# *设计指南：**TIDM-02006***
# *基于快速串行接口 **(FSI)** 的分布式多轴伺服驱动器参考设计*

## 说明

此参考设计展示的是基于快速串行接口 (FSI)、使用 C2000实时控制器的示例分布式多轴伺服驱动器。多轴伺服驱动器用于多种 应用 ，如工厂自动化和机器人应用。凭借每轴成本、性能和易用性等特性，该驱动器受到上述系统的高度青睐。FSI 是一种具有低抖动的可靠、成本优化型高速通信接口，能以菊花链形式连接多个 C2000 器件。在此设计中，每个 F28004x 器件均作为从动轴的实时控制器，控制电机的电流控制环。单个 F2838x 器件控制各轴的位置和速度控制环。上述 F2838x 还通过充分利用多个内核，执行主轴电机控制和 EtherCAT 通信。该设计采用 TI 的现有 EVM 套件，软件随附 C2000WARE MotorControl SDK 发布。

## 资源

| | |
|---|---|
| TIDM-02006 | 设计文件夹 |
| LAUNCHXL-F280049C | 工具文件夹 |
| TMDXCNCD28388D | 工具文件夹 |
| BOOSTXL-3PHGANINV | 工具文件夹 |
| TMDXIDDK379D | 工具文件夹 |
| C2000WARE-MOTORCONTROL-SDK | 工具文件夹 |

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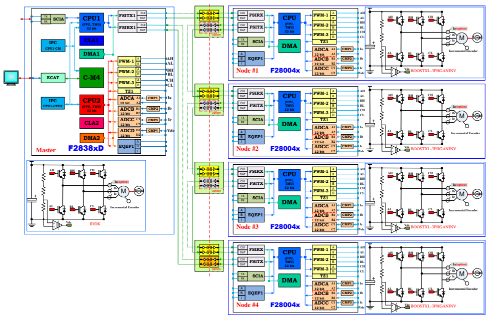
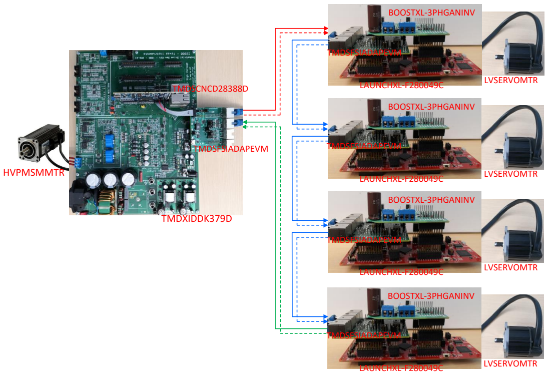
## 特性

- 此设计展示了通过快速串行接口 (FSI) 进行高速通信，在多个器件之间实现实时的速度、位置和电流命令数据通信。
- 在基于 F2838x 的主节点上对所有从动轴实施位置和速度控制环路，在基于 F28004x 的从节点上实施扭矩/电流环路。
- 借助一个 F2838x 可管理多达 16 个轴。可同时控制各轴启停。实现对分布式多轴电机驱动系统的高带宽、更高精度的控制。
- 借助基于 FSI 的所有从节点，使用 F2838x 多核功能实施速度和位置控制以及数据交换、执行主轴电机控制并与 PC 进行 EtherCAT 通信。
- 基于 F28004x 和 F2838x 的集成式 SFRA 工具，支持对速度和电流环进行在线调优。
- 增量系统构建，用于分步验证不同的软件模块。

## 应用

- 工业电机驱动器
- 工厂自动化和控制
- 交流驱动器控制模块





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# 1 System Description

Motion control is a fundamental concern in many industrial applications, especially, multi-axis motion control systems which are found in many applications such as factory automation and robots. The evaluation criteria for multi-axis control systems includes control performance, connectivity, ease of use and cost. Modern multi-axis systems require high resolution and bandwidth within each motor controller as well as very fast communication between master and slaves. Servo inverters in multi-axis applications are often linked by Ethernet based field bus systems and controlled by a primary controller, but Ethernet is a high cost and complex communication peripheral. C2000's Fast Serial Interface (FSI) is implemented in this design to ensure a real-time data communication link between the host and slave devices.

## *1.1 Key System Specifications*

表 1 lists the system specification of the distributed multi-axis servo drive over fast serial interface (FSI) reference design.

**表 1. Key System Specifications**

| PARAMETER | SPECIFICATIONS | DETAILS |
|---|---|---|
| Input power supply voltage | BOOSTXL-3PHGANINV : 60VDC or less | Nominal is 48V, default is 24V for this design |
| | TMDXIDDK379D: 400VDC/220VAC or less | Default is 300VDC for this design |
| DC input current | BOOSTXL-3PHGANINV : 10A or less each board | Not intended for long run times with full current output |
| | TMDXIDDK379D: 10A or less | |
| Connected motor capacity | BOOSTXL-3PHGANINV : 400W or less each board | 48V DC bus input voltage |
| | TMDXIDDK379D: 1000W or less | 300VDC/220VAC bus input voltage |
| Maximum three-phase output current | BOOSTXL-3PHGANINV : 10A(rms) or less | Not intended for long run times with full current |
| | TMDXIDDK379D: 10A(rms) or less | |
| Switching PWM frequency | BOOSTXL-3PHGANINV : 40 kHz or less, default is 10kHz | CPU MIPS limits the maximum switching frequency |
| | TMDXIDDK379D: 20 kHz or less, default is 10kHz | Power module limits the maximum switching frequency |
| Maximum modulation index at 10kHz | BOOSTXL-3PHGANINV : 96% | Single sampling |
| | TMDXIDDK379D: 98% | Single sampling |
| PWM update latency | BOOSTXL-3PHGANINV : <2.06us | FCL code executes with F28004x CPU |
| | TMDXIDDK379D: <1.03us | FCL code executes with F2838x CPU |
| FOC execution time | BOOSTXL-3PHGANINV : <7.8us | FOC code executes with F28004x CPU |
| | TMDXIDDK379D: <4.12us | FOC code executes with F2838x CPU |
| Speed setting | 0.1%~100% | Below 1% need to change the gain of speed controller. |
| Position detection method | Incremental encoder | Connect to QEP interface |
| Drive method | FOC with FCL | sensored-FOC based encoder |
| FSI speed | 100Mbps @ 50MHz Clock | LVDS interface |
| Communication topology | Daisy chain (16 nodes or less) | 1 master, 15 slaves |
| Communication cycle times | Free run mode, less than 1 ms every cycle | 4 slave nodes, daisy-chain topology network |
| Working temperature range | -40°C to 85°C | Industrial temperature range -40°C to 85°C. |

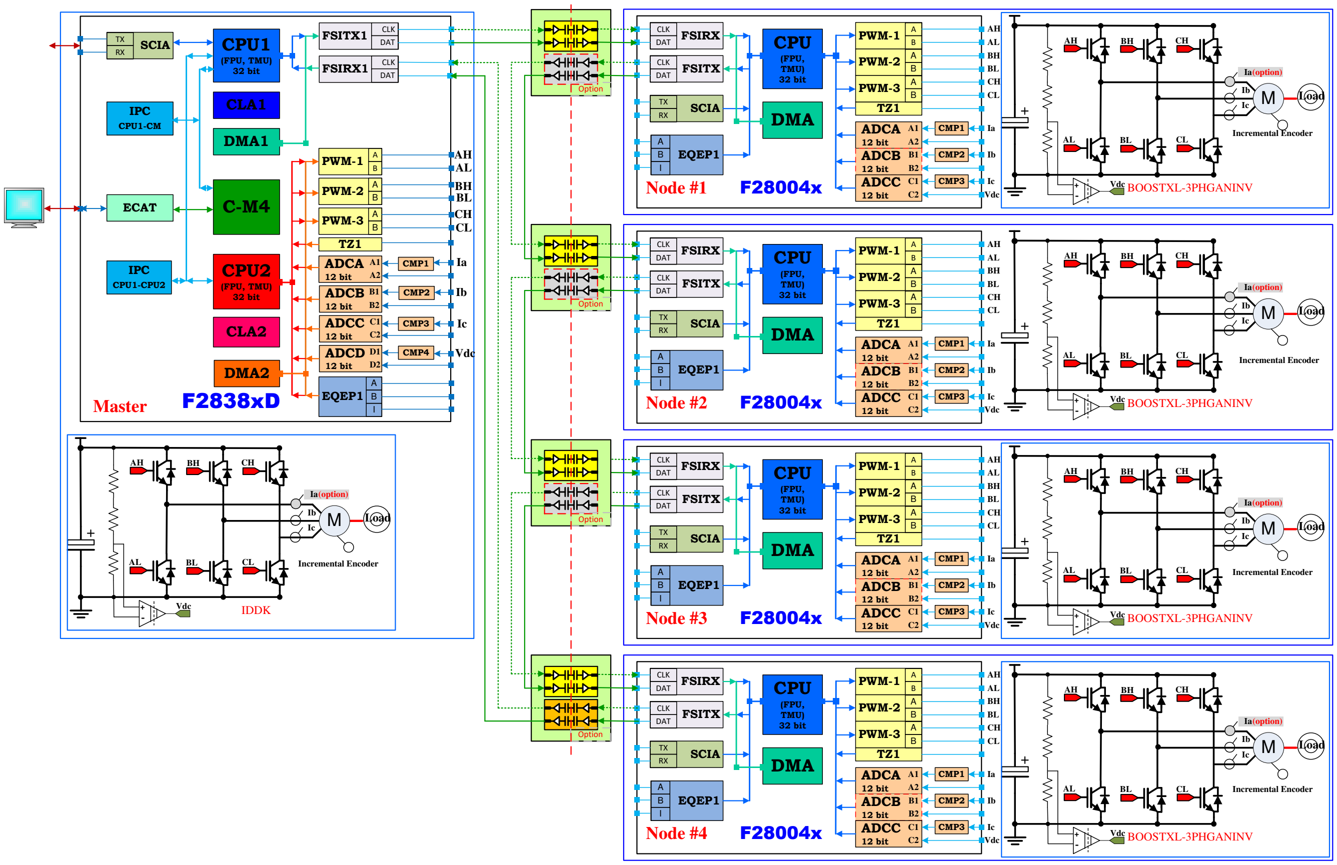
## 2 System Overview

### 2.1 Block Diagram

图 1 shows the system block diagram of TIDM-02006 reference design, which includes the following elements:

- Master node consists of one controller, one high voltage inverter, and one PM motor with incremental encoder. TMS320F28388D functions as the controller, which samples all the voltage and current inputs and generates the correct PWM signals for inverter. The controller also exchanges data as lead with slave controllers via FSI, and communication with EtherCAT master on PC.
- Four slave nodes, each node consists of one controller, one low voltage inverter, and one PM motor with incremental encoder. TMS320F280049C functions as the controller, which has all the voltage and current sensing inputs and generates the correct PWM signals for inverter. The controller also receives and transmits the data with master controller via FSI.

**图 1. TIDM-02006 System Block Diagram**



### 2.2 Highlighted Products

This distributed multi-axis servo drive system is based on a F2838x controller and multiple F28004x controllers. The F2838x device serves as the master and each F28004x serves as a slave node. The Fast Serial Interface (FSI) is used as the communication bus between master node and slave nodes.

### 2.2.1 TMS320F28004x

TMS320F28004x is a powerful 32-bit floating-point microcontroller unit (MCU) that lets designers incorporate crucial control peripherals, differentiated analog, and nonvolatile memory on a single device. The real-time control subsystem is based on TI's 32-bit C28x CPU, which provides 100 MHz of signal processing performance. The C28x CPU is further boosted by the new TMU extended instruction set, which enables fast execution of algorithms with trigonometric operations commonly found in transforms and torque loop calculations. The CLA allows significant offloading of common tasks from the main C28xCPU. The CLA is an independent 32-bit floating-point math accelerator that executes in parallel with the CPU. Additionally, the CLA has its own dedicated memory resources and it can directly access the key peripherals that are required in a typical control system. High-performance analog blocks are integrated on the F28004x MCU to further enable system consolidation. Three separate 12-bit ADCs provide precise and efficient management of multiple analog signals, which ultimately boosts system throughput. Seven PGAs on the analog front end enable on-chip voltage scaling before conversion. Seven analog comparator modules provide continuous monitoring of input voltage levels for trip conditions. The TMS320C2000™ devices contain industry-leading control peripherals with frequency independent PWM/HRPWM and eCAP allow for a best-in-class level of control to the system. A specially enabled device variant, TMS320F28004xC, allows access to the Configurable Logic Block (CLB) for additional interfacing features.

### 2.2.2 TMS320F2838x

The TMS320F2838x is a powerful 32-bit floating-point microcontroller unit (MCU) designed for advanced closed-loop control applications. The F2838x supports a dual-core C28x architecture along with a new Connectivity Manager that offloads critical communication tasks, significantly boosting system performance. The integrated analog and control peripherals with advanced connectivity peripherals like EtherCAT and Ethernet also let designers consolidate real-time control and real-time communications architectures, reducing requirements for multi controller systems. The dual real-time control subsystems are based on TI's 32-bit C28x floating-point CPUs, which provide 200 MHz of signal processing performance in each core. The C28x CPUs are further boosted by the TMU accelerator, which enables fast execution of algorithms with trigonometric operations common in transforms and torque loop calculations. The F2838x microcontroller family features two CLA real-time control coprocessors. The CLA is an independent 32-bit floating-point processor that runs at the same speed as the main CPU. The CLA responds to peripheral triggers and executes code concurrently with the main C28x CPU. This parallel processing capability can effectively double the computational performance of a real-time control system. By using the CLA to service time-critical functions, the main C28x CPU is free to perform other tasks, such as communications and diagnostics. The dual C28x+CLA architecture enables intelligent partitioning between various system tasks. For example, one C28x+CLA core can be used to track speed and position, while the other C28x+CLA core can be used to control torque and current loops. Performance analog and control peripherals are also integrated on the F2838x MCU to further enable system consolidation. Four independent 16-bit ADCs provide precise and efficient management of multiple analog signals, which ultimately boosts system throughput. The sigma-delta filter module (SDFM) works in conjunction with the sigma-delta modulator to enable isolated current shunt measurements. The Comparator Subsystem (CMPSS) with windowed comparators allows for protection of power stages when current limit conditions are exceeded or not met. Other analog and control peripherals include DACs, PWMs, eCAPs, eQEPs, and other peripherals. Peripherals such as EMIFs, CAN modules , EtherCAT, Ethernet, and MCAN (CAN-FD) extend the connectivity of the F2838x. Fast Serial Interface (FSI) with two transmitters and eight receivers is a serial communication peripheral capable of reliable high-speed communication across isolation devices.

## 2.3 System Design Theory

### 2.3.1 FOC and Control Loops in Servo Drive

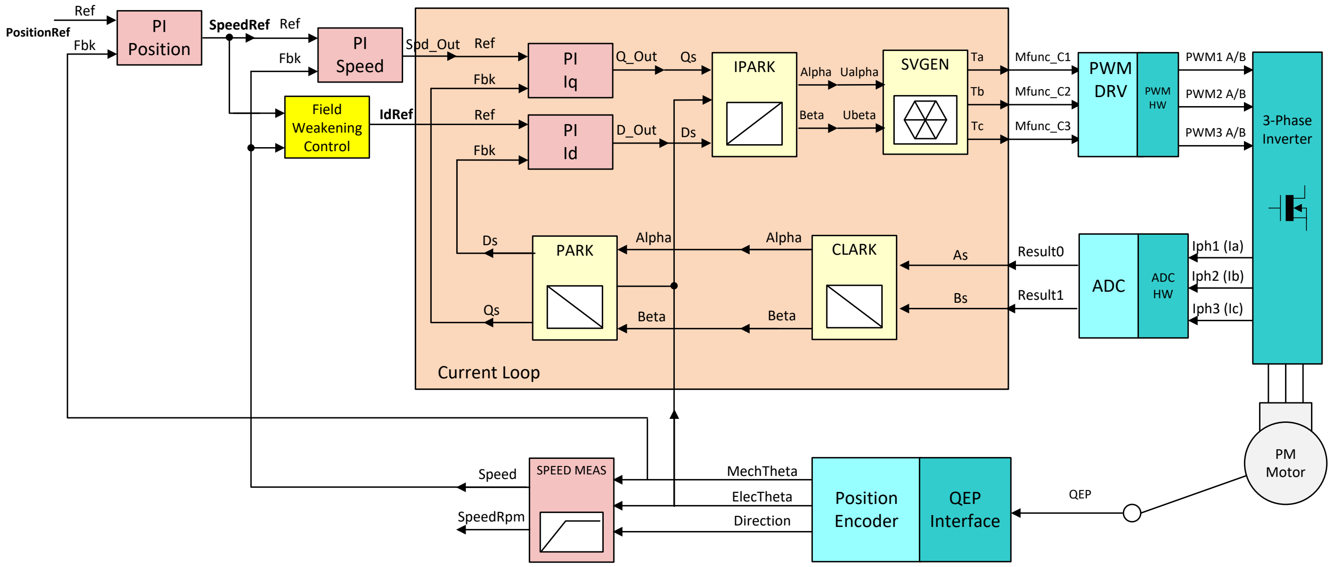
A servo drive system for a single motor axis generally consists of controller, inverter, motor and load, and feedback device. There are three closed loop control systems that are at work within the servo drive system: these are the position loop, speed loop and current loop as shown in 图 2.

The position loop compares position reference with the position feedback to determine the position error. This is used to generate a speed demand, also known as a speed reference, to regulate the position.

The speed loop compares the speed demand from the position loop to the speed feedback from the motor, and generates a torque reference.

The current loop is designed to regulate the torque producing output current to the motor. It takes the torque demand from the speed loop and current feedback signals from current sensors within inverter to generate the control signals to produce a power output from the power inverter module. In the current loop, any two of the motor phase currents are measured, while the third can be estimated from these two sensing currents. A minimal current loop time not only helps to improve the control bandwidth, but it also enables a higher modulation index for the inverter. A higher modulation index translates into the higher phase voltage that the inverter can apply on the motor. Higher current loop latency will reduce the maximum available voltage and restrict the rate of current change in the motor, thereby, adversely impacting the controller performance. To overcome these challenges, fast current loop (FCL) technology is used in this design for torque control loop.

图 2. Servo Drive Control System Block Diagram



### 2.3.2 Daisy-chain Communication Network Using FSI

The Fast Serial Interface (FSI) module is a serial communication peripheral capable of reliable high-speed communication across isolation devices. The FSI module consists of independent transmitter (FSITX) and receiver (FSIRX) cores. The FSITX and FSIRX cores are configured and operated independently. For more information on the FSI module on a specific C2000 devices, see the device-specific data sheet and technical reference manual.

There are a number of different types of communication network topology for connecting multiple devices via FSI, including point to point, bus, start, and ring. The ring topology is used in this design to connect multiple devices with FSI communication in a daisy-chain fashion as shown in 图 3.

图 **3. Daisy-chain Connection Topology**

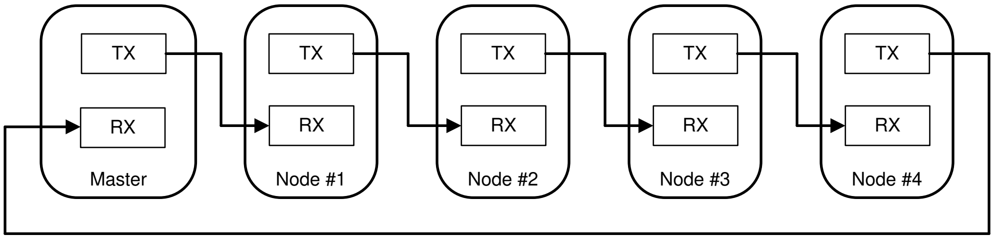
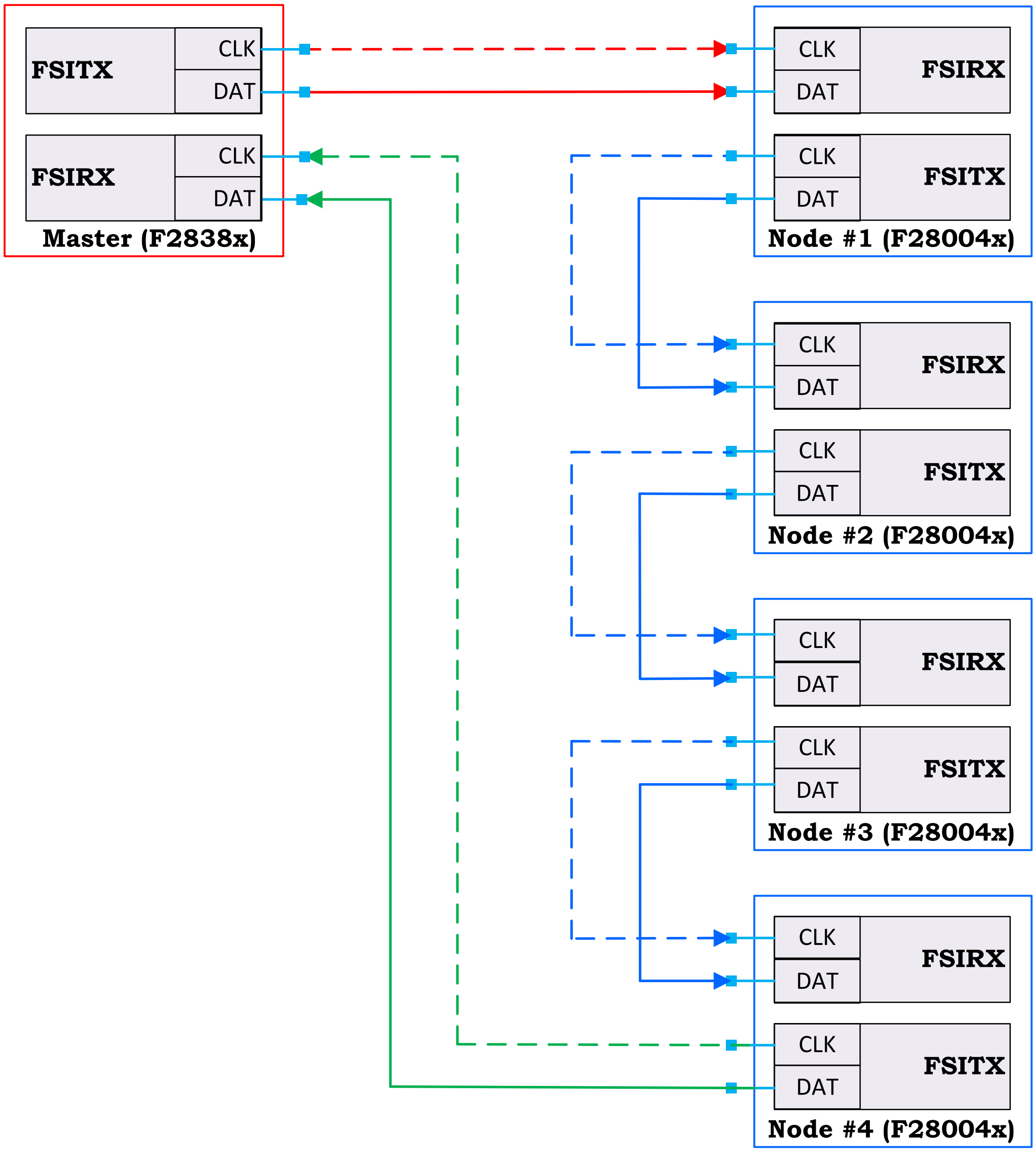


图 4 shows the implementation of the communication connect multiple C2000 devices in this design. The FSI module is operated using only one data line (RXD0 or TXD0). In this mode the RXCLK and RXD0 act as clock and data for receiver while RXD1 is unused, and the TXCLK and TXD0 act as clock and data for transmitter while TXD1 is unused. F2838x is the master node which will be the driver of the initialization sequence. The F28004x based nodes is the slave node, it will respond to the master's command.

图 4. FSI Master to Multiple Slaves Connection using C2000 Controllers



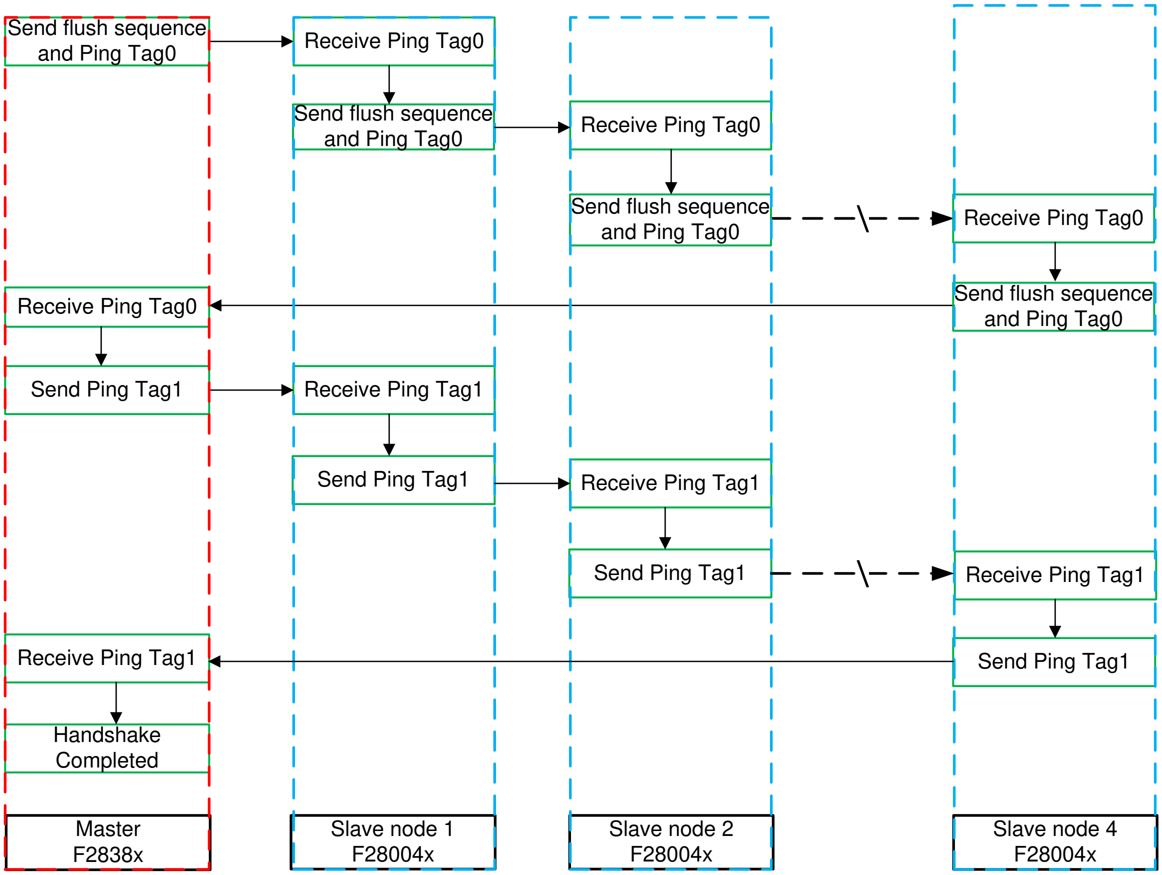
Use the following steps to establish FSI communication link for daisy-chain connection:

1. Configure the transmitter and receiver modules for synchronization.
2. Using the handshaking process to implement synchronization to ensure that the receiver is properly flushed and ready to receive a complete frame without error before the modules may exchange data. 图 5 shows the data flow for handshake. There are two ping loops for the daisy-chain connection handshake.
   a. Ping loop 0 has the purpose of establishing the communication path along the chain of devices and ping loop 1 acts as the acknowledgment to the nodes that the communication path is good. In ping loop 0, the node devices wait for receiving a Ping Tag0 from the previous device in the chain. Once a Ping Tag0 is successfully received, it will be forwarded on to the next device in the chain. The ping loop 0 will fail if a device in the chain has not powered up or is not ready for the reception.
   b. Once ping loop 0 has succeeded, in which ping tag0 has made its way back to the lead device, ping loop 1 is initiated to inform the node devices that the handshake sequence has completed. At

this point, both the transmit and receive modules have successfully received ping frames from their master counterparts. The link has been established and regular communication may now proceed.

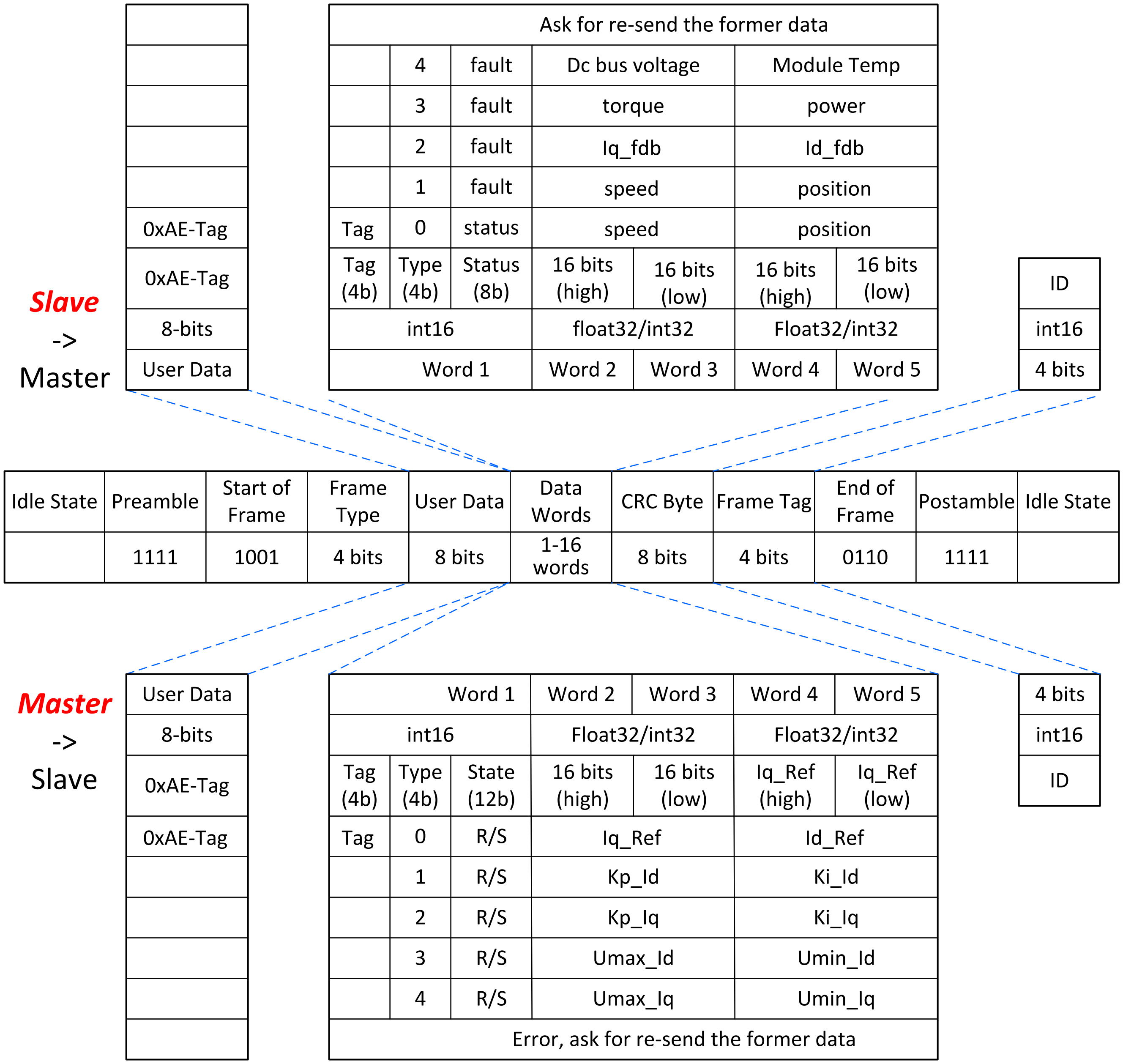
3. Configure FSI for exchanging the regular data. The desired application configuration includes the frame type, frame tag, data words, number of data line.

图 **5. FSI Handshake Data Flow**



In this design, position and velocity control loops are implemented for all axes on the F2838x based master node, while the torque loop utilizing the fast current loop (FCL) technique is implemented on the F28004x based slave nodes for each individual axis. The running command or status, speed and position data are exchanged between master and slave nodes. 图 6 shows a simplified FSI communication protocol used in this design.

图 6. FSI Data Communication Protocol



Slave -> Master

| |
|---|
| |
| |
| |
| |
| |
| 0xAE-Tag |
| 0xAE-Tag |
| 8-bits |
| User Data |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ask for re-send the former data | | | | | | |
| | 4 | fault | Dc bus voltage | | Module Temp | |
| | 3 | fault | torque | | power | |
| | 2 | fault | Iq_fdb | | Id_fdb | |
| | 1 | fault | speed | | position | |
| Tag | 0 | status | speed | | position | |
| Tag (4b) | Type (4b) | Status (8b) | 16 bits (high) | 16 bits (low) | 16 bits (high) | 16 bits (low) |
| int16 | | | float32/int32 | | Float32/int32 | |
| Word 1 | | | Word 2 | Word 3 | Word 4 | Word 5 |

| |
|---|
| ID |
| int16 |
| 4 bits |

| Idle State | Preamble | Start of Frame | Frame Type | User Data | Data Words | CRC Byte | Frame Tag | End of Frame | Postamble | Idle State |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1111 | 1001 | 4 bits | 8 bits | 1-16 words | 8 bits | 4 bits | 0110 | 1111 | |

Master -> Slave

| |
|---|
| User Data |
| 8-bits |
| 0xAE-Tag |
| 0xAE-Tag |
| |
| |
| |
| |
| |

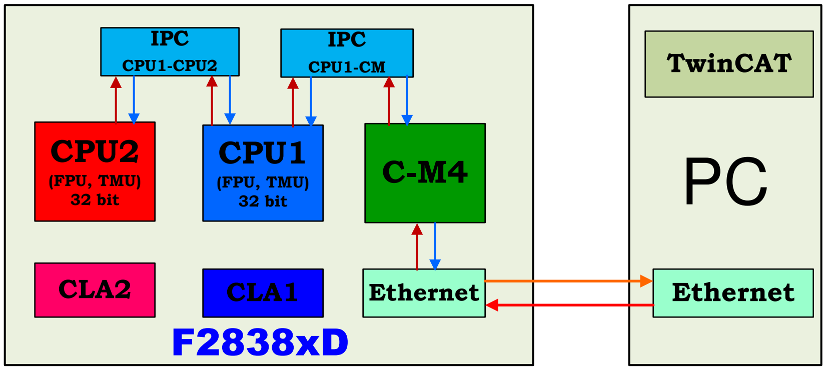
| | | | | | | |
|---|---|---|---|---|---|---|
| Word 1 | | | Word 2 | Word 3 | Word 4 | Word 5 |
| int16 | | | Float32/int32 | | Float32/int32 | |
| Tag (4b) | Type (4b) | State (12b) | 16 bits (high) | 16 bits (low) | Iq_Ref (high) | Iq_Ref (low) |
| Tag | 0 | R/S | Iq_Ref | | Id_Ref | |
| | 1 | R/S | Kp_Id | | Ki_Id | |
| | 2 | R/S | Kp_Iq | | Ki_Iq | |
| | 3 | R/S | Umax_Id | | Umin_Id | |
| | 4 | R/S | Umax_Iq | | Umin_Iq | |
| Error, ask for re-send the former data | | | | | | |

| |
|---|
| 4 bits |
| int16 |
| ID |

### 2.3.3 EtherCAT Communication

The F2838x device offers enhanced connectivity options and increases control performance while enabling system-level flexibility in industrial and high-power-grid applications. Real-time communications are enabled by a dedicated Arm® Cortex-M4 based Connectivity Manager (CM), which offloads processing-intensive communications and optimizes connectivity. 图 7 shows the EtherCAT slave in F2838x device to link up with a PC using TwinCAT as master. Among the three cores of F2838x MCU (two C28x CPU cores (CPU1, CPU2) and one Cortex-M4 core), the EtherCAT peripheral can be connected to CPU1 or M4. In this design, M4 based connectivity manager is chosen to interact with the EtherCAT peripheral.

图 7. EtherCAT Configuration in Multi-Axis Servo System



### 2.3.4 Mutli-Axis Servo Drive System

图 8 shows the layout of a typical multi-axis servo drive system, all control loops up to the position controller are implemented on the servo inverters. They are often linked via a high speed communication field bus to a high performance processor based primary controller. The primary controller distributes reference-values and receives feedback values from the servo inverter.

图 8. Typical Layout of a Multi-axis Servo Drive System

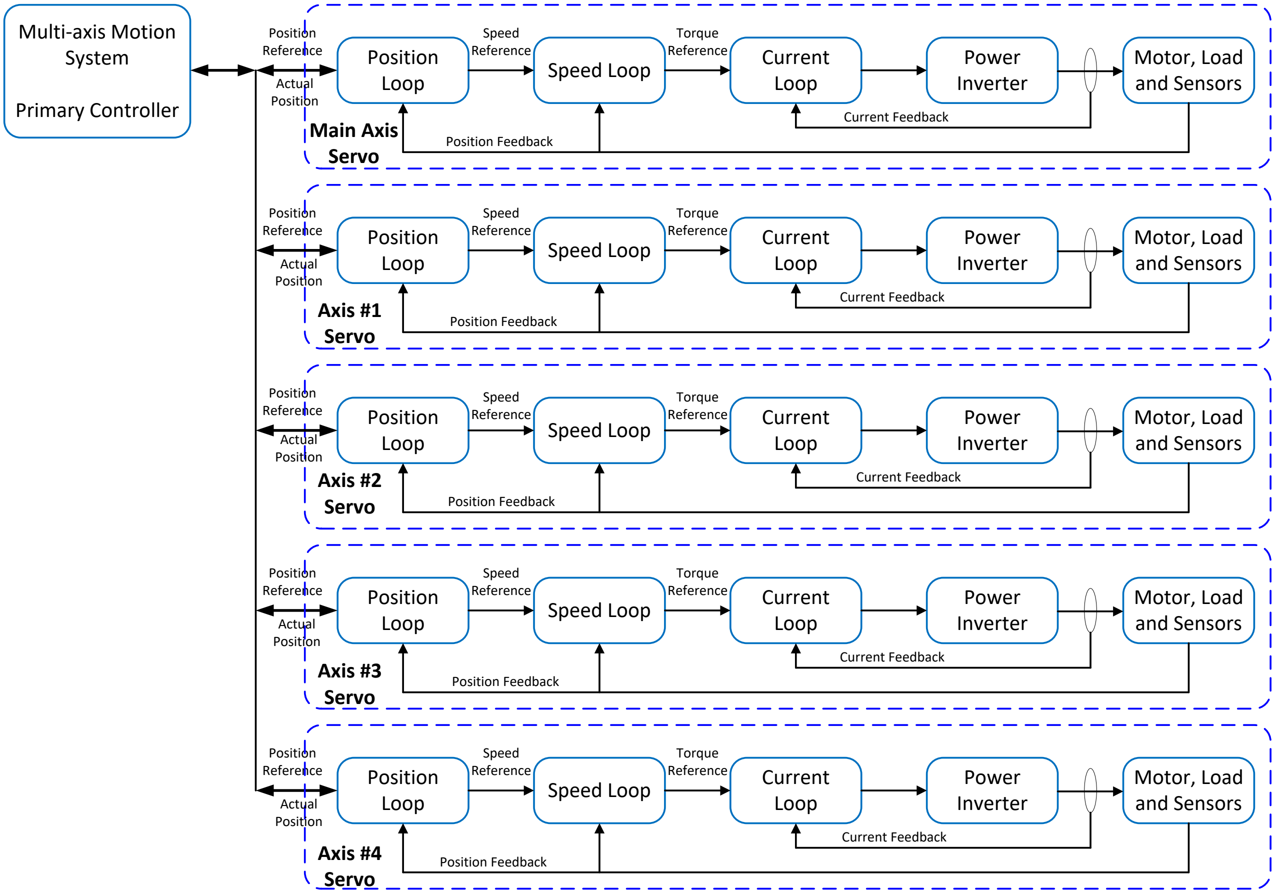


图 9 shows the control structure used in this design. The inverters only perform current control algorithms, and send the speed and position feedback signal to the position and speed controller via a high speed communication bus. All position and speed control loop functions are calculated on the position and speed controller for all axes.

图 9. Layout of a Distributed Multi-axis Servo Drive System

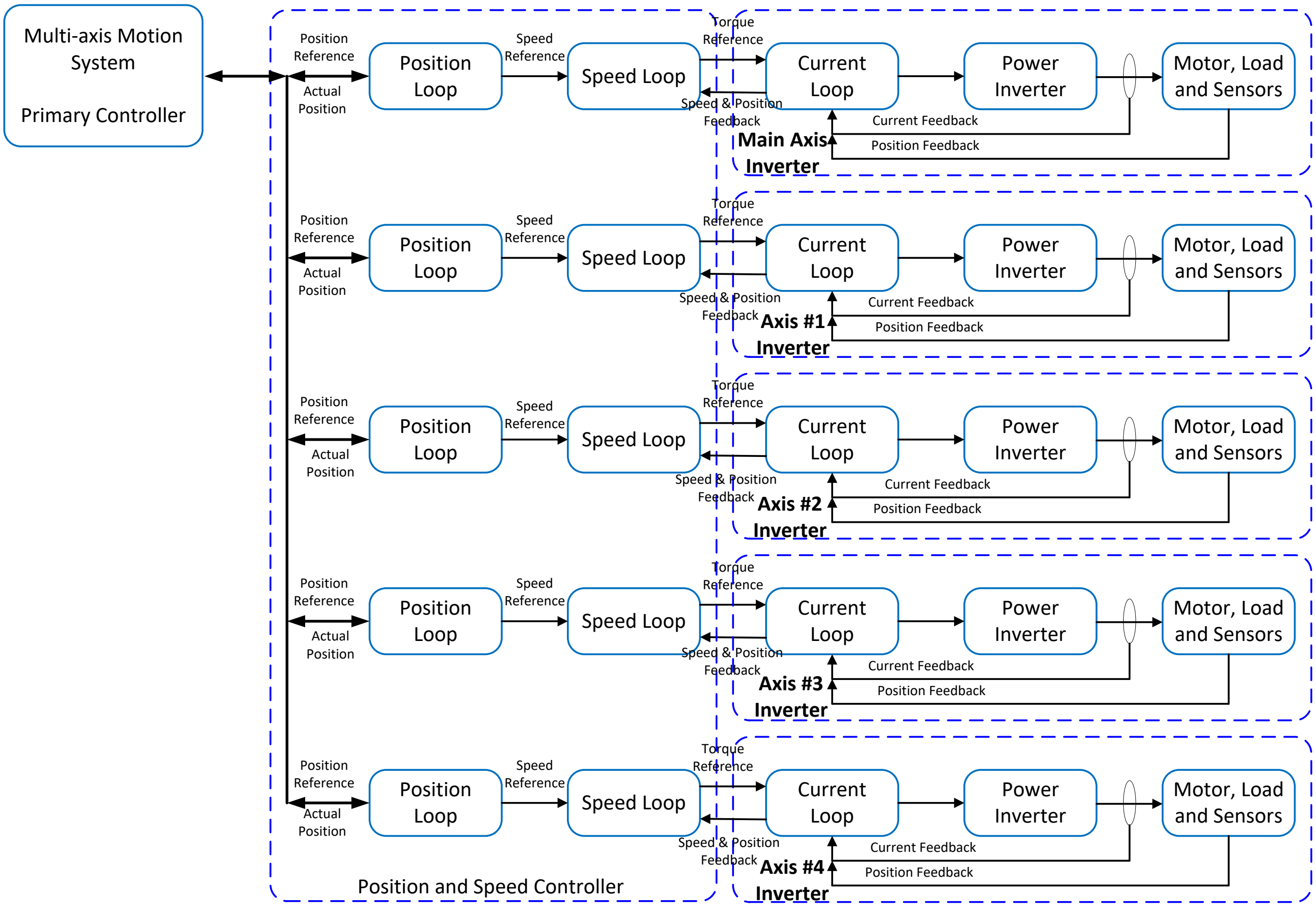
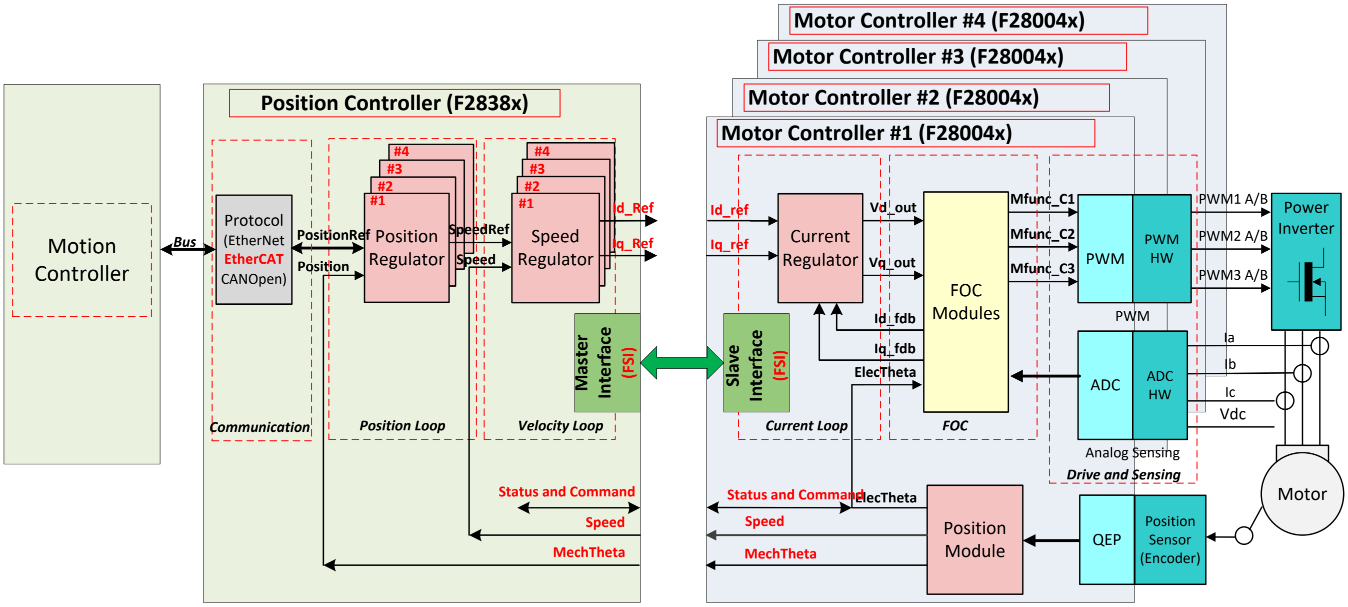


图 10 shows the implementation of a distributed multi-axis servo drive system based on C2000 devices, where all position and speed control functions are executed on the master node, torque control loop runs on slave node. Position and speed feedback values are transmitted via FSI link between master and slave nodes. The distributed control architecture utilizes the high speed and low signal count of FSI to transfer more data with fewer channels, leading to reduced overall cost and improved reliability of the system.

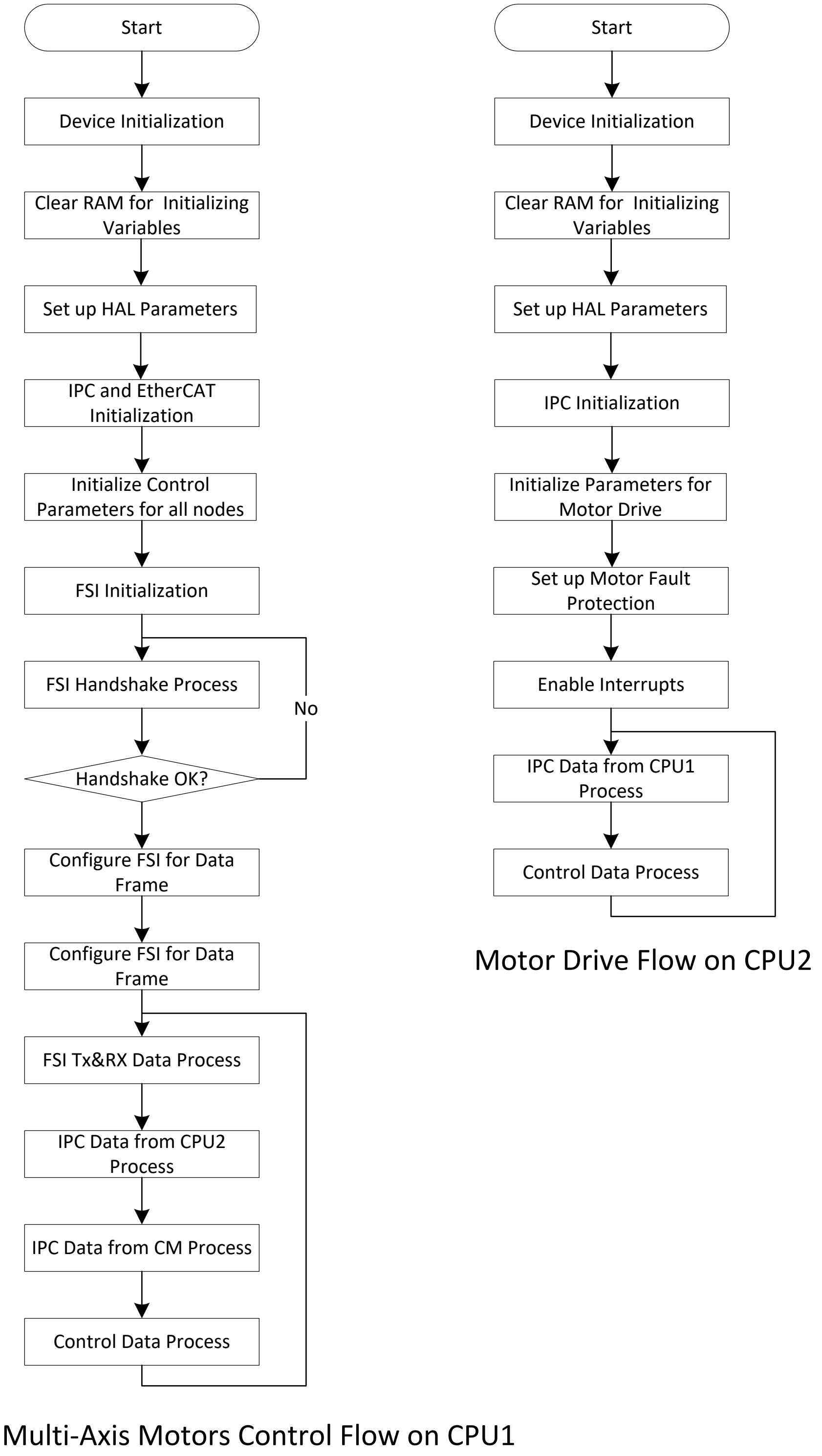
图 10. Implementation of A Distributed Multi-axis Servo Drive System Using C2000 Devices



### 2.3.5 System Control and Drive Software

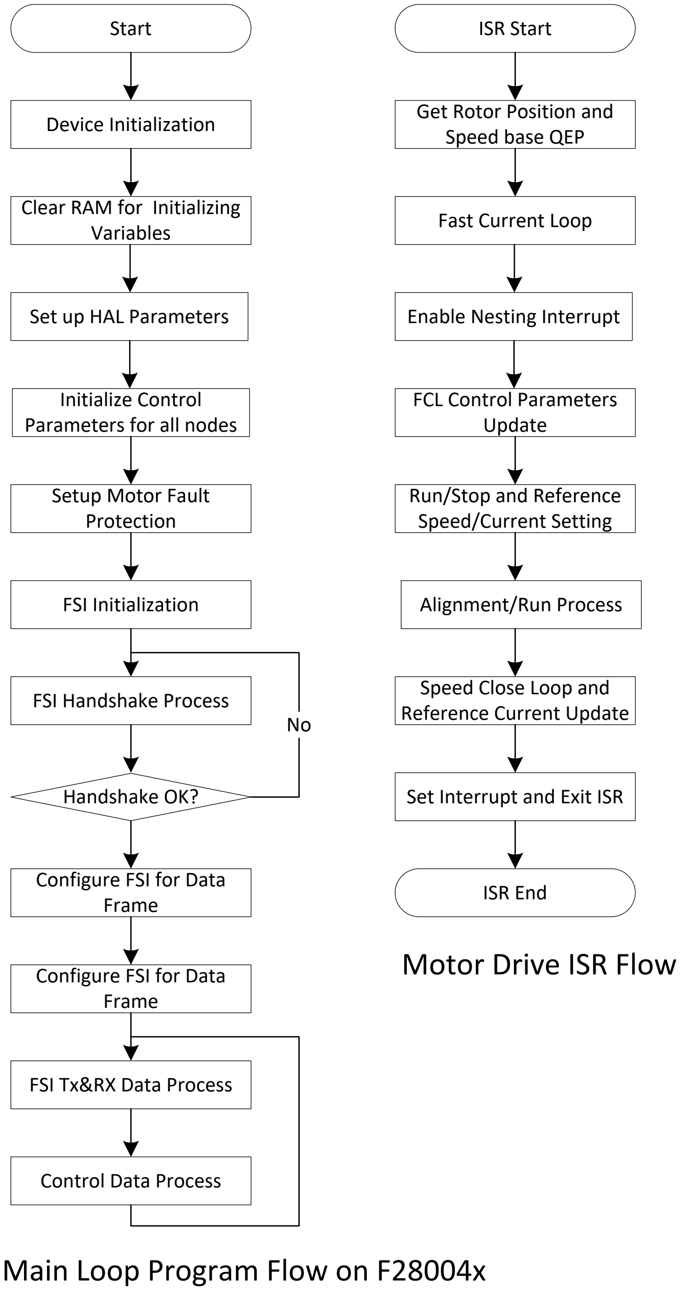
The reference design software is coded in C and master node software runs on F2838x device. The position and speed control loops for all axes are implemented on CPU1, sensored-FOC and current loop of main axis is implemented on CPU2. The main program flows are described in the 图 11. The ISR program flow of main-axis drive is the same as implementation on F28004x as shown in 图 12.

图 11. Main Program Flowchart on CPU1 and CPU2 of F2838x


Start
Device Initialization
Clear RAM for Initializing Variables
Set up HAL Parameters
IPC and EtherCAT Initialization
Initialize Control Parameters for all nodes
FSI Initialization
FSI Handshake Process
No
Handshake OK?
Configure FSI for Data Frame
Configure FSI for Data Frame
FSI Tx&RX Data Process
IPC Data from CPU2 Process
IPC Data from CM Process
Control Data Process
Multi-Axis Motors Control Flow on CPU1
Start
Device Initialization
Clear RAM for Initializing Variables
Set up HAL Parameters
IPC Initialization
Initialize Parameters for Motor Drive
Set up Motor Fault Protection
Enable Interrupts
IPC Data from CPU1 Process
Control Data Process
Motor Drive Flow on CPU2

The software of each slave node runs on a F28004x device respectively, implements sensored-FOC and torque control with FCL. The main and ISR program flows are shown in 图 12.

### 图 12. Main and ISR Program Flowcharts on F28004x


Start
Device Initialization
Clear RAM for Initializing Variables
Set up HAL Parameters
Initialize Control Parameters for all nodes
Setup Motor Fault Protection
FSI Initialization
FSI Handshake Process
No
Handshake OK?
Configure FSI for Data Frame
Configure FSI for Data Frame
FSI Tx&RX Data Process
Control Data Process
Main Loop Program Flow on F28004x
ISR Start
Get Rotor Position and Speed base QEP
Fast Current Loop
Enable Nesting Interrupt
FCL Control Parameters Update
Run/Stop and Reference Speed/Current Setting
Alignment/Run Process
Speed Close Loop and Reference Current Update
Set Interrupt and Exit ISR
ISR End
Motor Drive ISR Flow

# 3 Hardware, Software, Testing Requirements, and Test Results

## 3.1 Hardware

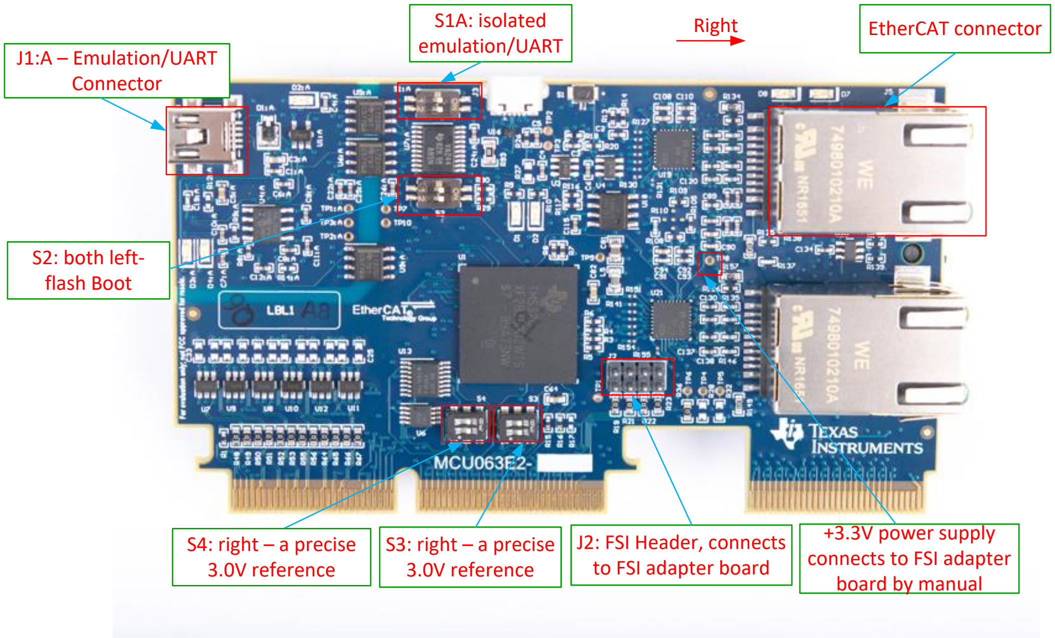
The reference design is based on the existing hardware tools, most of which are available from the TI Store. The details of the evaluation hardware and references to the user's guide are listed below:

- Controller
  - TMDSCNCD28388D: F28388D controlCARD evaluation module
  - LAUNCHXL-F280049C: C2000 Piccolo MCU F280049C LaunchPad™ development kit
- Inverter
  - BOOSTXL-3PHGANINV: 48-V Three-Phase Inverter With Shunt-Based In-Line Motor Phase Current Sensing Evaluation Module
  - TMDXIDDK379D: C2000 DesignDRIVE Development Kit for Industrial Motor Control
- Motor
  - LVSERVOMTR: Low Voltage Servo (encoder) Motor and wiring harness for BOOSTXL-3PHGANINV
  - HVPMSMMTR: High Voltage Permanent Magnet Synchronous Motor for TMDXIDDK379D
- Interface board
  - TMDSFSIADAPEVM : FSI Adapter Board ( will be available soon)
- DC Power Supply
  - A variable DC power supply rated at 100V/10A for BOOSTXL-3PHGANINV.
  - A variable DC power supply rated at 400V/2A for TMDXIDDK379D

### 3.1.1 TMDSCNCD28388D

图 13 shows the layout of TMS320F28388D controlCard, on-board switches setting as marked. Please refer to the *TMS320F28388D controlCARD Information Guide* for more details.

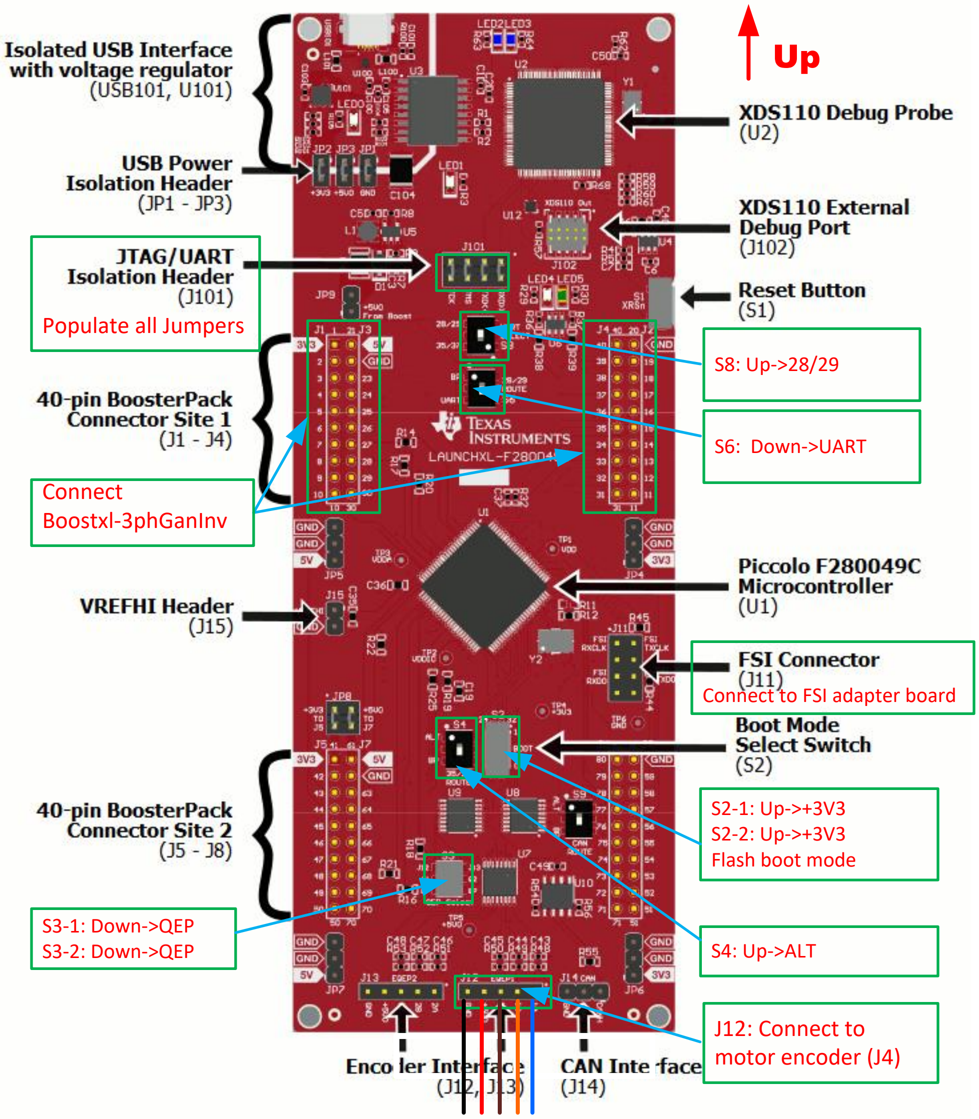
图 13. Layout of TMDSCNCD28388D and Switches Setting


S1A: isolated emulation/UART
Right
EtherCAT connector
J1:A – Emulation/UART Connector
S2: both left-flash Boot
S4: right – a precise 3.0V reference
S3: right – a precise 3.0V reference
J2: FSI Header, connects to FSI adapter board
+3.3V power supply connects to FSI adapter board by manual

### 3.1.2 LAUNCHXL-F280049C

图 14 shows the layout of TMS320F20049C LaunchPad, on-board switches setting as marked. Please refer to the *C2000™ Piccolo™ F28004x Series LaunchPad™ Development Kit* for details.

图 14. Layout of LAUNCHXL-F280049C and Switches Setting



Populate all Jumpers

Connect Boostxl-3phGanInv

S8: Up->28/29

S6: Down->UART

Connect to FSI adapter board

S2-1: Up->+3V3
S2-2: Up->+3V3
Flash boot mode

S3-1: Down->QEP
S3-2: Down->QEP

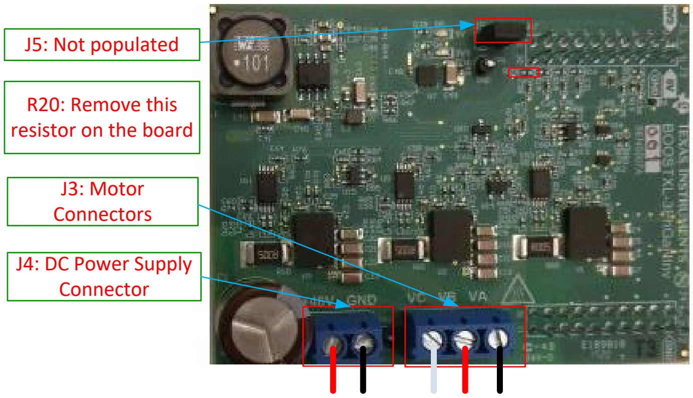
S4: Up->ALT

J12: Connect to motor encoder (J4)

### 3.1.3 BOOSTXL-3PHGANINV

图 15 shows the layout of BOOSTXL-3PHGANINV, on-board switches setting and wires connection as marked. Please refer to the BOOSTXL-3PhGaNInv Evaluation Module User's Guide for details.

**图 15. Layout, Switches Setting and Wires Connection of BOOSTXL-3PHGANINV**


J5: Not populated
R20: Remove this resistor on the board
J3: Motor Connectors
J4: DC Power Supply Connector

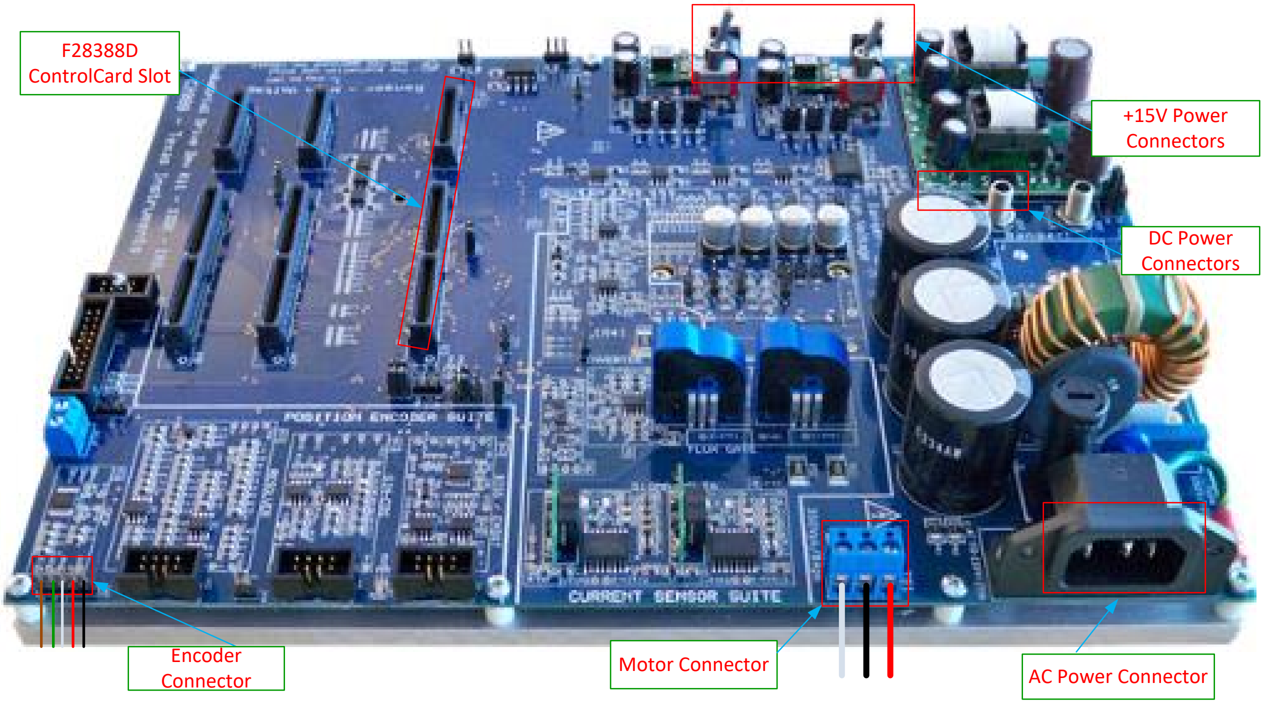
**注:**

- Don't populate the jumper on the J5.
- Remove the R20 resistor on the board, it is near the Pin30 of J3 and TP1.

### 3.1.4 TMDXIDDK379D

图 16 shows the layout of TMDXIDDK379D, on-board switches setting and wires connection as marked. Please refer to the *DesignDRIVE Development Kit IDDK v2.2.1 - User's Guide* for details.

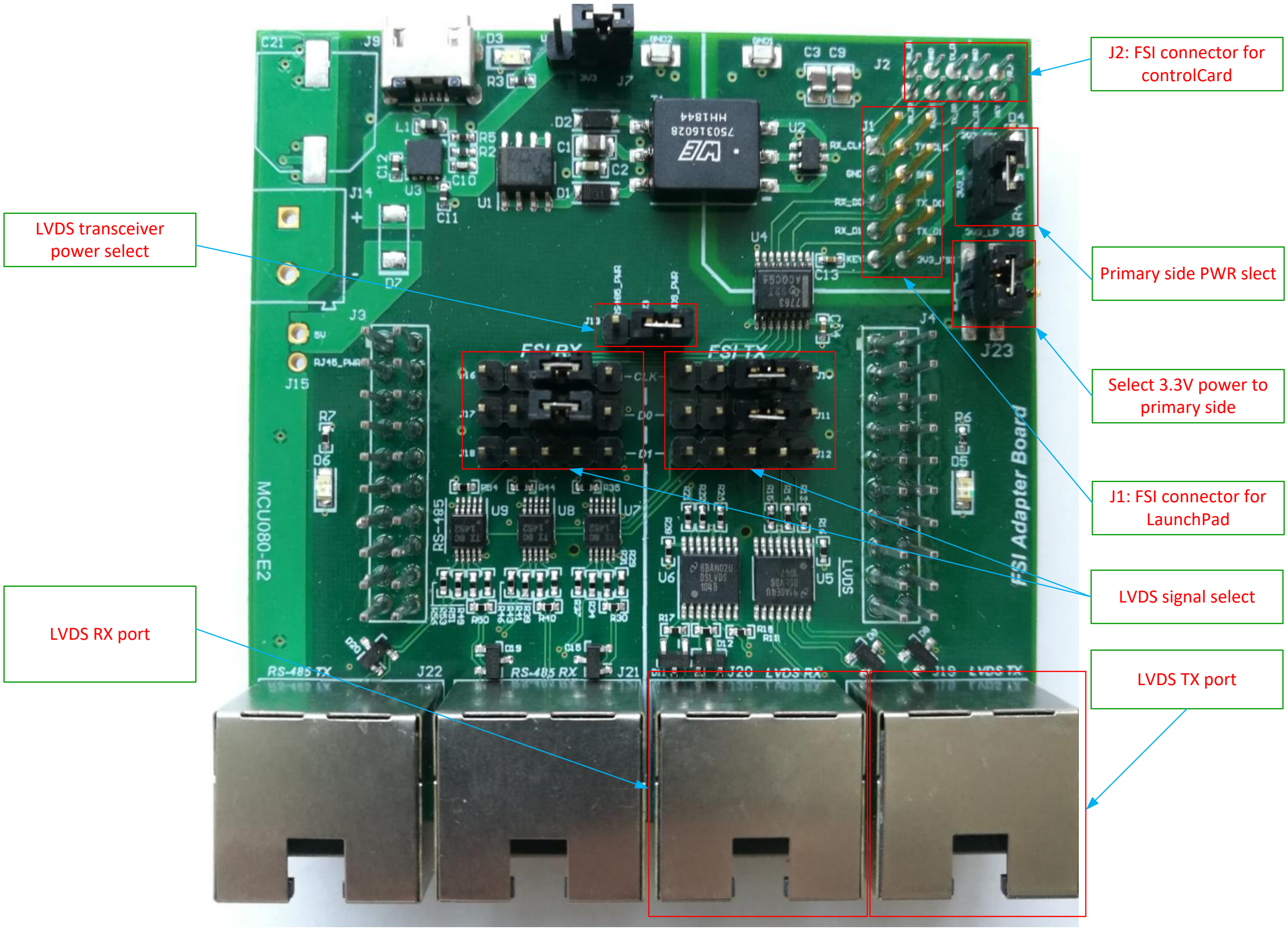
**图 16. Layout, switches setting and wires connection of TMDXIDDK379D**



### 3.1.5 TMDSFSIADAPEVM

图 17 shows the layout of TMDSFSIADAPEVM, on-board switches setting as marked. Please refer to the TMDSFSIADAPEVM FSI Adapter Board User's Guide for details.

图 17. Layout and Switches Setting of TMDSFSIADAPEVM


J2: FSI connector for controlCard
LVDS transceiver power select
Primary side PWR slect
Select 3.3V power to primary side
J1: FSI connector for LaunchPad
LVDS signal select
LVDS RX port
LVDS TX port

### 3.2 *Software*

The firmware of the design is released within the C2000Ware MotorControl SDK. To run the design the required software is the following:

- Download and install the latest version of Code Composer Studio
- Download and install he latest version of C2000Ware MotorControl SDK.
- Download and install TwinCAT3 from the Beckhoff

#### 3.2.1 Open project using CCS

The design includes multiple projects that run on F2838x for master node and on F28004x for slave nodes. Be sure to download and install MotorControl software development kit (SDK) for C2000™ MCUs software package revision 3.00.00.00 or later in the default install path.

- multi_axis_master_ctrl_f2838x_CPU1 - speed and position control loops for all axes on CPU1 of F2838x.
- multi_axis_master_drive_f2838x_CPU2 - main axis motor drive on CPU2 of F2838x.
- multi_axis_master_ecat_f2838x_cm - EtherCAT communication with PC on cortex-m4 of F2838x
- multi_axis_slave_node<n>_f28004x_cpu - slave axis #<n> motor drive on CPU of F28004x, where <n>

is 1, 2, 3, or 4.

Use the following steps to get started:

1. Install the CCS software (version 9.2 or later).
2. Open the CCS software. Create the CCS workspace.
3. Go to **View > Resource Explorer**. Below the **Resource Explorer**, go to **Software > C2000Ware_MotorControl_SDK_<version>**.
4. Below **C2000Ware_MotorControl_SDK_<version>**, select **Solutions > tidm_02006_multi_axis_drive > F2838x for master node, or F28004x for slave nodes**.
5. After selecting the CCS project, click **Import to IDE** on the top right corner. This action imports the project into the CCS workspace environment.

### 3.2.2 Project Structure

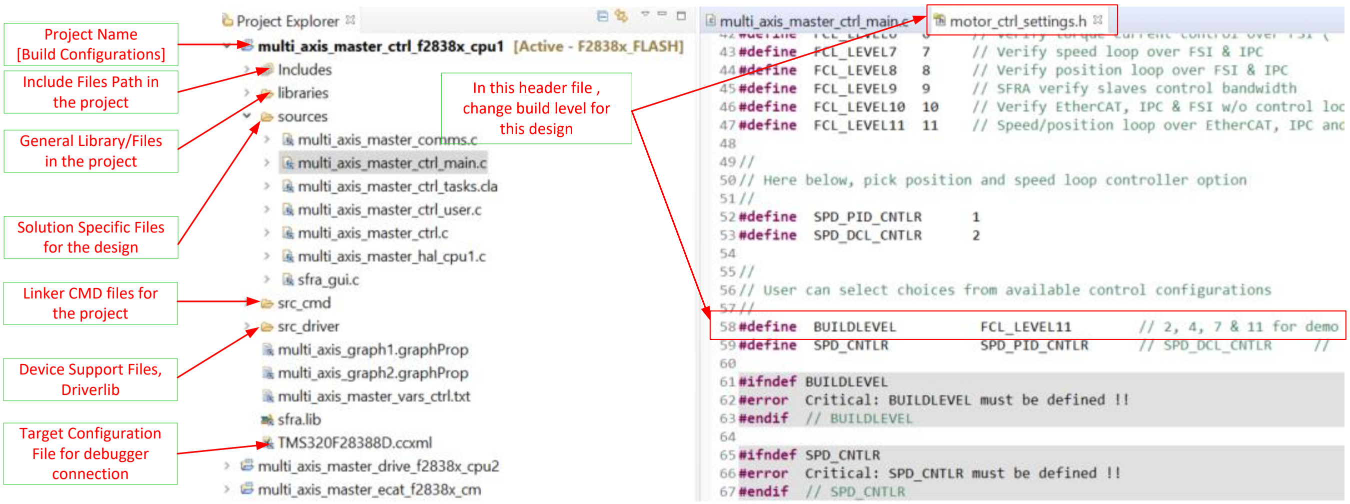
When the projects are imported in CCS respectively, the project includes device-independent and device-specific files.

The solution-specific and device-independent files are <solution>_<function>.c/.h, where <solution> is "multi_axis_", and <function> is ctrl, comm or drive. These files are responsible for the control, drive and communication functions of the solution.

The board-specific and device-specific files are <solution>_hal_<core>.c/.h, where <core> is CPU1, CPU2, or CM. These files consists of device-specific drivers to run the solution.

The project explorer displays the structure of "multi_axis_master_ctrl_f2838x_CPU1" project inside CCS as shown in 图 18.

**图 18. Project Explorer View of Master Control Project**

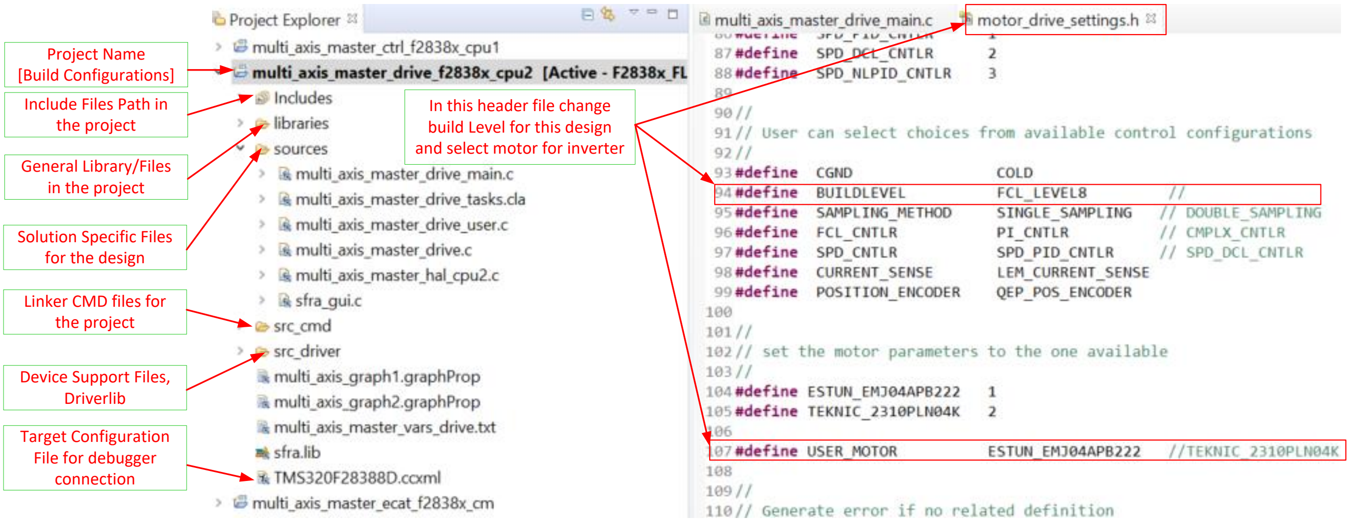

Project Name
[Build Configurations]
Include Files Path in the project
General Library/Files in the project
Solution Specific Files for the design
Linker CMD files for the project
Device Support Files, Driverlib
Target Configuration File for debugger connection
In this header file , change build level for this design
Project Explorer
multi_axis_master_ctrl_main.c
motor_ctrl_settings.h

```
multi_axis_master_ctrl_f2838x_cpu1 [Active - F2838x_FLASH]
    Includes
    libraries
    sources
        multi_axis_master_comms.c
        multi_axis_master_ctrl_main.c
        multi_axis_master_ctrl_tasks.cla
        multi_axis_master_ctrl_user.c
        multi_axis_master_ctrl.c
        multi_axis_master_hal_cpu1.c
        sfra_gui.c
    src_cmd
    src_driver
    multi_axis_graph1.graphProp
    multi_axis_graph2.graphProp
    multi_axis_master_vars_ctrl.txt
    sfra.lib
    TMS320F28388D.ccxml
multi_axis_master_drive_f2838x_cpu2
multi_axis_master_ecat_f2838x_cm
```

```
#define  FCL_LEVEL7   7     // Verify speed loop over FSI & IPC
#define  FCL_LEVEL8   8     // Verify position loop over FSI & IPC
#define  FCL_LEVEL9   9     // SFRA verify slaves control bandwidth
#define  FCL_LEVEL10  10    // Verify EtherCAT, IPC & FSI w/o control loc
#define  FCL_LEVEL11  11    // Speed/position loop over EtherCAT, IPC anc

//
// Here below, pick position and speed loop controller option
//
#define  SPD_PID_CNTLR      1
#define  SPD_DCL_CNTLR      2

//
// User can select choices from available control configurations
//
#define  BUILDLEVEL         FCL_LEVEL11     // 2, 4, 7 & 11 for demo
#define  SPD_CNTLR          SPD_PID_CNTLR   // SPD_DCL_CNTLR    //

#ifndef BUILDLEVEL
#error  Critical: BUILDLEVEL must be defined !!
#endif  // BUILDLEVEL

#ifndef SPD_CNTLR
#error  Critical: SPD_CNTLR must be defined !!
#endif  // SPD_CNTLR
```

The project explorer displays the structure of **multi_axis_master_drive_f2838x_CPU2** project inside CCS as shown in 图 19.

### 图 19. Project Explorer View of Main Axis Drive Project


Project Explorer
multi_axis_master_ctrl_f2838x_cpu1
multi_axis_master_drive_f2838x_cpu2 [Active - F2838x_FL
Includes
libraries
sources
multi_axis_master_drive_main.c
multi_axis_master_drive_tasks.cla
multi_axis_master_drive_user.c
multi_axis_master_drive.c
multi_axis_master_hal_cpu2.c
sfra_gui.c
src_cmd
src_driver
multi_axis_graph1.graphProp
multi_axis_graph2.graphProp
multi_axis_master_vars_drive.txt
sfra.lib
TMS320F28388D.ccxml
multi_axis_master_ecat_f2838x_cm
multi_axis_master_drive_main.c
motor_drive_settings.h

Project Name [Build Configurations]

Include Files Path in the project

General Library/Files in the project

Solution Specific Files for the design

Linker CMD files for the project

Device Support Files, Driverlib

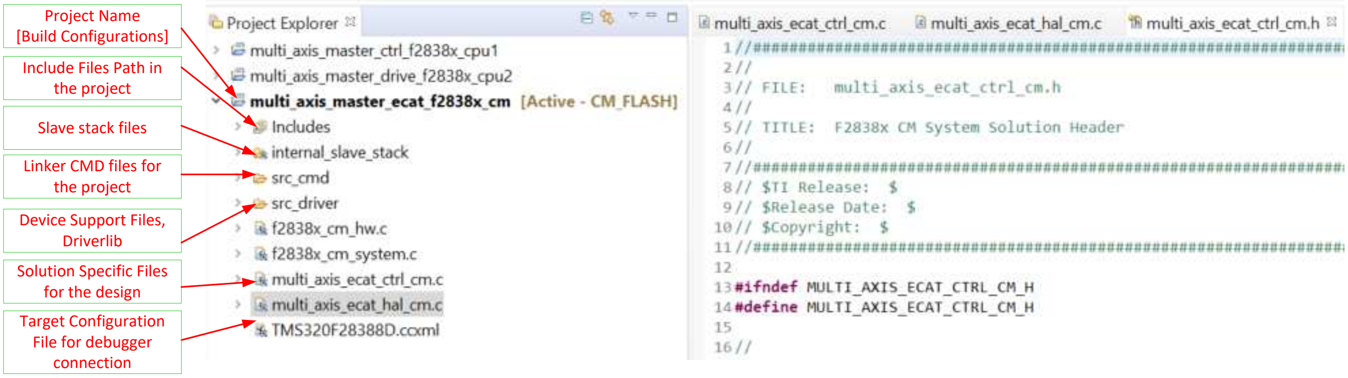
Target Configuration File for debugger connection

In this header file change build Level for this design and select motor for inverter

```
#define  SPD_DCL_CNTLR       2
#define  SPD_NLPID_CNTLR     3

//
// User can select choices from available control configurations
//
#define  CGND                COLD
#define  BUILDLEVEL          FCL_LEVEL8          //
#define  SAMPLING_METHOD     SINGLE_SAMPLING    // DOUBLE_SAMPLING
#define  FCL_CNTLR           PI_CNTLR           // CMPLX_CNTLR
#define  SPD_CNTLR           SPD_PID_CNTLR      // SPD_DCL_CNTLR
#define  CURRENT_SENSE       LEM_CURRENT_SENSE
#define  POSITION_ENCODER    QEP_POS_ENCODER

//
// set the motor parameters to the one available
//
#define ESTUN_EMJ04APB222   1
#define TEKNIC_2310PLN04K   2

#define USER_MOTOR          ESTUN_EMJ04APB222   //TEKNIC_2310PLN04K

//
// Generate error if no related definition
```

The project explorer displays the structure of **multi_axis_master_ecat_f2838x_cm** project inside CCS as shown in 图 20.

### 图 20. Project Explorer View of EtherCAT Communication Project


Project Explorer
multi_axis_master_ctrl_f2838x_cpu1
multi_axis_master_drive_f2838x_cpu2
multi_axis_master_ecat_f2838x_cm [Active - CM_FLASH]
Includes
internal_slave_stack
src_cmd
src_driver
f2838x_cm_hw.c
f2838x_cm_system.c
multi_axis_ecat_ctrl_cm.c
multi_axis_ecat_hal_cm.c
TMS320F28388D.ccxml
multi_axis_ecat_ctrl_cm.c
multi_axis_ecat_hal_cm.c
multi_axis_ecat_ctrl_cm.h

Project Name [Build Configurations]

Include Files Path in the project

Slave stack files

Linker CMD files for the project

Device Support Files, Driverlib

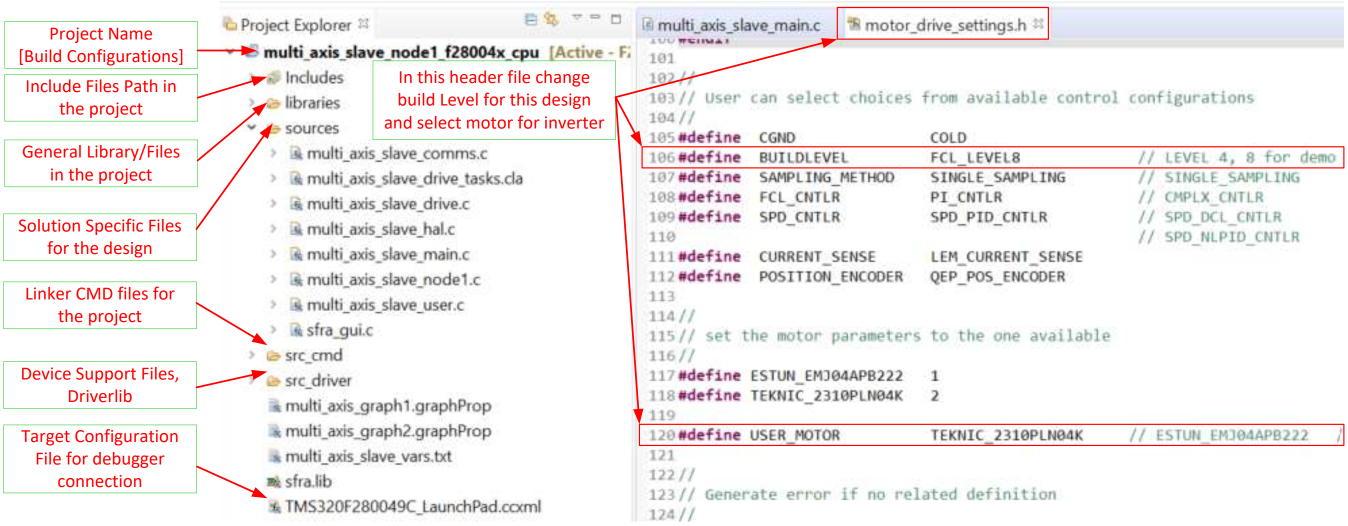
Solution Specific Files for the design

Target Configuration File for debugger connection

```
//##########################################################################
//
// FILE:   multi_axis_ecat_ctrl_cm.h
//
// TITLE:  F2838x CM System Solution Header
//
//##########################################################################
// $TI Release:  $
// $Release Date:  $
// $Copyright:  $
//##########################################################################

#ifndef MULTI_AXIS_ECAT_CTRL_CM_H
#define MULTI_AXIS_ECAT_CTRL_CM_H

//
```

The project explorer displays the structure of **multi_axis_slave_node<n>_f28004x_cpu** project inside CCS as shown in 图 21, where <n> is 1, 2, 3 or 4. Each slave drive project uses the same project structure and shares most of files, the only different files are multi_axis_slave_node<n>.c and the included header file multi_axis_slave_node<n>.h, where n is 1, 2, 3, or 4.

### 图 21. Project Explorer View of Slave Axis Drive Project



Project Name [Build Configurations]

Include Files Path in the project

General Library/Files in the project

Solution Specific Files for the design

Linker CMD files for the project

Device Support Files, Driverlib

Target Configuration File for debugger connection

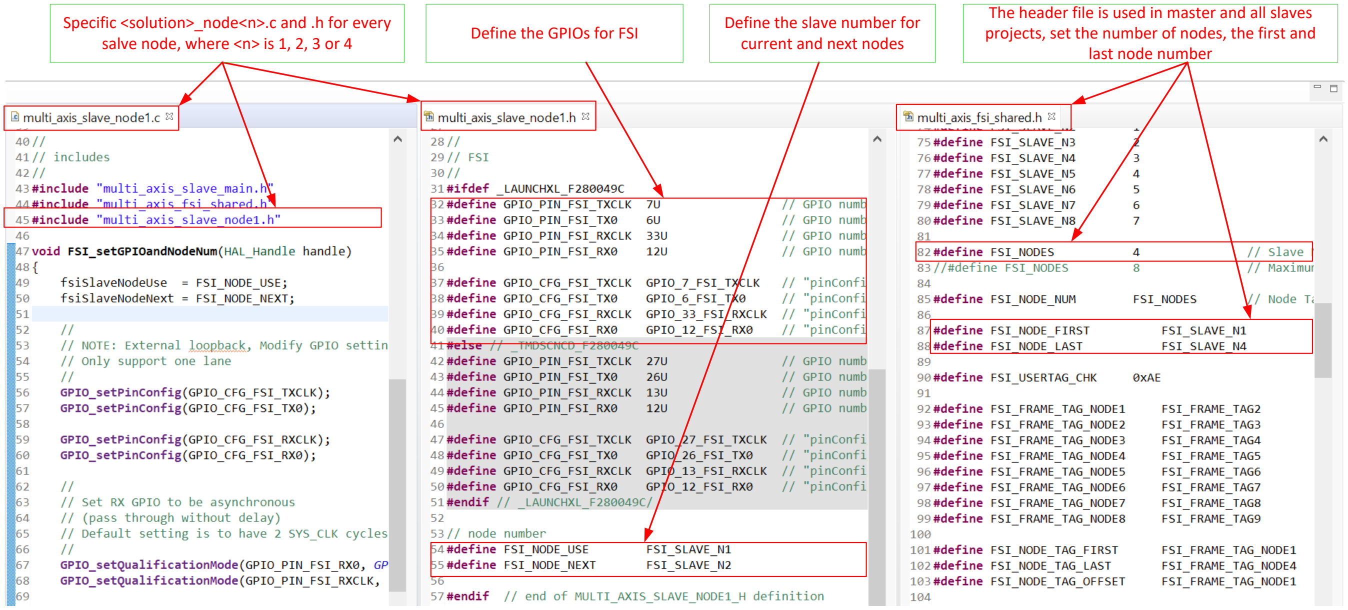
In this header file change build Level for this design and select motor for inverter

```
//
// User can select choices from available control configurations
//
#define  CGND                 COLD
#define  BUILDLEVEL           FCL_LEVEL8               // LEVEL 4, 8 for demo
#define  SAMPLING_METHOD      SINGLE_SAMPLING          // SINGLE_SAMPLING
#define  FCL_CNTLR            PI_CNTLR                 // CMPLX_CNTLR
#define  SPD_CNTLR            SPD_PID_CNTLR            // SPD_DCL_CNTLR
                                                       // SPD_NLPID_CNTLR
#define  CURRENT_SENSE        LEM_CURRENT_SENSE
#define  POSITION_ENCODER     QEP_POS_ENCODER

//
// set the motor parameters to the one available
//
#define ESTUN_EMJ04APB222    1
#define TEKNIC_2310PLN04K    2

#define USER_MOTOR           TEKNIC_2310PLN04K        // ESTUN_EMJ04APB222

//
// Generate error if no related definition
//
```

In this reference design, the number of the supported nodes is 4. The designer may increase or decrease the number as shown in 图 22.

1. Open the multi_axis_slave_node<n>.h.
2. Change the GPIO assignment for the FSI signals according to the hardware board.
3. Change the FSI_NODE_USE and FSI_NODE_NEXT definition. Define the FSI_NODE_USE to FSI_SLAVE_N<n>, where n represents the slave number in the daisy-chain loop (i.e. 1, 2, 3, etc.). Define FSI_NODE_NEXT to FSI_SLAVE_N<m>, where m must be equal to n+1. Both FSI_NODE_USE and FSI_NODE_NEXT can be set to FSI_SLAVE_N1 if there is only one slave node in the system.
4. Open multi_axis_fsi_shared.h
5. Define FSI_NODES to the maximum number of the supporting nodes which must be less than 15.
6. Define FSI_NODE_LAST to FSI_SLAVE_N<n>, where n equals to the total number of nodes in the chain. For example, the n should be equal to 4 if there are 4 slave nodes in the system.

### 图 22. The Files for Slave Nodes



Specific <solution>_node<n>.c and .h for every salve node, where <n> is 1, 2, 3 or 4

Define the GPIOs for FSI

Define the slave number for current and next nodes

The header file is used in master and all slaves projects, set the number of nodes, the first and last node number

```
//
// includes
//
#include "multi_axis_slave_main.h"
#include "multi_axis_fsi_shared.h"
#include "multi_axis_slave_node1.h"

void FSI_setGPIOandNodeNum(HAL_Handle handle)
{
    fsiSlaveNodeUse  = FSI_NODE_USE;
    fsiSlaveNodeNext = FSI_NODE_NEXT;

    //
    // NOTE: External loopback, Modify GPIO settin
    // Only support one lane
    //
    GPIO_setPinConfig(GPIO_CFG_FSI_TXCLK);
    GPIO_setPinConfig(GPIO_CFG_FSI_TX0);

    GPIO_setPinConfig(GPIO_CFG_FSI_RXCLK);
    GPIO_setPinConfig(GPIO_CFG_FSI_RX0);

    //
    // Set RX GPIO to be asynchronous
    // (pass through without delay)
    // Default setting is to have 2 SYS_CLK cycles
    //
    GPIO_setQualificationMode(GPIO_PIN_FSI_RX0, GP
    GPIO_setQualificationMode(GPIO_PIN_FSI_RXCLK,

```

```
//
// FSI
//
#ifdef _LAUNCHXL_F280049C
#define GPIO_PIN_FSI_TXCLK   7U                   // GPIO numb
#define GPIO_PIN_FSI_TX0     6U                   // GPIO numb
#define GPIO_PIN_FSI_RXCLK   33U                  // GPIO numb
#define GPIO_PIN_FSI_RX0     12U                  // GPIO numb

#define GPIO_CFG_FSI_TXCLK   GPIO_7_FSI_TXCLK     // "pinConfi
#define GPIO_CFG_FSI_TX0     GPIO_6_FSI_TX0       // "pinConfi
#define GPIO_CFG_FSI_RXCLK   GPIO_33_FSI_RXCLK    // "pinConfi
#define GPIO_CFG_FSI_RX0     GPIO_12_FSI_RX0      // "pinConfi
#else // _TMDSCNCD_F280049C
#define GPIO_PIN_FSI_TXCLK   27U                  // GPIO numb
#define GPIO_PIN_FSI_TX0     26U                  // GPIO numb
#define GPIO_PIN_FSI_RXCLK   13U                  // GPIO numb
#define GPIO_PIN_FSI_RX0     12U                  // GPIO numb

#define GPIO_CFG_FSI_TXCLK   GPIO_27_FSI_TXCLK    // "pinConfi
#define GPIO_CFG_FSI_TX0     GPIO_26_FSI_TX0      // "pinConfi
#define GPIO_CFG_FSI_RXCLK   GPIO_13_FSI_RXCLK    // "pinConfi
#define GPIO_CFG_FSI_RX0     GPIO_12_FSI_RX0      // "pinConfi
#endif // _LAUNCHXL_F280049C/

// node number
#define FSI_NODE_USE         FSI_SLAVE_N1
#define FSI_NODE_NEXT        FSI_SLAVE_N2

#endif  // end of MULTI_AXIS_SLAVE_NODE1_H definition
```

```
#define FSI_SLAVE_N3         2
#define FSI_SLAVE_N4         3
#define FSI_SLAVE_N5         4
#define FSI_SLAVE_N6         5
#define FSI_SLAVE_N7         6
#define FSI_SLAVE_N8         7

#define FSI_NODES            4                    // Slave
//#define FSI_NODES          8                    // Maximur

#define FSI_NODE_NUM         FSI_NODES            // Node Ta

#define FSI_NODE_FIRST           FSI_SLAVE_N1
#define FSI_NODE_LAST            FSI_SLAVE_N4

#define FSI_USERTAG_CHK      0xAE

#define FSI_FRAME_TAG_NODE1      FSI_FRAME_TAG2
#define FSI_FRAME_TAG_NODE2      FSI_FRAME_TAG3
#define FSI_FRAME_TAG_NODE3      FSI_FRAME_TAG4
#define FSI_FRAME_TAG_NODE4      FSI_FRAME_TAG5
#define FSI_FRAME_TAG_NODE5      FSI_FRAME_TAG6
#define FSI_FRAME_TAG_NODE6      FSI_FRAME_TAG7
#define FSI_FRAME_TAG_NODE7      FSI_FRAME_TAG8
#define FSI_FRAME_TAG_NODE8      FSI_FRAME_TAG9

#define FSI_NODE_TAG_FIRST       FSI_FRAME_TAG_NODE1
#define FSI_NODE_TAG_LAST        FSI_FRAME_TAG_NODE4
#define FSI_NODE_TAG_OFFSET      FSI_FRAME_TAG_NODE1

```

### 3.2.3 Running the Project

The system is gradually built up in order for the final system to be confidently operated. Multiple phases of the incremental system build are designed to verify the major software modules used in the system. 表 2, 表 3, and 表 4 summarize the core modules testing and use at each build level in the incremental system build approach.

**表 2. Functions Verified at Each Build Level in Master Control Project**

| | |
|---|---|
| Level 1 | Verify HAL, peripherals configuration, control ISR, IPC with CPU2 |
| Level 2 | verify main-axis drive via IPC, master (IDDK) runs standalone |
| Level 3 | verify EtherCAT and IPC for main-axis without running motor, master (IDDK) runs standalone |
| Level 4 | verify main-axis drive via EtherCAT&IPC |
| Level 5 | verify FSI functions, need setup the system with master node and at least one slave node. (No EtherCAT) |
| Level 6 | verify the torque current control over FSI. (No EtherCAT) |
| Level 7 | verify speed loop control over FSI (No EtherCAT) |
| Level 8 | verify position loop control over FSI (No EtherCAT) |
| Level 9 | integrate SFRA to verify the speed loop for slave node on master (No EtherCAT) |
| Level 10 | verify EtherCAT, IPC and FSI integartion without control loop |
| Level 11 | verify speed or position loop over EtherCAT, IPC and FSI |

**注:**

- Select the build level in motor_ctrl_settings.h
- Make sure that main-axis drive is verified by running level1~level5 one by one in 表 3 before run the level 2, 3, 4, 6, 7, 8, 9, 10, and 11 as shown in 表 2.
- Make sure that all slave axes drives are verified independently by running level1~level5 one by one as shown in 表 4 before run level 6, 7, 8, 9, 10 and 11 as shown in 表 2.

**表 3. Functions Verified at Each Build Level in Main Axis Drive Project**

| | |
|---|---|
| Level 1 | verify HAL configuration, SVGEN and PWM generation |
| Level 2 | verify ADC and offset calibration, QEP and speed measurement with open loop running |
| Level 3 | verify closed current (torque) loop suing FCL with the position angle from encoder and FCL |
| Level 4 | verify closed speed loop and FCL |
| Level 5 | verify closed position loop |
| Level 6 | integrate SFRA and verify closed speed loop |
| Level 7 | verify IPC without drive control |
| Level 8 | torque control on CPU2, the reference speed/position from CPU1 over IPC |
| Level 9 | integrate SFRA for tuning current loop over IPC |

**注:**

- Run level1~level5 one by one in 表 3 before run level 8 and level 9 to implement main axis drive over IPC

**表 4. Functions Verified at Each Build Level in Slave Axis Drive Project**

| | |
|---|---|
| Level 1 | verify HAL configuration, SVGEN and PWM generation |
| Level 2 | verify ADC and offset calibration, QEP and speed measurement with open loop running |
| Level 3 | verify closed current (torque) loop suing FCL with the position angle from encoder and FCL |
| Level 4 | verify closed speed loop and FCL |
| Level 5 | verify closed position loop |

表 4. Functions Verified at Each Build Level in Slave Axis Drive Project (continued)

| | |
|---|---|
| Level 6 | integrate SFRA and verify closed speed loop |
| Level 7 | verify IPC without drive control |
| Level 8 | torque control on slave, receive the reference speed/position from master over FSI |
| Level 9 | integrate SFRA for tuning current loop. Torque control on slave, the reference speed/position from master over FSI |

注:

- Run level1~level5 one by one in 表 4 before run level 8 and level 9 to implement slave axis drive over FSI.

#### 3.2.3.1 System Software Integration Configuration

Each project has multiple build levels, so there are many combinations of builds in the design. The following are some key combination selections at build level to run the design.

1. Verify IPC between CPU1 and CPU2 without motor drive
   a. Don't connect the motor to TMDXIDDK379D. It's not necessary to connect slave drive at this point.
   b. Set build level to level 1 in "motor_ctrl_settings.h" in "multi_axis_master_ctrl_f2838x_CPU1" project. Build, load and run the program on CPU1 of F2838x.
   c. Set build level to level 7 in "motor_drive_settings.h" in "multi_axis_master_drive_f2838x_cpu2" project. Build, load and run the program on CPU2 of F2838x.
2. Verify EtherCAT between F2838x and TwinCAT on PC
   a. Don't connect the motor to TMDXIDDK379D. It's not necessary to connect slave drive at this point.
   b. Set build level to level 3 in "motor_ctrl_settings.h" in "multi_axis_master_ctrl_f2838x_CPU1" project. Build, load and run the program on CPU1 of F2838x.
   c. Build, load and run the "multi_axis_master_ecat_f2838x_cm" project program on CM of F2838x.
3. Verify EtherCAT and IPC-CPU2&CPU1
   a. Don't connect the motor to TMDXIDDK379D. It's not necessary to connect slave drive at this point.
   b. Set build level to level 3 in "motor_ctrl_settings.h" in "multi_axis_master_ctrl_f2838x_CPU1" project. Build, load and run the program on CPU1 of F2838x.
   c. Set build level to level 7 in "motor_drive_settings.h"in "multi_axis_master_drive_f2838x_cpu2" project. Build, load and run the program on CPU2 of F2838x.
   d. Build, load and run the "multi_axis_master_ecat_f2838x_cm" project program on CM of F2838x.
4. Verify FSI between master and slaves without motor drive
   a. Don't connect the motor to both TMDXIDDK379D and BOOSTXL-3PHGANINV.
   b. Connect the FSI using TMDSFSIADAPEVM between master and slaves.
   c. Set build level to level 5 in "motor_ctrl_settings.h" in "multi_axis_master_ctrl_f2838x_CPU1" project. Build, load and run the program on CPU1 of F2838x.
   d. Set build level to level 7 in "motor_drive_settings.h"in "multi_axis_slave_node1_f28004x_cpu" project for each slave node. Build, load and run the program on F28004x.
5. Verify EtherCAT, IPC, and FSI
   a. Don't connect the motor to both TMDXIDDK379D and BOOSTXL-3PHGANINV.
   b. Connect the FSI using TMDSFSIADAPEVM between master and slaves.
   c. Set build level to level 10 in "motor_ctrl_settings.h" in "multi_axis_master_ctrl_f2838x_CPU1" project. Build, load and run the program on CPU1 of F2838x.
   d. Set build level to level 7 in "motor_drive_settings.h"in "multi_axis_master_drive_f2838x_cpu2" project. Build, load and run the program on CPU2 of F2838x.
   e. Build, load and run the "multi_axis_master_ecat_f2838x_cm" project program on CM of F2838x.

   f. Set build level to level 7 in "motor_drive_settings.h"in "multi_axis_slave_node1_f28004x_cpu" project for each slave node. Build, load and run the program on F28004x.

6. Verify multi-axis drive over FSI without EtherCAT
   a. Don't connect the motor to TMDXIDDK379D.
   b. Connect the FSI using TMDSFSIADAPEVM between master and slaves.
   c. Connect the motor BOOSTXL-3PHGANINV and the encoder to LAUNCHXL-F280049C.
   d. Set build level to level 7 in "motor_ctrl_settings.h" in "multi_axis_master_ctrl_f2838x_CPU1" project. Build, load and run the program on CPU1 of F2838x.
   e. Set build level to level 8 in "motor_drive_settings.h"in "multi_axis_slave_node1_f28004x_cpu" project for each slave node. Build, load and run the program on F28004x.

**注:** Each slave axes must be verified by using level 1 to level 5 independently before run this combination.

7. Verify multi-axis drive over FSI with EtherCAT
   a. Connect the motor and its encoder to TMDXIDDK379D.
   b. Connect the FSI using TMDSFSIADAPEVM between master and slaves.
   c. Connect the motor BOOSTXL-3PHGANINV and the encoder to LAUNCHXL-F280049C.
   d. Set build level to level 11 in "motor_ctrl_settings.h" in "multi_axis_master_ctrl_f2838x_CPU1" project. Build, load and run the program on CPU1of F2838x.
   e. Set build level to level 8 in "motor_drive_settings.h"in "multi_axis_master_drive_f2838x_cpu2" project. Build, load and run the program on CPU2 of F2838x.
   f. Build, load and run the "multi_axis_master_ecat_f2838x_cm" project program on CM of F2838x.
   g. Set build level to level 8 in "motor_drive_settings.h"in "multi_axis_slave_node1_f28004x_cpu" project for each slave node. Build, load and run the program on F28004x.

**注:**

- Main axis and slave axes motor drive must be verified by using level 1 to level 5 independently before control the motor over FSI or IPC.
- The detailed operation steps about combination 7 as show in 节 3.2.3.2, 节 3.2.3.3, 节 3.2.3.4, and 节 3.2.3.5. The other combinations can refer to these sections also, only need to set the specific build level as above lists.

### 3.2.3.2 Run the Master Control Code on CPU1 of F2838x

1. Open the CCS workspace of the master, and import the master control project by clicking **Project > Import CCS Projects...** in CCS menu. Select the **multi_axis_master_ctrl_f2838x_CPU1** by browsing to the folder: \ti\c2000\C2000Ware_MotorControl_SDK_<version>\solutions\tidm_02006_multi_axis_drive\f2838x\ccs\sensored_foc.
2. Open **motor_ctrl_settings.h** and then select the build level 11 by setting the BUILDLEVEL to FCL_LEVEL11 (#define BUILDLEVEL FCL_LEVEL11).

**注:**

- This reference design only shows the final build level, FCL_LEVEL11 to test the whole functions. To understand and operate the design, the builds must be done individually.
- The detailed operation of CCS are introduced in *Dual-Axis Motor Control Using FCL and SFRA On a Single C2000™ MCU*.
- Control power supply to the IDDK is only needed for this build level, therefore, you can turn off the high voltage dc power at this point.

3. Right-click the project name and then click **Rebuild Project**.
4. When the build is completed, click the **Debug** button or **Run > Debug**, that launches a debugging session. In the case of dual CPU devices, a window might appear to select the CPU debug must be performed. In this step, select **CPU1**. The project then loads on the device for CPU1, and CCS debug

perspective becomes active. The code halts at the start of the main routine.

5. To add the variables in the watch and expressions window by right-clicking within the Expressions Window and importing the **multi_axis_master_vars.txt** file from the debug directory at: **\ti\c2000\C2000Ware_MotorControl_SDK_<version>\solutions\common\sensored_foc\debug**.
6. With appropriate variables required to debug the system. Click the **Continuous Refresh** button on the watch window to enable continuous update of values from the controller.
7. To enable real-time mode by hovering the mouse on the buttons on the buttons on thee horizontal toolbar and clicking the "Enable Silicon Real-time Mode" button.
8. Run the project by clicking on "Resume" button.
9. Set "enableCtrlFlag" to 1 in watch window. In the build levels without enabling FSI, such as level1~level4, the variable named "sysVars.isrTicker" is incrementally increased as seen in the watch windows, to confirm the interrupt working properly. In other levels, the variable is only increased after FSI handshake completed successfully.

**注:** In *F2838x_FLASH* build configuration, the *enableCtrlFlag* is set to 1 automatically after a delay.

10. Monitor fsiHandShakeState in the watch window if the value of the variable equals to FSI_HANDSHAKE_DONE, that means the handshake process completes.
11. Set sysVars.ecatCtrlSet to enable or disable the setting command or reference value from TwinCAT3 over EtherCAT.
    a. If set sysVars.ecatCtrlSet to ECAT_CTRL_DISABLE, the control command and speed/position reference values are set in the watch window.
        i. If set sysVars.ctrlSynSet to CTRL_SYN_DISABLE, the main axis and each slave axis are controlled respectively. The main axis is controlled by setting ctrlVars[0].ctrlStateSet and ctrlVars[0].ctrlSpeedRef, the slave axis #1, #2, #3 or #4 is control by setting ctrlVars[n].ctrlStateSet and ctrlVars[n].ctrlSpeedRef (n= 1, 2, 3, or 4 accordingly).
        ii. If set sysVars.ctrlSynSet to CTRL_SYN_ENABLE, the main axis and all slave axes are controlled simultaneously by setting sysVars.ctrlStateSet and sysVars.speedSet.
    b. If set sysVars.ecatCtrlSet to ECAT_CTRL_ENABLE, the control command and speed/position reference values are set by the communication data from TwinCAT3 on PC as 节 3.2.3.4.

#### 3.2.3.3 Run the Main Axis Drive Code on CPU2 of F2838x

1. Open the CCS workspace of the master, and import main axis drive project by clicking **Project > Import CCS Projects...** in CCS menu. Select the **multi_axis_master_drive_f2838x_cpu2** by browsing to the folder: \ti\c2000\C2000Ware_MotorControl_SDK_<version>\solutions\tidm_02006_multi_axis_drive\f2838x\ccs\sensored_foc
2. Open motor_drive_settings.h and select the build level 8 by setting the BUILDLEVEL to FCL_LEVEL8 (#define BUILDLEVEL FCL_LEVEL8).

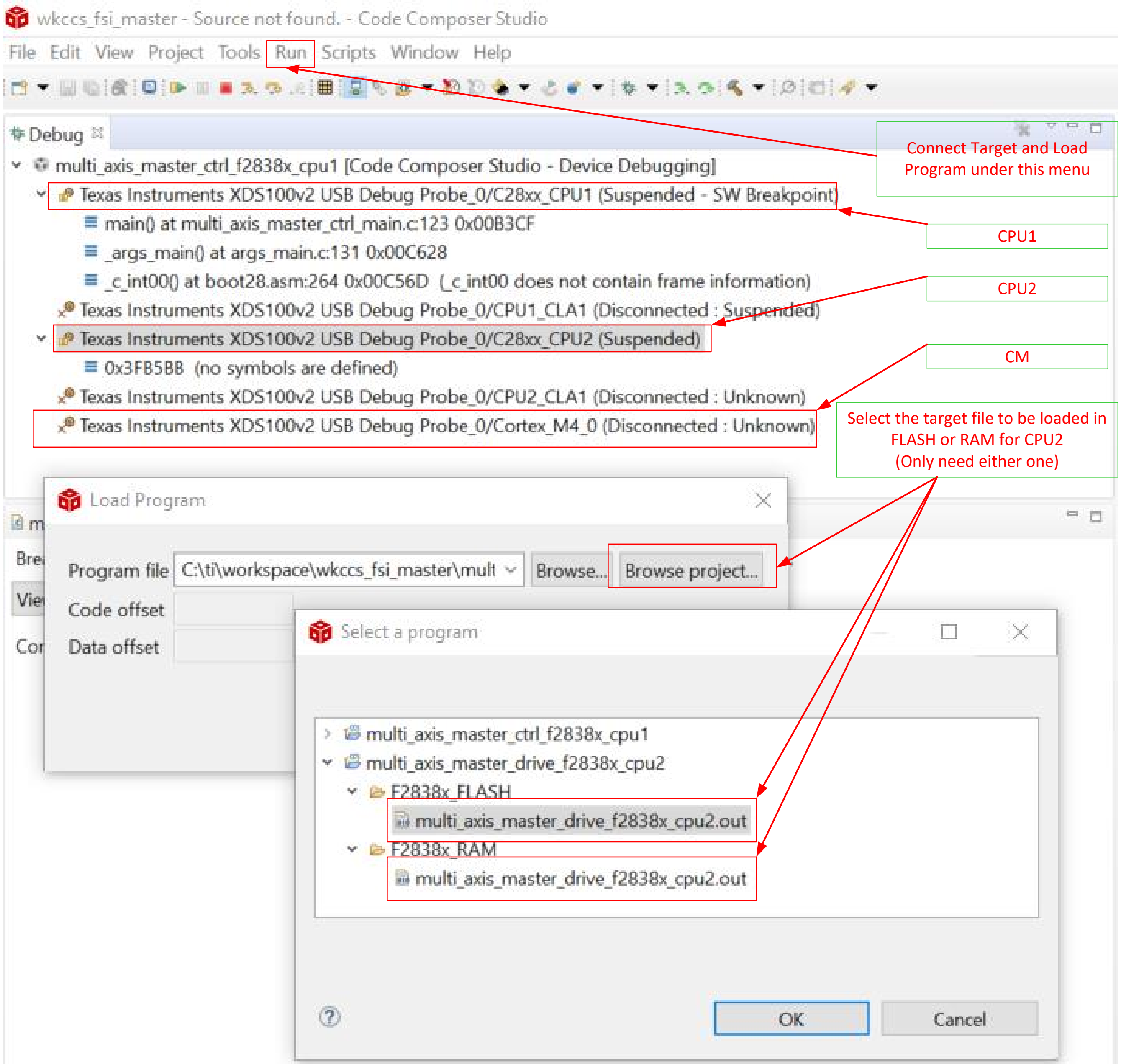
**注:**

- In this design guide, just shows the final build level, FCL_LEVEL8 to test whole system functions. The builds from LEVEL1 to LEVEL6 must be done one by one for the main axis drive code to validate motor drive modules on the inverter. Refer to *Dual-Axis Motor Control Using FCL and SFRA On a Single C2000™ MCU* to do these steps to build and run the code with different incremental builds.
- Do not "turn on" the high voltage dc power until indicated. Control power supply to the IDDK is alone needed for this build level, therefore, you can turn off the high voltage dc power at this point.

3. Right-click the project name and click **Rebuild Project**.

4. When the build is completed, go to **Debug Perspective**. From within the debug window, click **Debug Probe/C28x_CPU2**, right click and select **Connect Target**.
5. After connected the target, select **Run > Load > Load Program..**, and then select the related program for CPU2 by clicking **Browse project..** as shown in 图 23. Click the **OK** button on the pop-up window, the program then loads on the device for CPU2. The code halts at the start of the main routine.

**图 23. Load Program to Memory for CPU2 or CM**



multi_axis_master_ctrl_f2838x_cpu1 [Code Composer Studio - Device Debugging]
Texas Instruments XDS100v2 USB Debug Probe_0/C28xx_CPU1 (Suspended - SW Breakpoint)
main() at multi_axis_master_ctrl_main.c:123 0x00B3CF
_args_main() at args_main.c:131 0x00C628
_c_int00() at boot28.asm:264 0x00C56D (_c_int00 does not contain frame information)
Texas Instruments XDS100v2 USB Debug Probe_0/CPU1_CLA1 (Disconnected : Suspended)
Texas Instruments XDS100v2 USB Debug Probe_0/C28xx_CPU2 (Suspended)
0x3FB5BB (no symbols are defined)
Texas Instruments XDS100v2 USB Debug Probe_0/CPU2_CLA1 (Disconnected : Unknown)
Texas Instruments XDS100v2 USB Debug Probe_0/Cortex_M4_0 (Disconnected : Unknown)

Program file: C:\ti\workspace\wkccs_fsi_master\mult

multi_axis_master_ctrl_f2838x_cpu1
multi_axis_master_drive_f2838x_cpu2
F2838x_FLASH
multi_axis_master_drive_f2838x_cpu2.out
F2838x_RAM
multi_axis_master_drive_f2838x_cpu2.out

Connect Target and Load Program under this menu

CPU1

CPU2

CM

Select the target file to be loaded in FLASH or RAM for CPU2 (Only need either one)

6. Run the project by clicking the **Resume** button.
7. Set enableDriveFlag to 1 in watch window. The variable named motorVars.isrTicker is incrementally increased as seen in the watch windows, to confirm the interrupt working properly.

注: In F2838x_FLASH build configuration, the enableDriveFlag will be set to 1 automatically after a delay.

8. Unlike the previous build levels (LEVEL1 ~ LEVEL6), here the commands received by the controller

are not looped back and are used to actually set the operational mode or references for the main axis drive. The operational command and status of the main-axis drive is set via CPU1 > IPC > CPU2 and sent back via CPU2 > IPC > CPU1.

注: Since this build level attempts to drive the motor, high voltage dc power to IDDK can be turned on at this point.

9. Check motorVars.faultStatusFlag value in watch window, if the value equals to 0, that means there is no any fault trip.

#### 3.2.3.4 Run the EtherCAT Communication Code on CM of F2838x

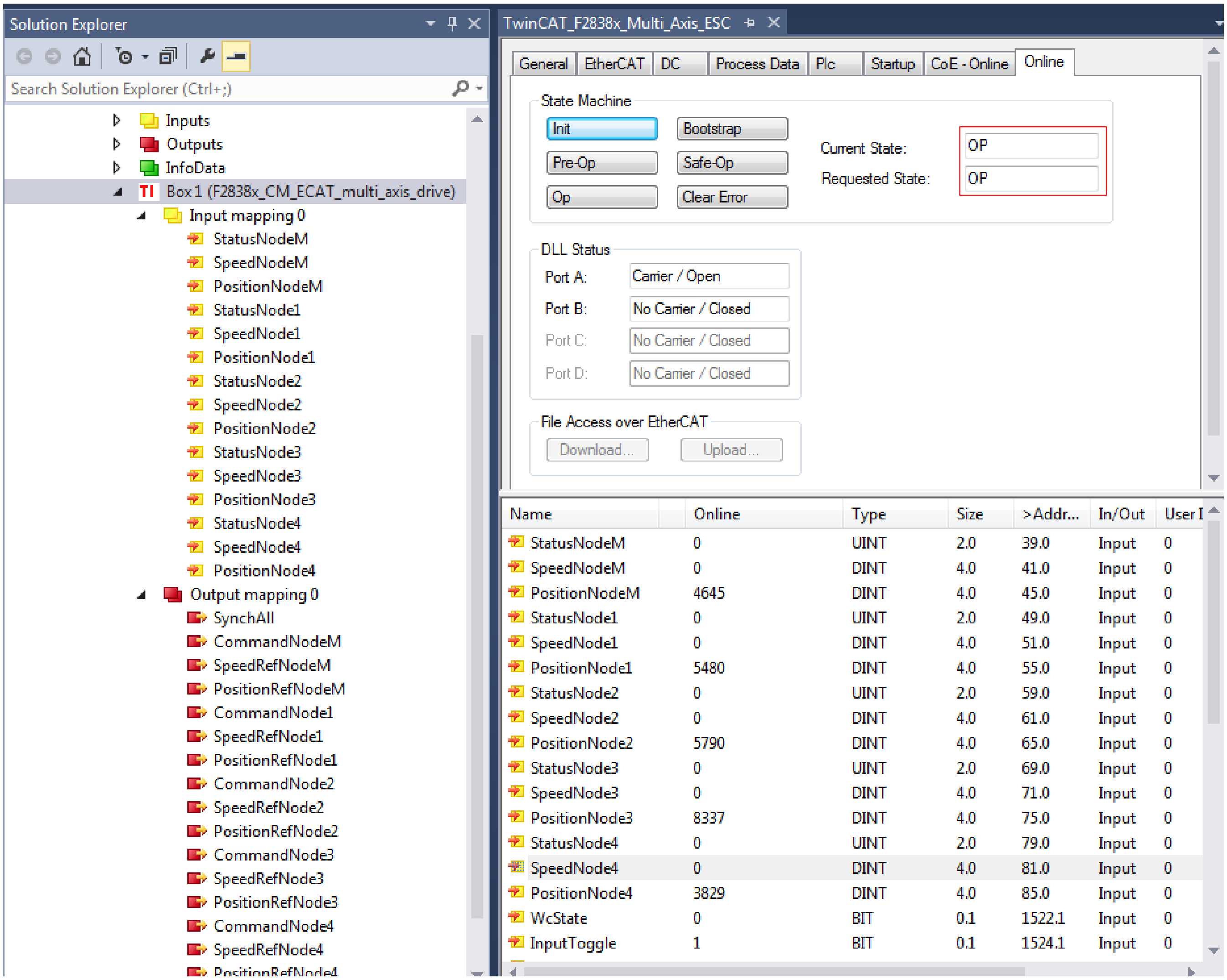
1. Open the CCS workspace of the master, and import main axis drive project by clicking the **Project > Import CCS Projects...** in the CCS menu. Select the multi_axis_master_ecat_f2838x_cm by browsing to the folder: \ti\c2000\C2000Ware_MotorControl_SDK_<version>\solutions\tidm_02006_multi_axis_drive\f2838x\ccs\sensored_foc
2. Ensure that CPU1 is actively running the project described in the previous section handing off the EtherCAT ownership to CM.
3. Besides USB connection between controlCARD and computer for JTAG purposes, connect an Ethernet cable between controlCARD RJ45 Port 0 and computer
4. Right-click the project name and click Rebuild Project.
5. When the build is completed, go to Debug Perspective. From within the Debug Probe/Cortex_M4_0, right-click and select Connect Target.
6. After connecting the target, select **Run > Load > Load Program..**, and then select the related program for CM by clicking **Browse project..** as similarly shown in 图 23. Click the OK button on the pop-up window, the program then loads on the device for CM. The code halts at the start of the main routine.
7. Run the project by clicking the Resume button. This would configure the F2838x EtherCAT slave controller and also the IPC on CM side for data transfer between CM and CPU1.
8. Set enableECATFlag to 1 in watch window. The variable named mainLoopCntr is incrementally increased as seen in the watch windows, to confirm the program working properly.

   Now the EtherCAT slave controller is ready to connect to EtherCAT master, and in this design, the EtherCAT master is TwinCAT3 running on PC.
9. Please refer to Section 12. (Setup TwinCAT), Section 12.4 (Scanning for EtherCAT Devices via TwinCAT ), and Section 12.5 (Program ControlCard EEPROM for ESC ) in EtherCAT-Based Connected Servo Drive Using Fast Current Loop on PMSM. In this step, use the ESI file ( F2838x_CM_ECAT_multi_axis_drive.xml available at \ti\c2000\C2000Ware_MotorControl_SDK_<version>\solutions\tidm_02006_multi_axis_drive\f2838x\ssc_configuration ).

注: Please refer to the EtherCAT Slave Controller Software User's Guide details details how to setup the EtherCAT master software (TwinCAT) on your compute. The guide available at \ti\c2000\C2000Ware_<version>\libraries\communications\Ethercat\f2838x\docs

10. Within TwinCAT, expand the explorer to the EtherCAT box (**I/O > Devices > Device 2 (EtherCAT) > TI Box 1** (F2838x_CM_ECAT_multi_axis_drive). The Input mapping and Output mapping as shown in 图 24.

图 24. Inputs and Outputs in TwinCAT Solution Explorer



Current State: OP

Requested State: OP

Port A: Carrier / Open

Port B: No Carrier / Closed

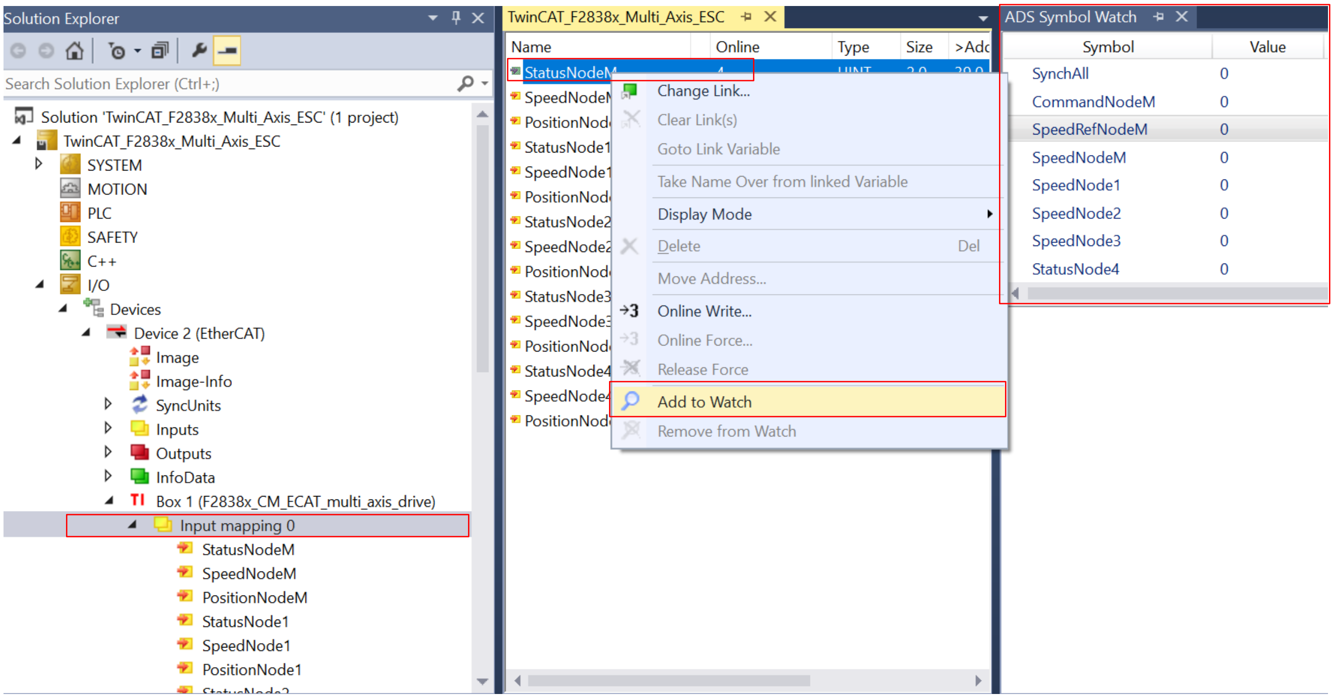
Port C: No Carrier / Closed

Port D: No Carrier / Closed

| Name | Online | Type | Size | >Addr... | In/Out | User I |
|---|---|---|---|---|---|---|
| StatusNodeM | 0 | UINT | 2.0 | 39.0 | Input | 0 |
| SpeedNodeM | 0 | DINT | 4.0 | 41.0 | Input | 0 |
| PositionNodeM | 4645 | DINT | 4.0 | 45.0 | Input | 0 |
| StatusNode1 | 0 | UINT | 2.0 | 49.0 | Input | 0 |
| SpeedNode1 | 0 | DINT | 4.0 | 51.0 | Input | 0 |
| PositionNode1 | 5480 | DINT | 4.0 | 55.0 | Input | 0 |
| StatusNode2 | 0 | UINT | 2.0 | 59.0 | Input | 0 |
| SpeedNode2 | 0 | DINT | 4.0 | 61.0 | Input | 0 |
| PositionNode2 | 5790 | DINT | 4.0 | 65.0 | Input | 0 |
| StatusNode3 | 0 | UINT | 2.0 | 69.0 | Input | 0 |
| SpeedNode3 | 0 | DINT | 4.0 | 71.0 | Input | 0 |
| PositionNode3 | 8337 | DINT | 4.0 | 75.0 | Input | 0 |
| StatusNode4 | 0 | UINT | 2.0 | 79.0 | Input | 0 |
| SpeedNode4 | 0 | DINT | 4.0 | 81.0 | Input | 0 |
| PositionNode4 | 3829 | DINT | 4.0 | 85.0 | Input | 0 |
| WcState | 0 | BIT | 0.1 | 1522.1 | Input | 0 |
| InputToggle | 1 | BIT | 0.1 | 1524.1 | Input | 0 |

11. Select Input mapping 0 to view all the feedback from the system. Or add the inputs to the Symbol Watch as shown in 图 25. Right click the selected input, and then click **Add to Watch**. The following inputs are the feedback parameters monitored via EtherCAT.
    a. StatusNode<n>, the status from the main axis or slave axes, where n is M (Main Axis), 1 (Axis #1), 2 (Axis #2), 3 (Axis #3), 14(Axis #4). 0-Stop the motor, 1-Speed control, 2-Position control, 3-Reset the state, 4-Had a fault from the axis controller.
    b. SpeedNode<n>, the feedback speed from main and slave nodes.
    c. PositionNode<n>, the feedback position from main and slave nodes.

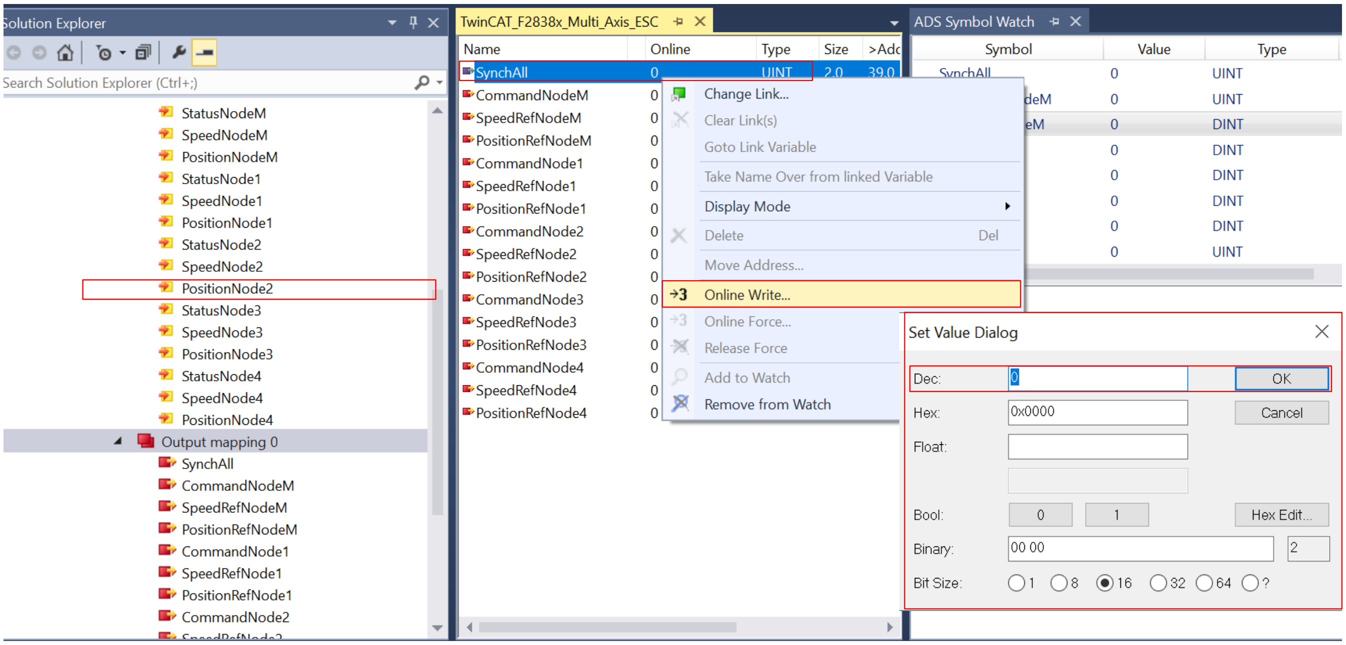
图 25. Add Inputs to Symbol Watch



| Symbol | Value |
|---|---|
| SynchAll | 0 |
| CommandNodeM | 0 |
| SpeedRefNodeM | 0 |
| SpeedNodeM | 0 |
| SpeedNode1 | 0 |
| SpeedNode2 | 0 |
| SpeedNode3 | 0 |
| StatusNode4 | 0 |

12. Select Output mapping 0 to set the control command or reference value to the main axis and slave axes as shown in 图 26. Right click the output, select Online Write, set the target value for the output, and then click the **OK** button.
    a. SynchAll, 0-disable synchronization to control all axes respectably. 1- enable synchronization to control simultaneously. All reference command/speed/position will be set by CommandNodM/SpeedRefNodM/PositionRefNodeM.
    b. CommandNode<n>, the command to the nodes, where n is M (Main Axis), 1 (Axis #1), 2 (Axis #2), 3 (Axis #3), 14(Axis #4). 0-Stop the motor, 1-Speed control, 2-Position control, 3-Reset the state.
    c. SpeedRefNode<n>, the reference speed for the related node
    d. PositionRefNode<n>, the reference speed for the related node

图 26. Set Control Command or Reference to Main and Slave Axes



| Name | Online | Type | Size | >Add |
|---|---|---|---|---|
| SynchAll | 0 | UINT | 2.0 | 39.0 |
| CommandNodeM | 0 | | | |
| SpeedRefNodeM | 0 | | | |
| PositionRefNodeM | 0 | | | |
| CommandNode1 | 0 | | | |
| SpeedRefNode1 | 0 | | | |
| PositionRefNode1 | 0 | | | |
| CommandNode2 | 0 | | | |
| SpeedRefNode2 | 0 | | | |
| PositionRefNode2 | 0 | | | |
| CommandNode3 | 0 | | | |
| SpeedRefNode3 | 0 | | | |
| PositionRefNode3 | 0 | | | |
| CommandNode4 | 0 | | | |
| SpeedRefNode4 | 0 | | | |
| PositionRefNode4 | 0 | | | |

| Symbol | Value | Type |
|---|---|---|
| SynchAll | 0 | UINT |
| deM | 0 | UINT |
| eM | 0 | DINT |
| | 0 | DINT |
| | 0 | DINT |
| | 0 | DINT |
| | 0 | DINT |
| | 0 | UINT |

Dec: 0
Hex: 0x0000
Float:
Bool: 0 1
Binary: 00 00 2
Bit Size: ○ 1 ○ 8 ● 16 ○ 32 ○ 64 ○ ?

### 3.2.3.5 Run the slave axis drive code on CPU of F28004x

1. Open a CCS workspace of the slave, and import slave axis drive project by clicking **Project->Import CCS Projects...** in CCS menu. Select the multi_axis_slave_node<n>_f28004x_cpu by browsing to the folder: \ti\c2000\C2000Ware_MotorControl_SDK_<version>\solutions\tidm_02006_multi_axis_drive\f28004x\ccs\sensored_foc.
2. Open motor_drive_settings.h.h and select the build level 8 by setting the BUILDLEVEL to FCL_LEVEL8 (#define BUILDLEVEL FCL_LEVEL8)
3. Right-click the project name and click **Rebuild Project**.
4. When the build is completed, click the **Debug** button or **Run > Debug**, which launches a debugging session and CCS debug perspective becomes active. The code halts at the start of the main routine.

注:

- This design guide only shows the final build level, FCL_LEVEL8 to test whole system functions. The builds from LEVEL1 to LEVEL6 must be done one by one for the slave axis drive code to validate motor drive modules on the inverter. Refer to *Dual-Axis Motor Control Using FCL and SFRA On a Single C2000™ MCU* to do these steps to build and run the code with different incremental builds.
- Must *turn on* the dc power to the BOOSTXL-3PHGANINV at this point.

5. To add the variables in the watch and expressions window by right-clicking within the Expressions Window and importing the multi_axis_slave_vars.txt file from the debug directory at: \ti\c2000\C2000Ware_MotorControl_SDK_<version>\solutions\common\sensored_foc\debug.
6. With appropriate variables required to debug the system. Click the **Continuous Refresh** button in the watch window to enable continuous update of values from the controller.
7. Enable real-time mode by hovering the mouse on the buttons of the horizontal toolbar and clicking the Enable Silicon Real-time Mode button.
8. Run the project by clicking the **Resume** button.

9. Set enableFlag to 1 in watch window. In the build levels without enabling FSI, such as level1~level6, the variable named motorVars.isrTicker is incrementally increased as seen in the watch windows, to confirm the interrupt working properly. In other levels, the variable is only increased after FSI handshake completed successfully.

**注:**

- In F28004x_FLASH build configuration, the enableFlag will be set to 1 automatically after a delay.

10. Monitor fsiHandShakeSate in watch window if the value of the variable equals to FSI_HANDSHAKE_DONE, that means the handshake process completes.
11. Unlike the previous build levels (LEVEL1 ~ LEVEL6), here the commands received by the controller are not looped back and are used to actually set the operational mode or references for the slave axis drive. The operational command and status of the slave axis drive is set over FSI.
12. Check the motorVars.faultStatusFlag value in watch window, if its value equals to 0, that means there is no any fault trip.

    In this design, there are four slave nodes, follow the same operation steps for open and load these four projects in the slave controller.

### 3.2.3.6 Run the system

As 节 3.2.3.2 , 节 3.2.3.3, 节 3.2.3.4, and 节 3.2.3.5, load the related project into the master and slave controllers. And then follow the power-up or running sequencing to run the system.

1. If the code runs in FLASH standalone, the enable<nn>Flag will be set automatically after a delay. The system requires strict power-up sequencing as one of the following two options.
   a. Power on the master board first, and then power on the last slave node (#4) to the first slave node (#1) one by one.
   b. Or, power on all slave nodes first, wait for a delay, and then power the master board.
2. If the code runs in RAM with CCS, the enable<nn>Flag need to set to 1 by manual in CCS.
   a. Run the multi_axis_master_ctrl_f2838x_cpu1 project and set the enableCtrlFlag to 1 in the debug window of CCS.
   b. Run the multi_axis_master_drive_f2838x_cpu2 project and set the enableDriveFlag to 1 in the debug window of CCS.
   c. Run the multi_axis_master_ecat_f2838x_cm, the enableECATFlag is set automatically by the program.
   d. Run all slave nodes one by one from the last slave node (#4) to first slave node (#1). Set the enableFlag to 1 in CCS accordingly.

   The LED (D1) on F28388D controlCard flashes quickly that means the motor drive program on CPU2 works well via IPC with CPU1. The LED (D2) flashes slowly that means handshake completes on master. A LED (D4) on LaunchPad flashes quickly that means handshake completes on this node. If these LED don't work as above, the system needs reset to make the handshaking work.

## 3.3 Testing and Results

### 3.3.1 Test Setup

**CAUTION**

Before you begin to test, to prevent damage to the motor drive board, ensure all boards are turned off, and then follow 节 3.2.3 running projects for the design.

Before mounting the BoosterPack and FSI adapter board to the F280049C Launchpad, ensure that jumpers on LaunchPad, FSI Adapter board and BoosterPack are set correctly as shown in 图 14, 图 15 and 图 17. The motor is a PMSM motor with both QEP and HALL sensors available on its headers J4 and J10, respectively. The control scheme is based on QEP feedback; therefore, only the QEP header J4 is fed into the LaunchPad. The BoosterPack and FSI adapter board suggested for this evaluation will mount directly on to the LAUNCHXL-F280049C. Make sure to match the orientation of inverter BoosterPacks as shown in Figure 9 before mounting. Mount the inverter BoosterPack on LaunchPad connectors J1-J4, mount the FSI adapter board on LaunchPad connectors J5–J8. Until instructed, leave the BOOSTXL-3PhGaNInv output headers and QEP headers open. When instructed to connect motor, connect the motor terminal to BOOSTXL-3PhGaNInv connector terminal and motor's encoder header to J12(EQEP1) connector on LaunchPad listed in 表 5. The slave node system setup as shown in 图 27.

**图 27. BOOSTXL-3PhGaNInv and TMDSFSIADAPEVM Assembly with LAUNCHXL-F280049C**

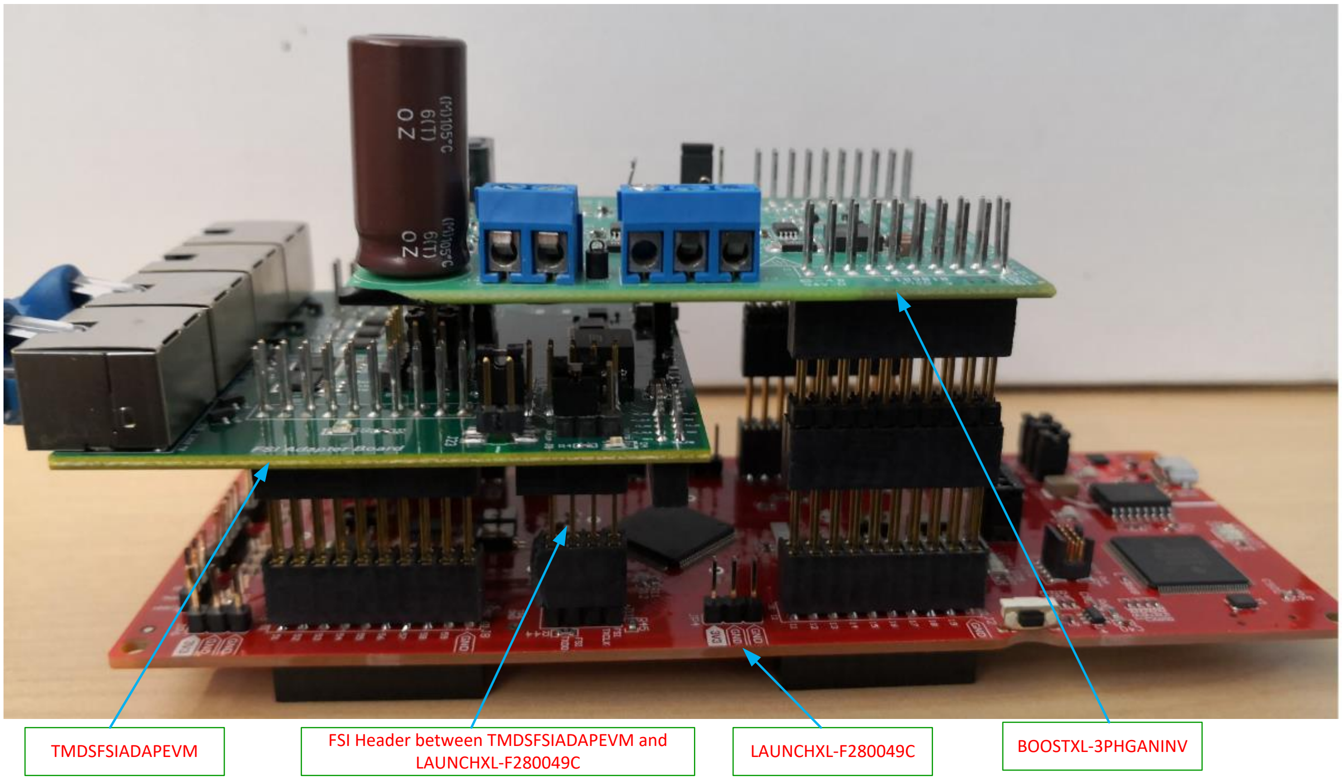


**表 5. Motor Power Lines and Encoder Wires Connections for Slave Node**

| PIN NUMBER | SIGNAL | PIN NUMBER | SIGNAL | COLOR |
|---|---|---|---|---|
| J3 on BOOSTXL-3PhGaNInv | | LVSERVOMTR Motor Connector | | |
| 1 | VA | 1 | U | Black |
| 2 | VB | 2 | V | Red |
| 3 | VC | 3 | W | White |
| J12 on LAUNCHXL-F280049C | | Encoder Connector (J4) | | |
| 1 | QEP1A | 1 | ENC A+ | Blue |
| 2 | QEP1B | 2 | ENC B+ | Orange |
| 3 | QEP1I | 3 | ENC I+ | Brown |
| 4 | +5V | 4 | +5VDC IN | Red |
| 5 | GND | 5 | GND | Black |

Before assembling TMDXCNCD28388D and TMDSFSIADAPEVM with TMDXIDDK379D, ensure that jumpers on these three boards are set correctly as shown in 图 13, 图 16, and 图 17. When instructed to connect motor, connect the motor terminal to connector terminal and motor's encoder header to QEP connector TMDXIDDK379D listed in 表 6. The master node system setup as shown in 图 28.

图 28. TMDXCNCD28388D and TMDSFSIADAPEVM Assembly with TMDXIDDK379D

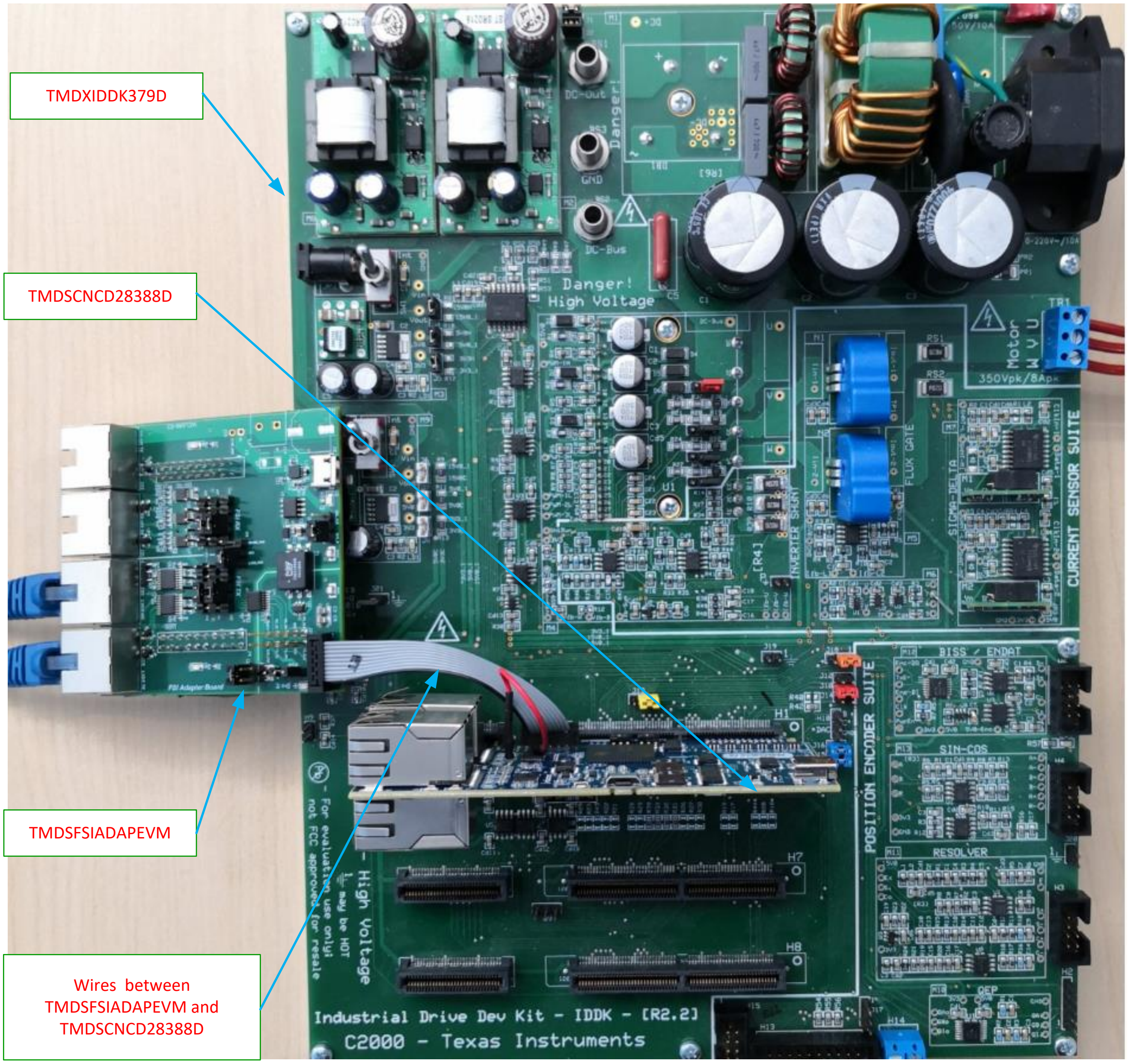
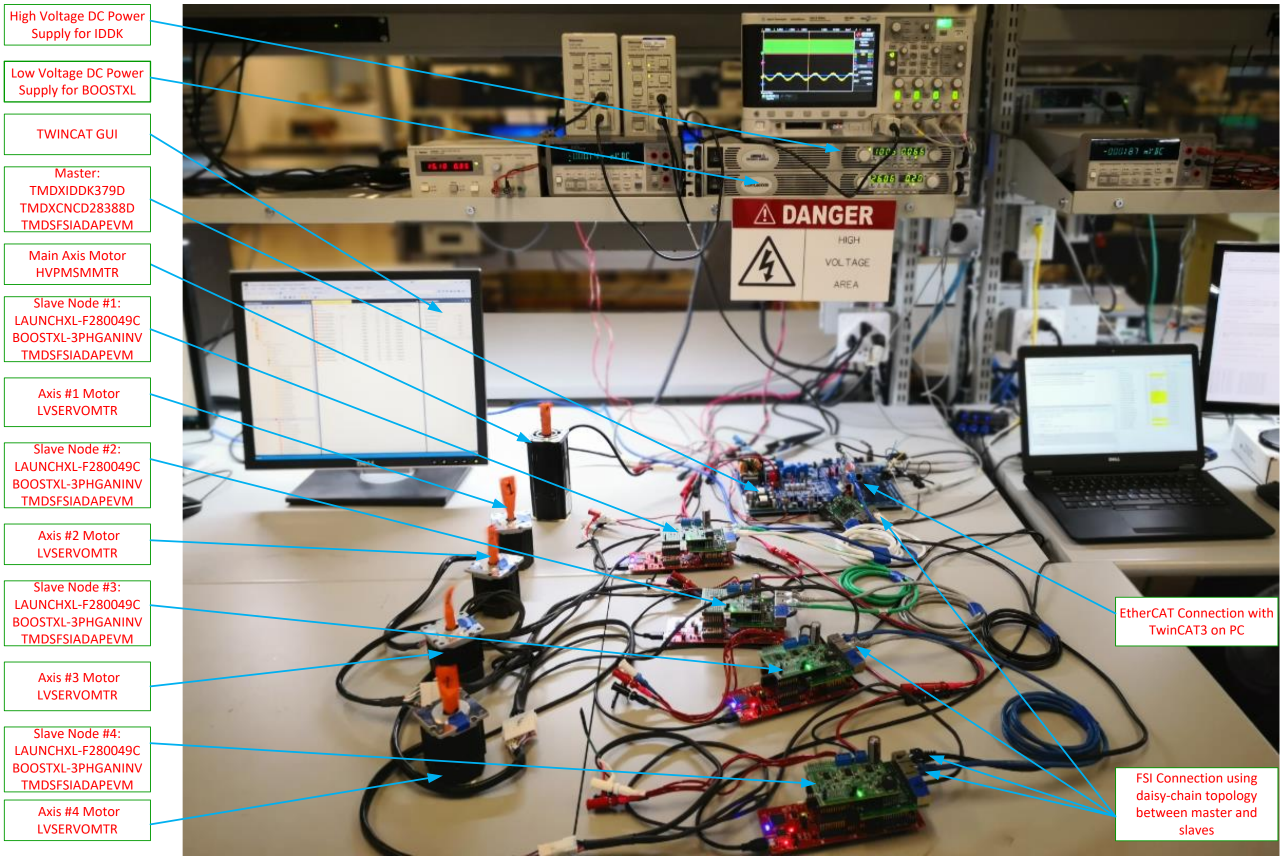

TMDXIDDK379D
TMDSCNCD28388D
TMDSFSIADAPEVM
Wires between TMDSFSIADAPEVM and TMDSCNCD28388D
Industrial Drive Dev Kit - IDDK - [R2.2]
C2000 - Texas Instruments

表 6. Motor Power Lines and Encoder Wires Connections for Master Node

| Pin No. | Signal | Pin No. | Signal | Color |
|---|---|---|---|---|
| TB1 on TMDXIDDK379D | | HVPMSMMTR Motor Connector | | |
| 1 | U | 1 | U | Red |
| 2 | V | 2 | V | Black |
| 3 | W | 3 | W | White |
| H2 on TMDXIDDK379D | | Encoder Connector | | |
| 1 | QA | 1 | A+ | Brown |
| 2 | QB | 2 | B+ | Yellow |
| 3 | QI | 3 | C+ | White |
| 4 | +5V | 4 | PG 5V | Red |
| 5 | GND | 5 | PG 0V | Black |

图 29 shows the test platform setup for this design. The master and slave nodes of multi-axis drive system are connected over FSI using daisy-chain topology.

图 29. Test Platform for Multi-axis Drive over FSI


High Voltage DC Power Supply for IDDK
Low Voltage DC Power Supply for BOOSTXL
TWINCAT GUI
Master: TMDXIDDK379D TMDXCNCD28388D TMDSFSIADAPEVM
Main Axis Motor HVPMSMMTR
Slave Node #1: LAUNCHXL-F280049C BOOSTXL-3PHGANINV TMDSFSIADAPEVM
Axis #1 Motor LVSERVOMTR
Slave Node #2: LAUNCHXL-F280049C BOOSTXL-3PHGANINV TMDSFSIADAPEVM
Axis #2 Motor LVSERVOMTR
Slave Node #3: LAUNCHXL-F280049C BOOSTXL-3PHGANINV TMDSFSIADAPEVM
Axis #3 Motor LVSERVOMTR
Slave Node #4: LAUNCHXL-F280049C BOOSTXL-3PHGANINV TMDSFSIADAPEVM
Axis #4 Motor LVSERVOMTR
EtherCAT Connection with TwinCAT3 on PC
FSI Connection using daisy-chain topology between master and slaves
DANGER
HIGH VOLTAGE AREA

### 3.3.2 Test Results

The operation and test result at those build levels (LEVEL1~LEVEL6) for motor drive in main or slave axis are described in application report *Dual-Axis Motor Control Using FCL and SFRA On a Single C2000™ MC* in detail.

The following results are tested in the final system by setting the build level in each project separately as below

- multi_axis_master_ctrl_f2838x_cpu1 - define BUILDLEVEL to FCL_LEVEL11
- multi_axis_master_drive_f2838x_cpu2 - define BUILDLEVEL to FCL_LEVEL8
- multi_axis_master_ecat_f2838x_cm - only one build level
- multi_axis_slave_node(n)_f28004x_cpu - define BUILDLEVEL to FCL_LEVEL8

图 30 shows the speed curve of each slave axis and main axis using CCS graph tool with datalog function. The result shows there is no significant difference between all the axes.

### 图 30. Experiment of Main Axis and 4 Slave Axes Speed Synchronization

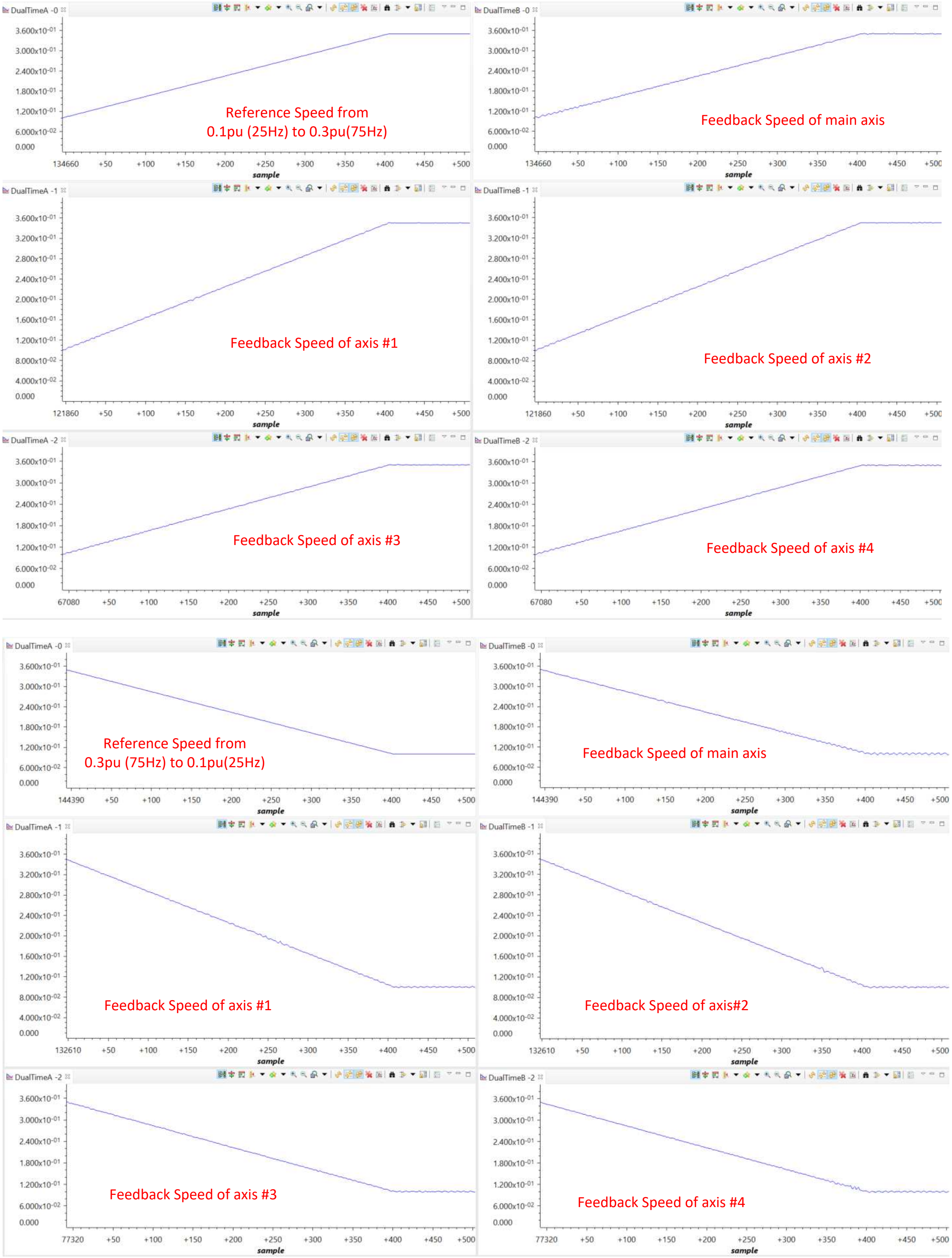


图 31 shows the speed curve of a slave axis and main axis, or reference and feedback speed of a motor using buffer DAC and oscilloscope. The result shows there is no significant difference between the two axes, or no significant delay between the reference and real running speed of the motor.

**图 31. Experiment of Speed Synchronization**

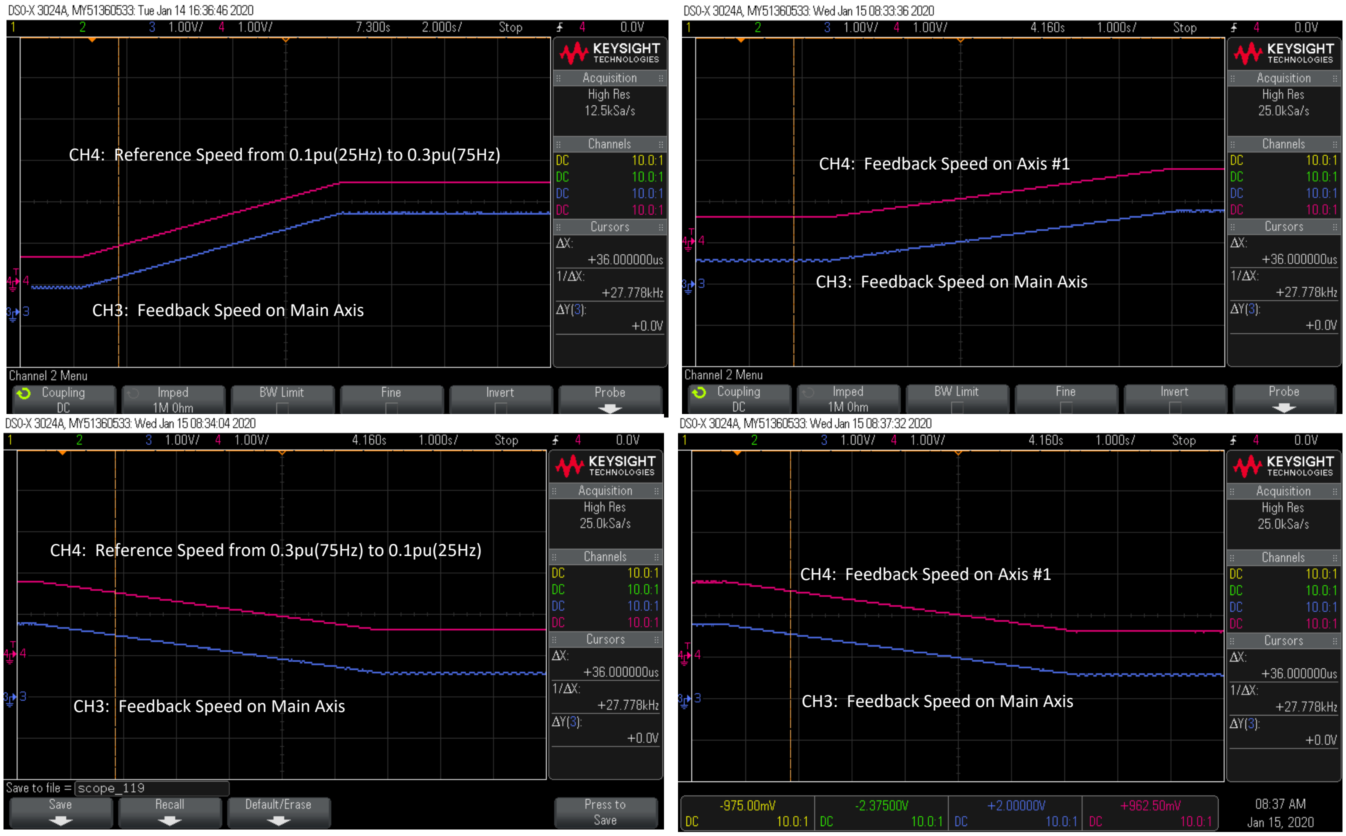


图 32 shows the speed curve of a slave axis and main axis, or reference and feedback speed of a motor using buffer DAC and oscilloscope.

图 32. The Reference Speed and Feedback Position of Different Motor

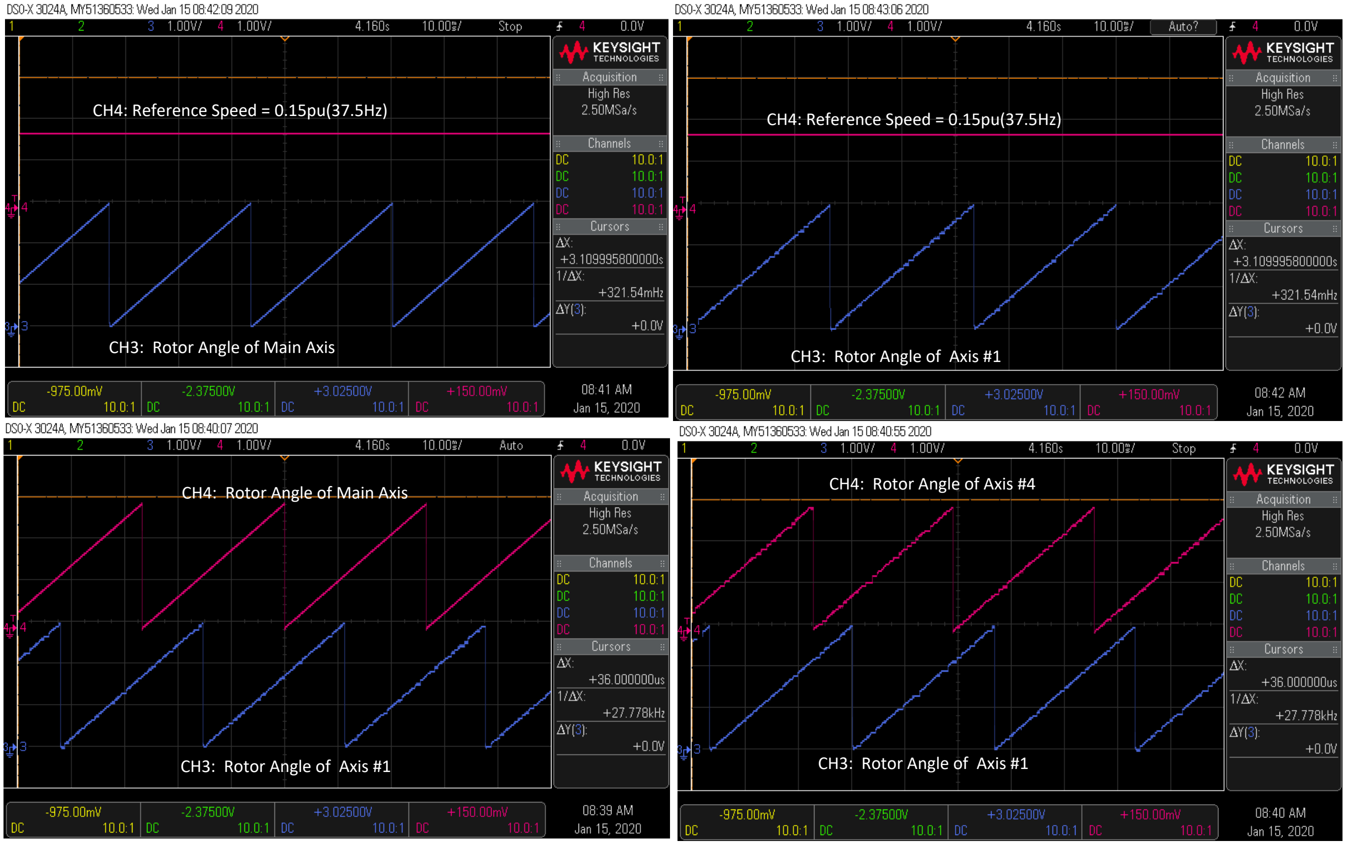
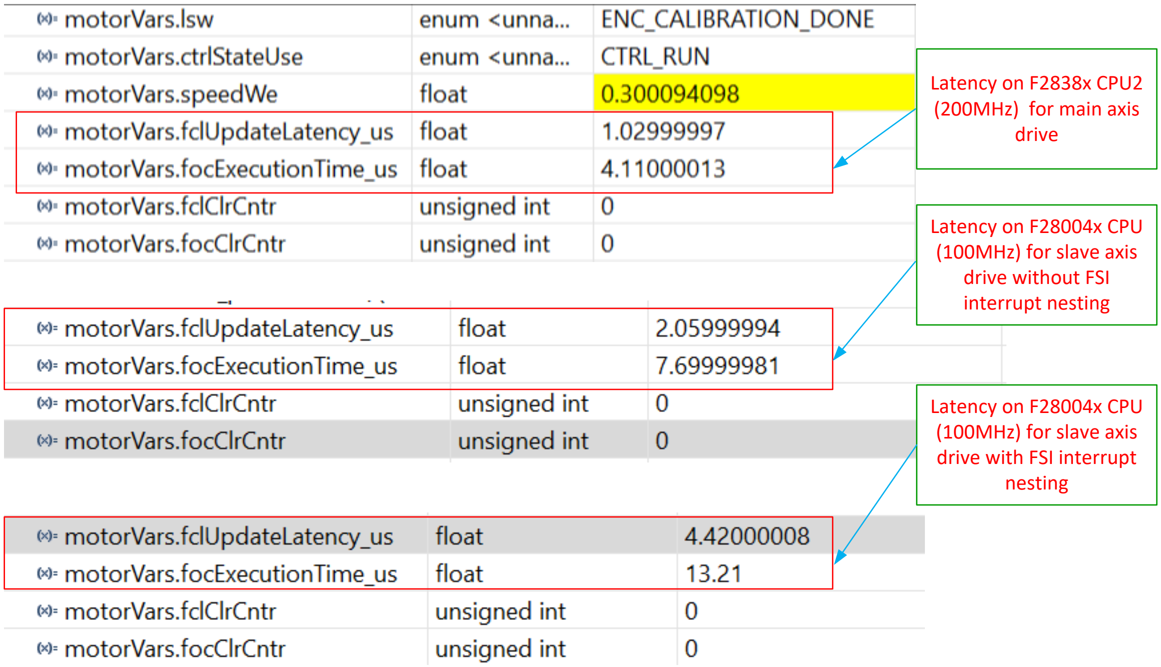

DSO-X 3024A, MY51360533: Wed Jan 15 08:42:09 2020
CH4: Reference Speed = 0.15pu(37.5Hz)
CH3: Rotor Angle of Main Axis
DSO-X 3024A, MY51360533: Wed Jan 15 08:43:06 2020
CH4: Reference Speed = 0.15pu(37.5Hz)
CH3: Rotor Angle of Axis #1
DSO-X 3024A, MY51360533: Wed Jan 15 08:40:07 2020
CH4: Rotor Angle of Main Axis
CH3: Rotor Angle of Axis #1
DSO-X 3024A, MY51360533: Wed Jan 15 08:40:55 2020
CH4: Rotor Angle of Axis #4
CH3: Rotor Angle of Axis #1
3 1.00V/ 4 1.00V/ 4.160s 10.00s/
KEYSIGHT TECHNOLOGIES
Acquisition
High Res
2.50MSa/s
Channels
DC 10.0:1
Cursors
ΔX:
+3.109995800000s
1/ΔX:
+321.54mHz
+36.000000us
+27.778kHz
ΔY(3):
+0.0V
-975.00mV
-2.37500V
+3.02500V
+150.00mV
08:41 AM Jan 15, 2020
08:42 AM Jan 15, 2020
08:39 AM Jan 15, 2020
08:40 AM Jan 15, 2020

图 33 shows a snapshot of the expressions window in CCS. The variable, motorVars.fclUpdateLatency_us indicates the PWM latency that is the amount of time elapsed between the feedback sampling and PWM updating. Another variable, motorVars.focExecutionTime_us indicates the amount of time executed by the whole FOC algorithm.

**图 33. PWM latency and FOC execution time**



| | | |
|---|---|---|
| motorVars.lsw | enum <unna... | ENC_CALIBRATION_DONE |
| motorVars.ctrlStateUse | enum <unna... | CTRL_RUN |
| motorVars.speedWe | float | 0.300094098 |
| motorVars.fclUpdateLatency_us | float | 1.02999997 |
| motorVars.focExecutionTime_us | float | 4.11000013 |
| motorVars.fclClrCntr | unsigned int | 0 |
| motorVars.focClrCntr | unsigned int | 0 |

Latency on F2838x CPU2 (200MHz) for main axis drive

| | | |
|---|---|---|
| motorVars.fclUpdateLatency_us | float | 2.05999994 |
| motorVars.focExecutionTime_us | float | 7.69999981 |
| motorVars.fclClrCntr | unsigned int | 0 |
| motorVars.focClrCntr | unsigned int | 0 |

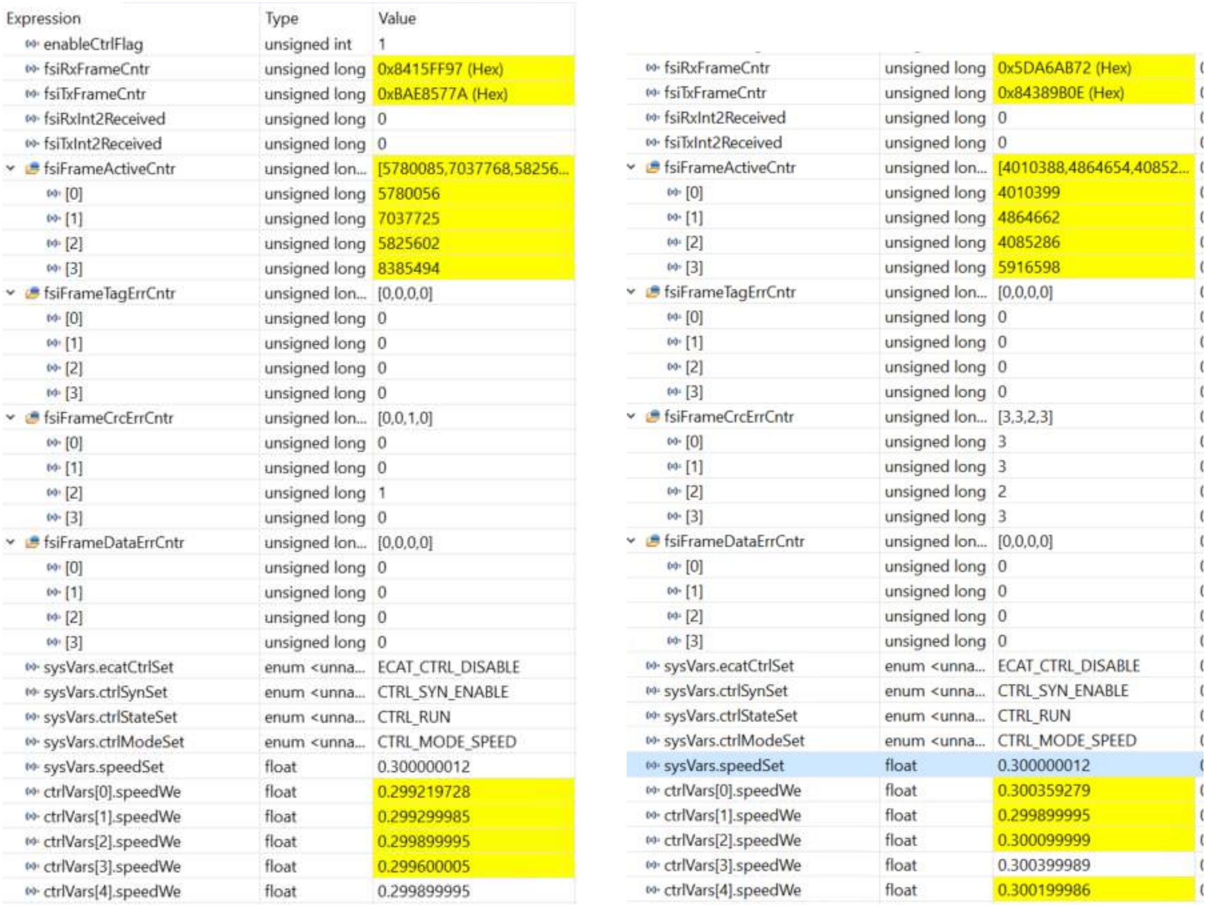
Latency on F28004x CPU (100MHz) for slave axis drive without FSI interrupt nesting

| | | |
|---|---|---|
| motorVars.fclUpdateLatency_us | float | 4.42000008 |
| motorVars.focExecutionTime_us | float | 13.21 |
| motorVars.fclClrCntr | unsigned int | 0 |
| motorVars.focClrCntr | unsigned int | 0 |

Latency on F28004x CPU (100MHz) for slave axis drive with FSI interrupt nesting

图 34 shows a snapshot of the expressions window in CCS. These variables indicate the number of transmission times and failures. The result shows that the failure rate is very low after running over a long time.

### 图 34. Long Time Experiment of FSI Communication



| Expression | Type | Value |
|---|---|---|
| enableCtrlFlag | unsigned int | 1 |
| fsiRxFrameCntr | unsigned long | 0x8415FF97 (Hex) |
| fsiTxFrameCntr | unsigned long | 0xBAE8577A (Hex) |
| fsiRxInt2Received | unsigned long | 0 |
| fsiTxInt2Received | unsigned long | 0 |
| fsiFrameActiveCntr | unsigned lon... | [5780085,7037768,58256... |
| [0] | unsigned long | 5780056 |
| [1] | unsigned long | 7037725 |
| [2] | unsigned long | 5825602 |
| [3] | unsigned long | 8385494 |
| fsiFrameTagErrCntr | unsigned lon... | [0,0,0,0] |
| [0] | unsigned long | 0 |
| [1] | unsigned long | 0 |
| [2] | unsigned long | 0 |
| [3] | unsigned long | 0 |
| fsiFrameCrcErrCntr | unsigned lon... | [0,0,1,0] |
| [0] | unsigned long | 0 |
| [1] | unsigned long | 0 |
| [2] | unsigned long | 1 |
| [3] | unsigned long | 0 |
| fsiFrameDataErrCntr | unsigned lon... | [0,0,0,0] |
| [0] | unsigned long | 0 |
| [1] | unsigned long | 0 |
| [2] | unsigned long | 0 |
| [3] | unsigned long | 0 |
| sysVars.ecatCtrlSet | enum <unna... | ECAT_CTRL_DISABLE |
| sysVars.ctrlSynSet | enum <unna... | CTRL_SYN_ENABLE |
| sysVars.ctrlStateSet | enum <unna... | CTRL_RUN |
| sysVars.ctrlModeSet | enum <unna... | CTRL_MODE_SPEED |
| sysVars.speedSet | float | 0.300000012 |
| ctrlVars[0].speedWe | float | 0.299219728 |
| ctrlVars[1].speedWe | float | 0.299299985 |
| ctrlVars[2].speedWe | float | 0.299899995 |
| ctrlVars[3].speedWe | float | 0.299600005 |
| ctrlVars[4].speedWe | float | 0.299899995 |

| | | |
|---|---|---|
| fsiRxFrameCntr | unsigned long | 0x5DA6AB72 (Hex) |
| fsiTxFrameCntr | unsigned long | 0x84389B0E (Hex) |
| fsiRxInt2Received | unsigned long | 0 |
| fsiTxInt2Received | unsigned long | 0 |
| fsiFrameActiveCntr | unsigned lon... | [4010388,4864654,40852... |
| [0] | unsigned long | 4010399 |
| [1] | unsigned long | 4864662 |
| [2] | unsigned long | 4085286 |
| [3] | unsigned long | 5916598 |
| fsiFrameTagErrCntr | unsigned lon... | [0,0,0,0] |
| [0] | unsigned long | 0 |
| [1] | unsigned long | 0 |
| [2] | unsigned long | 0 |
| [3] | unsigned long | 0 |
| fsiFrameCrcErrCntr | unsigned lon... | [3,3,2,3] |
| [0] | unsigned long | 3 |
| [1] | unsigned long | 3 |
| [2] | unsigned long | 2 |
| [3] | unsigned long | 3 |
| fsiFrameDataErrCntr | unsigned lon... | [0,0,0,0] |
| [0] | unsigned long | 0 |
| [1] | unsigned long | 0 |
| [2] | unsigned long | 0 |
| [3] | unsigned long | 0 |
| sysVars.ecatCtrlSet | enum <unna... | ECAT_CTRL_DISABLE |
| sysVars.ctrlSynSet | enum <unna... | CTRL_SYN_ENABLE |
| sysVars.ctrlStateSet | enum <unna... | CTRL_RUN |
| sysVars.ctrlModeSet | enum <unna... | CTRL_MODE_SPEED |
| sysVars.speedSet | float | 0.300000012 |
| ctrlVars[0].speedWe | float | 0.300359279 |
| ctrlVars[1].speedWe | float | 0.299899995 |
| ctrlVars[2].speedWe | float | 0.300099999 |
| ctrlVars[3].speedWe | float | 0.300399989 |
| ctrlVars[4].speedWe | float | 0.300199986 |

# 4 Design Files

This reference design is based on the released C2000 development kits and Evaluation Module, which include LAUNCHXL-F280049C, TMDSCNCD28388D, BOOSTXL-3PHGANINV and TMDXIDDK379D. The latest FSI adapter board (TMDSFSIADAPEVM) design files are as shown in subsections, the official release TMDSFSIADAPEVM board will be available at a later time.

## *4.1 Schematics*

To download the schematics of TMDSFSIADAPEVM, see the design files at TIDA-02006.

## *4.2 Bill of Materials*

To download the bill of materials (BOM) of TMDSFSIADAPEVM, see the design files at TIDA-02006.

# 5 Software Files

To download the software files, see the design files at C2000WARE-MOTORCONTROL-SDK the multi-axis servo supporting version 3.00.00.00 will be released at a later date.

# 6 Related Documentation

1. Texas Instruments, *C2000™ Piccolo™ F28004x Series LaunchPad™ Development Kit*
2. Texas Instruments, *BOOSTXL-3PhGaNInv Evaluation Module User's Guide*
3. Texas Instruments, *TMS320F28388D controlCARD Information Guide*
4. Texas Instruments, *TMDSFSIADAPEVM FSI Adapter Board User's Guide* (released at a later date)
5. Texas Instruments, *DesignDRIVE Development Kit IDDK v2.2.1 - User's Guide*
6. Texas Instruments, *DesignDRIVE Development Kit IDDK v2.2.1 - Hardware Reference Guide*
7. Texas Instruments, *TMS320F28004x Piccolo Microcontrollers Technical Reference Manual*
8. Texas Instruments, *TMS320F2838x Microcontrollers TRM*
9. Texas Instruments, *Fast Serial Interface (FSI) Skew Compensation*
10. Texas Instruments, *Using the Fast Serial Interface (FSI) With Multiple Devices in an Application*
11. Texas Instruments, *Dual-Axis Motor Control Using FCL and SFRA On a Single C2000™ MCU*
12. Texas Instruments, *Dual-Axis Motor Drive Using Fast Current Loop (FCL) and SFRA on a Single MCU Reference Design*
13. Texas Instruments, EtherCAT-Based Connected Servo Drive Using Fast Current Loop on PMSM

## *6.1 Trademarks*

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# 7 Terminology

**ADC** - Analog-to-Digital Convert

**CLA** - Control Law Accelerator

**CM** - Cortex-M4 core

**CMPSS** - Comparator Subsystem Peripheral

**CNC** - Computer Numerical Control

**DAC** - Digital to Analog Converter

**eQEP** - Enhanced Quadrature Encoder Pulse Module

**EtherCAT** - Ethernet for Control Automation Technology

**FCL** - Fast Current Loop

**FOC** - Field-Oriented Control

**FSI** - Fast Serial Interface

**MCU** - Microcontroller Unit

**PMSM** - Permanent Magnet Synchronous Motor

**PWM** - Enhanced Pulse Width Modulator

**SFRA**- Software Frequency Response Analyzer

**TMU** - Trigonometric Mathematical Unit

## 8 About the Author

**YANMING LUO** is a Systems Application Engineer in the system solutions team of C2000 at Texas Instruments, where he is responsible for developing reference design solutions for motor-drive applications based C2000 controllers. Yanming has been with TI since 2003 and earned an M.S. degree from Northeastern University, China in 1998.

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