High Voltage Motor Control and PFC Kit Hardware Reference Guide

Version 1.3 – October 2010 *C2000 Systems and Applications Team*

Fig 1: TMDSHVMTRPFCKIT

1 Introduction

The High Voltage Digital Motor Control (DMC) and Power Factor Correction (PFC) kit (TMDSHVMTRPFCKIT, Figure 1), 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.

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.

2 Getting Familiar with the Kit

2.1 Kit Contents

The kit consists of

- F28035 controlCARD
- F28335 controlCARD
- High Voltage DMC board
- 15V Power Supply
- AC power Cord (configured for your local country mains connection)
- Banana Plug Cords
- USB-B to A Cable

The High Voltage DMC board if fitted inside a plastic enclosure (Fig 2). 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 heatsink. Do not touch the heatsink and or other parts of the kit while in operation).

The board can accept any of the C2000 series controlCARDs. A F28035 and F28335 control card is shipped with the kit, the F28035 control card is installed on the board to work with the Quick Start GUI.

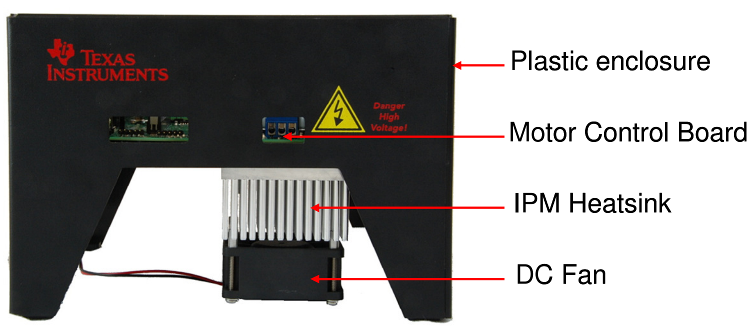

Fig 2: Kit assembly

2.2 Kit Features: The kit has the following features

- **3-Phase Inverter Stage** to control high voltage motors.
  - 350V DC max input voltage
  - 1KW*/1.5KW* maximum load (for > 250W load, the fan** attached to the IPM heatsink must be used)
  - Sensorless and Sensored Field Oriented Control of ACI Motor
  - Sensorless and Sensored Field Oriented Control of PMSM Motor
  - Sensorless and Sensored Trapezoidal Control of BLDC Motor
  - Sensorless and Sensored Sinusoidal Control of BLDC Motor
  - QEP and CAP inputs available for speed and position measurement
  - High precision low-side current sensing using the C2000's high-performance ADC, Texas Instruments OPA2350 high speed op-amps and Texas Instrument 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 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 90% efficiency
    - 200Khz switching frequency for the power stage
    - Upto100Khz PFC control loop frequency
    - Uses Texas Instruments UCC27324, high speed dual MOSFET drivers.

- **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** (400Vto15V&5V 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 JTAG emulation**

- **Isolated UART** through the SCI peripheral and the FTDI chip.

- **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 heatsink. 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 4 Amps fuse in the AC power entry fuse holder, for higher power operation this fuse needs to be replaced with an appropriate rating fuse.

3 Hardware Overview

Fig 3, 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 5).

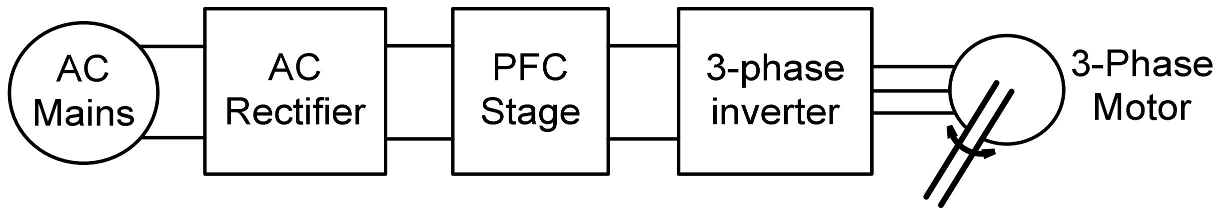

Fig3: Block Diagram for a typical motor drive system using power factor correction

3.1 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, 400V to 5V and 15V module can generate 15V,5V power for the board from rectified AC power.
- [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, to enable 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 4, 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.

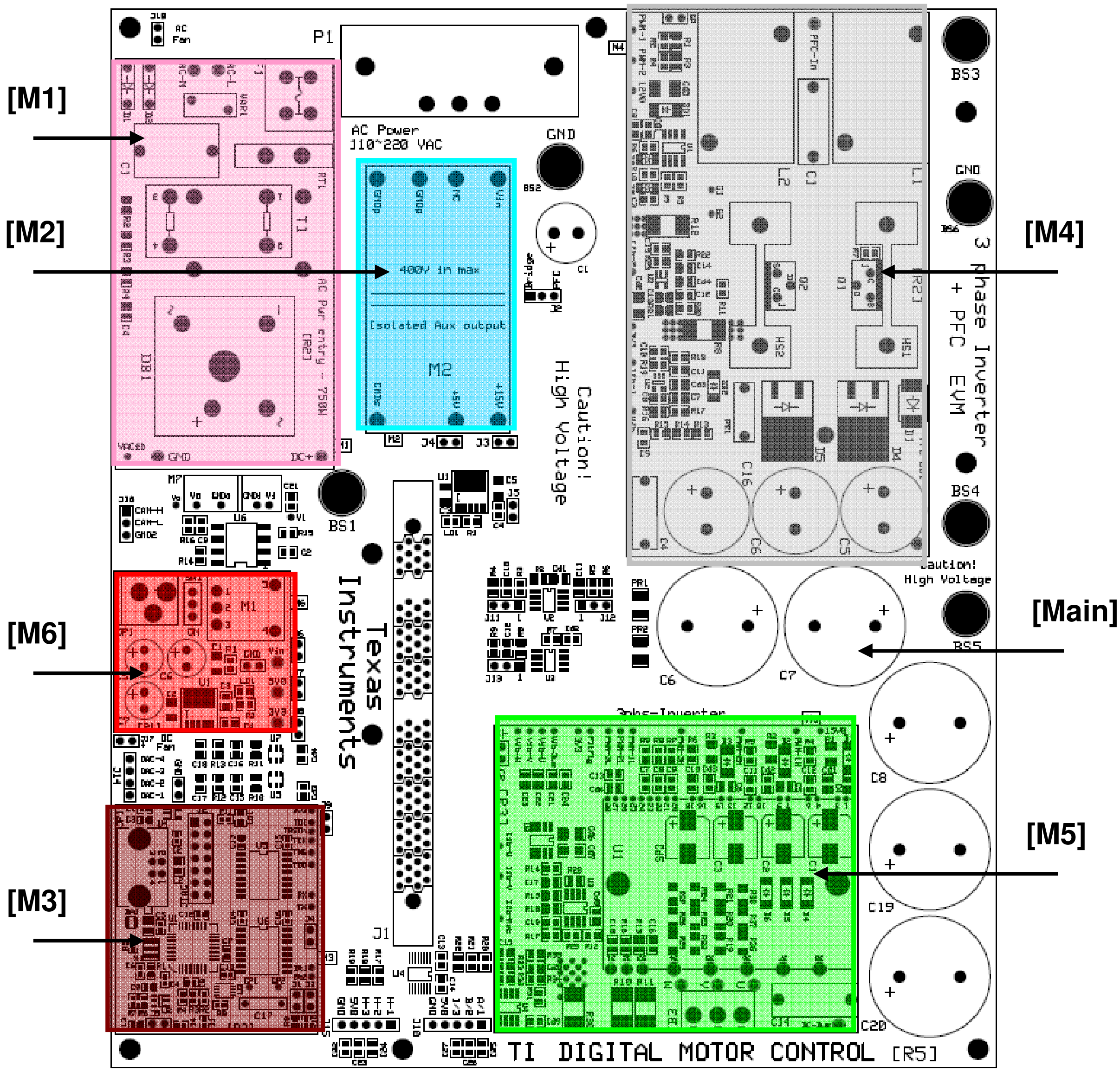

Fig4: The Layout of HVDMC Board

▪ [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

3.2 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).

(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 b/w [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 b/w [Main]-BS1 to [Main]-BS3 to connect the rectified AC output to the PFC input and another banana cable b/w [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 PID 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.

3.3 Boot Modes

Table1, describes the jumper and switch settings that are needed for booting from FLASH and SCI for the board.

	Boot from FLASH	**Boot from SCI (using iso JTAG macro)**
F2802x	SW1 on controlCARD- Position 1 = 1 Position 2 = 1 Remove the jumper [Main]-J9	SW1 on controlCARD- Position 1 = 1 Position 2 = 0 Unpopulate R10 on controlCARD Remove the jumper [Main]-J9 Populate the jumper [M3]-J4
F2803x	SW2 on controlCARD- Position 1 = 1 Position 2 = 1 Remove the jumper [Main]-J9	SW2 on controlCARD- Position 1 = 1 Position 2 = 0 SW3 on controlCARD should be OFF Remove the jumper [Main]-J9 Populate the jumper [M3]-J4
F2833x	Note the settings below are valid for TMDSCNCD28335PGF R1.0 control card. SW2 on controlCARD Position 1 =1 (ON) Position 2 =1 Position 3 =1 Position 4 =1 Remove the jumper [Main]-J9	Note the settings below are valid for TMDSCNCD28335PGF R1.0 control card. SW2 on controlCARD Position 1 =0 (OFF) Position 2 =1 Position 3 =1 Position 4 =1 SW1 on controlCARD should be OFF Remove the jumper [Main]-J9 Populate the jumper [M3]-J4

Table 1: Boot Options

3.4 GUI Connection

The FTDI chip present on the board can be used as an isolated SCI for communicating with a HOST i.e. PC. The following jumper settings must be done to enable this connection.

As the GUI software is provided for F28035 control card only, F28035 settings are discussed below,

1. Populate the jumper [M3]-J4
2. Remove the jumper [Main]-J9
3. For F28035, put SW3 on the F28035 Control Card to OFF position
4. Connect a USB cable from [M3]-JP1 to host PC.

Note: If you are going to boot from Flash & connecting using the GUI, you would nee to do the Boot from Flash settings as described in the Table Boot Options.

3.5 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.

4 Hardware Resource Mapping

4.1 Resource Allocation

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-B4	Low side U-phase current sense
	Ifb-V	ADC-B6	Low side V-phase current sense
	Ifb-Ret	ADC-A4	DC Bus Return current sense
	Vfb-Bus	ADC-A1	DC Bus Voltage sense
	Vfb-U	ADC-B3	U-phase voltage sense
	Vfb-V	ADC-B2	V-phase voltage sense
	Vfb-W	ADC-B1	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-A	ADC-A2	Phase 1 current sense
	Ipfc-B	ADC-A6	Phase 2 current sense
	Vpfc	ADC-A0	PFC Output voltage sense
AC Rectifier	VAC-fb	ADC-A3	Rectified AC voltage sense
Main –Board	DAC-1	PWM-5A	Driving DAC signal
	DAC-2	PWM-6A	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

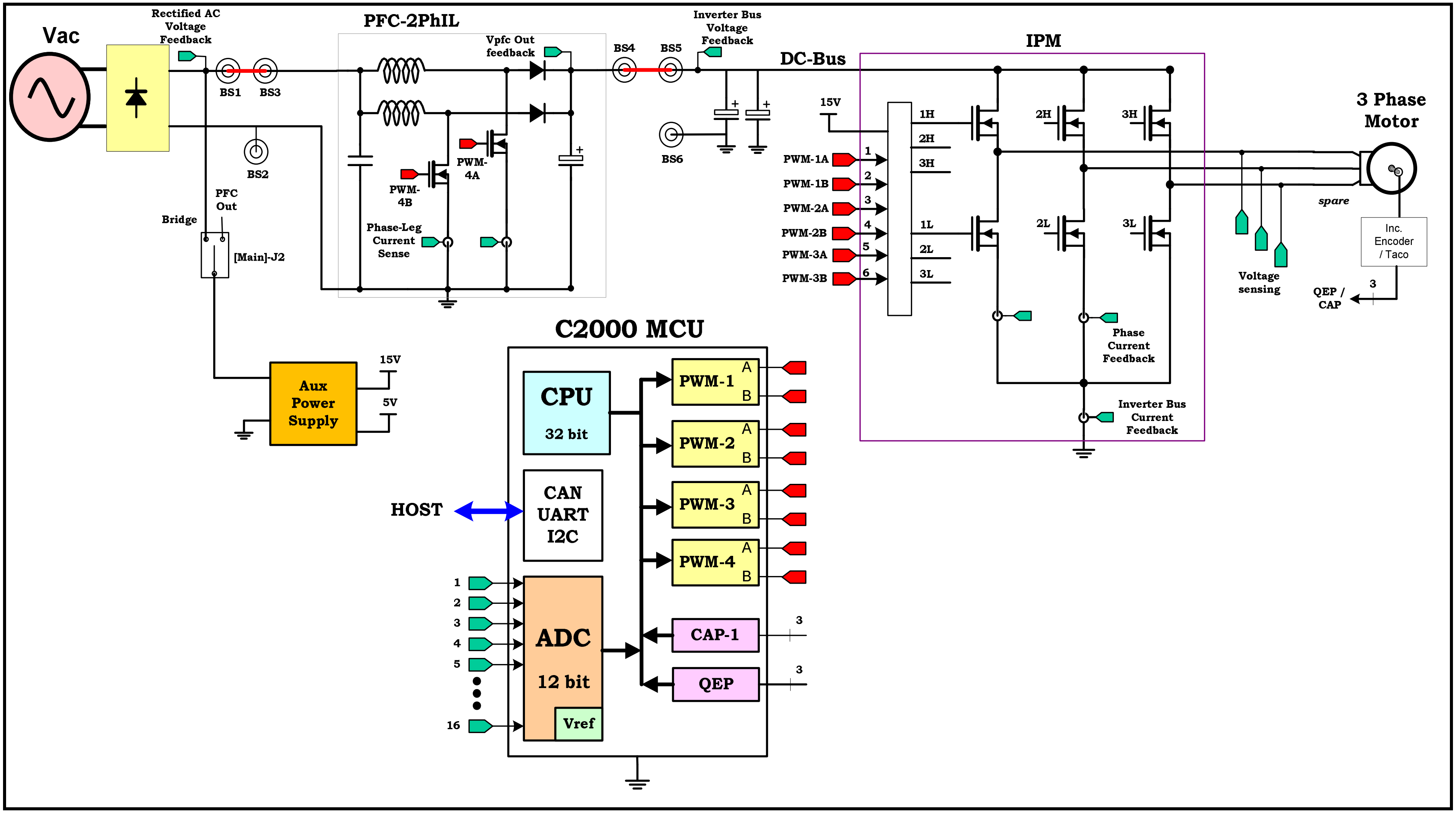

Fig5: High Voltage DMC + PFC board Block diagram with C2000 MCU
(For F28027 QEP and CAN are unavailable)

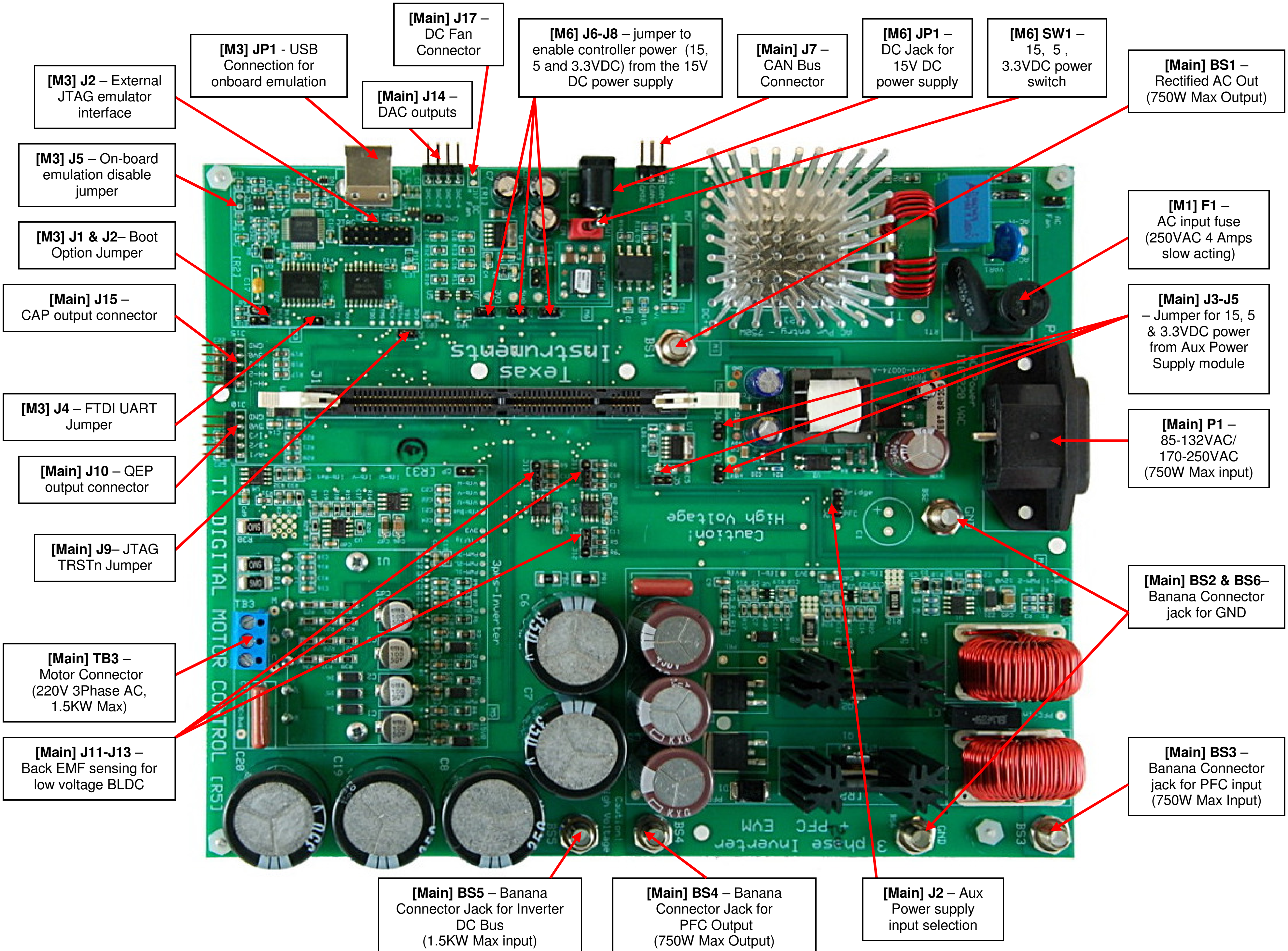

Fig6. HVMotorCtrl+PFC Kit Jumpers and Connectors Diagram

4.2 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. When populated the aux power supply module is used as the source. Make sure when these jumpers are populated jumpers J6,J7 and J8 are not be populated and that an appropriate jumper setting for [Main]-J2 is selected.
[Main] J6,J7,J8	Jumpers J6,J7 and J8 are used for sourcing 15V, 5V and 3.3V power respectively for the board from the 15V DC Power supply. When populated make sure that jumpers J3,J4 and J5 are not populated.
[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	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.
[Main] J11, J12, J13	Back EMF sense amplification selection jumpers (used for BLDC Motor) • When populated b/w pins 1 & 2, amplifier stage is bypassed, this is used for high voltage BLDC Motor. • When populated b/w pins 2 & 3, the back emf sense signal passes through an amplifier stage with gain of four. This is used for low voltage BLDC Motor.
[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	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.
[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.
[M1]-F1	Fuse for the AC input

[M3]-JP1	USB connection for on-board emulation
[M3]-J1&J3	Boot Option Jumpers, not used for F2802x, F2803x or F2833x devices.
[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]-J4	Populate when using FTDI chip as a UART i.e. when using a GUI to interact with the MCU.
[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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