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Resonant LLC Half-Bridge DC/DC Converter Hardware Design Guide

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Design Features

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- Onboard Isolated JTAG Emulation
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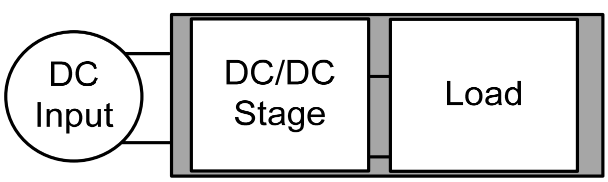

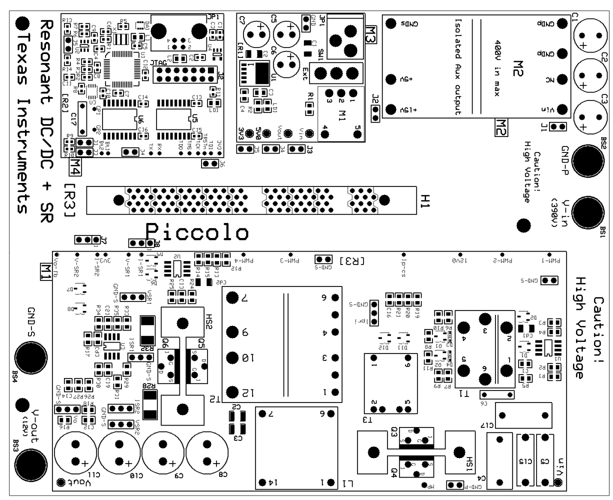

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Save all warnings and instructions for future reference.

Failure to follow warnings and instructions may result in personal injury, property damage, or death due to electrical shock and burn hazards.

The term TI HV EVM refers to an electronic device typically provided as an open framed, unenclosed printed circuit board assembly. It is **intended strictly for use in development laboratory environments, solely for qualified professional users having training, expertise and knowledge of electrical safety risks in development and application of high voltage electrical circuits. Any other use and/or application are strictly prohibited by Texas Instruments**. If you are not suitable qualified, you should immediately stop from further use of the HV EVM.

1. Work Area Safety
   (a) Keep work area clean and orderly.
   (b) Qualified observer(s) must be present anytime circuits are energized.
   (c) Effective barriers and signage must be present in the area where the TI HV EVM and its interface electronics are energized, indicating operation of accessible high voltages may be present, for the purpose of protecting inadvertent access.
   (d) All interface circuits, power supplies, evaluation modules, instruments, meters, scopes and other related apparatus used in a development environment exceeding 50Vrms/75VDC must be electrically located within a protected Emergency Power Off EPO protected power strip.
   (e) Use stable and nonconductive work surface.
   (f) Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.
2. Electrical Safety
   As a precautionary measure, it is always a good engineering practice to assume that the entire EVM may have fully accessible and active high voltages.
   (a) De-energize the TI HV EVM and all its inputs, outputs and electrical loads before performing any electrical or other diagnostic measurements. Revalidate that TI HV EVM power has been safely de-energized.
   (b) With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment connection, and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
   (c) After EVM readiness is complete, energize the EVM as intended.

   WARNING: WHILE THE EVM IS ENERGIZED, NEVER TOUCH THE EVM OR ITS ELECTRICAL CIRCUITS AS THEY COULD BE AT HIGH VOLTAGES CAPABLE OF CAUSING ELECTRICAL SHOCK HAZARD.
3. Personal Safety
   (a) Wear personal protective equipment (for example, latex gloves or safety glasses with side shields) or protect EVM in an adequate lucent plastic box with interlocks to protect from accidental touch.

Limitation for safe use:

EVMs are not to be used as all or part of a production unit.

1 System Description

The TMDSHVRESLLCKIT provides a great way to learn and experiment with using a single MCU to control a Half-Bridge LLC Resonant DC/DC Converter with Synchronous Rectification. This document goes over kit contents, the kit 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 hardware of this kit.

CAUTION

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

2 Getting Started

2.1 Kit Contents

This kit contains the following:

- Half-Bridge LLC Resonant DC/DC Converter with Synchronous Rectification board
- Piccolo F28027 controlCARD
- 12V power adapter
- USB Cable
- USB drive with GUI executable and CCS v4 software

The board can accept any of the C2000 series controlCARDs. A F28027 control card is shipped with the kit. Some software changes may be necessary to have the board work with a different controlCARD. All features may not be supported by all controlCARDs.

2.2 Kit Specifications

The High-Voltage Half-Bridge LLC Resonant DC/DC Converter with Synchronous Rectification Kit board has the following electrical specifications:

- Input Voltage: 375 to 405 VDC
- Rated Output Power: 300 W
- Output Voltage: 12 VDC
- Rated Output Current: 25 A
- Output Voltage Line Regulation (Io = 1 A): ≤1%
- Output Voltage Load Regulation (Vin = 390 V): ≤1%
- Output Voltage Peak-to-Peak Ripple (Vin = 390 V and Io = 25 A): ≤120mV
- Efficiency (Vin = 390 V and Io = 25 A): >90%
- Switching frequency (normal operation): 80 kHz to 150 kHz
- Resonant Frequency: fo = ~130 kHz

3 Hardware

Figure 1 illustrates a DC/DC power conversion application running from DC power.

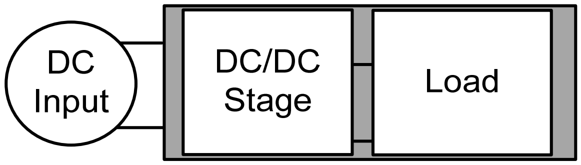


Figure 1. Block Diagram for a DC-DC Power Conversion Application

On this board, we use the C2000 to control a Half-Bridge LLC Resonant DC/DC Converter with Synchronous Rectification. The power stage regulates the output voltage using 2P2Z/PID closed-loop control. Figure 2 shows the circuit diagram.

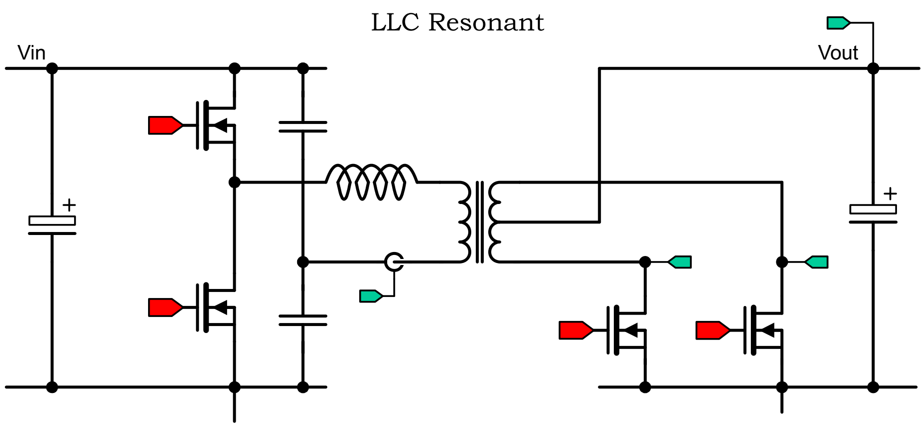


Figure 2. TMDSHVRESLLCKIT Circuit Diagram

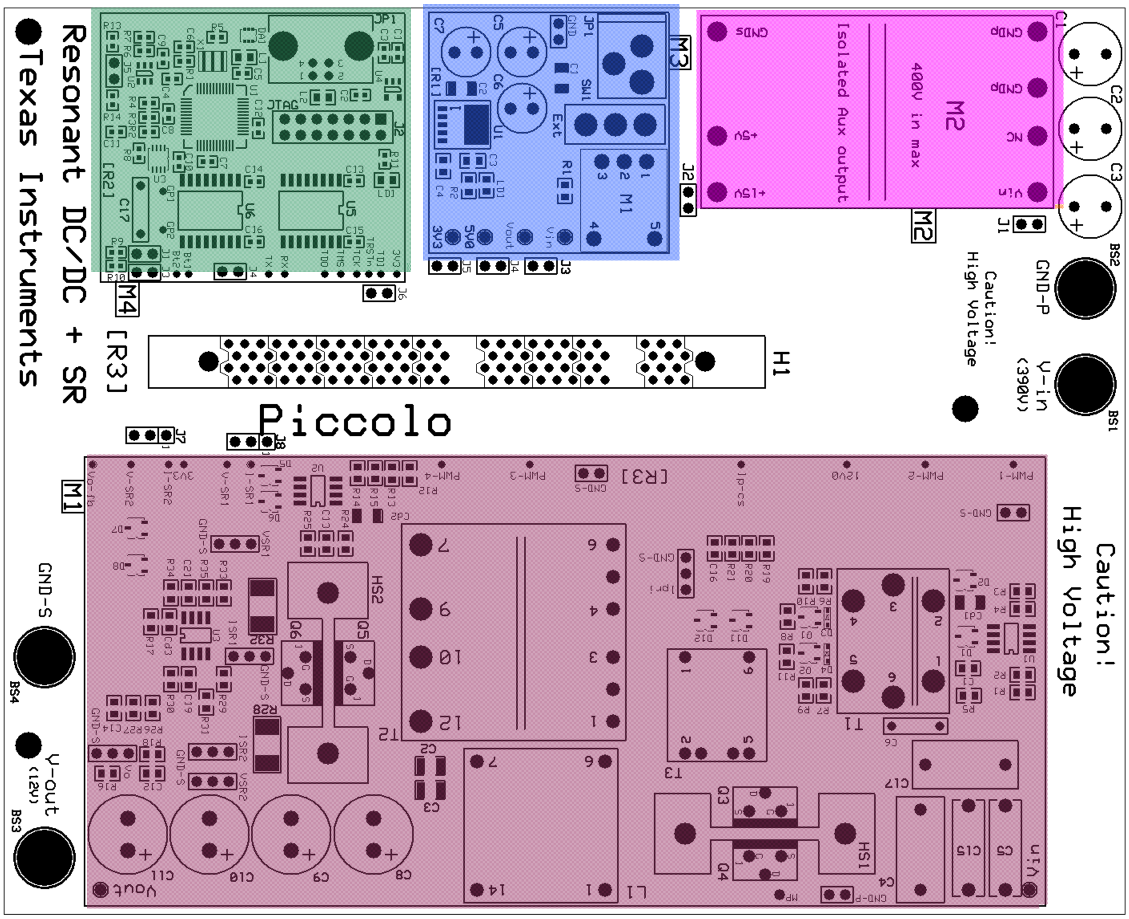
3.1 *Macro Blocks*

The High-Voltage Half-Bridge LLC Resonant DC/DC Converter with Synchronous Rectification board is divided into functional groups referred to as macro blocks. The use of a macro block approach enables easy debug and testing of one section at a time. All of the PWM and ADC signals have designated test points on the board which makes it easy for a developer to not only debug but try out new algorithms and strategies.

The following is a list of the macro blocks present on the board and brief descriptions of each:

- **Main Board Area – [Main]** – Contains the controlCARD socket, power connectors, jumpers, and the routing of signals between the controlCARD and the macro blocks. This section includes any area outside of other defined macro blocks.
- **Aux-DC-Power macro – [M3]** – Generates the 12-15V, 5V, and 3.3V DC power rails from a 12V DC supply included with the kit, an external DC power supply, or the on-board 400V-to-15V DC/DC module.
- **Isolated-USB-to-JTAG macro– [M4]** – Provides an on-board isolated JTAG connection through USB to the host as well as isolated SCI (UART) communication.
- **LLC Resonant + SR macro – [M1]** – Isolated Resonant LLC DC/DC power stage with Synchronous Rectification.
- **400V-to-15V DC/DC macro – [M2]** – Generates an isolated 15V from the 400V input voltage.

Refer to Figure 3 for placement of each macro block.



(1) [Main] – Main Board area

(2) [M3] – Aux-DC-Power macro

(3) [M4] – Isolated-USB-to-JTAG macro

(4) [M1] – LLC Resonant + SR macro

(5) [M2] – 400V-to-15V DC/DC macro

Figure 3. TMDSHVRESLLCKIT Macro Block Locations

In this guide, each component is named first with their macro number followed by the reference name. For example, [M2]-J1 would refer to the jumper J1 located in the macro M2 and [Main]-J1 would refer to the J1 located on the board outside of the other defined macro blocks.

3.2 Powering the Board

The High-Voltage Half-Bridge LLC Resonant DC/DC Converter with Synchronous Rectification Kit board has two separate power domains and two major modes of operation. The two power domains are the primary power rail which feeds the power stage, and the auxiliary power rail which powers the MCU and support chips. Depending on the user's intent, two modes of operation can be used.

Demo Mode — Uses the GUI to quickly show how the board functions. All power used by the board is provided from a single 390V DC power supply.

1. Insert a pre-flashed F28027 control card into socket [Main]-H1.
2. Connect your computer to the board using a USB cable.
3. Verify the following jumper settings:
   - Jumpers are placed on [Main]-J1, J2, J3, J4, J5.
   - Jumpers are placed on pins 1-2 on [Main]-J7, J8.
   - A jumper is placed on [M4]-J4.
   - No jumper is placed on [Main]-J6.
4. Verify that no DC power supply is connected to [M3]-JP1.
5. Connect a 390V DC power supply across [Main]-BS1, BS2.
6. Connect a load across [Main]-BS3, BS4.

Experimentation Mode — Uses CCSv4 to experiment with how the board functions. Two different power supplies are used to minimize the risk of damage while experimenting. The primary and auxiliary power rails will each use a separate power supply. This mode allows the user to verify PWM output and ADC feedback signals before energizing the DC/DC power stage and helps protect the MCU if a fault occurs on the primary power rail.

1. Insert a F28027 control card into socket [Main]-H1.
2. Connect your computer to the board using a USB cable.
3. Verify the following jumper settings:
   - Jumpers are placed on [Main]-J3, J4, J5, J6.
   - Jumpers are placed on pins 1-2 on [Main]-J7, J8.
   - A jumper is placed on [M4]-J4.
   - No jumpers are placed on [Main]-J1, J2.
4. Connect a 12V DC power supply to [M3]-JP1.
5. Connect a 390V DC power supply across [Main]-BS1, BS2.
6. Connect a load across [Main]-BS3, BS4.

3.3 Boot Modes

Table 1 describes the jumper and switch settings that are needed for booting from FLASH and SCI for the board.

Table 1. Boot Options

	Boot from FLASH	Boot from SCI (using iso JTAG macro)
F2802x	SW1 on controlCARD- • Position 1 = 1 • Position 2 = 2 Remove the jumper [Main]-J6	SW1 on controlCARD- • Position 1 = 1 • Position 2 = 0 Unpopulate R10 on controlCARD Remove the jumper [Main]-J6 Populate the jumper [M4]-J4
F2803x	SW2 on controlCARD- • Position 1 = 1 • Position 2 = 1 Remove the jumper [Main]-J6	SW2 on controlCARD- • Position 1 = 1 • Position 2 = 0 SW3 on controlCARD should be OFF Remove the jumper [Main]-J6 Populate the jumper [M4]-J4

3.4 GUI Connection

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

1. Populate jumper [M4]-J4
2. Remove jumper [Main]-J6
3. For F28035, put SW3 on the F28035 controlCARD to OFF position
   For F28027, verify that R10 on the controlCARD is removed
4. Connect a USB cable from [M4]-JP1 to the HOST

NOTE: If you are going to boot from Flash & connect using the GUI, you will need to use the proper "Boot from FLASH" settings described in Table 1.

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 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

Figure 5 shows the various stages of the board in a circuit diagram format and illustrates the major connections and feedback values being mapped to the C2000 MCU. Table 2 lists these resources. It is important to note that not all resources are available on every C2000 MCU. Please refer to the schematics and device datasheets for more detailed information.

Table 2. PWM and ADC resource allocation

Macro Name			Signal Name	PWM/ADC Channel	Description
LLC Resonant + SR	M[1]	PWM-1	PWM-1A	PWM-1A	Half-Bridge High-Side PWM signal
		PWM-2	PWM-1B	PWM-1B	Half-Bridge Low-Side PWM signal
		PWM-3	PWM-2A	PWM-2A	Rectifier 1 PWM signal (negative half-cycle)
		PWM-4	PWM-3A	PWM-3A	Rectifier 2 PWM signal (positive half-cycle)
		Vo-fb	Vo-fb	ADC-A7	Output voltage sense
		V-SR1	V-SR1	ADC-A2	Rectifier 1 Vds voltage sense (muxed with I-SR1)
		V-SR2	V-SR2	ADC-A4	Rectifier 2 Vds voltage sense (muxed with I-SR2)
		Ip-cs	Ipri-cs	ADC-B1	Resonant tank current sense (rectified)
		I-SR1	I-SR1	COMP1 (ADC-A2)	Rectifier 1 current sense (muxed with V-SR1)
		I-SR2	I-SR2	COMP2 (ADC-A4)	Rectifier 2 current sense (muxed with V-SR1)

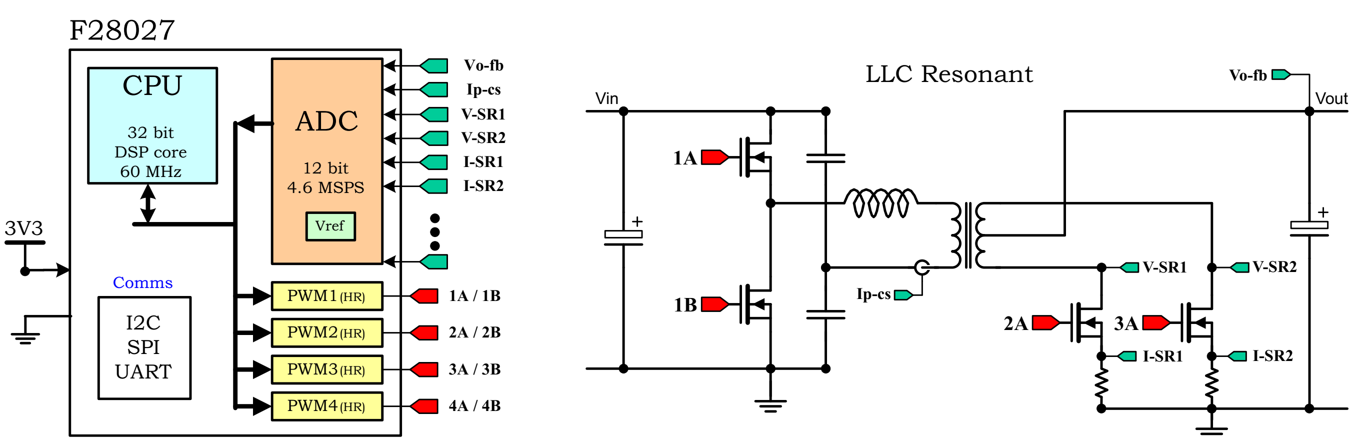


Figure 4. TMDSHVRESLLCKIT Circuit Diagram

4.2 Jumpers, Connectors, and Switches

Table 3 lists the jumpers, connectors, and switches available on the board. Figure 6 shows the location of these items with help of a board image.

Table 3. Description of Jumpers, Connectors, and Switches

[Main]-BS1	Banana Jack for DC input
[Main]-BS2	Banana Jack for Primary Ground connection
[Main]-BS3	Banana Jack for DC output
[Main]-BS4	Banana Jack for Secondary Ground connection
[Main]-H1	100-pin DIM100 controlCARD socket
[Main]-J1	Vin to 400V-to-15V Jumper. Connects the DC input power rail to the 400V-to-15V DC/DC module input.
[Main]-J2	400V-to-15V to Aux-DC-Power Jumper. Connects the 400V-to-15V DC/DC module output to the Aux-DC-Power macro input.
[Main]-J3	12-15V Enable Jumper. Enables the 12-15V auxiliary power rail.
[Main]-J4	5V Enable Jumper. Enables the 5V auxiliary power rail.
[Main]-J5	3V3 Enable Jumper. Enables the 3V3 auxiliary power rail.
[Main]-J6	JTAG enable jumper. Enables JTAG connection to the microcontroller. This jumper needs to be unpopulated when booting from FLASH, SCI, or another medium.
[Main]-J7	Mux selection between V-SR2 (pins 2-3) and I-SR2 (pins 1-2).
[Main]-J8	Mux selection between V-SR1 (pins 2-3) and I-SR1 (pins 1-2).
[M1]-GND-P	Primary Ground. Provides a connection to the primary ground.
[M1]-GND-S	Secondary Ground. Provides a connection to the secondary ground.
[M3]-JP1	Aux-DC-Power Input. This connector is designed to connect up with the 12V power supply included with this kit and supplies power to the auxiliary power rail powering the C2000 MCU and support chips.
[M3]-SW1	Aux-DC-Power Switch. Turns power to the Aux-DC-Power macro on/off.
[M4]-J2	External JTAG connector. This connector gives access to the JTAG emulation pins. If external emulation is desired, place a jumper across [M4]-J5 and connect the emulator to the board. However, a USB connector will still need to be connected to [M2]-JP1 to power the emulation logic.
[M4]-J4	FTDI UART enable jumper. Populate this jumper when using the FTDI chip as a UART (e.g.- when using a GUI to interact with the MCU).
[M4]-J5	On-board emulation disable jumper: Place a jumper here to disable the on-board emulator and give access to the external JTAG interface.
[M4]-JP1	USB connector for on-board JTAG emulation and SCI (UART) communication.

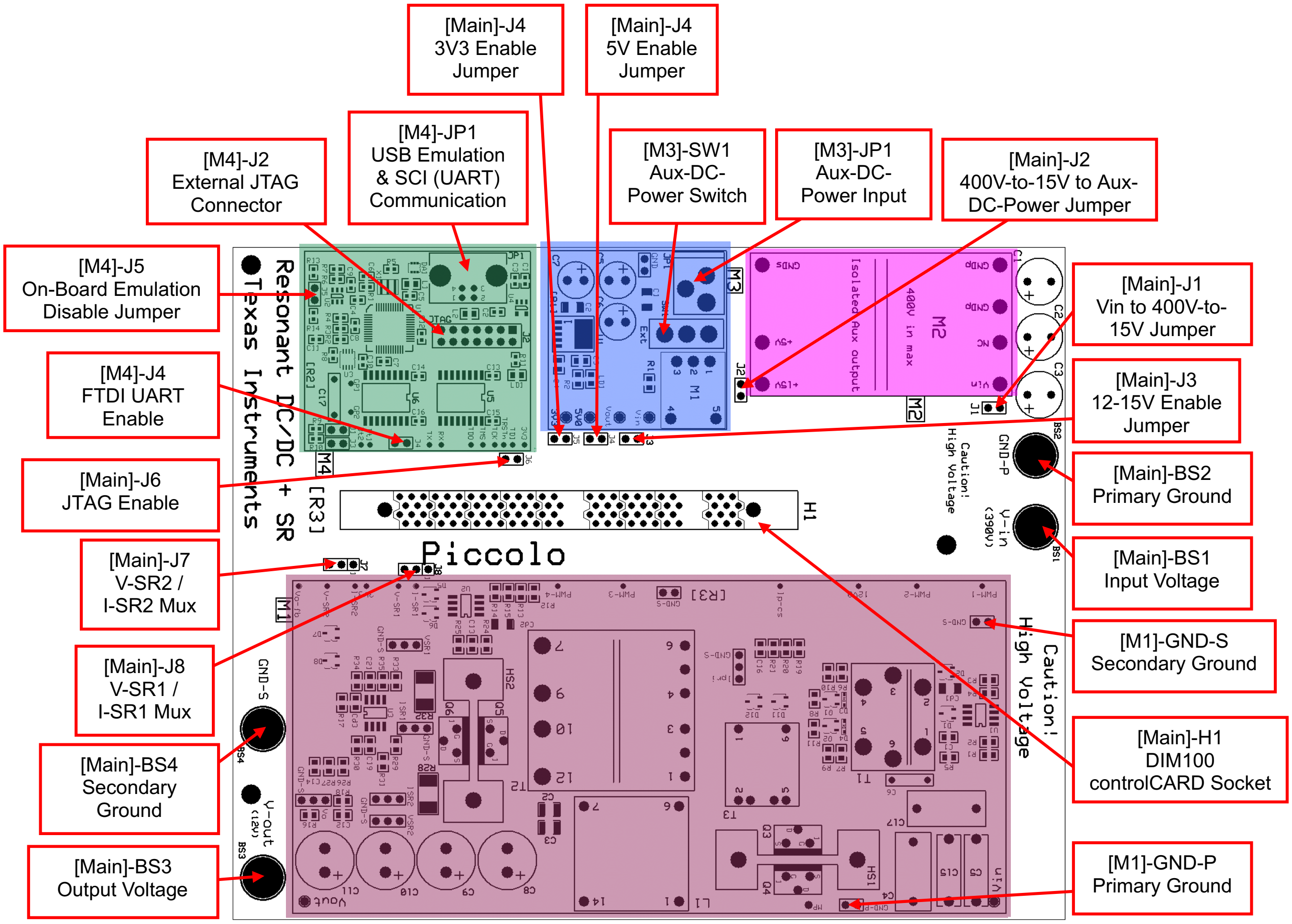


Figure 5. TMDSHVRESLLCKIT Jumpers, Connectors, and Switches Locations

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