Dale
R108	1	RES, 27.4 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040227K4FKED	Vishay-Dale
R109	1	RES, 1.00 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04021K00FKED	Vishay-Dale
R6, R36, R100, R101, R102, R104	0	Not used, 0402		
R12	0	Not used, 1206		
RT1	1	Thermistor NTC, 47k ohm, 5%, 0603	NCP18WB473J03RB	MuRata
SH-J1	1	Shunt, 100mil, Tin plated, Black	SNT-100-BK-T-H	Samtec
T1	1	160uH TRANSFORMER	RLTI-1431	Renco Electronics

Table 11-1. UCC28781EVM-053 List of Materials (continued)

Designator	Quantity	Description	PartNumber	Manufacturer
TP1, TP3	2	Test Point, Multipurpose, Black, TH	5011	Keystone
TP2, TP4, TP5	3	Test Point, Multipurpose, White, TH	5012	Keystone
U1	1	UCC28781-Q1, RTW0024B (WQFN-24)	UCC28781QRTWRQ1	Texas Instruments
U2	1	4-A/6-A, Single-Channel Reinforced Isolation Gate Driver with High Noise Immunity, DWV0008A (SOIC-8)	UCC5304DWV	Texas Instruments
U3	1	2.5V Low Iq Adjustable Precision Shunt Regulator, DBZ0003A (SOT-23-3)	ATL431AIDBZR	Texas Instruments
U4	1	Optoisolator Transistor Output 5000Vrms 1 Channel 6-SO	TLP383(GR-TPL,E)	Toshiba
U100	0	Not used, SC70-5		