EVM User's Guide: UCC217XXQDWEVM-054

UCC217xx and ISO5x5x Half-Bridge EVM User's Guide for Wolfspeed 1200-V SiC Platforms

ABSTRACT

The UCC217XXQDWEVM-054 is a compact, half-bridge gate driver board consisting of two single-channel isolated gate drivers. It provides isolated bias supply, drive current, protection and monitoring needed for driving several different models of Wolfspeed silicon-carbide (SiC) MOSFET modules and other IGBT or SiC MOSFET modules with a similar pinout. The on-board DC-DC transformers can provide adjustable isolated voltage. The board's compact form factor, combined with UCC217xx's 5.7kVrms reinforced isolation, makes it a good candidate for doing high voltage tests, such as double-pulse tests and short-circuit tests, with the Wolfspeed SiC modules. The board can also be used with all variants of the UCC217xx and ISO5x5x family with minimal on-board modifications.

This user's guide describes the characteristics, operation and use of the UCC217XX-054 Evaluation Module (EVM). It also includes instructions to adjust different gate driver parameters, such as voltage supply and drive strength, as well as instructions to modify the EVM to be compatible with different UCC217xx and ISO5x5x variants. A complete schematic diagram, printed circuit board layouts, and bill of materials are included in this document.

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1 General TI High Voltage Evaluation User Safety Guidelines

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 must immediately stop from further use of the HV EVM.

- **Work Area Safety:**
  - Maintain a clean and orderly work area .
  - Qualified observer(s) must be present anytime circuits are energized.
  - 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.
  - 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.
  - Use a stable and non-conductive work surface.
  - Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.
- **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.

  - De-energize the TI HV EVM and all its inputs, outputs, and electrical loads before performing any electrical or other diagnostic measurements. Confirm that TI HV EVM power has been safely de-energized.
  - 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.
  - When EVM readiness is complete, energize the EVM as intended.

> **WARNING**
>
> **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.**

- **Personal Safety:**
  - Wear personal protective equipment, for example, latex gloves and/or safety glasses with side shields or protect EVM in an adequate lucent plastic box with interlocks from accidental touch.
- **Limitation for Safe Use:**
  - EVMs are not to be used as all or part of a production unit.

The EVM is designed for professionals who have received the appropriate technical training, and is designed to operate from an AC power supply or a high-voltage DC supply. Please read this user guide and the safety-related documents that come with the EVM package before operating this EVM.

CAUTION

Do not leave the EVM powered when unattended.

WARNING

High Voltage! Electric shock is possible when connecting board to live wire. Board must be handled with care by a professional.

For safety, use of isolated test equipment with overvoltage and overcurrent protection is highly recommended.

2 Module and Gate Driver Compatibility

2.1 Supported Wolfspeed Modules and Evaluation Platforms

Below is a list of Wolfspeed evaluation platforms and SiC modules supported by the half-bridge gate driver board.

Table 2-1. Wolfspeed Evaluation Platforms and SiC Modules Supported

Wolfspeed Design	Wolfspeed Parts Supported	Description
SpeedVal Kit	650-1200V Discrete MOSFETs, FM Half-Bridge Modules	Dynamic Characterization and Power Testing Platform
KIT-CRD-CIL12N-XM3	1200V XM Power Modules	Dynamic Characterization Platform
KIT-CRD-CIL12N-GMA	1200V GM Half-Bridge Modules	Dynamic Characterization Platform
KIT-CRD-CIL12N-FMA	1200V Half-Bridge FM Power Modules	Dynamic Characterization Platform
KIT-CRD-CIL12N-FMB	1200V FM Full-Bridge Modules	Dynamic Characterization Platform
KIT-CRD-CIL12N-FMC	1200V 6-Pack FM Power Modules	Dynamic Characterization Platform

Other SiC MOSFET modules and IGBT modules with similar pinouts are directly supported as well.

2.2 Supported Gate Drivers

For details on how to modify the board to fit different gate driver variants, see Section 6.3.

Table 2-2. Supported Gate Drivers

Gate Driver	Support	EVM Part Number	Miller Clamp	Peak Current Rating	SC Protection	External Buffer	Modifications to Install on UCC21710 EVM	Modifications to Install on UCC21750 EVM
UCC21710 UCC21710-Q1	Available as EVM	UCC21710Q DWEVM-054	Internal	10A	OC (0.7V)	Not populated by default	None	• Short-circuit detection
UCC21750 UCC21750-Q1	Available as EVM	UCC21750Q DWEVM-054	Internal	10A	DESAT (9V)	Not populated by default	• Short-circuit detection	None
UCC21717-Q1	Direct Drop-in to UCC21710 EVM	N/A	Internal	10A	DESAT (9V)	Optional use	None	• Short-circuit detection
UCC21759-Q1	Direct Drop-in to UCC21750 EVM	N/A	Internal	10A	DESAT (9V)	Optional Use	• Short-circuit detection	None
UCC21755-Q1 UCC21756-Q1	Supported	N/A	Internal	10A	DESAT (5V)	Optional Use	• Short-circuit detection	• Short-circuit detection (adjust threshold)
UCC21732 UCC21732-Q1 UCC21739-Q1	Supported	N/A	External	10A	OC (0.7V)	Optional use	• Miller clamp	• Short-circuit detection • Miller clamp
UCC21737-Q1	Supported	N/A	External	10A	OC (0.7V)	Optional Use	• Miller clamp • AIN/ASC circuit	• Short-circuit detection • Miller clamp • AIN/ASC circuit

Table 2-2. Supported Gate Drivers (continued)

Gate Driver	Support	EVM Part Number	Miller Clamp	Peak Current Rating	SC Protection	External Buffer	Modifications to Install on UCC21710 EVM	Modifications to Install on UCC21750 EVM
ISO5452 ISO5452-Q1 ISO5852S ISO5852S-Q1 ISO5852S-EP	Supported	N/A	Internal	+2.5/-5A	DESAT (9V)	Recommended use	• Short-circuit detection • External buffer (optional) • Bypass AIN/ APWM	• External buffer (optional) • Bypass AIN/ APWM
ISO5451 ISO5451-Q1 ISO5851 ISO5851-Q1	Supported	N/A	Internal	+2.5/-5A	DESAT (9V)	Recommended use	• Short-circuit detection • External buffer (optional) • Bypass AIN/ APWM • Single output (optional)	• External buffer (optional) • Bypass AIN/ APWM • Single output (optional)

3 System Overview and Functions

3.1 Features

- Fully compatible with every UCC217xx and ISO5x5x variant
  - Available OPNs using either UCC21710 and UCC21750; other variants can be swapped with resistor changes
- Directly compatible with Wolfspeed's FM3 and XM3 modules
- UCC25800 LLC converter supplies up to 2 W to each driver
  - Only a +12-V input voltage needed to generate the primary-side and secondary-side bias voltages
- Status LEDs indicate power-good and fault feedback from each driver
- Isolated temperature sensing when using UCC217xx variants
- Test points for all critical nodes to expedite debugging
- Ability to install external buffer to increase drive strength

3.2 Specifications

Recently, wide bandgap SiC FET based power modules are introduced in power electronics instead of Si IGBT because of their excellent conduction and switching performance. Compact driver board UCC21710/50QDWEVM-054 supports SiC modules by reducing parasitics, minimizing switching loss, EMI and providing full required protection and diagnostics features.

Table 3-1. Electrical Specifications

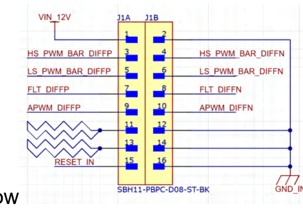
Parameter		Test Conditions	Min	Nom	Max	Unit
SUPPLY VOLTAGES AND CURRENTS						
Vcc	VCC supply voltage		4.5	5.0	5.5	V
Vdd2u, Vdd2l	VDD supply voltages	From transformer and LDO		15		V
Vee2u, Vee2l	VEE supply voltages	From transformer and shunt regulator		-3		V
DRIVE CURRENT						
Ioh	Peak source current	CLOAD = 10nF		10		A
Iol	Peak sink current	CLOAD = 10nF		10		A
INPUT/OUTPUT SIGNALS						
Vinr, Vrstr	IN+, IN-, RST/EN rising threshold				0.7 x VCC	V
Vinf, Vrstf	IN+, IN-, RST/EN falling threshold		0.3 x VCC			V
Vinh, Vrsth	INL+, INU+, RST hysteresis			0.1 x VCC		V
TIMING PARAMETERS						
Trise	Drive output rise time	CLOAD = 10 nF		33		ns
Tfall	Drive output fall time	CLOAD = 10 nF		27		ns
Tprop	Propagation delay	CLOAD = 100 pF		90		ns
SHORT CIRCUIT PROTECTION - OC						
Voc	Nominal overcurrent threshold		0.63	0.7	0.77	V
Tocfil	OC fault deglitch filter	Ioc = 5mA		120		ns
Isto	Soft turn-off pull down current			400		mA
Vclamp	Miller Clamp threshold	Reference to VEE	1.5	2.0	2.5	V
Iclamp	Miller Clamp current	VCLMPI = 0 V, VEE = –2.5 V		4		A
SHORT CIRCUIT PROTECTION - DESAT						
Ichg	Blanking capacitor charging current		430	500	570	uA
Tdesatleb	Leading edge blank time			200		ns
Tdesatfil	DESAT deglitch filter			140		ns

Table 3-1. Electrical Specifications (continued)

Parameter		Test Conditions	Min	Nom	Max	Unit
Isto	Soft turn-off pull down current			400		mA
Vclmpi	Miller Clamp threshold	Reference to VEE	1.5	2	2.5	V
Iclmpi	Miller Clamp current	VCLMPI = 0 V, VEE = –2.5 V		4		A
ISOLATION						
Viso	Withstand isolation voltage for gate driver	Reinforced, 60s	5.7			kVrms
Cio	Barrier capacitance for gate driver				20	pF
Ta	Operating Ambient Temperature for gate driver		-40	25	125	°C

3.3 PCB Pinout

Table 3-2. PCB Pinout

Pinout	Location (top/bottom)	Function
J1	Top	16-pin connector, connection shown  below
J2	Top	LS DESAT drain connection
J3	Bottom	LS gate/source connection
J4	Top	Temperature sense thermistor connection
J5	Top	HS DESAT drain connection
J6	Bottom	HS gate/source connection
J7, J8	Bottom	For temperature sense adaptor board only
TP2	Top, orange	HS RDY
TP3	Top, red	LS nFLT
TP4	Top, white	+12 V from power supply
TP5	Top, black	Ground from power supply with respect to +12 V
TP6	Top, red	HS nFLT
TP7	Top, orange	LS RDY
TP8	Top, blue	LS PWM input
TP9	Top, brown	LS APWM output
TP10	Top, green	HS PWM input
TP11, 12, 13	Top, gray	Primary side GND
TP15	Top, white	HS and LS combined nRST
GATE1	Top	MMCX connector, HS gate
GATE2	Top	MMCX connector, LS gate
GND1, 2, 3	Top	Primary side GND

3.4 Block Diagram

3.4.1 Primary-Side Power

The primary-side power supply block fulfills the following functions:

- Provides +12-V input to the board via the connector or the test point hooks.

- Converts the +12-V input voltage to +5-V VCC for the gate drivers. This functionality is realized by a TPS7A25 LDO.
- Uses an ACM4520 common-mode choke to filter out common-mode noise.

  The +12-V power supply and the PWM signals should be connected to the same board, either the differential board or the EVM. Failure to do so might result in EVM component damage.

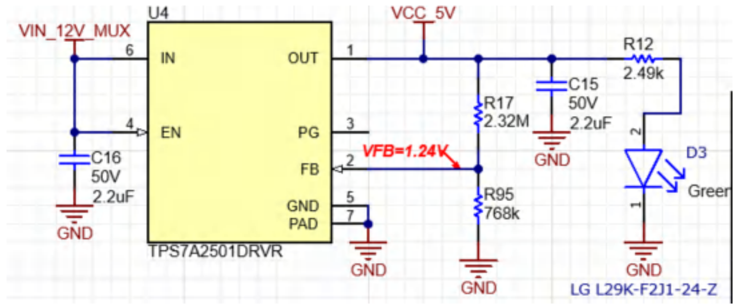


Figure 3-1. Primary-Side Power

3.4.2 Primary-Side I/O and Diagnostics

The primary-side I/O and diagnostic block fulfills the following functions:

- Provides signal input, including high-side and low-side PWM and RESET, as well as +12-V voltage input to the half-bridge board.
  - If the power and signal inputs are given via the differential board connector, the status output pin of a power MUX, TPS2121, is used to turn on the SN65C1167 dual differential driver and receiver. The dual differential driver and receiver then converts the differential gate driver inputs to single-ended gate driver inputs, and converts single-ended gate driver outputs to differential outputs that will be transmitted to the differential board.
  - If the power and signal inputs are given via the test point hooks on this EVM, the power MUX turns off the SN65C1167 dual differential driver and receiver. This protects the dual differential driver and receiver from damage.
- Filters out the high frequency noise in the high-side and low-side differential signals through RLC filters.
- Combines high-side and low-side RDY and nFLT signal into one FLT_OUT signal through an SN74LV21 AND gate.
- Combines the nRST signal coming from the differential board and the on-board reset button into one RESET signal through an SN74LV21 AND gate.

  The +12-V power supply and the PWM signals should be connected to the same board, either the differential board or the EVM. Failure to do so might result in EVM component damage.

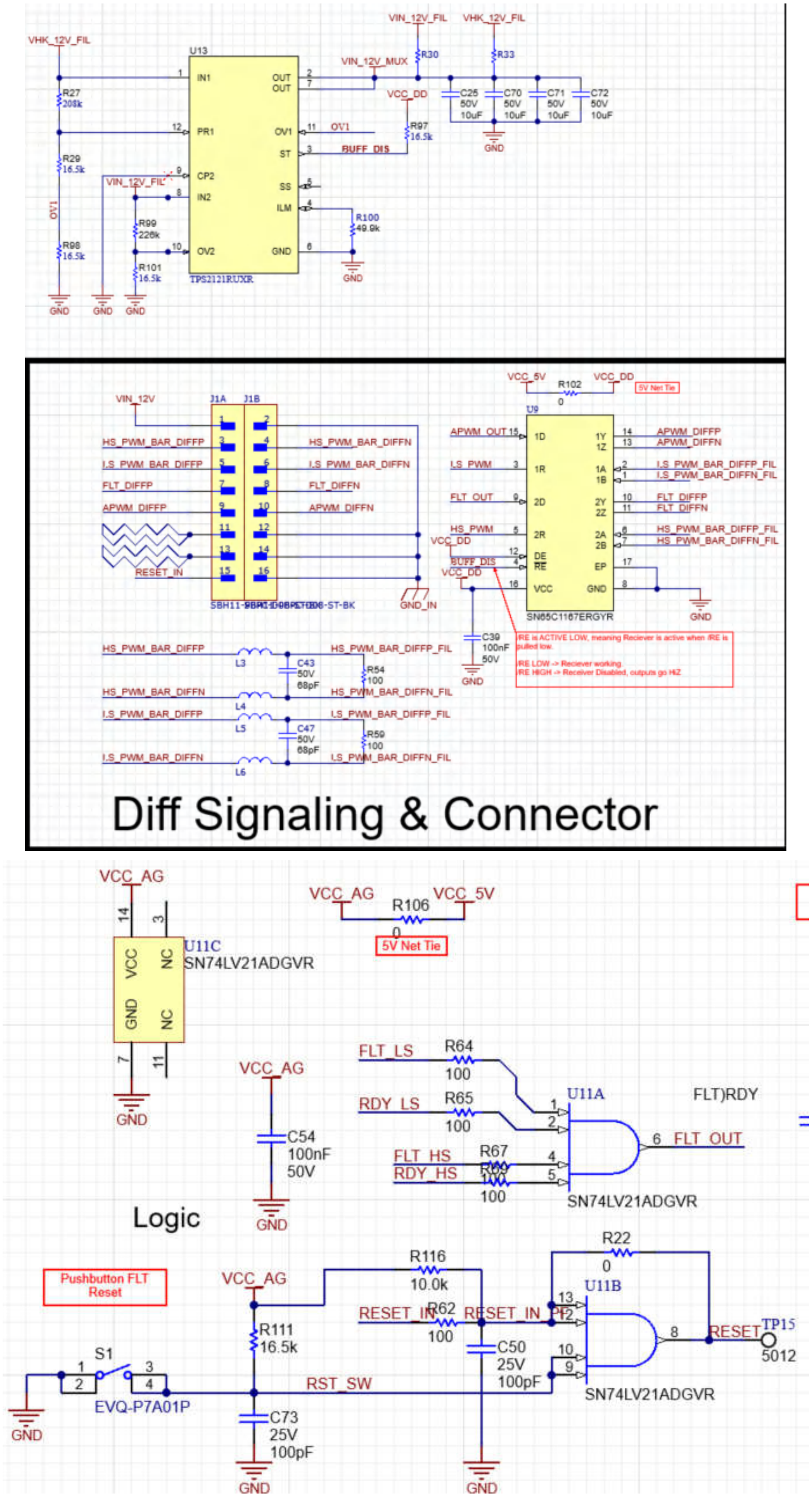


Figure 3-2. Primary-Side I/O

3.4.3 Secondary-Side Bias Supply

The secondary-side power supply block fulfills the following functions:

- Converts the +12-V input voltage to +15-V/-3-V bipolar bias voltage supply for the secondary side of the gate drivers. Each gate driver has its own bias supply. This is achieved by using one UCC25800 transformer driver, one Würth Elektronik 750319177 transformer, and one ATL431-Q1 programmable shunt regulator for each gate driver.
  - The bias supply voltage can be adjusted by following the instructions in Section 6.1.1 and Section 6.1.2.
- Reduces the noise of the positive secondary side supply voltage by using an TPS7B84-Q1 LDO.
  - This LDO can also be bypassed by following the instructions in Section 6.1.4.

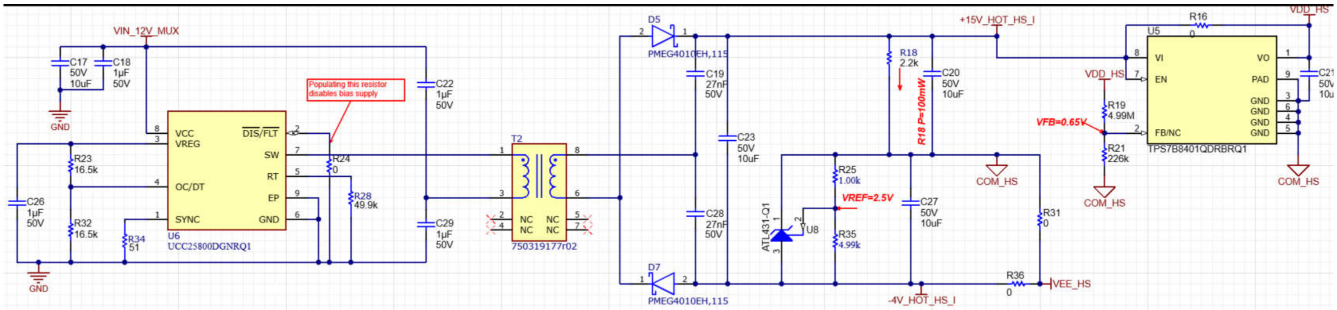


Figure 3-3. Secondary-Side Bias Supply

3.4.4 Output Stage Gate Loop

The gate driver output block consists of the turn-on gate resistor, the turn-off gate resistor, and the connectors to the SiC MOSFET/IGBT module. Test points are also placed near the output pins for easy measurement of the gate voltage.

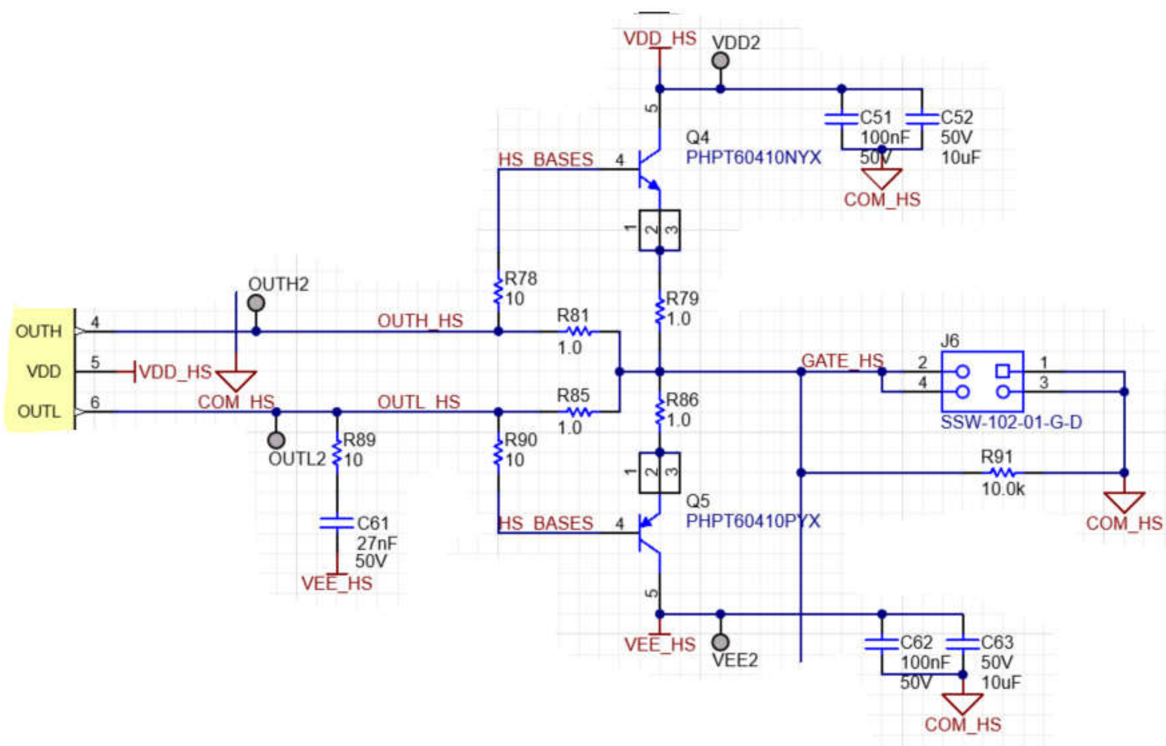


Figure 3-4. Output Stage Gate Loop

3.4.5 Current Booster

The current booster is optional and not populated by default, but can be populated as desired to increase the gate drive strength. To use the current booster, follow the instructions in Section 6.2.2. There is also an RC damper circuit connected to the bases of the current booster circuit. This RC damper circuit helps with the soft turn-off functionality to reduce Vds overshoot during a short-circuiting event.

3.4.6 Short-Circuit Detection System

The short-circuit detection system on the board provides protection in case of a short-circuit event. When a short circuit is detected, the gate driver pulls the OUTL low with a fixed current soft turn-off, and the FLT flag will be raised on the primary side. If the short-circuit detection system is not used or if an IGBT/MOSFET is not connected to the board, J2 and J5 should be shorted to COM to prevent false short-circuit triggering.

3.4.6.1 Short-Circuit Detection - DESAT

The Vds voltage detection threshold can be calculated with the equation below mentioned in this FAQ:

$$V_{DET} = V_{DESAT} - V_Z - n \times V_F - I_{chg} \times R_{lim} \tag{1}$$

With the 9V internal DESAT detection threshold, the two STTH122A diode with forward voltage of 0.6 V each, the 475-Ω limiting resistor, the Zener diode with 2.7-V Zener voltage, and the 500-μA internal charging current, the Vds DESAT detection threshold is calculated to be 4.86 V. If another Vds voltage detection threshold is desired, use the "DESAT calculator" tab in this UCC217xx calculator to calculate how different parameters can result in a different voltage detection threshold.

In this EVM, method mentioned in this FAQ is implemented to increase the DESAT charging current in case of a short-circuiting event. Increasing the DESAT charging current can decrease the blanking time of the capacitor and provide better protection for SiC MOSFETs. The blanking time for this circuit can be calculated by the equation mentioned in the same FAQ, which is calculated to be 125 ns. This blanking time calculation is valid for VDD = 15 V; if another VDD value is used, the blanking time will vary. Note that the tBLK calculation in the UCC217xx calculator mentioned above is not accurate since it does not take into consideration of the additional charging current.

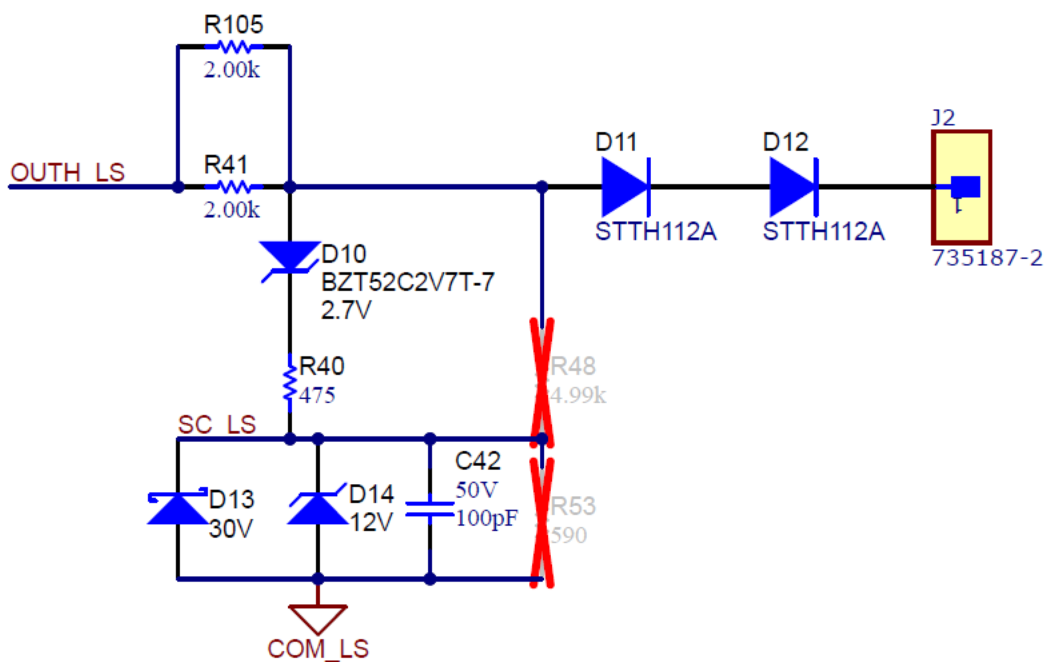


Figure 3-5. DESAT Circuit

3.4.6.2 Short-Circuit Detection - OC

This EVM implemented the configuration mentioned in page 41 of the UCC21710 data sheet. The Vds voltage detection threshold can be calculated with the equation below mentioned on the same page of the data sheet:

$$V_{DET} = V_{OCTH} \times \frac{R_2 + R_3}{R_3} - V_Z - n \times V_F \quad (2)$$

With the 0.7-V internal OC detection threshold, the two STTH122A diode with forward voltage of 0.6 V each, R2 = 4990 Ω, and R3 = 590 Ω, the Vds DESAT detection threshold is calculated to be 5.42 V. This detection threshold is valid for VDD = 15 V. If another Vds voltage detection threshold is desired, use the "DESAT Using OC Calculator" tab in this UCC217xx calculator to calculate how different parameters can result in a different voltage detection threshold.

The blanking time can also be calculated by the equation on the same page of the UCC21710 data sheet. With a 220-pF blanking capacitor, the blanking time is calculated to be 156 ns. This blanking time is valid for VDD = 15 V. The UCC217xx calculator mentioned above can also be used to calculate the change in blanking time as the circuit parameter changes.

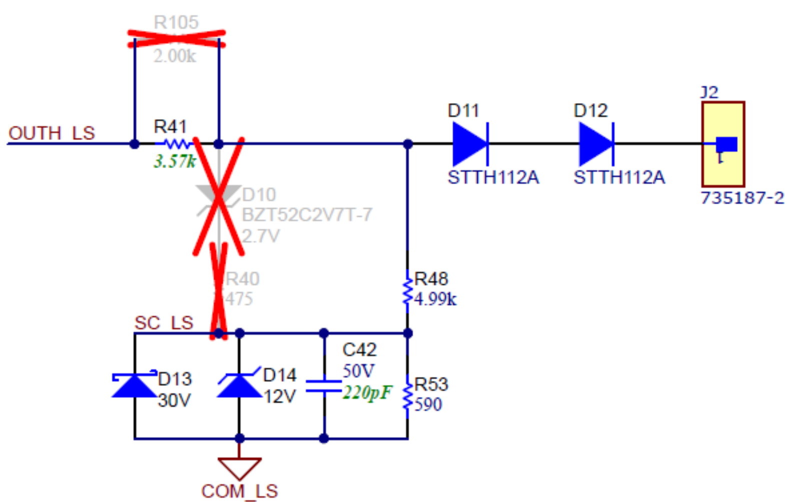


Figure 3-6. OC Circuit

3.4.7 Temperature-Sense System

The temperature-sensing system is available for certain UCC217xx variants with the AIN-APWM channel. The AIN pin has a 200-µA internal current source. Connect a thermistor or thermodiode to J4; as the temperature varies, the voltage monitored by the AIN pin will be different. The APWM will output a PWM wave with a duty cycle proportional to the voltage monitored by the AIN pin.

If the AIN-APWM channel is not used, J4 can be left open or populated by a jumper. The APWM pin should be floated.

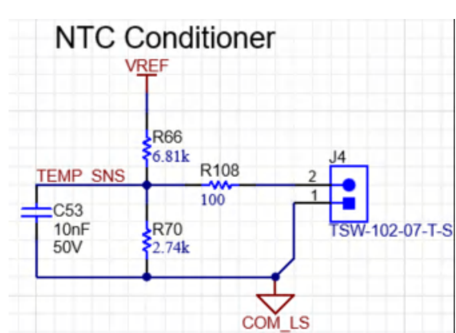


Figure 3-7. Temperature-Sense System

4 Using the EVM

4.1 Equipment List

- Power Supplies
  – Need to provide at least 12 V and 1 A to power up the EVM
- Function Generator and Accessories
  – One 2-channel function generator
  – Two standard 50-Ω BNC coaxial cables
- Oscilloscope and Accessories
  – Oscilloscope 500 MHz or higher with at least four channels
  – Four passive voltage probes with at least 500-MHz bandwidth
- Digital Multimeters
  – Two digital multimeters
- Other
  – Connection wires of various length

4.2 Test Setups and Procedures

4.2.1 Power-On and Bias Supply Check

Note

This is a low voltage only test; do not attempt to manually probe the test points when a high bus voltage is applied to this EVM.

1. Tie J2 and J5 to low-side and high-side COM respectively to prevent false triggering of DESAT.
2. Turn on the power supply and adjust the voltage output to 12 V. The power supply can be connected to either TP4/TP5 on the EVM or to the Wolfspeed differential board.
3. Probe the VCC-GND voltage between the VCC test via and TP11 with a multimeter. This value should be 5 V.
4. Probe the high side VDD-COM voltage by using the VDD2 test point and the COM4 or COM5 test point. Probe the low side VDD-COM voltage by using the VDD1 test point and the COM1 or COM2 test point. These values should be 15 V.
5. Probe the high side VEE-COM voltage by using the VEE2 test point and the COM4 or COM5 test point. Probe the low side VEE-COM voltage by using the VEE1 test point and the COM1 or COM2 test point. These values should be -3 V.
6. Make sure the 5-V green LED, the HS-BIAS blue LED, and the LS-BIAS blue LED are on. The two red RDY LEDs and the two red FLT LEDs should be off.

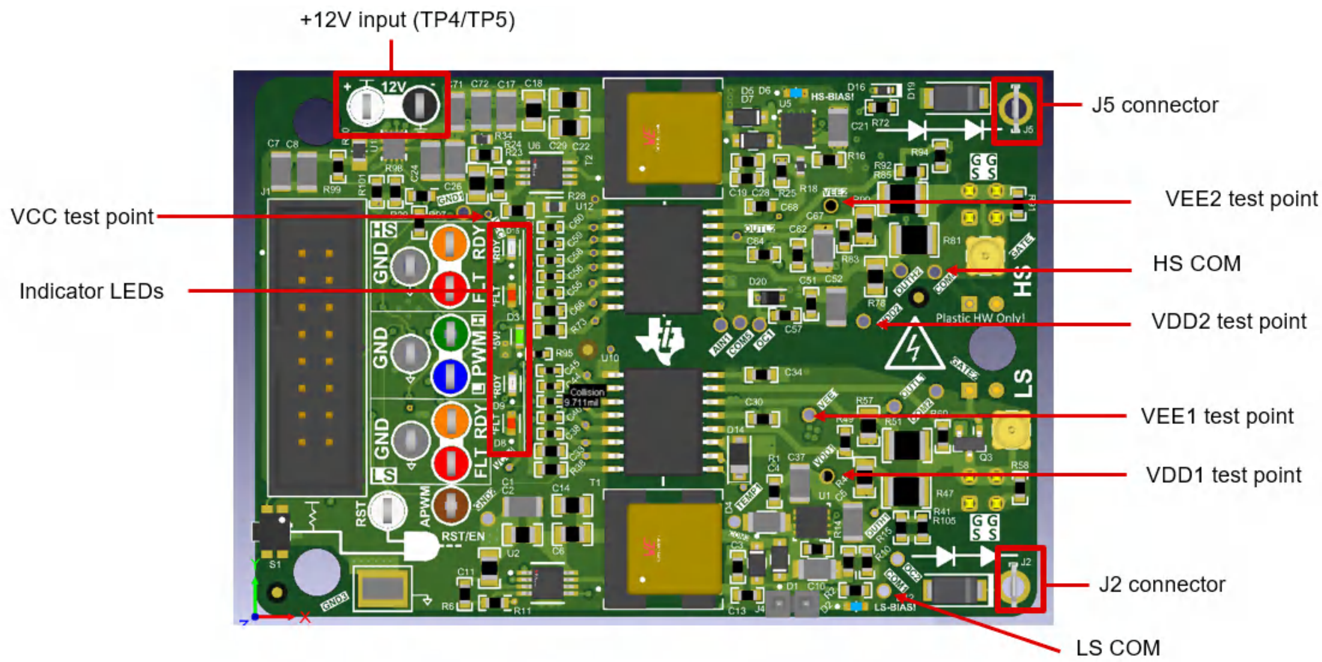


Figure 4-1. Test Point Locations for Power On Check

4.2.2 Output Switching

To perform this test, make sure tests in Section 4.2.1 has been performed and the gate drivers are powered up properly.

1. Generate two 10-kHz, 0 V to 5 V complementary PWM waves on two function generator channels. Deadtime can be added between the two PWM waves. These are the high-side and low-side PWM signals.
2. Connect these channel probes to the Wolfspeed differential board or to the test points on the EVM. The +12V power supply and the PWM signals should be connected to the same board, either the differential board or the EVM. If directly connecting the probes to the EVM, connect the high-side PWM channel probe to TP10 and the low-side PWM channel probe to TP8.
3. Measure the high-side gate voltage with the MMCX connector GATE1, and measure the low-side gate voltage with the MMCX connector GATE2.

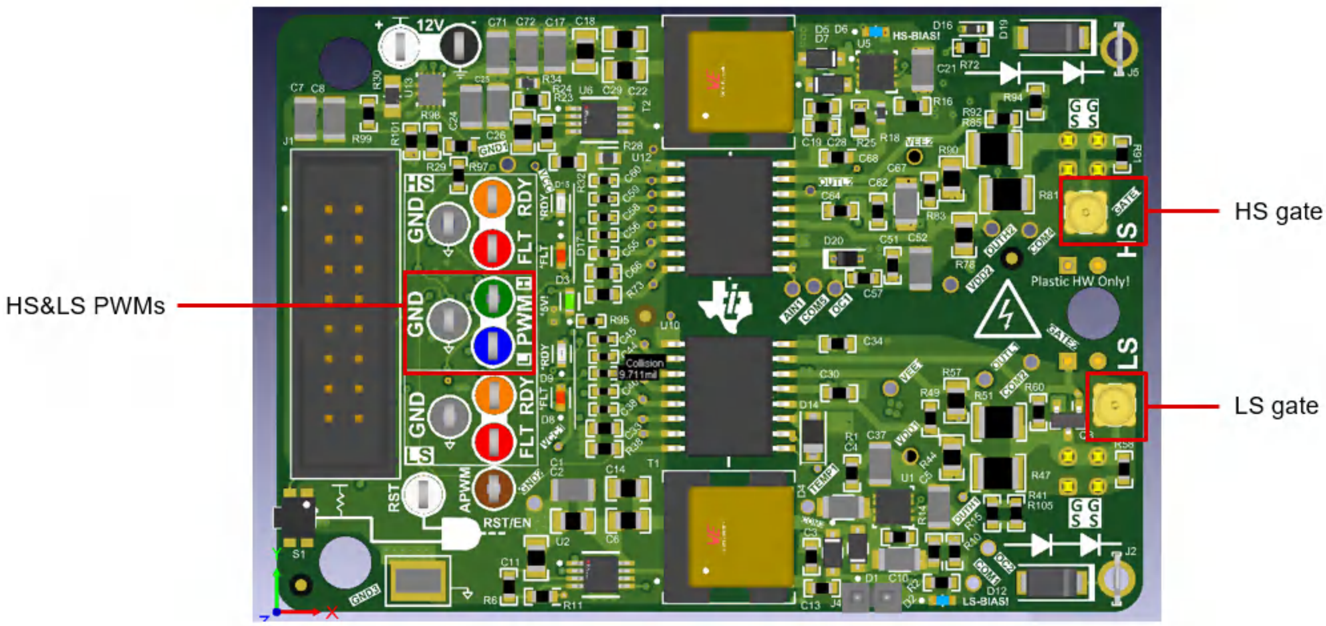


Figure 4-2. Test Point Locations for Output Switching Check

4.2.3 AIN-APWM Test

To perform this test, make sure tests in Section 4.2.1 have been performed and the gate drivers are powered up properly. This test is only valid for devices with the AIN-APWM channel, such as UCC21750.

1. Disconnect any jumper or thermistor from J4.
2. Measure the AIN voltage at the TEMP1 via close to pin 1 of the low-side gate driver. This voltage should be around 3.92 V if VDD = 15 V.
3. Measure the APWM duty cycle. According to AIN = 3.92 V and

$$D_{APWM} = -20 \times V_{AIN} + 100 \quad (3)$$

the duty cycle should be 21.6% with ±3% accuracy.

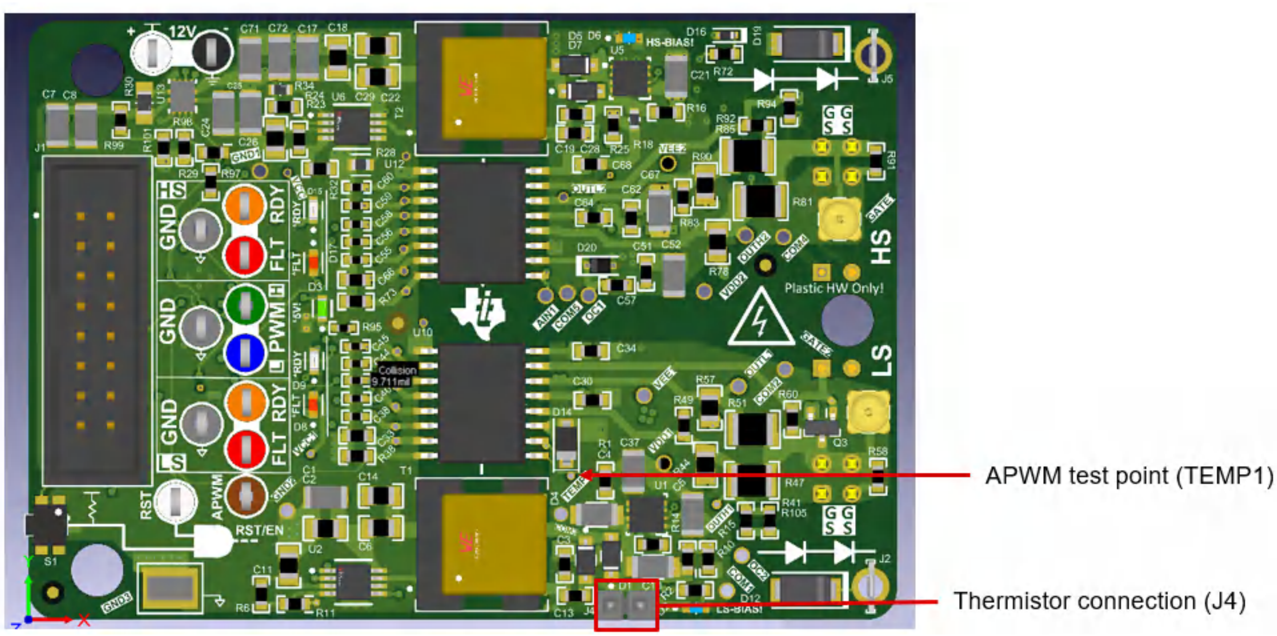


Figure 4-3. Test Point Locations for AIN-APWM Check

5 EVM Example Measurements

5.1 Short-Circuit Testing

5.1.1 OC Variant: Normal Switching vs Short Circuit Soft Turn-Off

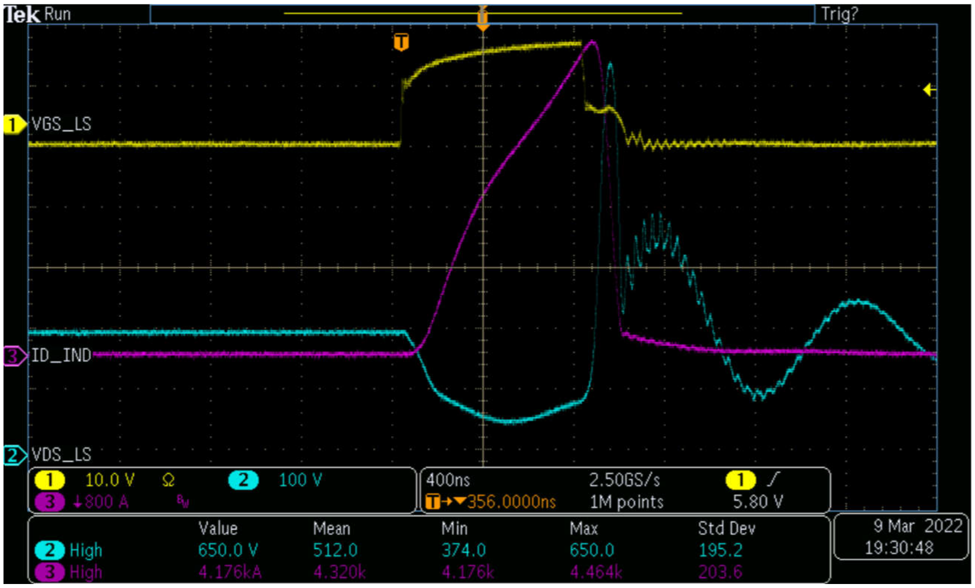


Figure 5-1. OC Variant Normal Turn-Off

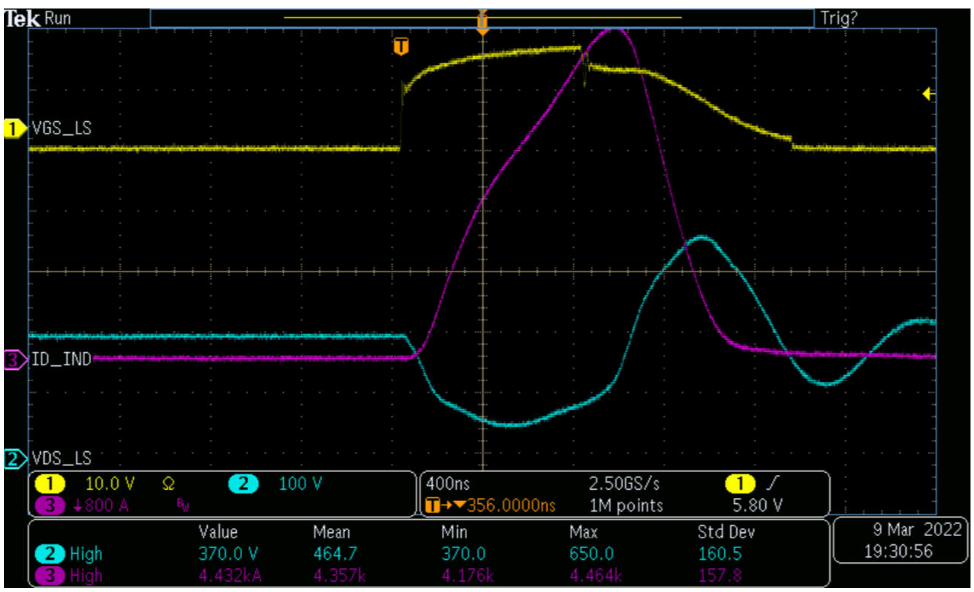


Figure 5-2. OC Variant Soft Turn-Off

These two tests were carried out under 200-V bus voltage for an OC variant, UCC21737. An Wolfspeed SiC WAB400M12BM3 module together with the Wolfspeed KIT-CRD-CIL12N-BM evaluation module were used for these tests.

Figure 5-1 contains the waveforms of a short-circuit test with normal switching. As the figure shows, when the SiC MOSFET module is switched off, the Vds overshoot value is approximately 450 V. Figure 5-2 contains the waveforms of a short-circuit test with the soft turn-off feature activated. As the figure shows, when the SiC MOSFET undergoes soft turn-off, the Vds overshoot is greatly reduced to approximately 170 V.

5.1.2 DESAT Variant: Normal Switching vs Short Circuit Soft Turn-Off

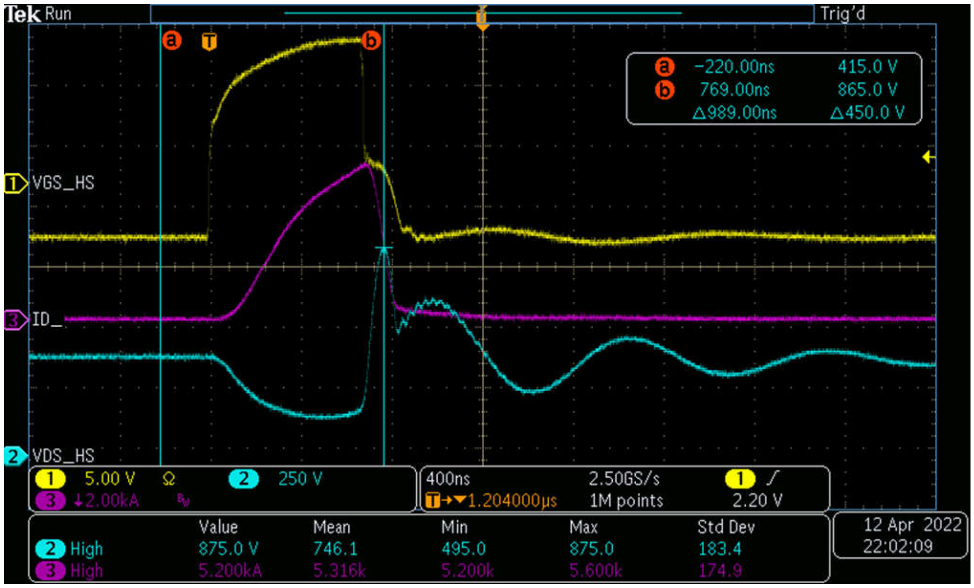


Figure 5-3. DESAT Variant Normal Turn-Off

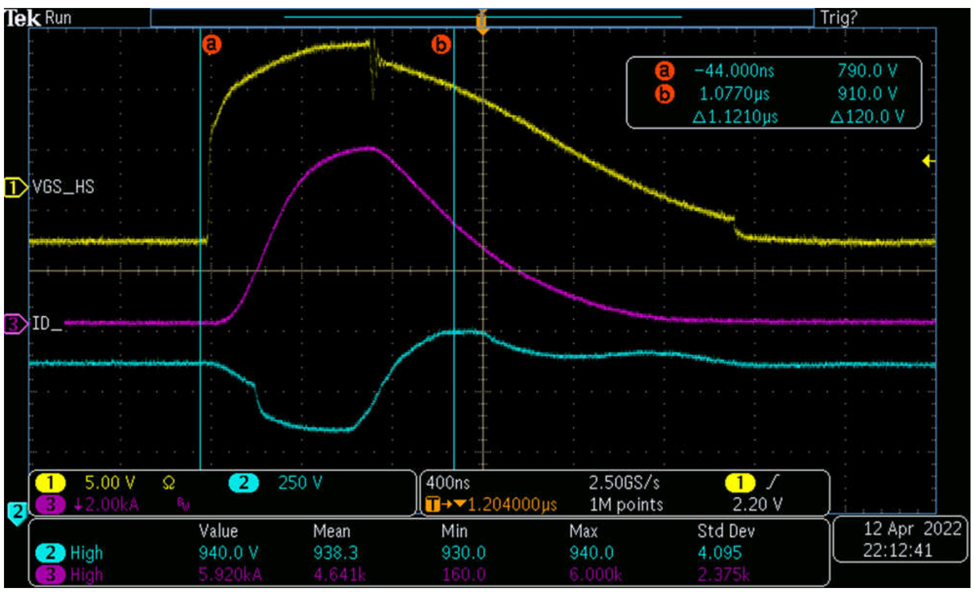


Figure 5-4. DESAT Variant Soft Turn-Off

These two tests were carried out under 400-V bus voltage for a DESAT variant, UCC21755. An Wolfspeed SiC WAB400M12BM3 module together with the Wolfspeed KIT-CRD-CIL12N-BM evaluation module were used for these tests.

Figure 5-3 contains the waveforms of a short-circuit test with normal switching. As the figure shows, when the SiC MOSFET module is switched off, the Vds overshoot value is approximately 450 V. Figure 5-4 contains the waveforms of a short-circuit test with the soft turn-off feature activated. As the figure shows, when the SiC MOSFET undergoes soft turn-off, the Vds overshoot is greatly reduced to approximately 120 V.

5.2 Analog Sensing

The table below shows a test carried out by connecting resistors of different values onto the J4 headers. The AIN voltage, APWM duty cycle, and duty cycle error are included in the table.

Table 5-1. Isolated Analog Sensing

AIN Voltage	Measured APWM Duty Cycle	Expected APWM Duty Cycle	APWM Duty Cycle Error
0.44V	91.24%	91.2%	+0.04%
0.54V	89.36%	89.2%	+0.16%
0.73V	8557%	85.4%	+0.17%
1.12V	77.62%	77.6%	+0.02%
1.72V	65.71%	65.6%	+0.11%
2.45V	50.90%	51.0%	-0.10%
3.43V	31.30%	31.4%	-0.10%
3.98V	20.57%	20.4%	+0.17%
4.20V	16.03%	16.0%	+0.03%
4.32V	13.58%	13.6%	-0.02%
4.45V	10.83%	11.0%	-0.17%
4.51V	9.59%	9.8%	-0.21%
4.73V	5.17%	5.4%	-0.23%

6 EVM Tuning

6.1 Adjust Power Supplies

6.1.1 Adjust VDD Bias Supply

To decrease the VDD bias supply voltage, change the resistor divider connected to the FB/NC pin of the TPS7B84-Q1 LDO. The resistors are R4/R5 for the high-side LDO, and R19/R21 for the low-side LDO. The equation below, mentioned in the TPS7B84-Q1 data sheet, can be used to select the resistors.

$$V_{DD} = V_{FB} \times \left(1 + \frac{R_4}{R_5}\right) = 0.65 \times \left(1 + \frac{R_4}{R_5}\right) \tag{4}$$

$$V_{DD} = V_{FB} \times \left(1 + \frac{R_{19}}{R_{21}}\right) = 0.65 \times \left(1 + \frac{R_{19}}{R_{21}}\right) \tag{5}$$

Equation 4 and 5 are used for high-side and low-side VDD resistor selection, respectively.

To increase the VDD bias supply voltage, first increase the +12V input voltage, Vin. The maximum VDD voltage at a given Vin can be calculated by:

$$V_{DD,\,max} = V_{in} \times 1.67 - \left|V_{EE}\right| \tag{6}$$

since the on-board transformer has a turn ratio of 1:1.67. The default VEE value is -3 V. Then, change the resistor divider connected to the FB/NC pin of the TPS7B84-Q1 LDO. The resistors are R4/R5 for the high-side LDO, and R19/R21 for the low-side LDO. The resistor values can be selected based on equation 4 and equation 5 above, with any VDD<VDD,max.

Be aware that VDD-COM should be below 19 V when this board is used to drive Wolfspeed's SiC modules, as 19 V is the absolute max Vgs for the module.

6.1.2 Adjust VEE Bias Supply

The VEE bias supply can be adjusted by adjusting the resistors connecting to the shunt regulator. VEE for the high-side gate driver and low-side driver can be adjusted separately. If VEE for the high side gate driver needs to be adjusted, R8/R14 values should be changed; if VEE for the low side gate driver needs to be adjusted, R25/R35 values should be changed. The table below outlines the VEE bias supply voltage with corresponding recommended resistor values.

Table 6-1. VEE Bias Supply Voltage and Recommended Resistor Values

VEE Voltage (V)	R8/R25 Value (Ω)	R14/R35 Value (Ω)
-3	1.00k	4.99k
-3.2	1.40k	4.99k
-3.5	2.00k	4.99k
-3.75	2.49k	4.99k
-4	2.00k	3.32k

If another VEE voltage is desired, equations from the ATL431-Q1 data sheet can be used. Equations 7 and 8 below can be used to select resistor values for high-side VEE and low-side VEE respectively.

$$V_{EE} = -\left(1 + \frac{R_8}{R_{14}}\right) \times V_{ref} + I_{ref} \times R_8 = -\left(1 + \frac{R_8}{R_{14}}\right) \times 2.5V + 30nA \times R_8 \tag{7}$$

$$V_{EE} = -\left(1 + \frac{R_{25}}{R_{35}}\right) \times V_{ref} + I_{ref} \times R_{25} = -\left(1 + \frac{R_{25}}{R_{35}}\right) \times 2.5V + 30nA \times R_{25} \tag{8}$$

6.1.3 Switch to Unipolar Bias Supply

The secondary side bipolar power supply can be switched to a unipolar power supply. The high side and low side can be adjusted separately. To change the high-side gate driver to a unipolar power supply, short R10 and remove R15; to change the low-side gate driver to a unipolar power supply, short R31 and remove R36.

Be aware that VDD-COM should be below 19 V when this board is used to drive Wolfspeed's SiC modules, as 19 V is the absolute max Vgs for the module. If this method is used to change the bipolar supply to a unipolar supply, either reduce the VIN to below 11.3 V or regulate the voltage by using the U4 and U5 LDO. Otherwise, the gate-source voltage is likely to exceed the maximum operating value of the Wolfspeed SiC MOSFET module.

6.1.4 Bypass VDD LDO

The VDD LDO can be bypassed on either the high side gate driver or the low side. To bypass the VDD LDO on the high side gate driver, populate R1. To bypass the VDD LDO on the low side gate driver, populate R16.

6.2 Adjust Drive Strength

6.2.1 Without Booster

To adjust the drive strength, change the gate resistors, R47 and R51. The maximum drive strength for the UCC217xx family can be calculated by the equation below:

$$I_{source\_peak} = \min\left(10A, \frac{V_{DD} - V_{EE}}{R_{OH\_EFF} + R_{ON} + R_{G\_Int}}\right) \quad (9)$$

$$I_{sink\_peak} = \min\left(10A, \frac{V_{DD} - V_{EE}}{R_{OL} + R_{OFF} + R_{G\_Int}}\right) \quad (10)$$

R_{ON} and R_{OFF} stand for the external gate resistors. R_{G_Int} stands for the internal gate resistor of the IGBT/SiC MOSFET. R_{OH_EFF} and R_{OL} values can be obtained from the electrical characteristic section of the UCC217xx data sheet.

6.2.2 Enabling/Disabling Booster Stage

If a higher drive strength is required, an on-board booster stage can be populated. To populate the booster stage, remove R47 and R51, populate Q1 with PHPT60410NYX, and populate Q2 with PHPT60410PYX for the low-side gate driver. Remove R81 and R85, populate Q4 with PHPT60410NYX, and populate Q5 with PHPT60410PYX for the high-side driver. Other BJTs with the same package can also be used.

The booster stage might impede the soft turn-off feature. To realize soft turn-off after enabling the booster stage, a damper circuit, the R56/C46 combination for low-side driver and the R89/C61 combination for high-side driver, can be used. Without the damper circuit, the OUTL pin will try to sink the soft turn-off current from the base of the booster stage. The booster stage will amplify this current and result in a larger turn-off current for the IGBT/SiC MOSFET and a higher Vds overshoot. The capacitor in the damper circuit can help mediate this issue by supplying current to the OUTL pin during a soft turn-off event, thus resulting in lower current being pulled from the base of the booster stage and lower turn-off current for the SiC MOSFET/IGBT.

6.3 Adaptations for Other ISO5x5x / UCC217xx Variants

6.3.1 Adapting EVM for UCC21732/39

Main Difference	Pins/Parts Affected	Actions
UCC21732 and UCC21739 do not have internal Miller clamp; an external Miller clamp can be used.	• Pin 7: CLMPE • R60 and R92 • Q3 and Q6	• Desolder R60 and R92 • Populate Q3 and Q6 with Miller Clamp FETs

6.3.2 Adapting EVM for UCC21737

Main Difference	Pins/Parts Affected	Actions
UCC21737 does not have internal Miller clamp; an external Miller clamp can be used.	• Pin 7: CLMPE • R60 and R92 • Q3 and Q6	• Desolder R60 and R92 • Populate Q3 and Q6 with Miller Clamp FETs
UCC21737 has the ASC (active short circuit) pin instead of the AIN-APWM channel. ASC should be tied to COM if not using.	• Pin 1: ASC • R74 • J4	• Populate R74 • Populate J4 with a jumper
UCC21737 has -3V VEE UVLO functionality; make sure the VEE bias voltage is lower than -3V.	• Pin 8: VEE • U3 and U8	• Refer to Section 6.1.2 to change VEE if necessary.

6.3.3 Adapting EVM for ISO5451/ISO5851

Main Difference	Pins/Parts Affected	Actions
ISO5451 and ISO5851 have single outputs instead of split outputs.	• Pin 4: NC • R49 and R83 • R47 and R81	• Desolder R47 and R81 • Populate R49 and R83 with 0-Ω resistors or jumpers
ISO5451's and ISO5851's pin 1 should be connected to VEE.	• Pin 1: VEE • R37 and R71 • R39 and R74	• Desolder R39 and R74 • Populate R37 and R71 with 0-Ω resistors or jumpers
ISO5451's and ISO5851's pin 16 should be connected to GND.	• Pin 16: GND • R38 and R73	• Populate R38 and R73 with 0-Ω resistors or jumpers

7 Hardware Design Files

7.1 Schematics

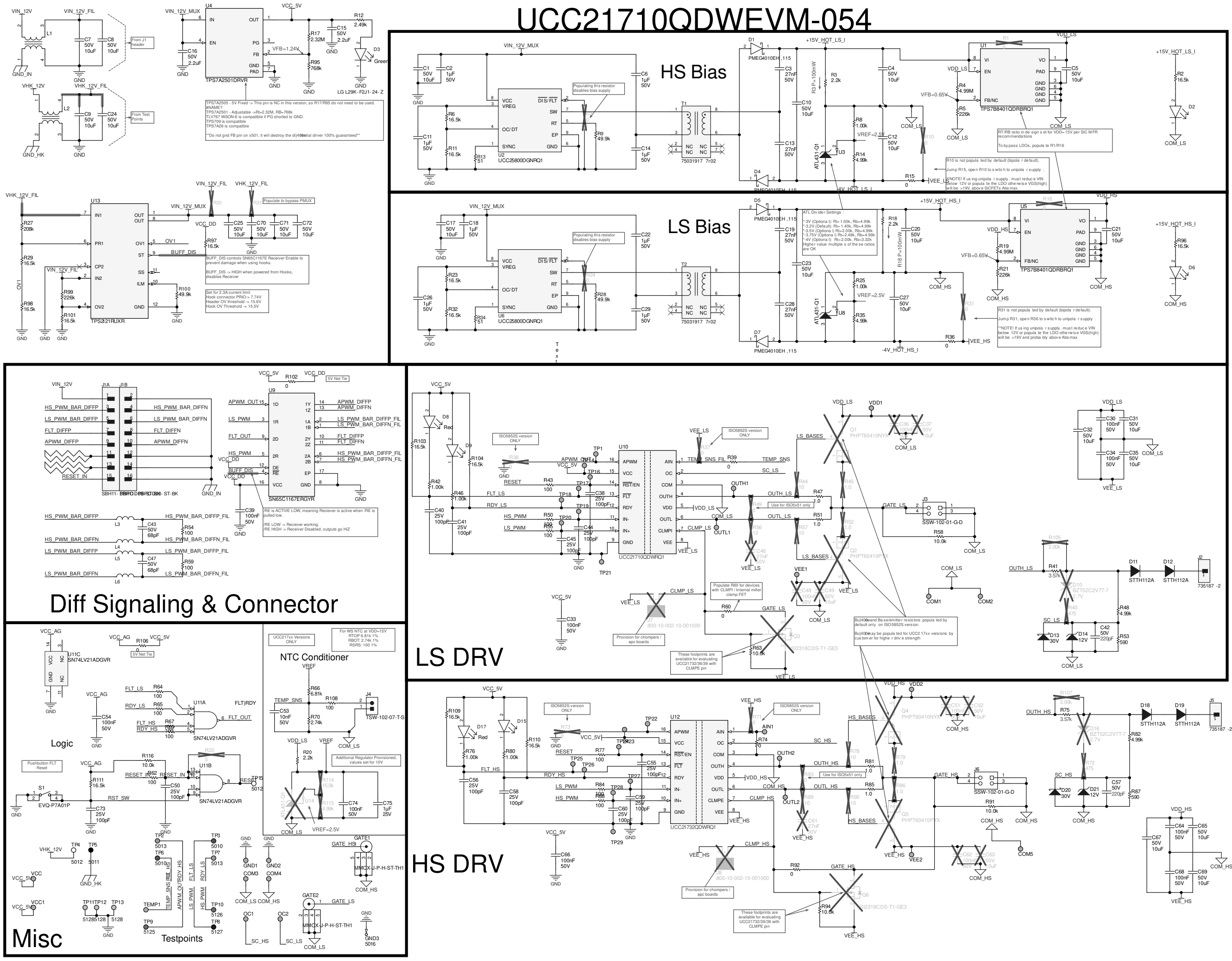


Figure 7-1. UCC21710 EVM Schematic

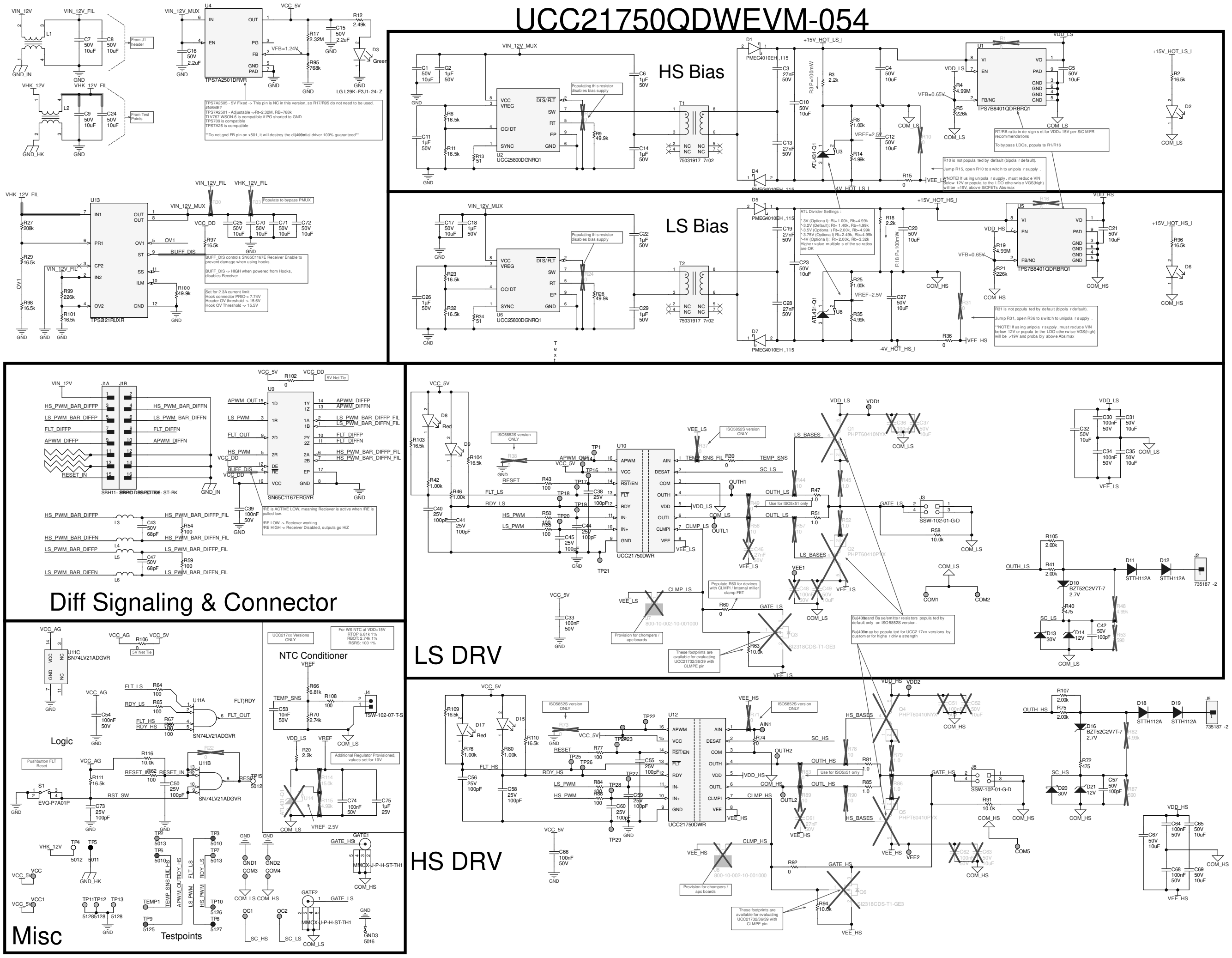


Figure 7-2. UCC21750 EVM Schematic

7.2 PCB Layouts

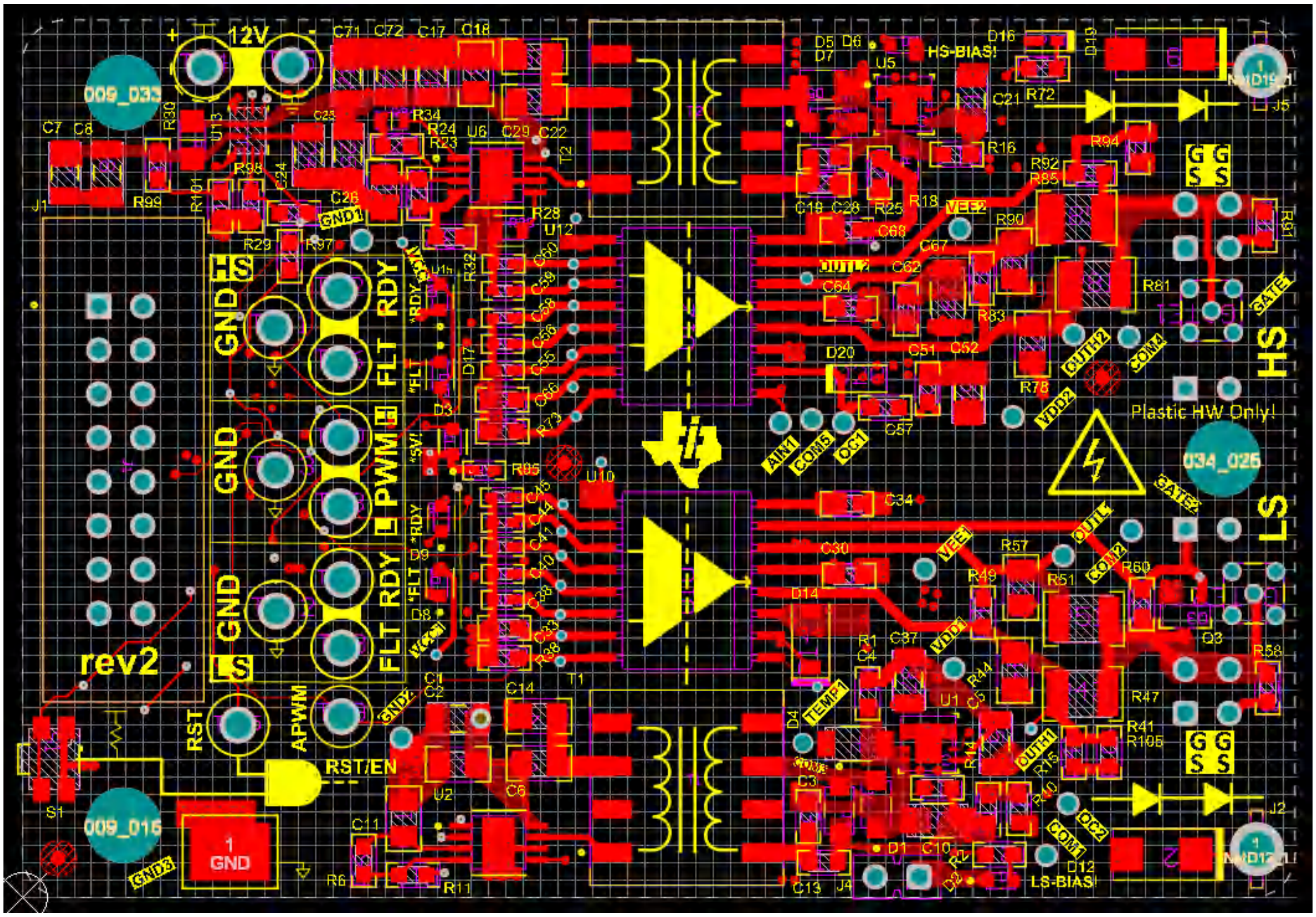


Figure 7-3. Top Layer

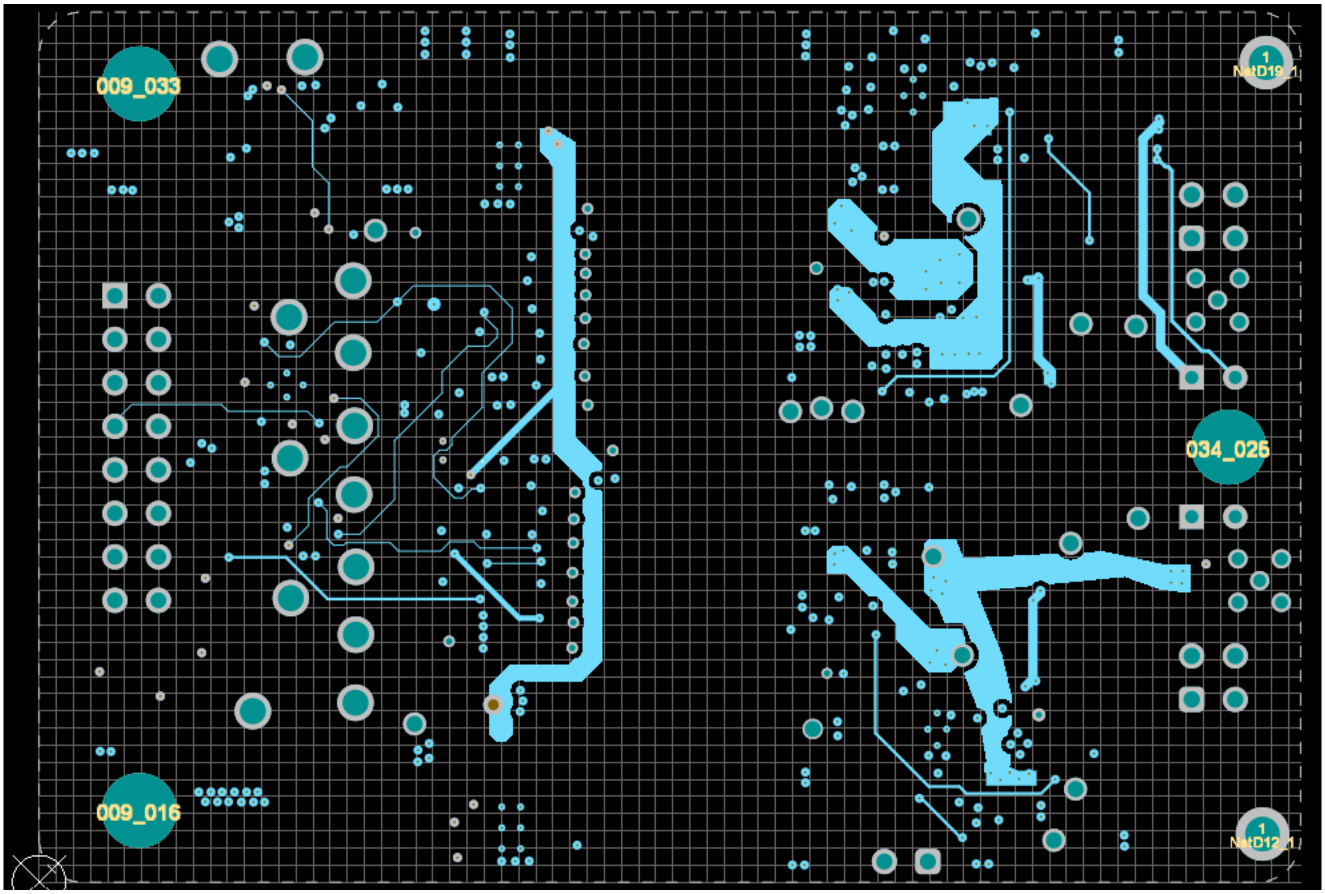


Figure 7-4. Signal Layer 1

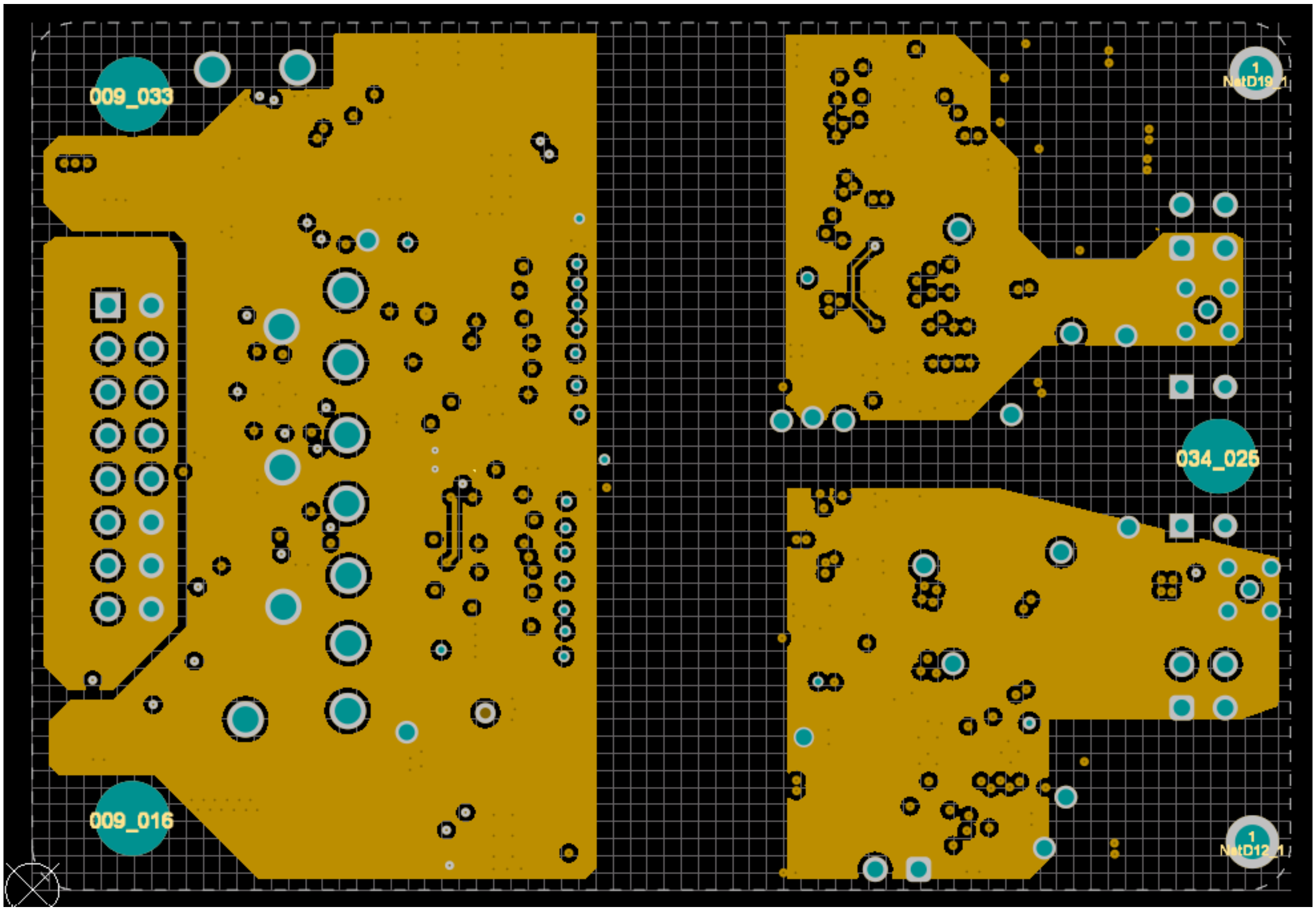


Figure 7-5. Signal Layer 2

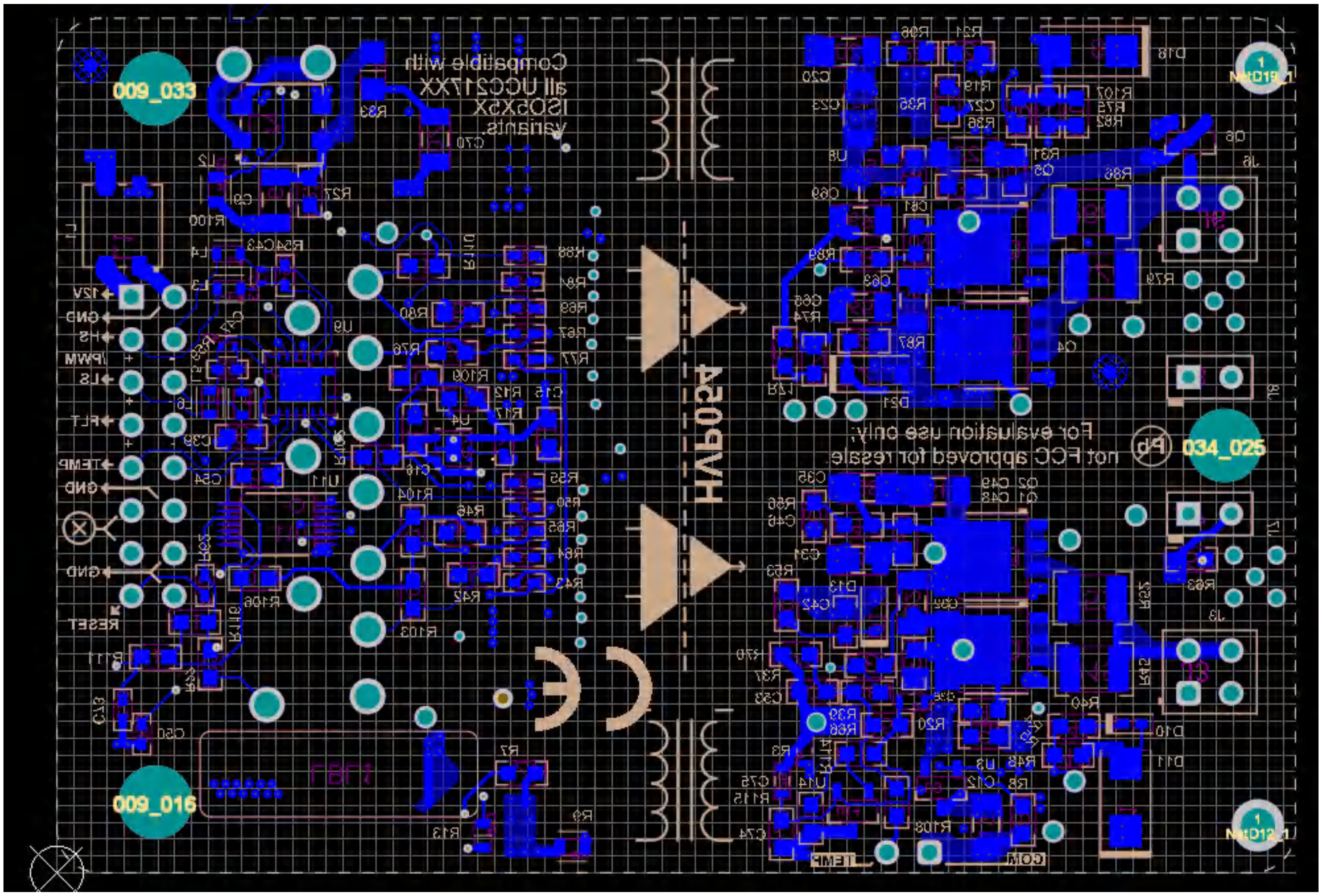


Figure 7-6. Bottom Layer

7.3 Bill of Materials (BOM)

Table 7-1. UCC21710 EVM BOM

Designator	Quantity	Value	Description	Part Number
!PCB1	1		Printed Circuit Board	HVP054
C1, C4, C5, C7, C8, C9, C10, C12, C17, C20, C21, C23, C24, C25, C27, C31, C32, C35, C65, C67, C69, C70, C71, C72	24	10uF	CAP, CERM, 10 uF, 50 V, +/- 10%, X5R, 1206	GRM31CR61H106KA12L
C2, C6, C11, C14, C18, C22, C26, C29	8	1uF	CAP, CERM, 1 µF, 50 V,+/- 20%, X7R, AEC-Q200 Grade 1, 0805	GCJ21BR71H105MA01L
C3, C13, C19, C28	4	0.027uF	CAP, CERM, 0.027 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	06035C273K4T2A
C15, C16	2	2.2uF	CAP, CERM, 2.2 uF, 50 V, +/- 10%, X5R, 0603	GRM188R61H225KE11D
C30, C33, C34, C39, C54, C64, C66, C68, C74	9	0.1uF	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X7R, 0603	C0603C104K5RACTU
C38, C40, C41, C44, C45, C50, C55, C56, C58, C59, C60, C73	12	100pF	CAP, CERM, 100 pF, 25 V, +/- 5%, C0G/NP0, 0402	C0402C101J3GACTU
C42, C57	2	220pF	CAP, CERM, 220 pF, 50 V, +/- 5%, C0G/NP0, 0603	C0603C221J5GACTU
C43, C47	2	68pF	68pF ±5% 50V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	GCM1555C1H680JA16D
C53	1	0.01uF	CAP, CERM, 0.01 uF, 50 V, +/- 10%, X7R, 0603	C0603X103K5RACTU

Table 7-1. UCC21710 EVM BOM (continued)

Designator	Quantity	Value	Description	Part Number
C75	1	1uF	CAP, CERM, 1 µF, 25 V,+/- 10%, X7R, AEC-Q200 Grade 1, 0603	CGA3E1X7R1E105K080AC
COM3, COM4, GND1, GND2	4		Testpoint	TP_H0.45P0.75
D1, D4, D5, D7	4		Diode Schottky 40V 1A (DC) Surface Mount SOD-123F	PMEG4010EH,115
D2, D6	2		LED Uni-Color Blue 0.07lm 465nm Chip LED 2-Pin 0603 T/R	LB Q39G-L2OO-35-1
D3	1		Green 570nm LED Indication - Discrete 1.7V 0603 (1608 Metric)	LG L29K-F2J1-24-Z
D8, D17	2		Red 630nm LED Indication - Discrete 1.5V 0603 (1608 Metric)	LS L29K-G1J2-1-Z
D9, D15	2		LED Uni-Color Amber 622nm 2-Pin SMD T/R	LA L296-Q2R2-1-0-20-R18-Z
D11, D12, D18, D19	4	1200V	Diode, Ultrafast, 1200 V, 1 A, SMA	STTH112A
D13, D20	2	30V	Diode, Schottky, 30 V, 0.2 A, SOD-323	BAT54WS-7-F
D14, D21	2	12V	Diode, Zener, 12 V, 500 mW, SOD-123	MMSZ5242B-7-F
FID1, FID2, FID3, FID4, FID5, FID6	6		Fiducial mark. There is nothing to buy or mount.	N/A
GATE1, GATE2	2		Connector, MMCX 50 ohm, TH	MMCX-J-P-H-ST-TH1
GND3	1		Test Point, 1-Pin SMT, RoHS, Tape and Reel	
J1	1			SBH11-PBPC-D08-ST-BK
J2, J5	2		FASTON 110, PCB Terminals, Tab, Tab, PCB Terminal Mating Tab Width .11 in [2.8 mm], PCB Terminal Mating Tab Thickness .02 in [.51 mm]	735187-2
J3, J6	2		Receptacle, 2.54mm, 2x2, Gold, TH	SSW-102-01-G-D
J4	1		Header, 2.54 mm, 2x1, Tin, TH	TSW-102-07-T-S
L1, L2	2		Coupled inductor, 2.8 A, 0.055 ohm, SMD	ACM4520-421-2P-T000
L3, L4, L5, L6	4		1µH Shielded Multilayer Inductor 600mA 150mOhm 0603 (1608 Metric)	MLZ1608A1R0WT000
LBL1	1		Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	THT-14-423-10
R2, R6, R11, R23, R29, R32, R96, R97, R98, R101, R103, R104, R109, R110, R111	15	16.5k	RES, 16.5 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	ERJ-3EKF1652V
R3, R18, R20	3	2.2k	2.2kΩ ±5% 0.25W 0603 Anti-Surge Chip Resistor AEC-Q200	ESR03EZPJ222
R4, R19	2	4.99Meg	RES, 4.99 M, 1%, 0.1 W, 0603	CRCW06034M99FKEA
R5, R21, R99	3	226k	RES, 226 k, 1%, 0.1 W, 0603	CRCW0603226KFKEA
R8, R25, R42, R46, R76, R80	6	1.00k	RES, 1.00 k, 1%, 0.1 W, 0603	ERJ-3EKF1001V
R9, R28, R100	3		49.9 kOhms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	CRCW060349K9FKEA
R12	1	2.49k	RES, 2.49 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06032K49FKEA
R13, R34	2	51	Res Thin Film 0603 51 Ohm 0.1% 1/10W 25ppm/C Molded SMD SMD Punched Carrier T/R	ERA-3AEB510V
R14, R35, R48, R82	4	4.99k	RES, 4.99 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06034K99FKEA
R15, R36, R39, R60, R74, R92, R102, R106	8	0	RES, 0, 5%, 0.125 W, 0603	MCT06030Z0000ZP500

Table 7-1. UCC21710 EVM BOM (continued)

Designator	Quantity	Value	Description	Part Number
R17	1	2.32Meg	RES, 2.32 M, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04022M32FKED
R27	1	208k	RES, 208 k, 0.5%, 0.1 W, 0603	RT0603DRE07208KL
R41, R75	2	3.57k	RES, 3.57 k, 1%, 0.1 W, 0603	RC0603FR-073K57L
R43, R50, R54, R55, R59, R62, R64, R65, R67, R69, R77, R84, R88	13	100	RES, 100, 5%, 0.063 W, 0402	CRCW0402100RJNED
R47, R51, R81, R85	4	1	RES, 1.0, 5%, 0.5 W, 1210	RC1210JR-071RL
R53, R87	2	590	RES, 590, 1%, 0.1 W, 0603	RC0603FR-07590RL
R58, R63, R91, R94, R116	5	10.0k	RES, 10.0 k, 1%, 0.1 W, 0603	RC0603FR-0710KL
R66	1	6.81k	RES, 6.81 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06036K81FKEA
R70	1	2.74k	RES, 2.74 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06032K74FKEA
R95	1	768k	RES, 768 k, 1%, 0.063 W, 0402	CRCW0402768KFKED
R108	1	100	RES, 100, 1%, 0.1 W, 0603	RC0603FR-07100RL
S1	1		Switch, Tactile, SPST-NO, 0.05A, 12V , SMD	EVQ-P7A01P
T1, T2	2		Transformer, 1:1.67, 0.045Ohm Pri, 0.122Ohm Sec, 16.5uH	750319177r02
TP2, TP7	2		Test Point, Multipurpose, Orange, TH	5013
TP3, TP6	2		Test Point, Multipurpose, Red, TH	5010
TP4, TP15	2		Test Point, Multipurpose, White, TH	5012
TP5	1		Test Point, Multipurpose, Black, TH	5011
TP8	1		Test Point, Multipurpose, Blue, TH	5127
TP9	1		Test Point, Multipurpose, Brown, TH	5125
TP10	1		Test Point, Multipurpose, Green, TH	5126
TP11, TP12, TP13	3		Test Point, Multipurpose, Grey, TH	5128
U1, U5	2		150-mA, wide VIN, low IQ, low-dropout regulator, DRB0008F (VSON-8)	TPS7B8401QDRBRQ1
U2, U6	2		Open Loop LLC Transformer Driver for Isolated Bias Supplies	UCC25800DGNRQ1
U3, U8	2		Programmable Shunt Regulator with Optimized Reference Current, DBZ0003A (SOT-23-3)	ATL431LIBQDBZRQ1
U4	1		300-mA, 18-V, Low IQ, Low Dropout Voltage Regulator with Power Good, DRV0006A (WSON-6)	TPS7A2501DRVR
U9	1		Dual Differential Driver and Receiver with +/-15-kV IEC ESD Protection, 2 TX / 2 RX, 5V, -40 to 85 degC, 16-Pin VQFN(RGY), Green (RoHS & no Sb/Br)	SN65C1167ERGYR
U10, U12	2		Single Channel Isolated Gate Driver for SiC/ IGBT with Advanced Protection and High-CMTI, DW0016B (SOIC-16)	UCC21710QDWRQ1
U11	1		Dual 4-Input Positive-AND Gate, DGV0014A (TVSOP-14)	SN74LV21ADGVR
U13	1		2.7V-22V, 4A, 50mohm Priority Power MUX, RUX0012A (VQFN-HR-12)	TPS2121RUXR
C36, C48, C51, C62	0	0.1uF	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X7R, 0603	C0603C104K5RACTU
C37, C49, C52, C63	0	10uF	CAP, CERM, 10 uF, 50 V, +/- 10%, X5R, 1206	GRM31CR61H106KA12L
C46, C61	0	0.027uF	CAP, CERM, 0.027 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	06035C273K4T2A

Table 7-1. UCC21710 EVM BOM (continued)

Designator	Quantity	Value	Description	Part Number
D10, D16	0	2.7V	Diode, Zener, 2.7 V, 300 mW, SOD-523	BZT52C2V7T-7
J7, J8	0		Header, 100mil, 2x1, TH	800-10-002-10-001000
Q1, Q4	0	40 V	Transistor, NPN, 40 V, 10 A, AEC-Q101, 4.9x3.95mm	PHPT60410NYX
Q2, Q5	0	40 V	Transistor, PNP, 40 V, 10 A, AEC-Q101, 4.9x3.95mm	PHPT60410PYX
Q3, Q6	0	40V	MOSFET, N-CH, 40 V, 5.6 A, SOT-23	SI2318CDS-T1-GE3
R1, R7, R10, R16, R22, R24, R31, R37, R38, R49, R71, R73, R83	0	0	RES, 0, 5%, 0.125 W, 0603	MCT06030Z0000ZP500
R30, R33	0	0	0 Ohms Jumper 0.5W, 1/2W Chip Resistor 0805 (2012 Metric) Automotive AEC-Q200 Metal Foil	HCJ0805ZT0R00
R40, R72	0	475	RES, 475, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW0603475RFKEA
R44, R57, R78, R90	0	10	RES, 10, 5%, 0.125 W, AEC-Q200 Grade 0, 0805	ERJ-6GEYJ100V
R45, R52, R79, R86	0	1	RES, 1.0, 5%, 0.5 W, 1210	RC1210JR-071RL
R56, R89	0	10	RES, 10, 5%, 0.25 W, 0603	CRCW060310R0JNEAHP
R105, R107	0	2.00k	RES, 2.00 k, 1%, 0.1 W, 0603	RC0603FR-072KL
R114	0	15.0k	RES, 15.0 k, 0.1%, 0.1 W, 0603	RG1608P-153-B-T5
R115	0	4.99k	RES, 4.99 k, 0.1%, 0.1 W, 0603	RT0603BRD074K99L
U14	0		Programmable Shunt Regulator with Optimized Reference Current, DBZ0003A (SOT-23-3)	ATL431LIBQDBZRQ1

Table 7-2. UCC21750 EVM BOM

Designator	Quantity	Value	Description	Part Number
!PCB1	1		Printed Circuit Board	HVP054
C1, C4, C5, C7, C8, C9, C10, C12, C17, C20, C21, C23, C24, C25, C27, C31, C32, C35, C65, C67, C69, C70, C71, C72	24	10uF	CAP, CERM, 10 uF, 50 V, +/- 10%, X5R, 1206	GRM31CR61H106KA12L
C2, C6, C11, C14, C18, C22, C26, C29	8	1uF	CAP, CERM, 1 µF, 50 V,+/- 20%, X7R, AEC-Q200 Grade 1, 0805	GCJ21BR71H105MA01L
C3, C13, C19, C28	4	0.027uF	CAP, CERM, 0.027 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	06035C273K4T2A
C15, C16	2	2.2uF	CAP, CERM, 2.2 uF, 50 V, +/- 10%, X5R, 0603	GRM188R61H225KE11D
C30, C33, C34, C39, C54, C64, C66, C68, C74	9	0.1uF	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X7R, 0603	C0603C104K5RACTU
C38, C40, C41, C44, C45, C50, C55, C56, C58, C59, C60, C73	12	100pF	CAP, CERM, 100 pF, 25 V, +/- 5%, C0G/NP0, 0402	C0402C101J3GACTU
C42, C57	2	100pF	CAP, CERM, 100 pF, 50 V, +/- 5%, C0G/NP0, AEC-Q200 Grade 0, 0603	CGA3E2NP01H101J080AA
C43, C47	2	68pF	68pF ±5% 50V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	GCM1555C1H680JA16D
C53	1	0.01uF	CAP, CERM, 0.01 uF, 50 V, +/- 10%, X7R, 0603	C0603X103K5RACTU
C75	1	1uF	CAP, CERM, 1 µF, 25 V,+/- 10%, X7R, AEC-Q200 Grade 1, 0603	CGA3E1X7R1E105K080AC
COM3, COM4, GND1, GND2	4		Testpoint	TP_H0.45P0.75

Table 7-2. UCC21750 EVM BOM (continued)

Designator	Quantity	Value	Description	Part Number
D1, D4, D5, D7	4		Diode Schottky 40V 1A (DC) Surface Mount SOD-123F	PMEG4010EH,115
D2, D6	2		LED Uni-Color Blue 0.07lm 465nm Chip LED 2-Pin 0603 T/R	LB Q39G-L2OO-35-1
D3	1		Green 570nm LED Indication - Discrete 1.7V 0603 (1608 Metric)	LG L29K-F2J1-24-Z
D8, D17	2		Red 630nm LED Indication - Discrete 1.5V 0603 (1608 Metric)	LS L29K-G1J2-1-Z
D9, D15	2		LED Uni-Color Amber 622nm 2-Pin SMD T/R	LA L296-Q2R2-1-0-20-R18-Z
D10, D16	2	2.7V	Diode, Zener, 2.7 V, 300 mW, SOD-523	BZT52C2V7T-7
D11, D12, D18, D19	4	1200V	Diode, Ultrafast, 1200 V, 1 A, SMA	STTH112A
D13, D20	2	30V	Diode, Schottky, 30 V, 0.2 A, SOD-323	BAT54WS-7-F
D14, D21	2	12V	Diode, Zener, 12 V, 500 mW, SOD-123	MMSZ5242B-7-F
FID1, FID2, FID3	3		Fiducial mark. There is nothing to buy or mount.	N/A
GATE1, GATE2	2		Connector, MMCX 50 ohm, TH	MMCX-J-P-H-ST-TH1
GND3	1		Test Point, 1-Pin SMT, RoHS, Tape and Reel	
J1	1			SBH11-PBPC-D08-ST-BK
J2, J5	2		FASTON 110, PCB Terminals, Tab, Tab, PCB Terminal Mating Tab Width .11 in [2.8 mm], PCB Terminal Mating Tab Thickness .02 in [.51 mm]	735187-2
J3, J6	2		Receptacle, 2.54mm, 2x2, Gold, TH	SSW-102-01-G-D
J4	1		Header, 2.54 mm, 2x1, Tin, TH	TSW-102-07-T-S
L1, L2	2		Coupled inductor, 2.8 A, 0.055 ohm, SMD	ACM4520-421-2P-T000
L3, L4, L5, L6	4		1µH Shielded Multilayer Inductor 600mA 150mOhm 0603 (1608 Metric)	MLZ1608A1R0WT000
LBL1	1		Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	THT-14-423-10
R2, R6, R11, R23, R29, R32, R96, R97, R98, R101, R103, R104, R109, R110, R111	15	16.5k	RES, 16.5 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	ERJ-3EKF1652V
R3, R18, R20	3	2.2k	2.2kΩ ±5% 0.25W 0603 Anti-Surge Chip Resistor AEC-Q200	ESR03EZPJ222
R4, R19	2	4.99Meg	RES, 4.99 M, 1%, 0.1 W, 0603	CRCW06034M99FKEA
R5, R21, R99	3	226k	RES, 226 k, 1%, 0.1 W, 0603	CRCW0603226KFKEA
R8, R25, R42, R46, R76, R80	6	1.00k	RES, 1.00 k, 1%, 0.1 W, 0603	ERJ-3EKF1001V
R9, R28, R100	3		49.9 kOhms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	CRCW060349K9FKEA
R12	1	2.49k	RES, 2.49 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06032K49FKEA
R13, R34	2	51	Res Thin Film 0603 51 Ohm 0.1% 1/10W 25ppm/C Molded SMD SMD Punched Carrier T/R	ERA-3AEB510V
R14, R35	2	4.99k	RES, 4.99 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06034K99FKEA
R15, R36, R39, R60, R74, R92, R102, R106	8	0	RES, 0, 5%, 0.125 W, 0603	MCT06030Z0000ZP500
R17	1	2.32Meg	RES, 2.32 M, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04022M32FKED
R27	1	208k	RES, 208 k, 0.5%, 0.1 W, 0603	RT0603DRE07208KL

Table 7-2. UCC21750 EVM BOM (continued)

Designator	Quantity	Value	Description	Part Number
R40, R72	2	475	RES, 475, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW0603475RFKEA
R41, R75, R105, R107	4	2.00k	RES, 2.00 k, 1%, 0.1 W, 0603	RC0603FR-072KL
R43, R50, R54, R55, R59, R62, R64, R65, R67, R69, R77, R84, R88	13	100	RES, 100, 5%, 0.063 W, 0402	CRCW0402100RJNED
R47, R51, R81, R85	4	1	RES, 1.0, 5%, 0.5 W, 1210	RC1210JR-071RL
R58, R63, R91, R94, R116	5	10.0k	RES, 10.0 k, 1%, 0.1 W, 0603	RC0603FR-0710KL
R66	1	6.81k	RES, 6.81 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06036K81FKEA
R70	1	2.74k	RES, 2.74 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06032K74FKEA
R95	1	768k	RES, 768 k, 1%, 0.063 W, 0402	CRCW0402768KFKED
R108	1	100	RES, 100, 1%, 0.1 W, 0603	RC0603FR-07100RL
S1	1		Switch, Tactile, SPST-NO, 0.05A, 12V , SMD	EVQ-P7A01P
T1, T2	2		Transformer, 1:1.67, 0.045Ohm Pri, 0.122Ohm Sec, 16.5uH	750319177r02
TP2, TP7	2		Test Point, Multipurpose, Orange, TH	5013
TP3, TP6	2		Test Point, Multipurpose, Red, TH	5010
TP4, TP15	2		Test Point, Multipurpose, White, TH	5012
TP5	1		Test Point, Multipurpose, Black, TH	5011
TP8	1		Test Point, Multipurpose, Blue, TH	5127
TP9	1		Test Point, Multipurpose, Brown, TH	5125
TP10	1		Test Point, Multipurpose, Green, TH	5126
TP11, TP12, TP13	3		Test Point, Multipurpose, Grey, TH	5128
U1, U5	2		150-mA, wide VIN, low IQ, low-dropout regulator, DRB0008F (VSON-8)	TPS7B8401QDRBRQ1
U2, U6	2		Open Loop LLC Transformer Driver for Isolated Bias Supplies	UCC25800DGNRQ1
U3, U8	2		Programmable Shunt Regulator with Optimized Reference Current, DBZ0003A (SOT-23-3)	ATL431LIBQDBZRQ1
U4	1		300-mA, 18-V, Low IQ, Low Dropout Voltage Regulator with Power Good, DRV0006A (WSON-6)	TPS7A2501DRVR
U9	1		Dual Differential Driver and Receiver with +/-15-kV IEC ESD Protection, 2 TX / 2 RX, 5V, -40 to 85 degC, 16-Pin VQFN(RGY), Green (RoHS & no Sb/Br)	SN65C1167ERGYR
U10, U12	2		Single Channel Isolated Gate Driver for SiC/IGBT with Advanced Protection and High-CMTI, DW0016B (SOIC-16)	UCC21750DWR
U11	1		Dual 4-Input Positive-AND Gate, DGV0014A (TVSOP-14)	SN74LV21ADGVR
U13	1		2.7V-22V, 4A, 50mohm Priority Power MUX, RUX0012A (VQFN-HR-12)	TPS2121RUXR
C36, C48, C51, C62	0	0.1uF	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X7R, 0603	C0603C104K5RACTU
C37, C49, C52, C63	0	10uF	CAP, CERM, 10 uF, 50 V, +/- 10%, X5R, 1206	GRM31CR61H106KA12L
C46, C61	0	0.027uF	CAP, CERM, 0.027 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	06035C273K4T2A
FID4, FID5, FID6	0		Fiducial mark. There is nothing to buy or mount.	N/A

Table 7-2. UCC21750 EVM BOM (continued)

Designator	Quantity	Value	Description	Part Number
J7, J8	0		Header, 100mil, 2x1, TH	800-10-002-10-001000
Q1, Q4	0	40 V	Transistor, NPN, 40 V, 10 A, AEC-Q101, 4.9x3.95mm	PHPT60410NYX
Q2, Q5	0	40 V	Transistor, PNP, 40 V, 10 A, AEC-Q101, 4.9x3.95mm	PHPT60410PYX
Q3, Q6	0	40V	MOSFET, N-CH, 40 V, 5.6 A, SOT-23	SI2318CDS-T1-GE3
R1, R7, R10, R16, R22, R24, R31, R37, R38, R49, R71, R73, R83	0	0	RES, 0, 5%, 0.125 W, 0603	MCT06030Z0000ZP500
R30, R33	0	0	0 Ohms Jumper 0.5W, 1/2W Chip Resistor 0805 (2012 Metric) Automotive AEC-Q200 Metal Foil	HCJ0805ZT0R00
R44, R57, R78, R90	0	10	RES, 10, 5%, 0.125 W, AEC-Q200 Grade 0, 0805	ERJ-6GEYJ100V
R45, R52, R79, R86	0	1	RES, 1.0, 5%, 0.5 W, 1210	RC1210JR-071RL
R48, R82	0	4.99k	RES, 4.99 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06034K99FKEA
R53, R87	0	590	RES, 590, 1%, 0.1 W, 0603	RC0603FR-07590RL
R56, R89	0	10	RES, 10, 5%, 0.25 W, 0603	CRCW060310R0JNEAHP
R114	0	15.0k	RES, 15.0 k, 0.1%, 0.1 W, 0603	RG1608P-153-B-T5
R115	0	4.99k	RES, 4.99 k, 0.1%, 0.1 W, 0603	RT0603BRD074K99L
U14	0		Programmable Shunt Regulator with Optimized Reference Current, DBZ0003A (SOT-23-3)	ATL431LIBQDBZRQ1

8 Additional Information

8.1 Trademarks

All trademarks are the property of their respective owners.

STANDARD TERMS FOR EVALUATION MODULES

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

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

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

2 *Limited Warranty and Related Remedies/Disclaimers*:

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

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

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

WARNING

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

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

NOTE:

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

3 *Regulatory Notices:*

3.1 *United States*

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

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

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

CAUTION

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

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

FCC Interference Statement for Class A EVM devices

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

FCC Interference Statement for Class B EVM devices

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

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

3.2 *Canada*

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

Concerning EVMs Including Radio Transmitters:

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

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

Concernant les EVMs avec appareils radio:

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

Concerning EVMs Including Detachable Antennas:

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

Concernant les EVMs avec antennes détachables

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

3.3 *Japan*

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

https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

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。

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3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html

3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY EPIDEMIC FAILURE WARRANTY OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT, REGARDLESS OF WHEN MADE, CONCEIVED OR ACQUIRED.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVMS , REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, , EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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