TI Spins Motors

HVMTR Rev 1p1 Hardware Quick Start Guide

Version 1.0.3   *Motor Solutions*

Plastic enclosure

Motor Control Board

IPM Heatsink

DC Fan
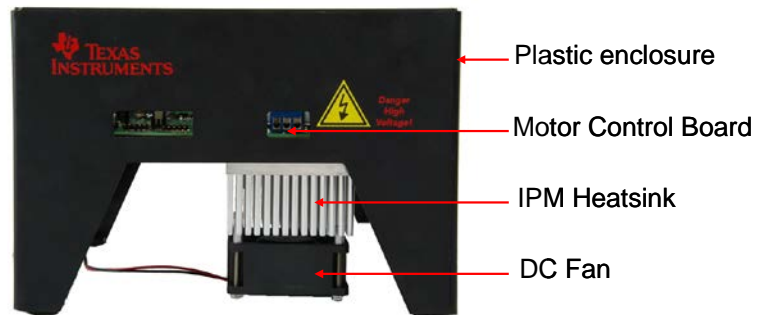
Fig 1: HVMTR EVM

Abstract

The High Voltage Digital Motor Control (DMC) and Power Factor Correction (PFC) kit (TMDSHVMTRPFCKIT; TMDSHVMTRINSPIN), provides a great way to learn and experiment with digital control of high voltage motors and to use PFC to increase efficiency of operation. This document goes over the kit contents and hardware details, and explains the functions and locations of jumpers and connectors present on the board. This document supersedes all the documents available for the kit.

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Version: 1.0.3

Revision History:

1.03	July 11, 2013	Updated with TMDSCNCD28027F support (key items on page 13)
1.0.2	March 21, 2013	Added Revision History
1.0.1	February 26, 2013	First release

TEXAS INSTRUMENTS

WARNING

This EVM is meant to be operated in a lab environment only and is not considered by TI to be a finished end-product fit for general consumer use

This EVM must be used only by qualified engineers and technicians familiar with risks associated with handling high voltage electrical and mechanical components, systems and subsystems.

This equipment operates at voltages and currents that can result in electrical shock, fire hazard and/or personal injury if not properly handled or applied. Equipment must be used with necessary caution and appropriate safeguards employed to avoid personal injury or property damage.

It is the user's responsibility to confirm that the voltages and isolation requirements are identified and understood, prior to energizing the board and or simulation. When energized, the EVM or components connected to the EVM should not be touched.

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# Getting Familiar with the Kit

Kit Contents

The kit consists of

- controlCARD(s)
- High Voltage three phase inverter board
- 15V Power Supply
- AC power Cords
- Banana Plug Cords
- USB Cables

The High Voltage DMC board is fitted inside a plastic enclosure (Fig 1). A heat sink is mounted underneath the board to the motor inverter and a DC Fan is attached to this heat sink to increase airflow. (Note: Although the heat sink is isolated induced voltages can exist on the heat sink. Do not touch the heat sink and or other parts of the kit while in operation).

The board can accept any of the C2000 series controlCARDs. Primary use is for TMDSCNCD28069MISO and TMDSCNCD28027F

　　　Note: the Piccolo 5x controlCARDs use a special version of this high voltage inverter TMDXHVMTRKIT5X or TMDSHVMTRKIT5X

Plastic enclosure

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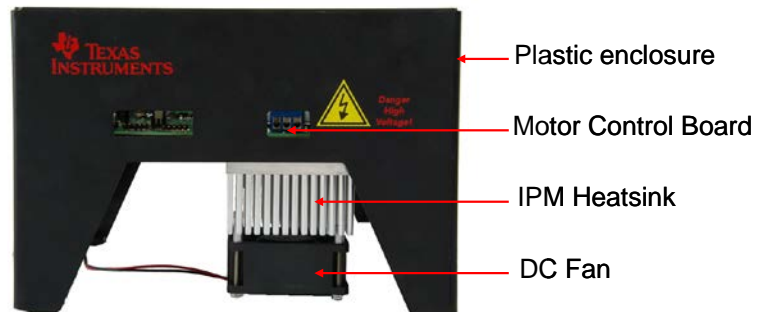
Board Features:

The board has the following features

- **3-Phase Inverter Stage** to control high voltage motors.
  - 350V DC max input voltage

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- 1KW*/1.5KW* maximum load (for loads > 150W, the fan** attached to the IPM heat sink must be used)
- Sensorless and Sensored Field Oriented Control of Synchronous and Asynchronous Motors
- QEP and CAP inputs available for optional rotor sensor interfaces
- High precision low-side current sensing using the C2000's high-performance ADC, Texas Instruments OPA2350 high speed op-amps and Texas Instruments REF5025 high precision voltage reference chip

- **Power Factor Correction** stage rated for 750W*, can be used to increase the efficiency by current shaping the input AC current and regulate the DC bus voltage for the inverter to the desired level.

  - Two phase interleaved topology, capable of phase shedding
  - 85-132VAC/ 170-250VAC rectified input
  - 400V DC Max output voltage
  - 750W* max power rating
  - Up to 96% efficiency
  - 200KHz switching frequency for the power stage
  - Upto100KHz PFC control loop frequency
  - Uses Texas Instruments UCC27524, high speed dual MOSFET drivers.
  - Software controlled by the microcontroller, look for example projects

- **AC Rectifier** stage rated for delivering up to 750W* power. This stage can be used to either generate the DC Bus voltage for the inverter directly or provide input for the Power Factor Correction stage present on the board.

  - 85-132VAC/ 170-250VAC input
  - 750W max power rating

- **Aux Power Supply Module** can generate 15V and 5V DC from rectified AC voltage or the PFC output (input Max voltage 400V).

- **Isolated CAN interface** for communication over CAN bus. The CAN interface is isolated from the high voltages on the board using Texas Instruments ISO1050 isolated CAN transceiver with 4000V-Vpeak Isolation and Texas Instruments DCH01Series miniature 1W, 3kV isolated DC/DC converter module.

- **Onboard Isolated serial connectivity through FTDI chip (XDS100v1 emulator)**
  - PC USB to MCU JTAG emulation
  - PC UART to MCU UART
  - If your controlCARD includes an on-card isolated USB-JTAG/UART connection use the controlCARD and not the high voltage board

- o **Do NOT use the onboard XDS100 emulator when using a controlCARD with its own onbard emulation (ex: TMDSCNCDF28069MISO)**
  - ▪ **populate jumper M3-J5 to disable emulator on HVKIT.**
- o **Do use onboard XDS100 emulator when using a standard controlCARD (ex: TMDSCNCD28027F)**
  - ▪ **no jumper on M3-J5 to enable the HVKIT emulator**

- **Four PWM DAC's** generated by low pass filtering the PWM signals to observe the system variables on an oscilloscope to enable easy debug of control algorithms.

- **Over-current protection** for PFC stage (both phases) and the inverter stage, PWM **trip zone** protection for IPM faults.

- Hardware Developer's Package that includes schematics and bill of materials is available through controlSUITE.

*All the power rating tests for the power stages have been performed at room temperature. The motor stage is rated for 1KW with the usage of DC Fan and heat sink shipped with the board. Operation up till 1.5KW is possible with a combination of more airflow and a different heat sink. For high power tests a high voltage external power supply was used (PFC and AC power stage was not used as these stages are rated for 750W).

** Make sure that the DC Fan shipped with the kit is connected to the DC Fan Jumper [Main]-J17 when operating the motor under load > 150W.

Note that the board is shipped with a 10 Amp fuse in the AC power entry fuse holder.

Hardware Overview

Fig 2, illustrates a typical motor drive system running from AC power. The power factor correction stage enables wave shaping of the input AC current enabling efficient operation. The TMDSHVMTRPFCKIT's motor control board has all the power and control blocks that constitute a typical motor drive system (Fig 4).
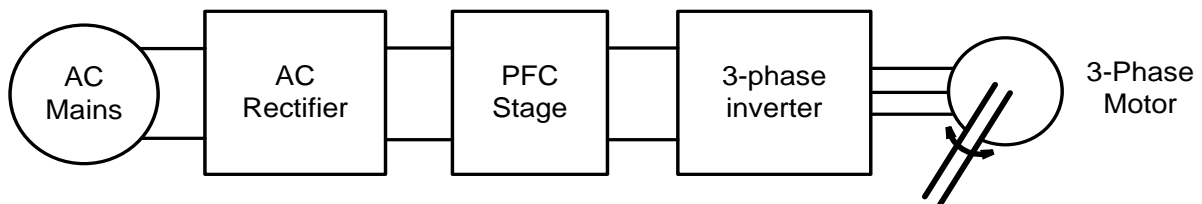
Fig3 Block Diagram for a typical motor drive system using power factor correction

Macro Blocks

The motor control board is separated into functional groups that enable a complete motor drive system; these are referred to as macro blocks. Following is a list of the macro blocks present on the board and their functions:

- [Main] - controlCARD connection, jumpers, communications (isoCAN), Instrumentation (DAC's), QEP and CAP connection and voltage translation.
- [M1] AC power entry - takes AC power from the wall/mains power supply and rectifies it. This can then be used for input of the PFC stage or used to generate the DC bus for the inverter directly.
- [M2] Auxiliary power supply - can generate 15V, 5V power for the board from rectified AC power (400V max input).
- [M3] Isolated USB Emulation - provides isolated JTAG connection to the controller and can be used as isolated SCI when JTAG is not required.
- [M4] Two-phase interleaved PFC stage - can be used to increase efficiency of operation.
- [M5] Three-phase inverter - enables control of high voltage 3-phase motors.
- [M6] DC power entry - generates 15V, 5V and 3.3V for the board from DC power fed through the DC-jack using the power supply shipped with the board.

Fig 3, illustrates the position of these macro blocks on the board. The use of a macro block approach, for different power stages enables easy debug and testing of one stage at a time. Banana jack connectors can be used to interconnect the power line of these power stages / blocks to construct a complete system. All the PWM's and ADC signals which are the actuation and sense signals have designated test points on the board, which makes it easy for an application developer to try out new algorithms and strategies.

Nomenclature: A component on the board is referred to with a macro number in the brackets followed by a dash and the reference number. For example, [M3]-J1 refers to the jumper J1 located in the macro M3 and [Main]-J1 refers to the J1 located on the board outside of the defined macro blocks.
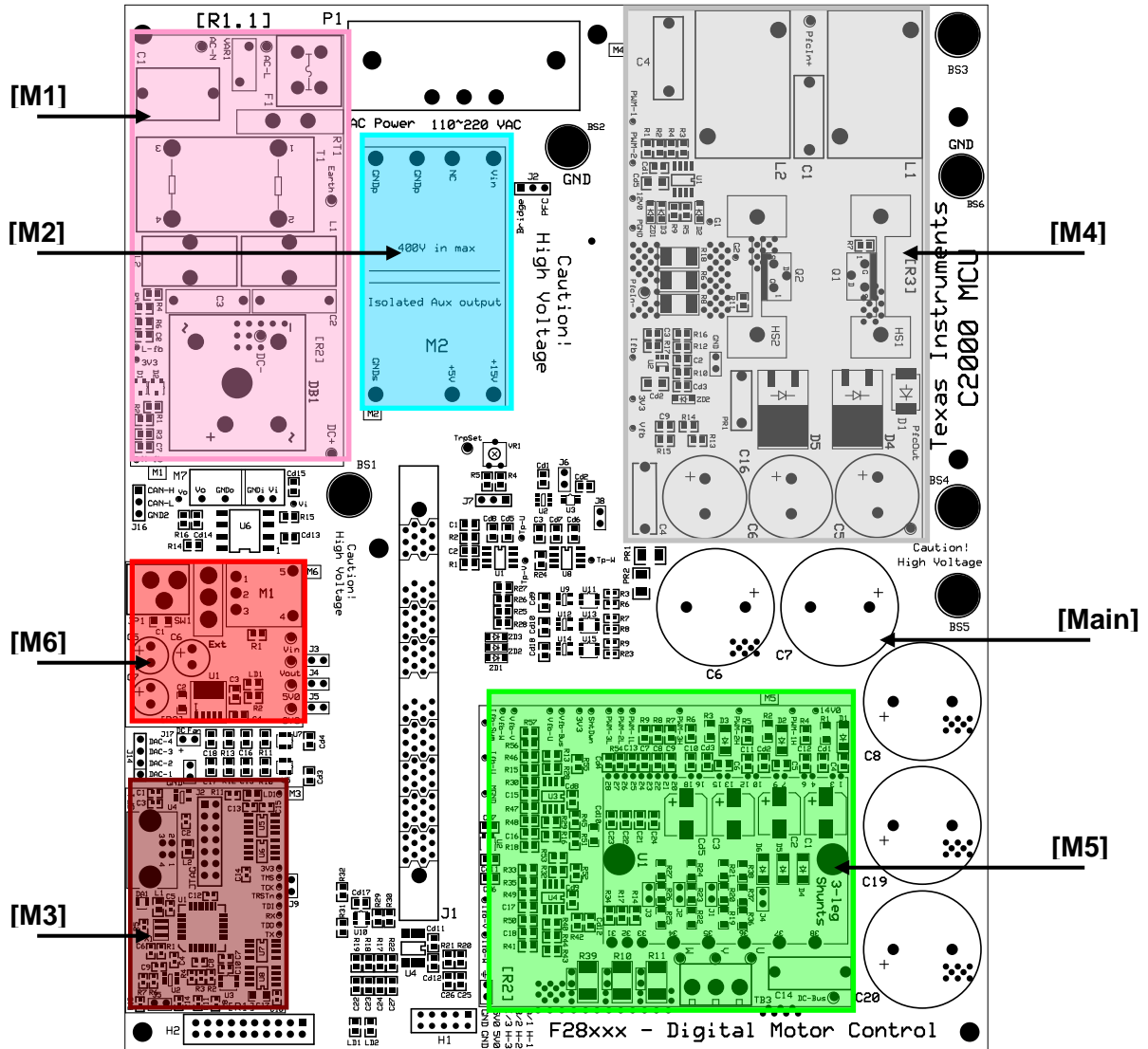
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Fig 3 The Layout of HVDMC Board

▪ [Main] - controlCARD connection, jumper configurations, trip zones
▪ [M1] - AC power entry
▪ [M2] - Auxiliary power supply, 400V to 5V and 15V
▪ [M3] - Isolated USB Emulation
▪ [M4] - Two-phase interleaved PFC stage
▪ [M5] - Three-phase inverter
▪ [M6] - DC Power entry

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Powering the Board

The board is separated into two power domains*, the low voltage Controller Power domain that powers the microcontroller and the logic circuit present on the board, and the high voltage power delivery line that is used to carry the high voltage and current like the DC power for the Inverter also referred to as DC Bus.

⚠️ **WARNING: Always use caution when using the EVM electronics due to presence of high voltages.**

1) **Controller Power** comprises of the 15V, 5V and 3.3V that the board uses to power the microcontroller and the logic and sensing circuit present on the board. This power can be sourced from two places:

   (i) **DC power Entry Macro [M6]:** Using the **TI supplied CE Mark, TUV certified 15VDC, 1Amp ITE power supply**, connecting to the DC Jack ([M6]-JP1) present on the DC Power entry Macro.

   (ii) **Aux Power supply module [M2]:** Can generate 15V and 5V DC from rectified AC.

2) **DC Bus Power** is the high voltage line that provides the voltage to the inverter stage to generate 3 phase AC to control the motor. [Main]-BS5 and [Main]-BS6 are the power and ground connector for this inverter bus. There are three options to source this power

   (i) **External isolating DC power supply:** An external isolating DC power source can be used by connecting to Banana Jacks [Main]-BS5 and [Main]-BS6 the power and ground of the supply respectively (Max 350V). **Recommended for control evaluation.**

   (ii) **AC Power Entry [M1]:** The [M1] macro can rectify AC input (85-132VAC/ 170-250VAC) fed to the board through [Main]-P1. This rectified AC can then generate DC voltage with help of capacitor bank present at input of the inverter stage. For this a cable needs to be connected between [Main]-BS1 and [Main]-BS5. Note that no connection to the ground i.e. [Main]-BS6 is necessary as the GND after rectification is the same as the board ground. See section 3.5.

   (iii) **AC Power Entry [M1] & PFC Stage [M4]:** The [M1] macro can rectify AC input (85-132VAC/ 170-250VAC**) fed to the board through [Main]-P1. This rectified AC can then feed the PFC stage present on the board to shape the input AC current. This would increase efficiency of operation for the board. Connect banana cable between [Main]-BS1 to [Main]-BS3 to connect the rectified AC output to the PFC input and another banana

cable between [Main]-BS4 to [Main]-BS5 to connect the PFC output voltage to the inverter DC bus input. Note that no connection to the ground i.e. [Main]-BS6 is necessary as the GND after rectification is the same as the board ground.

* Note that the ground planes of both the power domains are the same

** Note that the 3-ph Induction motors are typically rated at 220V AC, so the 320 V DC-bus voltage is needed. Thus when using 110V AC power source to generate the DC Bus for the inverter the motor can run properly only at a certain speed and torque range without saturating the PI regulators in the control loop. As an option, the user can run the PFC on HV DMC drive platform as boost converter to increase the DC bus voltage level or directly connect a DC power supply

Boot Modes

Device	Boot from FLASH	Use of UART via [M3] on the HVMTRKIT baseboard	JTAG Debug access via CCS
F2802x	SW1 on controlCARD - Position 1 = 1 Position 2 = 1 **Remove jumper [Main]-J9**	Depopulate R10 on the controlCARD	Insert jumper [Main]-J9 Remove jumper [M3]-J5
F2803x	SW2 on controlCARD- Position 1 = 1 Position 2 = 1 Remove jumper [Main]-J9	SW3 on controlCARD should be OFF	Insert jumper [Main]-J9 Remove jumper [M3]-J5
F2806xISO	SW1 on controlCARD- Position 1 = 1 Position 2 = 1 SW3's Position 1 on the controlCARD should be OFF	SW3's Position 2 on the controlCARD should be OFF **See the subsection IMPORTANT below**	SW3's Position 1 on controlCARD should be ON Insert jumper [M3]-J5 Remove jumper [Main]-J9 (JTAG connection will occur via USB connector on controlCARD)
F2833x	Note the settings below are	Note the settings below	Insert jumper [Main]-J9

	valid for TMDSCNCD28335ZJZ R2.2 control card.	are valid for TMDSCNCD28335ZJZ R2.2 control card.	Remove jumper [M3]-J5
	SW2 on controlCARD		
	Position 1 =1 (ON)	SW1 on controlCARD should be OFF	
	Position 2 =1		
	Position 3 =1		
	Position 4 =1		
	Remove the jumper [Main]-J9		

Table 1, describes the jumper and switch settings that are needed for booting from FLASH and SCI for the board. Be sure to verify settings before attempting to use the supplied GUI.

IMPORTANT: The kit may also be used with isolated versions of these controlCARDs. The "-*ISO*" suffix on the controlCARD model i.e. *TMDSCNCD28069MISO*, indicates the card provides emulation and USB-to-UART functionality. There are additional switches present on the card one of which can disconnect the UART-to-Serial adapter on the card from the C2000 device. **Due to a contention problem with the UART connection on the board, the UART-to-Serial adapter on "–*ISO*" controlCARDs MUST ALWAYS be disconnected.** Refer to the controlCARD documentation found in controlSUITE for switch settings. If not disabled, the UART-to-Serial adapters on the controlCARD and board may be damaged. Currently, there is no means to disconnect the UART interface on the HVDMC board. Future revisions of the kit will correct this issue.   Meanwhile, if UART is to be used, use the connection provided on the *TMDSHVMTRPFCKIT* board. Fig 4 provides a graphical representation of the issue.
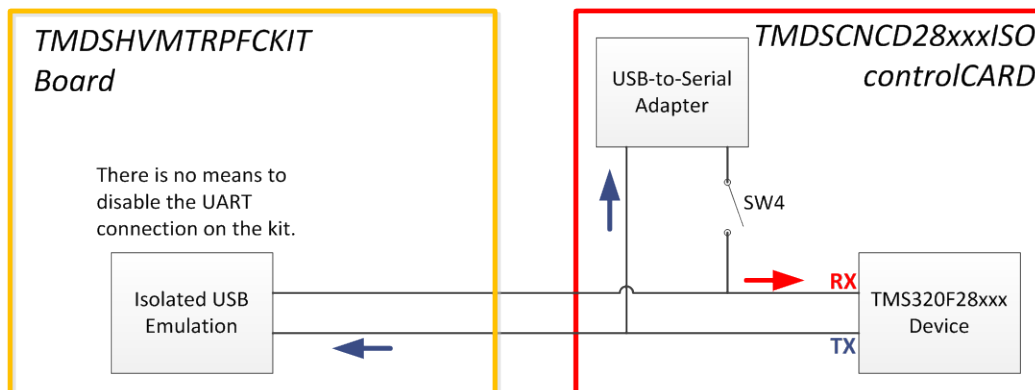
*To prevent problems, the USB-to-Serial Adapter on the controlCARD **must** be disabled. Use the UART connection on the TMDSHVMTRPFCKIT if necessary.

Fig 4: UART contention block representation

Jumper Settings for standard evaluation and development

    i.   Populate: J3, J4, J5, J8,

    ii.   Emulation: Power M3-J5 and TRST J9

        1. For controlCARDs with on-card isolated emulation, ex: TMDSCNCD28069MISO:

            a. Populate M3-J5 (disables power to HVKIT emulator)

            b. Do NOT populate J9 (disables JTAG connection)

        2. For controlCARDs without on-card isolated emulation, ex: TMDSCNCD28027F:

            a. Do NOT Populate M3-J5 (enables power to HVKIT emulator)

            b. Populate J9 (enables JTAG connection) when running projects from MCU RAM

               1. If you run a project from the MCU Flash you will need to remove this jumper to sever the JTAG connection and boot to flash properly

        3. Make sure switches are set properly on the controlCARD according to the appropriate qsg_hw_cncd280xxx.pdf

    iii.   J7: Right-Middle (towards capacitors)

    iv.   Motor Phase Wires to U, V, W

        1. Order does not matter for sensorless solutions

    v.   J2

        1. For DC bus input (recommended): Do NOT Populate J2 and

            a. connect 50-350V DC supply from BS6 to BS5

        2. For AC input: Populate J2 Bridge-Middle

            a. connect banana cable from BS5 to BS1

            b. connect AC power cord to P1

        3. DO NOT APPLY HIGH VOLTAGE AC OR DC UNTIL ALL CONNECTIONS ARE CHECKED AND VERIFIED

    vi.   15V DC power supply to JP1 and SW1 ON

Ground Levels and Safety

- The user must not touch any part of the board or components connected to the board while energized.

- The kit can accept power from the AC Mains/wall power supply, the board only uses the live and the neutral line from the wall supply, the protective earth is unconnected (floating).

- The AC rectifier generates the DC voltage the ground of which is floating from the protective earth ground. Hence appropriate caution must be taken while connecting scopes and other test equipment to the board.

- The IPM Heat sink is isolated from the board. However high voltage switching generates some capacitively coupled voltages over the heat sink body. Hence the user must not touch any part of the board, the kit or its assembly while energized.

- The power stages on the board are individually rated. It is the user's responsibility to make sure that these ratings (i.e. the voltage, current and power levels) are well understood and complied with, prior to connecting these power blocks together and energizing the board and / or simulation.

Hardware Resource Mapping

The Fig 5 shows the various stages of the board in a block diagram format and illustrates the major connections and feedback values that are being mapped to the C2000 MCU. Table 2, below lists these resources.

Macro Name	Signal Name	PWM Channel/ ADC Channel No Mapping	Function
3-Phase Inverter	PWM-1L	PWM-1A	Inverter drive PWM
	PWM1-H	PWM-1B	Inverter drive PWM
	PWM2-L	PWM-2A	Inverter drive PWM
	PWM2-H	PWM-2B	Inverter drive PWM
	PWM3-L	PWM-3A	Inverter drive PWM
	PWM3-H	PWM-3B	Inverter drive PWM
	Ifb-U	ADC-B3, A1	Low side U-phase current sense
	Ifb-V	ADC-B5, B1	Low side V-phase current sense
	Ifb-W	ADC-A3, A5	Low side W-phase current sense
	Ifb-Sum	ADC-A2	DC Bus Return current sense
	Vfb-Bus	ADC-A7	DC Bus Voltage sense
	Vfb-U	ADC-B7	U-phase voltage sense
	Vfb-V	ADC-B6	V-phase voltage sense
	Vfb-W	ADC-B4	W-phase voltage sense
2-Phase PFC	PWM-1	PWM-4A	PFC phase 1 drive PWM
	PWM-2	PWM-4B	PFC phase 2 drive PWM
	Ipfc	ADC-A6	Return current sense
	Vpfc	ADC-A4	PFC Output voltage sense
	L-fb	ADC-B2	Line voltage sense
	N-fb	ADC-B0	Neutral voltage sense
Main –Board	DAC-1	PWM-6A	Driving DAC signal
	DAC-2	PWM-6B	Driving DAC signal
	DAC-3	PWM-7A*	Driving DAC Signal
	DAC-4	PWM-7B*	Driving DAC Signal

PWM7A and B are not available using this board when using F28335

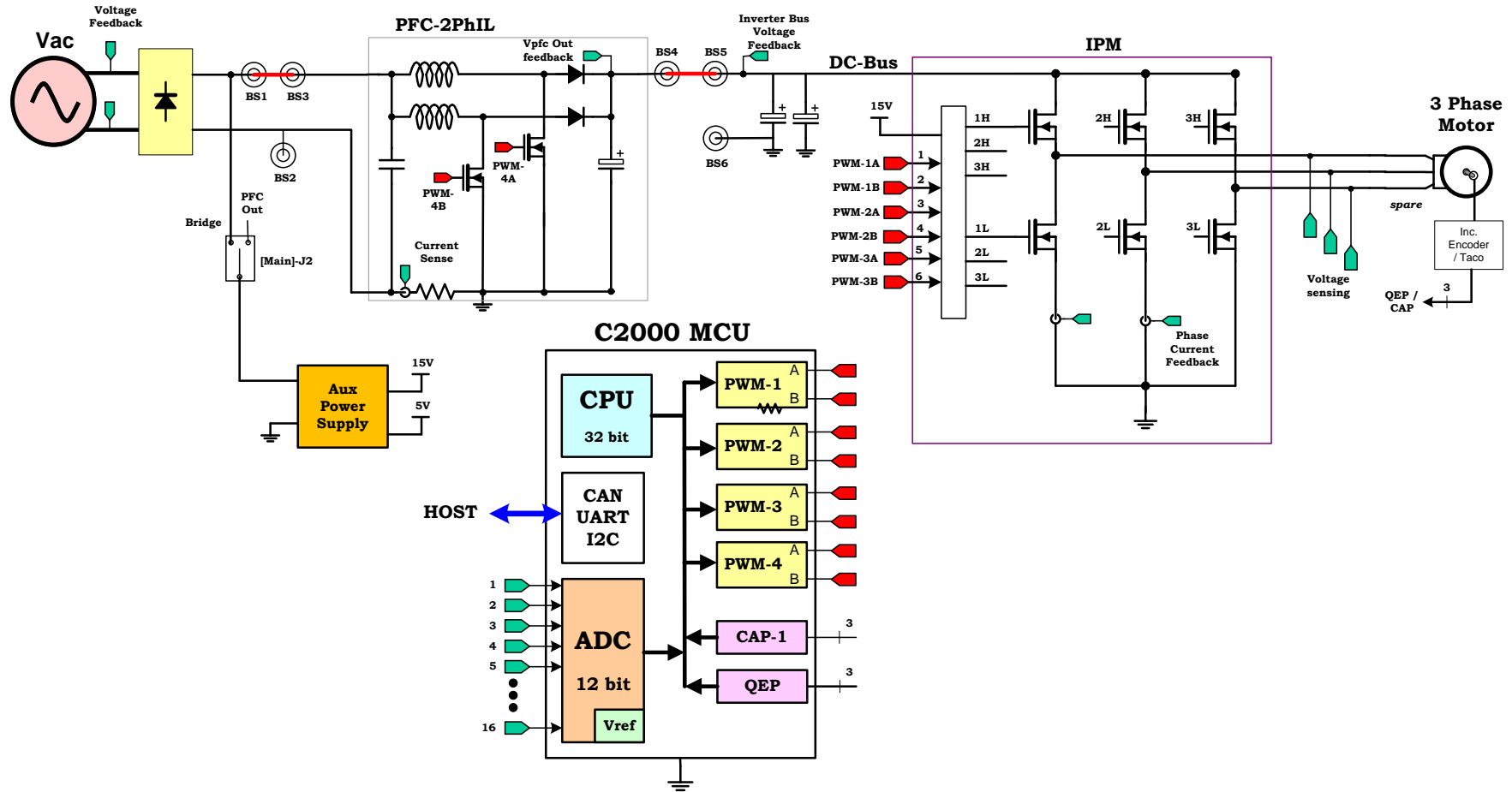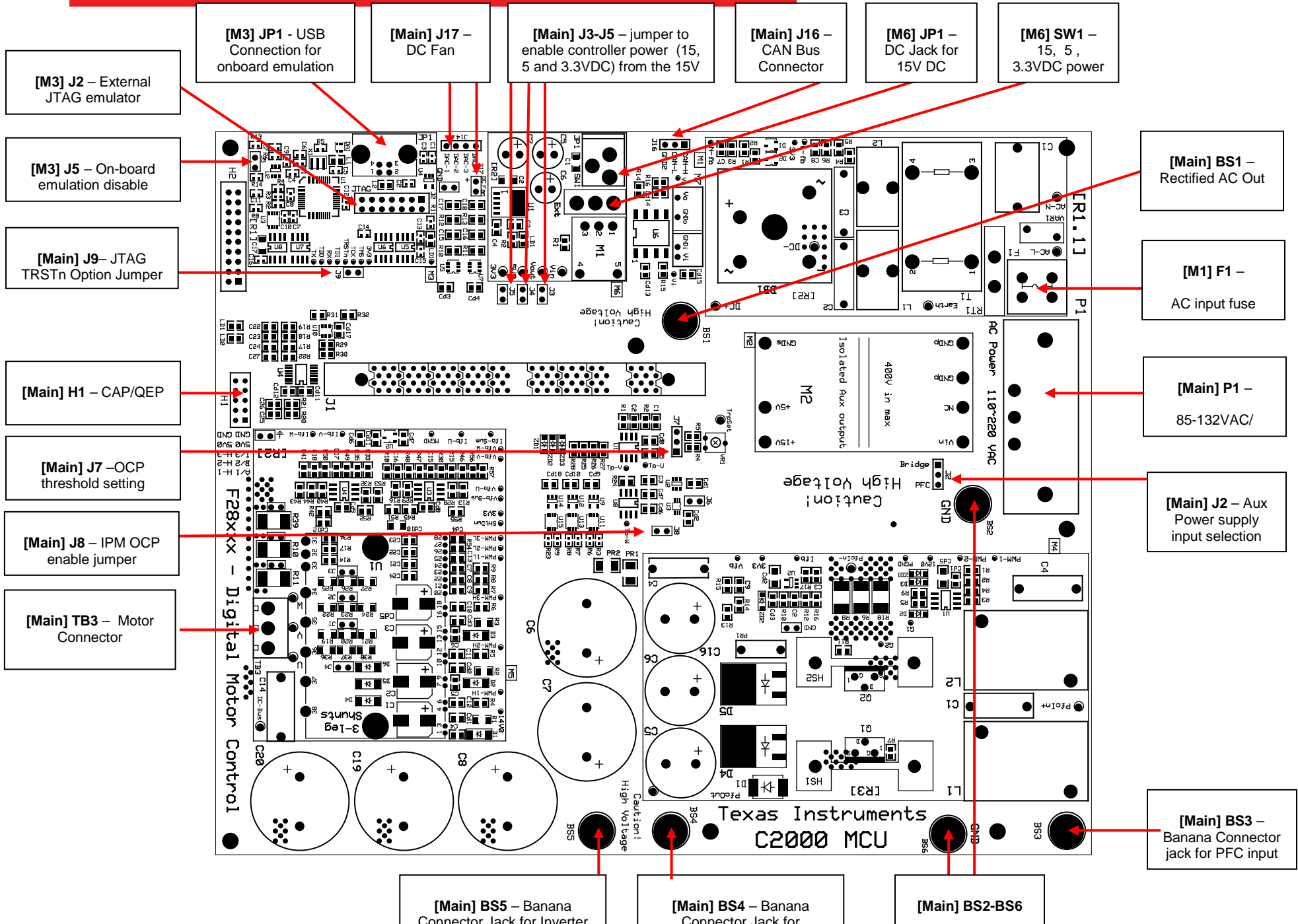*Table 2: PWM and ADC resource allocation*

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Fig5 High Voltage DMC + PFC board diagram with C2000 MCU

(For F28027 QEP and CAN are unavailable)

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[M3] JP1 - USB Connection for onboard emulation

[Main] J17 – DC Fan

[Main] J3-J5 – jumper to enable controller power (15, 5 and 3.3VDC) from the 15V

[Main] J16 – CAN Bus Connector

[M6] JP1 – DC Jack for 15V DC

[M6] SW1 – 15, 5, 3.3VDC power

[M3] J2 – External JTAG emulator

[M3] J5 – On-board emulation disable

[Main] J9– JTAG TRSTn Option Jumper

[Main] H1 – CAP/QEP

[Main] J7 –OCP threshold setting

[Main] J8 – IPM OCP enable jumper

[Main] TB3 – Motor Connector

[Main] BS1 – Rectified AC Out

[M1] F1 – AC input fuse

[Main] P1 – 85-132VAC/

[Main] J2 – Aux Power supply input selection

[Main] BS3 – Banana Connector jack for PFC input

[Main] BS5 – Banana Connector Jack for Inverter

[Main] BS4 – Banana Connector Jack for

[Main] BS2-BS6

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Jumpers and Connectors

Table 3 below shows the various connections available on the board, and is split up by the macro each connection is included in. Fig 6, above, illustrates the location of these connections on the board with help of a board image:

[Main] P1	AC input connector (110V – 220V AC)
[Main]-TB3	Terminal Block to connect motor
[Main]-BS1	Banana Jack for Output from AC Rectifier
[Main]-BS2,BS6	Banana Jack for GND Connection
[Main]-BS3	Banana Jack for connecting an input voltage for the PFC stage, this would typically be rectified AC voltage from the [Main]-BS1 connector.
[Main]-BS4	Banana Jack for connecting a load to the output from the PFC stage, When using PFC+Motor project the output of the PFC stage would connect to the input for the inverter bus i.e. [Main]-BS5
[Main]-BS5	Banana Jack for input of DC bus voltage for the inverter
[Main] J2	Aux power supply module input voltage selection jumper, • When jumper connected to Bridge position the aux power supply module sources power from the AC rectifier bridge output. • When Jumper connected to PFC position the aux power supply module sources power from the output of the PFC stage
[Main] J3,J4,J5	Jumpers J3,J4 and J5 are used for sourcing 15V, 5V and 3.3V power respectively for the board from the 15V DC Power supply.
[Main] J7	J7 is used to select the over current protection threshold source
[Main] J8	J8 is used to enable/disable the IPM overcurrent protection
[Main] J9	JTAG TRSTn disconnect jumper, populating the jumper enables JTAG connection to the microcontroller. The jumpers needs to be unpopulated when no JTAG connection is required such as when booting from FLASH.
[Main] J10	
[Main] J14	DAC outputs: Gives voltage outputs that result from a PWM being attached to a first-order low-pass filter. Pins 1,2,3 and 4 are attached to low pass filtered PWM-5A, PWM-6A, PWM-7A and PWM-7B respectively. These are used in conjunction with the PWMDAC DMC library components to observe system variables on an oscilloscope.

[Main]-J15	
[Main]-J16	Isolated CAN bus connector. Not accessible by the F28027 controlCARD.
[Main]-J17	Connector to supply power to the DC fan (shipped with the board) that is attached to the IPM heatsink.
[Main]-H1	QEP connector: connects with a 0-5V QEP sensor to gather information on a motor's speed and position. Not accessible by the F28027 controlCARD. CAP/Hall effect sensor connector: connects with a 0-5V sensor to gather information on a motor's speed and position. Accessible to the F28027, F28335 and F28035 controlCARDs.
[M1]-F1	Fuse for the AC input
[M3]-JP1	USB connection for on-board emulation
[M3]-J2	External JTAG interface: this connector gives access to the JTAG emulation pins. If external emulation is desired, place a jumper across [M3] J5 and connect the emulator to the board. To power the emulation logic a USB connector will still need to be connected to [M3] JP1.
[M3]-J5	On-board emulation disable jumper: Place a jumper here to disable the on-board emulator and give access to the external interface.

Table 3: Key features explanation

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SCHEMATIC DISCLAIMER AND WARNINGS

TI provides the High Voltage DMC and PFC kit schematic drawings to help users develop C2000 based reference design products. Application safety, safety of the High Voltage DMC and PFC kit and design integrity of such reference designs are solely responsibility of the user. Any reference designs generated off these schematics must take into account necessary product safety design requirements, including interface components and load motors in order to avoid user risks including potential for fire hazard, electrical shock hazard and personal injury, including considerations for anticipated agency certification compliance requirements.

Such product safety design criteria shall include but not be limited to critical circuit creepages and clearances, component selection, ratings compatibility of controlled motor loads, and required protective means (ie output fusing) depending on the specific loads being controlled.

TI accepts no responsibility for design integrity of any reference designs based on supplied schematic drawings and the schematics are strictly for development purposes.

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Should this evaluation board/kit not meet the specifications indicated in the User's Guide, the board/kit may be returned within 30 days from the date of delivery for a full refund. THE FOREGOING WARRANTY IS THE EXCLUSIVE WARRANTY MADE BY SELLER TO BUYER AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE.

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FCC Warning

This evaluation board/kit is intended for use for **ENGINEERING DEVELOPMENT, DEMONSTRATION, OR EVALUATION PURPOSES ONLY** and is not considered by TI to be a finished end-product fit for general consumer use. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to part 15 of FCC rules, which are designed to provide reasonable protection against radio frequency interference. Operation of this equipment in other environments may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be required to correct this interference.