User's Guide
SLUUBP1A–June 2017–Revised April 2018

BOOSTXL-3PhGaNInv Evaluation Module

The BOOSTXL-3PhGaNInv EVM (also referred to as "EVM" throughout this document) realizes a 48-V and 10-A three-phase GaN inverter with precision in-line shunt-based phase current sensing for accurate control of precision drives such as servo drives. The EVM offers a TI BoosterPack™ compatible interface to connect to a C2000™ MCU LaunchPad™ development kit for easy performance evaluation.

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1 Introduction

1.1 Features

This EVM supports the following features:

- Wide input voltage range 12 V to 60 V
- LMG5200 GaN half-bridge power stage simplifies PCB layout and reduces parasitic inductances for optimized switching performance; less than 2-ns rise and fall time
- Precision in-line phase current sensing with 5-mΩ shunt (for theoretical ±16.5-A full-scale range), and ±10-A peak nominal range for this EVM
- TI BoosterPack Compatible Interface With 3.3-V I/O for Easy Performance Evaluation With C2000 MCU LaunchPad Development Kit

1.2 Applications

This EVM can be used in the following applications:

- Servo drives and motion control
- Computer numerical control (CNC) drives
- Manufacturing robots
- Service robots
- Non-military drones

1.3 Description

1.3.1 System Description

For low-voltage drives, shunt-based current sensing is typically implemented as shown in Figure 1.

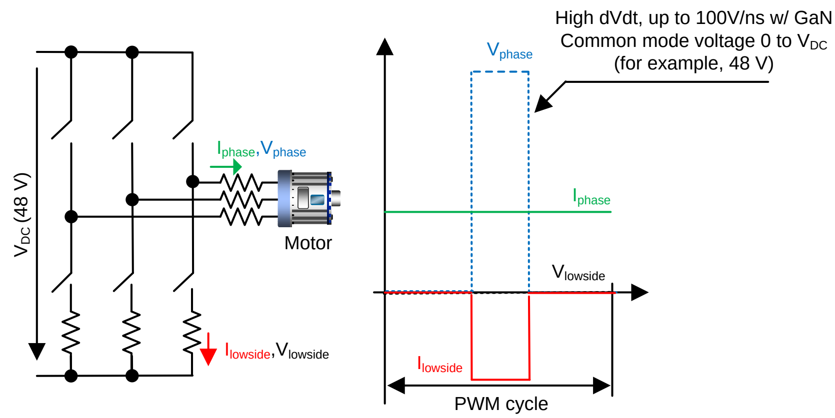

Figure 1. Typical Current Shunt Placement in Three-Phase Inverters

Depending on the location of the shunts, the configuration is either low-side or in-line current sensing. There are disadvantages with low-side sensing. The inline phase current shunt overcomes these problems and allows for high-precision, accurate phase current sensing.

However, one of the biggest challenges with in-line shunt-based current sensing is the presence of high common-mode voltage transients during PWM switching.

The INA240 is designed for common mode voltages from –4 V to 80 V. The high CMRR allows the INA240 to suppress common mode transients and provide a clean output voltage that corresponds to the differential input.

For three-phase inverters, the differential signal from the phase current shunts can be directly connected to the INA240 differential inputs and a highly-accurate output is available with minimal common-mode transient artifacts which typically settles out within 2 µs.

Figure 2 shows the in-line phase current shunt topology as realized with the BOOSTXL-3PhGaNInv EVM. For precision phase-current measurements with high linearity, the EVM design employs three in-line phase current shunts and three differential precision current sense amplifiers INA240 with high common-mode and high AC common-mode transient immunity.

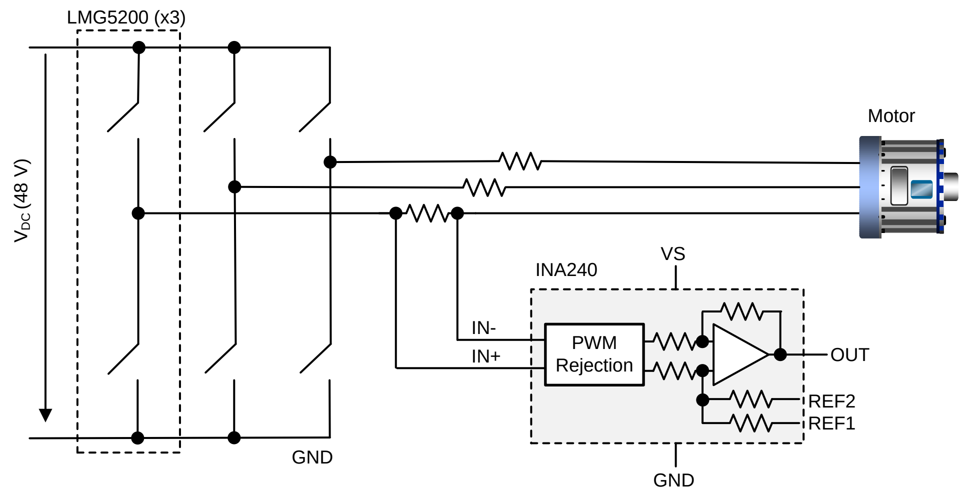

Figure 2. Inline Shunt Phase Current Sensing With INA240 Current Sense Amplifier

The EVM three-phase inverter is realized with three LMG5200 GaN half-bridge power modules to allow high PWM switching frequencies and low loss.

The LMG5200 device integrates the driver and two 80-V GaN FETs in a 6-mm × 8-mm QFN package, which is optimized for extremely-low-gate loop and power loop impedance.

1.3.2 Block Diagram

Figure 3 shows the system block diagram of the three-phase GaN inverter with the BOOSTXL-3PhGaNInv EVM device indicated in the red-dotted box.

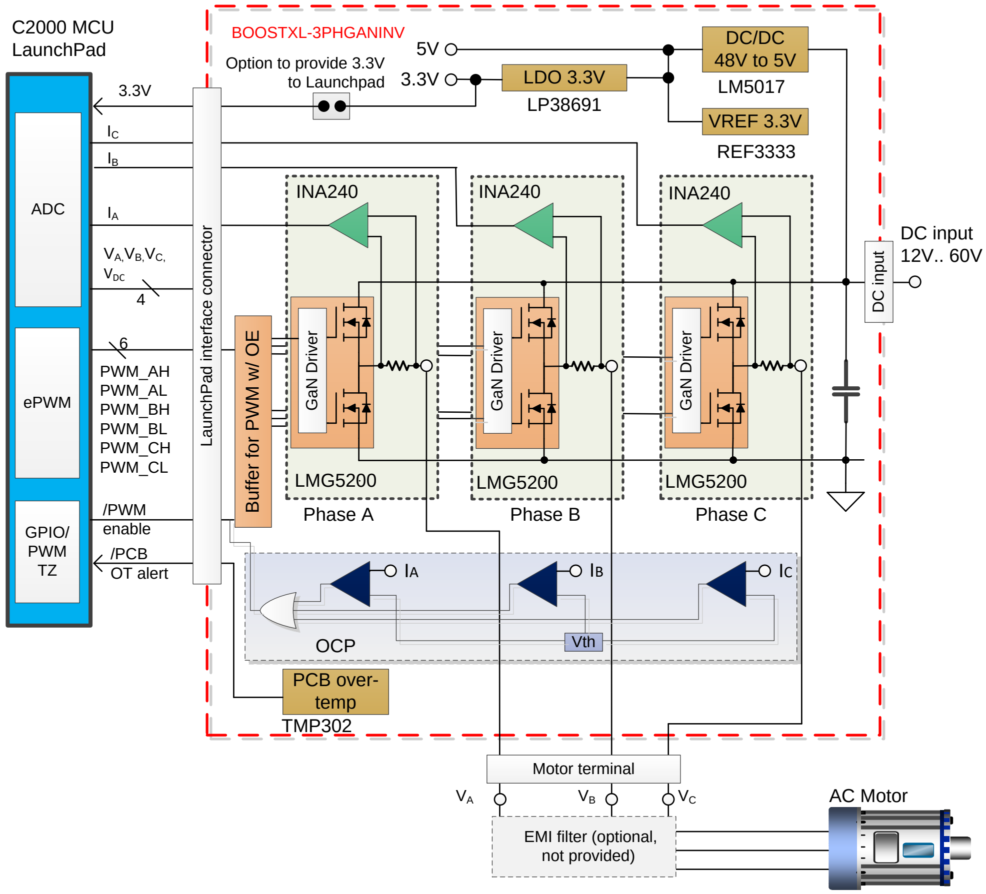

Figure 3. BOOSTXL-3PhGaNInv EVM Block Diagram

The EVM three-phase inverter with shunt-based precision phase current sensing accepts input DC voltages from 12 V to 60 V; the nominal DC input voltage is 48 V. A wide input voltage range, DC/DC converter LM5017 generates the 5-V rail to supply the LMG5200 gate driver and the 3.3-V band-gap reference, a 3.3-V LDO supplies the current sense amplifier, input buffer and other auxiliary circuits.

Each of the three inverter half-bridges employs an integrated 80-V and 10-A GaN half-bridge module (LMG5200), a 5-mΩ phase current shunt and a differential current sense amplifier (INA240) with a gain of 20 V / V and a midpoint voltage of 1.65 V, set by the 3.3-V reference (REF3333). A temperature switch (TMP302) monitors the PCB temperature close to the GaN power module.

The EVM interface connector to a host processor, like C2000 MCU provides the PWM high- and low-side input signals, the phase current sense amplifier output voltage and the scaled, low-pass filtered phase voltage for each of the three phases. The PWM signals are buffered. A PWM enable signal (active low) allows the host processor to enable and disable all three complementary PWM simultaneously through the onboard buffer. The interface connector also provides the scaled DC-link voltage as well as a PCB over-temperature alert (active low).

Hardware overcurrent protection is implemented with the TLV3201. The trip threshold is set to 12 A, with 1-A hysteresis.

The motor is connected to the three-phase motor terminal.

The C2000 MCU LaunchPad with the TMS320F28069M device is connected to the EVM and implements a sensorless, speed-variable, field-oriented control of a synchronous motor using the InstaSPIN-FOC™ software. An example firmware for the TMS320F28069M device on the InstaSPIN-MOTION™ LaunchPad has been provided to evaluate the BOOSTXL-3PhGaNInv EVM design with a 48-V low-voltage servo motor (http://www.ti.com/tool/lvservomtr).

2 Getting Started Hardware and Software

2.1 BOOSTXL-3PhGaNInv EVM PCB Overview

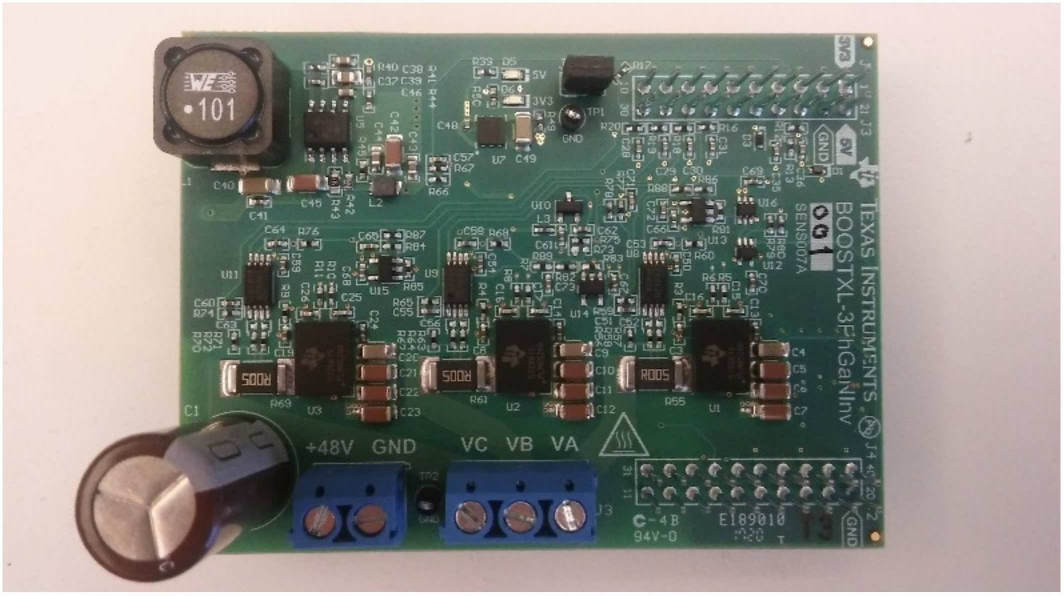

Figure 4. BOOSTXL-3PhGaNInv EVM PCB—Top View

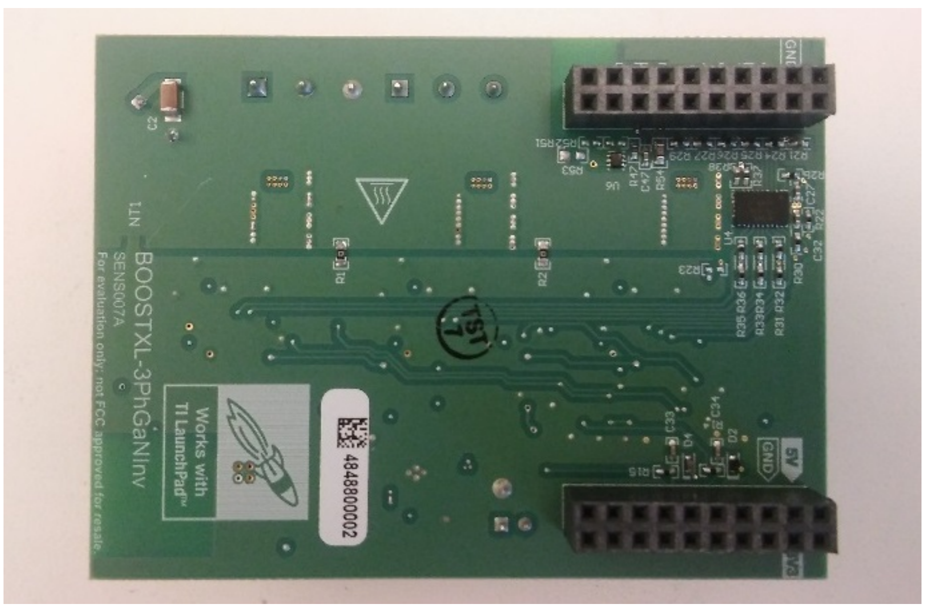

Figure 5. BOOSTXL-3PhGaNInv EVM PCB—Bottom View

2.2 BOOSTXL-3PhGaNInv EVM Jumper Settings

The jumper J6, when populated, provides 3.3 V to the J1-1 interface pin to supply the C2000 LaunchPad with 3.3 V. The maximum continuous current is 300 mA. When working in a debug session, J6 should be uninstalled if the C2000 LaunchPad is connected to and powered by a USB port.

Table 1 shows the BOOSTXL-3PhGaNInv EVM jumper settings.

Table 1. BOOSTXL-3PhGaNInv EVM Jumper Settings

Jumper	Function	Populated	Not Populated
J6	3.3-V supply at J1-1 interface connector to LaunchPad	3.3 V (default)	Not connected

CAUTION

When the jumper J6 is populated, ensure that the C2000 LaunchPad is not powered through USB. To ensure this, remove J6, or remove the JP1 and JP2 jumpers on the C2000 InstaSPIN-MOTION LaunchPad.

2.3 Interface to C2000 InstaSPIN-MOTION LaunchPad™

The BOOSTXL-3PhGaNInv EVM interface specification is compliant to the TI BoosterPack standard. The BOOSTXL-3PhGaNInv EVM board can either be connected to the C2000 InstaSPIN-MOTION LaunchPad headers J1 through J3 and J2 through J4 or to the extended headers J5 through J7 and J6 through J8.

CAUTION

- When connecting the BOOSTXL-3PhGaNInv EVM to the LaunchPad, pay attention that the bottom-side solder joints do not touch any jumpers or headers of the LaunchPad.
- The phase current I_A, I_B, and I_C equivalent output voltage at connectors J1-14, J1-16, and J1-18 is inverted versus the DRV8301 BoosterPack. This was done to facilitate layout.
- When J6 is populated so that the BOOSTXL-3PhGaNInv EVM provides the 3.3 V to supply the LaunchPad, ensure that the LaunchPad is not powered from a USB. Alternatively, remove J6 and power the LaunchPad through USB by populating JP1 and JP2 jumpers on the InstaSPIN-MOTION LaunchPad, as Figure 6 shows.

Figure 6 shows the BOOSTXL-3PhGaNInv EVM connected to the InstaSPIN-MOTION LaunchPad headers J5 through J7 and J6 through J8. Note that the BOOSTXL-3PhGaNInv EVM J6 is removed and the jumpers JP1 and JP2 on the LaunchPad are populated. The LaunchPad is powered by the USB port in this configuration.

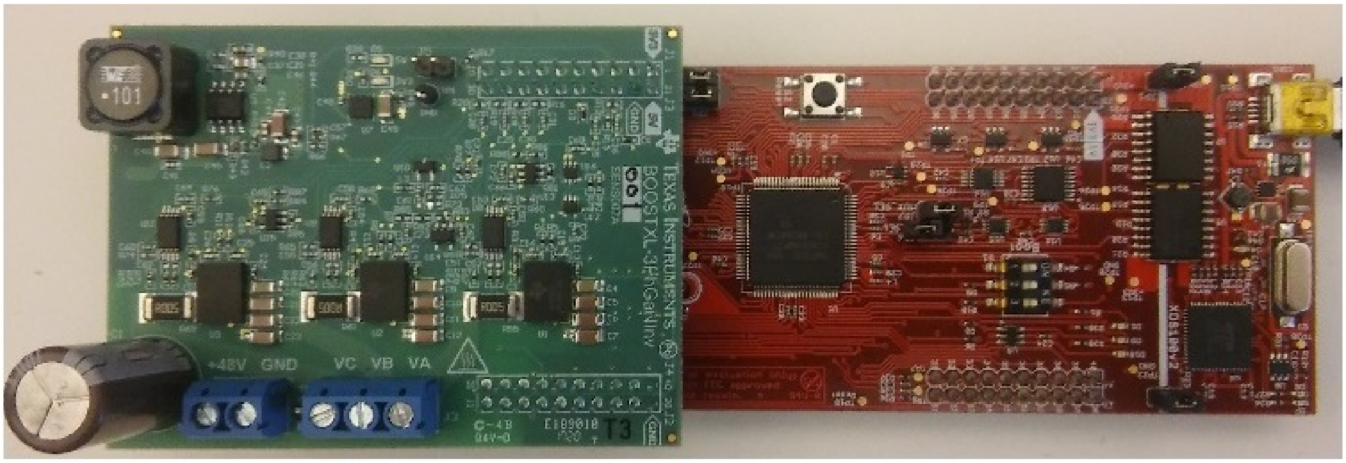

Figure 6. BOOSTXL-3PhGaNInv EVM LaunchPad™ Connection Example

Connect the DC power supply (12 to 60 V, 48-V nominal) to the DC input voltage connector (J4) and the three-phase motor to the three-phase output voltage connector (J3). Validate that the three-phase motor can handle the high slew rates of the phase voltages during PWM switching; otherwise, consider using a low-pass LCR filter to reduce the slew rate of the phase voltage according to the requirements of the motor.

2.4 InstaSPIN-FOC Example Project for Teknic Servo Motor M-2310P-LN-04K

The software example is created for the InstaSPIN-MOTION LaunchPad using headers J5 or J7 and J6 or J8. Ensure the EVM board is connected to the InstaSPIN-MOTION LaunchPad as Figure 6 shows.

Be sure to install Texas Instrument's MotorWare™ software package in the default install path, for example *C:\ti\motorware\motorware_1_01_00_18*.

Unzip the BOOSTXL-3PhGaNInv EVM software package.

Follow the steps in Section 2.4.1 to create an InstaSPIN-FOC project example for the EVM hardware connected to the InstaSPIN-MOTION LaunchPad.

2.4.1 Set up BOOSTXL-3PhGaNInv EVM Board Specific Project Folders in MotorWare™ Software

1. Navigate to folder: *C:\ti\motorware\motorware_1_01_00_18\sw\solutions\instaspin_foc\boards*.
2. Create a copy of the *boostxldrv8301_revB* folder in the same directory and rename it to *boostxl-3PhGanInv*.
3. Navigate to the folder: *C:\ti\motorware\motorware_1_01_00_18\sw\modules\hal\boards*.
4. Create a copy of the *boostxldrv8301_revB* folder in the same directory and rename it *boostxl-3PhGanInv*.
5. Copy the five source files provided with the EVM software package to the *boostxl-3PhGanInv* project folders, as follows:
   A. Copy *user.h* and *user_j5.h* to the following directory: *C:\ti\motorware\motorware_1_01_00_18\sw\solutions\instaspin_foc\boards\boostxl-3PhGanInv\f28x\f2806xF\src*. Note that this action replaces or overwrites the original files.
   B. Copy *hal.c* and *hal.h* to the following directory: *C:\ti\motorware\motorware_1_01_00_18\sw\modules\hal\boards\boostxl-3PhGanInv\f28x\f2806x\src*. Note that this action replaces or overwrites the original files.
   C. Copy *proj_lab02a-BOOSTXL-3PhGaNInv.c* to the following directory: *C:\ti\motorware\motorware_1_01_00_18\sw\solutions\instaspin_foc\src*.

2.4.2 Set up BOOSTXL-3PhGaNInv EVM Board Specific Project With Code Composer Studio™ (CCS) Software

1. Start the CCS software, choose boostxl-3PhGanInv as the new workspace, and import the *boostxl-3PhGanInv* project from: *C:\ti\motorware\motorware_1_01_00_18\sw\solutions\instaspin_foc\boards\boostxl-3PhGanInv\f28x\f2806xF\projects\ccs*.
2. Make the *proj_lab02a* project active.
3. In the *CCS Project* explorer for *proj_lab02a*, select the *proj_lab02a.c* source file and exclude it from the build.
4. Add *proj_lab02a-BOOSTXL-3PhGaNInv.c* to the project by browsing to the following folder: *C:\ti\motorware\motorware_1_01_00_18\sw\solutions\instaspin_foc\src*. In the dialog window, add the option for adding *proj_lab02a-BOOSTXL-3PhGaNInv.c* as per Figure 7 and click the *OK* button.

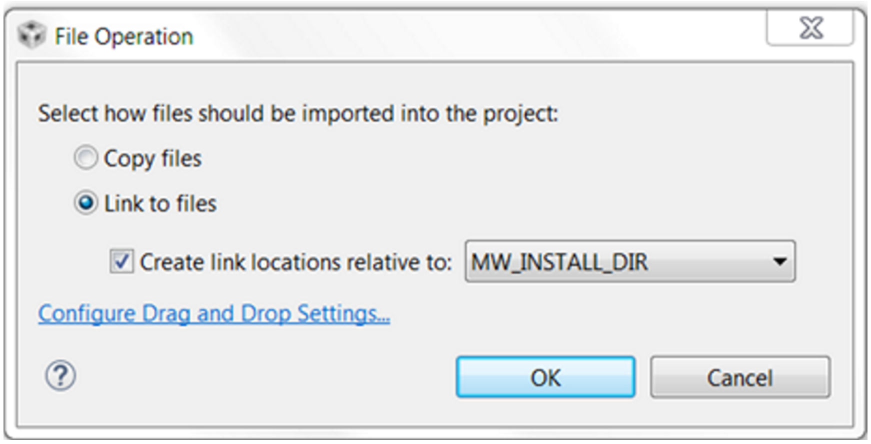

Figure 7. Dialog Window for Step 4

5. In the CCS Project explorer, open the properties window of the *proj_lab02* project.
   a. In the *File* menu, navigate to "Resources" → "Linked Resources", and in the dialog window click the tab on the right for linked resources, as Figure 8 shows:

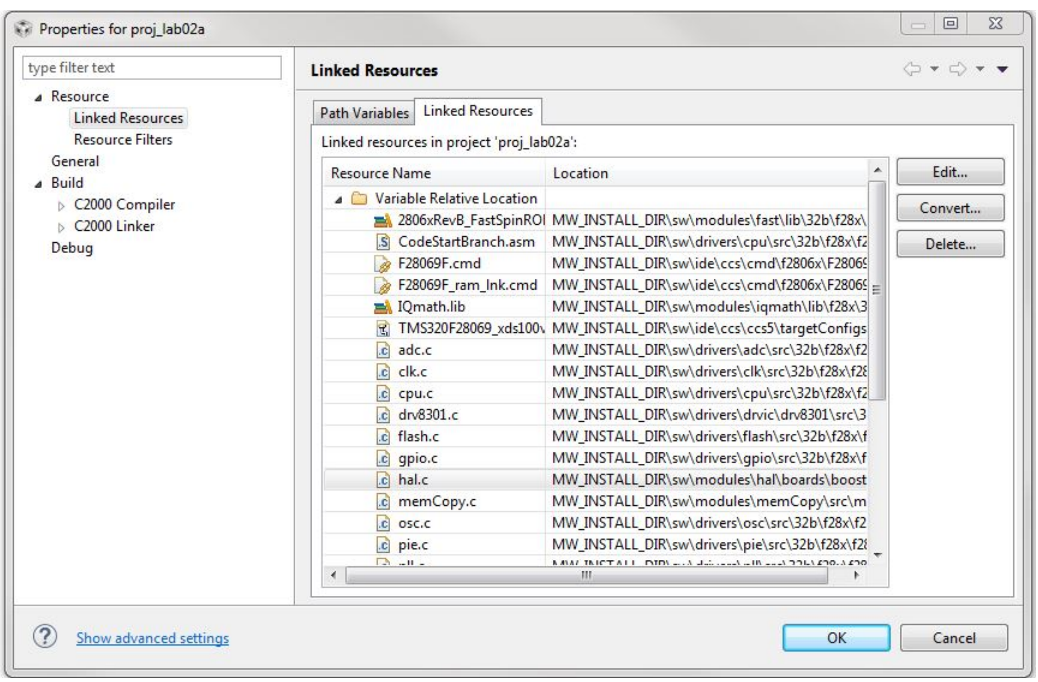

Figure 8. Dialog Window for Step 5a

b. Select the *hal.c* file (in the "Resource Name" column) and edit the existing link (in the "Location" column) with the new link to the boostxl-3PhGanInv project: *MW_INSTALL_DIR\sw\modules\hal\boards\boostxl-3PhGanInv\f28x\f2806x\src\hal.c*, as Figure 9 shows:

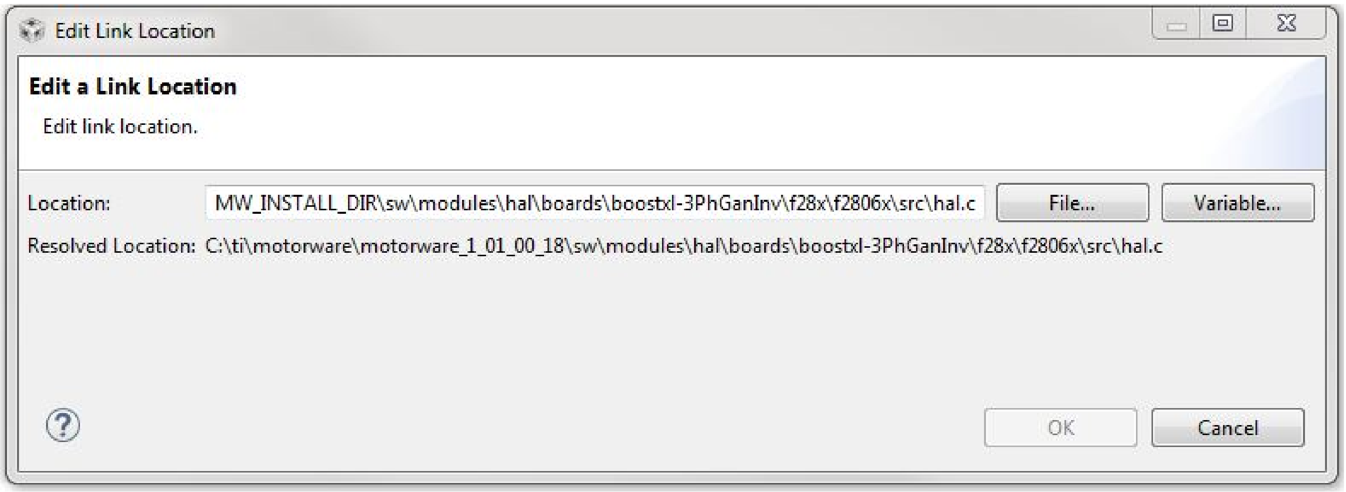

Figure 9. Dialog Window for Step 5b

c. Click the *OK* button to close the dialog window.

6. In the CCS Project explorer, open the properties window of the *proj_lab02* project.
   a. In the *File* menu, navigate to **Build** → **C2000 Compiler** → **Include Options** to view the following options in Figure 10:

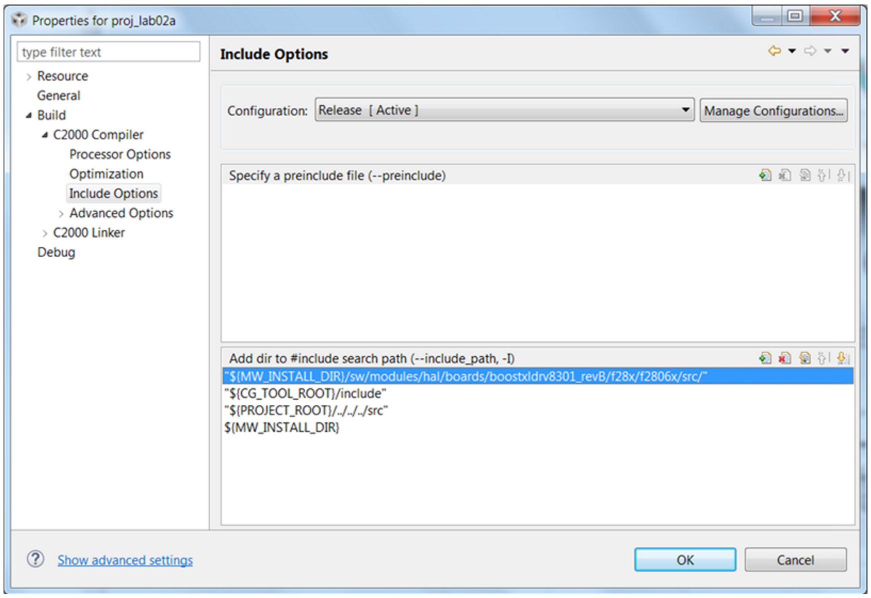

Figure 10. Dialog Window for Step 6a

b. Select the path highlighted *${MW_INSTALL_DIR}* and change this to *${MW_INSTALL_DIR}/sw/modules/hal/boards/boostxl-3PhGanInv\f28x/f2806x/src/* as Figure 11 shows:

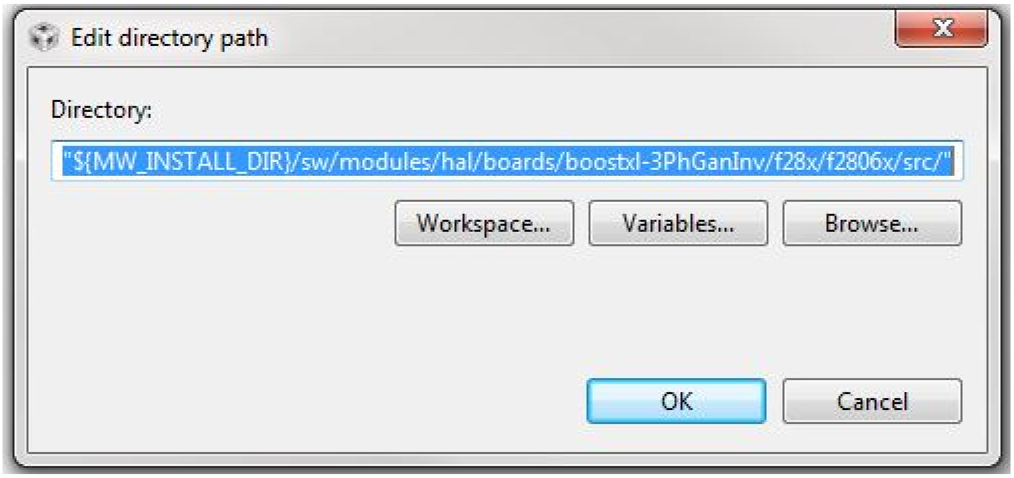

Figure 11. Dialog Window for Step 6b

c. Click the *OK* button to close the properties window.

2.4.3 Compile and Run BOOSTXL-3PhGaNInv EVM Project Example

1. Compile the *proj_lab02a* project and download to the TMS329F28069F target processor on the InstaSPIN-MOTION LaunchPad.
2. Open the document *instaspin_labs.pdf* from: *C:\ti\motorware\motorware_1_01_00_18\docs\labs\instaspin_labs.pdf*.
3. Navigate to the *Lab 2a* - "Using InstaSPIN for the First Time out of ROM", follow the instructions to identify and run your specific motor.

The default motor defined in this sample project is the Teknic M-2310P-LN-04K. Corresponding files have been properly setup so no further file editing is necessary if the same motor is used. When using a different motor, please follow the setup procedure outlined in the *instaspin_labs.pdf*. After the files are properly setup, follow the rest of the procedure to run the motor.

3 Schematic, Bill of Materials, and PCB Layout

3.1 Schematics, Bill of Materials and PCB files

To download the schematics, BOM and other PCB files, please visit BOOSTXL-3PhGaNInv EVM.

3.2 PCB Layout Recommendations

For design theory and layout recommendations of the LMG5200 device, see the TIDA-00909 design.

For design theory and layout recommendations of the INA240 device, see the TIDA-00913 design.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (June 2017) to A Revision **Page**

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   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.

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。 http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

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.

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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.

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