TI Designs

BidirectionDCDC converter

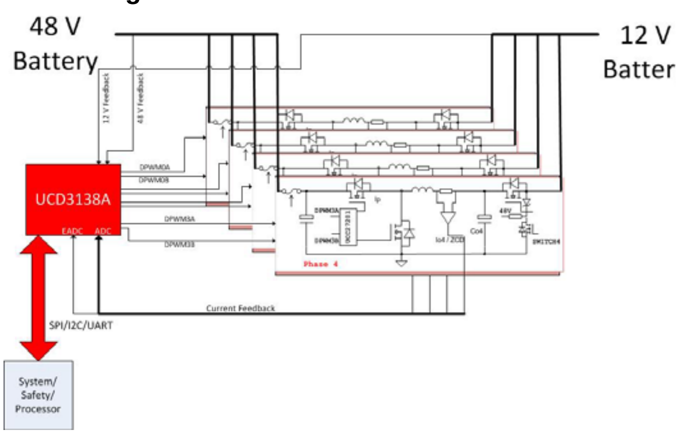
Design Overview

TIDA-00653 is a non-isolated 48 to 12-V bi-directional converter reference design for 48V battery applications enabled by the UCD3138 digital power controller. The design has the flexibility to work in either a ZVS transition-mode topology to optimize light-load efficiency, or a hard-switching topology for a simple system design. The bi-directional converter features auto-phase shedding, offset for light-load, and adaptive dead-time optimization for compounding efficiency gains greater than 96%. Due to the significant efficiency improvements, heat loss is reduced and no air or liquid cooling are needed automotive applications. Additionally, the use of the UCD3138 high-control frequency controller and hardware-based state machine enable a small form factor and frees the system CPU for other functions such as battery management.

Design Resources

TIDA-00653	Design Folder
UCD3138A	Product Folder
UCC27201A	Product Folder
TLV3202	Product Folder
CSD17570Q5B	Product Folder
REF1112	
OPA2211	
SN74AHC1G	

Block Diagram



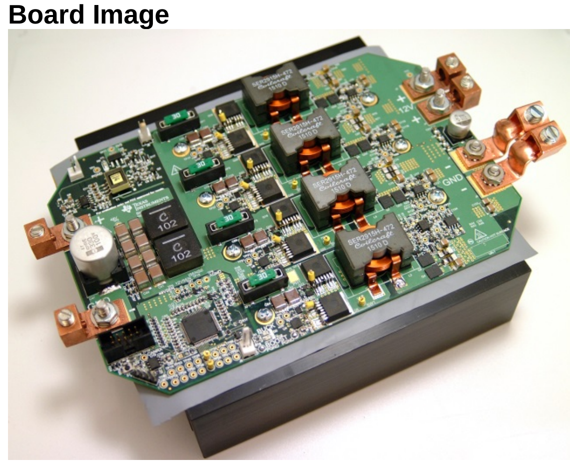
Design Features

- >96% efficiency
- No air or liquid cooling needed
- Multi phases interleaved
- 12V reverse connection prevention (20V maximum reversed voltage)
- Protection including OCP, OVP,OTP
- 100uA quiescent current when disabled (after 48V is disconnected)

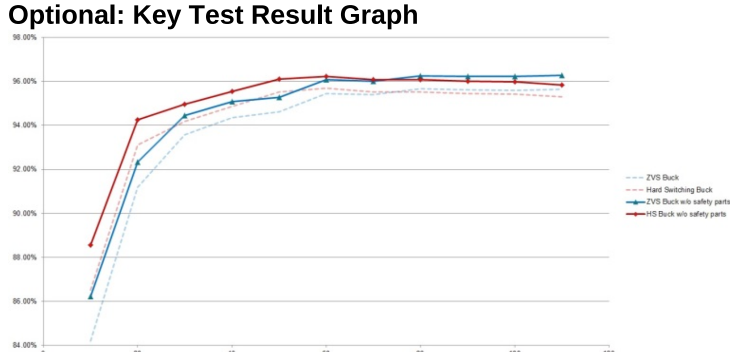
Featured Applications

- HEV's
- EV's
- Battery testing

Board Image



Optional: Key Test Result Graph



1 Key System Specifications

PARAMETER	2 TEST CONDITION	Min	Typ	Max	Units
48 V POWER NET					
48V Power Net voltage range		20	48	60	V
48V Power Net OV		56	57	58	V
48V Power Net Operating voltage without functional limitation		36		52	V
48V Power Net Operating voltage with functional limitation		24		54	V
Load dump transient	100mS			70	V
Max output power				1.6	KW
Max output current				42	A
12V POWER NET (LEAD ACID BATTERY)					
12V Power Net voltage range	(Minimum voltage occurs at cold cranking)	4.5	12		V
12V Power Net OV		13.00	13.5	14.00	V
12V Power Net Operating voltage without functional limitation		12.3		12.7	V
12V Power Net Operating voltage with functional limitation		11.75			V
Max output power				1.6	KW
Max intput current				133	A
Quiescent current				100	uA
Ambient temp				125	C
Current reporting accuracy @ 12V output Current reporting accuracy @ 48V output	 Calculated from 12V output current		1% 2%	2% 3%	
Current sharing tolerance				10%	
Current control accuracy				5%	
Efficiency in Buck mode In Boost mode	25% load and above			97% 94 %	

Figure 1: Key System specification

3 System Description

The BidirectionDCDC converter employs a digital controller that is optimized for power supply applications. This converter has four phases, each capable of performing either a Buck or a Boost operation. The power level for each phase is rated at 400 W. Once of the phase is a master phase that dictates the switching frequency.

3.1 UCD3138A

Control Architecture optimized for Power Supply Applications
Separation of High Speed Power Supply Control Loop from Housekeeping

- **Programmable hardware for High Speed Functions**
  - Advanced Power Peripherals operating autonomous from the processor, No need to rely on slower firmware decisions
  - Enhanced 2p / 2z Digital Compensator with Simplified PID Structure
  - Protection features, Mode Switching, Constant Current, Peak current mode, voltage feed forward
- **Ease of Firmware Development**
  - Dedicated resources for high speed functions hence No need for complex time-slicing of shared resources
- **Highest Levels of Integration**
  - **Enhanced EADC (DAC Accuracy) with Hardware Dithering** (3x 16 MHz, 1mV resolution offers best in class current sharing accuracy)
  - **ADC**
    - 12 bit SAR
    - Internal temp sensor
    - Dual sample and hold
    - Averaging
    - Digital comparators
    - PMBus addressing current sources
  - **Flexibility**
    - Digital Core enabling flexibility and manage housekeeping function.
    - Support on-the-Fly firmware update without power supply interruption
  - **DPWM**
    - Hardware mapped shut-down due to faults
    - Fixed or adaptive sample trigger positioning
    - Sync FET soft on/off and Ideal Diode Emulation
    - Mode switching and Light Load Burst mode
  - **Advanced Power Control**
    - Current Share
    - CPCC
    - Synchronization
    - Primary side Vtg sensing
    - Flex and Current Balancing
  - **Communications**
    - Several communication peripherals (e.g. PMBus, UART, SPI) providing flexibility for host communication.
- **Lower Power Consumption**
  - ~70mA-100mA during normal operation
  - Can shut down portions of chip for lower power ~25mA standby power capable

- **Cost and Package Size Optimized**
  - Capable of fitting in high density applications (i.e. 1/8th brick)

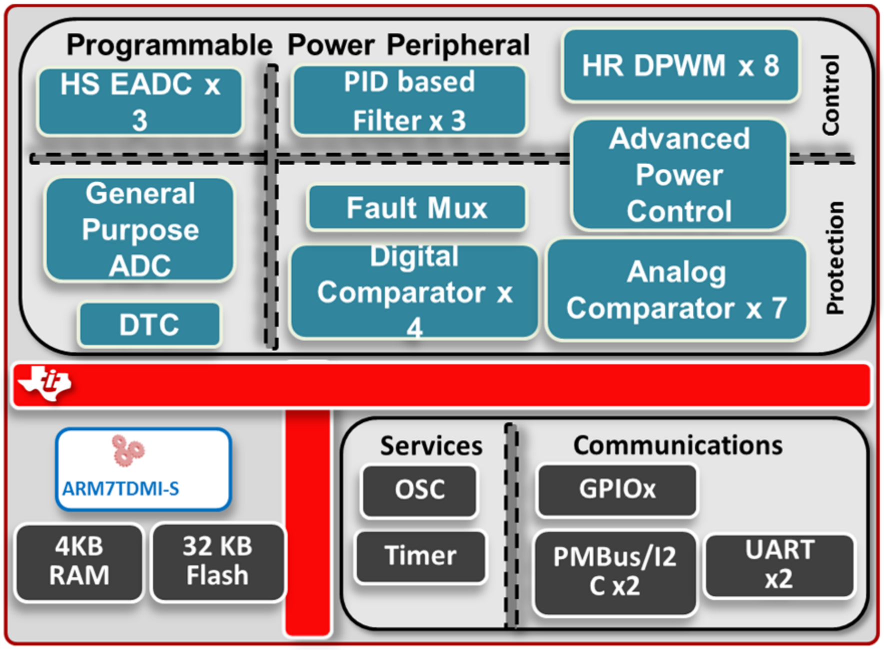


Figure 2: To insert a caption, right click picture > Insert Caption

4 Block Diagram

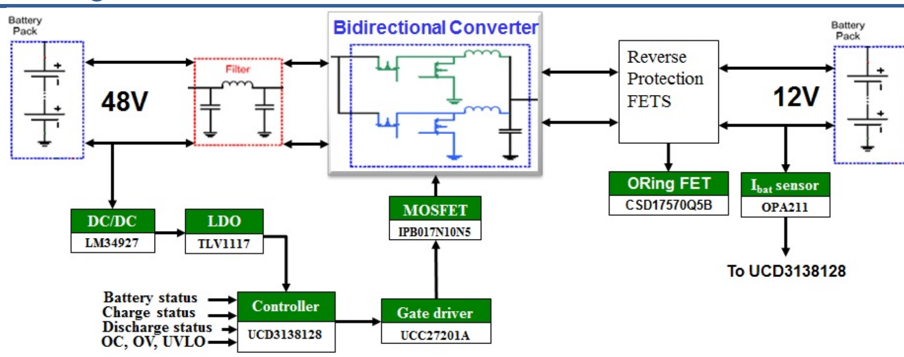


Figure 3: To insert a caption, right click picture > Insert Caption

4.1 Highlighted Products

4.1.1 UCD3138A

- 3 Independent Feedback Loops
- 16MHz Error Analog to Digital Converter (EADC)
- 14-bit (effective) DAC for Control Loop Reference
- *Synchronous Rectifier Dead Time Optimization Peripheral*
- Dedicated PID Hardware (2p/2z configurable)
- 8 High Resolution DPWM Outputs (250ps Pulse Width Resolution)
- 2MHz Max Switching Frequency
- 14 Channel, 12-bit, 265ksps General Purpose ADC
- 2 UARTs (HW Auto Baud)+ PMBus Interface
- 7 50ns Analog Comparators, Cycle-by-cycle I_{LIMIT}
- On-chip (BOD / POR), Single Supply Operation (3.3V)
- External Interrupt + Fault Input & Output
- Input Voltage Feed-forward

5 System Design Theory

The Bidirection DCDC converter can operate in synchronous buck and boost mode to transfer power in both the direction. This converter is designed to operate with a 48 V and a 12 V battery.

The Bidirection DCDC converter uses a UCD3138128 digtal power controller. It can control 4 phases using a single current loop. The current that is sensed is an average of all the 4 phases. The board allows current to be sensed from individual phases for current monitoring. It has a bias supply to power up the UCD device and otherIC's.

5.1 Device blocks used for control operation

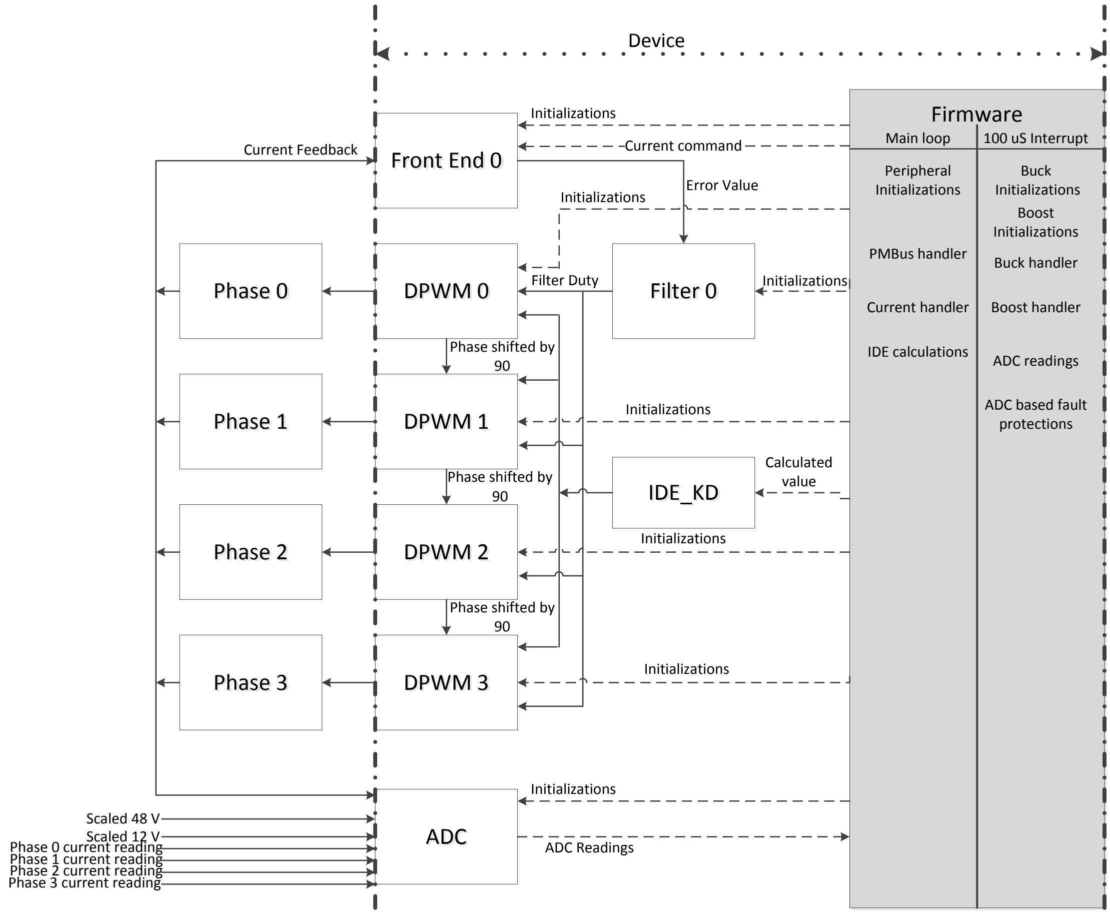


Figure 4 Internal working of the device.

The block diagram above shows the working of the UCD3138128 device on the Bidirection board. It uses a single front end for the current loop control. The DPWM's provide the appropriate PWM signals to the phases. The PWM signals from the DPWM's are phase shifted by 90 each to provide interleaving. A single filter (filter 0) provides the filter duty value for all the DPWM's. The DPWM's are configured in such a way that the a DPWM provides phase trigger to the other DPWM. For example DPWM 0 provides phase trigger to DPWM 1 and then DPWM1 provides the phase trigger to DPWM2. The phase trigger makes the DPWM module to restart its counter there by maintaining a phase difference between itself and the module that is sending the phase trigger.

The ADC of the device senses the 48 V,12 V and individual phase currents. The firmware then collects the ADC readings and calculates the average value. There are some protections being placed by the device using firmware based on the reading from the ADC.They are over voltage and under voltage protection, both for the 12 V and the 48 V battery.

The usual values are shown below in the table:

Protection limit	48 V Battery	12V Battery
Over voltage	56 V	14 V
Under voltage	36 V	9 V

Other protections are available in the device based on the cycle by cycle value of the current. These are implemented by the hardware and uses the fault mux and the DPWM module to make appropriate adjustment to the output waveform.

The IDE_KD hardware in the fault mux provide the DPWM modules with the ratio of the turn on and turn off times. The DPWM B is now a ratio of the size of DPWM A pulse .We can say that :

DPWM B pulse = IDE_KD * DPWM A pulse.

The IDE_KD value is calculated in firmware using the ADC reading of the 48 V and the 12 V battery.

6 Getting Started Hardware

The Bidirection DCDC converter is used to charge either the 12 V Battery or the 48 V Battery. But for demo purposes, user can use a power supply/load configuration to simulate a battery. The image shown below illustrates how the connections have to be made:

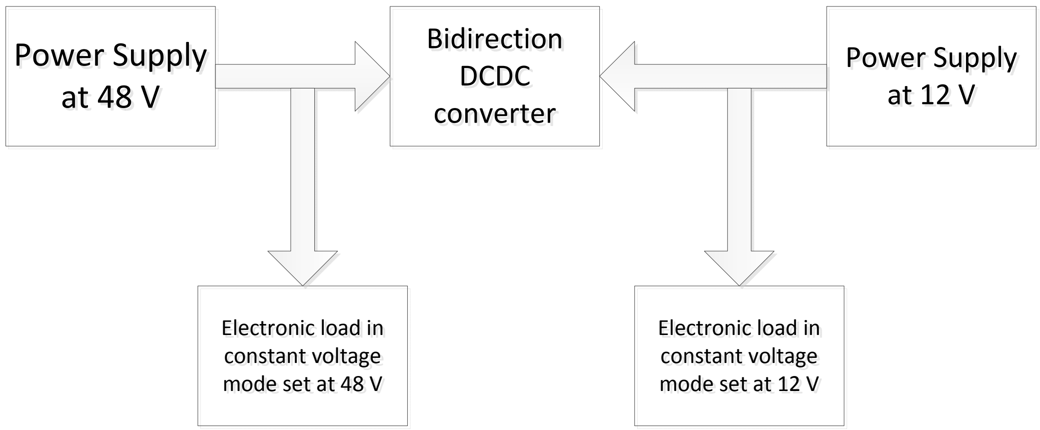


Figure 5 Basic setup for testing the converter.

After setting up the board as shown above, connect the PMBus connector to the converter.

Follow the below steps to get the Bidirection DCDC converter running:

1) Turn on the 48 V supply.
2) Turn on the 12 V supply.
3) Press the reset button on the converter to clear any operation to be pending.
4) Download the provided firmware.

7 Getting Started Firmware

Download and install the latest Fusion GUI from this link:

http://www.ti.com/tool/fusion_digital_power_designer

After installing the software go to the location as shown in the figure:

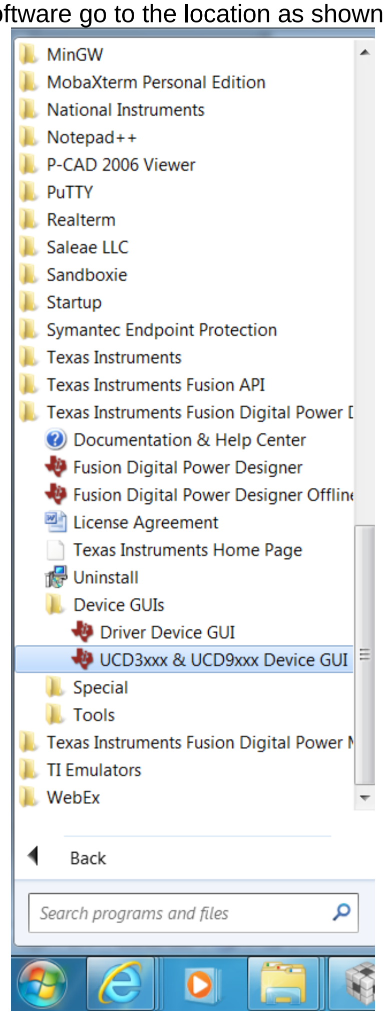


Figure 4

The window as shown should appear:

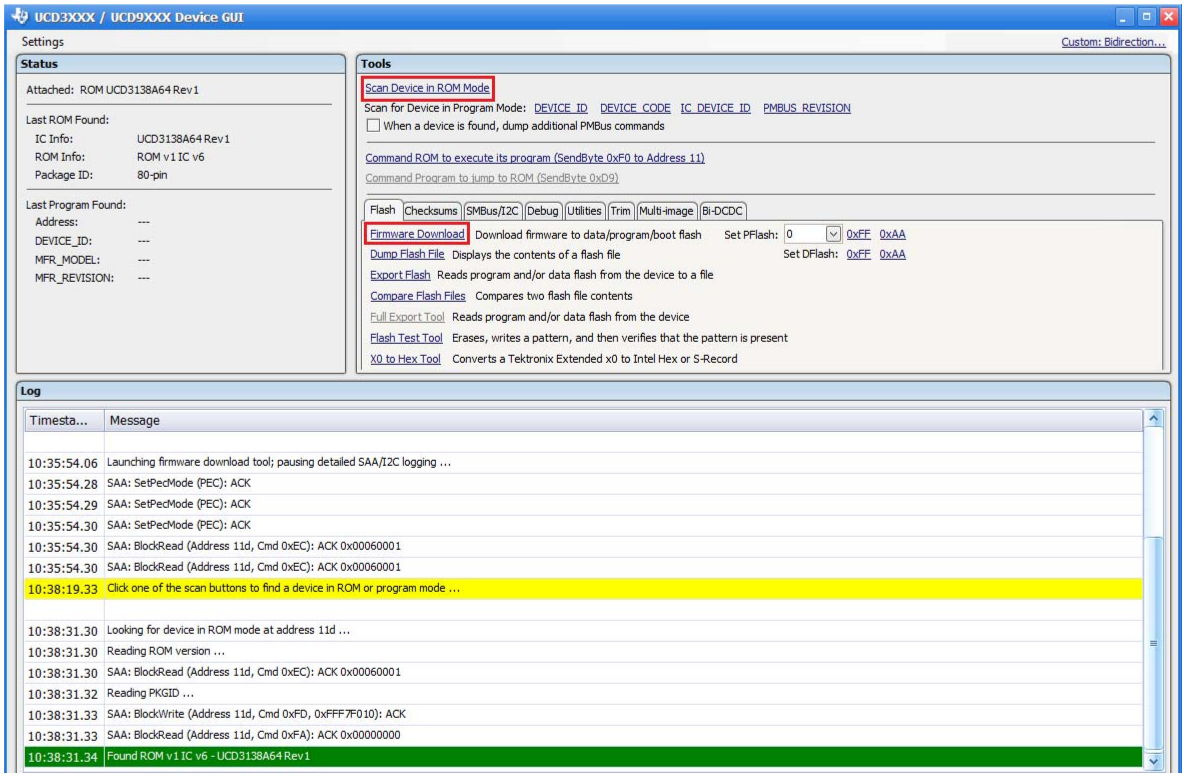


Figure 5

Click on the “Scan Device in ROM Mode” as shown. Then the device should be detected as shown in the Geen highlighted line.

If an error occurs then the device might be in program mode. Click on “Device ID” as shown in figure 17.

If the device was found in ROM mode then click on “Firmware Download” :

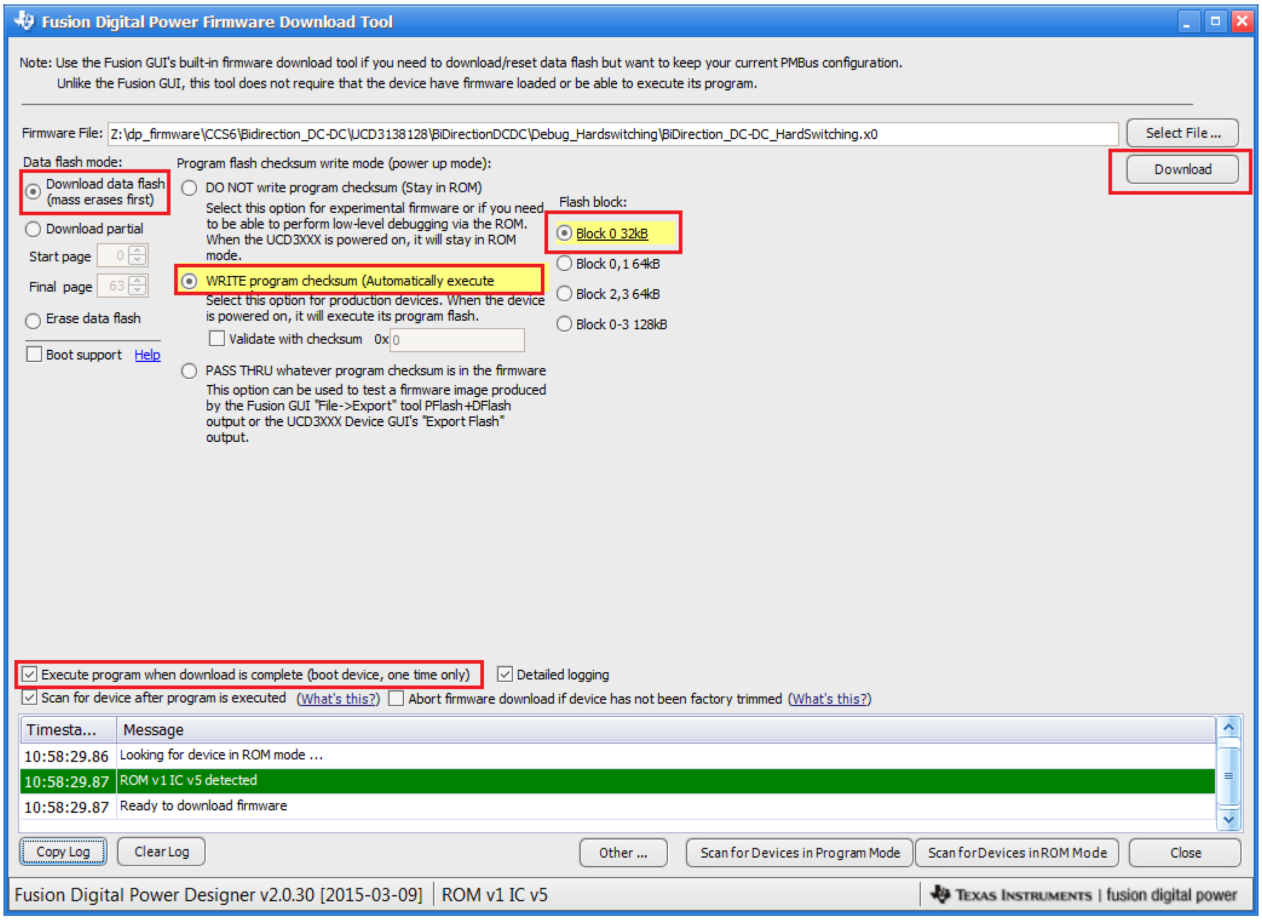


Figure 6

Click on “Select File…” and point it to the x0 file . The x0 file is usually located in the “Debug_Hardswitching” folder.

Keep the setting as shown in the figure above and click on the button “Download”. Once downloaded, the device has the firmware that can run the board. Now close the Download window.

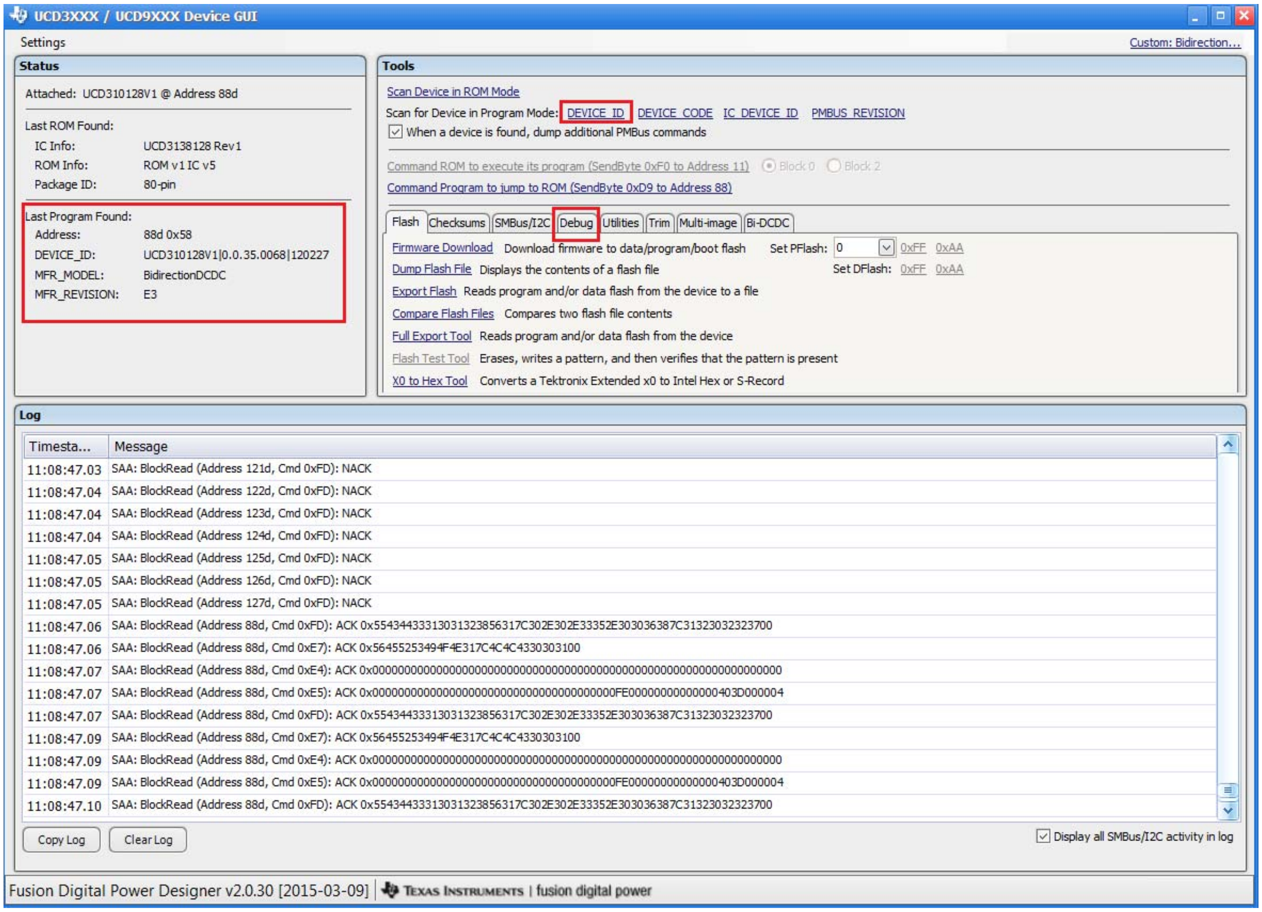


Figure 7

After detecting the device in program mode, click on the “Debug” tab as shown:

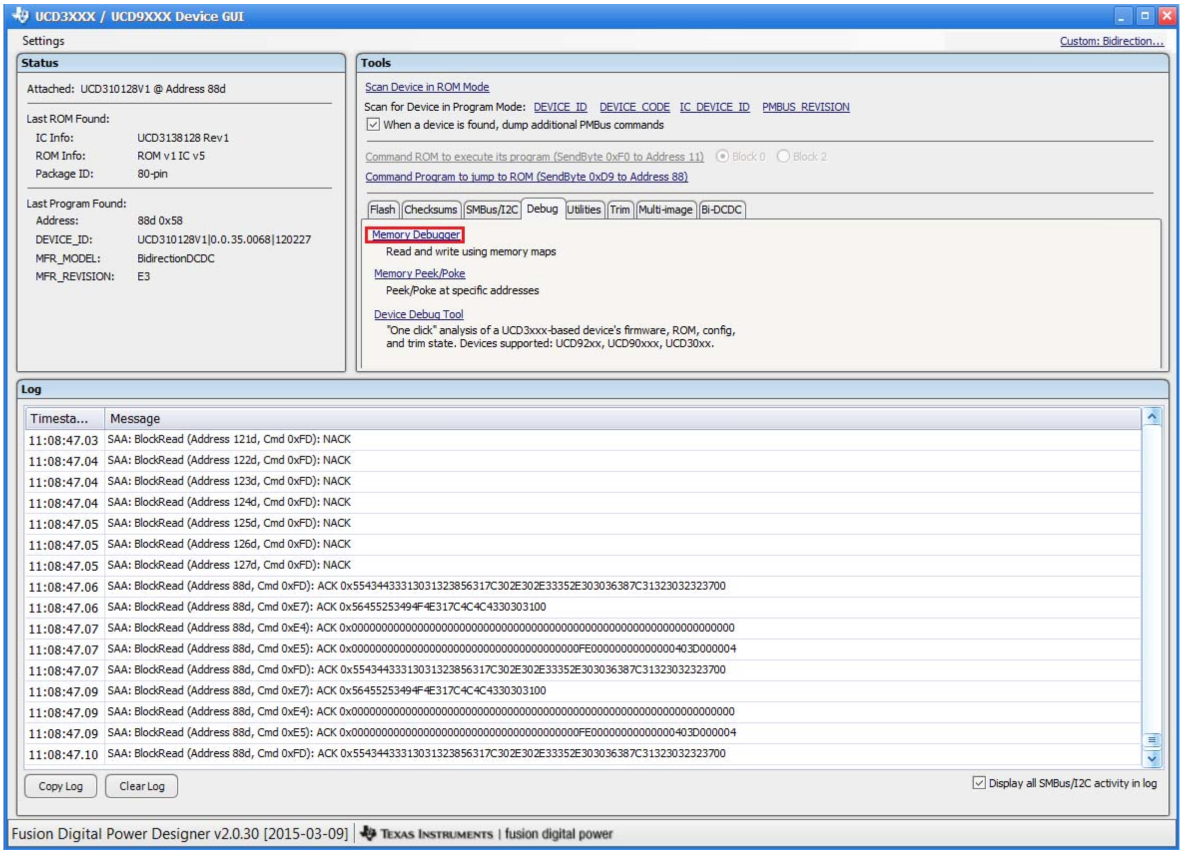


Figure 8

Click “Memory Debugger”. If you are opening the memory debugger for the first time then the GUI will ask for a password. Please enter “forestln” as the password.

Once the memory debugger is opened, click on the “File” tab as shown:

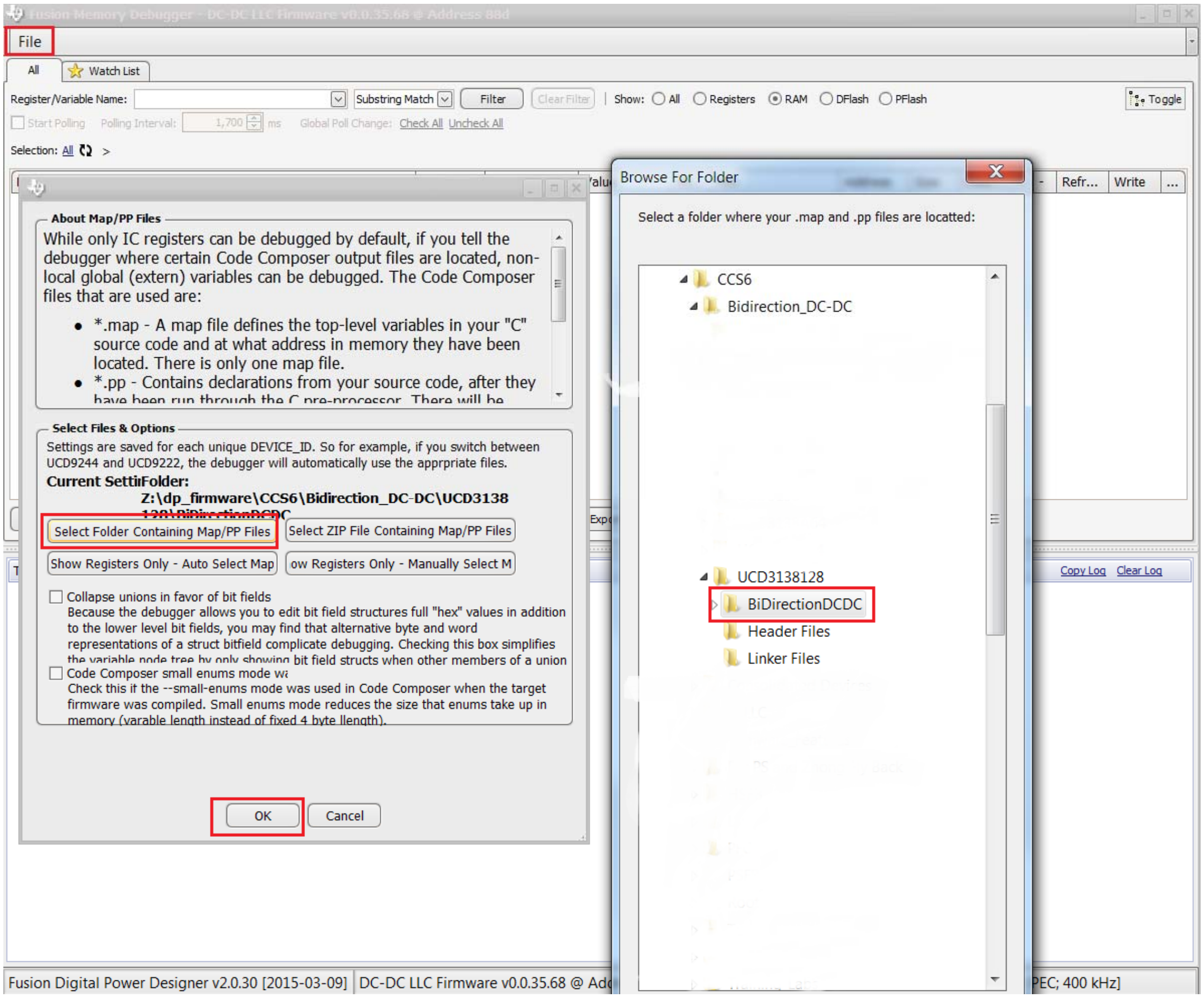


Figure 9

Click on the “Select Folder Containing the Map/PP Files” button and point it to the folder containing the project. Click “OK”.

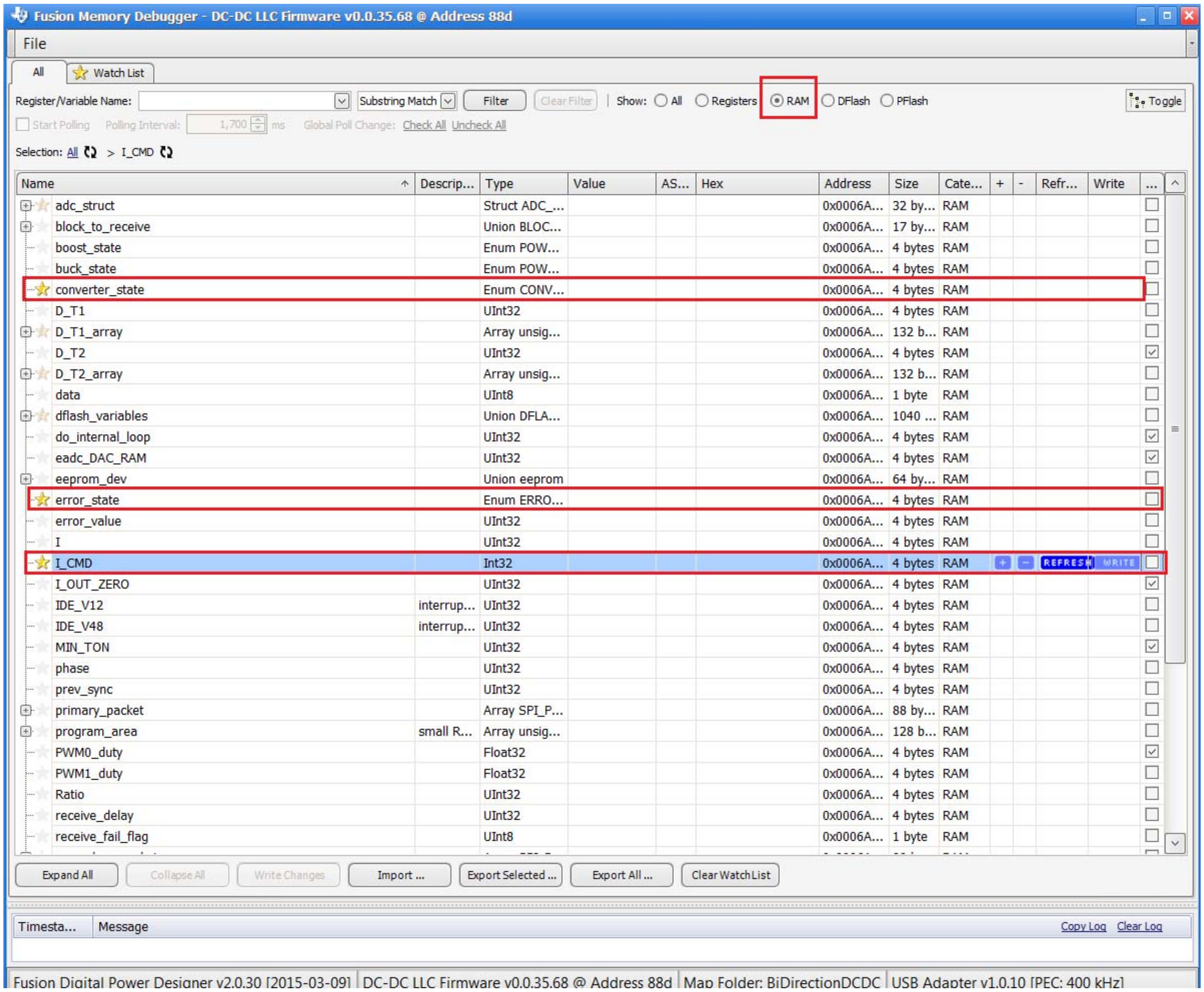


Figure 10

In the “All” tab, click on the “RAM” Radio button. Following that , all the RAM variables used in the device are displayed as shown. We are interested in only a few of the RAM varaibles. They are highlighted as shown. Click on the star icon on the left of those variables to make them available in the “Watch list”.

Now , click on the tab “Watch list” and click on the “RAM” Radio button.

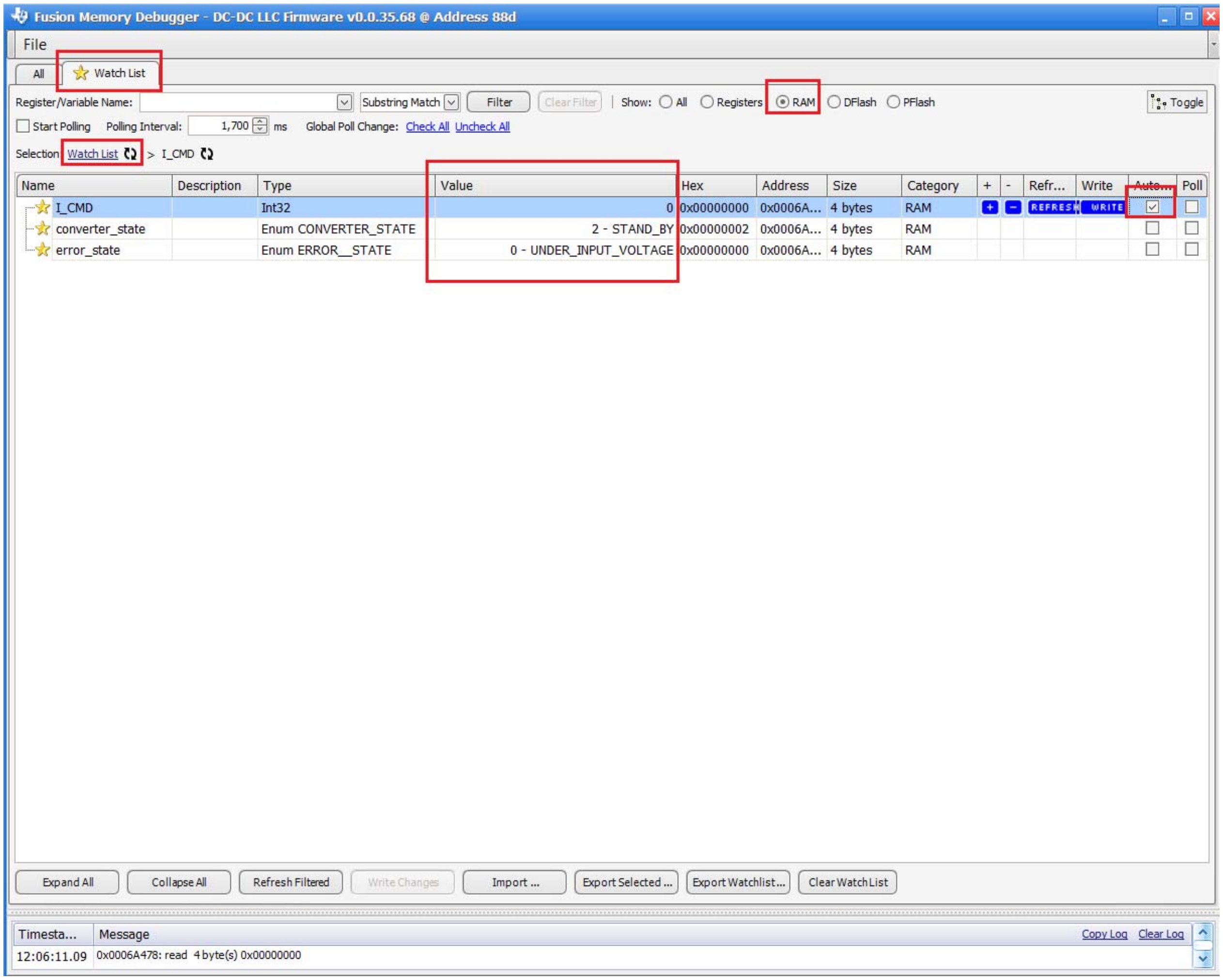


Figure 11

The variables that we had earlier "starred" will appear in this window as shown above. The three important variables are I_CMD, converter_state and error_state. The meaning of these variables is described in the table below:

Variable	Description	Read / write
I_CMD	This variable is used to set the current output of the converter. Positive values make the 48 V battery discharge and charge the 12 V battery. Hence the direction of current flow is from 48 V to 12 V . This direction is considered positive. For these values the board is operating in BUCK mode. Negative values make the 12 V battery discharge and charge the 48 V battery. The direction of current flow is from 12 V to 48 V.	Write

	For these values the board is operating in BOOST mode.	
converter_state	This variable simply indicates which state the board is .	Read only
error_state	This variable gives a error if any during the operation of the converter. It has nine values: UNDER_INPUT_VOLTAGE OVER_INPUT_VOLTAGE UNDER_OUTPUT_VOLTAGE OVER_OUTPUT_VOLTAGE SYNC_CRAZY NO_BATTERY_CONNECTED OPAMP_LOCK_UP FEED_BACK_ERROR NO_ERROR	Read only

Table 1. RAM variables description.

To run the converter, enter values between -120 to 120 for I_CMD variable. It is advised that you should start with smaller values like -20 to 20 to check if the connections are made well.

Also, before changing the sign of the current command, it is better to go to zero first and then change the command.

Click on the "Watch List" 

to read the values of the variables.

7.1 Compiling the firmware

To compile the given code, TI's Code Composer Studio has to be used. The latest version of Code composer Studio can be downloaded here:

http://www.ti.com/tool/CCSTUDIO

The steps below show how to compile the BidirectionDCDC code.

1) Identify the location of the project folder. These are the folders named "BiDirectionDCDC". They can be found under the device named folder like "UCD3138128".

2) Add the project to Code Composer Studio:

Go to the project menu in Code Composer studio as shown in the figure and click "Import CCS Project…"

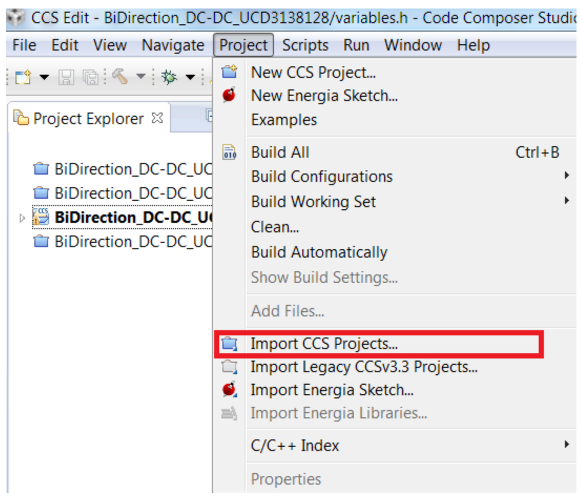


Figure 12 Project import for CCS

Select the folder and click on "OK".

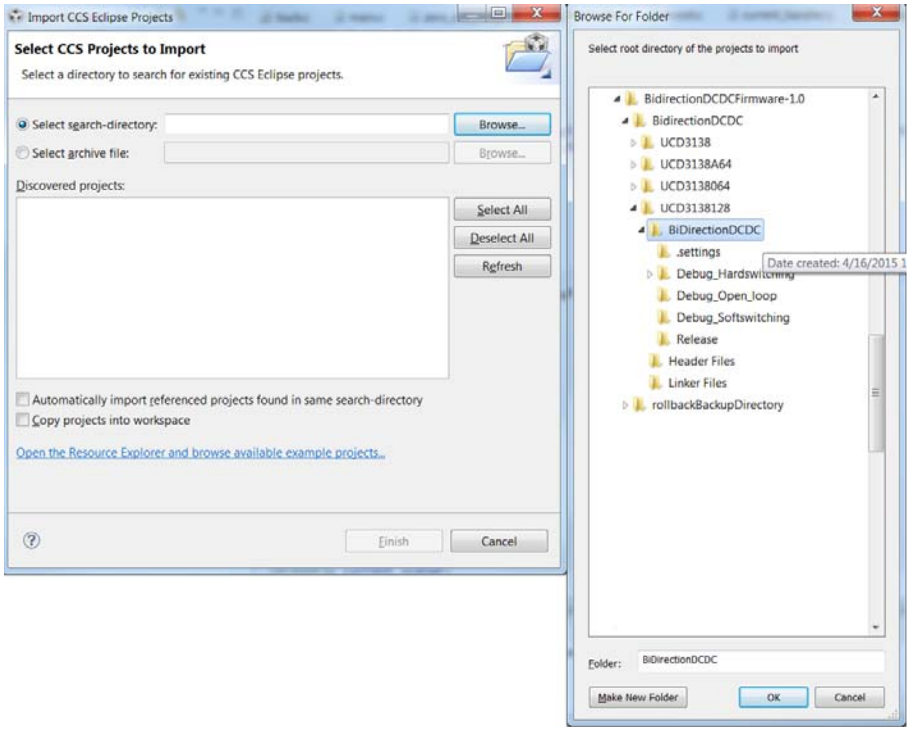


Figure 13 Project selection

Once added, the project will show up in the Projects Explorer. The default build configuration that Code Composer Studio sets is “Release”. We need to change it to the required build configuration. In our case, we have to set it to “Debug_Hardswitching” as shown in the figure.

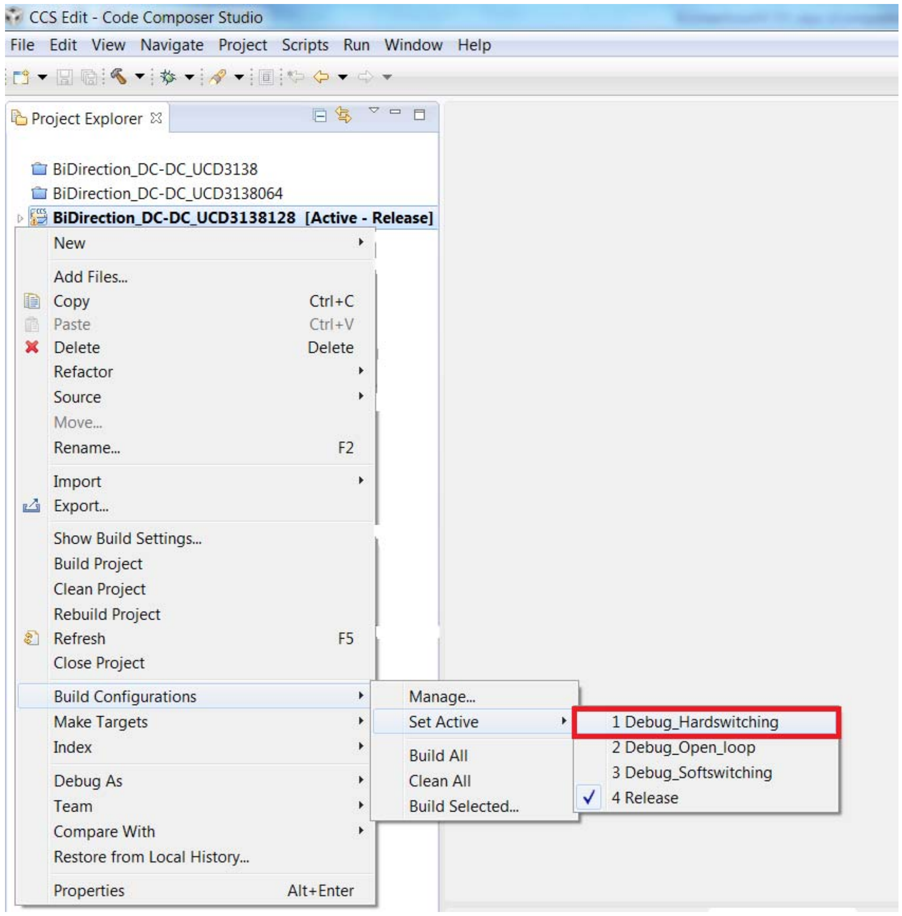


Figure 14 Build configuration setting

Now build the project as shown in the figure below:

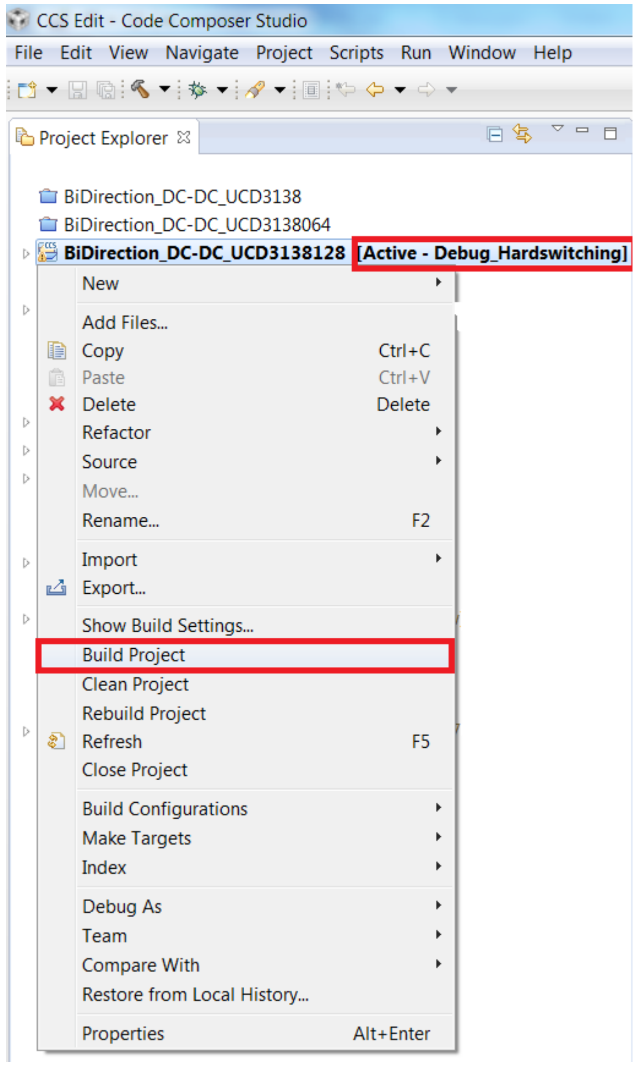


Figure 15 Compiling the project

If the compilation process was successful, then the output would be an x0 file which can be downloaded to the device.

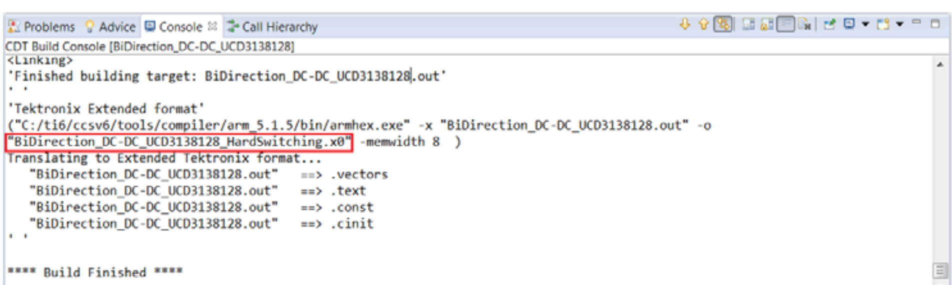


Figure 16 Compilation result and output

8 Test Setup

The Bidirection DCDC converter is used to charge either the 12 V Battery or the 48 V Battery. But for demo purposes, user can use a power supply/load configuration to simulate a battery. The image shown below illustrates how the connections have to be made:

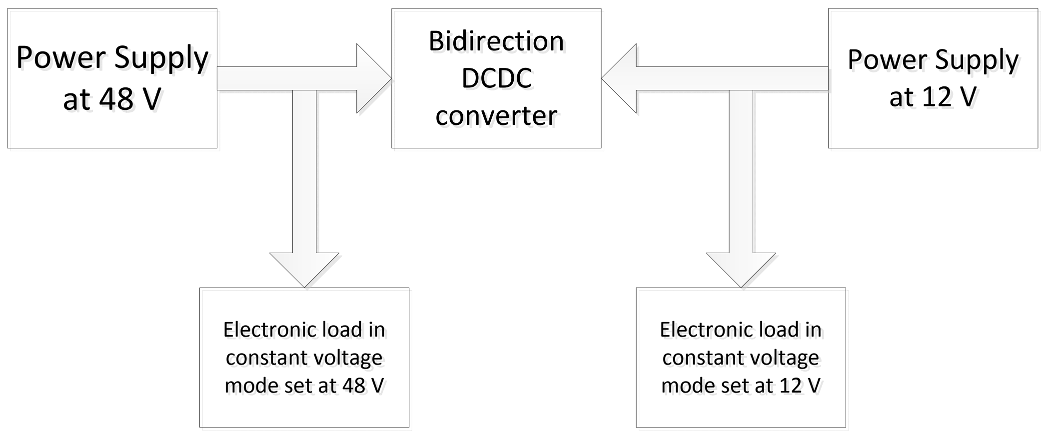


Figure 17

After setting up the board as shown above, connect the PMBus connector to the converter.

Follow the below steps to get the bidirection DCDC converter running:

1) Turn on the 48 V supply.
2) Turn on the 12 V supply.
3) Press the reset button on the converter to clear any operation to be pending.
4) Download the provided firmware.

9 Test Data

9.1 Efficiency plots

The efficiency for the hardswitching Bidirection DCDC converter in Buck operation is as shown below :

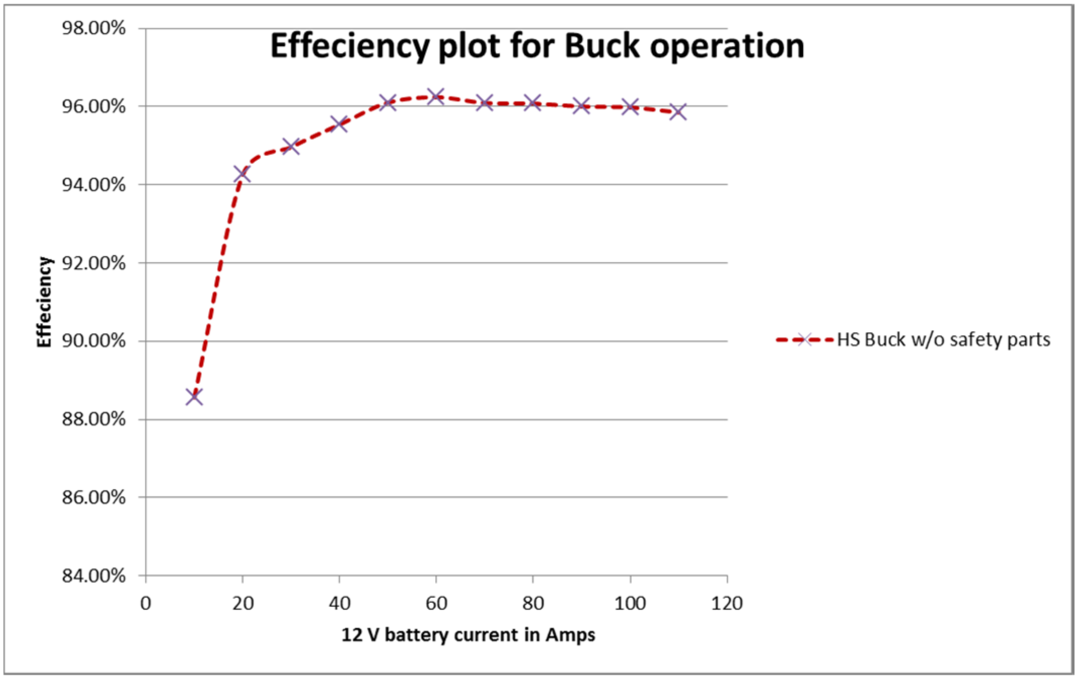


Figure 18 Efficiency plot for Hardswitching Buck operation

The data collected above was at an input voltage of 48 V and an output voltage of 12 V.The data was collected after deadtime optimization for each output current intervals of 4 Amps. The board was fitted on to a heat sink and placed in room temperature and no air cooling was provided.

The hardswitching Buck operation has a good efficiency at lower currents and this is because of the DCM operation. However, at higher currents the efficiency starts to take a slight dip.

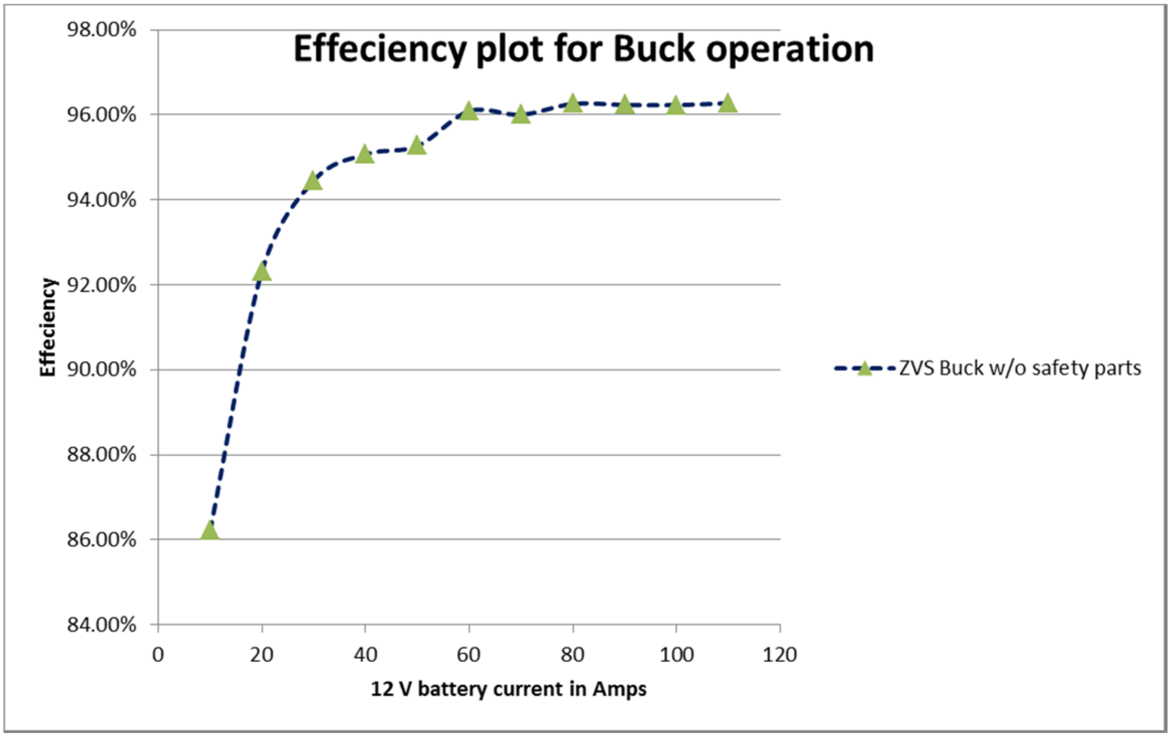


Figure 19 Efficiency plot for ZVS Buck operation

The data for the ZVS Buck operation was collected with the same conditions as the hardswitching Buck operation. As shown above, the efficiency at light load is not very impressive, but at higher loads, the efficiency is really flat and the higest efficiency of 96.28 % is achieved at its peak load of 110 A.

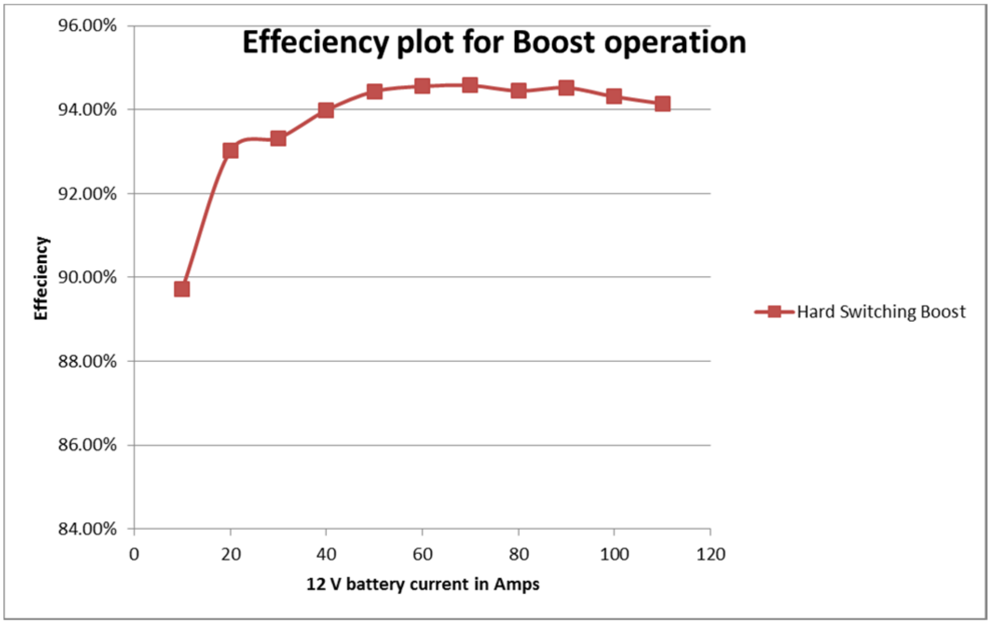


Figure 20 Efficiency plot for Hardswitching Boost operation

The data collected above was at an input voltage of 12 V and an output voltage of 48 V.The data was collected after deadtime optimization for each output current intervals of 4 Amps. The board was fitted on to a heat sink and placed in room temperature and no air cooling was provided.

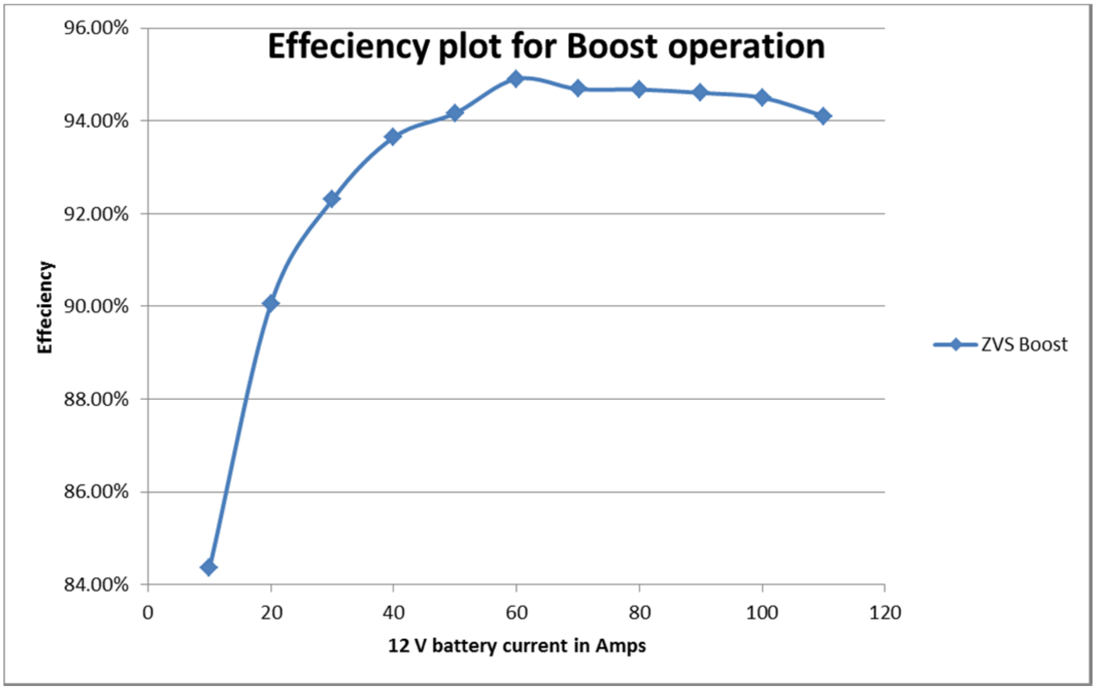


Figure 21 Efficiency plot for ZVS Boost operation

9.2 Loss analysis

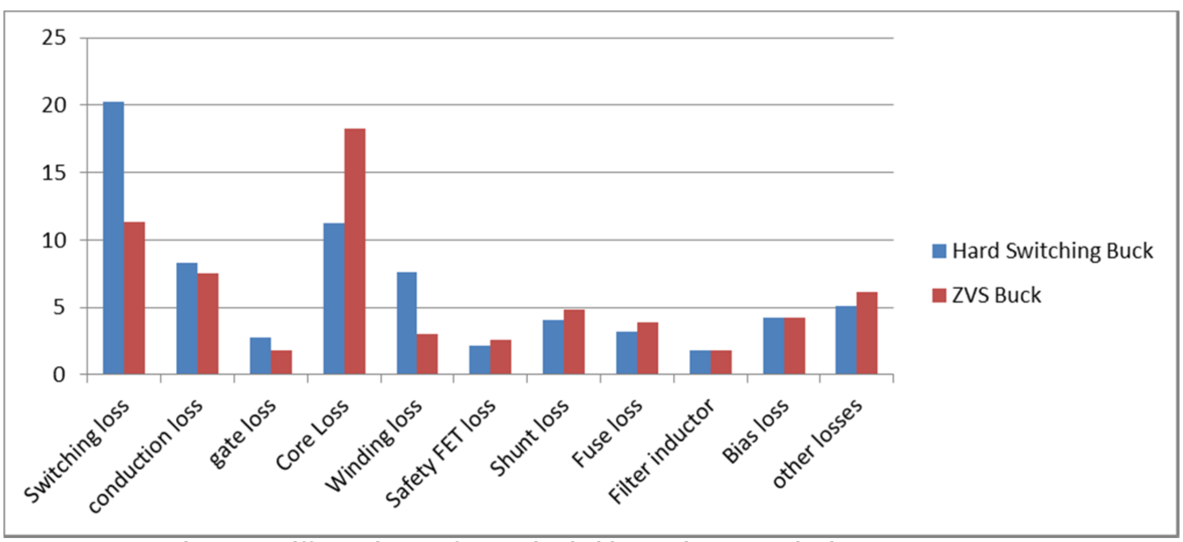
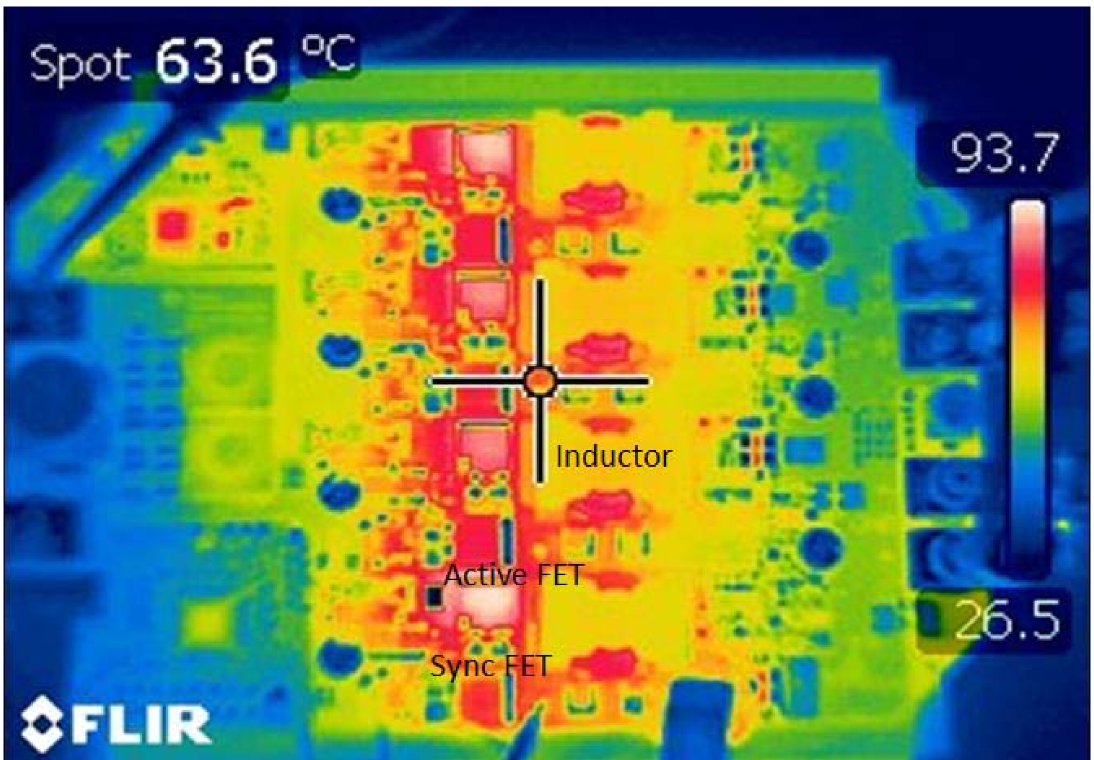


Figure 22 Different losses for Hardswitching and ZVS topologies.

The above bar graph shows losses from different components for the hardswitching and ZVS modes. From the data shown, we can see that there is more switching loss from the FETs in the Hardswitching Buck than the ZVS Buck. However, the ZVS buck has more core loss. This is because of high current ripple. This core loss can be minimized by using a better inductor having lower conduction loss.

Total Loss	
Hardswitching Buck	ZVS Buck
70.8 W	65.3 W

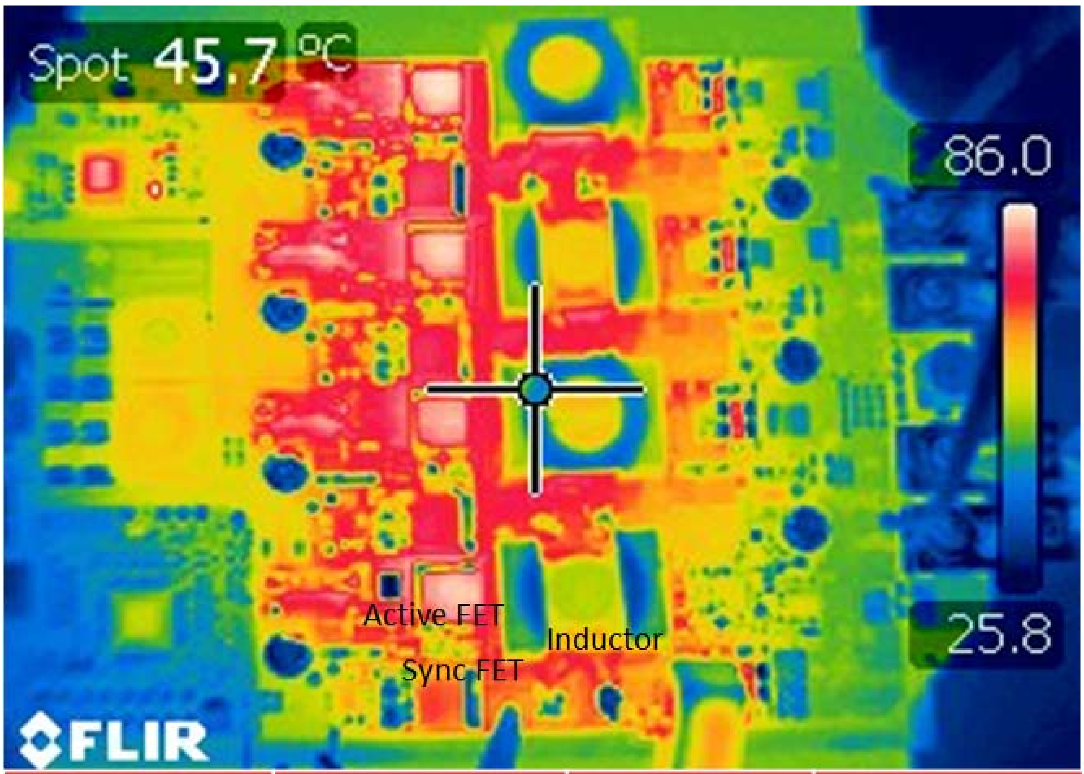
9.3 Thermal data



Top FET /C	Bottom FET /C	Core /C	Winding / C
84.75/92	68.25/69	64/65	77.5/78

Figure 23 Thermal image of the BidirectionDCDC board on a heat sink performing Hard switching Buck operation at 110 A.

The above image is a thermal image of the top view of the board operating in Hardswitching Buck mode at a total current of 110 A. The center of the image shows the FETs and the inductors of different phases. It can seen that the active FETs are relatively hot compared to the sync FETs.



Top FET /C	Bottom FET /C	Core /C	Winding / C
72.0/73*	61.5/64	56.5//59	62.3//64

Figure 24 Thermal image of the BidirectionDCDC board on a heat sink performing ZVS Buck operation at 110 A.

9.4 Operating the board in Buck and Boost mode.

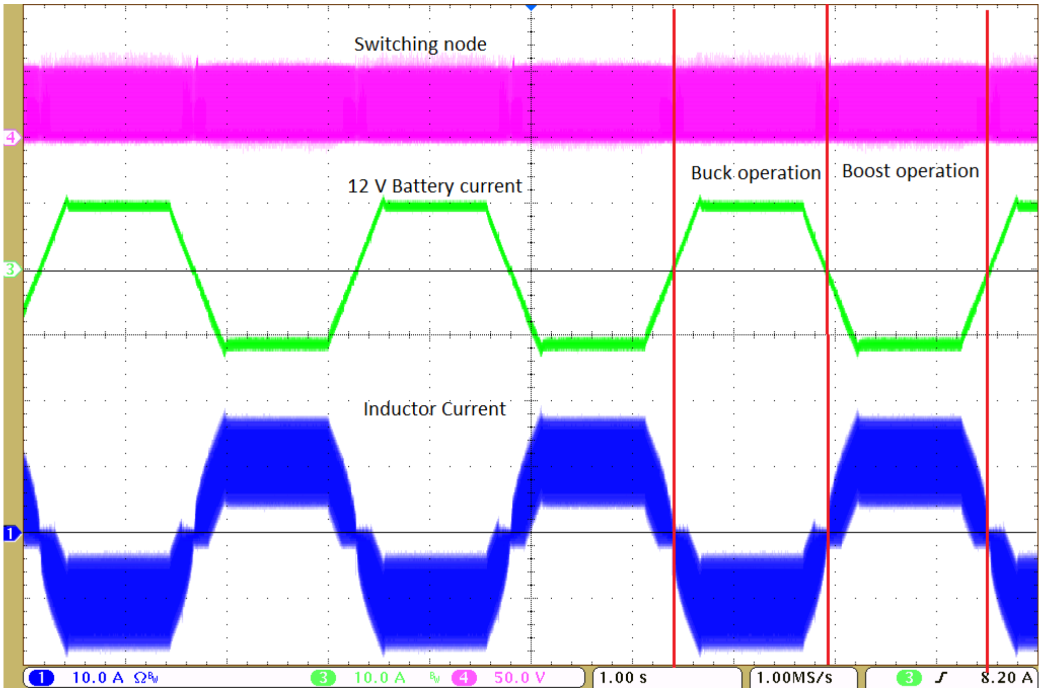


Figure 25 Output current and switch node waveforms

The above image shows the switching node waveform, 12 V battery current and the inductor current for a single phase. The Board is made to switch between Buck and Boost mode. The total current at the 12 V battery is ramped up or ramped down to have a smooth transition between Buck and Boost operation.

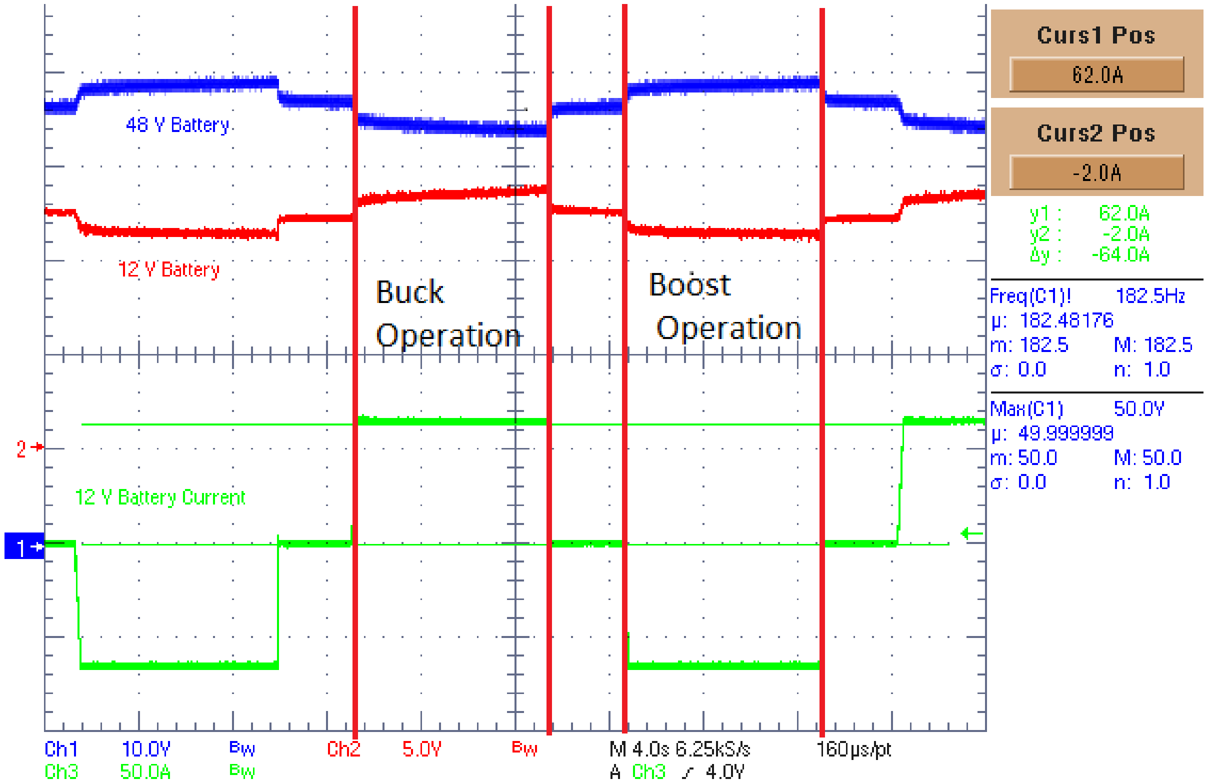


Figure 26 Battery voltage waveforms and total current for Buck and Boost operations.

The 48 V battery and the 12 V battery voltage wave forms are displayed for the buck and boost operation. As seen in the image, the 12 V battery's voltage ramps up during the Buck operation and the 48 V battery voltage ramps down. And during the Boost operation, the 48 V battery voltage ramps up and the 12 V battery voltage ramps down. Also the 12 V battery current waveform shows that the battery charging happens in constant current mode.

10 Design Files

10.1 Schematics

To download the Schematics for each board, see the design files at http://www.ti.com/tool/DESIGNNUMBER

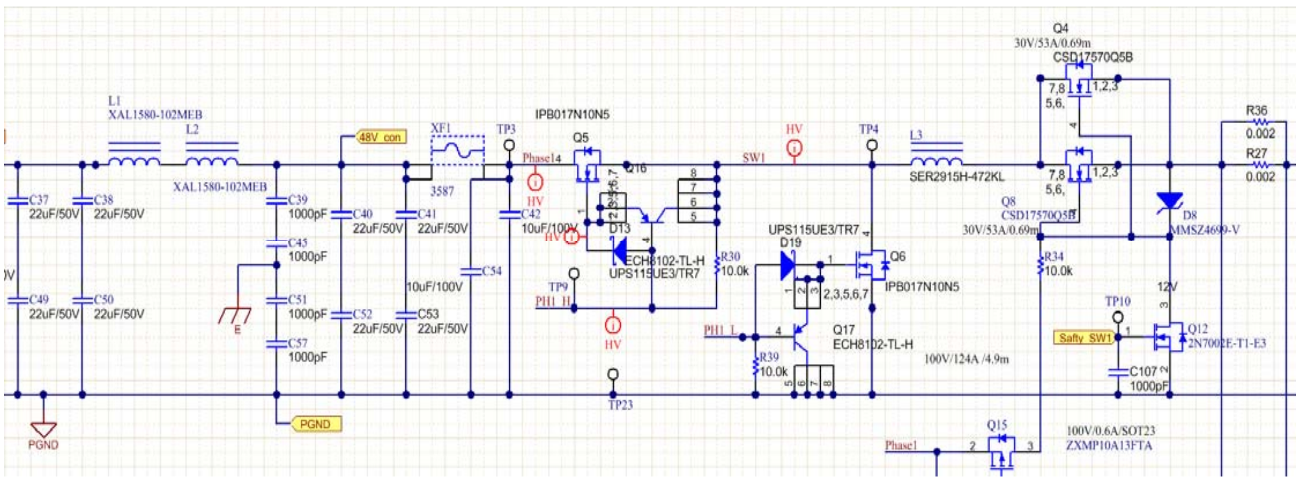


Figure 27

The schematic shown above represents the master phase, phase 1. Similar configuration is used for the rest of the three phases.

10.2 Bill of Materials

To download the Bill of Materials for each board, see the design files at http://www.ti.com/tool/DESIGNNUMBER

Table 1: To insert a table caption, right click picture > Insert Caption

Designator	Quantity	Value	Description	PackageReference	PartNumber	Manufacturer
!PCB	1		Printed Circuit Board		XX####	Any
C1	1	3300pF	CAP, CERM, 3300pF, 100V, +/-5%, X7R, 0603	0603	06031C332JAT2A	AVX
C2, C8, C11	3	10uF	CAP, CERM, 10uF, 16V, +/-20%, X5R, 0805	0805	0805YD106MAT2A	AVX
C3	1	0.1uF	CAP, CERM, 0.1uF, 50V, +/-10%, X7R, 0603	0603	06035C104KAT2A	AVX
C4, C28, C91, C93, C95, C97	6	0.1uF	CAP, CERM, 0.1uF, 25V, +/-5%, X7R, 0603	0603	06033C104JAT2A	AVX
C5, C114	2	100pF	CAP, CERM, 100pF, 50V, +/-5%, C0G/NP0, 0603	0603	C0603C101J5GAC	Kemet
C6	1	2.2uF	CAP, CERM, 2.2uF, 100V, +/-10%, X7R, 1206_190	1206_190	GRM31CR72A225KA73L	MuRata
C7	1	0.47uF	CAP, CERM, 0.47uF, 100V, +/-10%, X7R, 1206	1206	C3216X7R2A474K	TDK
C9, C61, C70, C79, C88, C99, C100, C101, C102	9	2.2uF	CAP, CERM, 2.2uF, 16V, +/-10%, X5R, 0805	0805	0805YD225KAT2A	AVX
C10	1	100pF	CAP, CERM, 100pF, 50V, +/-5%, C0G/NP0, 0603	0603	06035A101JAT2A	AVX

C12	1	10uF	CAP, CERM, 10uF, 25V, +/-10%, X5R, 0805	0805	C2012X5R1E106K125AB	TDK
C13	1	10uF	CAP, CERM, 10uF, 6.3V, +/-20%, X5R, 0603	0603	C0603C106M9PACTU	Kemet
C14, C15	2	33pF	CAP, CERM, 33pF, 100V, +/-5%, C0G/NP0, 0603	0603	06031A330JAT2A	AVX
C16, C25, C27, C63, C72, C81, C115	7	0.01uF	CAP, CERM, 0.01uF, 100V, +/-5%, X7R, 0603	0603	06031C103JAT2A	AVX
C17, C20, C23	3	1uF	CAP, CERM, 1uF, 16V, +/-10%, X5R, 0603	0603	C0603C105K4PACTU	Kemet
C18, C19, C21, C24, C90	5	0.1uF	CAP, CERM, 0.1uF, 16V, +/-5%, X7R, 0603	0603	0603YC104JAT2A	AVX
C22, C71, C80, C89, C94	5	2.2uF	CAP, CERM, 2.2uF, 10V, +/-10%, X5R, 0603	0603	C0603C225K8PACTU	Kemet
C26, C103	2	0.022uF	CAP, CERM, 0.022uF, 25V, +/-10%, X7R, 0603	0603	C0603C223K3RACTU	Kemet
C29, C30, C31	3	2.2uF	CAP, CERM, 2.2uF, 6.3V, +/-10%, X5R, 0603	0603	C0603C225K9PACTU	Kemet
C33	1	100pF	CAP, CERM, 100pF, 25V, +/-10%, X7R, 0603	0603	06033C101KAT2A	AVX
C37, C38, C40, C41, C49, C50, C52, C53	8	22uF	CAP, CERM, 22uF, 50V, +/-20%, X5R, 6x5x5mm	6x5x5mm	CKG57NX5R1H226M500JH	TDK
C39	1	0.1uF	CAP, CERM, 0.1uF, 25V, +/-10%, X7R, 0603	0603	GRM188R71E104KA01D	MuRata
C39, C45, C51, C57	4	1000pF	CAP, CERM, 1000pF, 100V, +/-5%, X7R, 0603	0603	06031C102JAT2A	AVX

C42, C54, C64, C66, C73, C75, C82, C84	8	10uF	CAP, CERM, 10uF, 100V, +/-20%, X7S, 2220	2220	C5750X7S2A106M	TDK
C43, C46, C55, C58	4	1uF	CAP, CERM, 1uF, 16V, +/-10%, X7R, 0805	0805	B37941K9105K62	EPCOS Inc
C44, C56, C65, C67, C74, C76, C83, C85, C116, C117, C118, C119, C120, C121, C122, C123	16	47uF	CAP, CERM, 47uF, 16V, +/-20%, X5R, 1210	1210	GRM32ER61C476ME15L	MuRata
C47	1	330uF	CAP, AL, 330uF, 100V, +/-20%, ohm, SMD	MN0	EMVE101GTR331MMN0S	Nippon Chemi-Con
C48	1	470uF	CAP, AL, 470uF, 25V, +/-20%, ohm, SMD	JA0	EMVA250ADA471MJA0G	Nippon Chemi-Con
C59, C68, C77, C86	4	330pF	CAP, CERM, 330pF, 50V, +/-5%, C0G/NP0, 0603	0603	06035A331JAT2A	AVX
C60, C69, C78, C87	4	0.1uF	CAP, CERM, 0.1uF, 25V, +/-10%, X7R, 0603	0603	06033C104KAT2A	AVX
C62	1	4.7uF	CAP, CERM, 4.7uF, 25V, +/-10%, X5R, 0805	0805	C2012X5R1E475K125AB	TDK
C104	1	22pF	CAP, CERM, 22pF, 50V, +/-5%, C0G/NP0, 0603	0603	06035A220JAT2A	AVX
C106, C108, C109, C112	4	1uF	CAP, CERM, 1 µF, 25 V, +/-10%, X7R, 0603_095	0603_095	C0603C105K3RACTU	Kemet

C107, C110, C111, C113	4	1000pF	CAP, CERM, 1000 pF, 50 V, +/-10%, X7R, 0603	0603	C0603X102K5RACTU	Kemet
D1, D3, D4	3	200V	Diode, Switching, 200V, 0.2A, SOT-23	SOT-23	BAS21-7-F	Diodes Inc.
D2, D7, D16	3	Red	LED, Red, SMD	LED_0805	LTST-C170KRKT	Lite-On
D5, D6, D17	3	40V	Diode, Schottky, 40 V, 0.5 A, SOD-123	SOD-123	MBR0540T1G	ON Semiconductor
D8, D9, D10, D11, D12, D14, D15, D18	8	12V	Diode, Zener, 12V, 500mW, SOD-123	SOD-123	MMSZ4699-V	Vishay-Semiconductor
D13, D19, D20, D21, D22, D23, D24, D25	8	15V	Diode, Schottky, 15 V, 1 A, DO-216-AA	DO-216-AA	UPS115UE3/TR7	Microsemi
FID1, FID2, FID3	3		Fiducial mark. There is nothing to buy or mount.	Fiducial	N/A	N/A
H1, H2, H3, H4, H5, H6, H7	7		Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	Screw	NY PMS 440 0025 PH	B&F Fastener Supply
J1	1		Header (shrouded), 100mil, 5x2, Gold, TH	5x2 Shrouded header	5103308-1	TE Connectivity
J2, J3, J4, J5, J6, J7	6		Connector Lug, wire range #6 - 4/0, 600V	Connector Lug, 1.075x0.45x0.45 inch	90562	Morris Products
J8, J9, J11	3		Header,2x1, 100mil, TH	Header, 2x1, 100mil, TH	22-27-2021	Molex
J10	1		Header, 2x1, 100mil, SMT	Header, 2x1, 100mil, TH	800-10-002-10-001000	Mill-Max

J12	1		Header, TH, 100mil, 4x1, Gold plated, 230 mil above insulator	4x1 Header	TSW-104-07-G-S	Samtec
L1, L2	2	1uH	Inductor, Shielded, Composite, 1uH, 57.5A, 0.000929 ohm, SMD	15.2x8x16.2mm	XAL1580-102MEB	Coilcraft
L3, L4, L5, L6	4	4.7uH	Inductor, Shielded E Core, Ferrite, 4.7 µH, 30 A, 0.00186 ohm, SMD	29.7x15.36x27.94mm	SER2915H-472KL	Coilcraft
LBL1	1		Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	PCB Label 0.650"H x 0.200"W	THT-14-423-10	Brady
Q1	1	-20V	MOSFET, P-CH, -20V, -2.4A, SOT-23	SOT-23	FDN302P	Fairchild Semiconductor
Q4, Q7, Q8, Q9, Q20, Q26, Q30, Q39	8	30V	MOSFET, N-CH, 30V, 51A, SON 5x6mm	SON 5x6mm	CSD17570Q5B	Texas Instruments
Q5, Q6, Q18, Q22, Q28, Q32, Q38, Q42	8	100V	MOSFET, N-CH, 100V, 1.7mOhm, DDPAK-7	DDPAK-7	IPB017N10N5	Infineon Technologies
Q11, Q14	2	60V	MOSFET, N-CH, 60V, 0.24A, SOT-23	SOT-23	2N7002E-T1-E3	Vishay-Siliconix
Q15, Q25, Q35, Q45	4	-100V	MOSFET, P-CH, -100V, -0.6A, SOT-23	SOT-23	ZXMP10A13FTA	Diodes Inc.
Q16, Q17, Q24, Q27, Q36, Q37, Q46, Q47	8	30 V	Transistor, PNP, 30 V, 12 A, SMD-8	SMD-8	ECH8102-TL-H	ON Semiconductor
R1, R16	2	330	RES, 330 ohm, 1%, 0.1W, 0603	0603	RC0603FR-07330RL	Yageo America
R2	1	39.0k	RES, 39.0k ohm, 1%, 0.1W, 0603	0603	RC0603FR-0739KL	Yageo America
R3	1	150k/1%	RES, 150k ohm, 1%, 0.1W, 0603	0603	CRCW0603150KFKEA	Vishay-Dale

R4	1	120k	RES, 120k ohm, 1%, 0.1W, 0603	0603	RC0603FR-07120KL	Yageo America
R5, R122	2	49.9	RES, 49.9 ohm, 1%, 0.1W, 0603	0603	CRCW060349R9FKEA	Vishay-Dale
R6	1	27.0k	RES, 27.0k ohm, 1%, 0.1W, 0603	0603	RC0603FR-0727KL	Yageo America
R7, R118	2	10.0k	RES, 10.0k ohm, 1%, 0.1W, 0603	0603	CRCW060310K0FKEA	Vishay-Dale
R8	1	1k_1%	RES, 1.0k ohm, 5%, 0.1W, 0603	0603	CRCW06031K00JNEA	Vishay-Dale
R9	1	330	RES, 330, 5%, 0.1 W, 0603	0603	CRCW0603330RJNEA	Vishay-Dale
R10	1	560	RES, 560 ohm, 1%, 0.1W, 0603	0603	RC0603FR-07560RL	Yageo America
R11	1	3.0k	RES, 3.0k ohm, 5%, 0.1W, 0603	0603	CRCW06033K00JNEA	Vishay-Dale
R12, R112, R116	3	100k	RES, 100 k, 5%, 0.1 W, 0603	0603	CRCW0603100KJNEA	Vishay-Dale
R13, R14	2	1.50k	RES, 1.50k ohm, 0.1%, 0.1W, 0603	0603	RG1608P-152-B-T5	Susumu Co Ltd
R15, R20, R21, R22, R23	5	0	RES, 0 ohm, 5%, 0.1W, 0603	0603	MCR03EZPJ000	Rohm
R17, R111, R115, R117, R119	5	1.00k	RES, 1.00k ohm, 1%, 0.1W, 0603	0603	CRCW06031K00FKEA	Vishay-Dale
R19, R38, R124, R125, R126, R127	6	1.0k	RES, 1.0k ohm, 5%, 0.1W, 0603	0603	CRCW06031K00JNEA	Vishay-Dale
R24, R26	2	100	RES, 100 ohm, 1%, 0.1W, 0603	0603	CRCW0603100RFKEA	Vishay-Dale

R27, R36, R52, R57, R71, R76, R90, R95	8	0.002	RES, 0.002, 1%, 1 W, 2512	2512	ERJ-M1WTF2M0U	Panasonic
R28	1	33.0k	RES, 33.0 k, 1%, 0.1 W, 0603	0603	CRCW060333K0FKEA	Vishay-Dale
R29	1	8.06k	RES, 8.06 k, 1%, 0.1 W, 0603	0603	CRCW06038K06FKEA	Vishay-Dale
R30, R39, R53, R59, R72, R78, R91, R97	8	10.0k	RES, 10.0k ohm, 0.1%, 0.1W, 0603	0603	RG1608P-103-B-T5	Susumu Co Ltd
R33	1	1.10k	RES, 1.10 k, 1%, 0.1 W, 0603	0603	RC0603FR-071K1L	Yageo America
R34, R41, R56, R63, R75, R82, R94, R101	8	10.0k	RES, 10.0 k, 1%, 0.1 W, 0603	0603	CRCW060310K0FKEA	Vishay-Dale
R35	1	1.00k	RES, 1.00 k, 1%, 0.1 W, 0603	0603	CRCW06031K00FKEA	Vishay-Dale
R40, R43, R45, R46, R61, R64, R65, R80, R83, R84, R99, R102, R103	13	1.0k_1%	RES, 1.0k ohm, 5%, 0.1W, 0603	0603	CRCW06031K00JNEA	Vishay-Dale
R42, R60, R79, R98	4	120	RES, 120, 5%, 0.1 W, 0603	0603	CRCW0603120RJNEA	Vishay-Dale
R43, R135	2	0	RES, 0 ohm, 5%, 0.125W, 0805	0805	CRCW08050000Z0EA	Vishay-Dale
R44, R47, R49, R62, R66, R68, R81, R85, R87, R100, R104, R106	12	26.1k	RES, 26.1k ohm, 1%, 0.1W, 0603	0603	CRCW060326K1FKEA	Vishay-Dale

R48, R67, R86, R105	4	40.2k	RES, 40.2k ohm, 1%, 0.1W, 0603	0603	CRCW060340K2FKEA	Vishay-Dale
R51, R70, R89, R108	4	1.64k_1%	RES, 1.65k ohm, 1%, 0.1W, 0603	0603	CRCW06031K65FKEA	Vishay-Dale
R109, R110, R113, R114	4	2.00k	RES, 2.00k ohm, 1%, 0.1W, 0603	0603	CRCW06032K00FKEA	Vishay-Dale
R120	1	0	RES, 0 ohm, 5%, 0.1W, 0603	0603	ERJ-3GEY0R00V	Panasonic
R121	1	31.6k_1%	RES, 31.6k ohm, 1%, 0.1W, 0603	0603	CRCW060331K6FKEA	Vishay-Dale
R128	1	75.0	RES, 75.0, 1%, 0.1 W, 0603	0603	CRCW060375R0FKEA	Vishay-Dale
R130	1	10.0	RES, 10.0 ohm, 1%, 0.1W, 0603	0603	CRCW060310R0FKEA	Vishay-Dale
S1	1		Switch, Push Button, SMD	2.9x2x3.9mm SMD	SKRKAEE010	Alps
T1	1	60 uH	xfmr, ?0%	12x12.5 mm	750342460	WURTH ELEKTRONIK

TP1, TP2, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP13, TP14, TP15, TP16, TP17, TP18, TP19, TP20, TP21, TP22, TP23, TP24, TP25, TP26, TP27, TP28, TP29, TP31, TP32, TP33, TP35, TP36, TP37, TP38, TP39, TP40, TP41, TP42, TP43, TP44,	55	White	Test Point, Miniature, White, TH	White Miniature Testpoint	5002	Keystone

TP45, TP46, TP47, TP48, TP49, TP50, TP51, TP52, TP53, TP55, TP56, TP57, TP58, TP59, TP60						

TP3	1	SMT	Test Point, Compact, SMT	Testpoint_Keystone_Compact	5016	Keystone
U1	1	LM34927MR	IC, Integrated Secondary Side Bias Regulator	PSOP	LM34927MR	TI
U2	1		FIXED LOW-DROPOUT VOLTAGE REGULATOR, DCY0003A	DCY0003A	TLV1117-33IDCY	Texas Instruments
U3	1		UCD3138128PFC, PFC0080	PFC0080A	UCD3138128PFC	Texas Instruments
U4, U6, U8, U10	4	UCC2721xDRM	IC, 120V Boot, 4A Peak, High Frequency High-Side Low-Side Driver	QFN-8	UCC2721xDRM	TI
U5	1		1.1 nV/rtHz Noise, Low Power, Precision Operational Amplifier, 4.5 to 36 V, -40 to 125 degC, 8-pin SOP (DDA0008C), Green (RoHS & no Sb/Br)	DDA0008C	OPA2211AIDDA	Texas Instruments
U7, U9, U11	3		1.1 nV/rtHz Noise, Low Power, Precision Operational Amplifier, 4.5 to 36 V, -40 to 125 degC, 8-pin SOIC (D0008A), Green (RoHS & no Sb/Br)	D0008A	OPA211AID	Texas Instruments
U12	1		40-ns, microPOWER, Push-Pull Output Comparators, D0008A	D0008A	TLV3202AID	Texas Instruments
U13	1		Single 2-Input Positive-AND Gate, DBV0005A	DBV0005A	SN74AHC1G08DBV	Texas Instruments
U14	1		DUAL BUFFER GATE, DRL0006A	DRL0006A	SN74LVC2G34DRL	Texas Instruments
U15, U16, U17, U18	4		1 uA Shunt Voltage Reference, 1.25 V, 10 ppm / degC, 5 mA, -40 to 85 degC, 3-pin SOT-23 (DBZ), Green (RoHS & no Sb/Br)	DBZ0003A	REF1112AIDBZT	Texas Instruments
U19	1		3.3V CAN Transceiver with Standby Mode, Loop-back, 6 mA, -40 to 125 degC, 8-pin	D0008A	SN65HVD233D	Texas Instruments

			SOIC (D), Green (RoHS & no Sb/Br)			
XF1, XF3, XF5, XF7	4		FuseHolder	780x320x345mil	3587	Keystone
C32, C34, C35, C36	0	22pF	CAP, CERM, 22pF, 50V, +/-5%, C0G/NP0, 0603	0603	06035A220JAT2A	AVX
C105	0	330pF	CAP, CERM, 330pF, 100V, +/-5%, X7R, 0603	0603	06031C331JAT2A	AVX
Q2, Q3, Q12, Q23, Q34, Q43	0	60V	MOSFET, N-CH, 60V, 0.24A, SOT-23	SOT-23	2N7002E-T1-E3	Vishay-Siliconix

10.2.1 Layout files

To download the Layout Prints for each board, see the design files at
http://www.ti.com/tool/DESIGNNUMBER

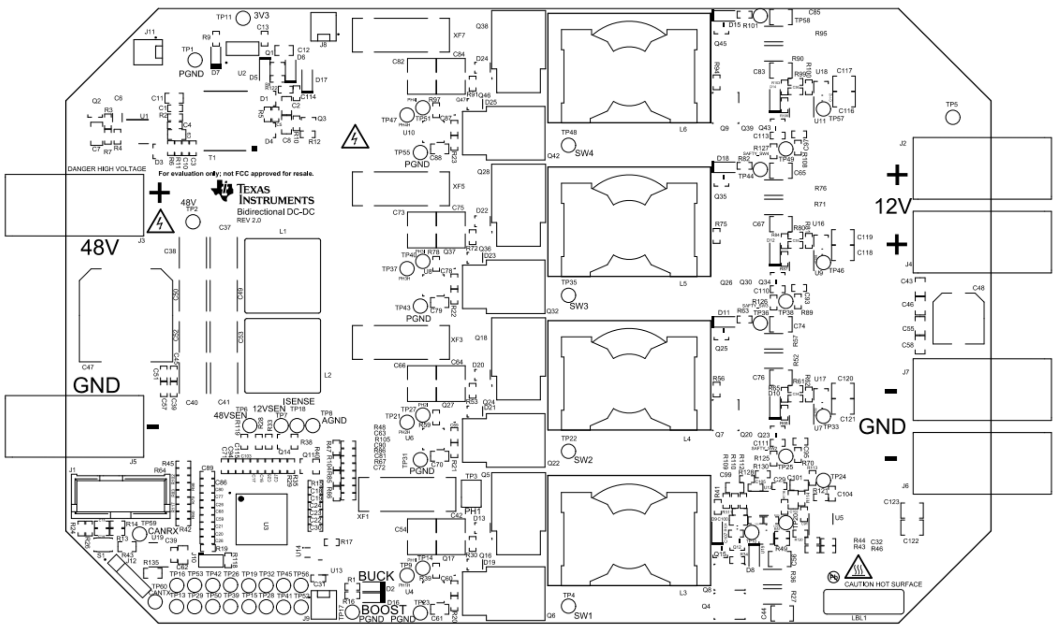


Figure 28 Top overlay

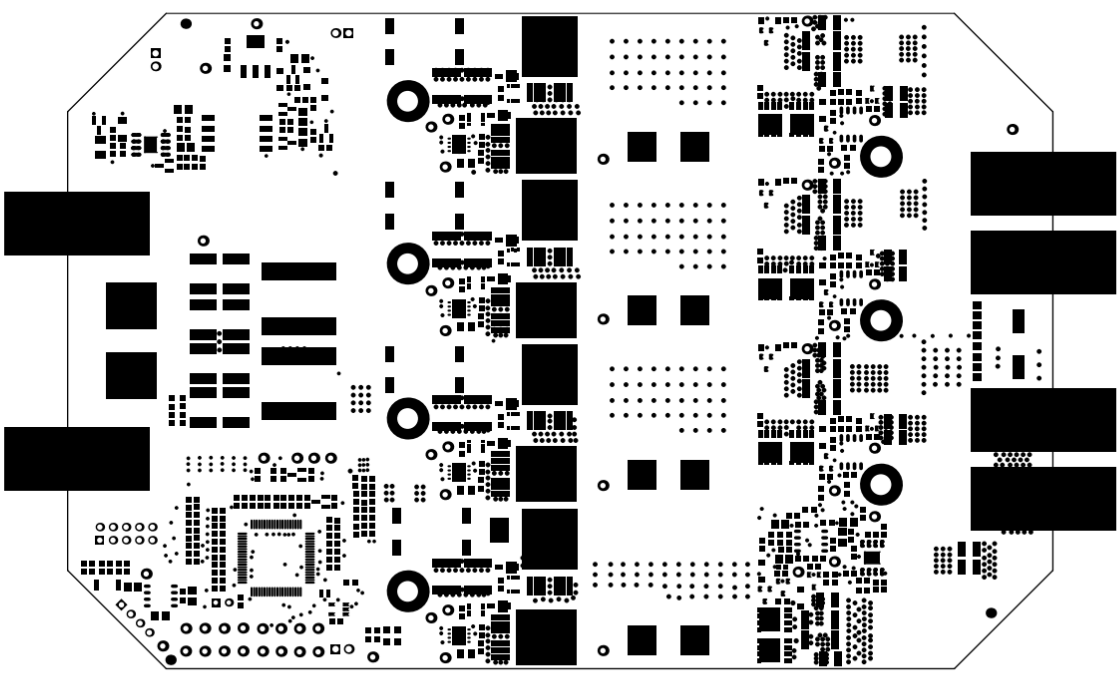


Figure 29 Top Solder

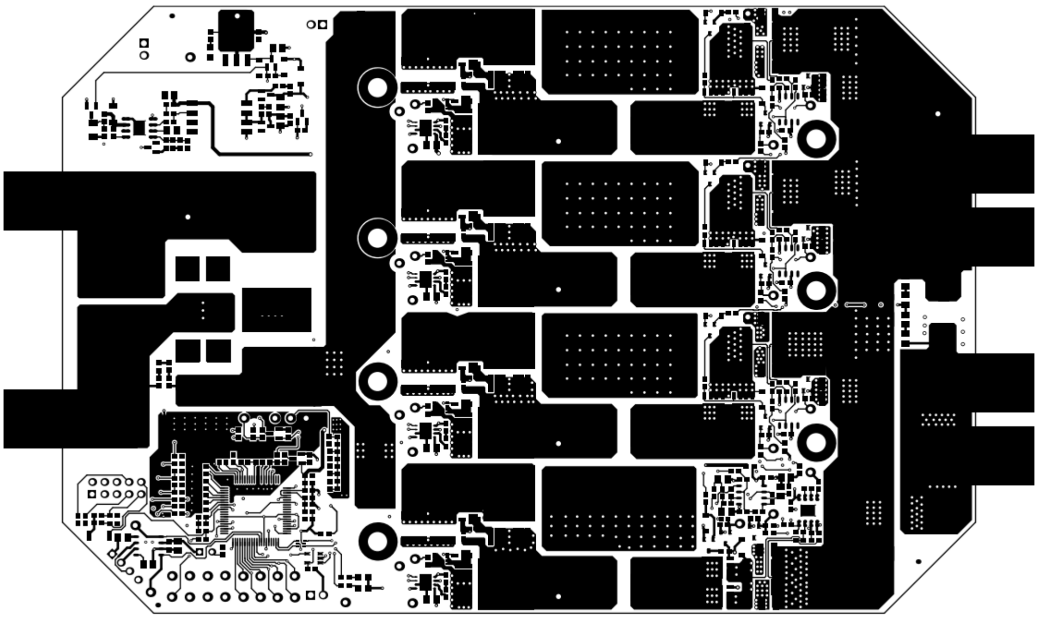


Figure 30 Top Layer

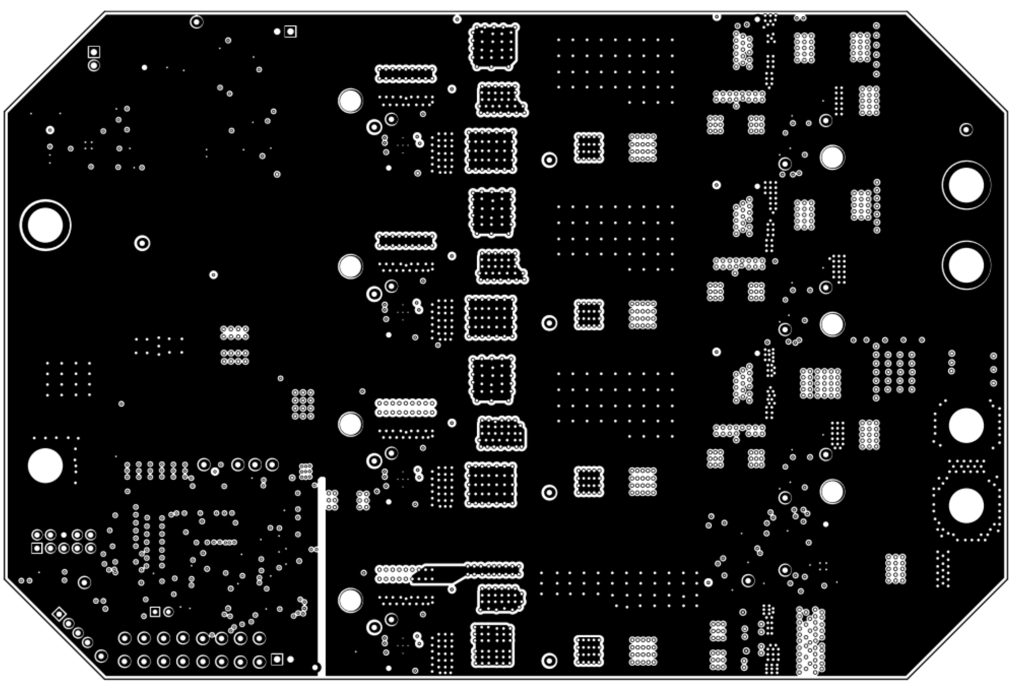


Figure 31 Midlayer 1

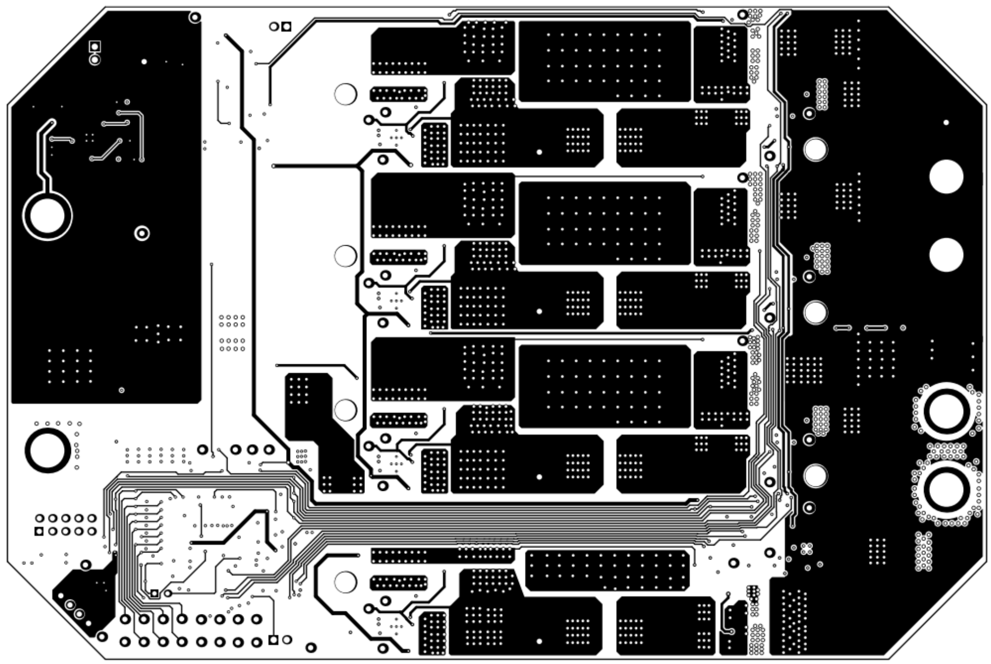


Figure 32 Midlayer 2

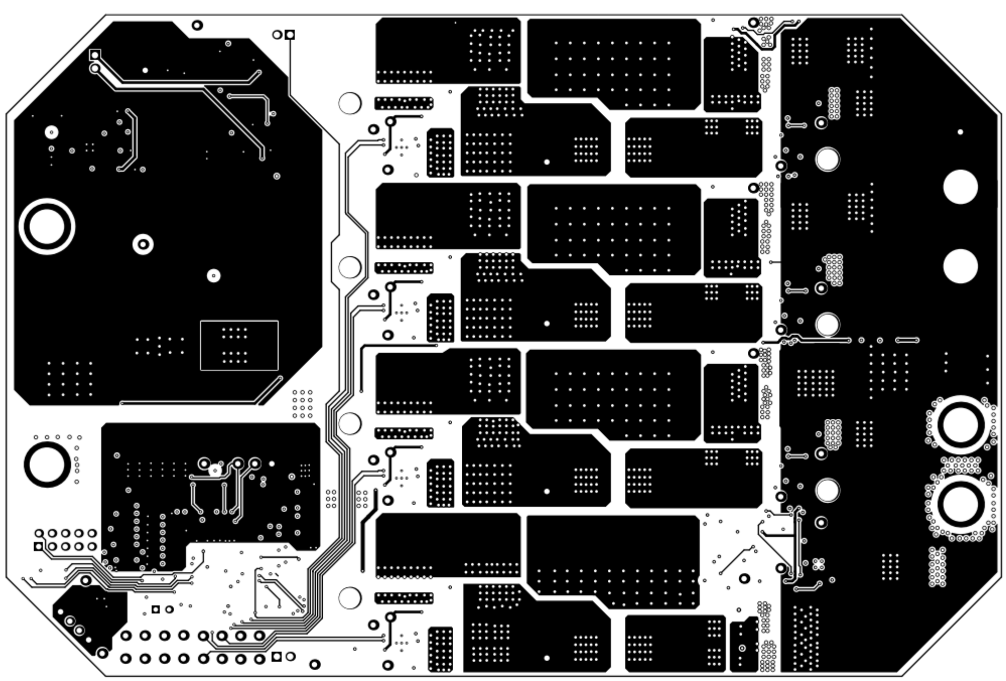


Figure 33 Bottom Layer

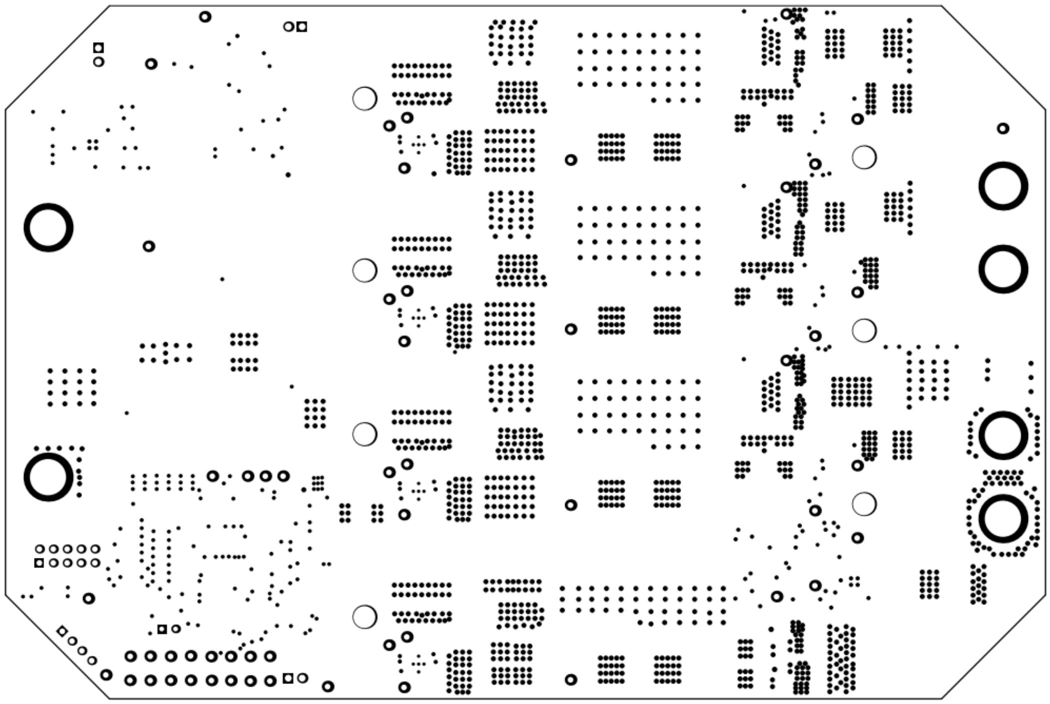


Figure 34 Bottom Solder

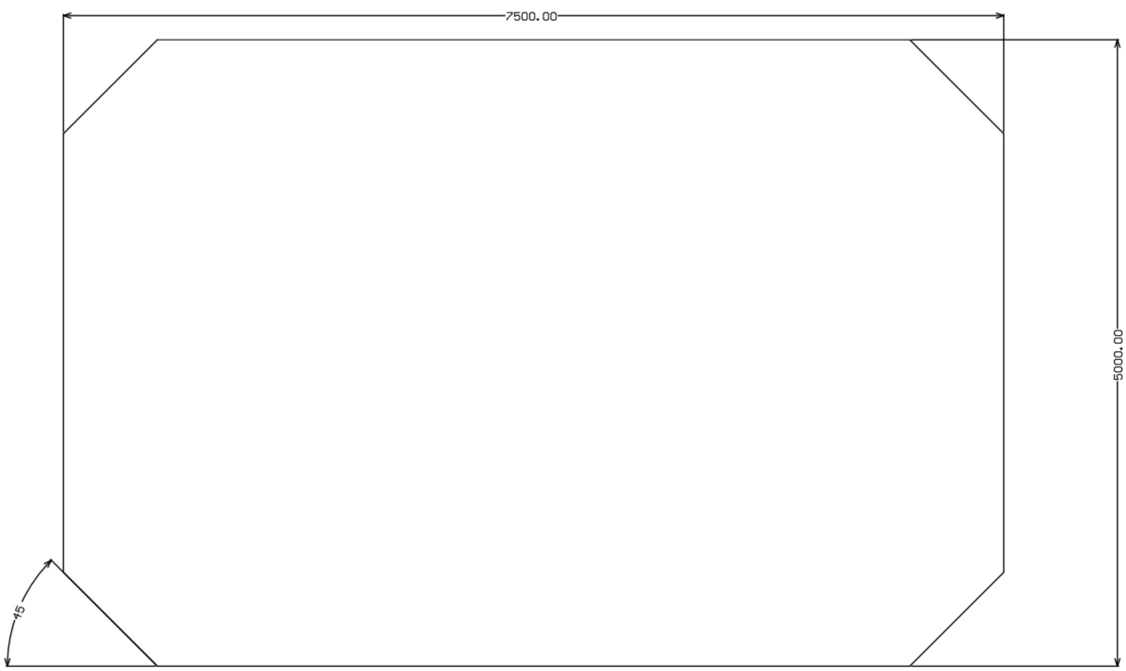


Figure 35 M2 Board Dimentions

10.3 Altium Project

To download the Altium project files for each board, see the design files at http://www.ti.com/tool/DESIGNNUMBER

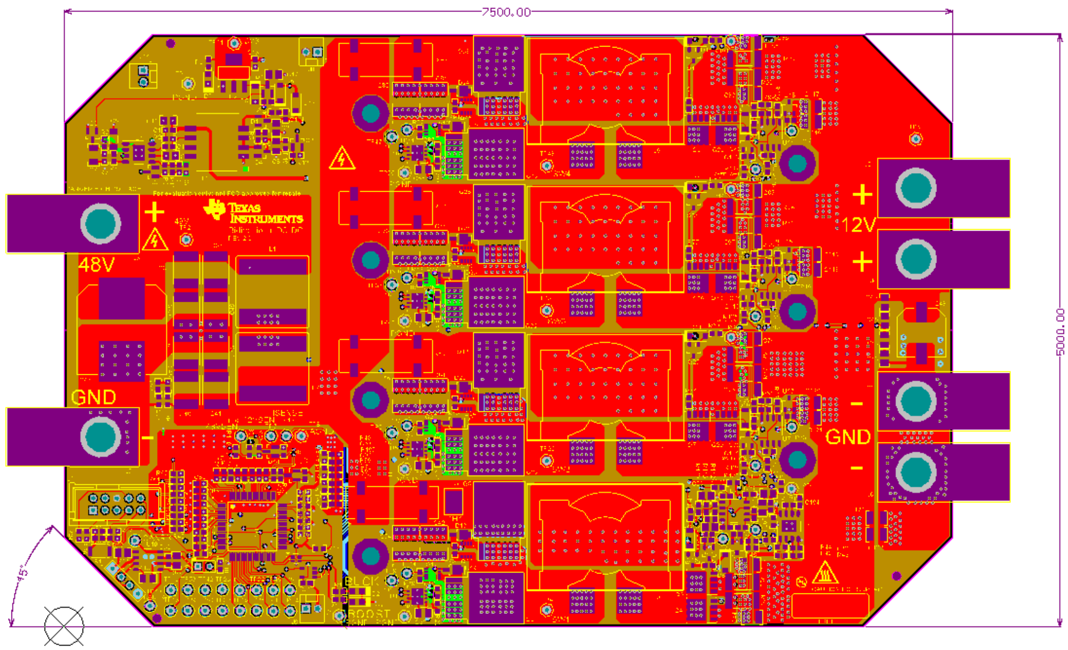


Figure 36: Altium Project

10.4 Assembly Drawings

To download the Assembly Drawings for each board, see the design files at
http://www.ti.com/tool/DESIGNNUMBER

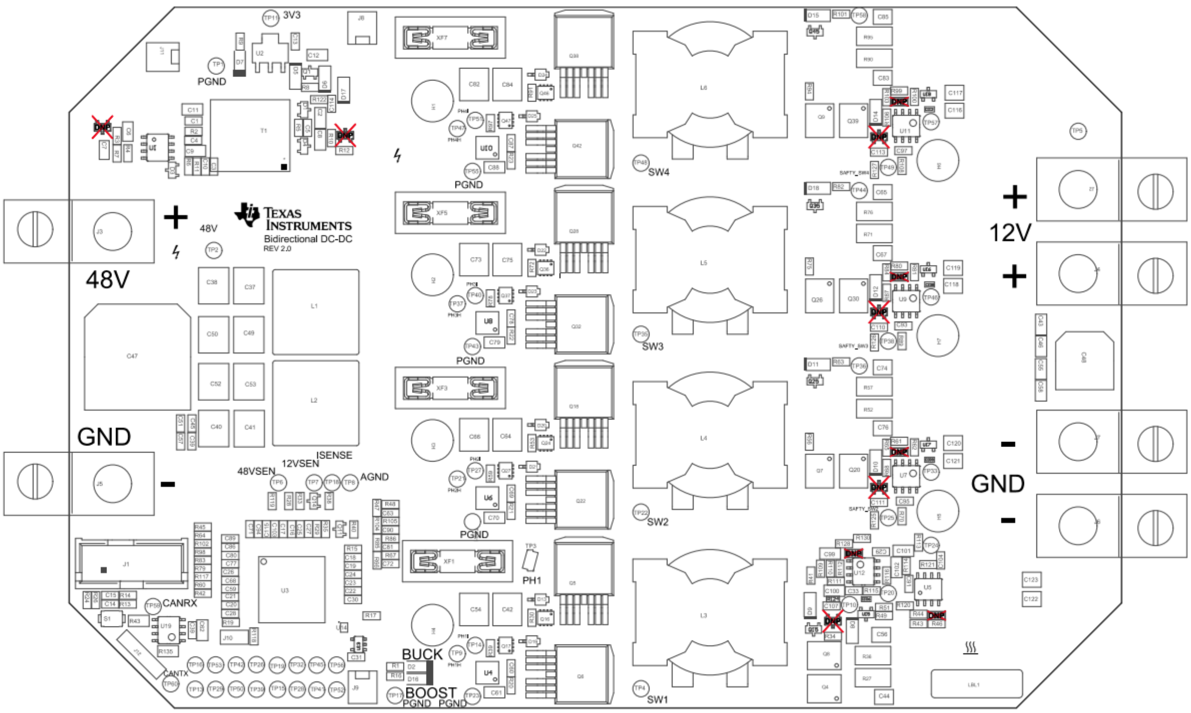


Figure 37: Assembly Drawing

11 Software Files

To download the software files for this reference design, please see the link at http://www.ti.com/tool/DESIGNNUMBER

12 References

1) Highly Integrated Digital Controller for Isolated Power (Rev. F)

   http://www.ti.com/lit/gpn/ucd3138

2) UCD3138 Monitoring and Communications Programmer's Manual (Rev. A)

   http://www.ti.com/lit/pdf/sluu996

3) UCD3138 Digital Power Peripherals Programmer's Manual (Rev. A)

   http://www.ti.com/lit/pdf/sluu995

4) UCD3138 ARM and Digital System Programmer's Manual (Rev. A)

   http://www.ti.com/lit/pdf/sluu994

13 About the Author

Sanatan Rajagopalan is a Systems/Apps engineer at Texas Instruments, where he is responsible for developing reference design solutions for the industrial and automotive segment. Sanatan earned his Master of Science in Electrical Engineering (MSEE) from Texas Tech University in Lubbock, TX.

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