C2000™ *F28P65x Series LaunchPad™ Development Kit*

TEXAS INSTRUMENTS

ABSTRACT

The LAUNCHXL-F28P65X is a low-cost development board for the Texas Instruments C2000™ Real-Time Microcontroller series of F28P65x devices. The LAUNCHXL-F28P65X is designed around the TMS320F28P650DK9 real-time MCU and highlights the control, analog, and communications peripherals, as well as the integrated nonvolatile memory. The LaunchPad also features two independent BoosterPack XL expansion connectors (80-pins), dedicated 12-bit/16-bit differential ADC header, on-board Controller Area Network (CAN) transceiver supporting both standard CAN (DCAN) and CAN-FD (MCAN), two 5 V encoder interface (eQEP) connectors, FSI connector, EtherCAT connector, power-domain isolation, and an on-board XDS110 debug probe.

Figure 1-1 highlights the key features of the F28P65x LaunchPad.
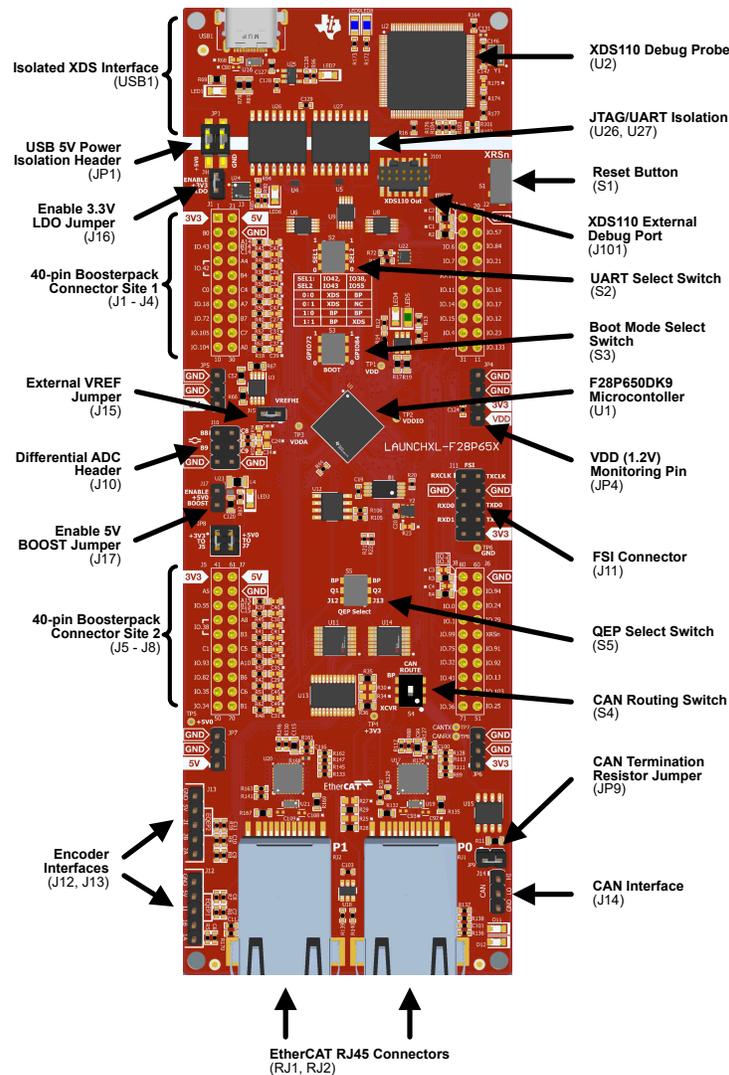
Figure 1-1. F28P65x LaunchPad Board Overview

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1 Board Overview

1.1 Kit Contents

The F28P65x Series LaunchPad Development Kit contains these items:

- C2000 F28P65x Series LaunchPad development board (LAUNCHXL-F28P65X)
- USB Type-A male to USB Type-C™ male cable
- Pinout Map

1.2 Features

The F28P65x LaunchPad has these features:

- C2000 Series F28P650DK9 (169-pin) microcontroller
    – With Configurable Logic Block (CLB) capability
- On-board XDS110 debug probe
- Two user-controlled LEDs
- One microcontroller reset switch
- Selectable power domains:
    – USB
    – BoosterPack
    – External power supply (5V or 3.3V)
- 12-bit/16-bit differential ADC header
    – The on-board REF6230 supports all 12-bit ADC modes and does not provide data sheet-specified performance in 16-bit mode. This REF6230 is not a recommended reference for designs requiring 16-bit ADC operation. Instead, refer to TMDSCNCD28P65X for recommended ADC reference circuit.
- CAN connector with on-board CAN transceiver
    – Supports both standard CAN (DCAN) and CAN-FD (MCAN)
- Two independent Enhanced Quadrature Encoder Pulse (QEP)-based encoder connectors
- FSI peripheral connector
- EtherCAT connectors
- Two independent BoosterPack XL standard connectors (80-pins) featuring stackable headers to maximize expansion through the BoosterPack ecosystem

1.3 Specifications

Table 1-1 summarizes the F28P65x LaunchPad specifications.

Table 1-1. LAUNCHXL-F28P65X Specifications

Parameter	Value
Board Supply Voltage	5 V_{DC} from one of the following sources: • USB Connector (USB1) - USB Type-C™ cable connected to PC or other compatible power source. • BoosterPack 1 • BoosterPack 2 • Auxiliary power connectors 3.3 V_{DC} from one of the following sources: • BoosterPack 1 • BoosterPack 2 • Auxiliary power connectors
Dimensions	6.75 in x 2.3 in x 0.925 in (17.14 cm x 5.84 cm x 2.35 cm) (L x W x H)
Break-out Power Output	• 3.3 V_{DC} to BoosterPacks, limited by output of TPS7A7401 LDO. This 3.3-V plane is shared with on-board components. Total output power limit of TPS7A7401 is 1.5 A.
Assumed Operating Conditions	This kit is assumed to run at standard room conditions. The EVM can run at approximately standard ambient temperature and pressure (SATP) with moderate-to-low humidity.

1.3.1 External Power Supply or Accessory Requirements

Nominal Output Voltage: *5 VDC*

Maximum Output Current: *3 A*

Efficiency Level V

Note

TI recommends using an external power supply or power accessory **that** complies with applicable regional safety standards such as (by example) UL, CSA, VDE, CCC, PSE, and so on.

1.4 Using the F28P65x LaunchPad

The recommended steps for using the F28P65x LaunchPad are:

1. **Follow the instructions in** Section 2.2 **to begin running the LaunchPad demo program.** Within just a few minutes, you can control and monitor the F28P65x LaunchPad with the pre-programmed quick start application. Additionally, the FAQ section included in this document can be helpful if there are any issues that can quickly be addressed.
2. **Experiment with BoosterPacks.** This development kit conforms to the latest revision of the BoosterPack pinout standard. This development kit has two independent BoosterPack sites to enable a variety of expansion opportunities, such as two boosterpacks being used simultaneously. For more information about the TI LaunchPad and BoosterPack standard, see the TI LaunchPad.
3. **Take the first step towards developing your own control applications.** The F28P65x LaunchPad is supported by the C2000Ware development package. After C2000Ware is installed, look for \f28p65x\examples\c28x\launchxl_f28p65x in the installation directory to find the pre-configured example applications for this board. Any of the other examples found within the \f28p65x\examples directory can be used with minor modifications to run on the LaunchPad as well. For more details about software development, see Section 2.
   a. For applications, features and benefits information, see the *TMS320F28P65x Real-Time Microcontrollers*.
   b. Check out this technical article featuring C2000 Real-Time Microcontrollers about how developers can take advantage of the scalability and sustainability benefits these devices bring.
4. **Customize and integrate the hardware to align to your end application.** This development kit can be used as a reference for building your own custom boards and circuits based on C2000 F28P65x series microcontrollers. The LaunchPad also functions as a foundation for expansion with custom BoosterPacks and other circuits. This document can serve as a starting point for such projects.
5. **Get Trained.** Review and download hours of written and video training materials on C2000 Real-time Microcontrollers and related LaunchPads.
   a. See *Getting Started With C2000™ Real-Time ControlMicrocontrollers (MCUs)*
   b. See the TI Training and Videos page
   c. See the *C2000 Academy* page

1.5 BoosterPacks

The LAUNCHXL-F28P65X provides a simple and inexpensive way to develop applications with the F28P65x series microcontroller. BoosterPacks are pluggable add-on boards for the LaunchPad ecosystem that follow a pin-out standard created by Texas Instruments. The TI and third-party ecosystem of BoosterPacks greatly expands the peripherals and potential applications that you can explore with the F28P65x LaunchPad.

Some examples of BoosterPacks that are compatible with the F28P65x LaunchPad are listed in Table 1-2. Note that this is not an exhaustive list of hardware supported BoosterPacks.

Table 1-2. Featured BoosterPacks for the F28P65x LaunchPad

BoosterPack/Board	Application and Usage
BOOSTXL-3PHGANINV	Features a 48-V/10-A three-phase GaN inverter with precision in-line shunt-based phase current sensing for accurate control of precision drives such as servo drives.
BOOSTXL-DRV8323RS BOOSTXL-DRV8323RH	DRV8323RS/H Three-Phase, 15A smart gate driver with buck, shunt amps (SPI or Hardware Interface) Evaluation Module.
TMDSFSIADAPEVM	FSI adapter board assists in understanding the functionality of the C2000's FSI communications peripheral. Enables evaluation of the peripheral for decentralized and point-to-point real-time control system use cases, such as those in industrial drives, servo, sensing networks, and solar system and industrial power.
DRV8353RS-EVM	15A, 3-phase brushless DC drive stage based on the DRV8353RS gate driver and CSD19532Q5B NexFET™ MOSFETs.
DRV8316REVM	DRV8316REVM provides three half-H-bridge integrated MOSFET drivers for driving a three-phase brushless DC (BLDC) motor with 8-A Peak current drive, for 12-V/24-V DC rails or battery powered applications.

Table 1-2. Featured BoosterPacks for the F28P65x LaunchPad (continued)

BoosterPack/Board	Application and Usage
BOOSTXL-BUCKCONV	Digital Power Buck Converter BoosterPack for learning the basics of digital power control with C2000 microcontrollers. The buck converter power stage supports dynamic loads and converts an external 9-VDC power supply to a configurable DC output voltage.
BOOSTXL-POSMGR	PositionManager BoosterPack is a flexible low voltage platform intended for evaluating interfaces to absolute encoders and analog sensors like resolvers and SinCos transducers.
BOOSTXL-SHARP128	Sharp® 128x128 Memory LCD and microSD Card BoosterPack, controlled using SPI. Display sensor readings, time, graphics, or other information using the LCD screen.

Note

Software support for the BoosterPacks and boards listed varies.

Users can also design their own BoosterPacks for the F28P65x LaunchPad. Make sure that compatibility requirements are met by referencing the signal pin mapping in the LAUNCHXL-F28P65X Pinout Map or LAUNCHXL-F28P65X Schematic.

1.6 Hardware Revisions

This section contains an abbreviated revision history of the LAUNCHXL-F28P65X as well as known issues with each revision.

1.6.1 Revision A

The first production revision of the LAUNCHXL-F28P65x was released in July 2023. This revision can be identified by the "MCU117A" silkscreen labeling on the back side of the EVM between the BoosterPack Connector site 1 towards the top of the board.

Issues and concerns that have been identified on the EVM are listed below:

Known issues:

• No issues to report at this time of initial release.

Special notes and considerations to be aware of:

• Nothing to report at this time of initial release.

2 Software Development

This section provides general information about software development, as well as instructions for programming the LaunchPad. Software tools and packages for C2000 real-time controllers, like the F28P65x, are listed in the C2000 Evaluation & Development page.

2.1 Software Tools and Packages

Code Composer Studio (CCS) is a free integrated development environment (IDE) that supports TI's Microcontroller and Embedded Processors portfolio. Code Composer Studio™ (CCS) IDE provides a feature rich environment for developing, programming, and debugging code on the C2000 family of MCUs.

C2000WARE is a repository of device-specific drivers, bit-field support files, libraries, peripheral examples, utilities, hardware files, and documentation for C2000 MCUs. C2000WARE provides a solid foundation to begin development and evaluation of the F28P65x device on the LAUNCHXL-F28P65X and minimize software development time.

Software Development Kits (SDKs) are provided to make it easy to evaluate C2000 MCUs within specific system use cases and reduce overall development time. The Motor Control SDK (C2000WARE-MOTORCONTROL-SDK) is targeted for various motor control applications, such as industrial drives. The Digital Power SDK (C2000WARE-DIGITALPOWER-SDK) is targeted for digital power system development for various AC-DC, DC-DC, and DC-AC power-supply applications.

2.2 F28P65x LaunchPad Demo Program

The LAUNCHXL-F28P65X includes a TMS320F28P650DK9NMR device pre-programmed with a demo program. When the LaunchPad is powered on, the demo program begins with an LED blink sequence on LED4 and LED5. After a few seconds, the device switches into an ADC sampling mode.

Every 1 second, the ADC samples pin ADCINA4 and the sampled value is represented as follows: If the sample is above mid-scale (2048), the red LED4 illuminates. If the sample is below mid-scale, the green LED5 illuminates.

By default, the ADC is configured in external voltage reference mode. Thus, the shunt on J15 must be connected to make use of the on-board 3.0 V high-precision voltage reference device (REF6230). The mid-scale point occurs around 1.5 V. For more information about the analog voltage reference, see Section 3.1.11.

In addition to the LED indicators, ADC sample results are also displayed on your PC through the USB/UART connection. To view the UART information on your PC, first determine the COM port associated with the LaunchPad (see Figure 2-1). To do this in Windows, open the *Device Manager.* Look for an entry under Ports (COM & LPT) titled "XDS110 Class Application/User UART (COM*X*)", where *X* is a number. Remember this number for when you open a serial terminal.
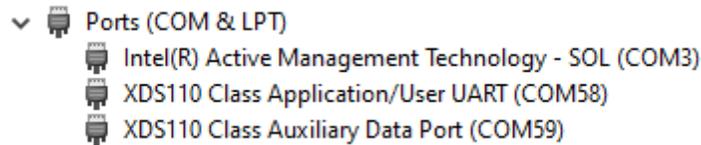
Figure 2-1. LaunchPad XDS110 COM Port

The demo application's UART data was tested using PuTTY, which is a free and open-source terminal emulator. To view the UART data in a serial terminal program, open the COM port found using the Windows *Device Manager* with the following settings:

```
115200 Baud, 8 data bits, no parity, 1 stop bit.
```

After properly opening the serial port in your serial terminal, reset the LaunchPad by pressing the S1 reset button and observe the serial terminal to see the TI logo in ASCII art (see Figure 2-2).
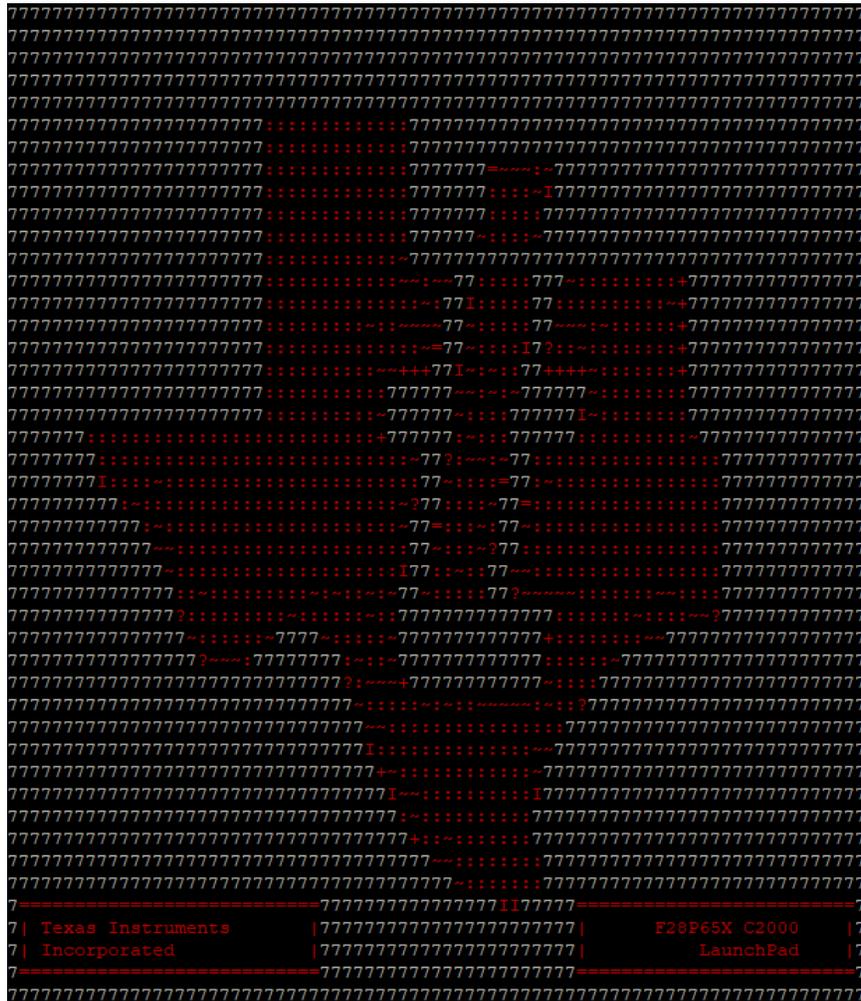
Figure 2-2. LaunchPad Demo Serial Terminal - TI Logo

After a few moments, the ADC value sampled on the ADCINA4 pin appears in the bottom right corner of the terminal and is updated each second (see Figure 2-3). Using a jumper wire, connect the ADCINA4 header to a 3.0 V, GND, or other 0-3.0 V signal to see the on-screen value change.
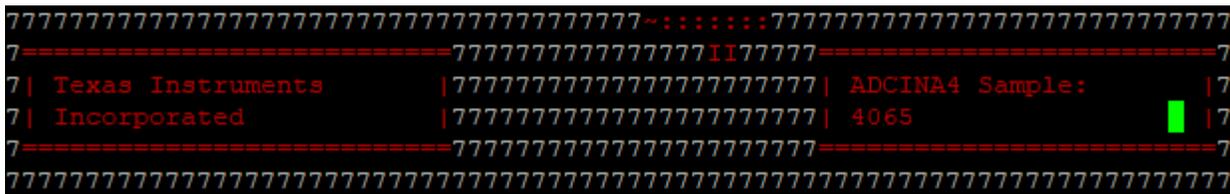
Figure 2-3. LaunchPad Demo Serial Terminal - ADC Sampling

2.3 Programming and Running Other Software on the F28P65x LaunchPad

The software packages described in Section 2.1 include example projects that can be loaded and run on the F28P65x LaunchPad. If you installed the C2000WARE software to the default installation path of *C:\ti\c2000\C2000Ware_<version>*, you can find DriverLib-based example applications in *C:\ti\c2000\C2000Ware_<version>\examples\f28p65x*. The on-board XDS110 is used with the On-Chip Flash Programmer tool to program applications to the F28P65x LaunchPad.

Follow these steps to program example applications onto the F28P65x LaunchPad development kit using the on-board XDS110 debug probe:

1. Install Code Composer Studio (CCS) IDE on a PC running Microsoft Windows.
2. Connect the USB-A cable plug in to an available USB port on the PC and plug the USB Type-C™ plug to the port (USB1) on the F28P65x LaunchPad.
3. Verify the following LEDs are illuminated:
    a. LED1, at the top left of the board, indicating 5 V USB power.
    b. LED7 indicating 3.3 V power to the XDS110 debug probe.
    c. LED3 indicating 5.0 V power to the F28P650DK9 MCU.
    d. LED6 indicating 3.3 V power to the F28P650DK9 MCU.
4. Install Windows XDS110 and Virtual COM Port drivers if prompted. Installation instructions can be found at XDS110 Product Page.
5. Run CCS IDE on the PC.
6. Import a F28P65x project from C2000WARE, or another installed software package, into the CCS IDE workspace.
7. Add the *_LAUNCHXL_F28P65X* predefined symbol to the imported DriverLib example project for the software to use relevant F28P65x LaunchPad signals.
    a. Open the projects Properties → Expand the *Build* tab → Expand the *C2000 Compiler* tab → Select *Predefined Symbol* → Add *_LAUNCHXL_F28P65X* pre-define NAME.
8. Right click the project name and select *Rebuild Project* in CCS IDE.
9. Launch the LAUNCHXL-F28P65X Target Configuration file and connect to the F28P65x device. Make sure that the Target Configuration file is configured to use the 4-pin JTAG advanced configuration. For additional details, see FAQ section.
10. Click 'Load Program' and select the program's binary to load. The binary is loaded onto the device and can now be run and debugged.

3 Hardware Description

The F28P65x LaunchPad includes a F28P650DK9NMR MCU, which isdesigned for advanced real-time control applications. A large number of these peripherals are made available to users using the on-board accessories and the BoosterPack connectors. This section explains how those peripherals operate and interface to the MCU.

Figure 3-1 shows a high-level block diagram of the F28P65x LaunchPad:
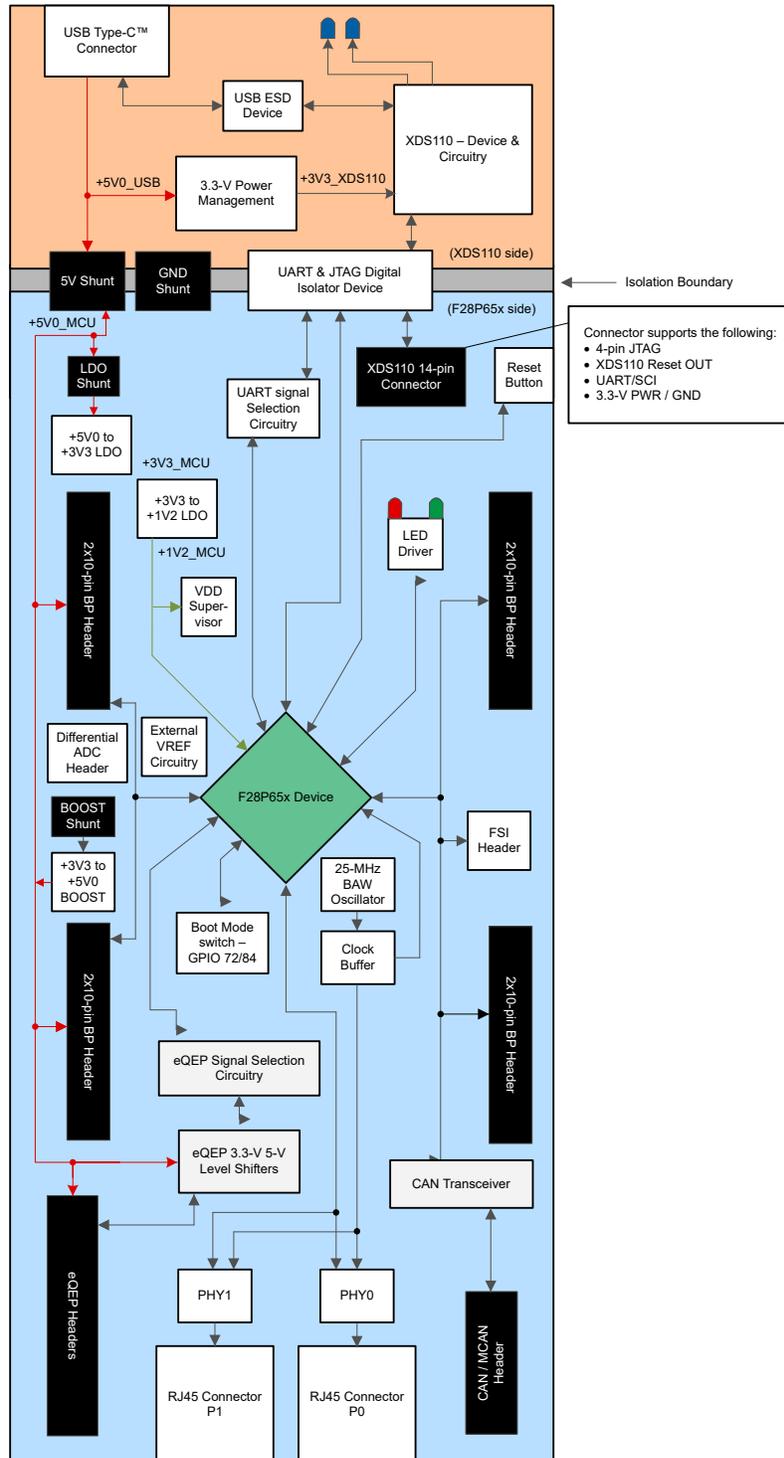

Figure 3-1. F28P65x LaunchPad Development Kit Block Diagram

3.1 Functional Description and Connections

3.1.1 Microcontroller

The TMS320F28P650DK9NMR is a dual-core 32-bit floating-point microcontroller with 1.28MB Flash memory, 248KB RAM, a programmable Control Law Accelerator (CLA) for offloading tasks, and operates at 200 MHz. The microcontroller includes advanced control peripherals, differentiated analog, and various communications peripherals. The device has been optimized for high-performance real-time control applications. For more details, see the *TMS320F28P65x Real-Time Microcontrollers*.

Most of the microcontroller's signals are routed to 0.1 inch (2.54 mm) pitch headers laid out to comply with the TI BoosterPack standards, with a few exceptions. The F28P65x MCU's internal multiplexer allows different peripheral functions to be assigned to each of the General-Purpose Input/Output (GPIO) pins. The multiplexing options can be found in the device-specific data sheet. When adding external circuitry, consider the additional load on the development board's power rails.

The F28P65x LaunchPad is factory-programmed with a quick start demo program. The quick start program resides in the on-chip Flash memory and executes each time power is applied, unless the application has been replaced with a user program. For details on the LaunchPad's demo program, see Section 2.2.

3.1.2 Power Domains

The F28P65x LaunchPad has several power domains that can be connected or isolated from each other with removable shunts. The different 3.3-V and 5-V power domains are further described in Figure 3-2.
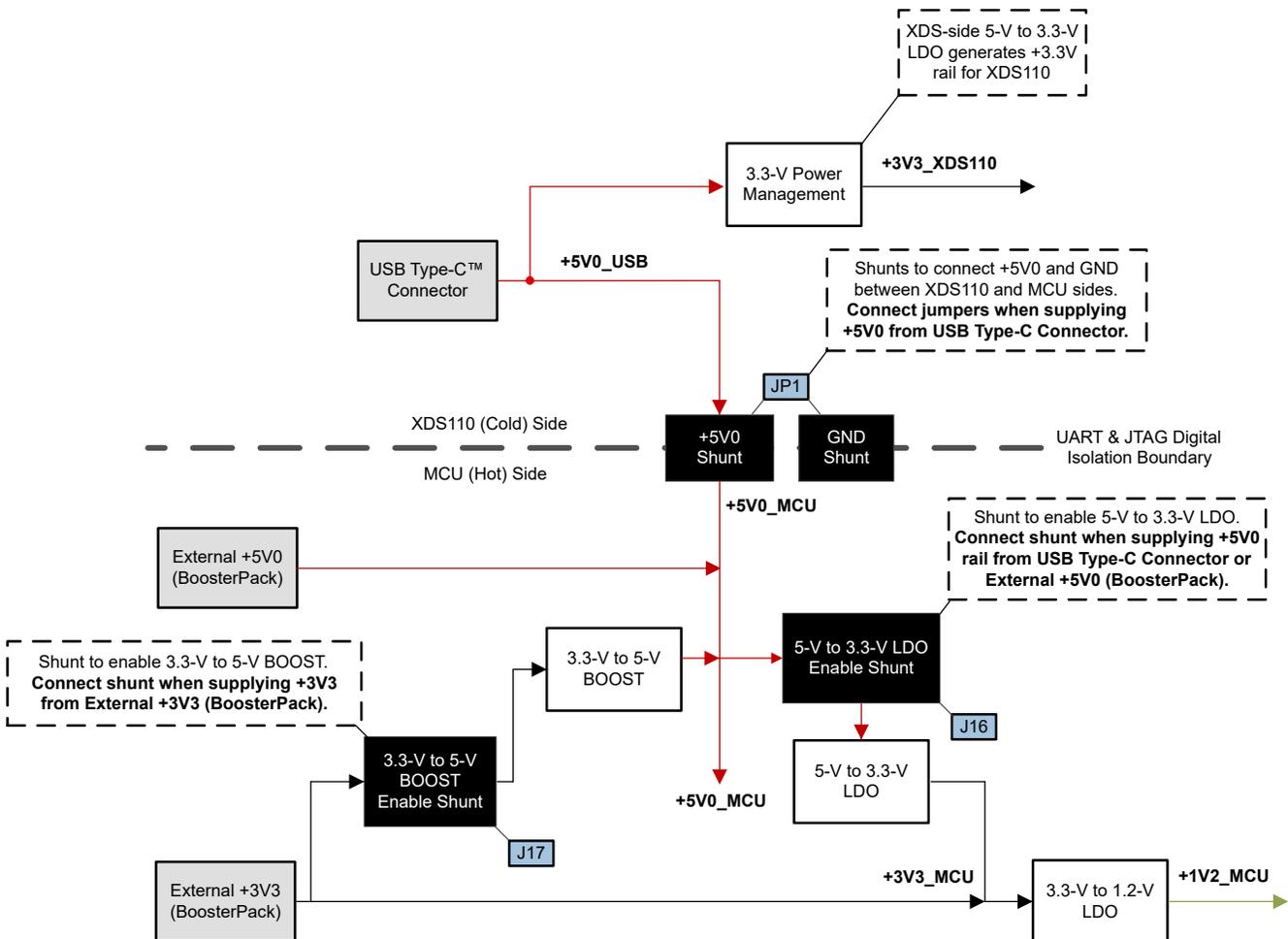

Figure 3-2. LaunchPad Power Distribution Diagram

Table 3-1 describes the usage of the different removable shunts on the LaunchPad board.

Table 3-1. Power Domain Shunts

Shunt Identifier	Usage Description
JP1, +5V0	Connects the +5-V power from the USB-C connector (+5V0_USB) to the +5-V power on the MCU side of the board (+5V0_MCU). Bridges the power and ground isolations between the two board sides.
JP1, GND	Connects the board Ground on the isolated USB-C connector side of the board (USB_GND) to the rest of the board ground (GND). Bridges the power and ground isolations between the two board sides.
J16	Enables the on-board MCU-side 5-V to 3.3-V LDO regulator to convert the +5-V power rail to a +3.3-V power rail.
J17	Enables the on-board 3.3-V to 5-V BOOST regulator to convert the +3.3-V power rail to a +5-V power rail.

The F28P65x LaunchPad features a flexible power domain scheme that allows users to supply power to the board in a variety of different configurations. Table 3-2 shows the different power configurations and the required shunts that need to be populated to supply power throughout the board.

Table 3-2. Power Configurations

Power Source	Connected Shunts	Description of Power Sources
USB-C Connector	JP1, J16	**+5V0_USB:** supplied from the USB-C connector **+5V0_MCU:** +5V0_USB passes through JP1 and is the same supply as +5V0_MCU **+3V3_MCU:** generated by the MCU-side 5-V to 3.3-V LDO regulator
External +3.3-V (connected to BoosterPack header)	J17	**+5V0_USB:** If debugging the device, +5V0_USB is supplied through the USB-C connector and is isolated from the MCU side +5V0 rail. Else if not debugging, +5V0_USB is not required. **+5V0_MCU:** generated by the 3.3-V to 5-V BOOST regulator **+3V3_MCU:** supplied by external +3.3V source
External +5.0-V (connected to BoosterPack header)	J16	**+5V0_USB:** If debugging the device, +5V0_USB is supplied through the USB-C connector and is isolated from the MCU side +5V0 rail. Else if not debugging, +5V0_USB is not required. **+5V0_MCU:** supplied by external +5.0V source **+3V3_MCU:** generated by the MCU-side 5-V to 3.3-V LDO regulator

3.1.3 LEDs

Power indicator LEDs (red) are included on the F28P65x LaunchPad board. Table 3-3 shows descriptions of each LED.

Table 3-3. Power LED Indication Descriptions

LED Number	Indication Description
LED1	+5-V power from the USB Type-C™ connector
LED7	+3.3-V power on the XDS110 side of the PCB
LED3	+5-V power on the F28P65x side of the PCB
LED6	+3.3-V power on the F28P65x side of the PCB

Two user LEDs are provided on the board: LED4 (red) and LED5 (green), see Table 3-4. These user LEDs are connected to GPIO12 and GPIO13 of the F28P650DK9, respectively. The signals are connected to the SN74LVC2G07DBVR LED driver IC and are connected in an active-low configuration; that is, drive the GPIO low to turn on the LED and high to turn off the LED. These LEDs are dedicated for use by the software application.

Table 3-4. User-Configurable LED Descriptions

LED Number	Description
LED4	Active-low user-configurable LED controlled by GPIO12
LED5	Active-low user-configurable LED controlled by GPIO13

Two blue LEDs, LED8 and LED9, are connected to the XDS110 debug probe, see Table 3-5. These indicate debugger activity and are not controllable by any application software.

Table 3-5. XDS110 LED Descriptions

LED Number	Indication Description
LED8	Indicates that the XDS110 device is actively connected to a debugger target session (for example, CCS IDE debug session)
LED9	Indicates that the XDS110 device is powered and functional

To properly conform with the EtherCAT protocol, the F28P65x LaunchPad comes equipped with a number of LEDs that indicate activity for EtherCAT communication. In addition to the PHY link status and link active LEDs, Table 3-6 lists the LEDs included on the board.

Table 3-6. EtherCAT Communication LED Descriptions

LED Number	Indication Description
D11	Controlled by GPIO33, EtherCAT run LED (green)
D12	Controlled by GPIO61, EtherCAT error LED (red)

3.1.4 Encoder Connectors

The F28P65x LaunchPad includes two headers, J12 and J13, which are used for connecting linear or rotary incremental encoders. These headers take 5 V input signals that are stepped down to 3.3 V and wired to the F28P650DK9 MCU. These signals are connected to the eQEP modules on the device when switch S5 is set appropriately, see Table 3-9. Each header has the EQEPA, EQEPB, and EQEPI signals available for each eQEP module (1 and 2) as well as pins for GND and 5 V.

3.1.5 FSI

The F28P65x MCU features the Fast Serial Interface (FSI) communications peripheral. The FSI enables robust high-speed communications and is intended to increase the amount of information transmitted while reducing the cost to communicate over an isolation barrier. The FSI signals TXCLK, TXD0, TXD1, RXCLK, RXD0, and RXD1 are available on J11. This header is set up in such a way that adding jumpers on the pins connects the TX to RX channels for external loopback and evaluation. Additionally, there are two GND signals on the connector that can be used for a wrapped-pair connection to an external board with FSI. The GPIOs connected to this header are only routed to the J11 FSI connector on this board, the GPIOs are not routed to the boosterpack headers.

The LAUNCHXL-F28P65X does not include any on-board isolation devices for the FSI signals. If interested in evaluating the FSI peripheral with isolation devices, or differential drivers/receivers, see the TMDSFSIADAPEVM plug on board.

3.1.6 CAN

The F28P65x LaunchPad includes a connector (J14) for a CAN network. GPIO4 and GPIO5 are routed from the F28P650DK9 to J14 through the on-board CAN Transceiver. Both standard CAN and CAN-FD Mux options exist on these F28P65x device pins. Switch S4 is used to route GPIO4 and GPIO5 to either the CAN transceiver and connector or the boosterpack headers. For more details, see Section 3.3.4.

3.1.7 EtherCAT

The F28P65x LaunchPad features two Ethernet PHY and two RJ45 connectors to enable EtherCAT communication capabilities. The DP83826 10/100-Mbps single-port physical layer transceiver used on the LaunchPad offers low and deterministic latency. In additional, the PHY also offers fixed phase between XI and TX_CLK and is low-power. These features, along with robust EMI/EMC performance, make DP83826E/I an excellent choice for real-time applications. For more details, see the *DP83826 Deterministic, Low-Latency, Low-Power, 10/100 Mbps, Industrial Ethernet PHY*.

3.1.8 CLB

The configurable logic block (CLB) is a collection of blocks that can be interconnected using software to implement custom digital logic functions or enhance existing on-chip peripherals. The CLB is able to enhance existing peripherals through a set of interconnections, which provide a high level of connectivity to existing control peripherals such as enhanced pulse width modulators (ePWM), enhanced capture modules (eCAP), and enhanced quadrature encoder pulse modules (eQEP). The crossbars also allow the CLB to be connected to other internal peripheral signals of the device or external GPIO pins. In this way, the CLB can be configured to perform small logical functions to augment device peripheral inputs and outputs. Through the CLB, functions that would otherwise be accomplished using external logic devices, such as FPGAs or CPLDs, can now be implemented inside the C2000 MCU.

For more information on the CLB, see the C2000™ Configurable Logic Block (CLB) training series video.

3.1.9 Boot Modes

The F28P650DK9 boot ROM contains bootloading software that executes every time the device is powered on or reset. Two pins, GPIO72 and GPIO84, are wired to the Boot Select switch (S3). By default, both pins are set HIGH (1) so the device boots from Flash. For more information on the F28P65x boot modes, see the *TMS320F28P65x Real-Time Microcontrollers*.

Table 3-7. Boot Select Switch Table - S3

Boot Mode	GPIO72 (LEFT)	GPIO84 (RIGHT)
Boot from Parallel GPIO	0	0
Boot from SCI / Wait boot	0	1
Boot from CAN	1	0
Boot from Flash (default)	1	1

3.1.10 BoosterPack Sites

The F28P65x LaunchPad features two fully independent BoosterPack XL connectors. Both BoosterPack sites 1 and 2 are compliant with the BoosterPack standard. To expand the functions available to the user on this LaunchPad, some signals are also routed to alternate locations on the board. These alternate routes can be selected by manipulating the on-board switches or by adding / removing 0 Ω resistors. This is described in Section 3.3.

The GPIO pin numbers as well as the BoosterPack compliant features can be viewed in the LAUNCHXL-F28P65X Pinout Map. Each GPIO has multiple functions available through the F28P65x device's GPIO mux. Some specific functions have been listed in the Pinout Map; the full GPIO mux table can be found in *TMS320F28P65x Real-Time Microcontrollers*.

All of the analog signals (denoted ADCIN) of the F28P65x MCU are routed to the J1/J3 and J5/J7 BoosterPack headers on the left side of the board. Close to the respective BoosterPack header each ADC input signal has component pads for a series resistor and parallel capacitor to create an RC filter. By default a 0-ohm resistor is populated and the capacitor is left unpopulated. Users can populate these components with specific values to filter out noise arriving at the device's ADC input.

3.1.11 Analog Voltage Reference

The analog subsystem of the F28P65x allows for flexible voltage reference sources. The ADC modules are referenced to the VREFHIx and VREFLOx pin voltages. VREFHIx can either be driven externally or can be generated by an internal bandgap voltage reference. The on-board REF6230 device provides a high-precision 3.0 V reference with integrated buffer and is actively connected to the C2000 device when J15 is populated with a shunt. Otherwise, an external voltage can be supplied to the right-side pin of header J15 as an external voltage source for VREFHIx. Note that there is no signal conditioning circuitry in place for an external voltage reference. For best performance, some additional circuitry may be required.

Note
The on-board REF6230 supports all 12-bit ADC modes and does not provide data sheet-specified performance in 16-bit mode. This REF6230 is not a recommended reference for designs requiring 16-bit ADC operation. Instead, refer to TMDSCNCD28P65X for recommended ADC reference circuit.

3.1.12 Differential ADC Header

J10 on the LaunchPad features two pairs of differentially-routed ADC signals to allow for evaluation of the F28P65x's 12-bit differential and 16-bit differential ADC sampling modes. ADCINB8 and ADCINB9 form one pair of differential ADC signals, and ADCINC8 and ADCINC9 form the second pair. Like the single-ended ADC input signals on the board, the differential ADC signals have component pads to allow for the addition of series resistor and parallel capacitor to create an RC filter. In addition, these ADC signals also feature a pad to connect a capacitor across the differential signals. Note: The differentially-routed ADC signals on the F28P65x LaunchPad are not buffered.

3.1.13 Other Headers and Jumpers

The LaunchPad has multiple jumpers to select different power sources for the board. This LaunchPad also provides a way to isolate the connected USB from the device, allowing for safe operation and debugging in higher voltage applications.

3.1.13.1 XDS Isolation Block

JP1 is provided to enable isolation between the device and the connected XDS in higher-voltage applications. The area of isolation is defined by the white outline on the upper-side of the LaunchPad. JP1 has two removable shunts to separate the GND and 5 V power of the USB/XDS region and the F28P65x MCU region of the LaunchPad. By default, both shunts are populated and the power is supplied by the connected USB, meaning that the USB and XDS110 are NOT isolated from the F28P65x MCU region. If power isolation is desired, remove the supplied shunts from JP1. In this configuration, one of the two external power options below are required:

* An external 5-V supply to power the 3.3-V LDO (TPS7A7401), which provides 3.3 V to the F28P65x MCU region of the board.
* An external 3.3-V supply to power the F28P65x MCU region of the board.

  5 V is generated using the on-board 5 V BOOST (TPS61241).

In an isolated power application with JP1 shunts removed, make sure the proper shunts on the F28P65x MCU region of the board are populated. Refer to Section 3.1.2 for greater detail.

3.1.13.2 BoosterPack Site 2 Power Isolation

JP8 is included to isolate 3.3 V and 5 V from the BoosterPack site 2 headers. This might be required if two BoosterPacks are simultaneously connected to the LaunchPad and both provide power to the LaunchPad. If this is the case, power can be isolated by removing the shunts on JP8 and there will be no contention between the two BoosterPacks.

3.1.13.3 Alternate Power

Additional jumpers are provided outside of the BoosterPack connector for additional external power connections for 3.3 V or 5 V. These can be used to supply an external board or for powering the LaunchPad with an external supply. When using these connection points, make sure that no other power supplies are connected.

* **JP4 and JP6** are provided as extra connection points for a 3.3 V supply to be connected to the LaunchPad.
* **JP5 and JP7** are provided as extra connection points for a 5 V supply to be connected to the LaunchPad.

CAUTION
The F28P65x LaunchPad features a VDD pin located on header JP4 that can only be used to monitor the voltage of the 1.2-V VDD rail of the TMS320F28P650DK9NMR device. This pin can not be used to supply power to an external device nor connected to an external supply.

3.2 Debug Interface

3.2.1 XDS110 Debug Probe

The F28P65x LaunchPad includes an on-board XDS110 Debug Probe. The XDS110 allows for the programming and debugging of the F28P650DK9 device using Code Composer Studio (CCS) IDE or any other supported tool chains. In the default configuration, the XDS110 is wired to support 4-pin JTAG mode. Due to the isolation scheme used on the F28P65x LaunchPad, 2-pin cJTAG mode is not supported.

3.2.2 XDS110 Output

The connector J101 is provided to debug an external target with the on-board XDS110 debug probe. This connector allows the LaunchPad to be used as a stand-alone XDS110 debug probe. For mating connector and cable, see Samtec FFSD or equivalent. UART TX and RX signals from the XDS110 device are also included on this connector.

If the LaunchPad is being used in this manner, the following 0 ohm resistors located on the bottom of the board must be desoldered. This isolates the JTAG signals from going to the F28P650DK9 MCU.

Component	Corresponding Signal
R74	3V3
R76	3V3
R97	TMS
R98	TCK
R99	TDI
R100	TDO
R165	RXD
R171	TXD

3.2.3 Virtual COM Port

When plugged into a USB host, the XDS110 enumerates as both a debugger and a virtual COM port. U26 and U27 are reinforced digital isolators which isolate the SCI signals between the F28P650DK9 and the debug probe. The SCI UART signals are then passed from the debug probe on to the USB host. By default the F28P65x SCIA maps to the virtual COM port of the XDS110 using GPIO42 and GPIO43. Alternately, GPIO38 and GPIO55 can be used for SCIB. This is accomplished by manipulating the on-board switch S2. For the appropriate switch settings, see Section 3.3.2.

3.3 Alternate Routing

3.3.1 Overview

The F28P650DK9 MCU is a very versatile device in a mid-size package. To balance compatibility with BoosterPack standards as well as showcasing the versatility of the F28P650DK9, some complexity was added to the design. Most features aligning with the BoosterPack standard are available by default. The additional functions are configured using switches or static resistors which can be added or removed. This section covers the alternate functions and how to enable them. Note that by enabling certain alternate features, standard BoosterPack functionality may be lost. The switches and resistors are configured such that it is not possible to connect multiple functions to the same header.

3.3.2 UART Routing

This LaunchPad allows for one of two sets of pins to be used for the SCI UART routed to the virtual COM port of the XDS110. By default, GPIO43 (SCIA_RX) and GPIO42 (SCIA_TX) are routed to the virtual COM port and not available on the BoosterPack connector. Alternately, GPIO55 (SCIB_RX) and GPIO38 (SCIB_TX) can be routed to the virtual COM port. When UART functionality is not needed at the virtual COM port, the GPIOs can be routed to the BoosterPack connectors for BoosterPack standard functions.

The routing destination of these signal pairs are selected using the on-board switch S2, as described in Table 3-8.

Table 3-8. SCI UART Select Table - S2

SEL1 (Left)	SEL2 (Right)	GPIO42/43	GPIO38/55
0	0	XDS110 COM Port	BP Headers
0	1	XDS110 COM Port	No Connect
1	0	BP Headers	BP Headers
1	1	BP Headers	XDS110 COM Port

Note that signals GPIO42/43 are compatible with both the SCIA and UARTA peripherals, allowing for greater flexibility. Signals GPIO38/55 are only compatible with the SCIB peripheral.

3.3.3 EQEP Routing

The LaunchPad has the ability to connect to two independent linear or rotary encoders through the F28P65x on-chip eQEP interfaces: Header J12 is connected to eQEP1 and header J13 is connected to eQEP2. By default, this connection is not active and the GPIOs are routed to the BoosterPack connectors. The 5 V eQEP input signals from the J12 and J13 connectors are stepped down through a TI SN74LVC8T245 Level Translator (U13) to 3.3 V. The signals are then routed through TI SN74LV4053A Triple 2-Channel Analog Multiplexer/ Demultiplexer ICs (U11/U14). Switch S5 controls the select inputs of the ICs to configure the eQEP signal destinations to be either the J12/J13 connectors or BoosterPack headers, as described in Table 3-9.

Table 3-9. QEP Select Table - S5

QEP1 SEL (LEFT)	QEP2 SEL (RIGHT)	QEP1 Signals (GPIO20/21/23)	QEP2 Signals (GPIO24/79/103)
0 (down)	0 (down)	J12	J13
0 (down)	1 (up)	J12	BP Headers
1 (up)	0 (down)	BP Headers	J13
1 (up)	1 (up)	BP Headers	BP Headers

3.3.4 CAN Routing

The LaunchPad can be connected to a CAN bus through J14. GPIO4 and GPIO5 are routed to the on-board TI TCAN332DR 3.3V CAN Transceiver, U15. By setting S4 to DOWN (XCVR), GPIO4 and GPIO5 are routed to the transceiver. If S4 is set to UP (BP), the GPIOs are routed to the BoosterPack connectors (default case).

3.3.5 FSI Routing

One set of GPIOs with available FSI functionality are directly connected to the FSI header, J11. The traces from the device to the FSI header are made short to make sure of higher signal integrity, as FSI signals can switch at frequencies up to 200 MHz on F28P65x devices.

3.3.6 PWM DAC

In addition to the buffered DAC outputs available on BP pin 30 and BP pin 70, the F28P65x LaunchPad provides up to four PWM DAC signals at the BoosterPack headers using GPIO8 (BP pin 40) and GPIO9 (BP pin 39) on site 1 and GPIO2 (BP pin 80) and GPIO3 (BP pin 79) on site 2. The intended purpose of the PWM DAC signals are to utilize PWMs of the F28P65x device as digitial-to-analog converters (DAC). This method involves low-pass filtering the PWM signal to remove its high-frequency components and ideally leave only the DC component. For more information, see the *Using PWM Output as a Digital-to-Analog Converter on a TMS320F280x Digital Signal Control*.

By default the RC filter is not populated. Instead a 0 ohm resistor is populated and the capacitor is left un-populated.

4 Board Design

The entire LAUNCHXL-F28P65X design files are available for download at this link: LAUNCHXL-F28P65X design files.

4.1 Schematic

The LaunchPad's schematic can be found at this link: LAUNCHXL-F28P65X Schematic.

4.2 PCB Layout

The layout source files for the LAUNCHXL-F28P65X are included in the LAUNCHXL-F28P65X design files download.

4.3 BOM

The BOM for the LAUNCHXL-F28P65X is included in the LAUNCHXL-F28P65X design files download.

Figure 4-1. Top Signal - Layer 1
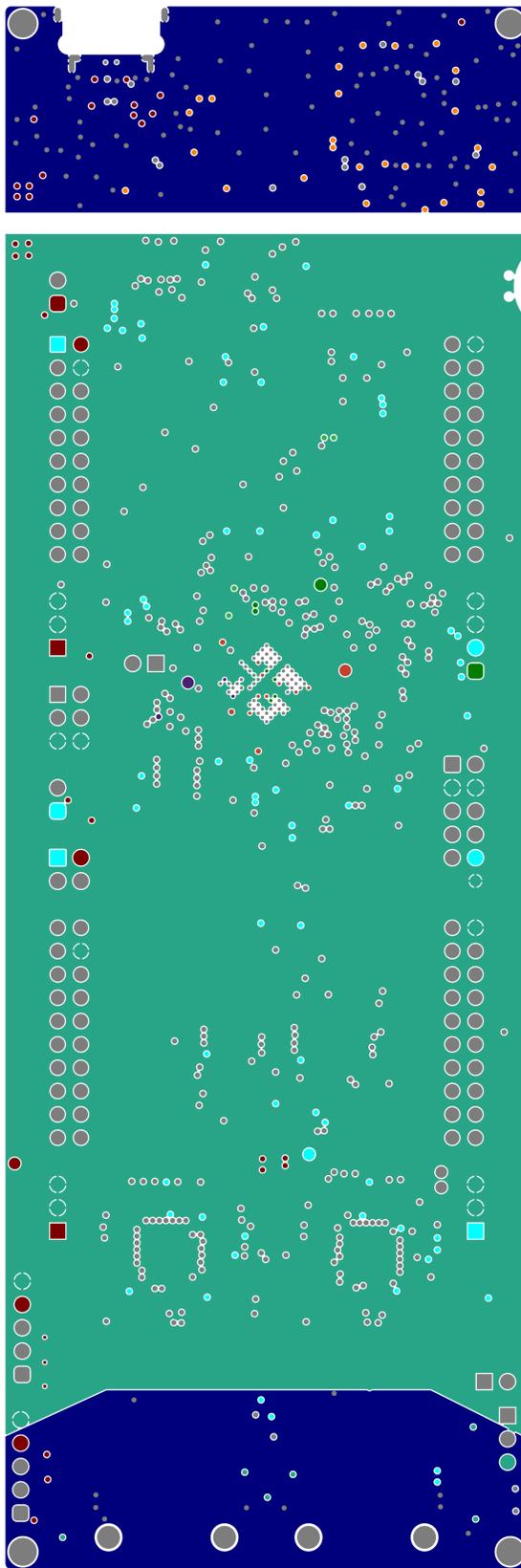
Figure 4-2. GND - Layer 2
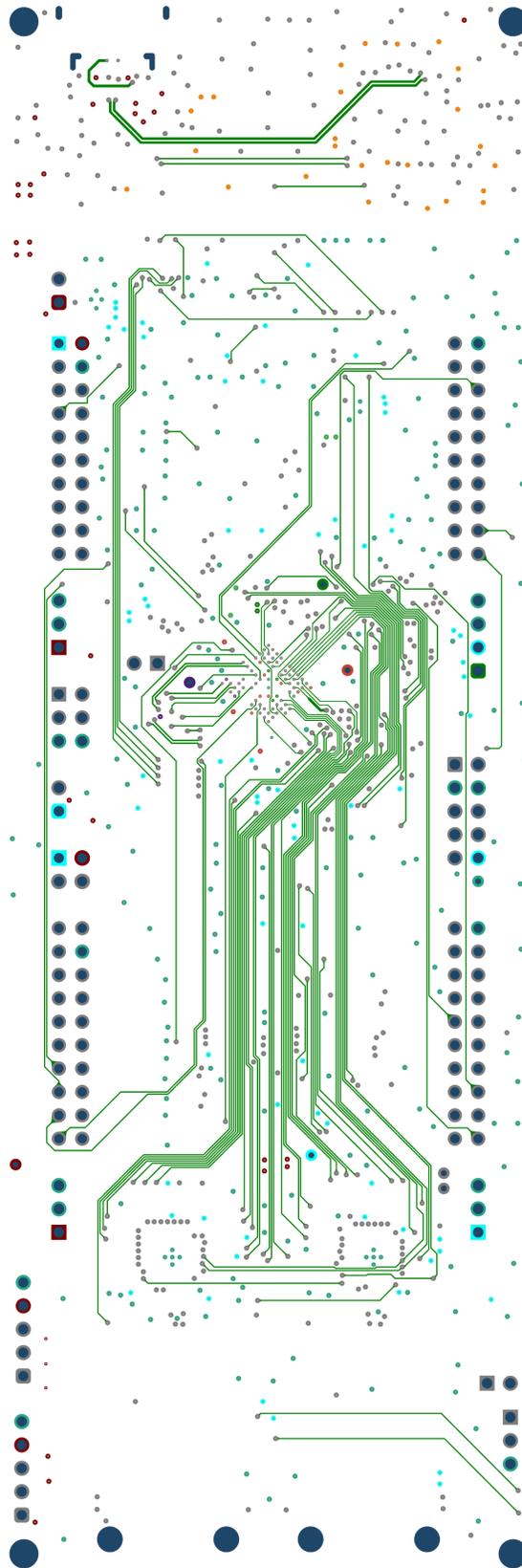
Figure 4-3. Middle Signal- Layer 3
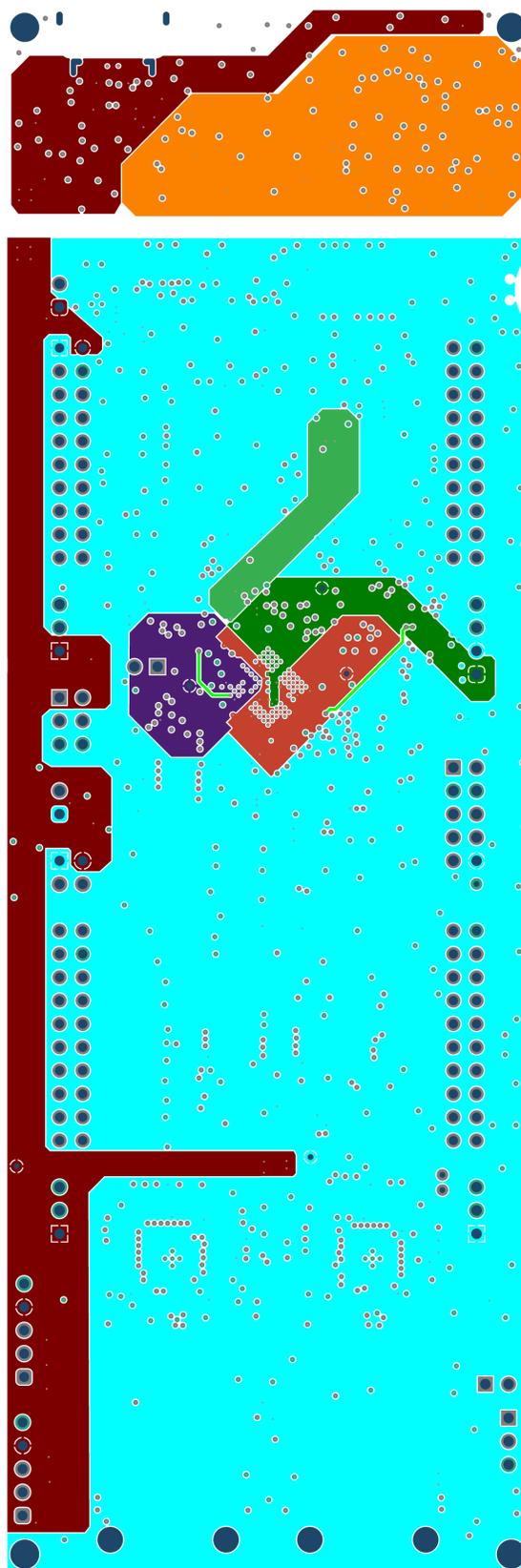
Figure 4-4. PWR - Layer 4

Figure 4-5. GND2- Layer 5

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Figure 4-6. Bottom Signal - Layer 6

4.4 LAUNCHXL-F28P65X Board Dimensions

Figure 4-7 is a dimensional drawing of the F28P65x LaunchPad that shows the location of selected features of the board as well as the component locations.

Figure 4-7. F28P65x LaunchPad Dimensions and Component Locations
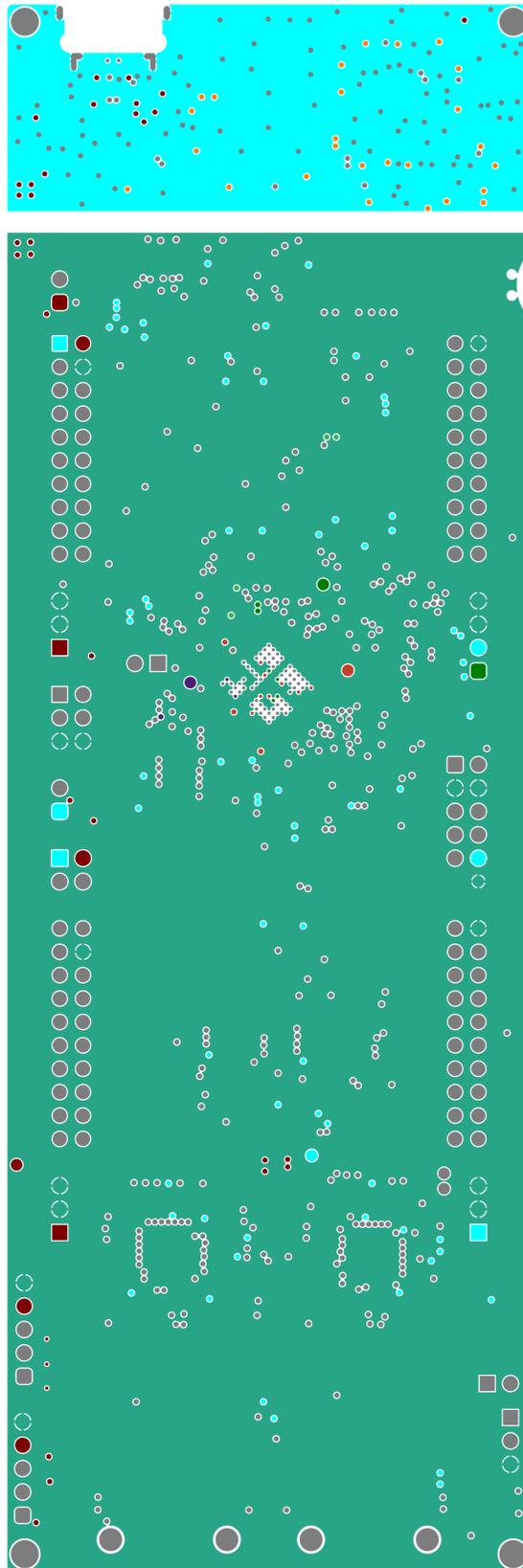
5 Frequently Asked Questions

1. Why isn't my C2000 device getting any power even though I have the USB-C cable connected to USB1?
    a. Make sure that the USB 5-V power and GND jumpers are connected (JP1).
    b. Make sure that "ENABLE +3V3 LDO" jumper header (J16) is populated with a jumper. This generates the 3.3-V rail for the board from the 5-V USB power.
        i. To avoid contention on the 5-V rail, make sure that the "ENABLE +5V0 BOOST" jumper (J17) is disconnected when supplying 5 V through the USB.
2. Can other programming and debug tools (such as an XDS200 debug probe) be used with the F28P65x LaunchPad?
    a. The F28P65x LaunchPad utilizes an on-board XDS110 debug probe in a 4-pin JTAG configuration.
3. What versions of Code Composer Studio IDE can be used to develop software for the F28P65x LaunchPad?
    a. The on-board XDS110 debug probe is compatible with Code Composer Studio development environment version 6.1.0 and later.
4. Why can't I connect to the LaunchPad in Code Composer Studio IDE?
    a. Are shunts present on J101 for TCK and TMS?
    b. Is the XDS110 and the F28P650DK9 MCU powered? Are LED1, LED7, LED3 and LED6 illuminated? For further details on powering the LaunchPad, see Section 3.1.2.
        i. If JP1 shunts are disconnected, the power provided through the USB is isolated from the rest of the board. Make sure that 3.3 V or 5 V is supplied to any of the available connectors on the target side of the isolation.
    c. Is the USB-C cable connected to the PCB and is the USB region receiving power? Is LED1 illuminated?
        i. The XDS region must be powered with the 5 V from the USB cable. LED1 illuminates when 5-V USB power is connected. The XDS-side 5-V to 3.3-V LDO regulator requires 5-V on the USB side to generate the +3V3 rail for the XDS110 device.
    d. Make sure that the target configuration is set up to use JTAG in 4-pin advanced mode. Open the Target Configuration file (.ccxml) in Code Composer Studio IDE. Click on the Advanced tab and select JTAG (1149.1) SWD and cJTAG are disabled. Alternately, a working Target configuration file is included in the launchxl_ex1_f28p65x_demo project "TMS320F28P650DK9.ccxml". You can use this without modifications.
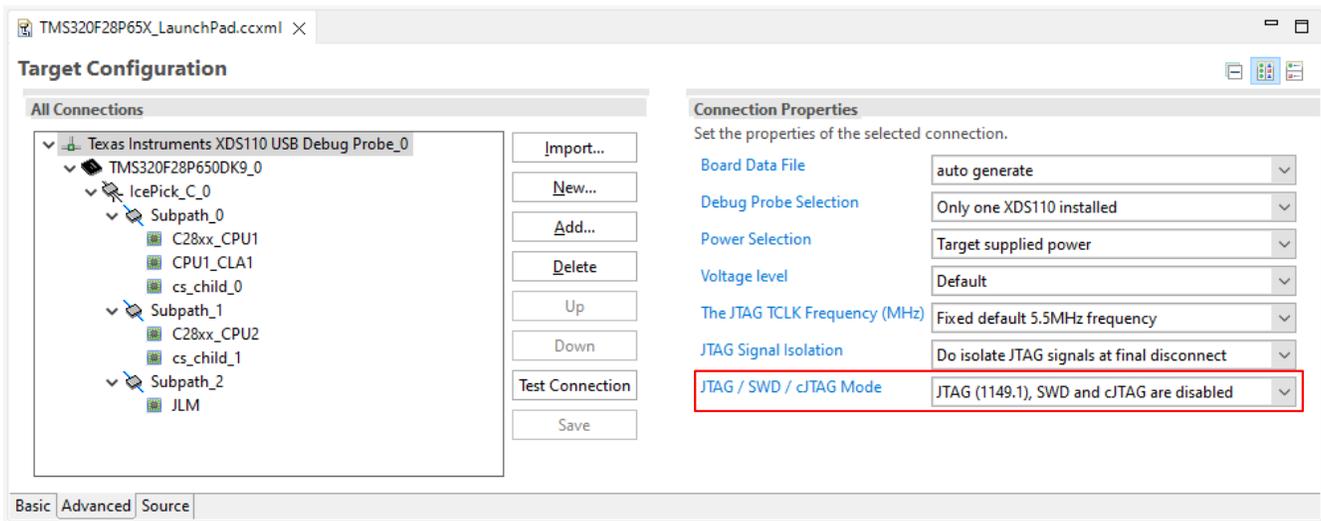
Figure 5-1. Target Configuration Advanced Options
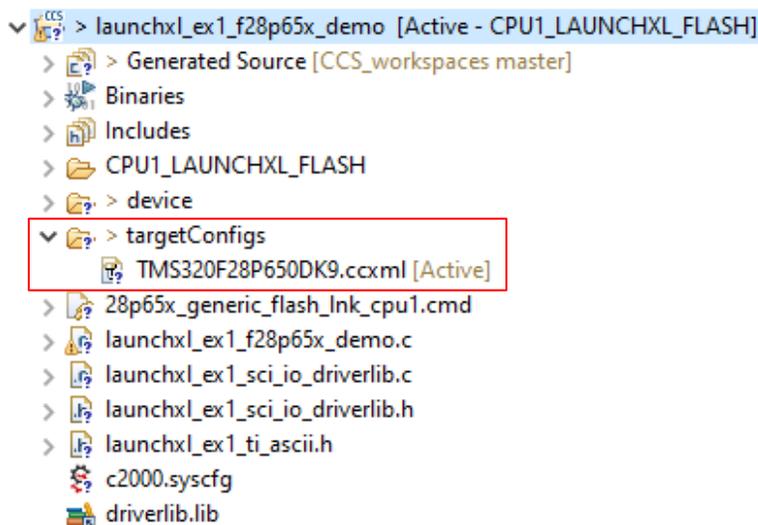
Figure 5-2. Target Configuration Included in the Demo Project

5. Why is the serial connection not working?
    a. Are you using the correct COM port?
        i. Right click on My Computer and select Properties. Navigate to the Hardware tab in the dialog box and open the device manager. Scroll to Ports (COM & LPT) and expand this entry. Is XDS110 Class Application/User UART listed? If so, read the COM number to the right of the entry; this is the COM number to use.
    b. Are you using the correct baud rate? Most, if not all, of the examples are configured for a baud rate of 115200 when the CPU is running at 200 MHz. If you have changed the PLL settings or developed your own code, you can recalculate the baud rate for your specific application. For information on how to do this, see the *TMS320F28P65x C2000 Real-Time Microcontrollers Technical Reference Manual.*
    c. Does the UART channel wired to the debug probe match the UART channel configured in software?
        i. The F28P65x LaunchPad provides an option for one of two possible UART channels to be routed to the debug probe. Make sure that S2 is configured to the appropriate UART channel for the application software. For details, see Section 3.3.2.

6 References

6.1 Reference Documents

In addition to this document, the following references are available for download at www.ti.com.

- *TMS320F28P650DK9 C2000 Real-Time Microcontrollers*
- Texas Instruments: *TMS320F28P65x C2000 Real-Time Microcontrollers Data Sheet*
- Texas Instruments: *TMS320F28P65x C2000 Real-Time Microcontrollers Technical Reference Manual*
- Texas Instruments: *Getting Started With C2000™ Real-Time Control Microcontrollers (MCUs)*
- Texas Instruments: *The Essential Guide for Developing with C2000™ Real-Time Microcontrollers*
- Texas Instruments: *TMS320F28P65x C2000 Real-Time Microcontrollers Silicon Errata*
- Texas Instruments: *LAUNCHXL-F28P65X LaunchPad Pinout Map*
- *C2000Ware for C2000 MCUs*
- *Application Specific Designs & Evaluation with C2000 Real-Time Microcontrollers*
- C2000WARE Quick Start Guide
- *Texas Instruments Code Composer Studio*
- *Texas Instruments LaunchPad Development Environment*

6.2 Other TI Components Used in This Design

This LaunchPad uses various other TI components for its functions. A consolidated list of these components with links to their TI product pages is shown below.

- *DP83826E Low latency 10/100-Mbps PHY with MII interface and enhanced mode*
- *ISO7731 Robust EMC, triple-channel, 2/1, reinforced digital isolator*
- *ISO7741 Robust EMC, quad-channel, 3/1, reinforced digital isolator*
- *LMK1C1104 4-channel output LVCMOS 1.8-V buffer*
- *LMK6C Low-jitter, high-performance, bulk-acoustic-wave (BAW) fixed-frequency LVCMOS oscillator*
- *MSP432E401Y SimpleLink™ 32-bit Arm Cortex-M4F MCU*
- *REF6230 3-V, 3-ppm/°C high-precision voltage reference with integrated buffer & enable pin*
- *SN74LV4053A Triple 2-Channel Analog Multiplexer/Demultiplexer IC*
- *SN74LVC2G06DBVR 2-ch, 1.65-V to 5.5-V inverters with open-drain outputs*
- *SN74LVC2G07 Dual Buffer/Driver With Open-Drain Output*
- *SN74LVC8T245 8-Bit Dual-Supply Bus Transceiver with Configurable Voltage-Level Shifting and Three-State Outputs*
- *TCAN332 3.3 V CAN Transceiver*
- *TLV703 300-mA, high-PSRR, low-IQ, low-dropout voltage regulator*
- *TLV759P 1-A, low-IQ, high-accuracy, adjustable ultra-low-dropout voltage regulator with enable*
- *TPD4E004 4-Channel ESD Protection Array for High-Speed Data Interfaces*
- *TPD4E05U06 4-Channel ESD Protection Array for for USB, HDMI & High Speed Interfaces*
- *TPS3703 High-accuracy window supervisor with reset time delay*
- *TPS61241 5V, 500mA, 4MHz Step-Up DC/DC Converter*
- *TPS7A74 1.5-A low-dropout (LDO) linear regulator with programmable soft start*
- *TS5A23157 5-V, 2:1 (SPDT), 2-channel analog switch*

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