TI Spins Motors

Texas Instruments

InstaSPIN Control for the Hercules RM48L952L95x

Version 1.0.1 *Motor Solutions*

Abstract

This application note presents a solution for sensorless control of Brushless DC motors using a Hercules RM48L952L95x microcontroller. The RM48L952L95xdevices is part of the family of Hercules R4F microcontrollers which enable cost-effective safety critical design of intelligent controllers for three phase motors by reducing the system components and increasing efficiency. Using these devices, it is possible to realize precise control algorithms for safety critical applications. A complete solution proposal is presented below: control structures, power hardware topology, control hardware and remarks on energy conversion efficiency can be found in this document.

This application note covers the following:

- A theoretical background on InstaSPIN BLDC motor control principle.
- A discussion of the BLDC drive imperfection handling the operating system

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Introduction

The economic constraints and new standards legislated by governments place increasingly stringent requirements on electrical systems. New generations of equipment must have higher performance parameters such as better efficiency and reduced electromagnetic interference. System flexibility must be high to facilitate market modifications and to reduce development time. All these improvements must be achieved while, at the same time, decreasing system cost.

Brushless motor technology makes it possible to achieve these specifications. Such motors combine high reliability with high efficiency, and for a lower cost in comparison with brush motors. This paper describes the use of a Brushless DC Motor (BLDC). Although the brushless characteristic can be applied to several kinds of motors – AC synchronous motors, stepper motors, switched reluctance motors, AC induction motors - the BLDC motor is conventionally defined as a permanent magnet synchronous motor with a trapezoidal Back EMF waveform shape. Permanent magnet synchronous machines with trapezoidal Back-EMF and (120 electrical degrees wide) rectangular stator currents are widely used as they offer the following advantages first, assuming the motor has pure trapezoidal Back EMF and that the stator phases commutation process is accurate, the mechanical torque developed by the motor is constant; secondly, the Brushless DC drives show a very high mechanical power density.

Directory Overview

Below is the MotorWare directory structure for the main files in the project:

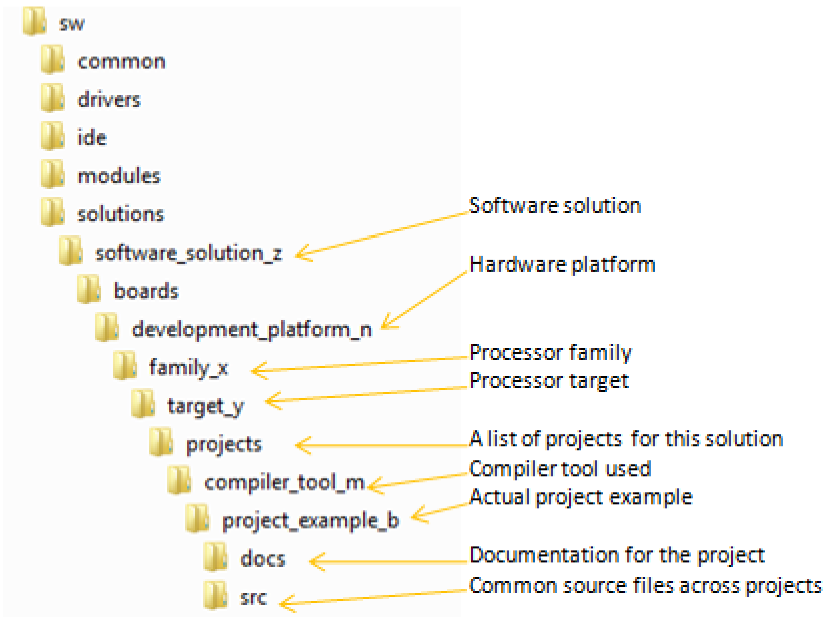


Fig 1 MotorWare Directory Structure

Below is the MotorWare directory structure for the driver files in the project:

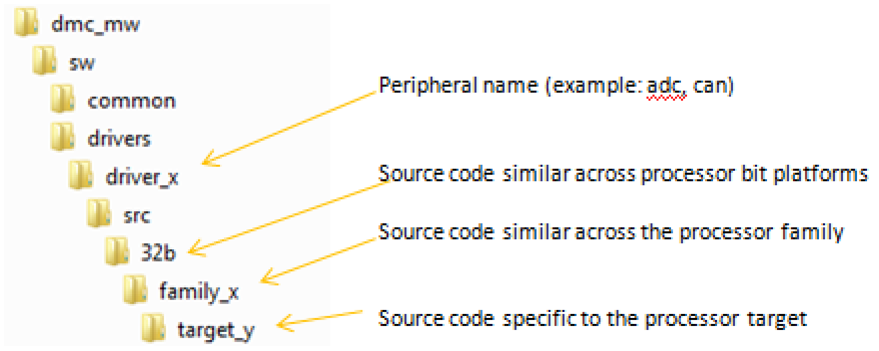

dmc_mw
sw
common
drivers
driver_x
src
32b
family_x
target_y
Peripheral name (example: adc, can)
Source code similar across processor bit platforms
Source code similar across the processor family
Source code specific to the processor target

Fig 2 Driver Files Directory Structure

Below is the MotorWare directory structure for the module files in the project:

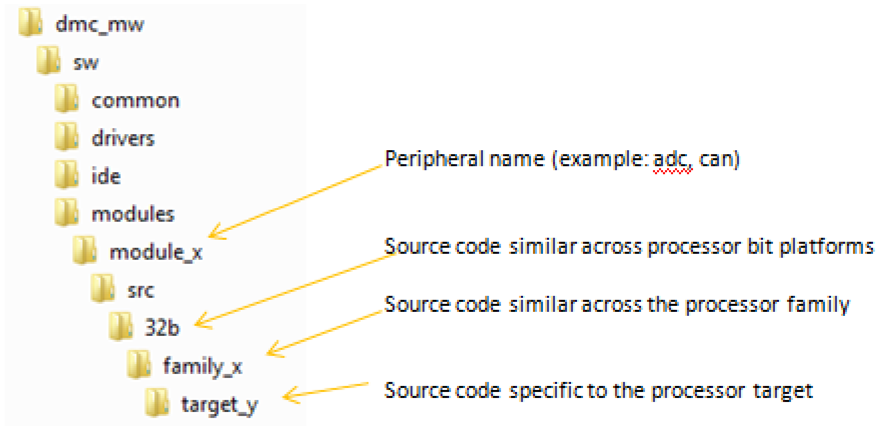

dmc_mw
sw
common
drivers
ide
modules
module_x
src
32b
family_x
target_y
Peripheral name (example: adc, can)
Source code similar across processor bit platforms
Source code similar across the processor family
Source code specific to the processor target

Fig 3 Module Files Directory Structure

System Overview

This document describes the “C” real-time control framework used to demonstrate the trapezoidal control of BLDC motors. The “C” framework is designed to run on Hercules R4F based controllers on Code Composer Studio.

The framework uses the following modules[1]:

Macro Names	Explanation
BLDCPWM	PWM Drivers
InstaSPINTM-BLDC	InstaSPIN-BLDC Library Functions
PID	PID Regulators
RC	Ramp Controller (slew rate limiter)
RC3	Ramp down Module
SPEED_PR	Speed Measurement (based on sensor signal period)
IMPULSE	Impulse Generator
MOD6_CNT	Mod 6 Counter

[1] Please refer to pdf documents in motor control folder explaining the details and theoretical background of each macro

In this system, the sensorless trapezoidal control of BLDC motors will be experimented with and will explore the performance of the speed controller. The BLDC motor is driven by a DRV8301 Three Phase PWM Motor Driver. The Hercules RM48L952L95x control card is used to generate three pulse width modulation (PWM) signals. The motor is driven by an integrated power module by means of BLDC specific PWM technique. Phase voltages and DC bus return current (I fb Ret) is measured and sent to the Hercules RM48L952L95x via analog-to-digital converters (ADCs).

InstaSPIN_BLDC project has the following properties:

C Framework		
System Name	**Program Memory Usage** RM48L952L95x	**Data Memory Usage**[1] RM48L952L95x
InstaSPIN_BLDC	32704 bytes	5300 bytes

[1] Excluding the stack size

CPU Utilization of Trapezoidal BLDC Control (Sensorless)	
Name of Modules*	**Number of Cycles**
BLDCPWM	225
InstaSPINTM-BLDC Library	81
PID	268**
RC	35
RC3	30√
SPEED_PR	44
IMPULSE	23√
MOD6_CNT	20
Data Update	47
Total Number of Cycles	**1015****
CPU Utilization @ 160 Mhz	**13%*****

* The modules are defined in the header files as "inline functions"
** Two Instances of PID in Cascade mode
*** At **20 kHz** ISR freq.
√ Not included in the speed loop

System Features	
Development /Emulation	Code Composer Studio v5.2.1 (or later) with Real Time debugging
Target Controller	Hercules RM48L952L95x
PWM Frequency	20kHz PWM (Default)
PWM Mode	Symmetrical with 4 quadrant switching and programmable dead-band.
Interrupts	adcNotification()
Peripherals Used	HET PINs 0, 2, 4, 6, 8, 10 for PWMs HET PINs 20, 30, and 31 for DRV8301 SPI ADC Channel A9 and A21 for low side current sensing, Channels 23, 15, and 20 for Bemf sensing (A, B, and C, respectively), and channel 18 for DC bus voltage sensing.

The overall system implementing a 3-ph InstaSPIN BLDC control is depicted in Fig.4.

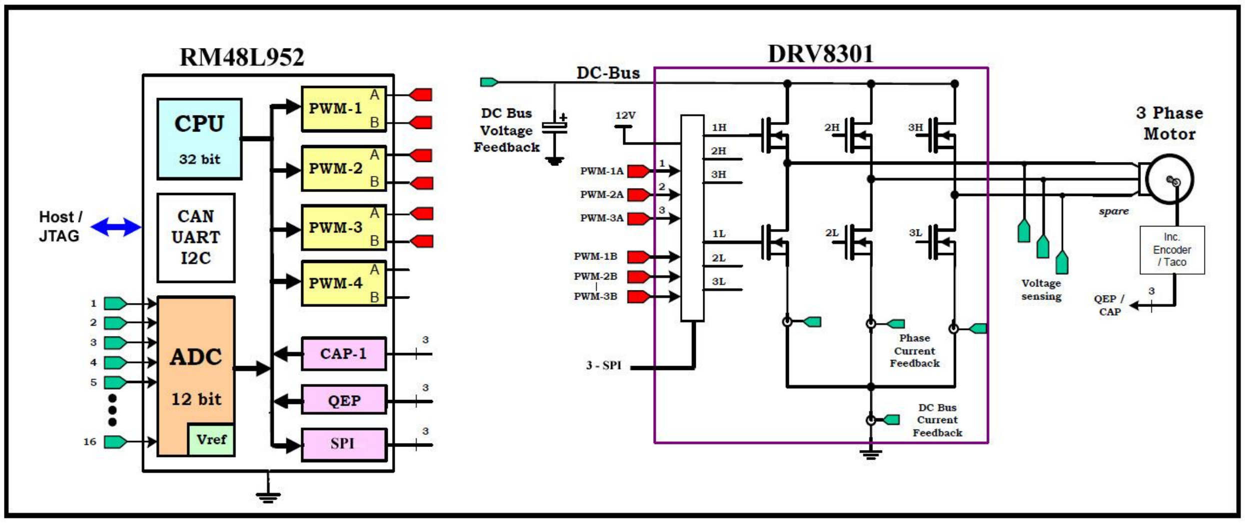


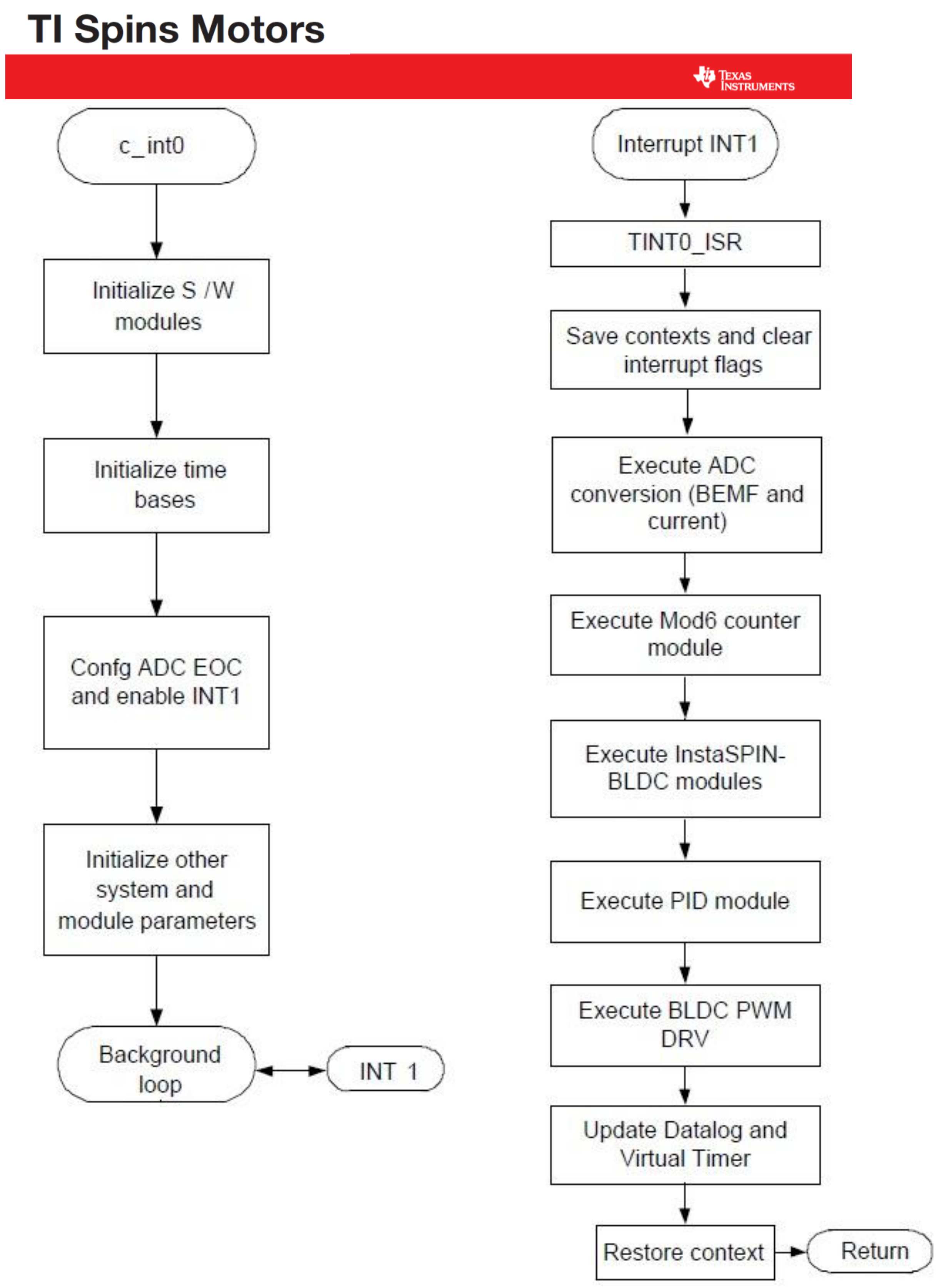
Fig 4 A 3-ph BLDC drive implementation

Special Setup Notes:

The DRV8301 driver chip has configurable PWM and protection modes that are configured with SPI at startup. The start-up sequence with the RM48 is as follows:

1) **RM48 Boots and Initializes the HET module.**
2) **The EN_GATE signal on the DRV8301 is driven high with a GPIO.**
3) **The RM48 waits for 50ms while the DRV8301 powers up.**
4) **The RM48 executes the HET code to write SPI commands to the DRV8301 for setup.**
    a. **For the InstaSPIN project:**
        i. **The Gate Driver Peak Current is set to 1.7A.**
        ii. **The Gate Driver Reset is Normal.**
        iii. **The PWM Mode is Independent.**
        iv. **The OC mode is Latched Shut down (to reset the fault a power cycle needs to occur).**
        v. **The Gain of the internal Amplifiers is set to 80V/V.**
5) **The RM48 puts the HET into PWM mode.**

The software flow is described in the Figure 5 below.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c_int0
Initialize S /W modules
Initialize time bases
Confg ADC EOC and enable INT1
Initialize other system and module parameters
Background loop
INT 1
Interrupt INT1
TINT0_ISR
Save contexts and clear interrupt flags
Execute ADC conversion (BEMF and current)
Execute Mod6 counter module
Execute InstaSPIN-BLDC modules
Execute PID module
Execute BLDC PWM DRV
Update Datalog and Virtual Timer
Restore context
Return

Fig 5 Software Flow Chart

Hardware Configuration (DRV8301-EVM)

Please refer to the DRV8301-EVM How to Run Guide and HW Reference Guide found:

sw/boards/drv8301kit_revB_revC/docs

for an overview of the kit's hardware and steps on how to setup this kit. Some of the hardware setup instructions are captured below for quick reference.

HW Setup Instructions

1. Unpack the DIMM style controlCARD.
2. Place the controlCARD in the connector slot of J1. Push vertically down using even pressure from both ends of the card until the clips snap and lock. (to remove the card simply spread open the retaining clip with thumbs)
3. Make sure the following jumpers & connector settings are vaild

   (i) JP2 is installed
4. Make sure that the switches for the controlCARD are set as described in the specific document for each controlCARD (they handle where power is supplied, how it boots, etc)
5. Connect a USB cable from the computer to the USB connector on the control card.
6. Connect a 24V power supply to the DRV8301-EVM with positive connected to J25 and ground connected to J26. Now LED1 and LED3 should turn on. Notice the control card LED would light up as well indicating the control card is receiving power from the board.

   The included power supplies are only capable of 2.5A maximum and have been shown to drop voltage and may not provide enough current during rapid speed or load changes, especially with motors that can draw more than 2.5A When doing full performance evaluation please use a power supply that more than meets the demands of the motor and application use.
7. Note that the motor should be connected to the OUTA, OUTB and OUTC terminals. For more details on motor wiring please refer to the datasheet provided with your motor.

For reference the pictures below show the connectors on the DRV8301-EVM

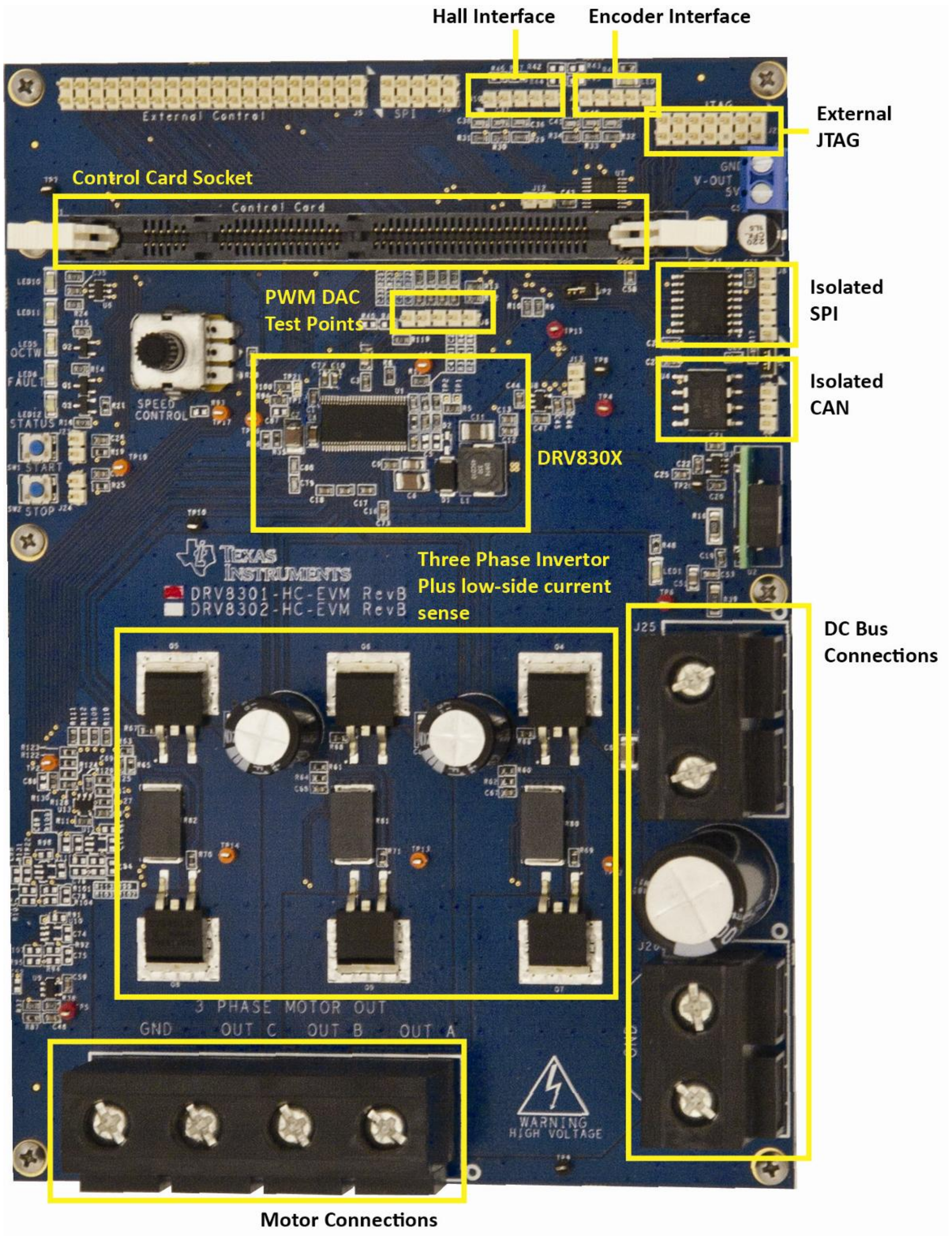


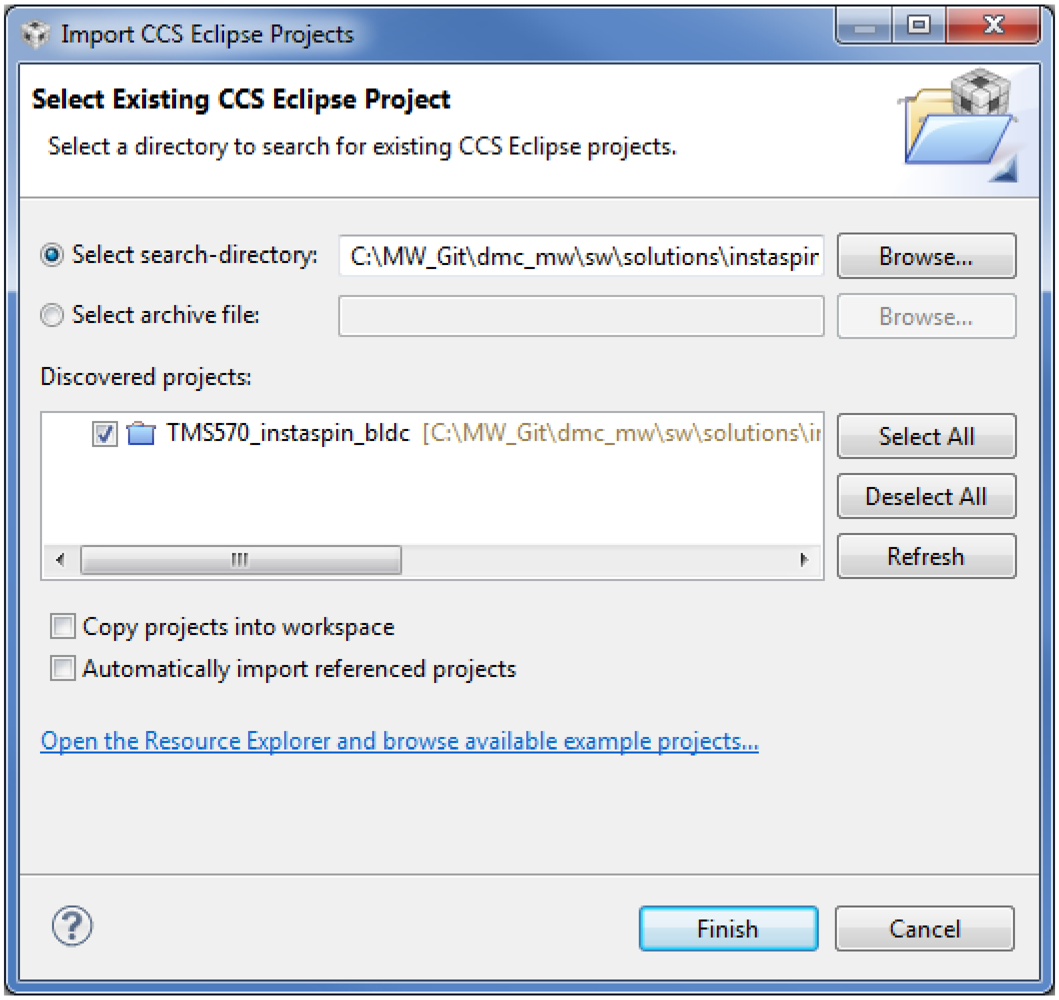
Fig. 6 DRV8301-EVM Connections

Software Setup Instructions to Run InstaSPIN_BLDC Project

For information on getting started with Code Composer Studio v5, use the CCSv5 Getting Started Guide online at http://processors.wiki.ti.com/index.php/CCSv5_Getting_Started_Guide. The Getting Started Guide will help you download, install, and run Code Composer Studio v5.

CCS v5.2.1.00018 or later needs to be used with ARM compiler 5.0.0 or later installed for the software to build correctly.

When CCSv5 has been downloaded, installed, and is running, the InstaSPIN project needs to be imported. In CCS, go to Project->Import Existing CCS/CCE Eclipse Project. Choose to browse and go to: **sw/solutions/instaspin_bldc/boards/drv8301kit_revD/Hercules/RM48L952L952/projects/ccs5/project01** in your MotorWare directory. The InstaSPIN project should be discovered. Make sure the checkbox next to the project is checked. Click on Finish to import the project into your workspace.


Import CCS Eclipse Projects

Select Existing CCS Eclipse Project

Select a directory to search for existing CCS Eclipse projects.

[● Select search-directory:] C:\MW_Git\dmc_mw\sw\solutions\instaspir

○ Select archive file:

Discovered projects:

[✓] TMS570_instaspin_bldc [C:\MW_Git\dmc_mw\sw\solutions\ir

☐ Copy projects into workspace

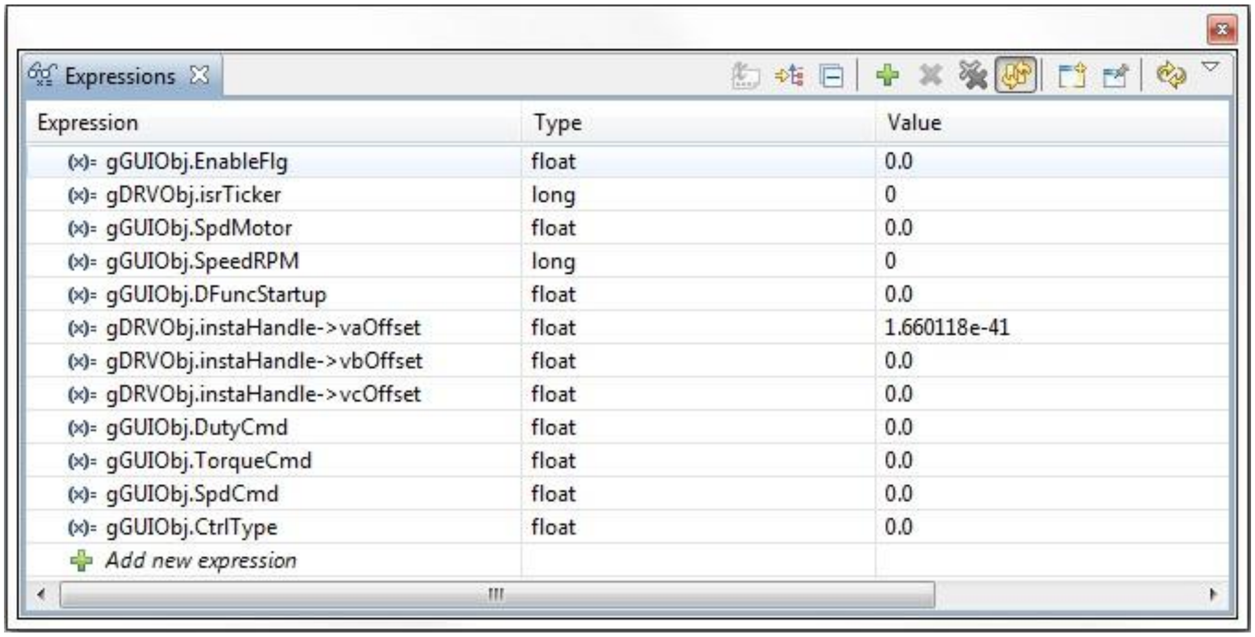
☐ Automatically import referenced projects

Open the Resource Explorer and browse available example projects...

Fig 7 Importing a Project

Right click on the project name and select “Clean Project” then “Build Project”. Once the build completes, launch a debug session to load the code into the controller. Make sure you are connected to the RM48L952L95x CortexR4 device (Run->Connect Target) and load the program (Run->Load->Load Program). Press the Run button .

Next, create a Watch Window and add the control variables by running a script. To run the script, open the Scripting Console by going to View->Scripting Console. In the Scripting Console, click on the folder icon to choose a script to run. Go to: **sw/solutions/instaspin_bldc/boards/drv8301kit_revD/Hercules/RM48L952L952/projects/ccs5/project01**, and choose InstaSPINWatch.js. The script should run. You should now have a watch window that looks like Figure 8.



Expression	Type	Value
(x)= gGUIObj.EnableFlg	float	0.0
(x)= gDRVObj.isrTicker	long	0
(x)= gGUIObj.SpdMotor	float	0.0
(x)= gGUIObj.SpeedRPM	long	0
(x)= gGUIObj.DFuncStartup	float	0.0
(x)= gDRVObj.instaHandle->vaOffset	float	1.660118e-41
(x)= gDRVObj.instaHandle->vbOffset	float	0.0
(x)= gDRVObj.instaHandle->vcOffset	float	0.0
(x)= gGUIObj.DutyCmd	float	0.0
(x)= gGUIObj.TorqueCmd	float	0.0
(x)= gGUIObj.SpdCmd	float	0.0
(x)= gGUIObj.CtrlType	float	0.0
Add new expression		

Fig 8 Watch Window Setup

Make sure you are connected to the RM48L952L95x CortexR4 device and load the program. Press the Run button .

Setup time graph windows by importing Graph1.graphProp and Graph2.graphProp (Tools->Graph->Dual Time: Import Button) from the following location:

sw/solutions/instaspin_bldc/boards/drv8301kit_revD/Hercules/RM48L952L952/projects/ccs5/project01. Click on Continuous Refresh button on the top left corner of the graph tab to enable periodic capture of data from the microcontroller.

Running/Modifying the Project

At any point in time, you can modify the settings in the Watch Window to control how the motor runs. While the motor is stopped (by setting “gGUIObj.EnableFlg” to 0), you may change which mode the motor runs in.

To change the mode that the motor is running, you will have to modify the “gGUIObj.CtrlType” variable in the Watch Window. The default value is 0, which represents a simply Duty Cycle (sensorless) commutation mode. The possible values of CtrlType are described below:

Value	Mode
0	Duty Cycle
1	Current
2	Velocity
3	Current + Velocity

Duty Cycle (Sensorless) Commutation Mode

In the software, the key variables to be adjusted are summarized below.

- gDRVObj.rmpCntlHandle->targetValue: for changing the targeted commutation interval.
- gDRVObj.rmpCntlHandle->setpointValue: for changing the initial startup commutation interval.
- gGUIObj.DFuncStartup: for changing the startup PWM duty cycle in per-unit.
- gGUIObj.DutyCmd: for changing the speed of the motor
- gGUIObj.CommThreshold: for changing the BEMF integration threshold in per-unit

To run in Duty Cycle mode, complete the following:

1. Make sure the program is currently running on the device. If so, also assure that “gGUIObj.EnableFlg” is set to 0.
2. Verify that “gGUIObj.CtrlType” is set to 0, for Duty Cycle Commutation Mode.
3. Set “gGUIObj.EnableFlg” to 1.
4. At this point, the variable “gDRVObj.isrTicker should be increasing. This confirms that the interrupt is running properly. The motor should start moving.

The key steps can be explained as follows:

- The motor will gradually speed up and finally switch to closed loop commutation mode.
- The switch over from open loop commutation to closed loop commutation occurs when gDRVObj.rmp3Handle->ramp3DoneFlag is set to 0x7FFFFFFF indicating the end of motor speed up phase. Until this switch over occurs MOD6_CNT module is triggered by the output of IMPULSE module. After the switch over, MOD6_CNT module is triggered by the output of the InstaSPIN^{TM}-BLDC module.
- When the speed up phase is over, vary the motor speed by changing gGUIObj.DutyCmd. This varies the power delivered to the motor and hence it’s speed.
- Adjust gGUIObj.CommThreshold to achieve the desired commutation.
- Bring the system to a safe stop as described below by setting gGUIObj.EnableFlg to 0, taking the controller out of realtime mode and reset.

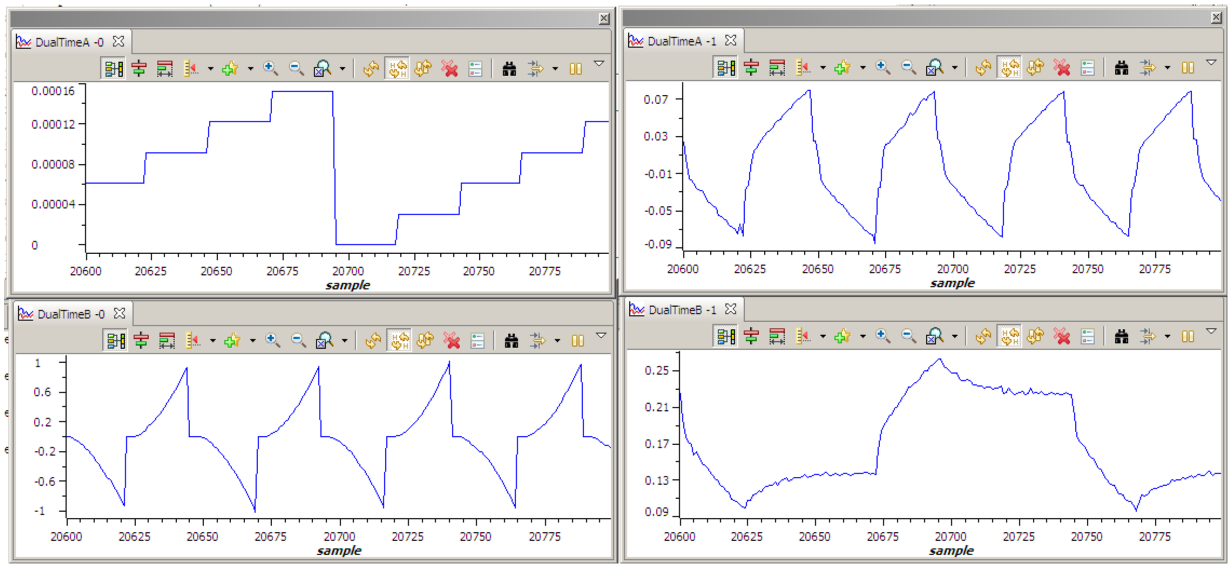


Fig 1 Graph Windows for Duty Cycle Commutation Mode (a) mod6 counter, (b) V_int, (c) Vphase and (d)Vag

Closed Current Loop Mode

In the software, the key variables to be adjusted are summarized below.

- gDRVObj.rmpCntlHandle->targetValue: for changing the targeted commutation interval.
- gDRVObj.rmpCntlHandle->setpointValue: for changing the initial startup commutation interval.
- gGUIObj.CurrentStartup: for changing the startup current in per-unit.
- gGUIObj.TorqueCmd: changing the running current in per-unit.
- gGUIObj.CommThreshold: for changing the BEMF integration threshold in per-unit

To run in Closed Current Loop mode, complete the following:

1. Make sure the program is currently running on the device. If so, also assure that “gGUIObj.EnableFlg” is set to 0.

2. Verify that “gGUIObj.CtrlType” is set to 1, for Closed Current Loop Mode.

3. Set “gGUIObj.EnableFlg” to 1.

4. At this point, the variable “gDRVObj.isrTicker should be increasing. This confirms that the interrupt is running properly. The motor should start moving.

The steps are explained as follows:

- The motor will gradually speed up and finally switch to closed loop commutation mode.

- Now use the variable gGUIObj.TorqueCmd to specify the reference current for the PI controller. The PI controller will start to regulate the DC bus current and hence the motor current. Gradually increase/decrease the command current (gGUIObj.TorqueCmd value) to change the torque command and adjust PI gains. Note that the speed is not controlled in this step and a non-zero torque reference will keep increasing the motor speed. Therefore, the motor should be loaded using a brake/generator (or manually if the motor is small enough) after closing the loop. Initially apply relatively light load and then gradually increase the amount of the load. If the applied load is higher than the torque reference, the motor cannot handle the load and stops immediately after closing the current loop.

- Verify the motor speed (both pu and rpm) calculated by SPEED_PR module. View the following variables in the Watch Window.
  - gGUIObj.SpdMotor (pu)
  - gGUIObj.SpeedRpm (rpm)
- Bring the system to a safe stop as described below by setting gGUIObj.EnableFlg to 0, taking the controller out of realtime mode and reset.

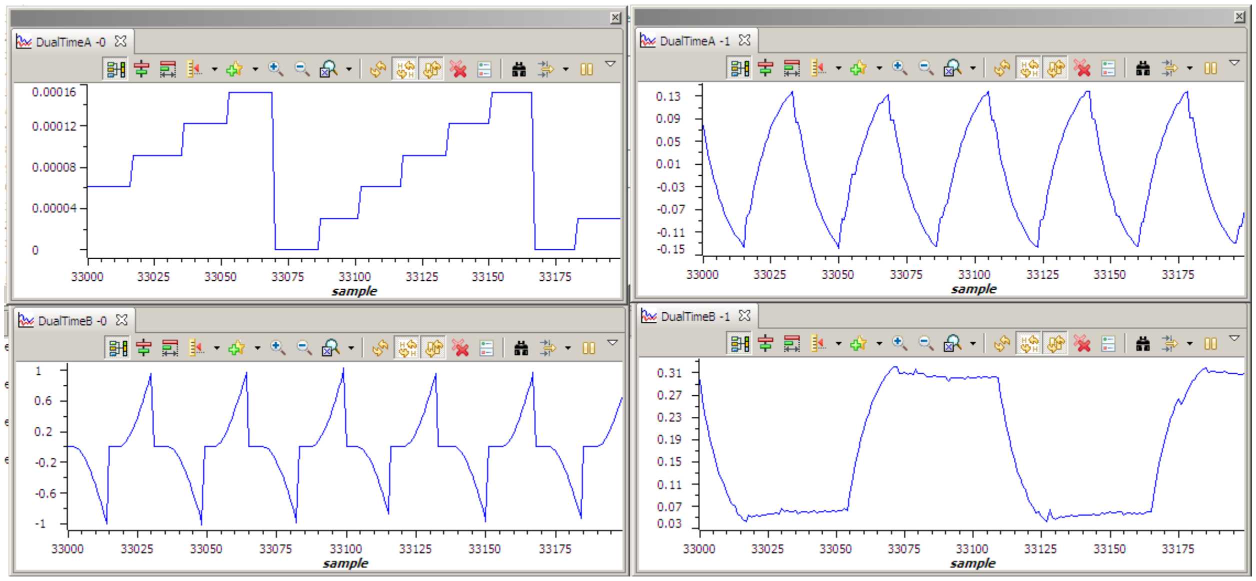


Fig 2 Graph Windows for Closed Current Loop Mode (a) mod6 counter, (b) V_int, (c) Vphase and (d)Vag

Velocity (Closed Loop Speed and Speed PI) Mode

In the software, the key variables to be adjusted are summarized below.

- gGUIObj.SpeedCmd: for changing the reference Speed in per-unit.

To run in Velocity Loop mode, complete the following:

1. Make sure the program is currently running on the device. If so, also assure that "gGUIObj.EnableFlg" is set to 0.
2. Verify that "gGUIObj.CtrlType" is set to 2, for Velocity Mode.
3. Set "gGUIObj.EnableFlg" to 1.

4. At this point, the variable “gDRVObj.isrTicker should be increasing. This confirms that the interrupt is running properly. The motor should start moving.

The steps are explained as follows:

- Compile/load/run program with real time mode.
- The motor will gradually speed up and finally switch to closed loop commutation mode.
- Now use the variable gGUObj.SpeedCmd to specify the reference speed for the PI controller PID_REG3. The gDRVObj.speedLoopFlag is automatically activated when the PI reference is ramped up from zero speed to gGUObj.SpeedCmd. Once this is done, the PI controller will start to regulate the motor speed. Gradually increase the command speed (gGUObj.SpeedCmd value) to increase the motor speed.
- Adjust speed PI gains to obtain the satisfied speed responses, if needed.
- Bring the system to a safe stop as described below by setting gGUIObj.EnableFlg to 0, taking the controller out of realtime mode and reset.

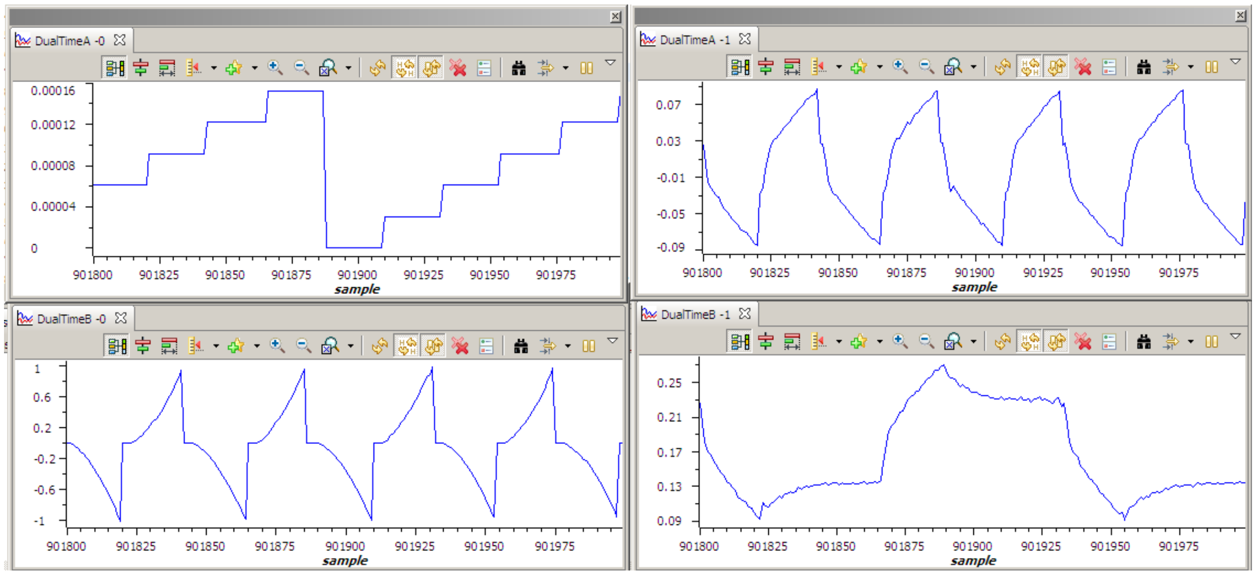


Fig 3 Graph Windows for Velocity Mode (a) mod6 counter, (b) V_int, (c) Vphase and (d)Vag

Cascaded Velocity + Current Loop Mode

In the software, the key variables to be adjusted are summarized below.

- gGUIObj.SpeedCmd: for changing the reference Speed in per-unit.

To run in Cascaded Velocity + Current Loop mode, complete the following:

1. Make sure the program is currently running on the device. If so, also assure that "gGUIObj.EnableFlg" is set to 0.
2. Verify that "gGUIObj.CtrlType" is set to 3, for Cascaded Velocity + Current Loop Mode.
3. Set "gGUIObj.EnableFlg" to 1.
4. At this point, the variable "gDRVObj.isrTicker should be increasing. This confirms that the interrupt is running properly. The motor should start moving.

The steps are explained as follows:

- The motor will gradually speed up and finally switch to closed loop commutation mode.
- Now use the variable gGUIObj.SpeedCmd to specify the reference speed for the PI controller PID_REG3. The gDRVObj.speedLoopFlag is automatically activated when the PI reference is ramped up from zero speed to gGUIObj.SpeedCmd. Once this is done, the PI controller will start to regulate the motor speed. Gradually increase the command speed (gGUIObj.SpeedCmd value) to increase the motor speed.
- Adjust speed PI gains to obtain the satisfied speed responses, if needed.
- Bring the system to a safe stop as described below by setting gGUIObj.EnableFlg to 0, taking the controller out of realtime mode and reset.

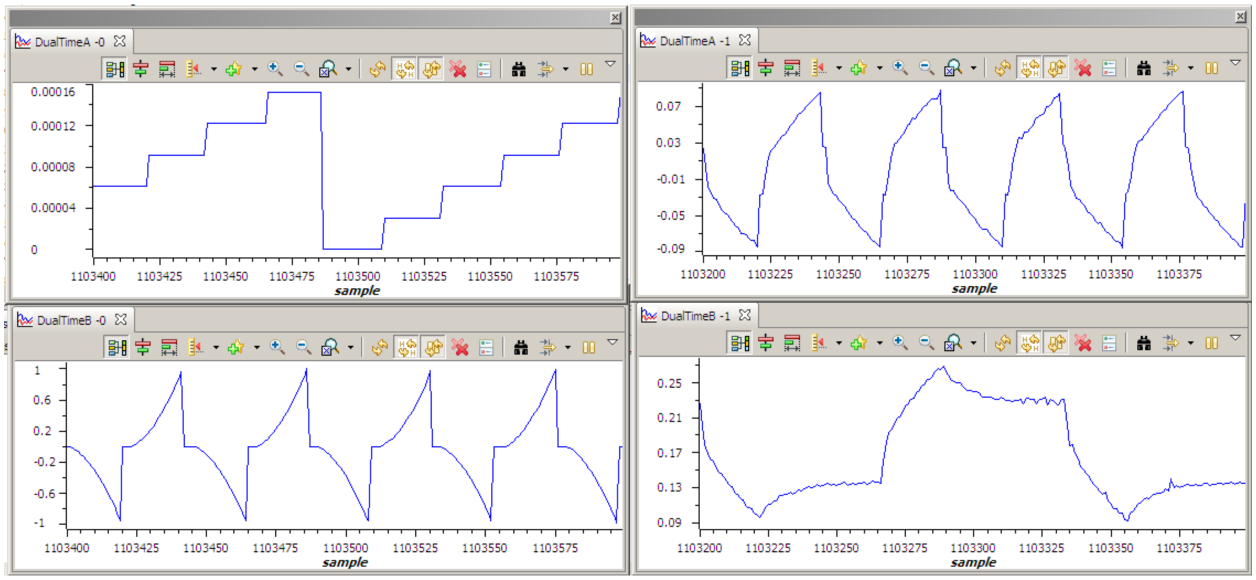
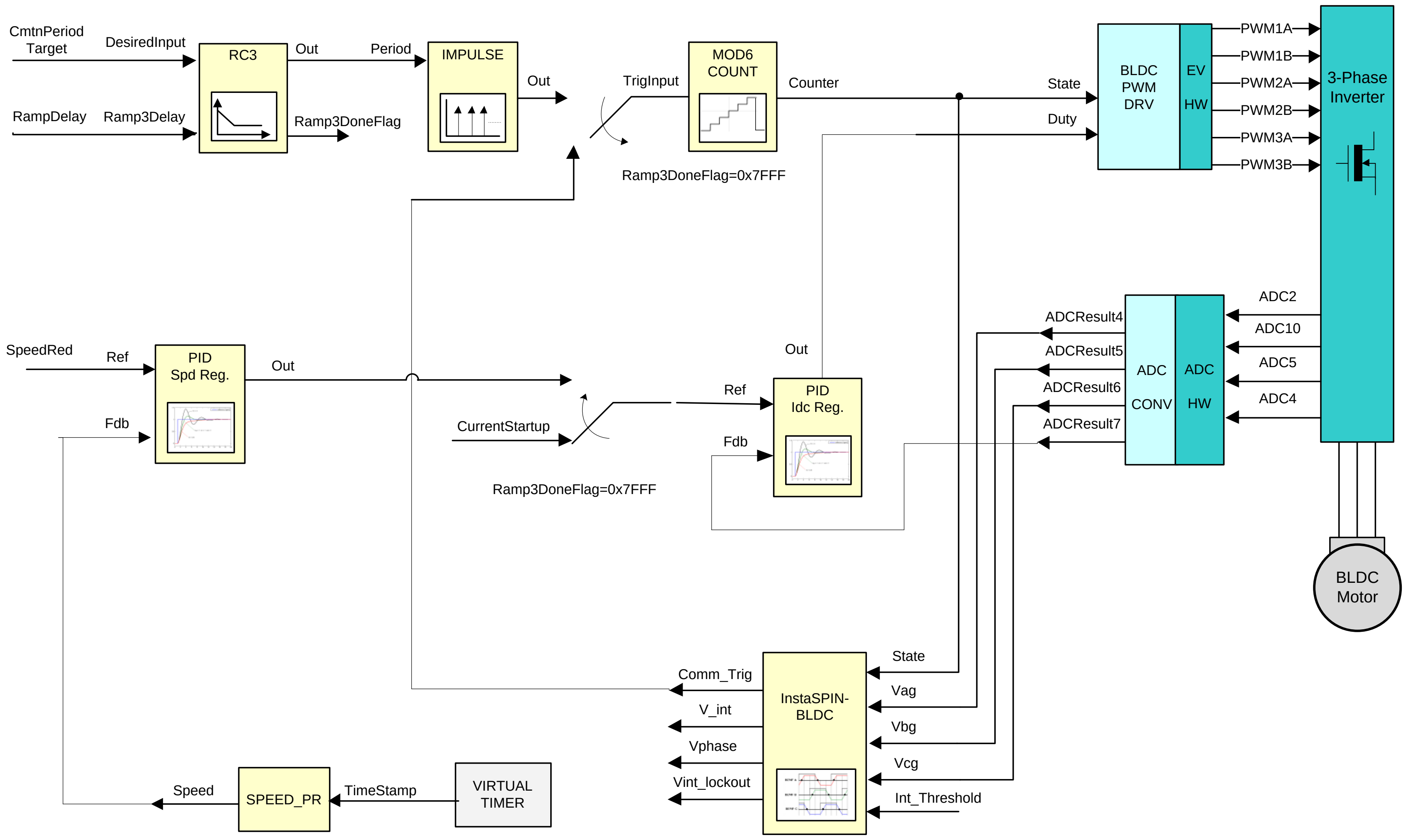


Fig 4 Graph Windows for Cascaded Velocity/Current Loop Mode (a) mod6 counter, (b) V_int, (c) Vphase and (d)Vag

Hercules InstaSPIN BLDC Block Diagram


CmtnPeriod Target
DesiredInput
RC3
Out
Period
IMPULSE
Out
TrigInput
MOD6 COUNT
Counter
State
Duty
BLDC PWM DRV
EV HW
PWM1A
PWM1B
PWM2A
PWM2B
PWM3A
PWM3B
3-Phase Inverter
RampDelay
Ramp3Delay
Ramp3DoneFlag
Ramp3DoneFlag=0x7FFF
ADC2
ADC10
ADC5
ADC4
ADCResult4
ADCResult5
ADCResult6
ADCResult7
ADC CONV
ADC HW
SpeedRed
Ref
PID Spd Reg.
Out
Fdb
CurrentStartup
Ramp3DoneFlag=0x7FFF
Out
Ref
PID Idc Reg.
Fdb
BLDC Motor
State
Comm_Trig
InstaSPIN-BLDC
Vag
V_int
Vbg
Vphase
Vcg
Vint_lockout
Int_Threshold
Speed
SPEED_PR
TimeStamp
VIRTUAL TIMER