Bidirection DCDC Converter User Guide

Sanatan Rajagopalan

HVPS

Contents

Introduction

The vehicles nowadays are trying to adopt a 48 -12 volt system to increase their vehicle efficiency. The 48 volt system provides support for the chassis and regenerative braking. The 12 volt system provides support for the ignition, lighting, and entertainment. To make best use of the energy available , a converter that can transfer energy in both dirctions i.e charge the 12 V batter using the 48 V and vice versa has to be employed.

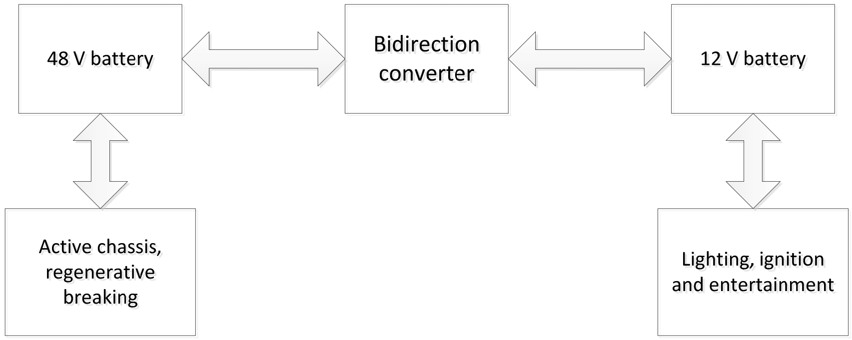
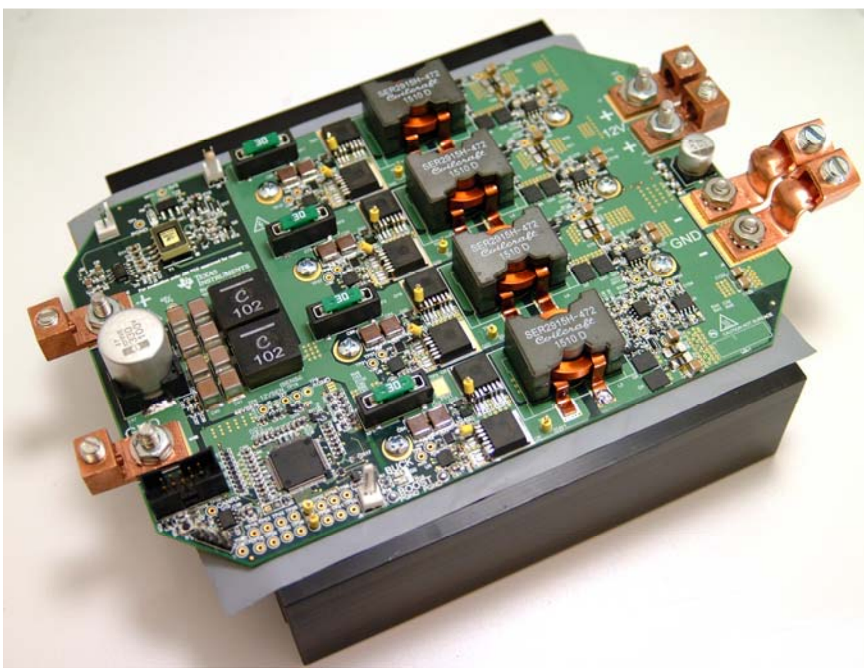


Figure 1

The above figure shows where the converter would fit in. It is expected to deliver large amount of power in a short amount of time. Due to limited space available, the converter has to be as small as possible requiring no extra cooling parts like a fan. The converter can be designed by stacking multiple converters for a higher power output.

This document discusses one such converter that uses a TI's high performace power controller.



Input : 44V~52V

Output : 11~13V

Max Power : 1.6kW

Figure 2

The converter shown above is a 4 phase Buck-Boost converter capable of handling up to 1.6 kW. It is placed above a heat sink to absorb the heat from the mosfets and inductors. It has protective fuses to prevent any short ciruit form happening.

Some of the features of the converter are mentioned below:

1) Buck-Boost operation in each phase for up to 400 Watts.
2) Ideal diode emulation.
3) Current balancing.
4) Phase shedding.
5) High efficiency (~ 96 %).
6) PMBus communication.

1 The Bidirection DCDC converter

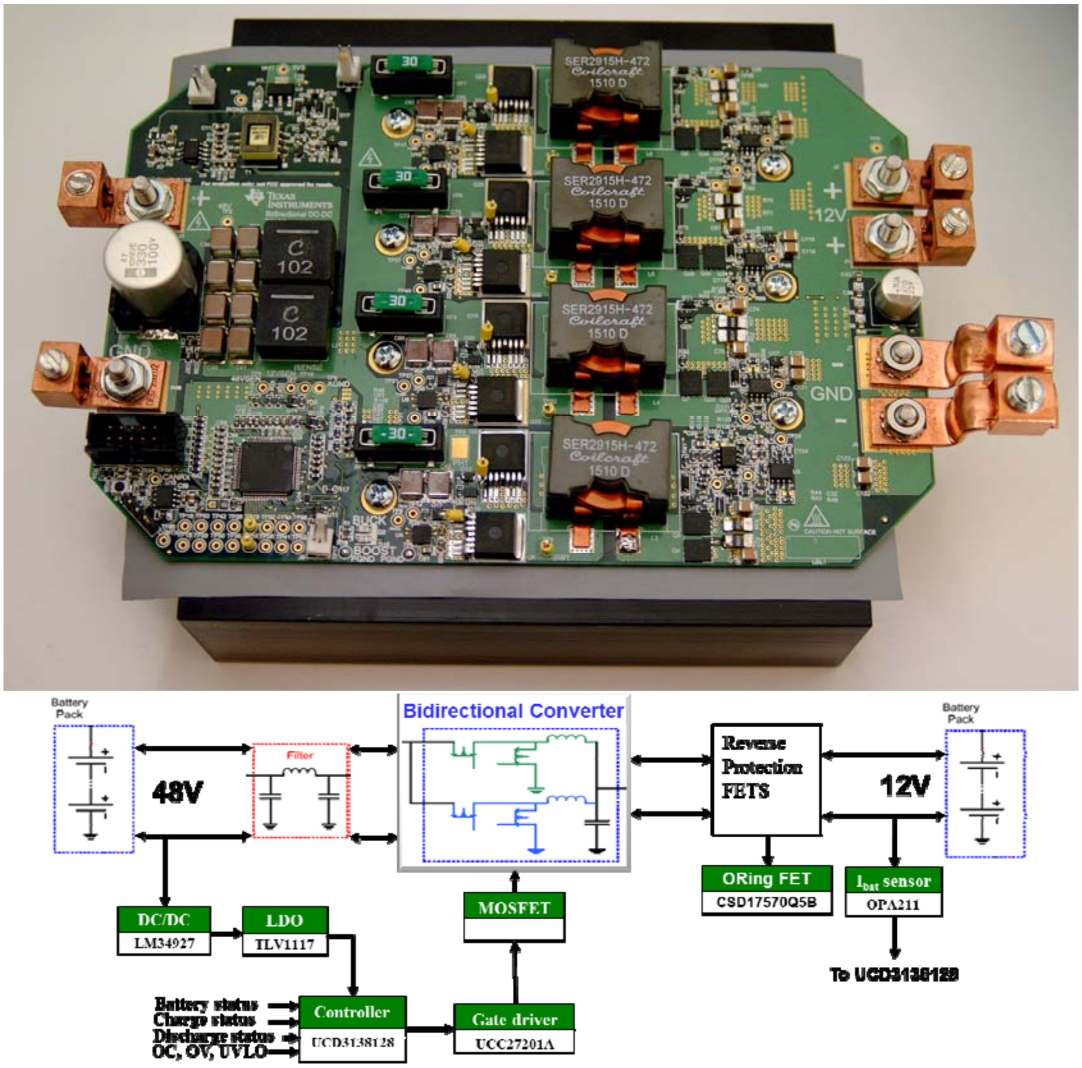


Figure 3

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 an bias supply to power up the UCD device and otherIC's. The bias works only when the 48 V battery is connected. Communication to the board is performed using PMBus. The board also uses other TI parts like the LM34927,TLV1117,OPA211 and UCC27201. The below image shows the power state of the converter:

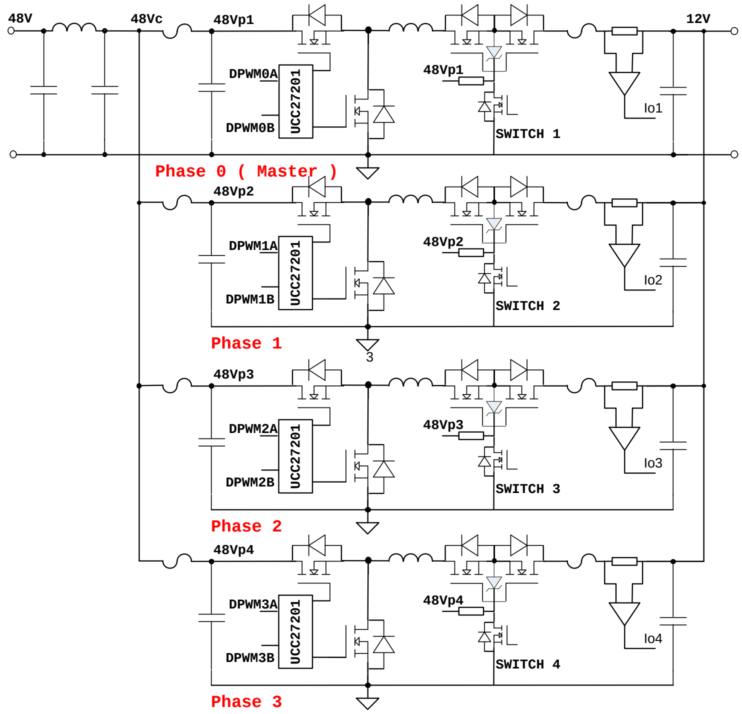


Figure 4

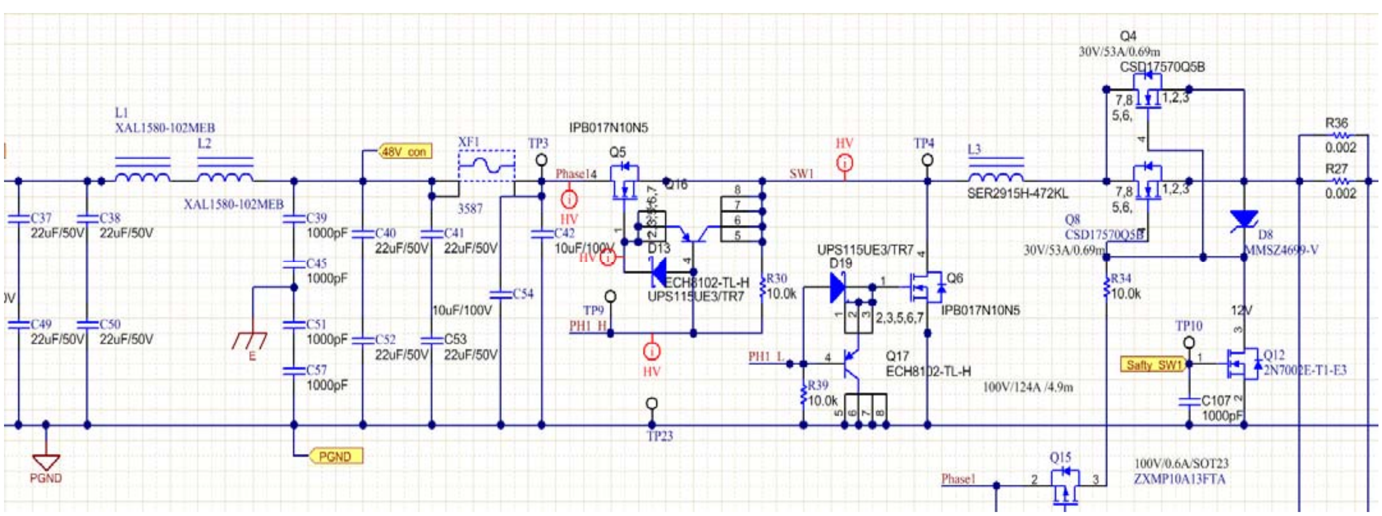


Figure 5

Figure 5 above shows the schematic for the power stage for a single phase. It uses four mosfets for the switching node. The active fets for BUCK mode are Q6 and Q7. The fets Q10 and Q13 are used as sync fets. During boost mode, the active fets are Q10 and Q13. The Fets Q6 and Q7 are used as sync fets. Following the switching node (TP 4) are the inductor and the oring fets. The oring fets are used to block any damaged phase and also to protect the controller in case the 12V battery was installed reversely. The fuses XF1 and XF2 provide safety especially when using the board with actual batteries.

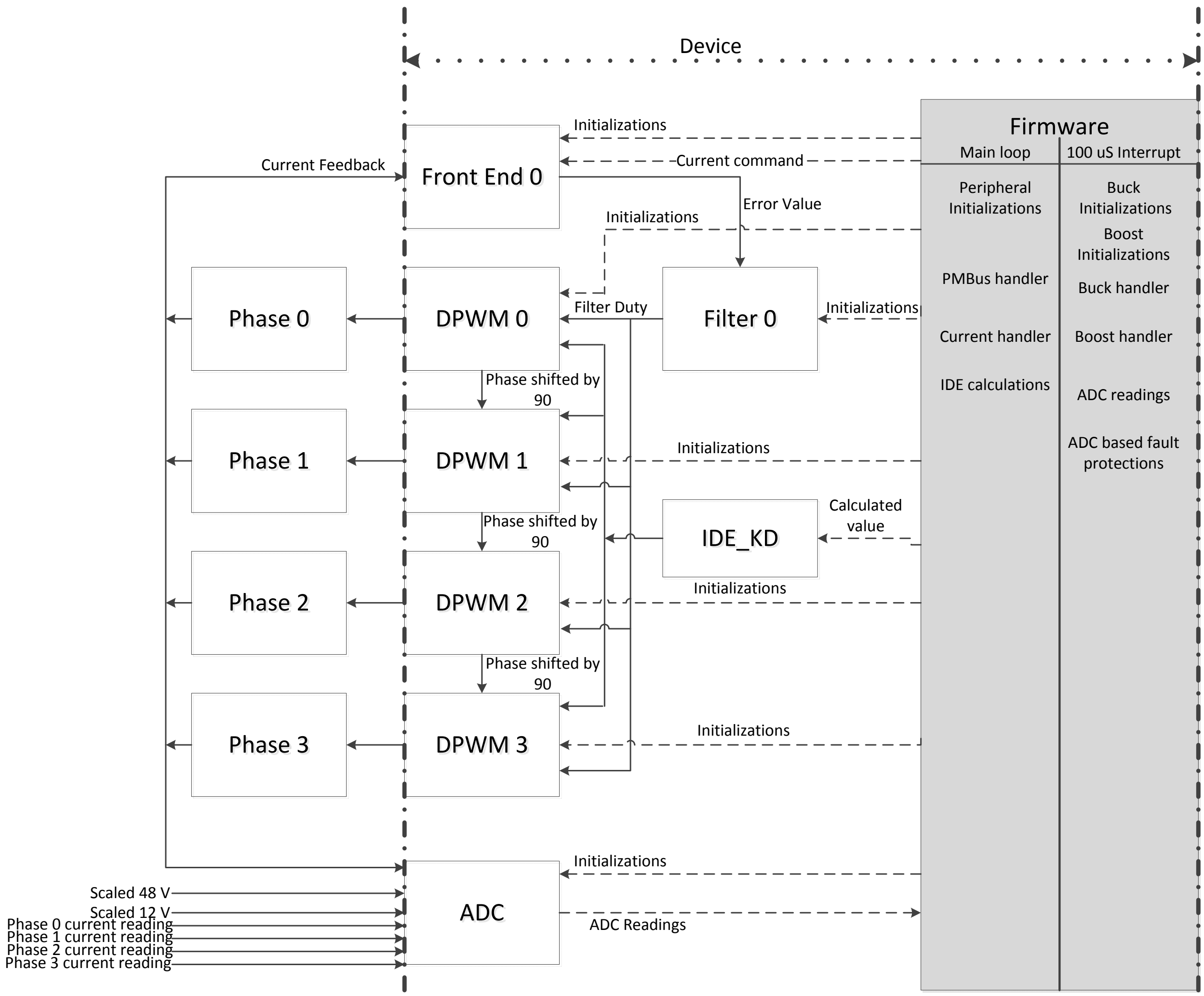


Figure 6

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 the table:

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

Table 1. ADC based protection limits

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.

2 BidirectionDCDC firmware

The code for the Bidirection DCDC converter is designed in such a way that it initializes power peripherals in the beginning for a specific topology and then lets the hardware take care of most of the control and PWM generation.

The firmware along with the hardware provides the following power supply features:

1) Buck operation.
2) Boost operation.
3) Ideal diode emulation.
4) Current ramp up/ramp down.

The following features are available for communications and firmware update :

1) PMBus communication.
2) UART communication.
3) SPI communication.
4) DFlash update.

The general flow of the program for the Bidirection DCDC converter is as shown below

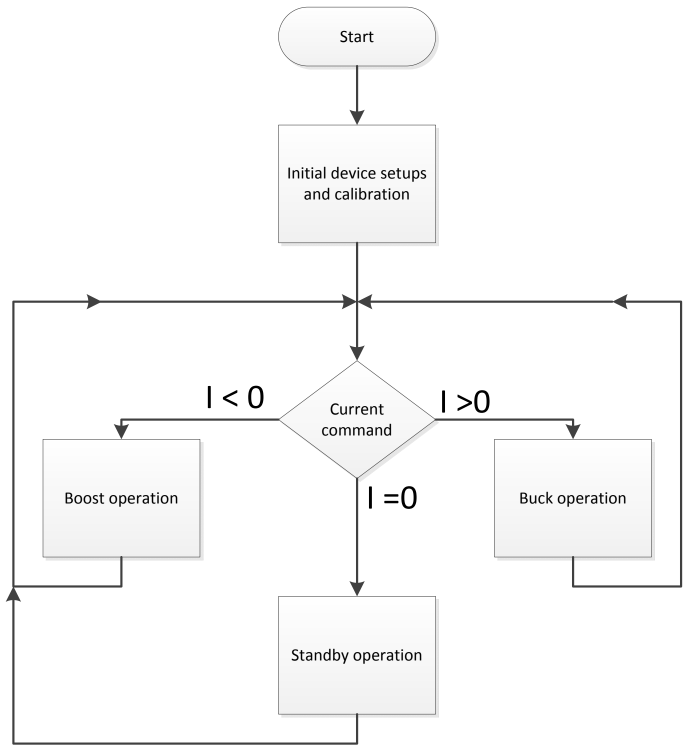


Figure 7 General code flow for Bidirection DCDC converter.

2.1 Initial device setups and calibration

When the converter is powered up, the device initially makes some sanity checks to see if the the converter is connected properly and has the components ready to do the power conversion. The following are checked in sequence :

1) 48 V battery check.
2) 12 V battery check.
3) Current feedback circuit check and calibration.
4) Peripheral initializations.

2.1.1 48 V battery check

The bias of the converter starts working as soon as a voltage of 24 and up is supplied. It is necessary that the 48 v source is checked for stability before starting any power supply converson operation. There is a minimum value required to accept the 48 V source as an input.

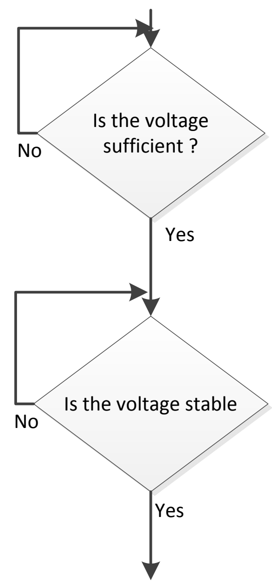


Figure 8 48 V battery check

2.1.2 12 V battery check

The 12 V battery or source has to be checked if it is present and stable. There is a minimum value required to be considered as an input. Once detected, the device waits till the 12 V source is stable.

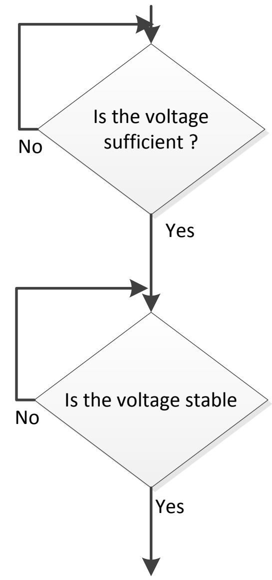


Figure 9 12 V battery check

2.1.3Current feedback circuit check and calibration.

The current feedback circuit of the Bidirection convertor is very critical for proper operation of the converter. A faulty circuit can lead to damage of the battery or switching components. Hence this circuit has to be tested for functionality and accuracy.

The current feedback circuit uses a shunt resistor and an amplifier to represent the current flowing through a phase. The output of the amplifier is setup in such a way that it can represent positive and negative currents flowing through the resistor. When no current flows through the resistor, a value of 1.25 V is expected from the amplifier output. This output is then scaled down to a value that can be taken as a current feed back and sent to EADC 0. This value can be read from the EADC as an error value to determine the actual input. But the EADC works with a reference value, hence an approximate value is needed to be fed to get the error. The approximate value can be calculated using the value read from the ADC.

Once the calculated reference value is available, it is placed in the EADC to get the error value .This error value represents the difference between the calculated value and the actual reference value needed to produce a zero error. This difference can then be added to the calculated value to represent the true reference value for zero current reading.

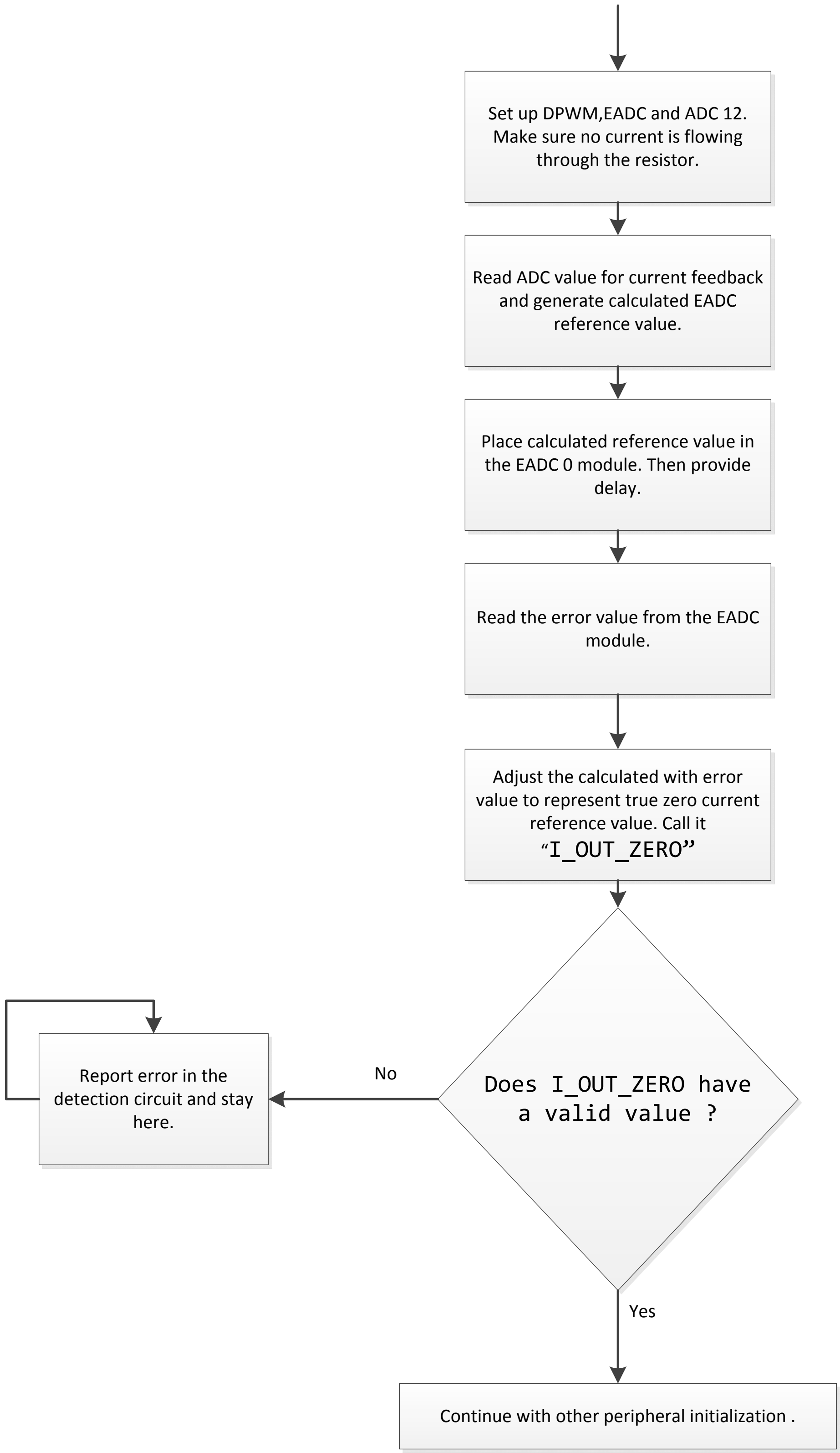


Figure 10 Current feedback circuit check and calibration

2.2 Current handler

The current handler function decides wheather the converter should operate in buck or boost mode. The current command is communicated through the PMBus and available in the background loop. The current handler looks at the polarity of current command value and makes the decision.

If the current command is positive then it puts the converter in buck mode. If it is negative, it puts the converter in boost mode. When zero, it puts the converter in standby mode.

2.3 Buck operation

The board is configured in buck mode when the received current command is positive. The firmware first initializes the peripherals to support buck operation. The code for implementing the buck mode is designed as a state machine which executes its state every 100uS.

The buck mode has 4 states:

1) Entry state : In this state the power peripherals are initialized uniquely to work with the buck mode. Peripherals affected are DPWM's,EADC 0, Filter 0 and IDE .
2) Prebias state : In this state the device senses the input and out voltage to decide on the starting duty cycle value.
3) Rampup state: In this state the device waits till the hardware ramp is complete.
4) Steady state : This is the state the device stays once all the setup and conditions have been meet. It allows the output current to be changed by doing a firmware ramp up/dowm depending on the current command. It also allows the dead time to be updated for a specific current command.

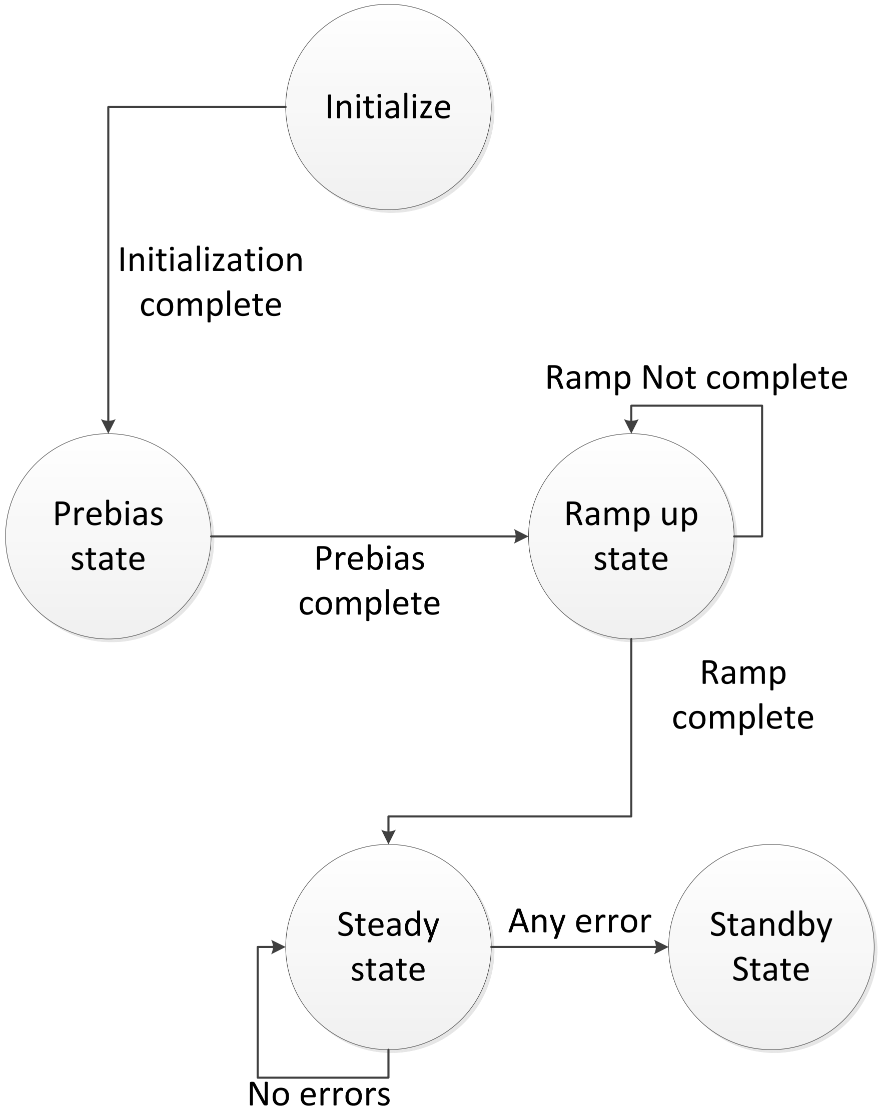


Figure 11 Buck operation state machine

2.4 Boost opertation

The boost operation is very similar to buck operation. The ony difference is is the initialization and the current ramp down implementations.

The boost mode has 4 states:

1) Entry state : In this state the power peripherals are initialized uniquely to work with the buck mode. Peripherals affected are DPWM's,EADC 0, Filter 0 and IDE .
2) Prebias state : In this state the device senses the input and output voltage to decide on

the starting duty cycle value.

3) Rampup state: In this state the device waits till the hardware ramp is complete.

4) Steady state : This is the state the device stays once all the setup and conditions have been meet. It allows the output current to be changed by doing a firmware ramp up/dowm depending on the current command. It also allows the dead time to be updated for a specific current command.

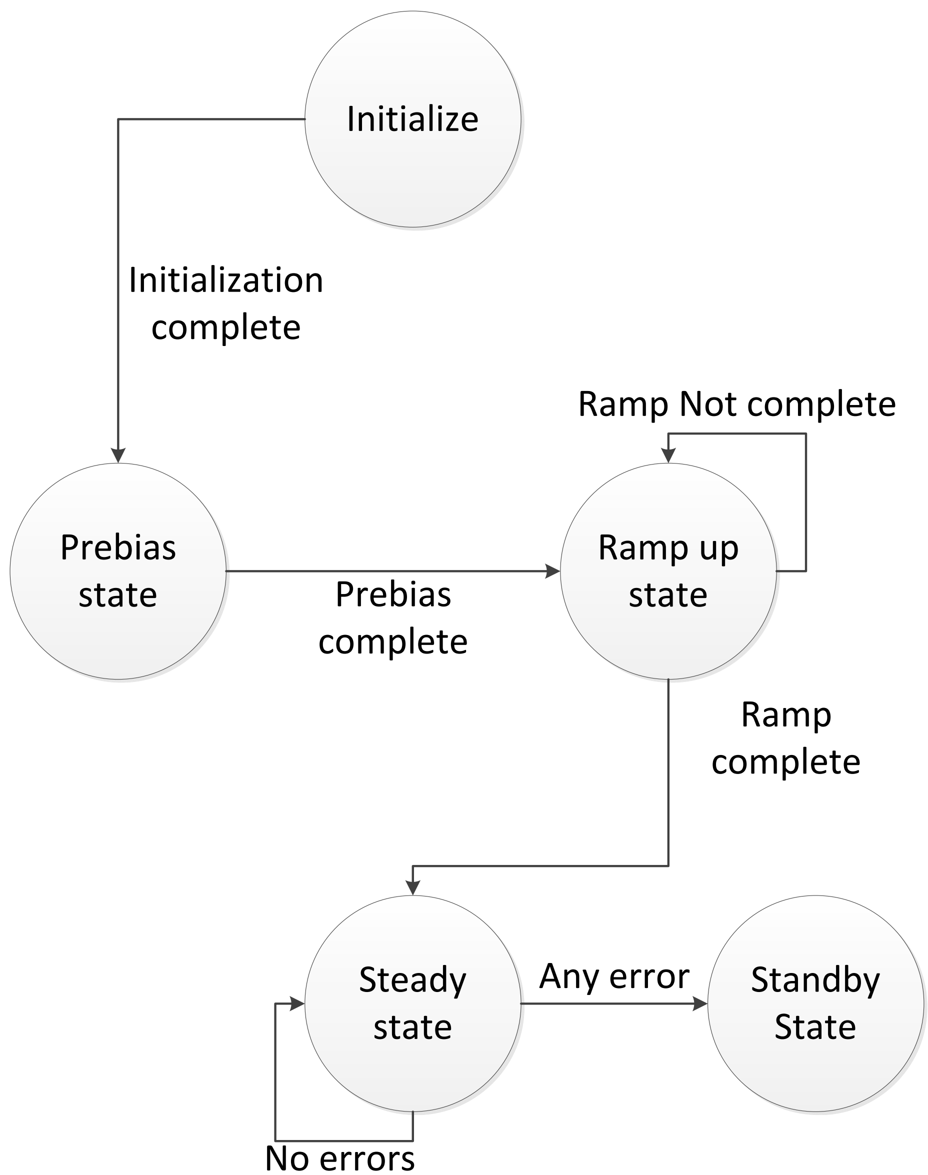


Figure 12 Boost operation state machine

2.5 ADC readings and current reading calibrations

The ADC readings form the device happens every 100 uS. The available readings are 48 V ,12 V and the phase currents. These values are averaged to 128 values.

The current detection circuits may have slightly different gains from each other and hence the ADC reading from a detection circuit of a particular phase may be different from others even though same currents are flowing through them. To compensate for this difference, the zero current reading of the detection circuit are used as the base for calculating the exact ADC reading.

2.6 Checking limits

To protect the board against any damage, limits are placed for the voltages and currents.

The protection limits are :

1) Over input voltage (The 48 V source)
2) Under input voltage .
3) Over output voltage (The 12 V source).
4) Under output voltage.
5) Cycle by cycle current limit.

The voltage limits are detected and protected by ADC 12 readings. Where as the Cycle by cycle current limit is protected using a hardware mechanism.This mechanism limits the peak current that can flow through the shunt resistor. If the current exceeds the specified limit , the hardware turns off the active switch.

2.7 Open loop operation

The firmware has a special mode called as the open loop mode where the converter acts as a simple switching device. This mode is especially useful for checking the hardware for proper connections and their working conditions after a new FET(s) has been placed. This mode provides test cases to test individual phases and also multi phase operation. To make this mode available, the firmware has to be compiled with build configuration set as “Debug_Open_loop” .

2.8 Data flash operations

The firmware allows to change some power supply related parameters like the deadtime and the protection limits. These value can be tweaked in the RAM and then placed in the DFlash for later use. The DFlash write operation can be initiated using the memory debugger GUI by writing a value “3” to the RAM variable “store”. This operation will happen in the background while the power supply is running.

During a fresh download of the firmware, default values are set to these parameters. Then after tweaking these parameters, they can be written to the DFlash.

Note : Please perform firmware updates without effecting the DFlash.

2.9 Compiling code in Code Composer Studio

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…”

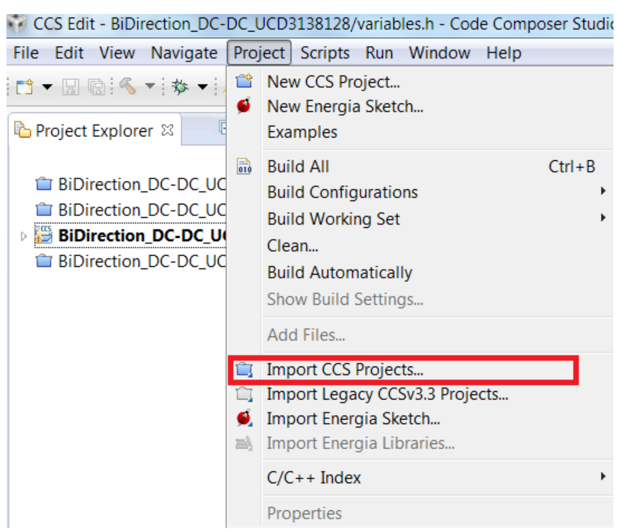


Figure 13 Project import for CCS

Select the folder and click on “OK”.

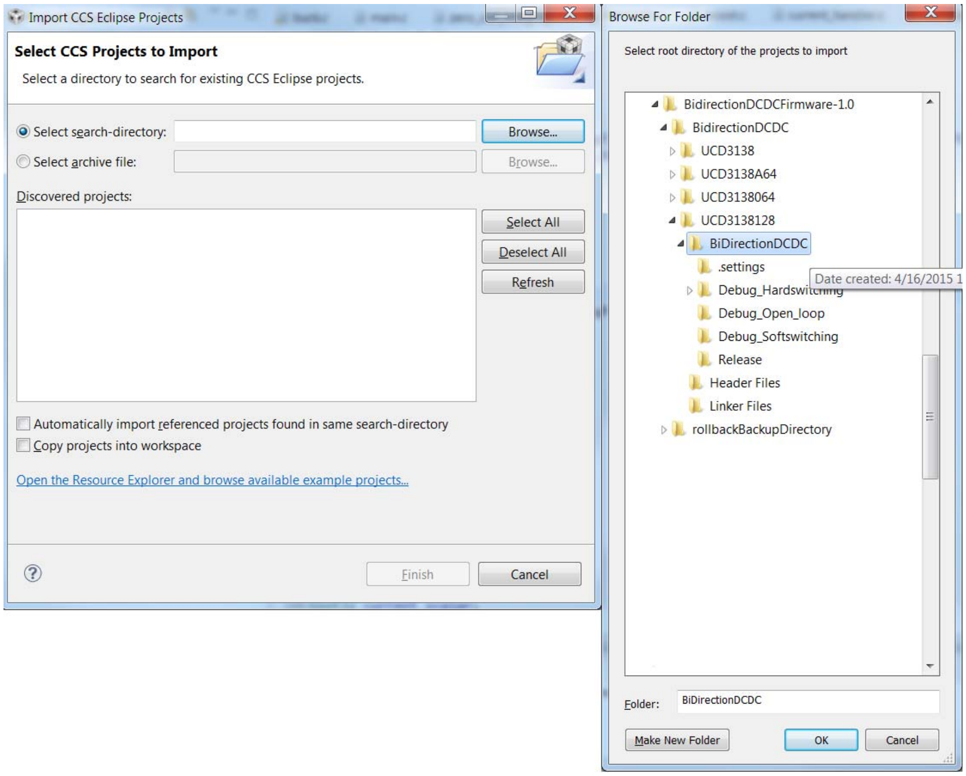


Figure 14 Project selection

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.

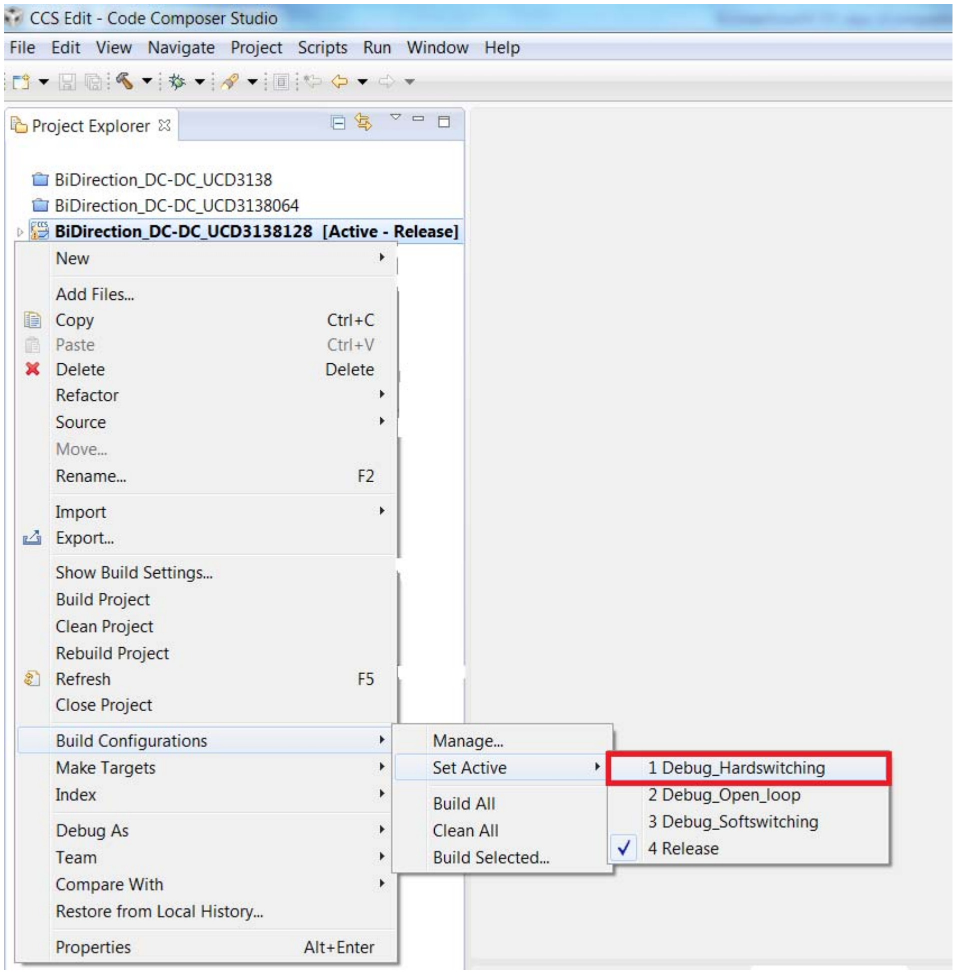


Figure 15 Build configuration setting

Now build the project as shown in the figure below:

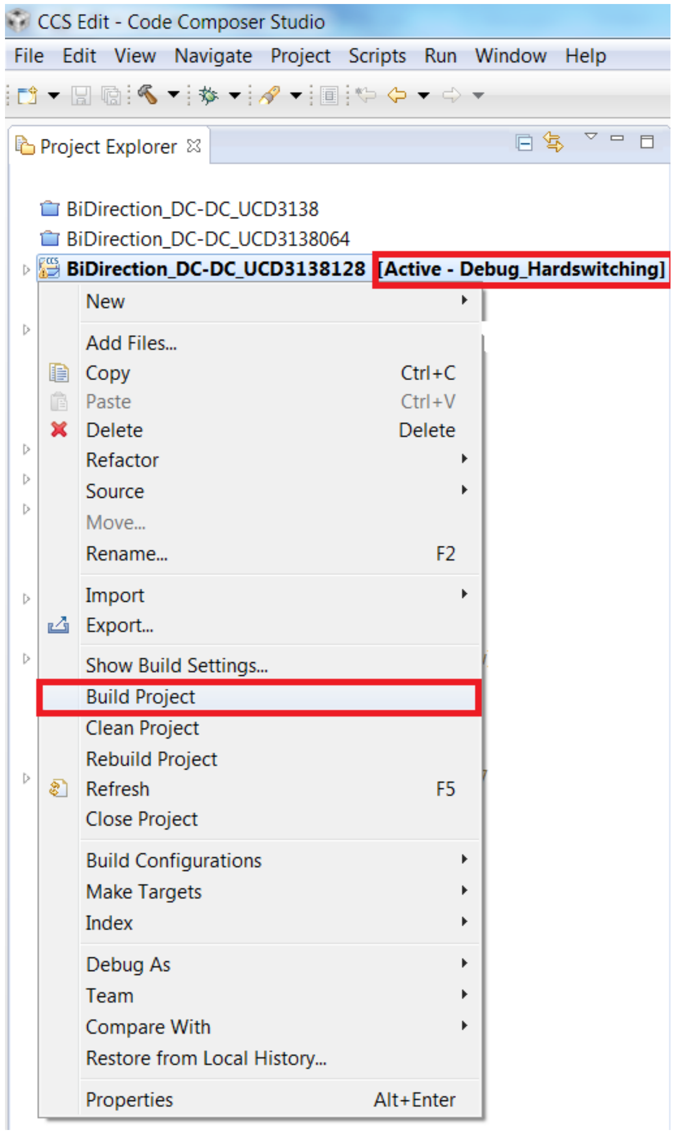


Figure 16 Compiling the project

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

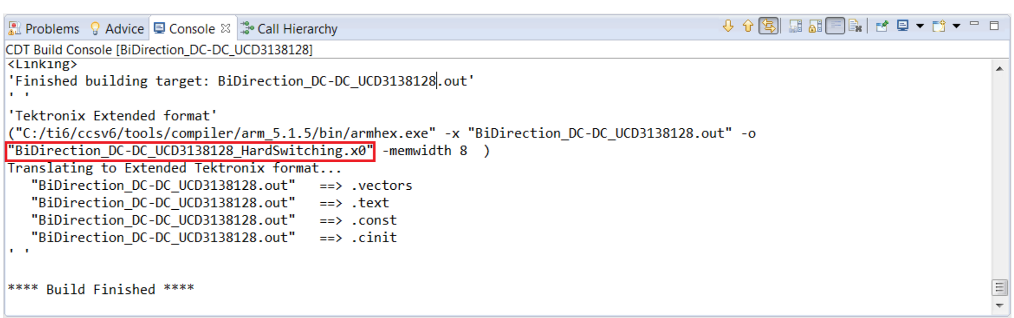


Figure 17 Compilation result and output

3 Using the Bidirection DCDC converter

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 powersupply/load configuration to simulate a battery. The image shown below illustrates how the connections has to be made:

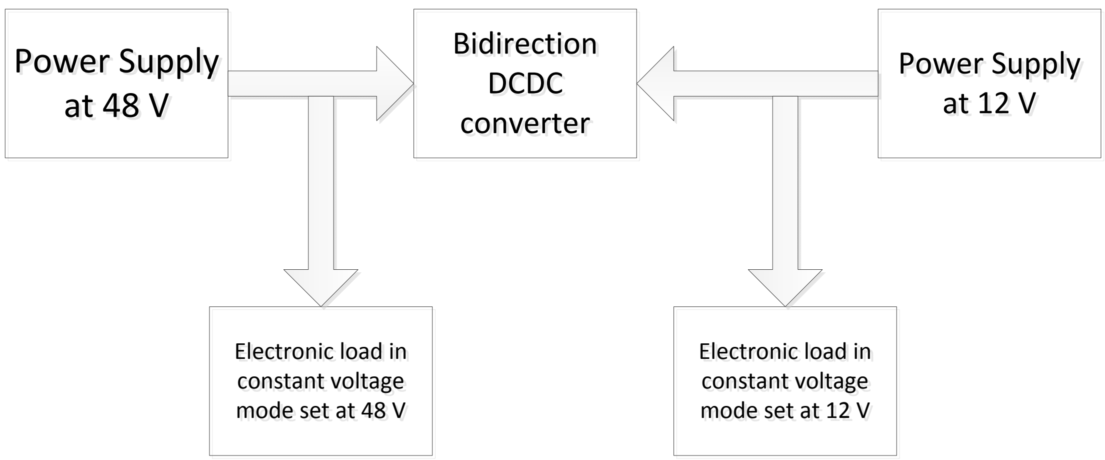


Figure 18

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.

Now lets explore the Fusion GUI that allows you to download the firmware and run the converter:

Downloading the 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:

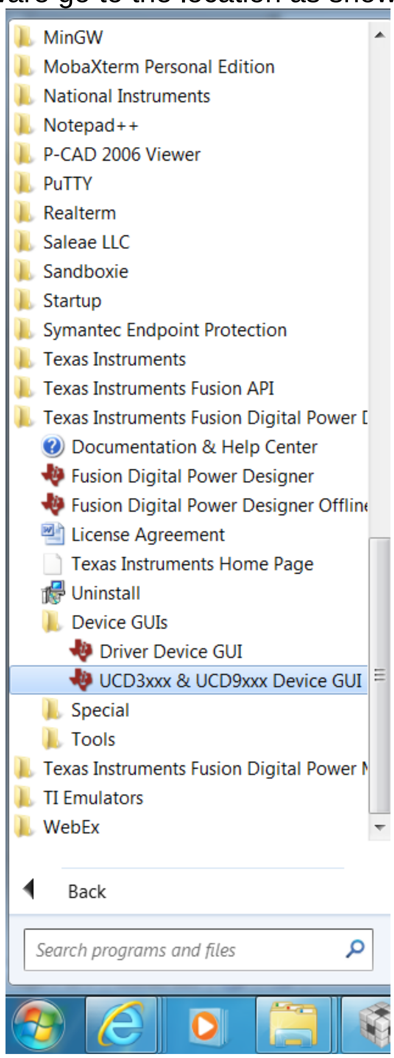


Figure 19

The window as shown should appear:

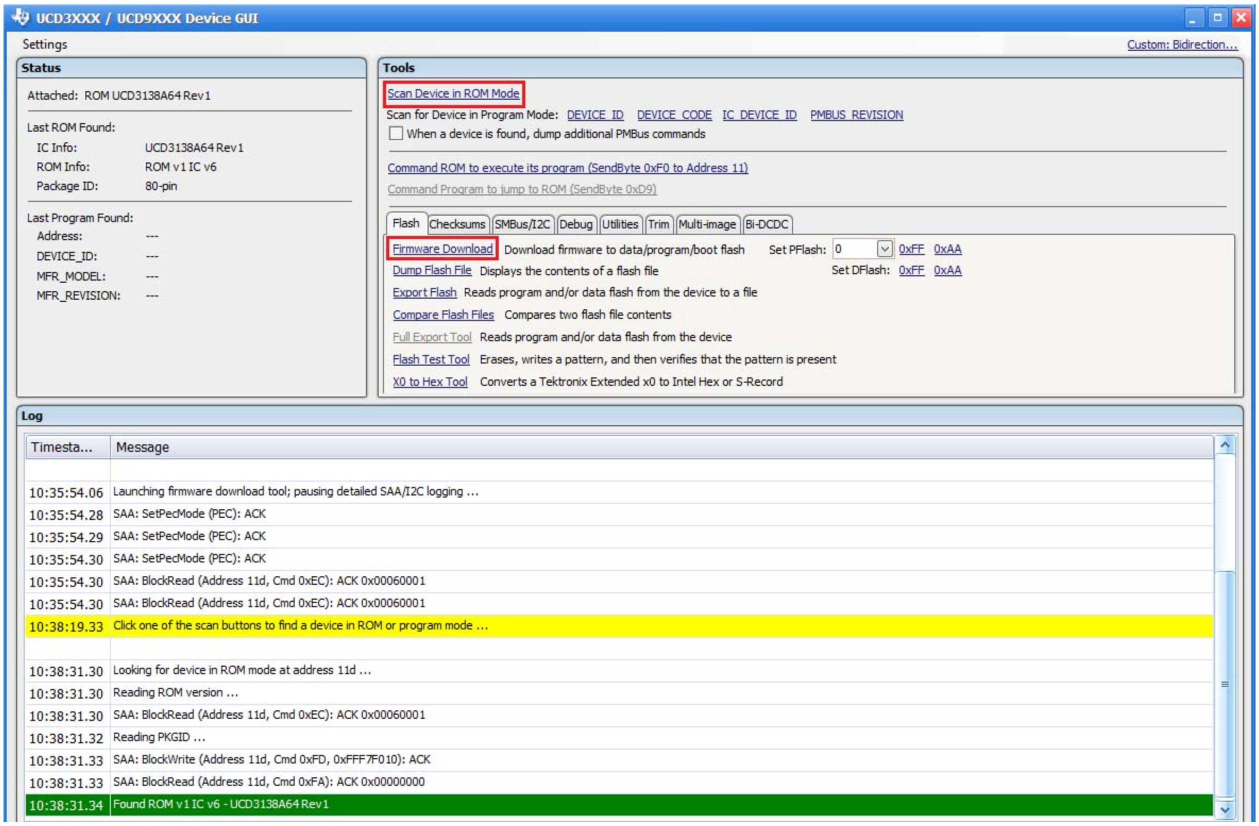


Figure 20

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” :

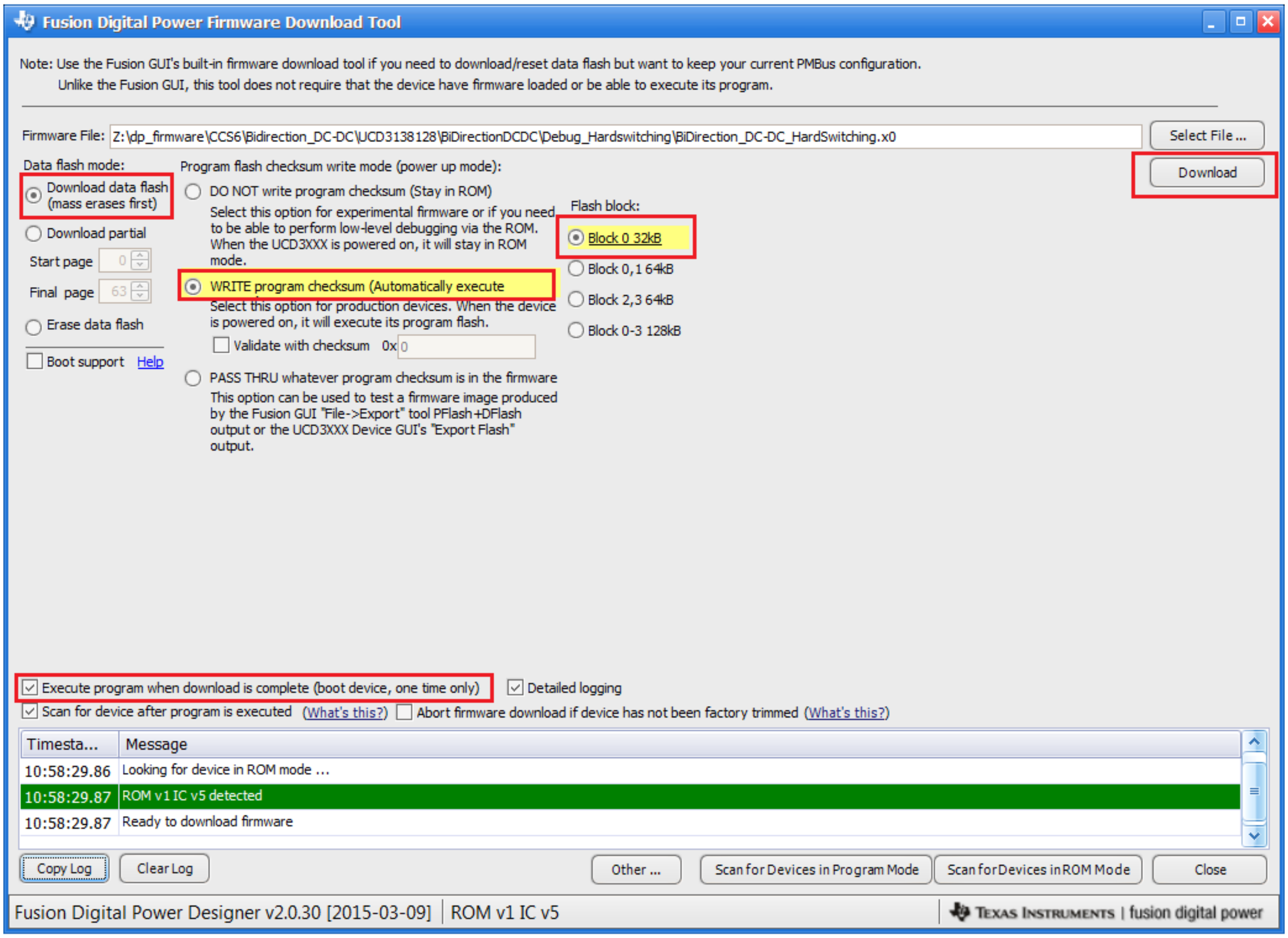


Figure 21

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.

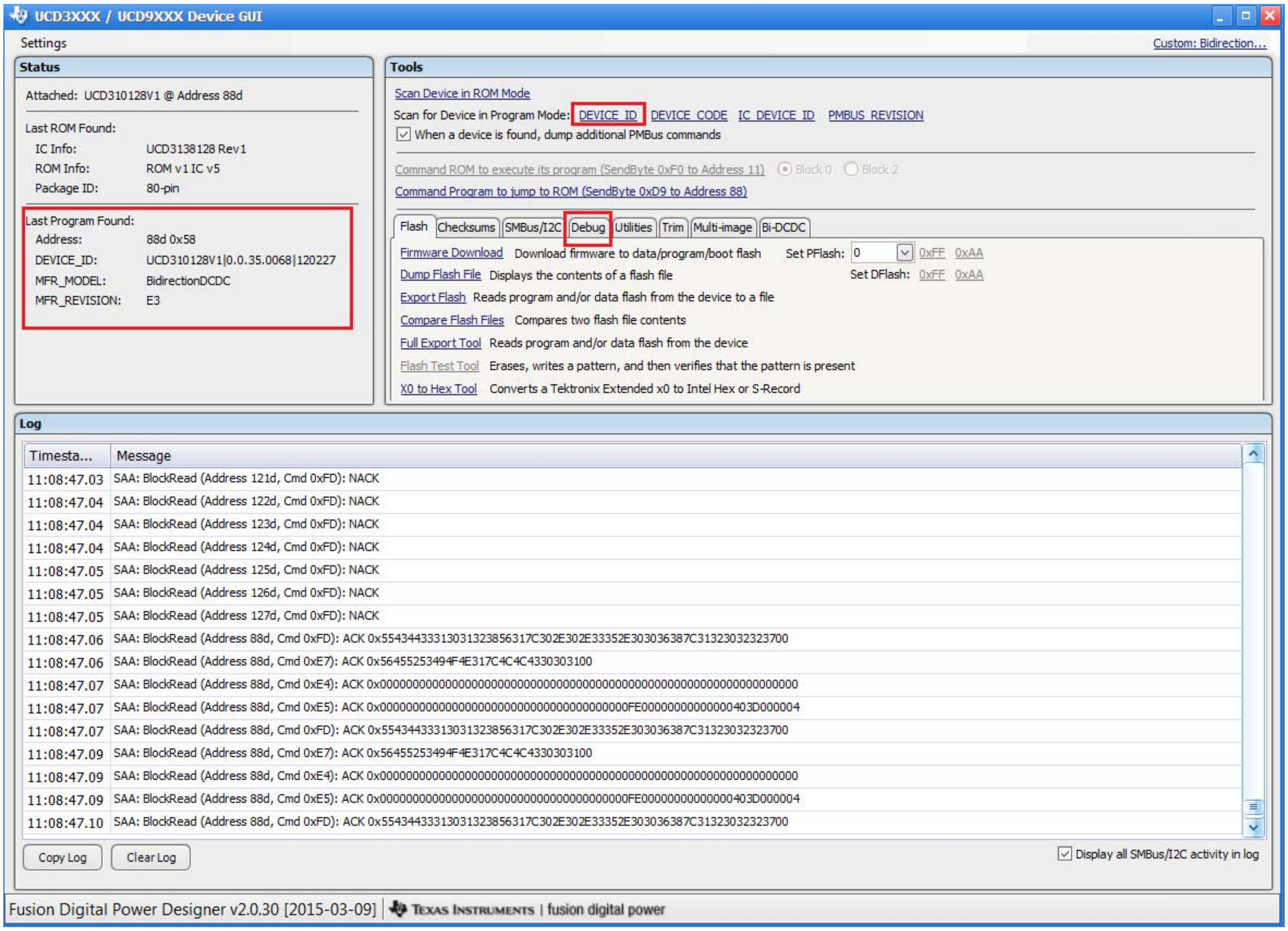


Figure 22

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

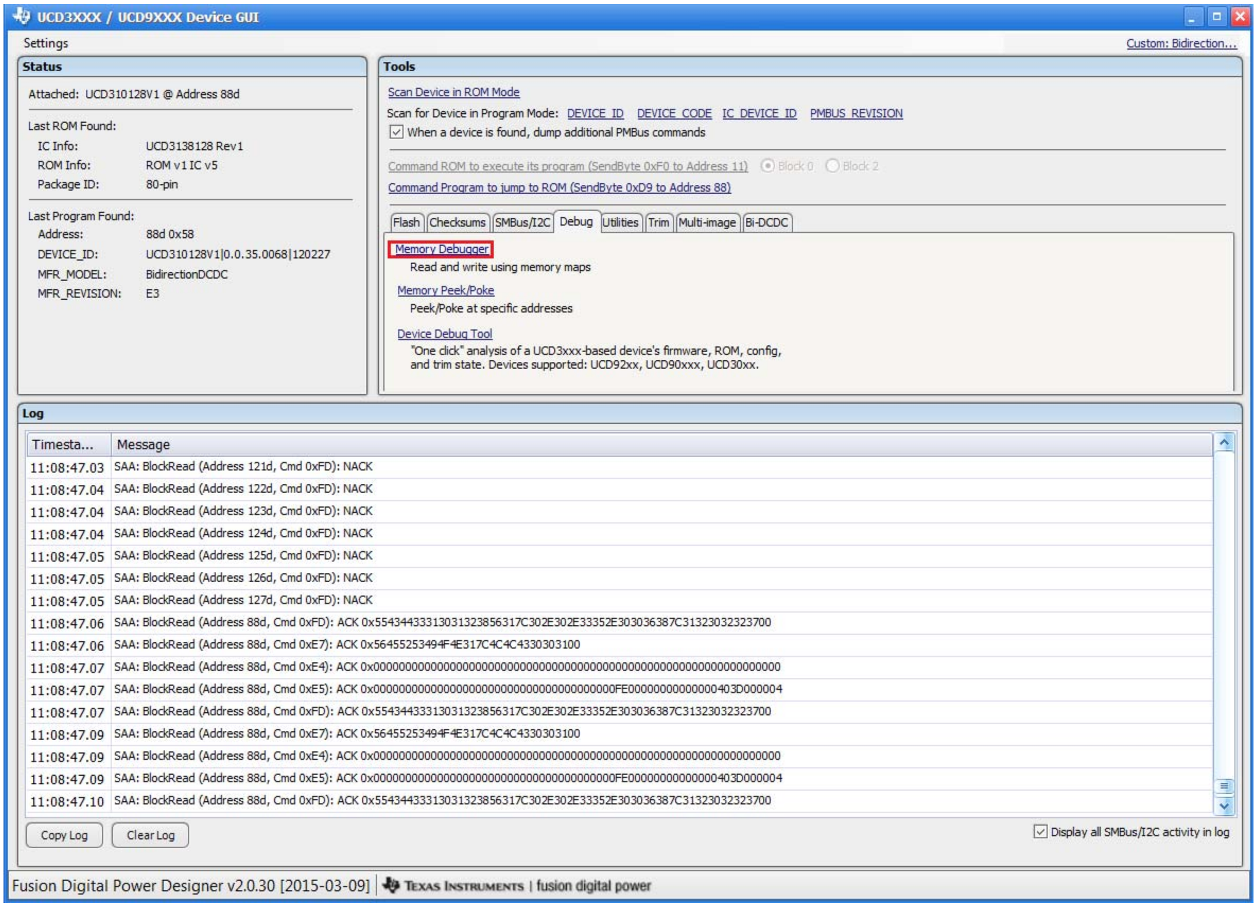


Figure 23

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

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

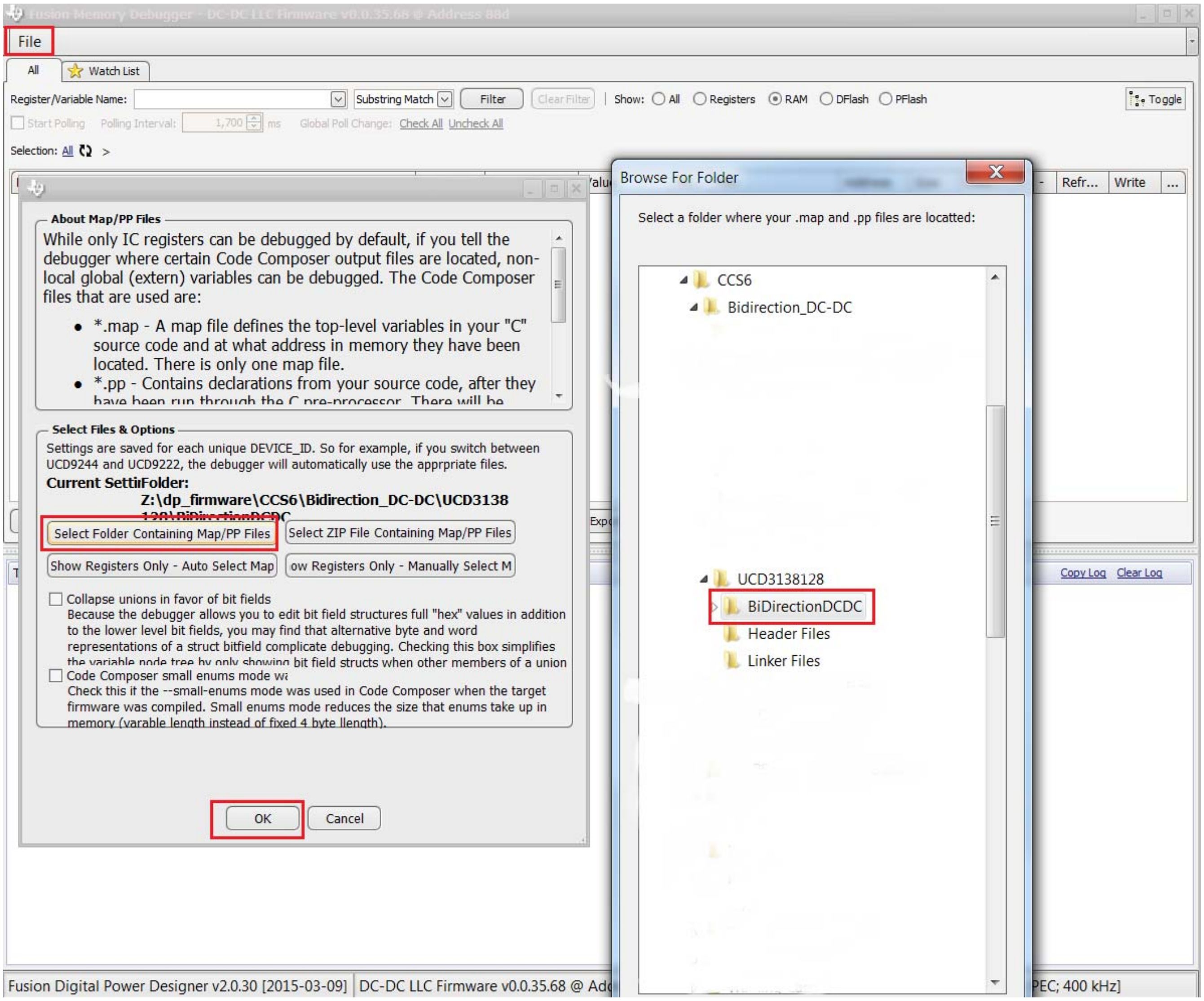


Figure 24

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

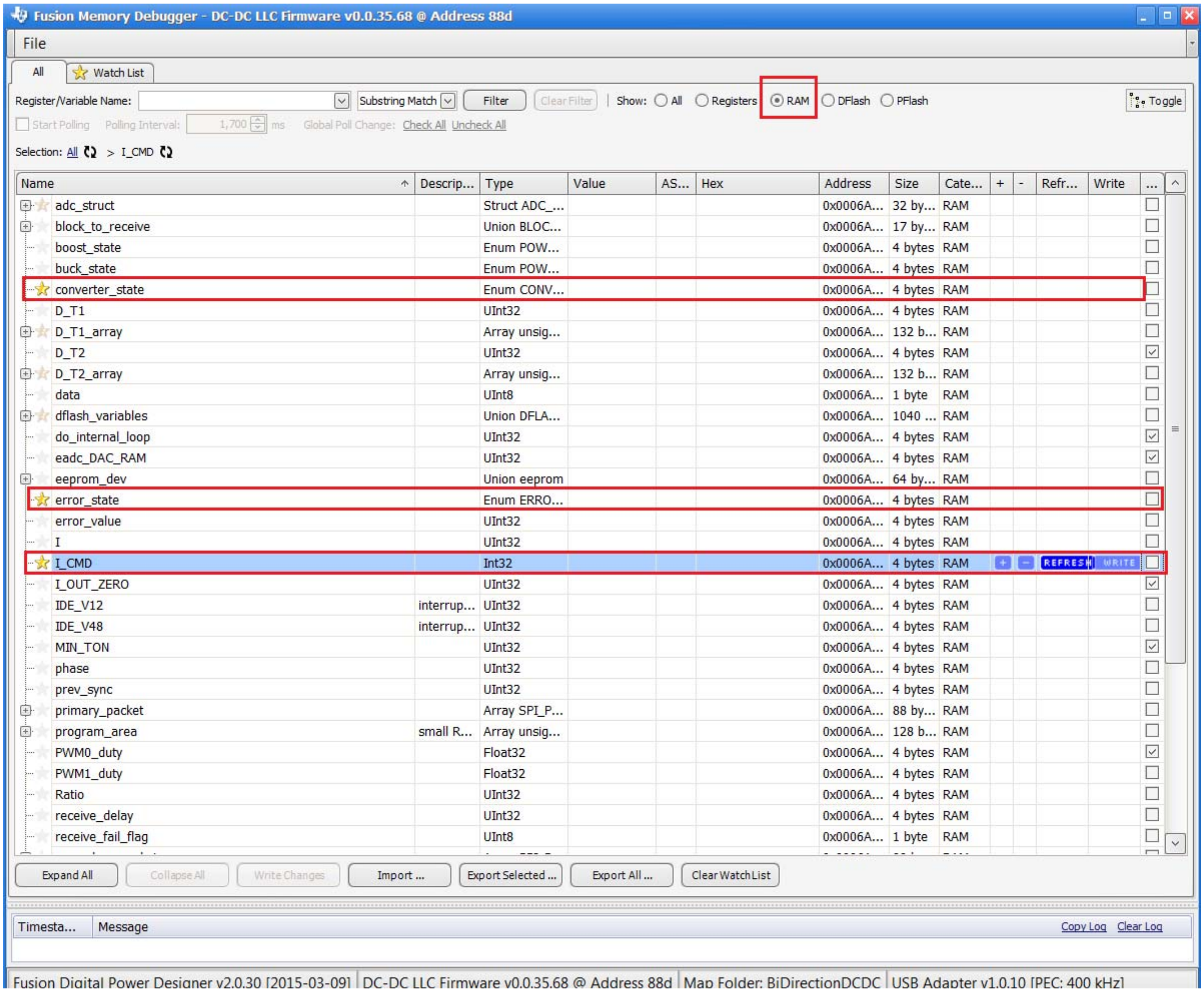


Figure 25

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.

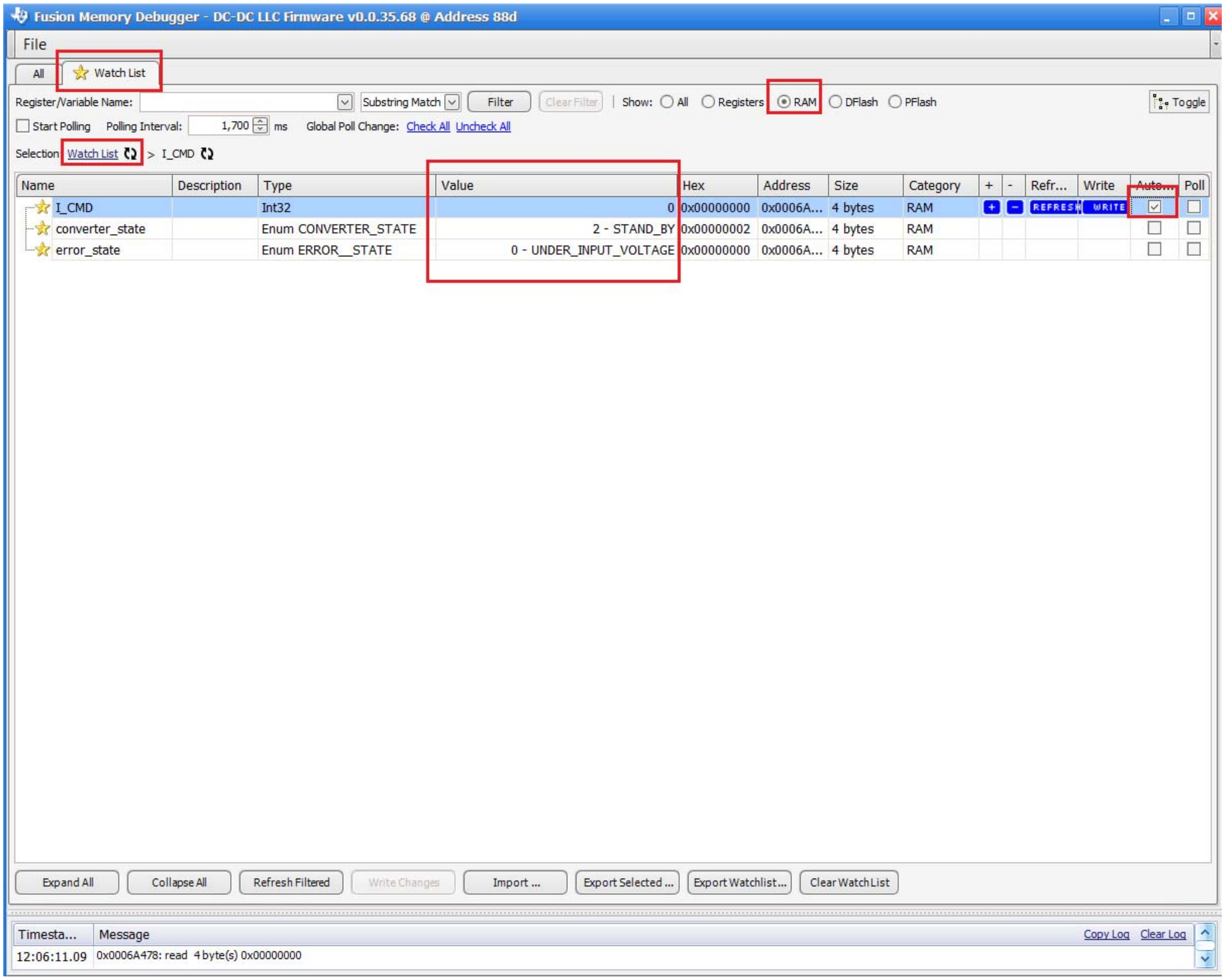


Figure 26

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	Write

	to 48 V. 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 2. 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.

4 Using the Bidirection DCDC GUI

The Fusion GUI has an in buit feature to support the Bidirection DCDC converter. It allows direct dontrol of the board in a more graphical form.

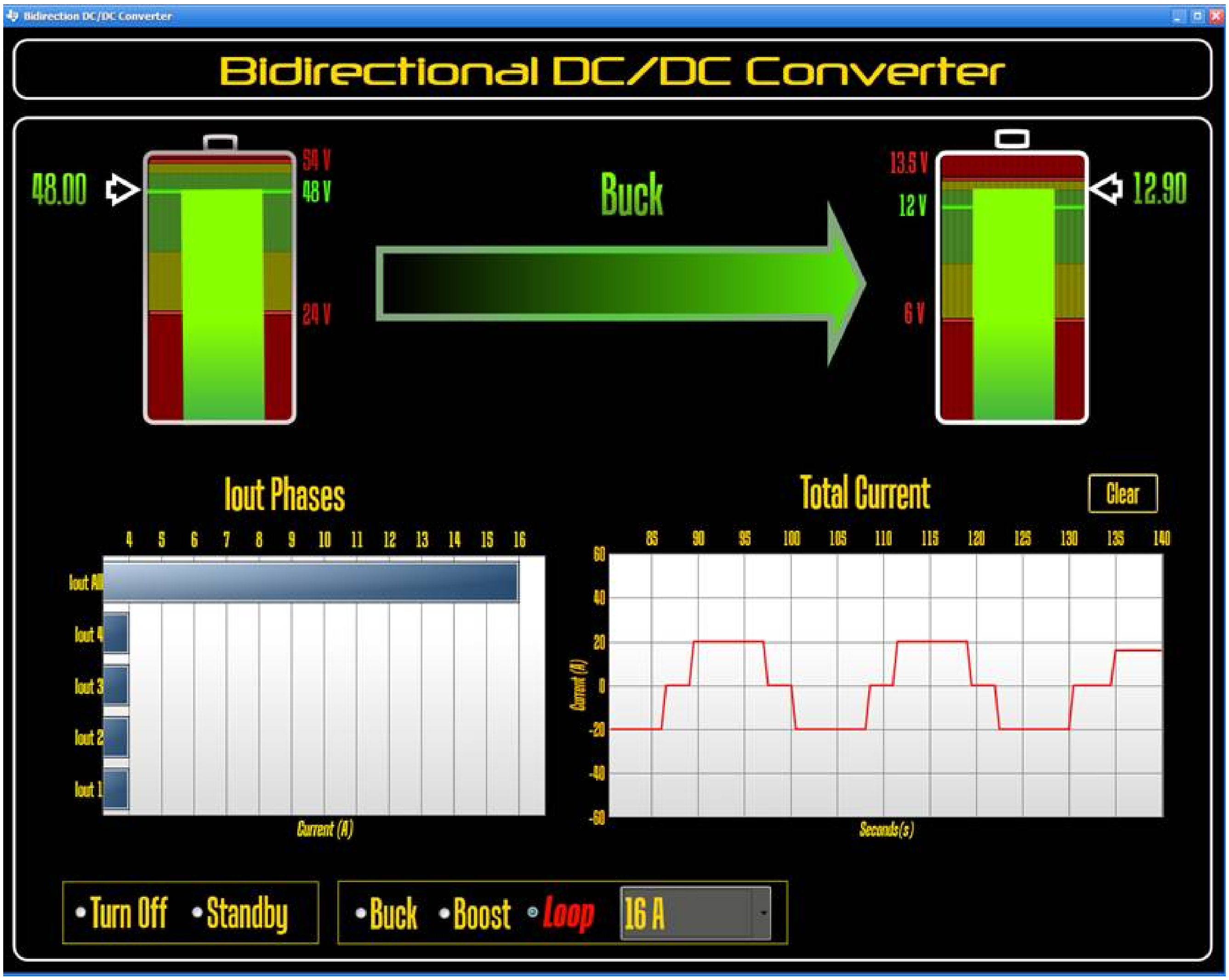


Figure 27

To launch the program , the Fusion GUI will need a custom code to activate this section.

Please follow the steps below to activate it:

Click on the “Settings” label in the GUI as shown:

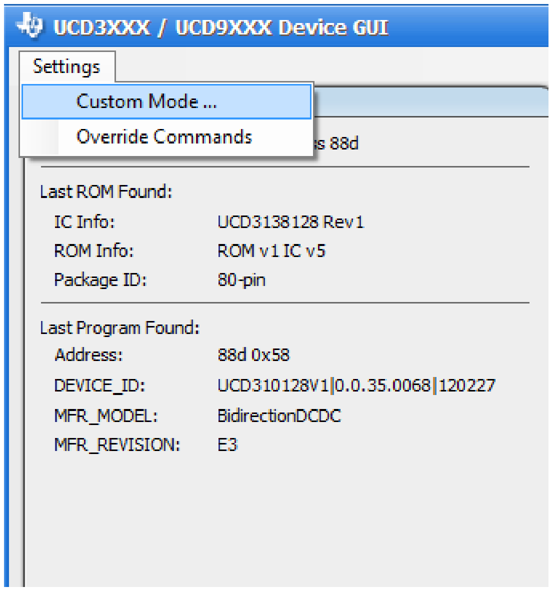


Figure 28

Enter the password “bidcdc” and click “OK”.

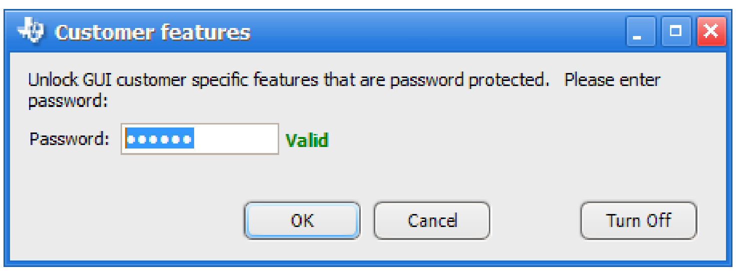


Figure 29

After entering the code, a new tab is available as shown :

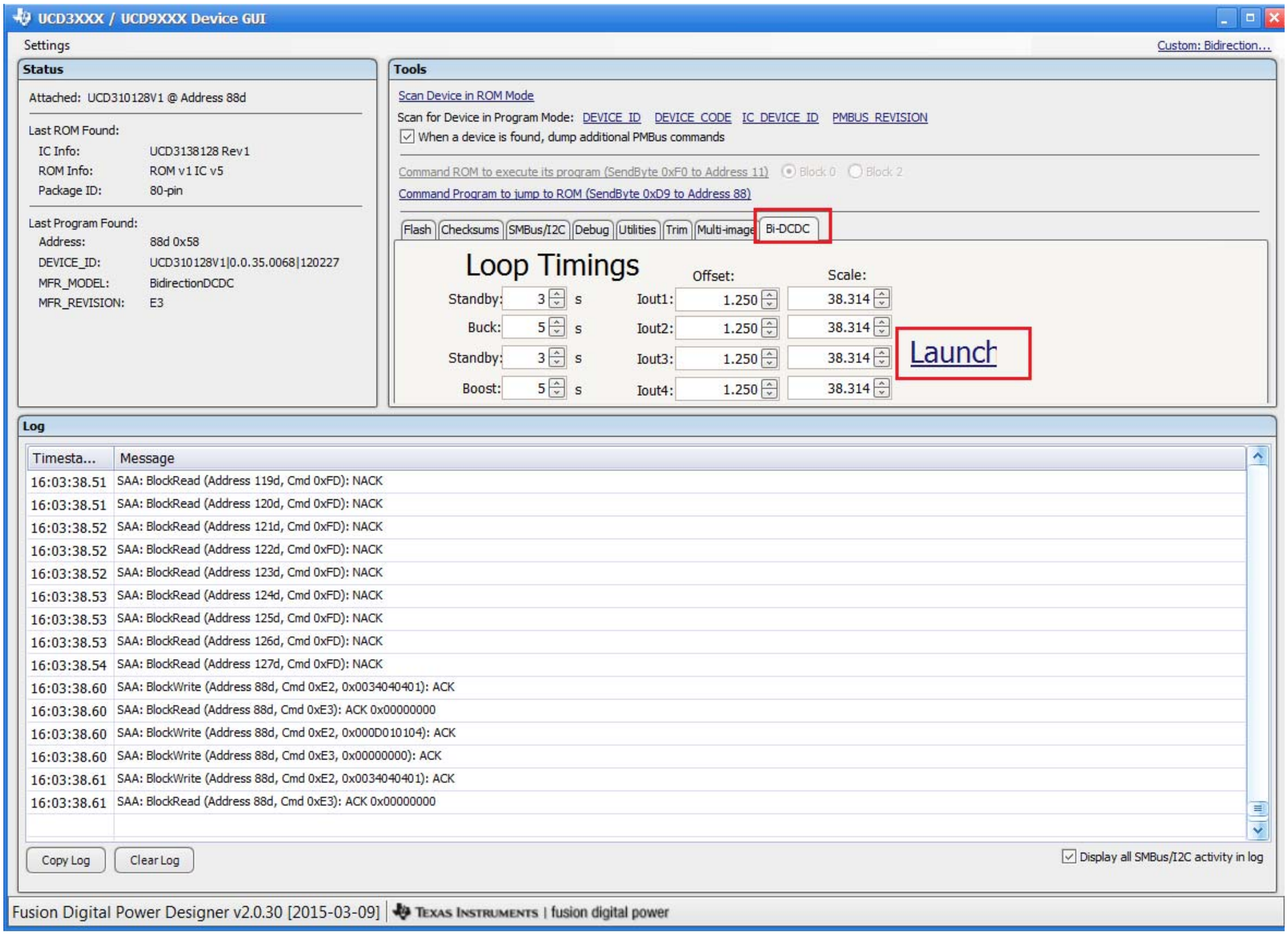


Figure 30

Click on “DEVICE ID” and then click on “Launch” to open the BidirectionDCDC converter GUI.

To run the converter, first, select the current at which you would be operating:

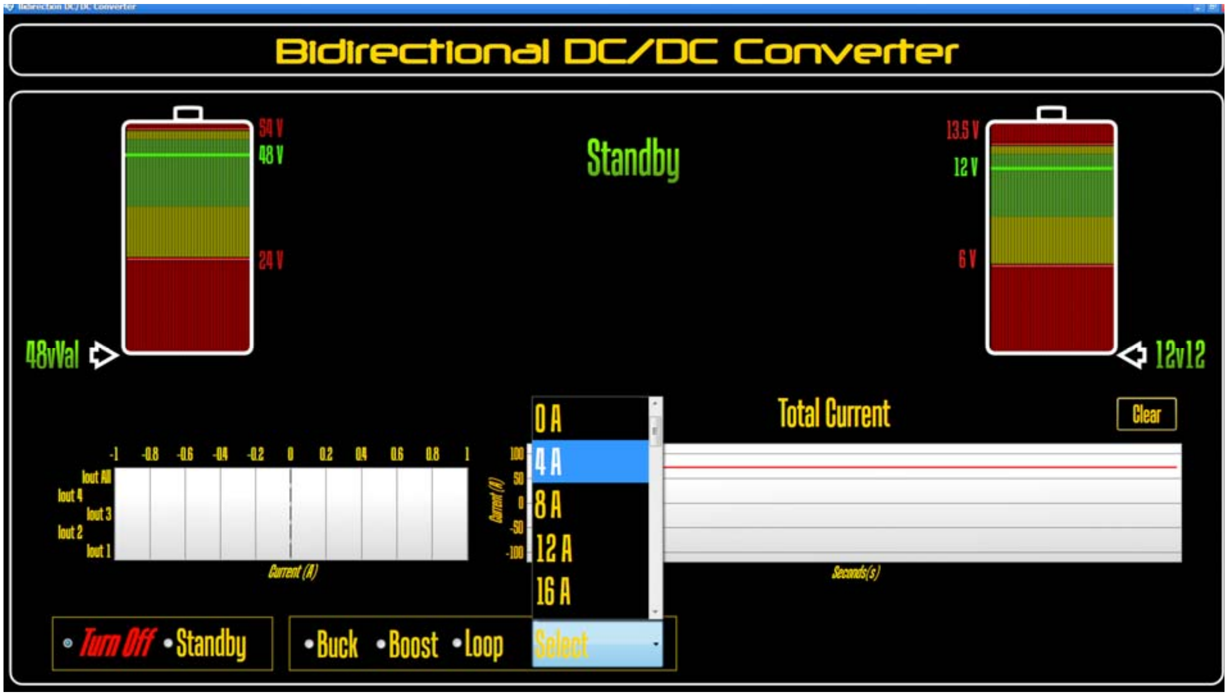


Figure 31

Then click on either Buck or the Boost radio button to run the converter.

The table below describes the operation of the radio buttons:

Radio Button	Decsription
Turn off	This button turns off the GUI and puts the converter in standby mode. Here the graphs are not updated.
Standby	This button puts the converter in standby i.e it is not doing any power supply operations. However, the graphs will be updated with their current values.
Buck	This button puts the converter in Buck mode. Here the 48 V source is being dischared and the 12 V source is being charged.
Boost	This button puts the converter in Boost mode. Here the 48 V source is being charged and the 12 V source is being discharged.
Loop	This button puts the converter alternating between Buck , standby and boost mode. The duration of each mode is decided by the value placed in the “Loop Timings” shown in the “Bi-DCDC” tab(See figure 19).

Table 3 Radio buttons description.

5 Results and test data

5.1 Effeciency plots

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

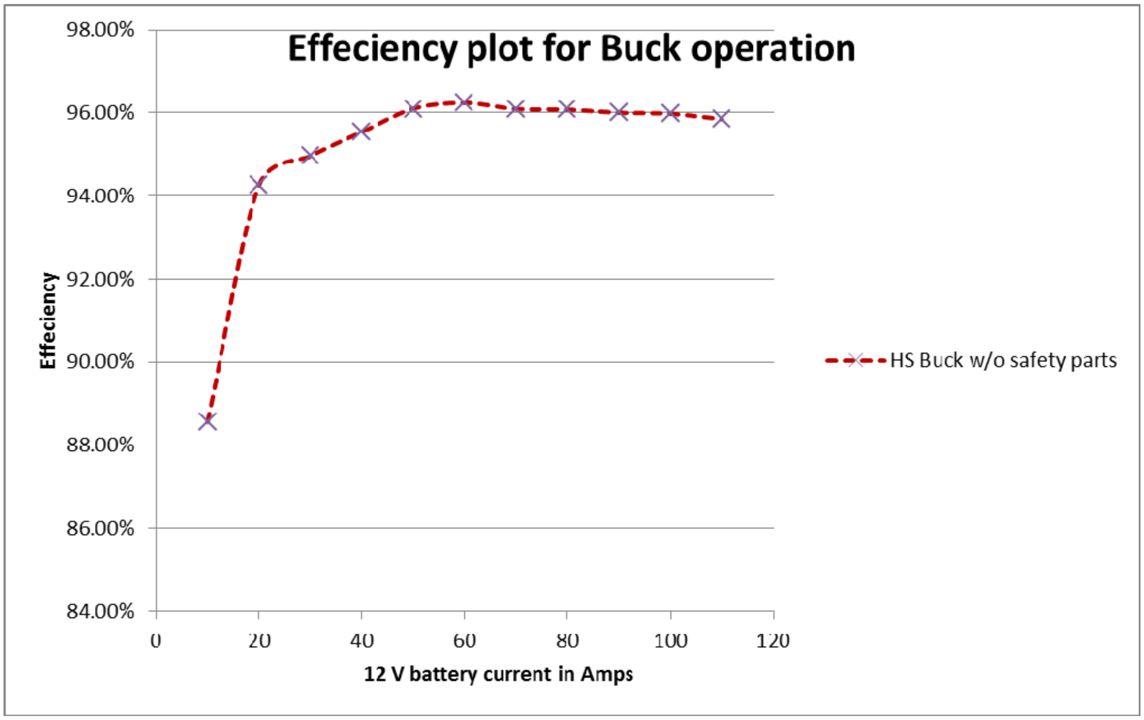


Figure 32 Efficiency plot for Hardswitching Buck operation

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.

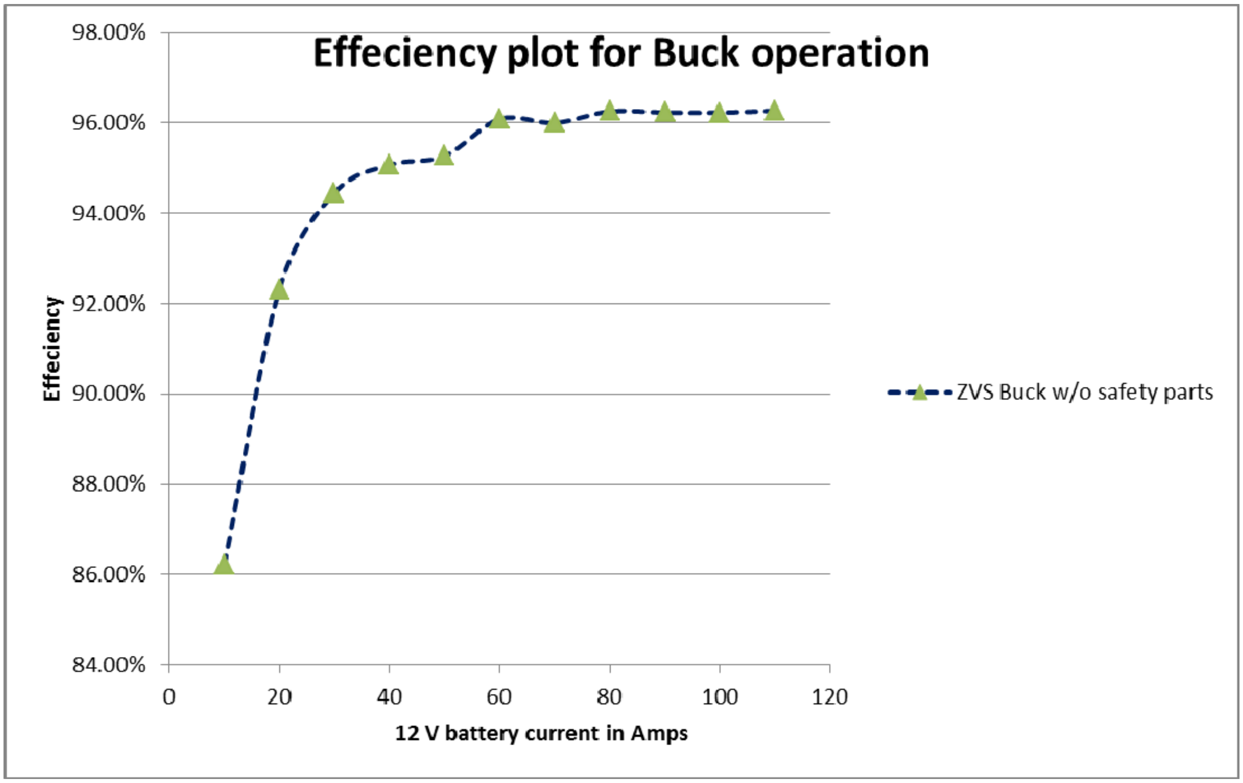


Figure 33 Efficiency plot for ZVS Buck operation

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.

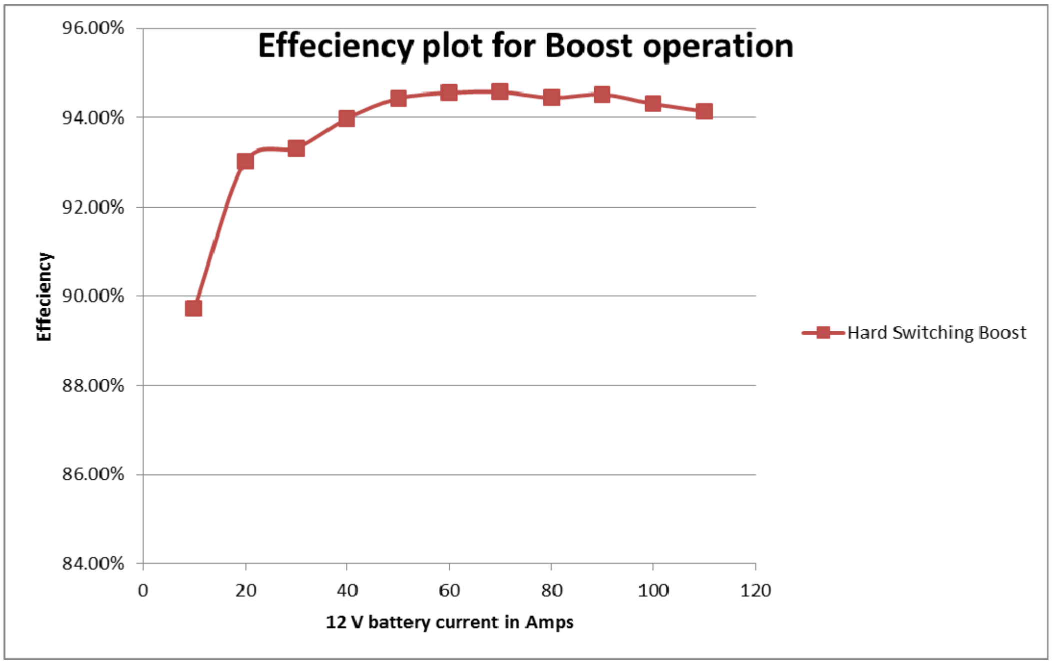


Figure 34 Efficiency plot for Hardswitching Boost operation

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.

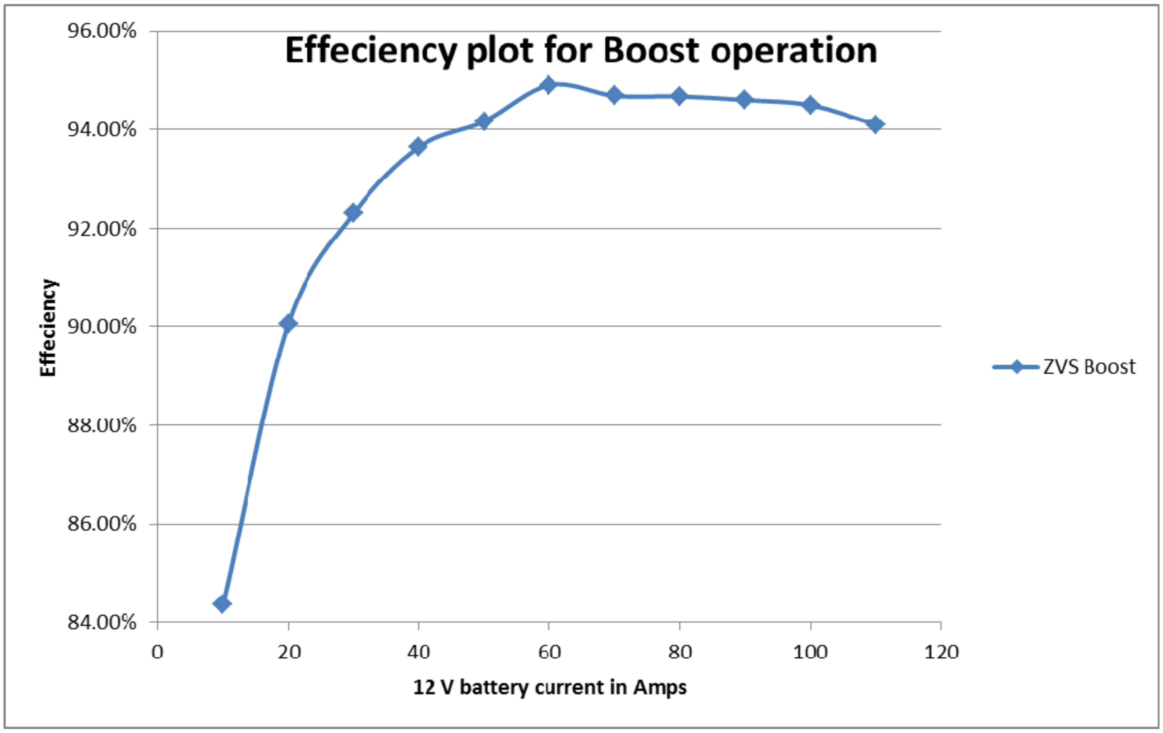


Figure 35 Efficiency plot for ZVS Boost operation

5.2 Loss analysis

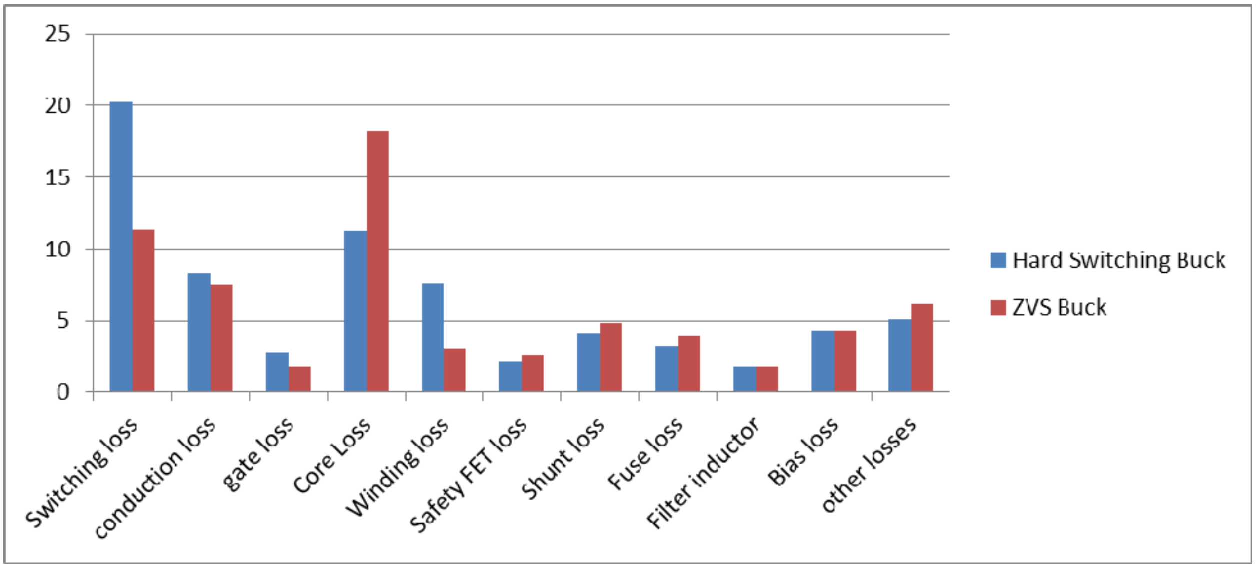
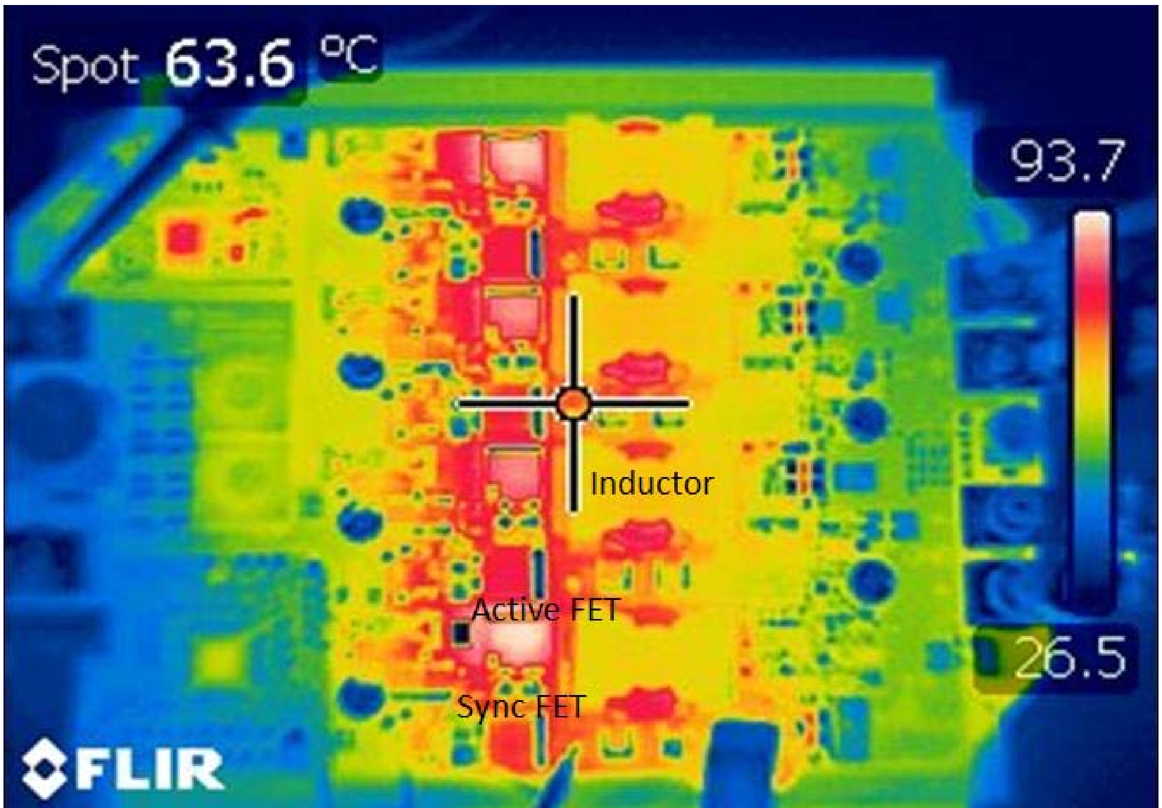


Figure 36 Different losses for Hardswitching and ZVS topologies.

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

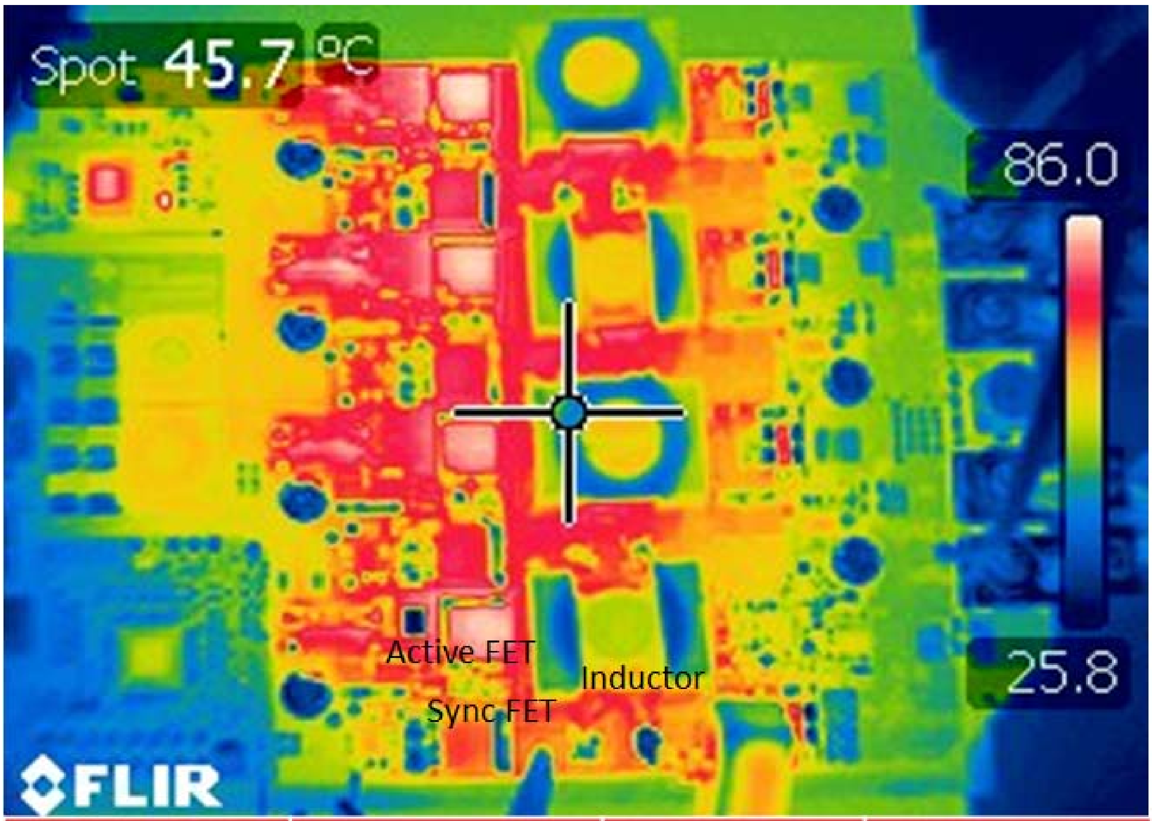
5.3 Thermal data



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

Figure 37 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 38 Thermal image of the BidirectionDCDC board on a heat sink performing ZVS Buck operation at 110 A.

5.4 Operating the board in Buck and Boost mode.

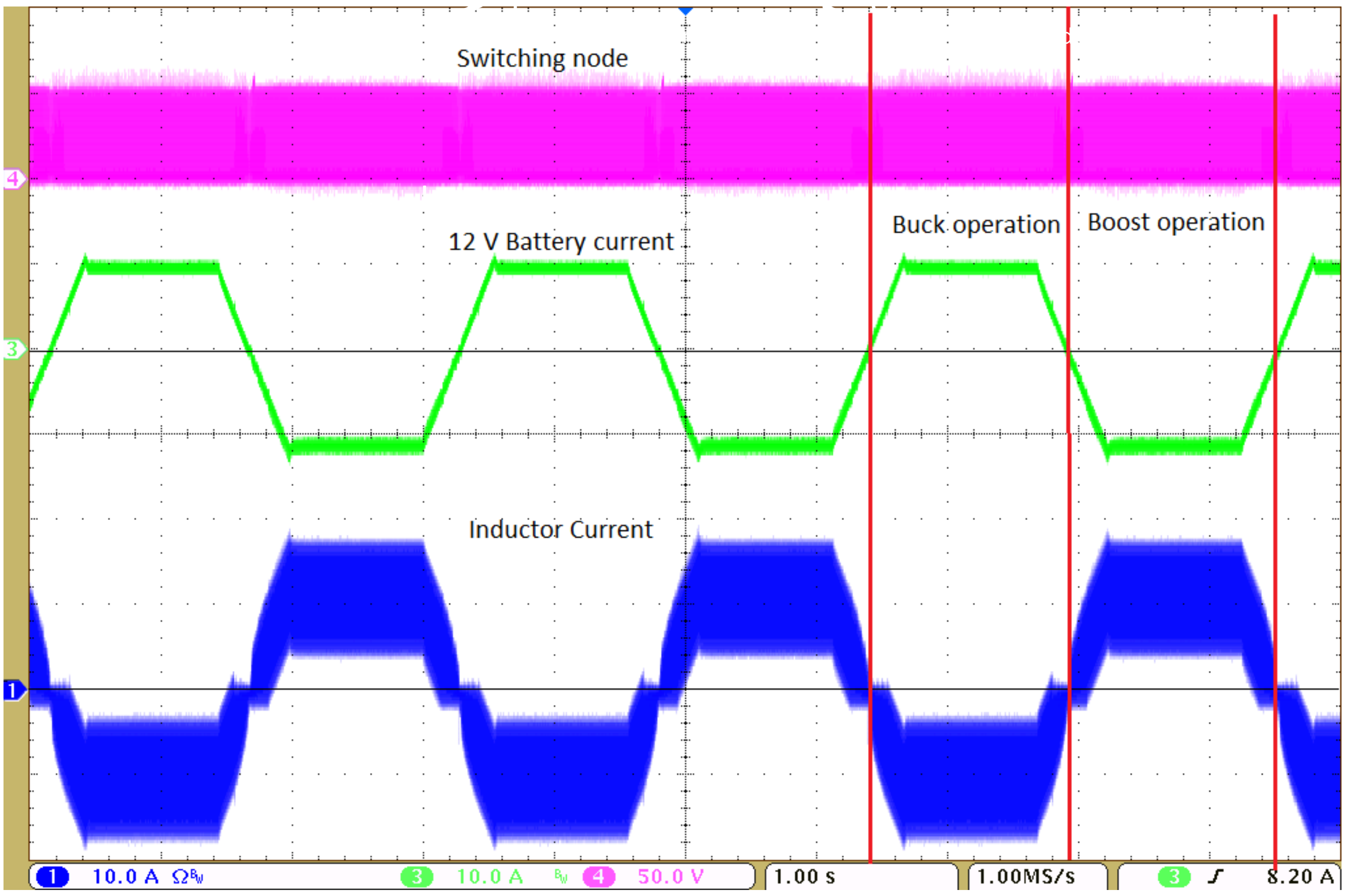


Figure 39 Output current and switch node waveforms

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.

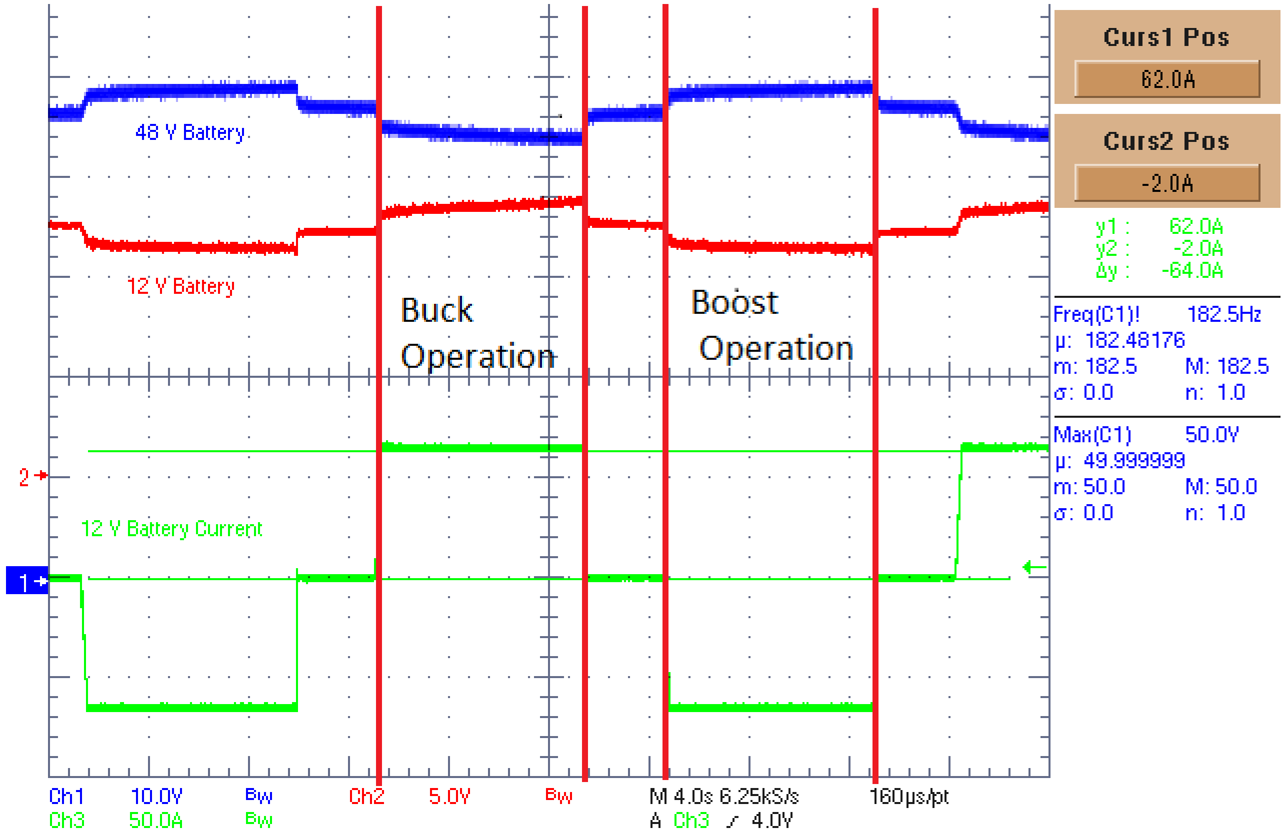


Figure 40 Battery voltage waveforms and total current for Buck and Boost operations.

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.

6 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

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2015, Texas Instruments Incorporated