



# High-Voltage Half-Bridge LLC Resonant DC/DC Converter With Synchronous Rectification Hardware Kit

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## ABSTRACT

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 application report 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.

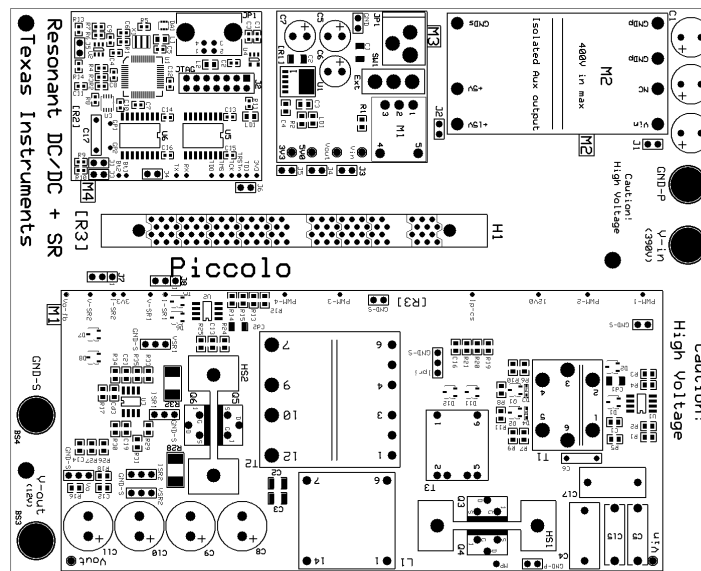


Figure 1. TMDSHVRESLLCKIT Board Picture

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## 1 Getting Familiar With the Kit

### 1.1 Kit Contents

The kit consists of:

- Half-bridge LLC resonant DC/DC converter with synchronous rectification board
- Piccolo™ F28027 controlCARD
- 12 V power adapter
- USB cable
- USB drive with GUI executable and Code Composer Studio™v4 software

The board can accept any of the C2000™ series controlCARDs. A F28027 control card is shipped with the kit. Software changes may be necessary so that the board will work with a different controlCARD. All features may not be supported by all controlCARDs.

## 1.2 Kit Features

The kit has the following features:

- Isolated power stage
- Onboard Isolated JTAG emulation
- Isolated universal asynchronous receiver/transmitter (UART) communication through the serial communications interface (SCI) peripheral and FTDI chip
- Hardware Developer's Package is available and includes schematics, bill of materials, Gerber files, and so forth.

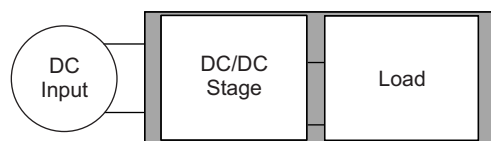
## 1.3 Kit Specifications

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 ( $I_o = 1 \text{ A}$ ):  $\leq 1\%$
- Output voltage load regulation ( $V_{in} = 390 \text{ V}$ ):  $\leq 1\%$
- Output voltage peak-to-peak ripple ( $V_{in} = 390 \text{ V}$  and  $I_o = 25 \text{ A}$ ):  $\leq 120 \text{ mV}$
- Efficiency ( $V_{in} = 390 \text{ V}$  and  $I_o = 25 \text{ A}$ ):  $>90\%$
- Switching frequency (normal operation): 80 kHz to 150 kHz
- Resonant frequency:  $f_0 = \sim 130 \text{ kHz}$

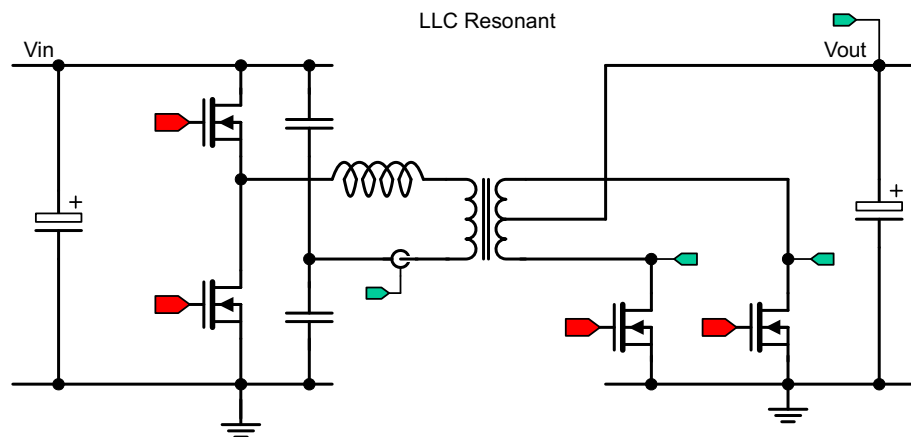
## 2 Hardware Overview

Figure 2 illustrates a DC/DC power conversion application running from DC power.



**Figure 2. Block Diagram for a DC/DC Power Conversion Application**

This board uses the C2000 to control a half-bridge LLC resonant DC/DC converter with synchronous rectification. The power stage regulates the output voltage using 2P2Z and PID closed-loop control. [Figure 3](#) shows the circuit diagram.



**Figure 3. TMDSHVRESLLCKIT Circuit Diagram**

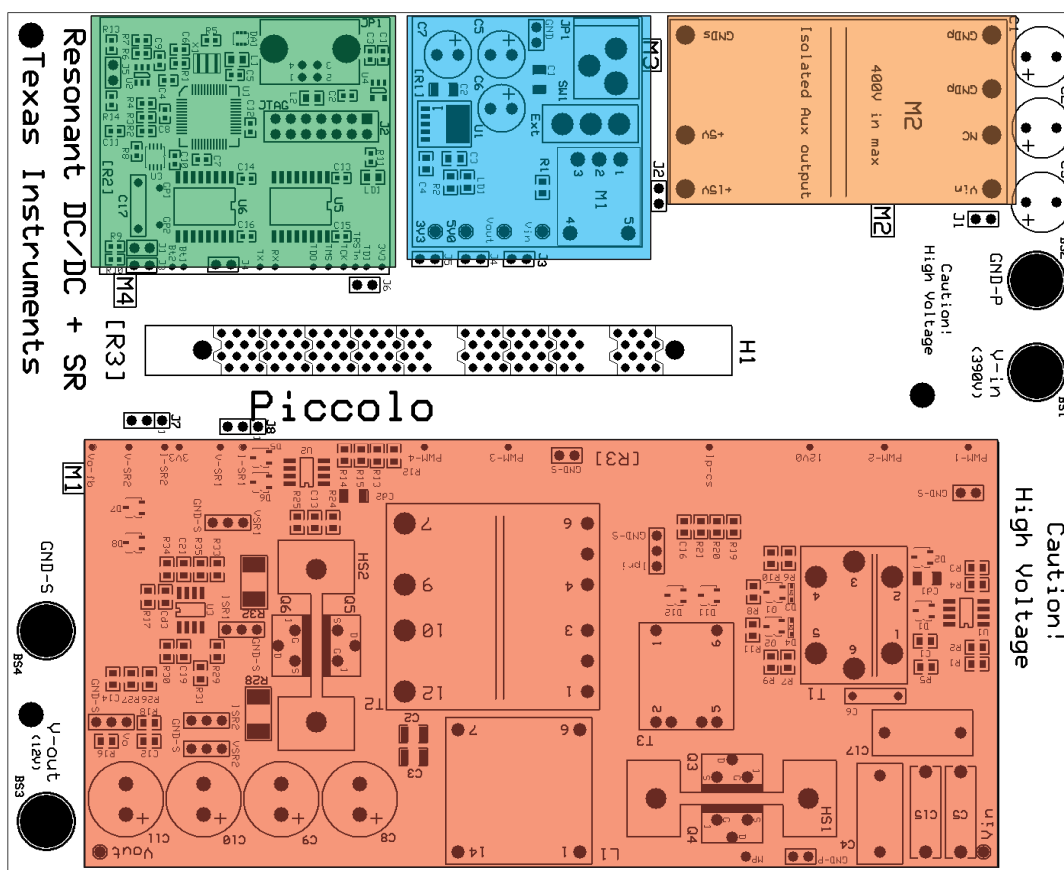
## 2.1 Macro Blocks

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 V - 15 V, 5 V, and 3.3 V DC power rails from a 12 V DC supply included with the kit, an external DC power supply, or the on-board 400 V-to-15 V DC/DC module.
- **[M2]** – A LLC resonant DC/DC conversion stage, used to decrease the input voltage to the voltage used by the LED strings.
- **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.
- **400 V-to-15 V DC/DC macro – [M2]** – Generates an isolated 15 V from the 400 V input voltage.

For the placement of each macro block, see [Figure 4](#). In this application report, 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.



[Main] – Main Board area
[M3] – Aux-DC-Power macro
[M4] – Isolated-USB-to-JTAG macro
[M1] – LLC Resonant + SR macro
[M2] – 400V-to-15V DC/DC macro

Figure 4. TMDSHVRESLLCKIT Macro Block Locations

## 2.2 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 that feeds the power stage, and the auxiliary power rail that powers the MCU and support chips. Depending on your intent, two modes of operation can be used.

**WARNING**

**Always use caution when using the board's electronics due to presence of high voltages.**

- **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:
    - (a) Jumpers are placed on [Main]-J1, J2, J3, J4, J5.
    - (b) Jumpers are placed on pins 1-2 on [Main]-J7, J8.
    - (c) A jumper is placed on [M4]-J4.
    - (d) No jumper is placed on [Main]-J6.
  4. Verify that no DC power supply is connected to [M3]-JP1.
  5. Connect a 390 V 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:
    - (a) Jumpers are placed on [Main]-J3, J4, J5, J6.
    - (b) Jumpers are placed on pins 1-2 on [Main]-J7, J8.
    - (c) A jumper is placed on [M4]-J4.
    - (d) No jumpers are placed on [Main]-J1, J2.
  4. Connect a 12V DC power supply to [M3]-JP1.
  5. Connect a 390 V DC power supply across [Main]-BS1, BS2.
  6. Connect a load across [Main]-BS3, BS4.

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## 2.3 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**

	<b>Boot From FLASH</b>	<b>Boot From SCI (using iso JTAG macro)</b>
F2802x	SW1 on controlCARD- Position 1 = 1 Position 2 = 1 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

## 2.4 GUI Connection

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

1. Populate the jumper [M4]-J4.
2. Remove the 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.

## 2.5 Ground Levels and Safety

- You 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 your responsibility to make sure that these ratings (the voltage, current and power levels) are well understood and complied with prior to connecting these power blocks together and energizing the board or simulation.

### 3 Hardware Resource Mapping

#### 3.1 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. For more detailed information, see the schematics and device-specific data sheets.

**Table 2. PWM and ADC Resource Allocation**

Macro Name		Signal Name	PWM and ADC Channel	Function	
LLC Resonant + SR	[M1]	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-SR1)
		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)

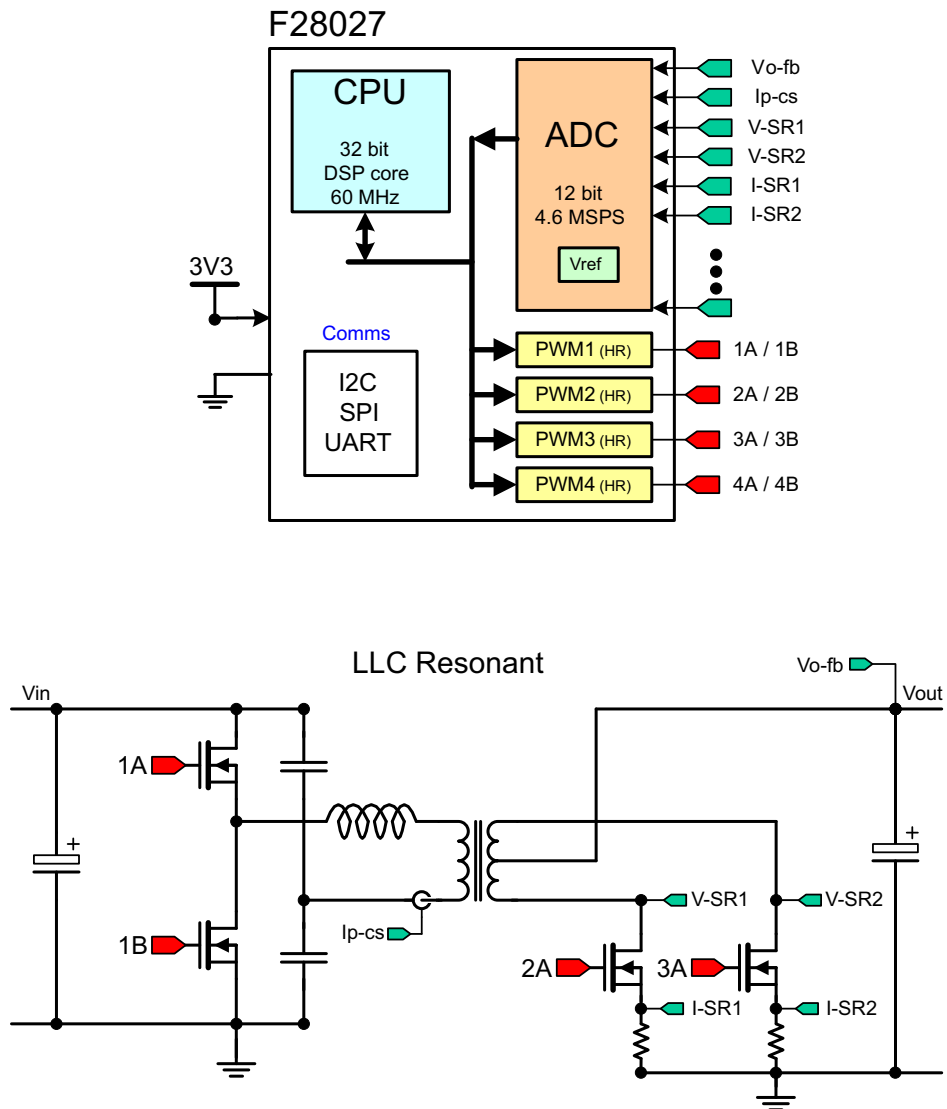


Figure 5. TMDSHVRESLLCKIT Circuit Diagram

### 3.2 Jumpers, Connectors, and Switches

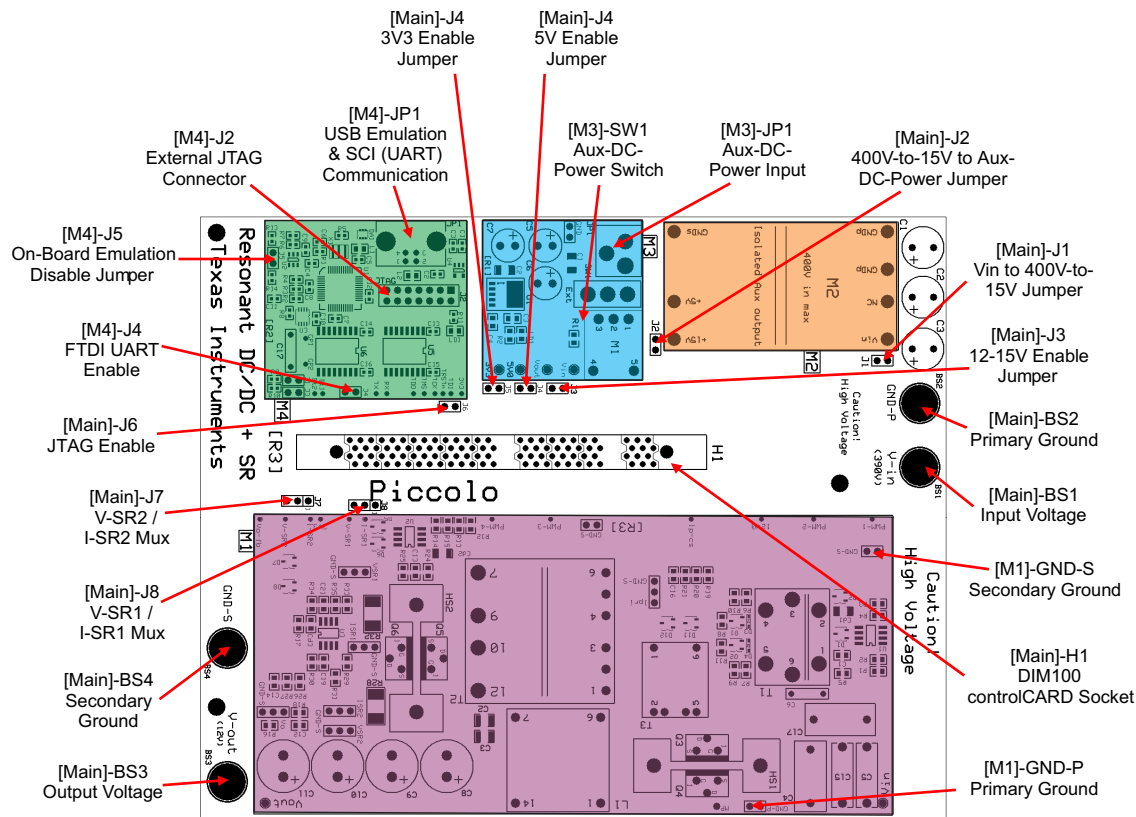
Table 3 lists the jumpers, connectors, and switches available on the board. Figure 6 shows the location of these items with help of a board image.

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	400 V-to-15 V to Aux-DC-Power Jumper. Connects the 400V-to-15V DC/DC module output to the Aux-DC-Power macro input.
[Main]-J3	12 V-15 V Enable Jumper. Enables the 12-15V auxiliary power rail.
[Main]-J4	5 V Enable Jumper. Enables the 5V auxiliary power rail.

**Table 3. Description of Jumpers, Connectors, and Switches (continued)**

[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 12 V 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 and 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 (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 6. TMDSHVRESLLCKIT Jumpers, Connectors, and Switches Locations**

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