Using the UCD3138LLCEVM-028

User's Guide

Literature Number: SLUU979A
August 2012–Revised July 2013

WARNING

Always follow TI's set-up 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 the safety of 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/or 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 suitably 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 50 V_{RMS}/75 VDC must be electrically located within a protected Emergency Power Off (EPO) protected power strip.
   (e) Use a stable and non-conductive work surface.
   (f) Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.
2. **Electrical Safety:**
   (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 hook-ups and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
   (c) Once 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 e.g. latex gloves and/or safety glasses with side shields or protect EVM in an adequate lucent plastic box with interlocks from accidental touch.
4. **Limitation for Safe Use:**
   (a) EVMs are not to be used as all or part of a production unit.

Digitally Controlled LLC Resonant Half-Bridge DC-DC Converter

1 Introduction

This EVM, UCD3138LLCEVM-028 is to help evaluate the UCD3138 64-pin digital control device in an off-line power converter application and then to aid in its design. The EVM is a standalone LLC resonant half-bridge DC-to-DC power converter. The EVM is used together with its control card, UCD3138CC64EVM-030, also an EVM on which is placed UCD3138RGC.

The UCD3138LLCEVM-028 together with UCD3138CC64EVM-030 can be used as they are delivered without additional work, from either hardware or firmware, to evaluate an LLC resonant half-bridge DC-to-DC converter. This EVM combination allows for some of its design parameters to be retuned using a GUI based tool, called Texas Instruments Fusion Digital Power Designer. It is also possible to load custom firmware with user's own definition and development.

Three EVMs are included UCD3138LLCEVM-028, UCD3138CC64EVM-030, and USB-TO-GPIO.

This user's guide provides basic evaluation instruction from a viewpoint of system operation in a standalone LLC resonant half-bridge DC-to-DC power converter.

WARNING

- High voltages are present on this evaluation module during operation and for a while even after power off. This module should only be tested by skilled personnel in a controlled laboratory environment.
- An isolated DC voltage source meeting IEC61010 reinforced insulation standards is recommended for evaluating this EVM.
- High temperature exceeding 60°C may be found during EVM operation and for a while even after power off.
- This EVM's purpose is to facilitate the evaluation of digital control in an LLC using the UCD3138, and cannot be tested and treated as a final product.
- Extreme caution should be taken to eliminate the possibility of electric shock and heat burn.
- Read and understand this user's guide thoroughly before starting any physical evaluation.

2 Description

The UCD3138LLCEVM-028 along with the UCD3138CC64EVM-030 demonstrates an LLC resonant half-bridge DC-DC power converter with digital control using the UCD3138 device. The UCD3138 device is located on the UCD3138CC64EVM-030 board. The UCD3138CC64EVM-030 is a daughter card with preloaded firmware that provides the required control functions for an LLC converter. For details of the firmware please contact TI. UCD3138LLCEVM-028 accepts a DC input from 350 V_{DC} to 400 V_{DC}, and outputs a nominal 12 V_{DC} with full load output power of 340 W, or full output current of 29 A.

NOTE: This EVM does not have an input fuse and relies on the input current limit from the input voltage source used.

2.1 Typical Applications

- Offline DC-to-DC Power Conversion
- Servers
- Telecommunication Systems

2.2 Features

- Digitally Controlled LLC Resonant Half-Bridge DC-to-DC Power Conversion
- DC Input from 350 V_{DC} to 400 V_{DC}
- 12 V_{DC} Regulated Output from No Load to Full Load
- Full-Load Power 340 W, or Full-Load Current 29 A
- High Efficiency
- Constant Soft-Start Time
- Protection: Over Voltage, Over Current, Brownout and Output Short-Circuit Protection
- Test Points to Facilitate Device and Topology Evaluation
- Synchronous Rectification
- Automatic Mode Switching between LLC Mode and PWM Mode
- Cycle-by-Cycle Current Limiting with Duty Cycle Matching
- Constant Current and Constant Power Control Mode
- PMBUS Communication
- Current Sharing Capability (GUI Enable), Across Paralleled Units

3 Performance Specifications

Table 1. UCD3138LLCEVM-028 Performance Specifications

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Input Characteristics					
Voltage operation range		350		400	V_{DC}
Input UVLO On			325		
Input UVLO Off			310		
Input current	Input = 350 V_{DC}, full load = 29 A			1.2	A
Input current	Input = 380 V_{DC}, full load = 29 A			1.1	
Input current	Input = 400 V_{DC}, full load = 29 A			1.0	
Output Characteristics					
Output voltage, V_{OUT}	No load to full load		12		VDC
Output load current, I_{OUT}	350 V_{DC} to 400 V_{DC}			29	A
Output voltage ripple	380 V_{DC} and full load = 29 A		200		mVpp
Output over current	Operation 10s then latch-off shutdown	30			A
Systems Characteristics					
Switching frequency	Resonant mode	35		150	kHz
	PWM Mode		150		
Peak efficiency	380 V_{DC}, full load = 29 A		93.5%		
Full-load efficiency	380 V_{DC}, load = 20 A		94.0%		
Operating temperature	Natural convection		25		ºC
Firmware					
Device ID (version)	UCD3100ISO1 | 0.0.44.0000 | 120517				
Filename	UCD3138LLCEVM_028_0_0_44_120517.x0				

4 Schematics

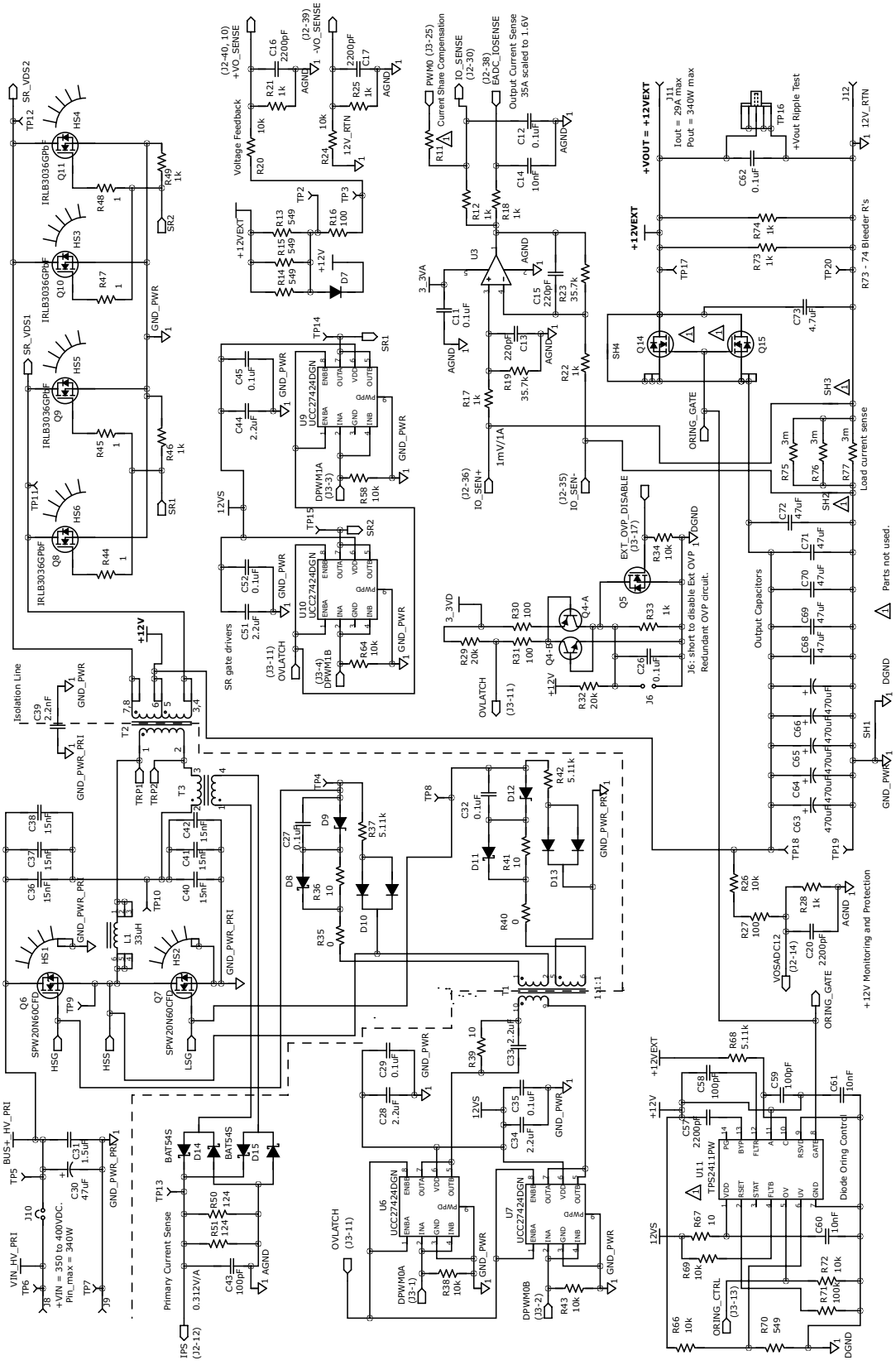

Figure 1. UCD3138LLCEVM-028 Schematic (image 1 of 2)

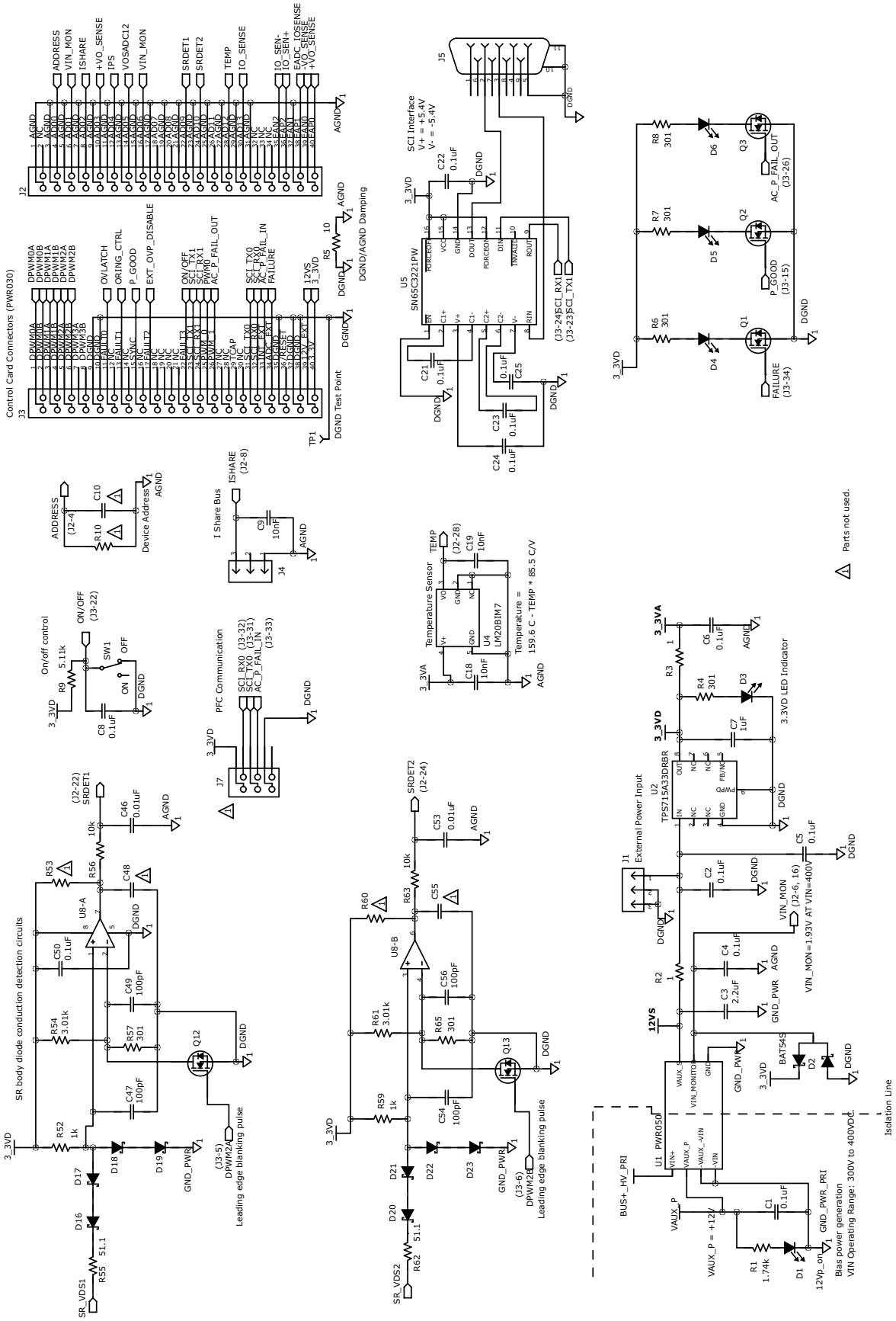

Figure 2. UCD3138PFCEVM-026 Schematic (image 2 of 2)

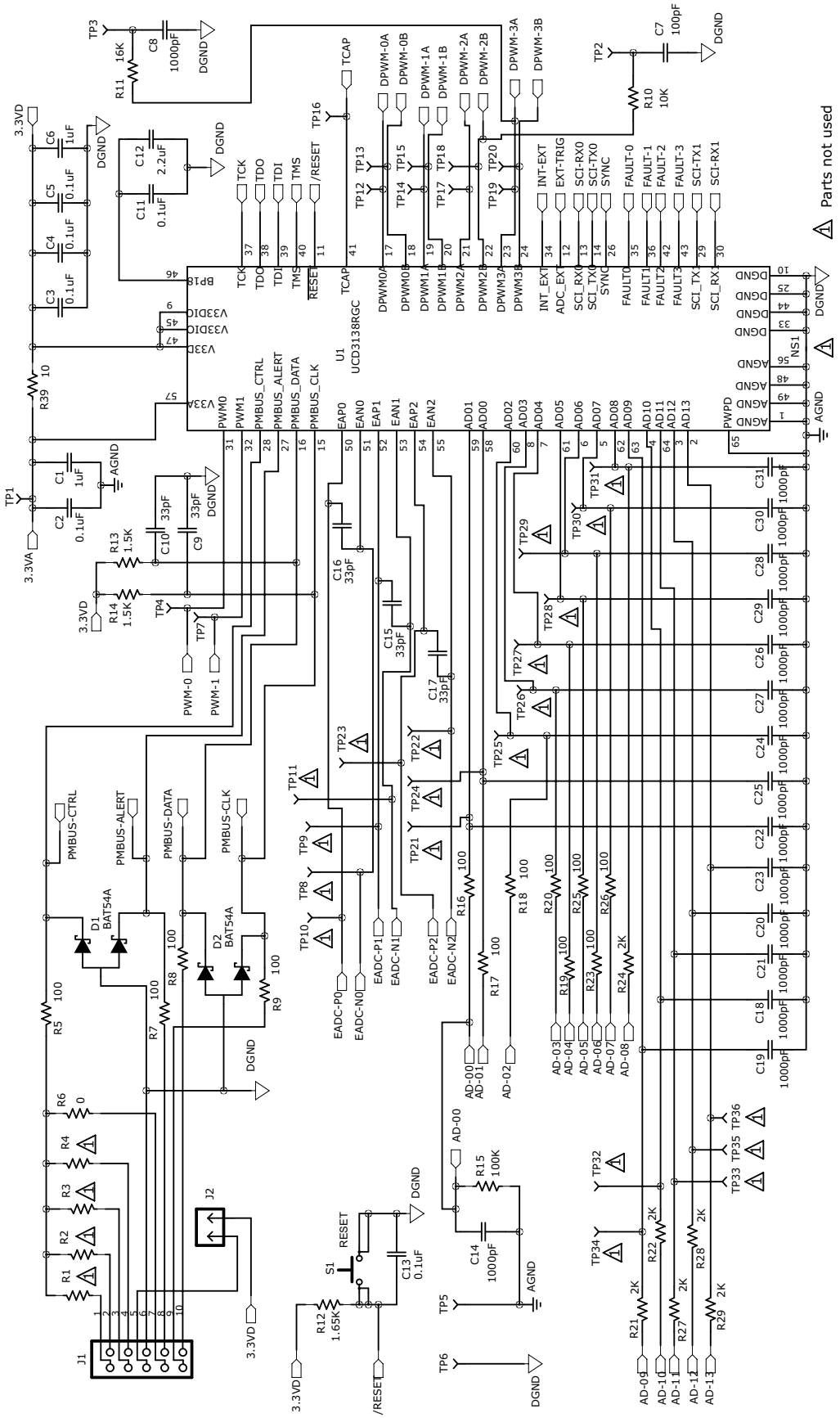

Figure 3. UCD3138CC64EVM-030 Schematic (image 1 of 2)

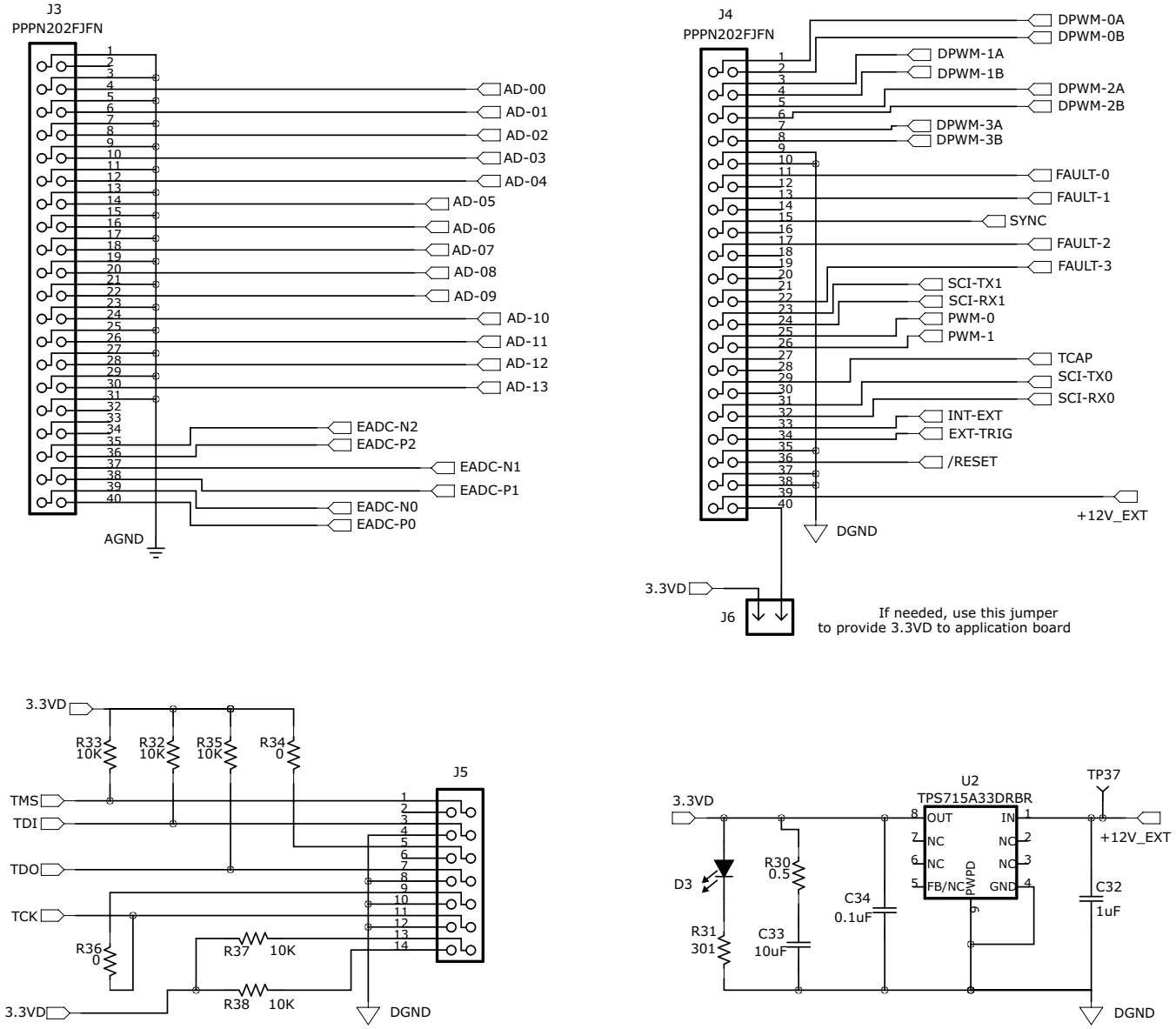

Figure 4. UCD3138CC64EVM-030 Schematic (image 2 of 2)

5 Test Setup

5.1 Test Equipment

DC Voltage Source: capable of 350 V_{DC} to 400 V_{DC}, adjustable, with minimum power rating of 400 W, or current rating not less than 1.5 A, with current limit function. The DC voltage source to be used should meet IEC61010 safety requirements.

DC Multimeter: One unit capable of 0-V_{DC} to 400-V_{DC} input range, four digits display preferred; and one unit capable of 0-V_{DC} to 15-V_{DC} input range, four digits display preferred.

Output Load: DC load capable of receiving 0 V_{DC} to 15 V_{DC}, 0 A to 30 A, and 0 W to 360 W or greater, with display such as load current and load power.

Current-meter, DC, optional in case the load has no display, one unit, capable of 0 A to 30 A. A low ohmic shunt and DMM are recommended.

Oscilloscope: capable of 500-MHz full bandwidth, digital or analog, if digital 5 Gs/s or better.

Fan: 200 LFM to 400 LFM forced air cooling is recommended, but not a must.

Recommended Wire Gauge: capable of 30 A, or better than number 14 AWG, with the total length of wire less than 8 feet (a four foot input and a four foot return).

5.2 Recommended Test Setup

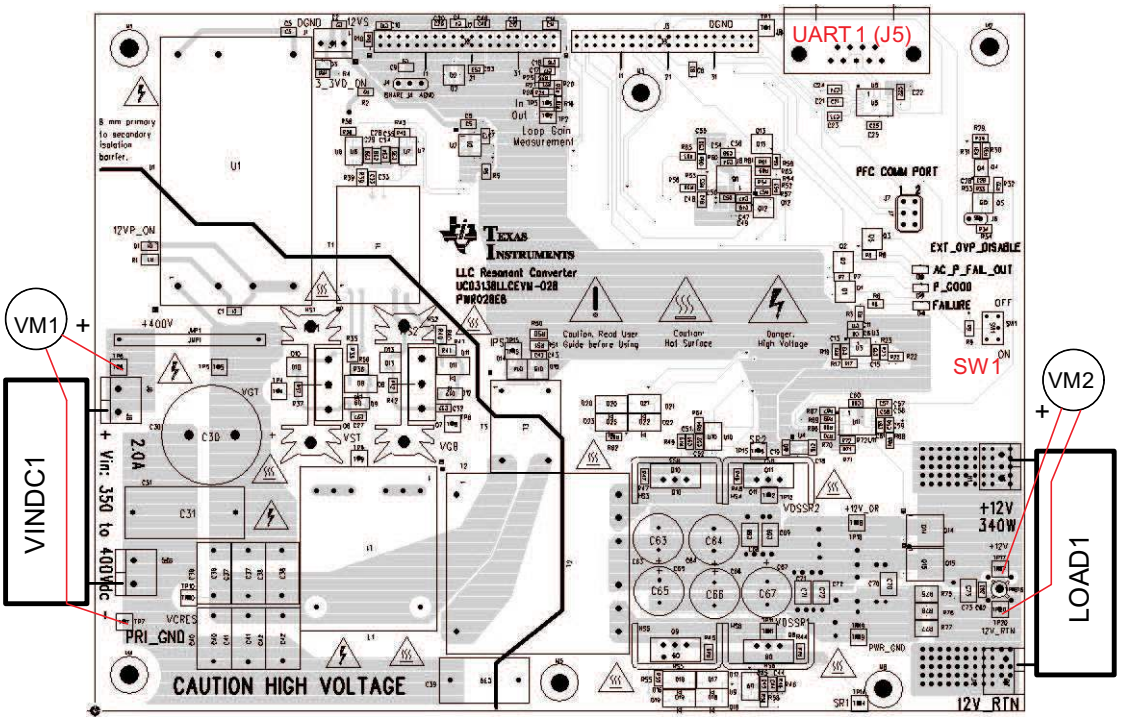

Figure 5. UCD3138LLCEVM-028 Recommended Test Set Up

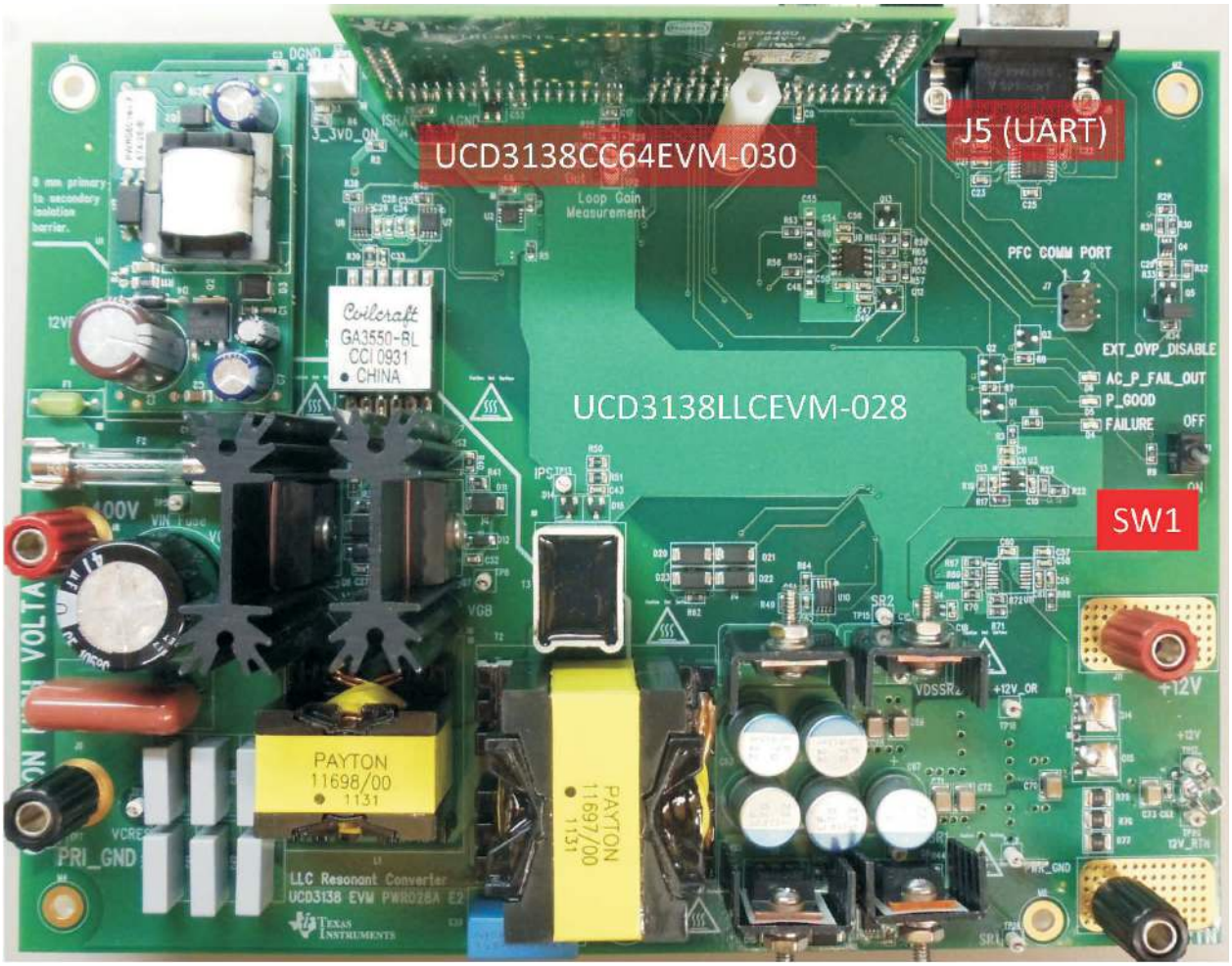

Figure 6. Orientation of Board UCD3138CC64EVM-030 on Board UCD3138LLCEVM-028

6 List of Test Points

Table 2. UCD3138CC64EVM-030 Test Points

TEST POINTS	NAME	DESCRIPTION
TP1	DGND	Digital GND
TP2	Not Used	
TP3	Not Used	
TP4	HSG	Primary high-side MOSFET gate, Q6
TP5	Input +	Input + after jumper J10
TP6	Input_P	Input voltage positive terminal
TP7	Input_N	Input voltage return terminal
TP8	LSG	Primary low-side MOSFET gate, Q7
TP9	HSS	Primary-side switch node, or the intersection of Q6 and Q7
TP10	SWC	Primary side, the intersection of bridge capacitors
TP11	SR_VDS1	Drain of secondary side sync FET Q8 and Q9
TP12	SR_VDS2	Drain of secondary side sync FET Q10 and Q11
TP13	IPS	Primary current sense
TP14	SR1	SR gate drive to Q8 and Q9
TP15	SR2	SR gate drive to Q10 and Q11
TP16	Vo_Ripple	Output voltage ripple
TP17	Vo_P	Output voltage positive terminal
TP18	Xmer_C	Power transformer center point of the secondary side windings.
TP19	GND_PWR	Power GND
TP20	Vo_N	Output voltage return

7 List of Terminals

Table 3. List of Terminals

TERMINAL	NAME	DESCRIPTION
J1	Bias Input	3 pin, external power input, 12 V
J2	Analog Signal	40-pin header, analog signal to control card (UCD3138CC64EVM-030)
J3	Digital Signal	40-pin header, digital signal to control card
J4	AJ	Analog signal connection, 40 pins
J5	UART1	Standard UART connection, RS232, 9 pin
J6	OVP-1	2-pin header, jump across to disable external OVP
J7	Not Used	
J8	Input_P	Input voltage positive terminal
J9	Input_N	Input voltage return terminal
J10	Jumper	Reserved to an input fuse substitution
J11	Output_P	Output voltage positive terminal
J12	Output_N	Output voltage return terminal

8 Test Procedure

8.1 Efficiency Measurement Procedure

WARNING

- Danger of electrical shock! High voltage present during the measurement.
- Do not leave EVM powered when unattended.
- Danger of heat burn from high temperature.

1. Refer to Figure 5 for basic set up to measure power conversion efficiency. The required equipment for this measurement is listed in Section 5.1.
2. Before making electrical connections, visually check the boards to make sure no shipping damage occurred.
3. In this EVM package, three EVMs are included, UCD3138LLCEVM-028, UCD3138CC64EVM-030, and USB-TO-GPIO. For this measurement, the UCD3138LLCEVM-028 and UCD3138CC64EVM-030 boards are needed.
4. First install the UCD3138CC64EVM-030 board onto the UCD3138LLCEVM-028. Care must be taken with the alignment and orientation of the two boards, or damage may occur. Refer to Figure 6 for UCD3138PFCEVM-030 board orientation.
5. Connect the DC voltage source to J8 (+) and J9 (-). The DC voltage source should be isolated and meet IEC61010 requirements. Set up the DC output voltage in the range specified in Table 1, between 350 V_{DC} and 400 V_{DC}; set up the DC source current limit 1.2 A.

NOTE: The board has no fuse installed and relies on the external voltage source current limit for circuit protection.

6. Connect an electronic load with either constant-current mode or constant-resistance mode. The load range is from zero to 29 A.
7. Check and make sure a jumper is installed on J6.
8. It is recommended to use the switch SW1 to turn on the board output after the input voltage is applied to the board. Before applying input voltage, make sure the switch, SW1, is in the *OFF* position.
9. If the load does not have a current or a power display, a current meter or low ohmic shunt and DMM is needed between the load and the board for current measurements.
10. Connect a volt-meter across the output connector and set the volt-meter scale 0 V to 15 V on its voltage, DC.
11. Turn on the DC voltage source output, flip SW1 to *ON* and vary the load. Record output voltage and current measurements.

8.2 Equipment Shutdown

1. Shut down the DC voltage source.
2. Shut down the electronic load.

9 Performance Data and Typical Characteristic Curves

Figure 7 through Figure 20 present typical performance curves for UCD3138LLCEVM-028.

9.1 Efficiency

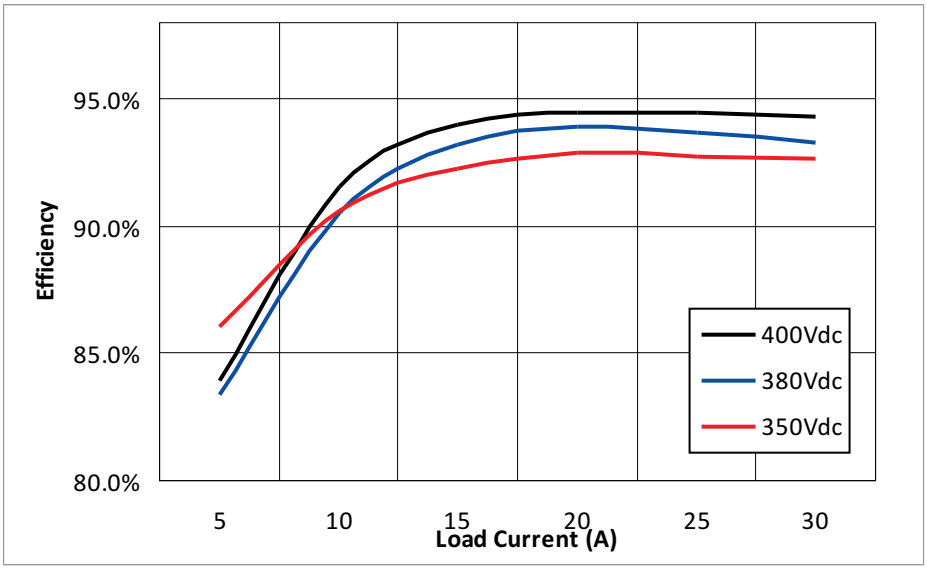

Figure 7. UCD3138LLCEVM-028 Efficiency

9.2 Load Regulation

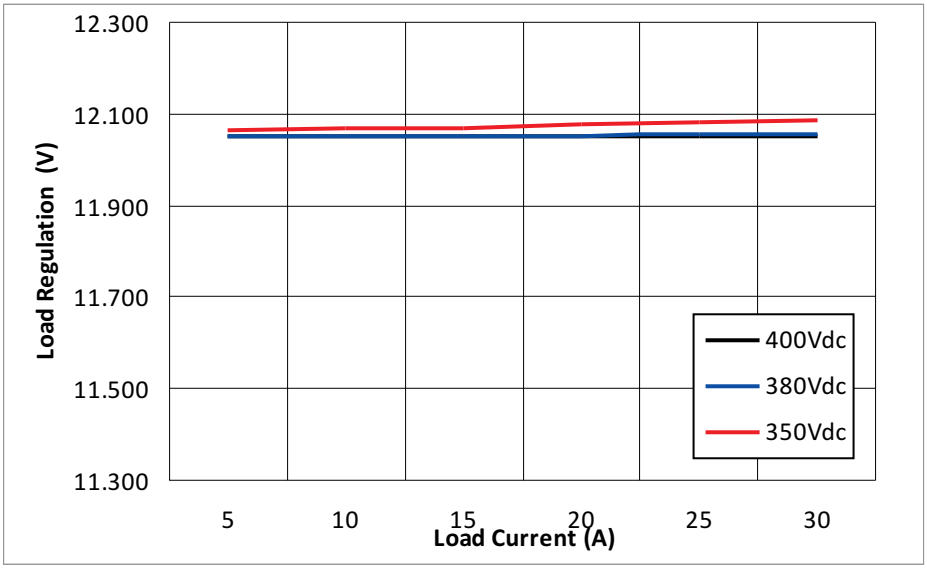

Figure 8. UCD3138LLCEVM-028 Load Regulation

9.3 Switching Frequency Control

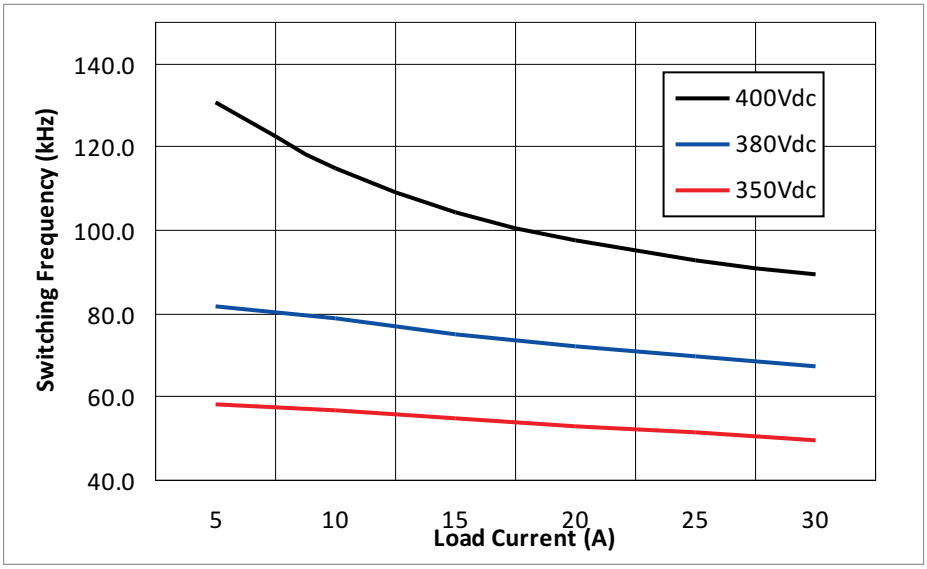

Figure 9. Switching Frequency Control in LLC Mode

9.4 Load Operation with LLC and PWM

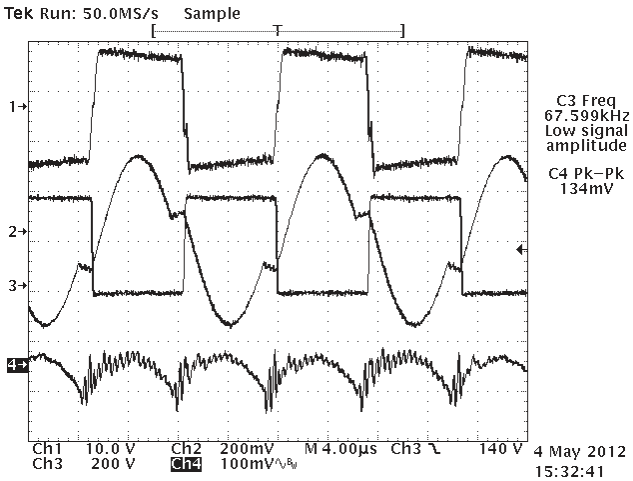

Figure 10. LLC Resonant Mode Operation at Full Load (Ch1 = V_{GS} of Q7, Ch2 = current in resonant network, 2 A/div, Ch3 = V_{DS} of Q7, Ch4 = V_O ripple)

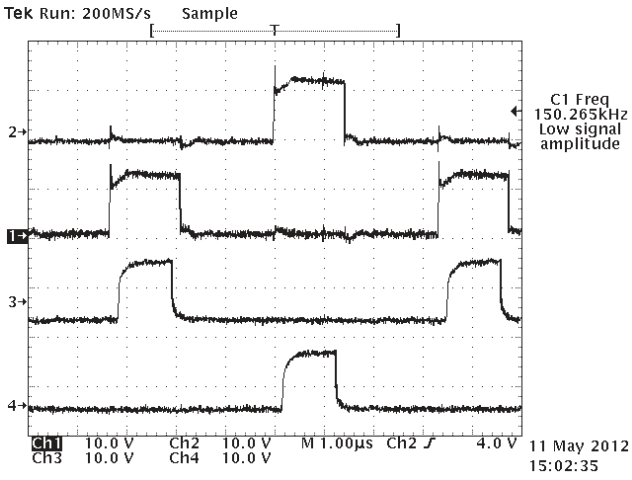

Figure 11. PWM Mode Operation after F_{SW} = 150 kHz (Ch1 = V_{GS} of Q7, Ch2 = V_{GS} of Q6, Ch3 = V_{GS} of SR2, Ch4 = V_{GS} of SR3)

9.5 Very Light-Load Operation at High Line of Input

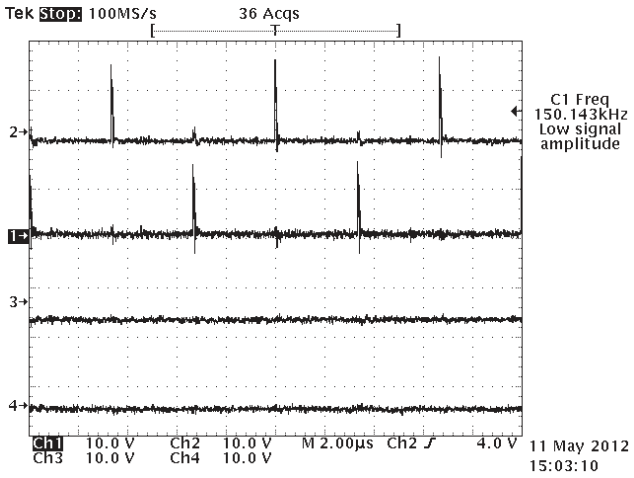

Figure 12. PWM Control at 400VDC Input and Light Load (SR off)
(Ch1 = V_{GS}, Q7, Ch2 = V_{GS}, Q6, Ch3 = V_{GS}, SR1, Ch4 = V_{GS}, SR2)

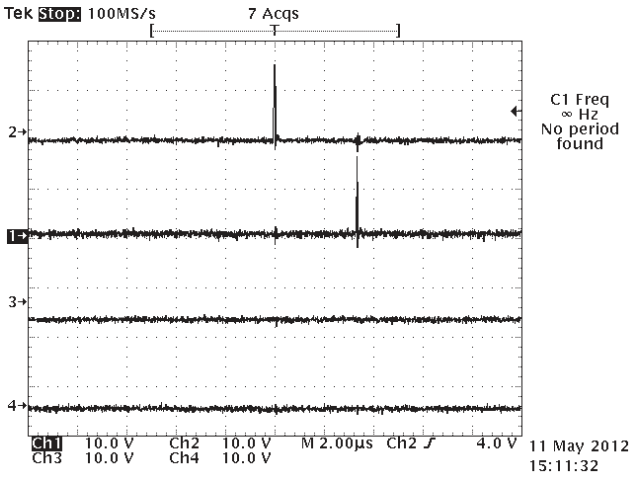

Figure 13. PWM Control with SR Off and Pulse Skipping
(Ch1 = V_{GS}, Q7, Ch2 = V_{GS}, Q6, Ch3 = V_{GS}, SR1, Ch4 = V_{GS}, SR2)

9.6 Output Voltage Ripple

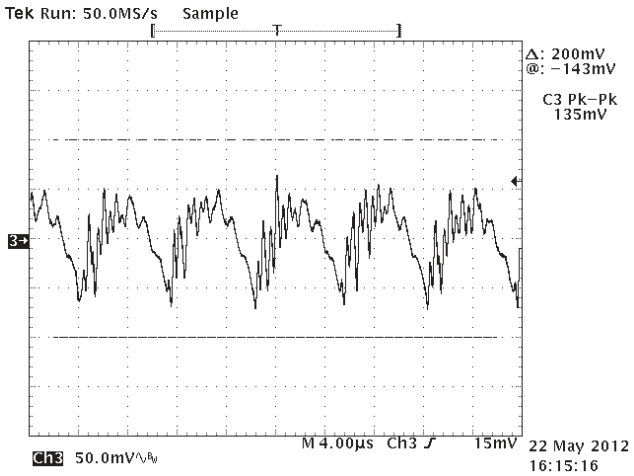

Figure 14. Output Voltage Ripple 380 V_{DC} and Full Load

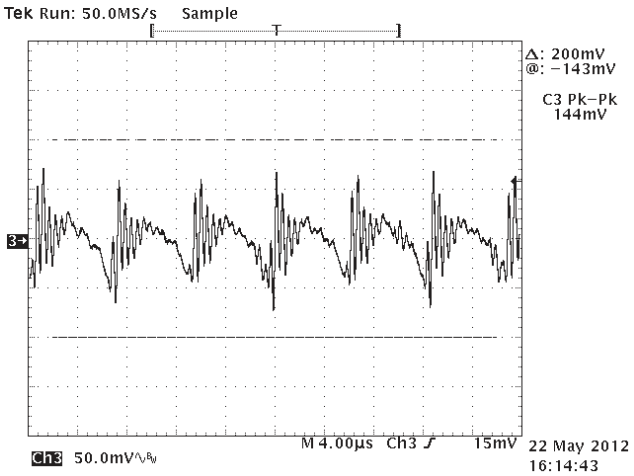

Figure 15. Output Voltage Ripple 380 V_{DC} and Half Load

9.7 Output Turn On

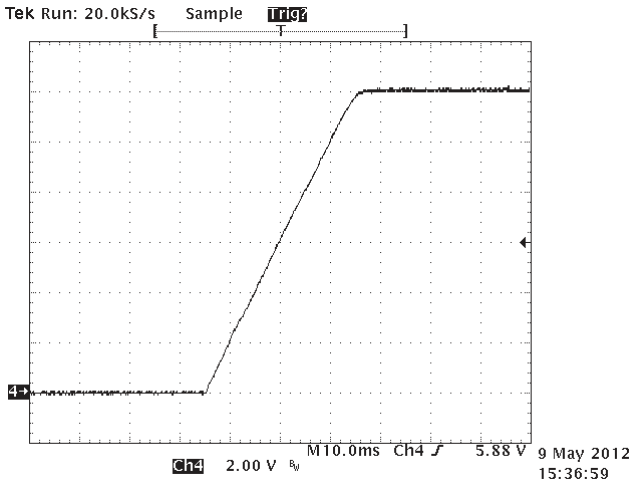

Figure 16. Output Turn On 380 V_{DC} with Load Range

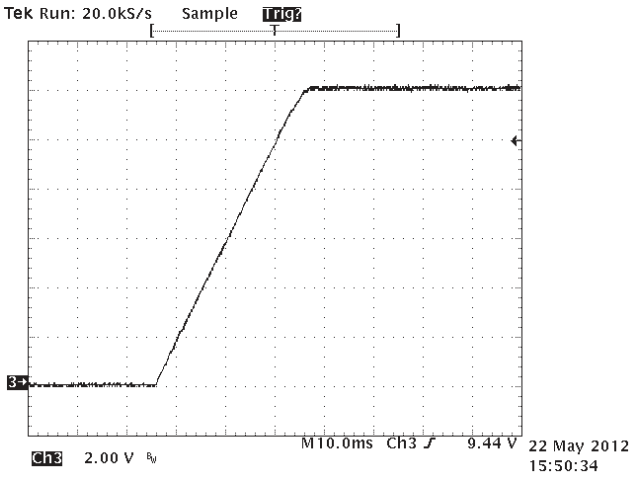

Figure 17. Output Turn On 350 V_{DC} with Load Range

9.8 Other Waveforms

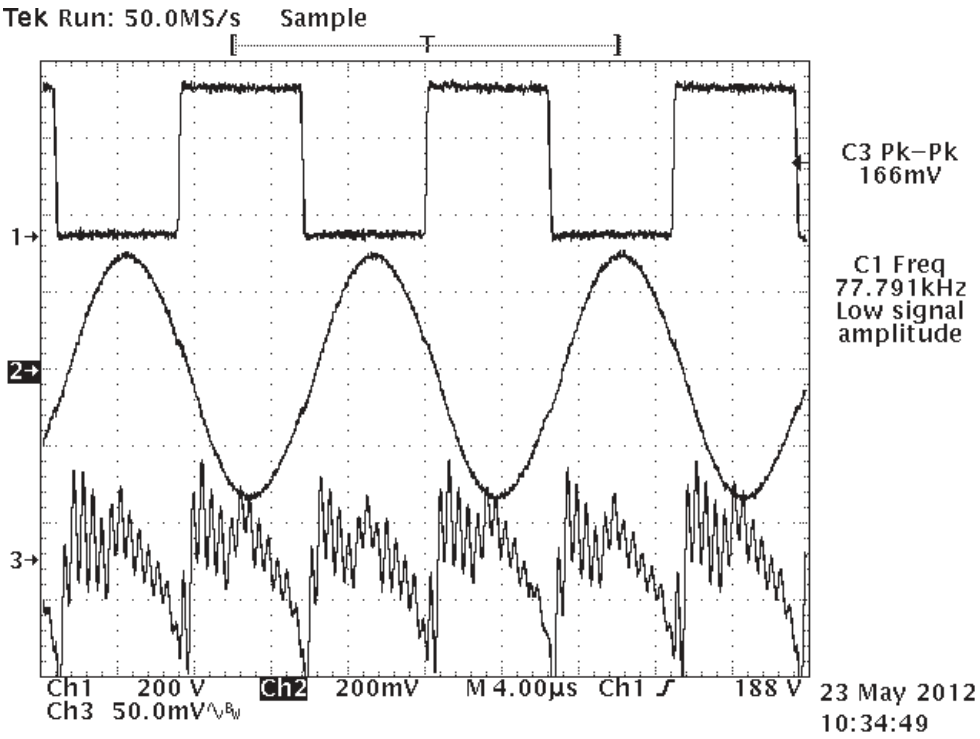

Figure 18. 380 V_{DC} and 30 A Before OCP Latch-Off Shutdown (Ch1 = V_{DS} of Q7, Ch2 = current of resonant network, Ch3 = V_O ripple)

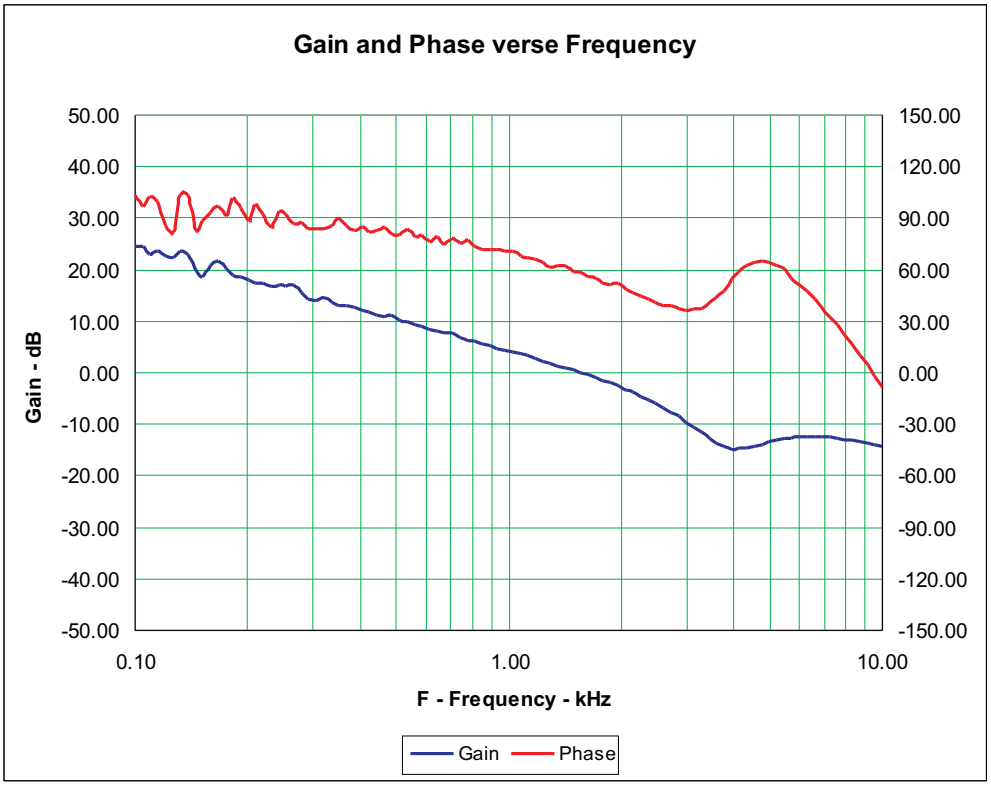

Figure 19. Control Loop Bode Plots at 380 V_{DC} and Full Load

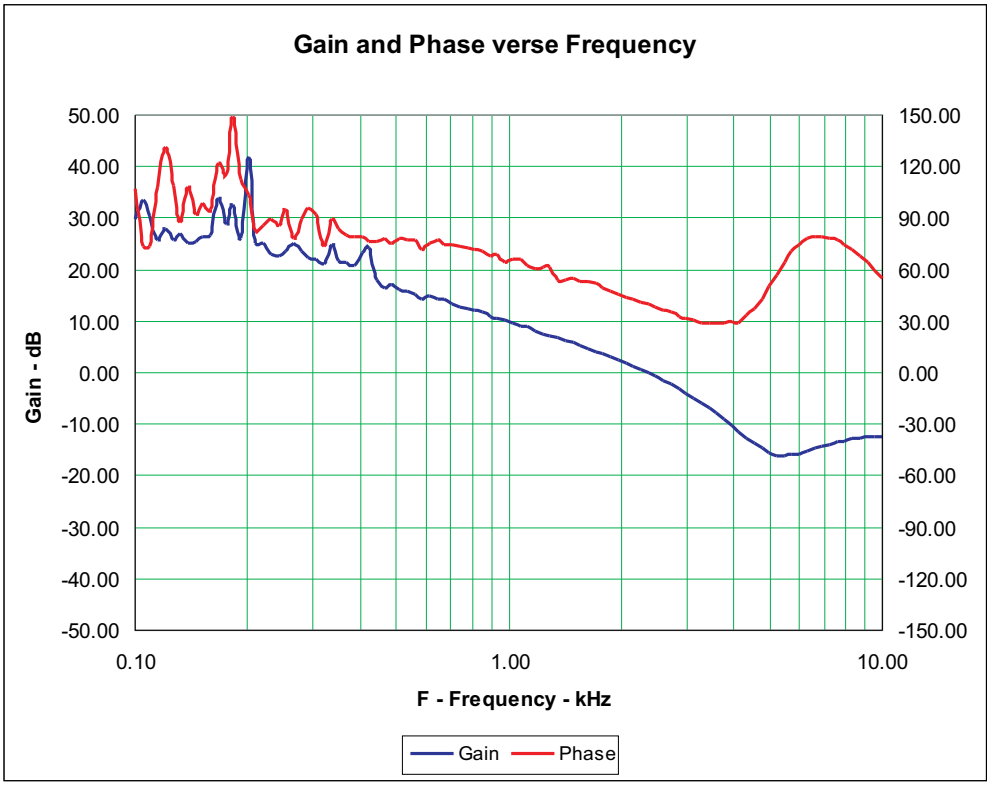

Figure 20. Control Loop Bode Plots at 400 V_{DC} and Full Load

10 EVM Assembly Drawing and PCB layout

The following figures (Figure 21 through Figure 26) show the design of the UCD3138LLCEVM-028 printed circuit board. PCB dimensions: L x W = 8.0 inch x 6.0 inch, PCB material: FR4 or compatible, four layers and 2-ounce copper on each layer

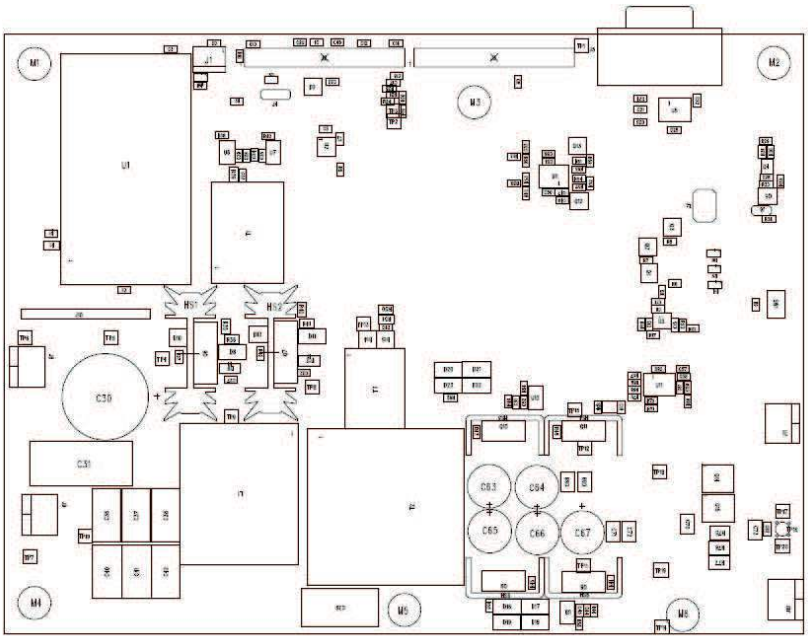

Figure 21. UCD3138LLCEVM-028 Top Layer Assembly Drawing (top view)

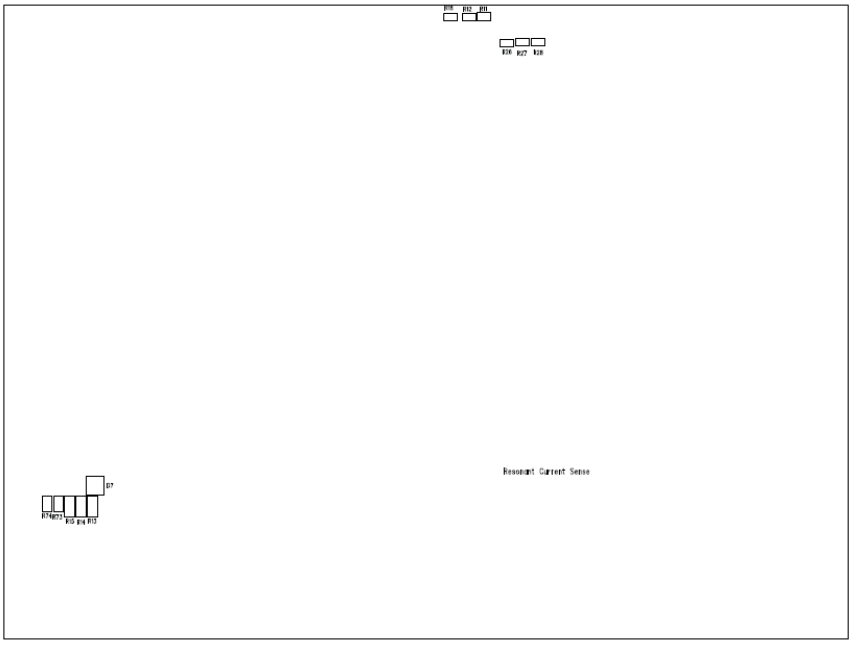

Figure 22. UCD3138LLCEVM-028 Bottom Assembly Drawing (bottom view)

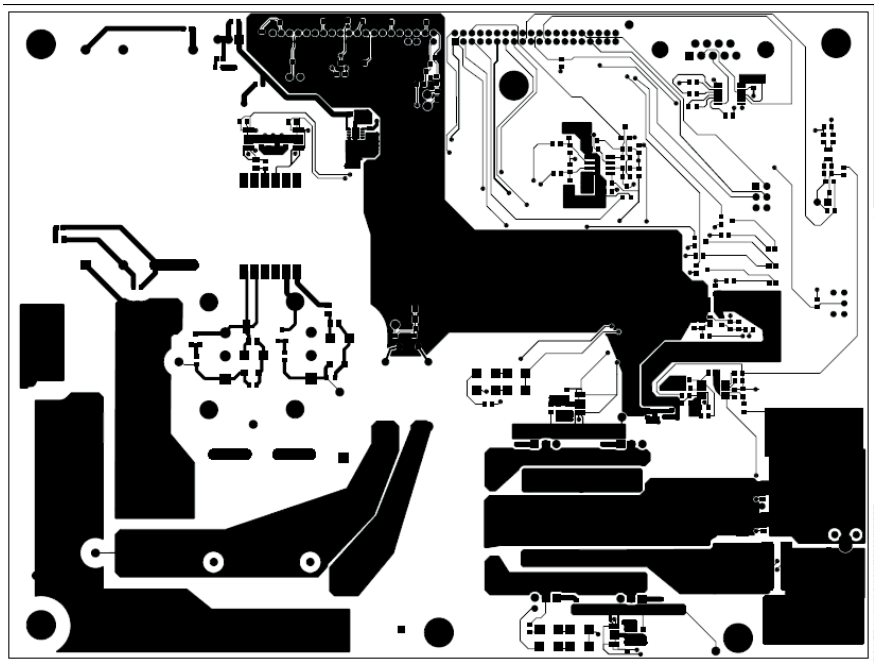

Figure 23. UCD3138LLCEVM-028 Top Copper (top view)

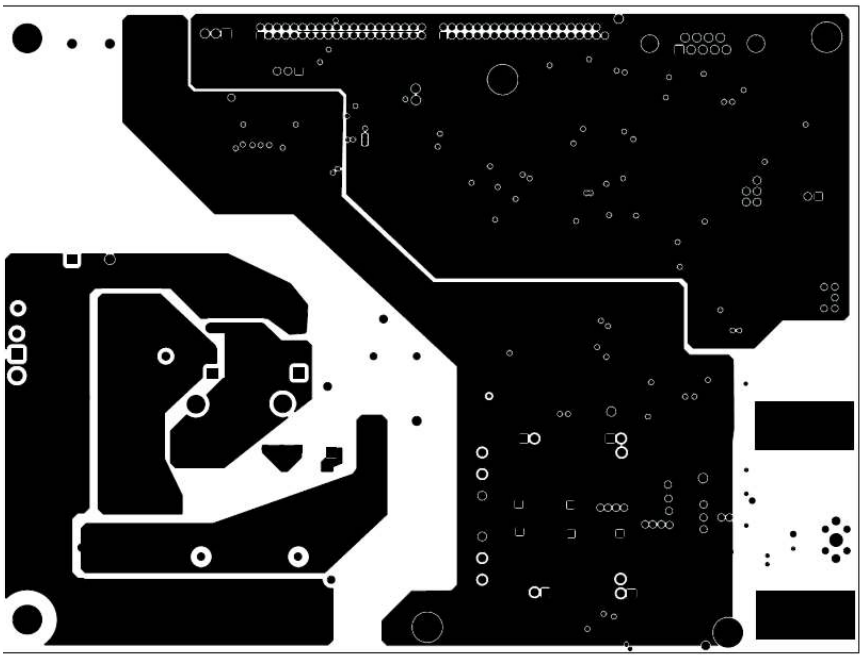

Figure 24. UCD3138LLCEVM-028 Internal Layer 1 (top view)

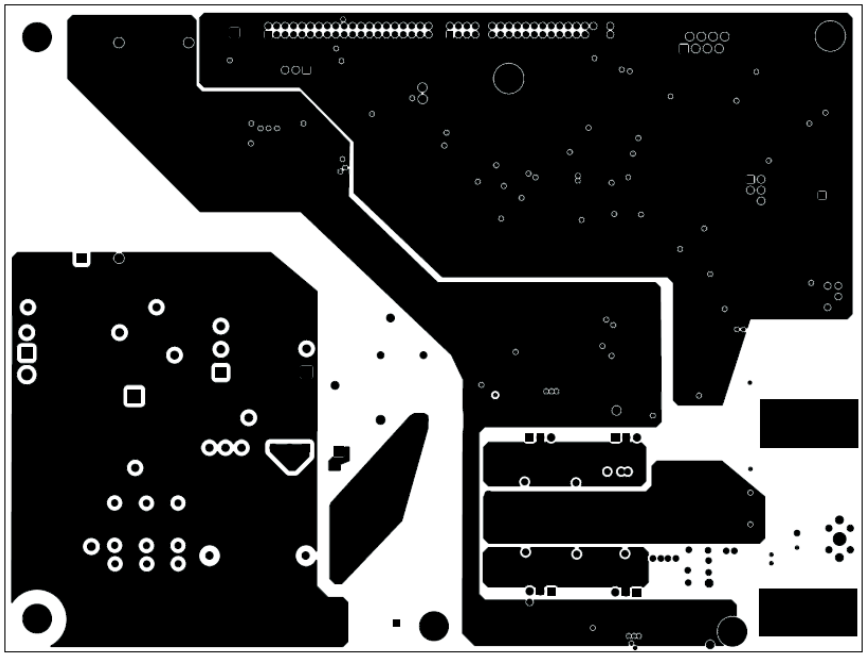

Figure 25. UCD3138LLCEVM-028 Internal Layer 2 (top view)

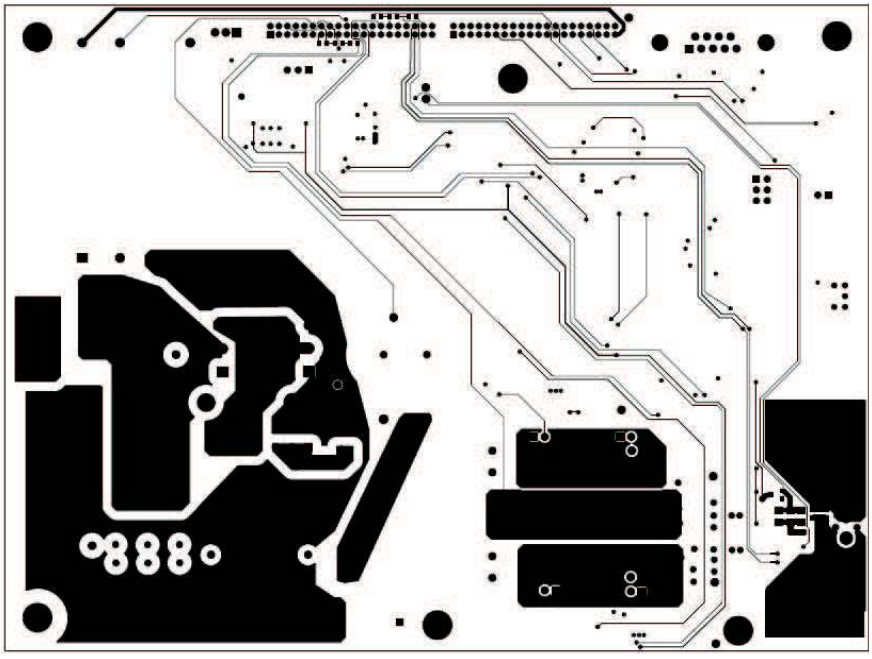

Figure 26. UCD3138LLCEVM-028 Bottom Copper (top view)

11 List of Materials

Component list based on Figure 1 and Figure 2

Table 4. UCD3138LLCEVM-028 List of Materials

QTY	REF DES	DESCRIPTION	PART NUMBER	MFR
22	C1, C2, C4, C5, C6, C8, C11, C12, C21, C22, C23, C24, C25, C26, C27, C29, C32, C35, C45, C50, C52, C62	Capacitor, ceramic, 16 V, X7R, 10%, 0.1 µF, 0603	STD	STD
0	C10, C48, C55	Capacitor, ceramic, 6.3 V, X7R, 10%, open, 0603	STD	STD
2	C13, C15	Capacitor, ceramic, 50 V, X7R, 10%, 220 pF, 0603	STD	STD
4	C16, C17, C20, C57	Capacitor, ceramic, 50 V, X7R, 10%, 2200 pF, 0603	STD	STD
6	C3, C28, C33, C34, C44, C51	Capacitor, ceramic, 16 V, X5R, 10%, 2.2 µF, 0603	STD	STD
1	C30	Capacitor, aluminum electrolytic, 450 V, ±20%, 47 µF, 10 mm x 20 mm	LGU2W470MELY	NichiCon
1	C31	Capacitor, polyester, 450 V, ±10%, 1.5 µF, 1.012 inch x 0.322 inch	ECQ-E2W155KH	Panasonic
6	C36, C37, C38, C40, C41, C42	Capacitor, film, TH, ±5%, 630 V, 0.015 µF, 5.9 mm x 12.5 mm	ECWF6153JL	Panasonic
1	C39	Capacitor, film 250 V_{AC}, ±20%, 0.0022 µF, 7 mm x 18 mm	B81123C1222M	Epcos
7	C43, C47, C49, C54, C56, C58, C59	Capacitor, ceramic, 16 V, X7R, 10%, 100 pF, 0603	STD	STD
2	C46, C53	Capacitor, ceramic, 16 V, X7R, 10%, 0.01 µF, 0603	STD	STD
5	C63, C64, C65, C66, C67	Capacitor, electrolytic, 16 V_{DC}, ±20%, 470 µF, 10 mm x 13 mm	PLF1C471MDO1	Nichicon
5	C68, C69, C70, C71, C72	Capacitor, ceramic, 16 V, X5R, ±20%, 47 µF, 1210	STD	STD
1	C7	Capacitor, ceramic, 16 V, X7R, 10%, 1 µF, 0603	STD	STD
1	C73	Capacitor, ceramic, 16 V, X5R, 10%, 4.7 µF, 1210	STD	STD
6	C9, C14, C18, C19, C60, C61	Capacitor, ceramic, 16 V, X7R, 10%, 10 nF, 0603	STD	STD
3	D1, D3, D5	Diode, LED, green, 2.1 V, 20 mA, 6 mcd, 0603	LTST-C190GKT	Lite On
2	D10, D13	Diode, switching, dual, 70 V, 250 mA, SOT23	BAV70-V	Zetex
3	D2, D14, D15	Diode, dual Schottky, 200 mA, 30 V, SOT23	BAT54S	Zetex
2	D4, D6	Diode, LED, red, 2.1 V, 20 mA, 6 mcd, 0603	LTST-C190CKT	Lite On
1	D7	Diode, switching, 100 V, 200 mA, SOT23	MMBD914	Fairchild
10	D8, D11, D16, D17, D18, D19, D20, D21, D22, D23	Diode, power Schottky, 1 A, 30 V, SMA	STPS130A	ST
2	D9, D12	Diode, Zener, 20 mA, 2.5 V, SOD123	MMSZ5222BT1G	On Semi
2	HS1, HS2	Heatsink, TO-218,TO-247, vertical mount, 5°C/W, 0.5 inch x 1.38 inch	513201B02500	Aavid
4	HS3, HS4, HS5, HS6	Heatsink, TO-220, vertical mount, 0.5 inch x 0.750 inch	507302B00000	Aavid
1	J1	Connector, friction lock 100-millimeter pitch, 0.230 inch x 0.300 inch	22-27-2031	Molex
1	J10	Jumper, 1.200-inch length, solid tinned copper, AWG 22, noninsulated, AWG 22	8021 000100	Belden
2	J2, J3	Header, 40 pin, 2 mm Pitch, 4.00 mm x 40.00 mm	87758-4016	Molex
1	J4	Header, male 3 pin, 100-millimeter spacing, 0.100 inch x 3 inch	PEC03SAAN	Sullins
1	J5	Connector, 9 pin D, right angle, female, 1.213 mm x 0.510 mm	182-009-213R171	Norcomp

Table 4. UCD3138LLCEVM-028 List of Materials (continued)

QTY	REF DES	DESCRIPTION	PART NUMBER	MFR
1	J6	Header, male 2 pin, 100-millimeter spacing, 0.100 inch x 2 inch	PEC02SAAN	Sullins
0	J7	Header, male 2 x 3 pin, 100-millimeter spacing, open, 0.20 inch x 0.30 inch	PEC03DAAN	Sullins
4	J8, J9, J11, J12	Terminal block, 2 pin, 15 A, 5.1 mm, 0.40 inch x 0.35 inch	ED120/2DS	OST
1	L1	Inductor, resonant, 33 µH, 20%, 26.6 mm x 34.55 mm	11698	Payton Planar Transformers
6	Q1, Q2, Q3, Q5, Q12, Q13	MOSFET, N-channel, 60 V, 115 mA, 1.2 Ω, SOT23	2N7002	Diodes
0	Q14, Q15	MOSFET, N-channel, 25 V, 33 A, 1.7 mΩ, open, QFN-8 power	CSD16325Q5	TI
1	Q4	Transistor, complementary, NPN/PNP 60 V and 40 V, 600 mA, SOT-363	MMDT4413	Diodes
2	Q6, Q7	MOSFET, N-channel, 650 V, 20.7 A, 0.22 Ω, TO-247	SPW20N60CFD	Infineon
4	Q8, Q9, Q10, Q11	MOSFET, N-channel, 60 V,195A, 2.4 mΩ, TO-220	IRLB3036GPbF	IR
1	R1	Resistor, chip, 1/10 W, 1%, 1.74 kΩ, 0805	STD	STD
0	R10, R11, R53, R60	Resistor, chip, 1/16 W, 1%, open, 0603	STD	STD
12	R12, R17, R18, R21, R22, R25, R28, R33, R46, R49, R52, R59	Resistor, chip, 1/16 W, 1%, 1 kΩ, 0603	STD	STD
3	R13, R14, R15	Resistor, chip, 1/4 W, 1%, 549 Ω, 1206	STD	STD
4	R16, R27, R30, R31	Resistor, chip, 1/16 W, 1%, 100 Ω, 0603	STD	STD
2	R19, R23	Resistor, chip, 1/16 W, 1%, 35.7 kΩ, 0603	STD	STD
6	R2, R3, R44, R45, R47, R48	Resistor, chip, 1/16 W, 1%, 1 Ω, 0603	STD	STD
13	R20, R24, R26, R34, R38, R43, R56, R58, R63, R64, R66, R69, R72	Resistor, chip, 1/16 W, 1%, 10 kΩ, 0603	STD	STD
2	R29, R32	Resistor, chip, 1/16 W, 1%, 20 kΩ, 0603	STD	STD
2	R35, R40	Resistor, chip, 1/10 W, 1%, 0 Ω, 0805	STD	STD
3	R36, R39, R41	Resistor, chip, 1/10 W, 1%, 10 Ω, 0805	STD	STD
6	R4, R6, R7, R8, R57, R65	Resistor, chip, 1/16 W, 1%, 301 Ω, 0603	STD	STD
2	R5, R67	Resistor, chip, 1/16 W, 1%, 10 Ω, 0603	STD	STD
2	R50, R51	Resistor, chip, 1/10 W, 1%, 124 Ω, 0805	STD	STD
2	R54, R61	Resistor, chip, 1/16 W, 1%, 3.01 kΩ, 0603	STD	STD
2	R55, R62	Resistor, chip, 1/16 W, 1%, 51.1 Ω, 0603	STD	STD
1	R70	Resistor, chip, 1/16 W, 1%, 549 Ω, 0603	STD	STD
1	R71	Resistor, chip, 1/16 W, 1%, 100 kΩ, 0603	STD	STD
2	R73, R74	Resistor, chip, 1/10 W, 1%, 1 kΩ, 0805	STD	STD
3	R75, R76, R77	Resistor, chip,1/2 W, 1%, 3 mΩ, 1210	STD	STD
4	R9, R37, R42, R68	Resistor, chip, 1/16 W, 1%, 5.11 kΩ, 0603	STD	STD
1	SW1	Switch, on-none-on, 0.28 inch x 0.18 inch	G12AP-RO	NKK
1	T1	Transformer, gate drive, ±25%, 460 µH, 0.685 inch x 0.950 inch	GA3550-BL	Coilcraft
1	T2	Transformer, half-bridge, turns-ratio = 16:1:1, 520 µH, 35.5 mm x 39.1 mm	11697	Payton Planar Transformers
1	T3	Transformer, current sense, 5mA - 35A, 1:200, 0.570 inch x 0.770 inch	CS4200V-01L	Coilcraft

Table 4. UCD3138LLCEVM-028 List of Materials (continued)

QTY	REF DES	DESCRIPTION	PART NUMBER	MFR
1	U1	Module, 5W, auxiliary bias PS, PCB assembly, 1.200 inch x 2.200 inch	PWR050	TI
0	U11	N+1 and Oring Power Rail Controller, open, TSSOP-14	TPS2411PW	TI
1	U2	High Input Voltage, Micropower, 3.2 µA at 80 mA LDO, 3.3 V, QFN-8	TPS715A33DRBR	TI
1	U3	Presicion, Low Noise, Low Quiescent Current Op-Amp, SOT23-5	OPA376AIDBVR	TI
1	U4	Micro SMD Temperature Sensor, 2.4 V, 10 µA, SC70-5	LM20BIM7/NOPB	TI
1	U5	3-V to 5.5V- Single Channel RS-232 Compatible Line Drive/Receiver, TSSOP-16	SN65C3221PW	TI
4	U6, U7, U9, U10	Dual Non-Inverting, 5-A High-Speed, Low-Side MOSFET Driver with Enable, HTSSOP	UCC27524DGN	TI
1	U8	4.5 ns R-R, High-Speed Comparator, SO-8	TLV3502AID	TI
1	U12	Control card, UCD3138 control card, PCB assembly, 3.400x1.800 inch	UCD3138CC64EVM-030	TI

NOTE: PWR050 is a bias board and its design documents can be found from www.ti.com in the UCD3138PFCEVM026 Technical Documents.

12 References

1. UCD3138 Datasheet, Highly Integrated Digital Controller for Isolated Power, (Texas Instruments Literature Number SLUSAP2), 2012
2. UCD3138CC64EVM-030 Evaluation Module and User's Guide, Programmable Digital Power Controller Control Card Evaluation Module, (Texas Instruments Literature Number SLUU886), 2012
3. SEM1900, 2010, Designing an LLC Resonant Half-Bridge Power Converter
4. TI Application Note, Feedback Loop Design of an LLC Resonant Power Converter, (Texas Instruments Literature Number SLUA582A), November 2010.
5. APEC 2006, *Optimal design methodology for LLC resonant converter*, Bing Lu; Wenduo Liu; Yan Liang; Lee, F.C.; van Wyk, J.D. pages 19-23
6. TI Application Manual, UCD3138 Digital Power Peripherals Programmer's Manual, (Texas Instruments Literature Number SLUU995)
7. TI Application Manual, UCD3138 Monitoring and Communications Programmer's Manual, (Texas Instruments Literature Number SLUU996)
8. TI Application Manual, UCD3138 ARM and Digital System Programmer's Manual, (Texas Instruments Literature Number SLUU994)
9. User Guide, *UCD3138 Isolated Power Fusion GUI*, (please contact TI)

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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

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

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.

For EVMs annotated as IC – INDUSTRY CANADA Compliant

This Class A or B digital apparatus complies with Canadian ICES-003.

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

Concerning EVMs including radio transmitters

This device complies with Industry Canada licence-exempt RSS standard(s). 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.

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.

Cet appareil numérique de la classe A ou B est conforme à la norme NMB-003 du Canada.

Les changements ou les modifications pas expressément approuvés par la partie responsable de la conformité ont pu vider l'autorité de l'utilisateur pour actionner l'équipement.

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.

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.

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If you use this product in Japan, you are required by Radio Law of Japan to follow the instructions below with respect to this product:

1. Use this product 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 this product only after you obtained the license of Test Radio Station as provided in Radio Law of Japan with respect to this product, or
3. Use of this product only after you obtained the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to this product. Also, please do not transfer this product, unless you give the same notice above to the transferee. Please note that if you could not follow the instructions above, you will be subject to penalties of Radio Law of Japan.

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