

DRV2605L Multiple ERM, LRA Haptic Driver Kit

1 Introduction

The DRV2605L device is a haptic driver designed for linear resonant actuators (LRA) and eccentric rotating mass (ERM) motors. The device has many features that help eliminate the design complexities of haptic motor control including:

- Reduced solution size
- High-efficiency output drive
- Closed-loop motor control
- Quick device startup
- Embedded waveform library
- Auto-resonance frequency tracking

The DRV2605LEVMD evaluation module (EVM) is an evaluation platform for the DRV2605LDGS. The kit includes 8 DRV2605L devices, MSP430F5510 microcontroller (MCU), terminal output support for up to eight LRAs or ERMs, DRV2605L-integrated waveforms licensed from Immersion, and capacitive touch buttons which demonstrate the capabilities of the DRV2605L.

This user's guide contains instructions for setting up and operating the DRV2605LEVMD.

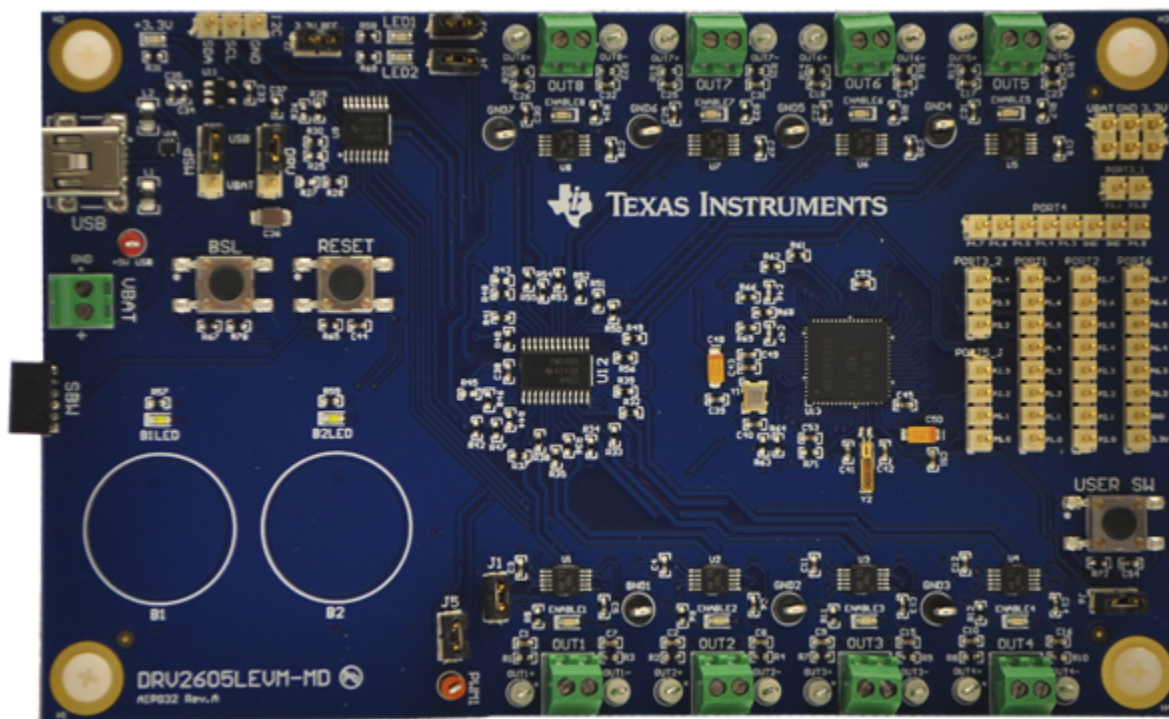


Figure 1. DRV2605LEVMD

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2 Getting Started

The DRV2605LEVM-MD demonstrates how the DRV2605L device can be used in applications that require multiple haptic drivers (same slave addresses) to be setup independently but be played simultaneously. The board integrates the TCA9548A I²C switch to control which I²C lines of the possible eight DRV2605L drivers are connected to the master input I²C bus. The switch has the ability to select any combination of channels to be connected to the master input I²C bus.

The board also integrates the MSP430F5510 device with USB interface capabilities and bootstrap loading (BSL) functionality. The USB interfacing provides the user flexibility in controlling the DRV2605L device without having to modify the firmware. The BSL functionality simplifies the firmware updating process without the additional hardware and the use of Code Composer Studio™ software.

The board receives power in two ways. For applications that require two or less active DRV2605L devices device at the same time, the board can be powered through a USB port. For applications that require more than two drivers, the use of the external power supply terminals with a current rating of 1.6 A is recommended. Manual selection of USB power or external power can be set using the jumper headers MSP and DRV. When powered up, button 1 and button 2 (B1, B2) can be used to demonstrate the functionality of the DRV2605L device. See [Section 3](#) for a detailed description of the demonstration application program.

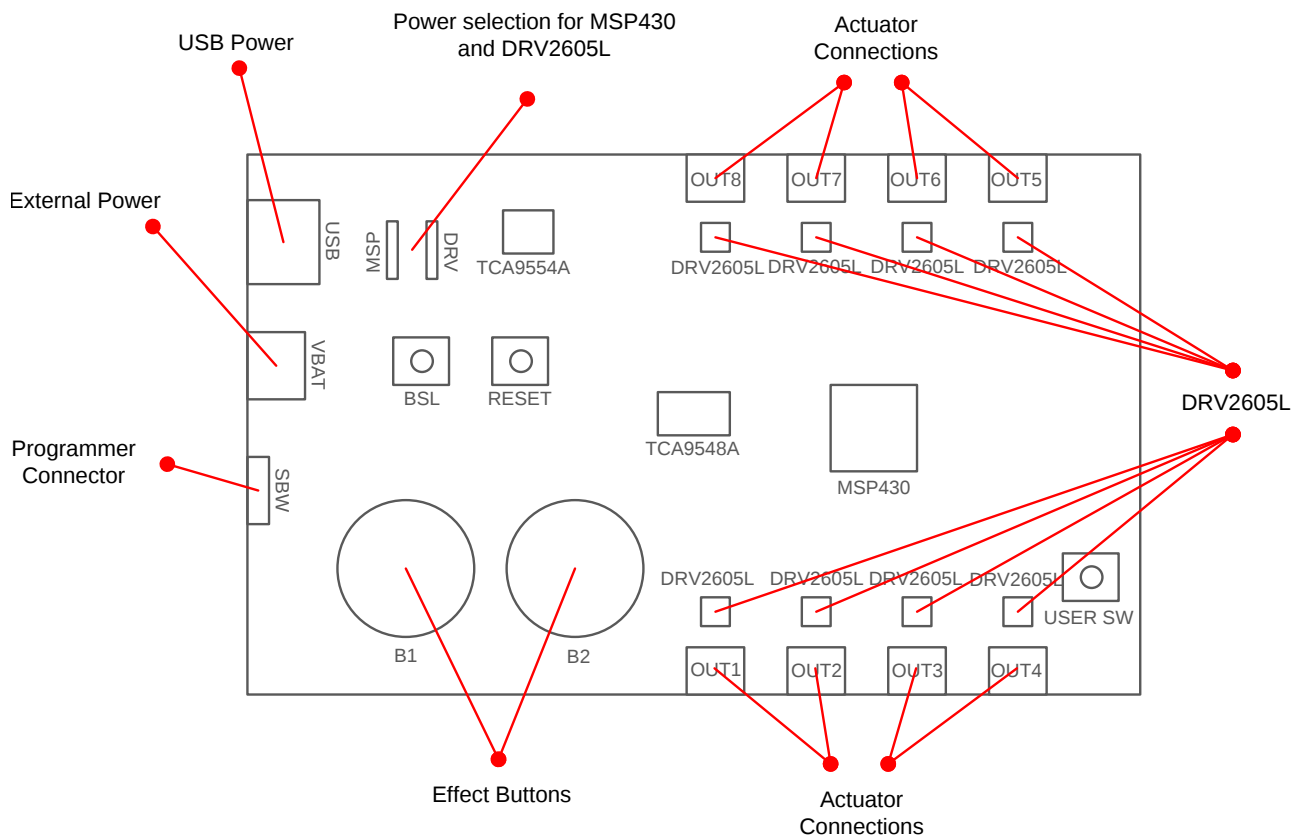


Figure 2. Board Diagram

2.1 Quick Start Board Setup

The DRV2605LEVM-MD firmware contains haptic waveform sequences that showcase the features and benefits of the DRV2605L device in a multi-driver application. Use the following setup instructions to begin the demand evaluation process:

1. Connect 4 ERM actuators to the terminal block outputs 1 through 4, and connect 4 LRA actuators to the terminal block outputs 5 through 8 on the board.
2. Connect the 5-V power supply to the VBAT terminal block.
3. Verify that the jumper connections on the board are correct as listed in [Table 1](#).
4. Turn on the power supply. If the DRV2605LEVM-MD is powered correctly, the button LEDs turn on and flash indicating that the board has been successfully initialized.

Table 1. Default Jumper Settings for Demonstration Program

JUMPER	POSITION	DESCRIPTION
J1	Shorted	Connects decoupling cap to the V _{DD} pin, used for power consumption measurements
J2	Shorted	3.3-V reference voltage for I ² C transactions on the TCA9548A device
J3	Shorted	User LED
J4	Don't care	User LED
J5	Shorted	Trigger and PWM input to the DRV2605L device
J6	Shorted	User switch
MSP	Short pins 2 to 3	VBAT power to the MSP430 device (Shown in Figure 3)
DRV	Short pins 2 to 3	VBAT power to the DRV2605L device (Shown in Figure 3)

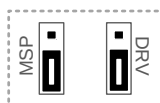


Figure 3. Jumper Position for MSP and DRV Headers

NOTE: This board has the ability to control both ERM and LRA actuators at the same time. The default firmware is set so that only the actuators that are connected to the board are active. The connected driver and the actuator type must be hardcoded in the firmware in order for the system to know the user's hardware configuration. If the default configuration of 4 ERM actuators on outputs 1 through 4 and 4 LRA actuators on outputs 5 through 8 is not desired, see [Section 3.4](#) for more details on how to customize the board.

3 DRV2605L Demonstration Program

Several functionality sections can be initiated to demonstrate how the DRV2605LEVM-MD can be used for multi-driver applications. The user can interact with the capacitive touch buttons to output a variety of waveform sequences to the actuators externally connected to the board and to enable all the drivers and I²C channels for full access to the DRV2605L devices through the I²C headers.

The user can also access USB functionality through the user switch. The capacitive touch buttons (B1 and B2) and user switch (USER SW) have the following functionality:

- B1: The DRV2605L devices are setup individually and RTP mode is configured. Sequential button presses activate the next DRV2605L device in sequential order starting at driver 1, ending at driver 8, and then looping back to driver 1.
- B2:
 - Mode 1 – Enables all of the drivers and channels of the TCA9548A device for the user to gain access to all of the DRV2605L devices.
 - Mode 2 – Drivers 1 through 4 are enabled, RTP mode is setup, and all drivers are played simultaneously

- Mode 3 – Drivers 5 through 8 are enabled, RTP mode is setup, and all drivers are played simultaneously
- Mode 4 – Driver 1 through 4 are setup in RTP mode, played sequentially in order, and then briefly played simultaneously.
- Mode 5 – Driver 5 through 8 are setup in RTP mode, played sequentially in order, and then briefly played simultaneously.
- USER SW: Turns on USB communication and disables capacitive touch buttons

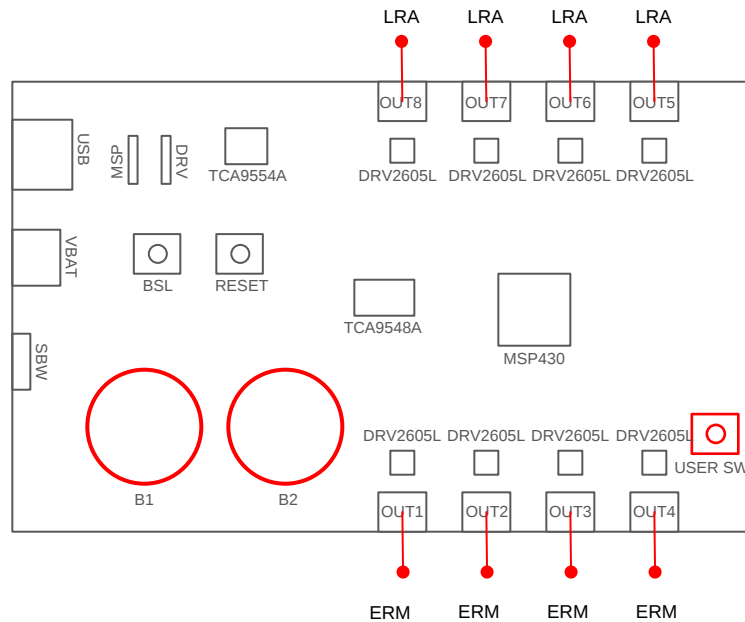


Figure 4. Board With Actuator Setup

Figure 4 shows the actuator setup of where the LRAs and ERMs are connected to the board. B1 and B2 are the capacitive touch buttons that, when pressed, play the waveform sequence as described in [Section 3.1](#) and [Section 3.2](#).

3.1 Button 1

For button 1, each of the DRV2605L devices is independently setup for RTP mode at full magnitude 0x7F and played sequentially. Each press of the capacitive touch button plays the next driver. The TCA9548A device (I²C switch) is configured so that only the corresponding DRV2605L device is connected to the master input I²C bus. When the configuration is complete, default register settings, RTP mode, and the RTP magnitude are sent to the DRV2605L device. After some time, the RTP mode shuts off.

3.2 Button 2

Button2 has 5 modes that can be accessed through sequential button presses. The user must sequentially cycle through all of the other modes to get back into the same mode.

3.2.1 Mode 1

Mode 1 allows the user full access to all of the DRV2605L devices on the board by enabling them and connecting all of the I²C lines. An external host processor can be connected to the I²C headers to allow communication to the DRV2605L devices without having to use the on-board MSP430F5510.

3.2.2 Mode 2 and Mode 3

Mode 2 and mode 3 enable and connect the I²C lines for drivers 1 through 4 and drivers 5 through 8, respectively. The four DRV2605L devices are sent the same default initialization settings for the ERM actuators (Mode 2) and LRA actuators (Mode 3). The drivers are then setup in RTP mode with magnitude 0x7F. The waveform plays for 2 s and then the drivers are changed to internal trigger mode (to stop RTP mode).

3.2.3 Mode 4 and Mode 5

Mode 4 and mode 5 enable and connect the I²C lines for drivers 1 through 4 and drivers 5 through 8, respectively. The four DRV2605L devices are sent the same default initialization settings for ERM actuators (Mode 4) and LRA actuators (Mode 5). When the settings are received by the DRV2605L devices, each DRV2605L device is individually enabled sequentially and setup for RTP mode with magnitude 0x7F at a 500-ms interval. Driver 1 or 5 outputs the RTP waveform for 500 ms, then the next sequential drivers (driver 2 or 6, 3 or 7, 4 or 8) repeat the same conditions as driver 1. As soon as driver 4 or 8 completes the waveform output, all drivers exit of RTP mode for 100 ms and then enter RTP mode with magnitude 0x7F for 100 ms to create a brief pulse action.

3.3 User Switch

At board startup, the capacitive touch buttons are automatically enabled and USB communication is disabled even though USB communication was initialized. To enter USB communication for use with the multi-driver graphical user interface (GUI), the user switch must be pressed. LED1 turns to indicate that the firmware is active for USB transactions. When the user switch is pressed and the board is in USB communication mode, the capacitive touch buttons are disabled. A power cycle or software reset is required to go back to capacitive-touch mode.

3.4 Firmware Modifications

Before the board can accept any combination of LRA and ERM actuators connected to the DRV2605L devices, the firmware is required to be modified because it must know which actuators are connected to which haptic drivers. Additional hardware-like dip switches are required to detect real-time changes with actuators or enable the drivers. The header file, *haptics.h*, contains the definitions of driver 1 through driver 8, and actuator 1 through actuator 8 which are mapped to arrays that are used in haptic methods as follows:

- Haptics_DriversEnableConfig()
- Haptics_EnableAvailableDrivers()
- Haptics_ActuatorTypeConnected()
- Haptics_SwitchAvailableDrivers()

The driver definitions can be either *CONNECTED* or *NOT_CONNECTED*. The actuator definitions can be either *ACTUATOR_ERM* or *ACTUATOR_LRA*. When each definition is defined properly, the methods provided configure the TCA9554A and TCA9548A devices to enable the DRV2605L devices and connect the I²C lines of the drivers to the master I²C bus properly.

4 Measurement and Analysis—Waveform Sequences

The DRV2605L device uses PWM modulation to create the output signal for both ERM and LRA actuators. To measure and observe the DRV2605L output waveform, connect an oscilloscope or other measurement equipment to the filtered output test points, *OUT+* and *OUT-*. Figure 5 shows the setup of the terminal block and test points used to connect external actuators and measure waveforms.

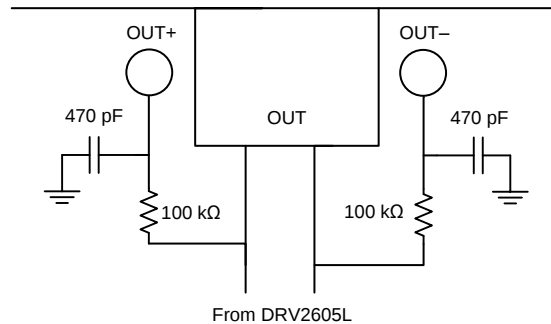


Figure 5. Terminal Block and Test Points

4.1 TripleClick and StrongClick Example Waveforms

Figure 6 displays the tripleClick waveform output for an LRA (trace C1 and C2) and the strongClick waveform for an ERM (trace C3 and C4) the same time. The differential output (trace Math) is trace C1-CT the ERM was operated in open-loop mode while the LRA was operated in auto-resonance (closed loop) mode.

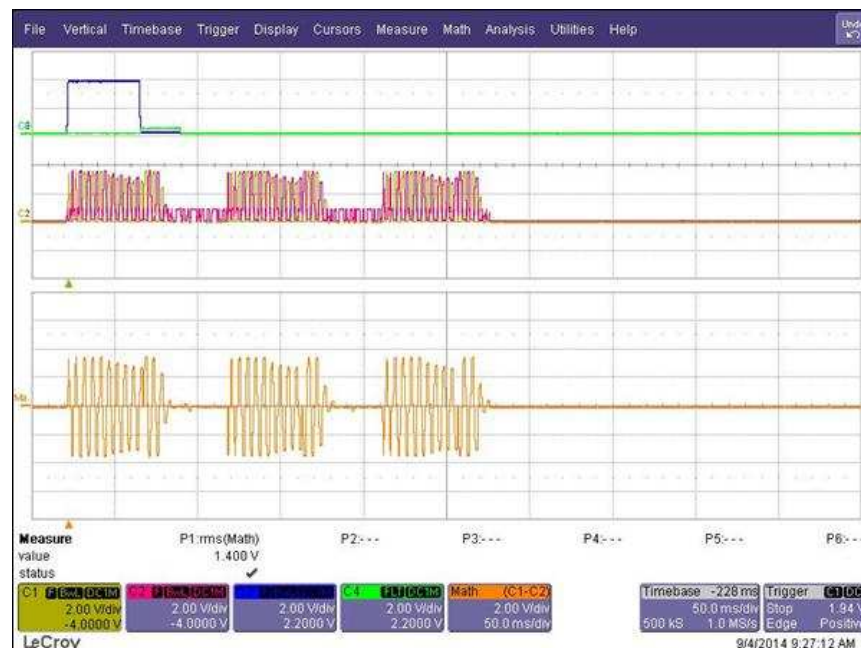


Figure 6. TripleClick and StrongClick Waveform Played at the Same Time

4.2 Pulsing Strong Example Waveforms

Figure 7 displays the pulsingStrong waveform output for an ERM (trace C1, C2). The differential output (trace Math) is trace C1-CT the ERM was operated in open-loop mode. The peak acceleration for the waveform is 156.1 mV_{pp} or 1.37 G.



Figure 7. Pulsing Strong waveform for ERM in Open-Loop Mode

4.3 Strong Buzz Example Waveforms

Figure 8 and Figure 9 show the output waveform (trace C1 and C2), the differential output (trace Math), and the acceleration profile (trace C4) for the buzz waveform. Figure 8 displays the waveform in auto-resonance mode while Figure 9 displays the same waveform in open-loop mode. Auto-resonance mode allows the acceleration profile to have a higher peak acceleration at a lower V_{RMS} voltage.



Figure 8. Strong Buzz Waveform for LRA in Auto-Resonance Mode



Figure 9. Strong Buzz Waveform for LRA in Open-Loop Mode

5 TCA9554 - I²C GPIO Expander

The TCA9554 GPIO expander is used to enable the DRV2605L device. Because the multi-driver board has the ability to control up to 8 haptic drivers, the TCA9554 device is able to control the enable lines of the DRV2605L device through I²C and free up GPIO pin space on the MSP430F5510 device for other peripherals. The following pseudo code shows how the TCA9554 device is used as an output configuration.

```
I2C_SetSlaveAddr(TCA9554_SLAVE_ADDR) //setslave address
I2C_WriteSingleByte(0x03, ~(bit_set_for_output)) //configure as output port
I2C_WriteSingleByte(0x01, output_bits) //output values
```

The TCA9554 device is configured completely through I²C commands. The expander must be configured as an output port for the corresponding drivers (8 drivers). The output port command register is 0x03. Each bit of the 8-bit value represents the 8 output ports of the device. A value of zero in each bit corresponds to an output configuration. The variable, *bit_set_for_output*, has the respective bits set as outputs. When the output port is configured, register 0x03 does not need to be accessed unless those ports will be used as some other port function. After the ports are configured as outputs, a write command to register 0x01 is used to set the value of the output to either 0 or 1. The default values for outputs are initialized to 0. See the TCA9554 data sheet, [SCPS233](#), for more information on the TCA9554 device.

5.1 I²C Register Value Examples

The following examples listed in [Table 2](#) and [Table 3](#) show exact I²C transactions with slave addresses, registers, and values to enable one DRV2605L device and to enable three or more DRV2605L devices.

Table 2. TCA9554 I²C Transaction for Enabling driver 1

	I ² C Action	Slave Address (7-bit)	Register	Value	Description
1	Write	0x20	0x03	0xFE	Configures IO expander for output port at channel 1
2	Write	0x20	0x01	0x01	Sends a high signal to output channel 1

Table 3. TCA9554 I²C Transaction for Enabling drivers 1, 4, 5, and 8

	I ² C Action	Slave Address (7-bit)	Register	Value	Description
1	Write	0x20	0x03	0x66	Configures IO expander for output port at channel 1, 4, 5, and (corresponds to drivers 1, 4, 5, 8).
2	Write	0x20	0x01	0x99	Sends a high signal to output channel 1, 4, 5, and (corresponds to drivers 1, 4, 5, 8).

6 TCA9548A - I²C Switch

The DRV2605LEVM-MD is designed for multi-driver applications. The TCA9548A I²C switch was used to independently setup haptic drivers and play the waveforms simultaneously. The pseudo code listed in the following code allows the user to verify proper operation of the I²C switch and communication with the DRV2605L device.

```
I2C_SetSlaveAddr(TCA9548_SLAVE_ADDR) //setslave address
I2C_WriteSingleByte(driver_position) //channelselection
```

This code lists the sequence for how to command the TCA9548A I²C switch. Any combination of channels can be selected. When the slave address of the TCA9548A device is set, a single byte is required to initialize channel selection. No register address is needed to send the channel selection value, but if a register input must be available for the I²C write function, use the data value as the register value because the device will take the last byte sent to it.

6.1 I²C Register Value Examples

The examples listed in Table 4 and Table 5 show exact I²C transactions with slave addresses, registers, and values to enable one DRV2605L device and to enable three or more DRV2605L devices.

Table 4. TCA9548A I²C Transaction for Enabling Driver 1

	I ² C Action	Slave Address (7-bit)	Register	Value	Description
1	Write	0x70	N/A	0x01	Configures I ² C switch to connect channel 1 I ² C lines

Table 5. TCA9548A I²C Transaction for Enabling Driver 1, 4, 5, and 8

	I ² C Action	Slave Address (7-bit)	Register	Value	Description
1	Write	0x70	N/A	0x99	Configures I ² C switch to contact channel 1, 4, 5, and (corresponds to drivers 1, 4, 5, 8).

6.2 Operation Analysis

The TCA9548A operation can be verified with a logic analyzer hooked up to the master I²C bus input into the device and to the channel outputs. Figure 10 shows the data and clock lines of the I²C commands to the switch and to the GPIO expander to show proper operation of the devices together.



Figure 10. TCA9548A Logic Analyzer Operation

The TCA9554 device is first configured for output ports for drivers 6 and 7 with a value of 1 at the output. The TCA9548A device is switched to driver 7 (channel 8) and sent a read command to the DRV2605L device to verify communication with the haptic driver. The switch is then configured to select driver 6 (channel 7) and is then sent the same read command. Figure 10 shows proper operation of the switch in the case of isolating specific channels.

7 Power Supply Selection

The DRV2605LEVM-MD can be powered by USB or an external power supply (VBAT). Jumpers *DRV* and *MSP* are used to select USB or VBAT for the DRV2605L and MSP430F5510 devices, respectively. [Table 6](#) lists the different supply configurations and supply voltages that the DRV2605L devices and MSP430 device could have.

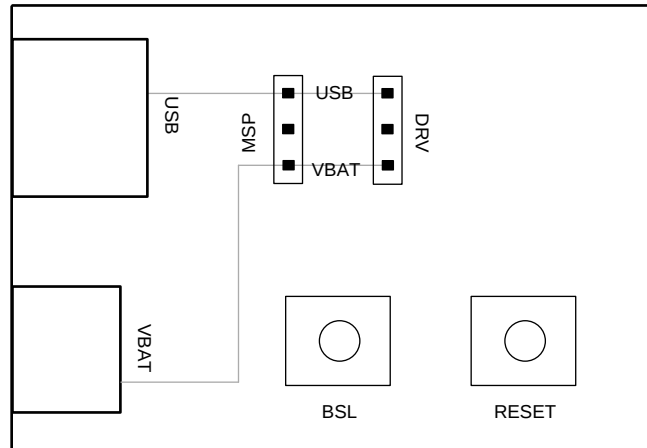


Figure 11. Power Jumper Selection

Table 6. Power Jumper Selection Options

SUPPLY CONFIGURATION	DRV	MSP	DRV2605L SUPPLY VOLTAGE
USB – both	USB	USB	5-V USB
DRV2605L external supply, MSP430 USB	VBAT	USB	VBAT
DRV2605L USB, MSP430 external supply	USB	VBAT	5-V USB
External Supply - both	VBAT	VBAT	VBAT

Because USB protocol allows for 500 mA per port, a conservative estimate allows two to three actuators and drivers to be operated with USB power (150 to 200 mA worst case per driver or actuator, depending on the actuator). If more actuators are required, use the VBAT terminal to ensure adequate power for the entire system.

8 Typical Usage Examples

8.1 Play a Waveform or Waveform Sequence from ROM Memory

1. Configure the TCA9554 channels as output ports and enable the appropriate DRV2605L devices by asserting the output pin (logic high).
2. Configure the TCA9548A device to select the appropriate channel that is connected to the desired DRV2605L I²C data and clock lines.
3. Initialize the DRV2605L device as listed in the *Initialization Procedure* section of the DRV2605L datasheet, .
4. Select the desired MODE[2:0] bit value of 0 (internal trigger), 1 (external edge trigger), or 2 (external level trigger) in the MODE register (address 0x01). If the STANDBY bit was previously asserted then it should be de-asserted (logic low) at this time. If register 0x01 already holds the desired value and the STANDBY bit is low, the user can skip this step.
5. Select the waveform index to be played and write it to address 0x04. Alternatively, a sequence of waveform indices can be written to register 0x04 through 0x0B. See the *Waveform Sequencer* section of the DRV2605L data sheet for details.

6. If using the internal trigger mode, set the Go bit (in register 0x0C) to fire the effect or sequence of effects. If using an external trigger mode, send an appropriate trigger pulse to the IN/TRIG pin. See the *Waveform Triggers* section of the DRV2605L datasheet for details.
7. If desired, the user can repeat step 5 to figure the effect or sequence again.
8. Put the device in low-power mode by deasserting the EN pin through the TCA9554 device to set the STANDBY bit.

NOTE: To send the same commands to multiple DRV2605L devices at the same time, configure the TCA9554 and TCA9548A devices to the appropriate channel selections. I²C write functions can be sent to multiple DRV2605L device, but I²C read functions for each DRV2605L device must be read individually. One issue with write functions is the inability to properly determine whether multiple DRV2605L devices are ACK (acknowledge) or NACK (not acknowledge) if the same command was sent, however writing actual bytes to the DRV2605L is not a problem. The bus acts as an AND bus and logic zero takes priority.

Table 7 lists examples of the I²C transactions that are required to play a triple click (100%) waveform using driver 1 in LRA, closed-loop mode. The yellow highlighted rows indicate auto-calibration mode and obtaining the results for the auto-calibration compensation and back-EMF results (if required to be performed for the first time).

Table 7. I²C Transaction Example of Playing a Triple Click Waveform Using Driver1 in LRA, Closed Loop mode

	I ² C ACTION	DEVICE	SLAVE ADDRESS (7-BIT)	REGISTER	VALUE	DESCRIPTION
1	Write	TCA9554	0x20	0x03	0xFE	Configures IO expander for output port at channel 1
2	Write	TCA9554	0x20	0x01	0x01	Sends a high signal to output channel 1
3	Write	TCA9548A	0x70	N/A	0x01	Configures I ² C switch to connect channel 1 I ² C lines
4	Write	DRV2605L	0x5A	0x16	0x53	Set rated voltage (2 V _{RMS})
5	Write	DRV2605L	0x5A	0x17	0xA4	Set overdrive clamp voltage (3.6-V peak)
6	Write	DRV2605L	0x5A	0x01	0x07	Change mode to AutoCalibration
7	Write	DRV2605L	0x5A	0x1E	0x20	Set AutoCalTime to 500 ms
8	Write	DRV2605L	0x5A	0x0C	0x01	Set GO Bit
9	Read	DRV2605L	0x5A	0x0C		Poll GO Bit until it clears to 0
12	Write	DRV2605L	0x5A	0x1A	0xB6	Set feedback control register
13	Write	DRV2605L	0x5A	0x1B	0x93	Set control 1 register
14	Write	DRV2605L	0x5A	0x1C	0xF5	Set control 2 register
15	Write	DRV2605L	0x5A	0x1D	0x80	Set control 3 register
16	Write	DRV2605L	0x5A	0x01	0x00	Set mode to internal trigger
17	Write	DRV2605L	0x5A	0x04	0x0C	Set waveform sequence 1 as triple-click waveform
18	Write	DRV2605L	0x5A	0x05	0x00	Indicator that there is only one waveform that should be played
19	Write	DRV2605L	0x5A	0x0C	0x01	Set GO bit
20	Read	DRV2605L	0x5A	0x0C		Poll GO bit until it clears to 0
21	Write	TCA9554	0x20	0x00	0x00	Deassert the EN pin for driver 1
22	Write	TCA9548A	0x70	N/A	0x00	No driver I ² C channels connected

9 Programming the MSP430

9.1 Bootstrap Loader Method

The following items are required to program the board using the bootstrap loading (BSL) method:

- Mini USB cable
- MSP430 USB firmware upgrade which is found in the MSP430 USB developers package (www.ti.com/tool/msp430usbdevpack)
- Code Composer Studios (CCS)

Use the following steps to program the board using the BSL method:

1. Open the firmware project in CCS and go to the build menu of the properties window as shown in [Figure 12](#).
2. Under the *Steps* tab of the build menu and in the *Apply Predefined Step* drop-down, select *Create flash image: TI-TXT* as shown in [Figure 12](#).

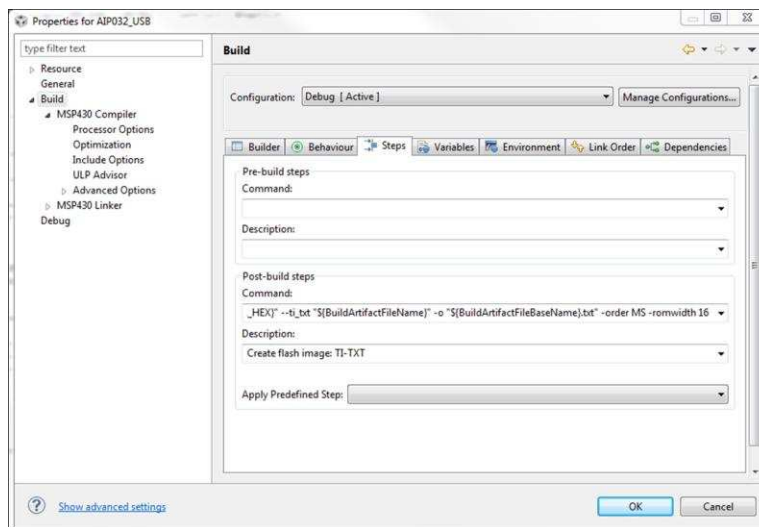


Figure 12. CCS Create Flash Image

3. Rebuild the project. The text image file can be found in debug folder with the name AIP032.txt
4. Hold the BSL button on the DRV2605LEVM-MD and connect the EVM to the computer through the USB mini cable to initiate it as a USB device.
5. Open up the MSP430 USB Firmware Uploader. If it does not say *ready* on the screen then retry the BSL powerup sequence again.
6. Go to *file* and select *open user firmware* to locate the text image file ([Figure 13](#) shows an example of a successful firmware update process).
7. Cycle the power on the board to restart the firmware.

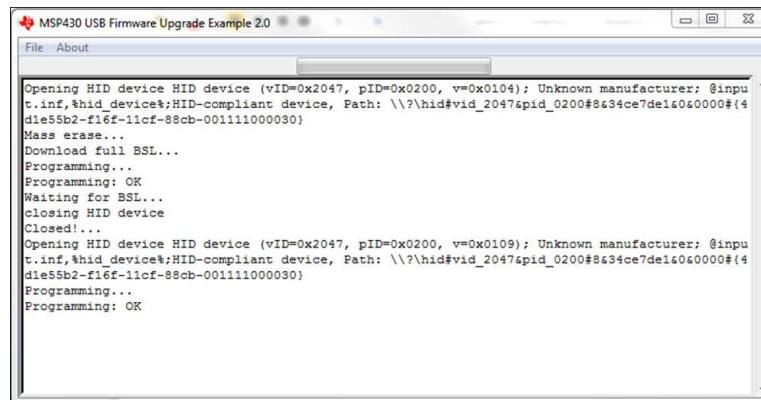


Figure 13. MSP430 USB Firmware Uploader Programming Sequence

9.2 Spy-By-Wire Method

The following items are required to program the board using the spy-by-wire (SBW) method.

- Mini USB cable
- MSP-JTAG2SBW Adapter
- MSP-FET430UIF Hardware Debugging Interface
- Code Composer Studios (CCS)

Use the following steps to program the board using the SBW method:

1. Connect the MSP-JTAG2SBW adapter to the SBW connector on the board
2. Connect the MSP-FET430UIF to the MSP-JTAG2SBW adapter.
3. Open up the firmware project in CCS.
4. Verify that the general-build properties are set as shown in [Figure 14](#).
5. Right click on the project title folder under the *project explorer* and click *build project* to ensure that no errors exist.
6. If no errors exist, select *RUN* → *DEBUG* in the title bar.
7. Exit the debugger when the firmware has been uploaded to the board.

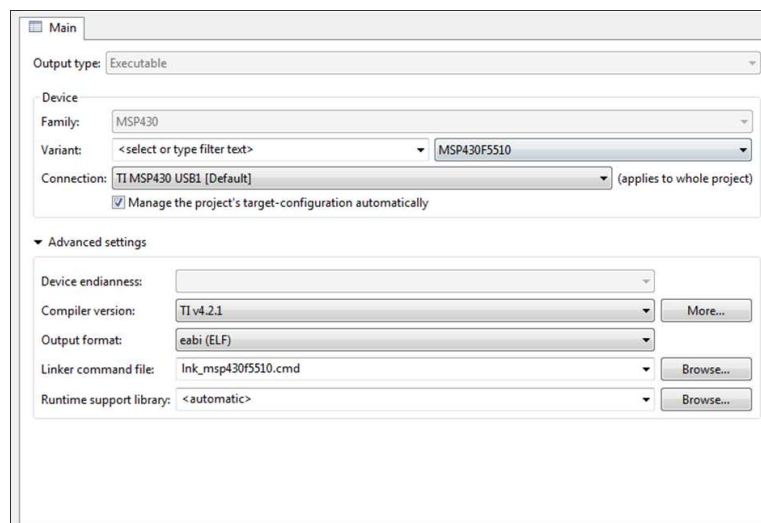


Figure 14. Build Properties of Firmware Project

9.3 MSP430 Pinout

Table 8 lists the pin functions the MSP430F5510 device. The yellow highlighted rows indicate pins that are used by the board. The non-highlighted rows indicate unused pins. All GPIO pins that are not highlighted are broken out to standard 100-mil pitch headers for prototype development and evaluation.

Table 8. Used and Unused Pins on the MSP430F5510

PIN		DESCRIPTION
NO.	NAME	
1	P6.0/CB0/A0	Button 1
2	P6.1/CB1/A1	Button 2
3	P6.2/CB2/A2	
4	P6.3/CB3/A3	
5	P6.4/CB4/A4	
6	P6.5/CB5/A5	
7	P6.6/CB6/A6	
8	P6.7/CB7/A7	
9	P5.0/A8	
10	P5.1/A9	
11	AVCC1	3.3 V
12	P5.4/XIN	XIN, 32.768-kHz crystal
13	P5.5/XOUT	XOUT, 32.768-kHz crystal
14	AVSS1	GND
15	DVCC1	3.3 V
16	DVSS1	GND
17	VCORE	Decoupling capacitor for VCore
18	P1.0/TA0CLK	
19	P1.1/TA0.0	
20	P1.2/TA0.1	
21	P1.3/TA0.2	
22	P1.4/TA0.3	
23	P1.5/TA0.4	
24	P1.6/TA1CLK/CBOUT	COMP_OUT, Feedback from B1 and B2 captouch
25	P1.7/TA1.0	
26	P2.0/TA1.1	
27	P2.1/TA1.2	
28	P2.2/TA2CLK/SMCLK	
29	P2.3/TA2.0	
30	P2.4/TA2.1	PWM, can be disconnected
31	P2.5/TA2.2	
32	P2.6/RTCCLK/DMAE0	
33	P2.7/UCB0STE/UCA0CLK	
34	P3.0/UCB0SIMO/UCB0SDA	
35	P3.1/UCB0SOMI/UCB0SCL	
36	P3.2/UCB0CLK/UCA0STE	
37	P3.3/UCA0TXD/UCA0SIMO	
38	P3.4/UCA0RXD/UCA0SOMI	
39	DVSS2	GND
40	DVCC2	3.3 V
41	P4.0/PM_UCB1STE/PM_UCA1CLK	
42	P4.1/PM_UCB1SIMO/PM_UCB1SDA	SDA_IN
43	P4.2/PM_UCB1SOMI/PM_UCB1SCL	SCL_IN
44	P4.3/PM_UCB1CLK/PM_UCA1STE	
45	P4.4/PM_UCA1TXD/PM_UCA1SIMO	
46	P4.5/PM_UCA1RXD/PM_UCA1SOMI	

Table 8. Used and Unused Pins on the MSP430F5510 (continued)

PIN		DESCRIPTION
NO.	NAME	
47	P4.6/PM_NONE	
48	P4.7/PM_NONE	
49	VSSU	GND
50	PU.0/DP	USB_DP, data+
51	PUR	PUR, BSL switch
56	AVSS2	GND
57	P5.2/XT2IN	XT2IN, 24-MHz oscillator
58	P5.3/XT2OUT	XT2OUT, 24-MHz oscillator
59	TEST/SBWTCK	SBWTCK, SBW programmer conn.
60	PJ.0/TDO	B1LED
61	PJ.1/TDI/TCLK	B2LED
62	PJ.2/TMS	USER LED1, can be disconnected
63	PJ.3/TCK	USER LED2, can be disconnected
64	nRST/NMI/SBWDIO	ResistorET button, SBW programmer
65	QFN PAD	GND

10 Layout

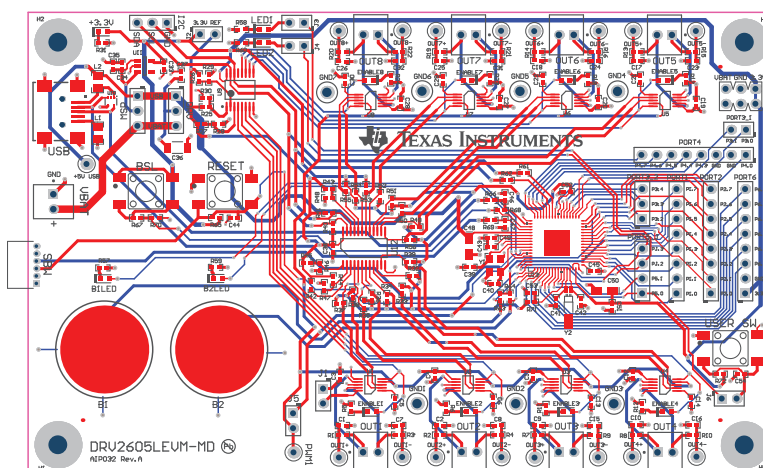


Figure 15. Xray Image of Top and Bottom Layer Traces

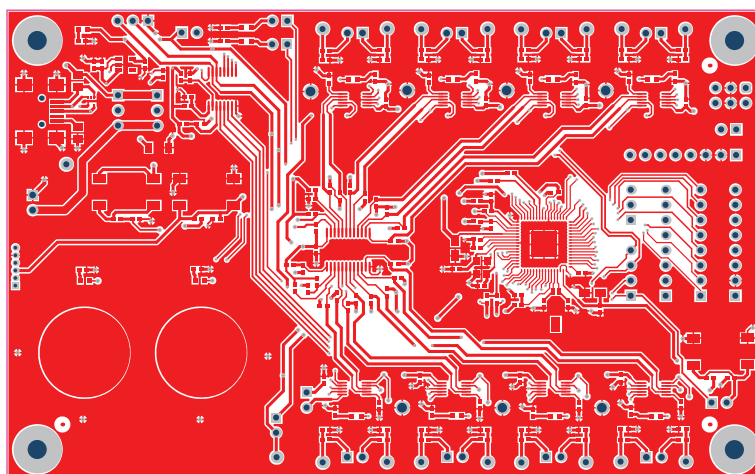


Figure 16. Top Layer

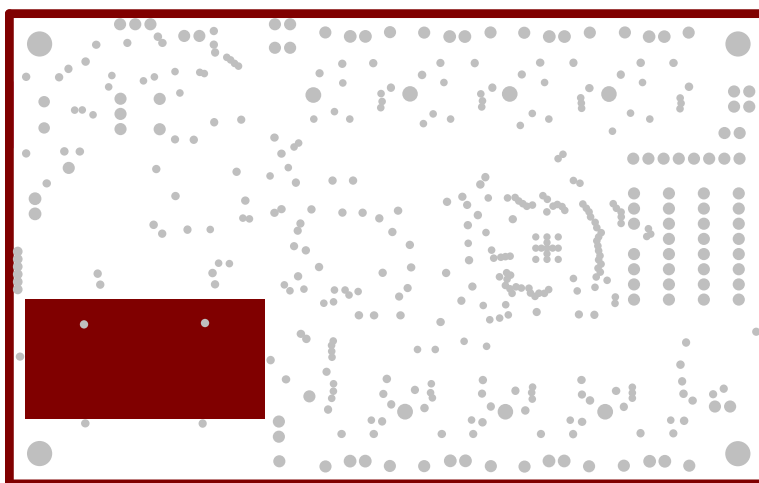


Figure 17. Middle Power Layer

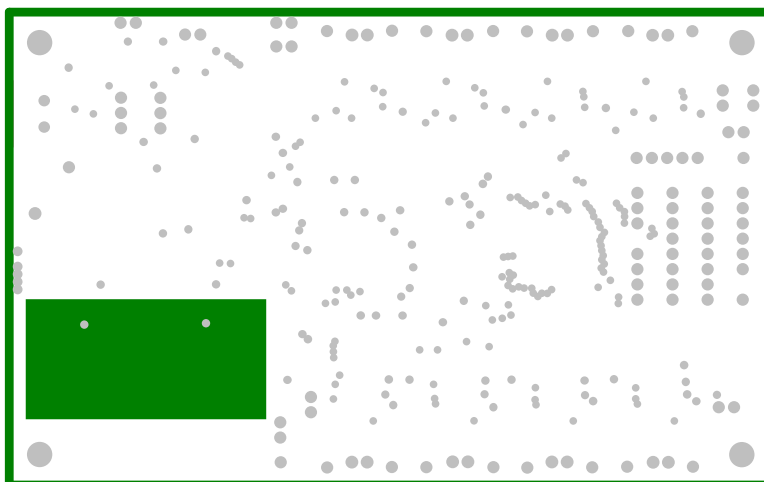


Figure 18. Middle Ground Layer

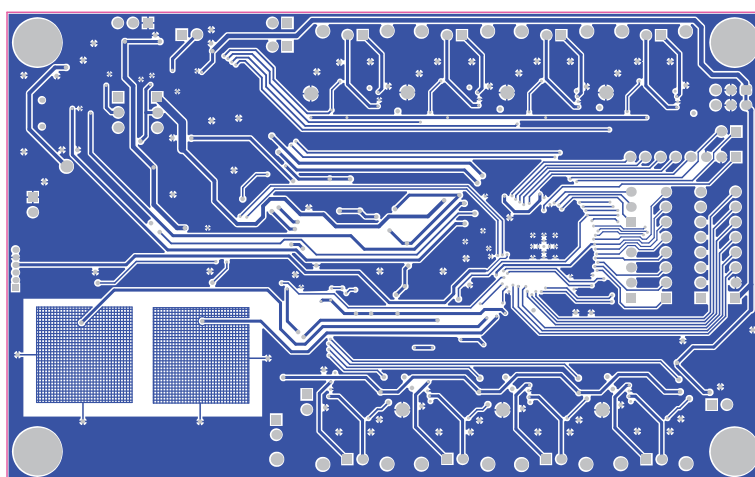


Figure 19. Bottom Layer

11 Schematic

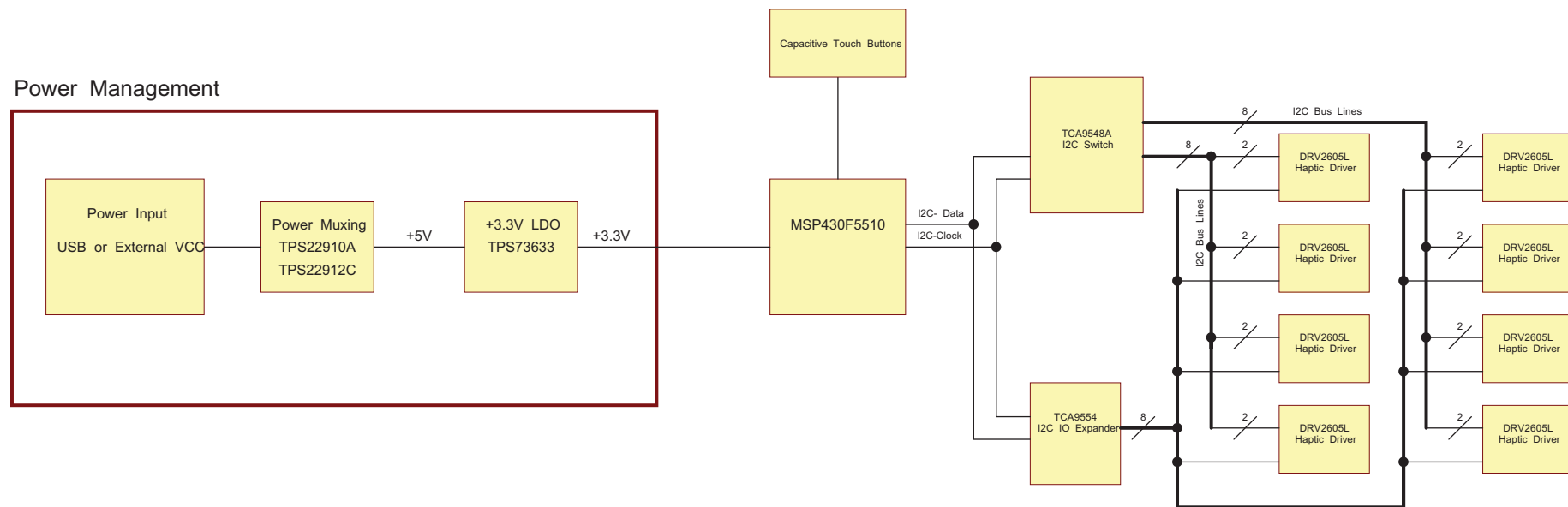


Figure 20. Schematic Block Diagram

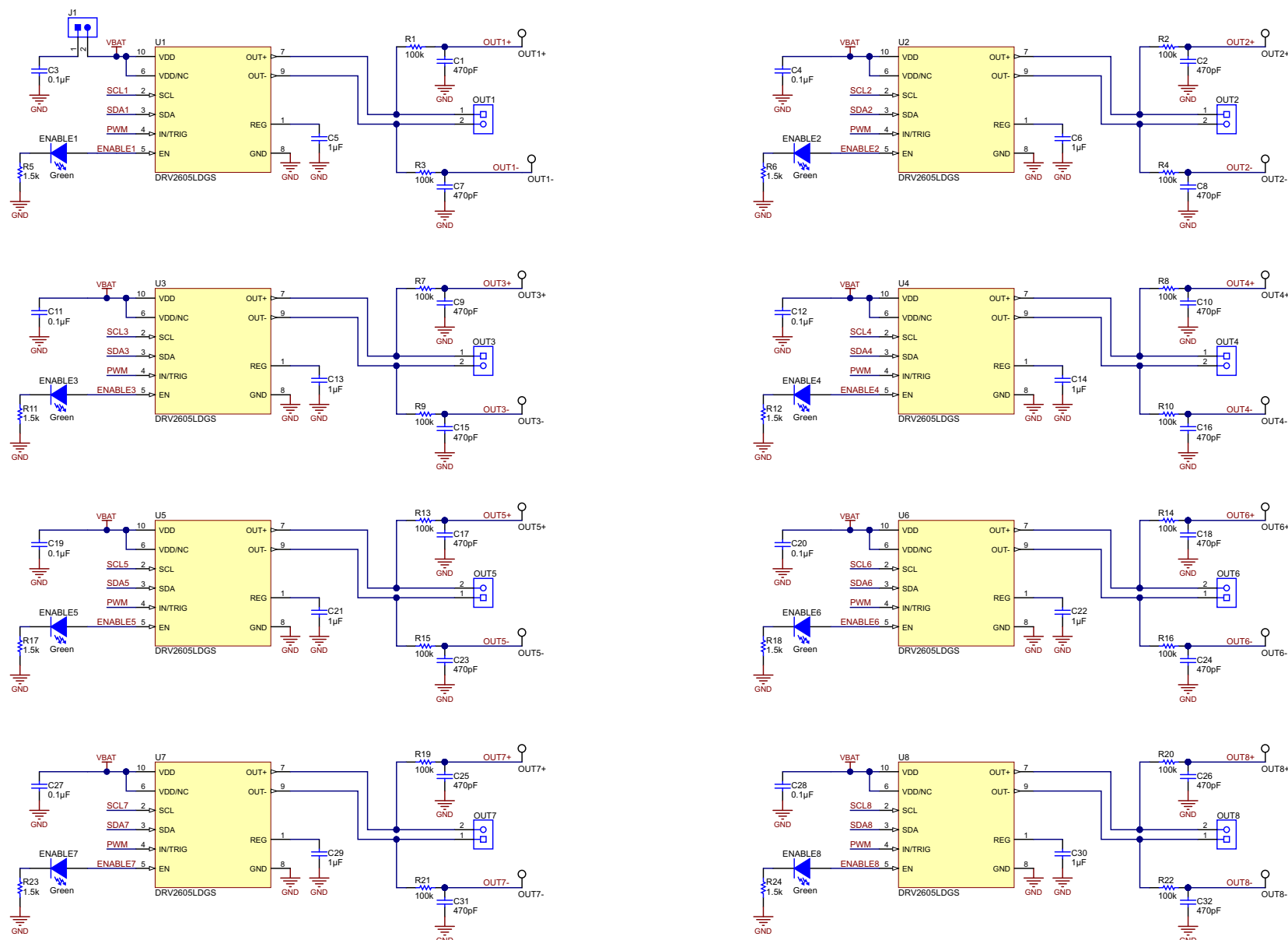


Figure 21. Schematic Page 1

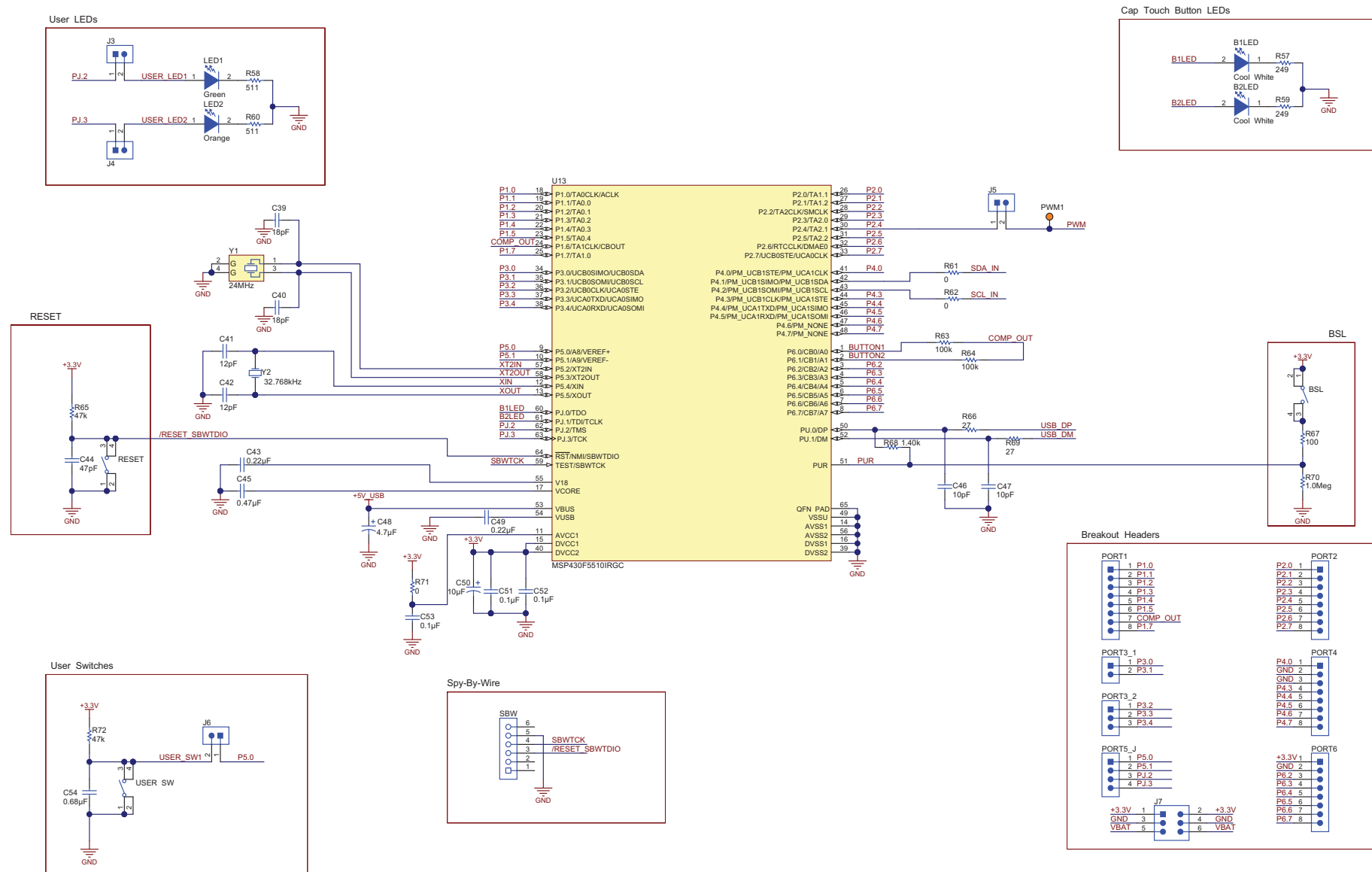
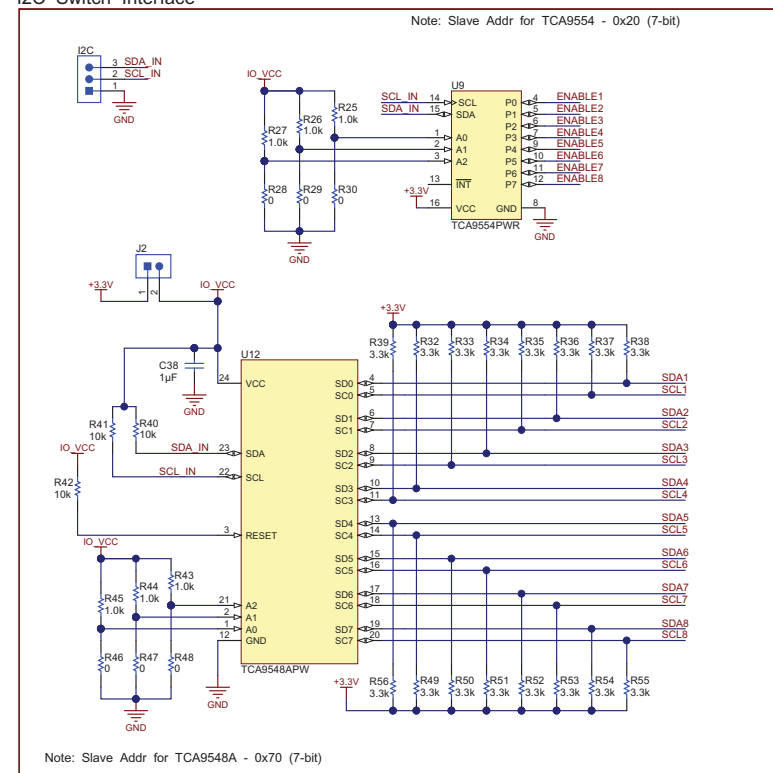


Figure 22. Schematic Page 2



12 Bill Of Materials

DESIGNATOR	QTY.	VALUE	PART NUMBER	DESCRIPTION	PACKAGE	MANUFACTURER
+3.3V, ENABLE1, ENABLE2, ENABLE3, ENABLE4, ENABLE5, ENABLE6, ENABLE7, ENABLE8, LED1	10	Green	LTST-C190GKT	LED, green, SMD	1.6 × 0.8 × 0.8 mm	Lite-On
5 V USB	1	Red	5000	Test point, miniature, red, TH	Red miniature test point	Keystone
B1LED, B2LED	2	Cool White	LNJ037X8ARA	LED, cool white, SMD	0603 LED	Panasonic
BSL, ResistorET, USER SW	3		4-1437565-1	Switch, tactile, SPST-NO, 0.05-A, 12-V, SMT	SW, SPST 6 × 6 mm	TE Connectivity
C1, C2, C7, C8, C9, C10, C15, C16, C17, C18, C23, C24, C25, C26, C31, C32	16	470 pF	GRM155R71H471KA01D	Capacitor, ceramic, 470-pF, 50-V, ±10%, X7R, 0402	0402	MuRata
C3, C4, C11, C12, C19, C20, C27, C28, C51, C52, C53	11	0.1 µF	GRM155R61C104KA88D	Capacitor, ceramic, 0.1-µF, 16-V, ±10%, X5R, 0402	0402	MuRata
C5, C6, C13, C14, C21, C22, C29, C30, C38	9	1 µF	C1005X5R1E105K050BC	Capacitor, ceramic, 1-µF, 25V, ±10%, X5R, 0402	0402	TDK
C33, C34, C37	3	1 µF	GRM155R61A105KE15D	Capacitor, ceramic, 1-µF, 10-V, ±10%, X5R, 0402	0402	MuRata
C35	1	0.1 µF	GRM155R61A104KA01D	Capacitor, ceramic, 0.1-µF, 10-V, ±10%, X5R, 0402	0402	MuRata
C36	1	100 µF	C3216X5R1A107M160AC	Capacitor, ceramic, 100-µF, 10-V, ±20%, X5R, 1206_190	1206_190	TDK
C39, C40	2	18 pF	GRM1555C1H180JA01D	Capacitor, ceramic, 18-pF, 50-V, ±5%, C0G/NP0, 0402	0402	MuRata
C41, C42	2	12 pF	GRM1555C1H120JA01D	Capacitor, ceramic, 12-pF, 50-V, ±5%, C0G/NP0, 0402	0402	MuRata
C43, C49	2	0.22 µF	GRM155R71C224KA12D	Capacitor, ceramic, 0.22-µF, 16-V, ±10%, X7R, 0402	0402	MuRata
C44	1	47 pF	GRM1555C1H470JZ01	Capacitor, ceramic, 47-pF, 50-V, ±5%, C0G/NP0, 0402	0402	MuRata
C45	1	0.47 µF	GRM155R61C474KE01	Capacitor, ceramic, 0.47-µF, 16-V, ±10%, X5R, 0402	0402	MuRata
C46, C47	2	10 pF	GRM1555C1H100JA01D	Capacitor, ceramic, 10-pF, 50-V, ±5%, C0G/NP0, 0402	0402	MuRata
C48	1	4.7 µF	TPSA475K010R1400	Capacitor, TA, 4.7uF, 10-V, ±10%, 1.4 Ω, SMD	3216-18	AVX
C50	1	10 µF	TPSA106K010R0900	Capacitor, TA, 10-µF, 10-V, ±10%, 0.9 Ω, SMD	3216-18	AVX
C54	1	0.68 µF	GRM155R61A684KE15D	Capacitor, ceramic, 0.68-µF, 10-V, ±10%, X5R, 0402	0402	MuRata
DRV, I1, MSP, PORT3_2	4		5-146278-3	Header, 100-mil, 3 × 1, tin, TH	Header, 3 × 1, 100-mil, TH	TE Connectivity
GND1, GND2, GND3, GND4, GND5, GND6, GND7	7	Black	5011	Test point, multipurpose, black, TH	Black multipurpose test point	Keystone
H1, H2, H3, H4	4		NY PMS 440 0025 PH	Machine screw, round, #4-40 × 1/4, nylon, Philips panhead	Screw	B&F Fastener Supply
H5, H6, H7, H8	4		1902C	Standoff, hex, 0.5"L #4-40 nylon	Standoff	Keystone
J1, J2, J3, J4, J5, J6, PORT3_1	7		5-146278-2	Header, 100-mil, 2 × 1, Tin, TH	Header, 2 × 1, 100-mil, TH	TE Connectivity
J7	1		5-146254-3	Header, 100-mil, 3 × 2, Tin, TH	Header, 100-mil, 3 × 2, TH	TE Connectivity
L1, L2	2	600 Ω	MPZ2012S601A	Ferrite bead, 600-Ω at 100 MHz, 2-A, 0805	0805	TDK
LED2	1	Orange	LTST-C190KFKT	LED, orange, SMD	1.6 × 0.8 × 0.8 mm	Lite-On
OUT1+, OUT1-, OUT2+, OUT2-, OUT3+, OUT3-, OUT4+, OUT4-, OUT5+, OUT5-, OUT6+, OUT6-, OUT7+, OUT7-, OUT8+, OUT8-	16	White	5002	Test point, miniature, white, TH	White Miniature Testpoint	Keystone
OUT1, OUT2, OUT3, OUT4, OUT5, OUT6, OUT7, OUT8, VBAT	9		282834-2	Terminal block, 2 × 1, 2.54mm, TH	Terminal Block, 2 × 1, 2.54-mm, TH	TE Connectivity
PORT1, PORT2, PORT4, PORT6	4		5-146278-8	Header, 100-mil, 8 × 1, Tin, TH	Header, 8 × 1, 100-mil, TH	TE Connectivity
PORT5_J	1		5-146278-4	Header, 100-mil, 4 × 1, Tin, TH	Header, 4 × 1, 100-mil, TH	TE Connectivity

Bill Of Materials

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DESIGNATOR	QTY.	VALUE	PART NUMBER	DESCRIPTION	PACKAGE	MANUFACTURER
PWM1	1	Orange	5003	Test point, miniature, orange, TH	Orange miniature testpoint	Keystone
R1, R2, R3, R4, R7, R8, R9, R10, R13, R14, R15, R16, R19, R20, R21, R22, R63, R64	18	100 kΩ	CRCW0402100KJNED	Resistor, 100-kΩ, 5%, 0.063 W, 0402	0402	Vishay-Dale
R5, R6, R11, R12, R17, R18, R23, R24, R31	9	1.5 kΩ	CRCW04021K50JNED	Resistor, 1.5-kΩ, 5%, 0.063-W, 0402	0402	Vishay-Dale
R25, R26, R27, R43, R44, R45	0	1 kΩ	CRCW04021K00JNED	Resistor, 1-kΩ, 5%, 0.063-W, 0402	0402	Vishay-Dale
R28, R29, R30, R46, R47, R48, R61, R62, R71	9	0	CRCW04020000Z0ED	Resistor, 0-Ω, 5%, 0.063-W, 0402	0402	Vishay-Dale
R32, R33, R34, R35, R36, R37, R38, R39, R49, R50, R51, R52, R53, R54, R55, R56	16	3.3 kΩ	CRCW04023K30JNED	Resistor, 3.3-kΩ, 5%, 0.063-W, 0402	0402	Vishay-Dale
R40, R41, R42	3	10 kΩ	CRCW040210K0JNED	Resistor, 10-kΩ, 5%, 0.063-W, 0402	0402	Vishay-Dale
R57, R59	2	249 Ω	CRCW0402249RFKED	Resistor, 249-Ω, 1%, 0.063-W, 0402	0402	Vishay-Dale
R58, R60	2	511 Ω	CRCW0402511RFKED	Resistor, 511-Ω, 1%, 0.063-W, 0402	0402	Vishay-Dale
R65, R72	2	47 kΩ	CRCW040247K0JNED	Resistor, 47-kΩ, 5%, 0.063-W, 0402	0402	Vishay-Dale
R66, R69	2	27 Ω	CRCW040227R0JNED	Resistor, 27-Ω, 5%, 0.063-W, 0402	0402	Vishay-Dale
R67	1	100 Ω	CRCW0402100RJNED	Resistor, 100-Ω, 5%, 0.063-W, 0402	0402	Vishay-Dale
R68	1	1.4 kΩ	CRCW04021K40FKED	Resistor, 1.4-kΩ, 1%, 0.063-W, 0402	0402	Vishay-Dale
R70	1	1 MΩ	CRCW04021M00JNED	Resistor, 1-MΩ, 5%, 0.063-W, 0402	0402	Vishay-Dale
SBW	1		LPPB061NGCN-RC	Receptacle, 50-mil, 6 × 1, R/A, TH	6 × 1 receptacle	Sullins Connector Solutions
U1, U2, U3, U4, U5, U6, U7, U8	8		DRV2605LDGS	DRV2605LDGS, DGS0010A	DGS0010A	Texas Instruments
U9	1		TCA9554PWR	Remote 8-bit I ² C and SMBus I/expander, 1.65 to 5.5-V, –40 to 85°C, 16-pin TSSOP (PW), green (RoHS & nSb/Br)	PW0016A	Texas Instruments
U10	1		TPD2E001IDRLRQ1	Automotive catalog low-capacitance ±15-kV ESD-protection array for high-speed data inter, 2 channels, –40 to 85°C, 5-pin SOT (DRL), Green (RoHS & nSb/Br)	DRL0005A	Texas Instruments
U11	1		TPS73633DBV	Capacitor-free, NMOS, 400-mA low-dropout regulator with reverse current protection, DBV0005A	DBV0005A	Texas Instruments
U12	1		TCA9548APW	Low voltage 8-channel I ² C switch with reset, PW0024A	PW0024A	Texas Instruments
U13	1		MSP430F5510IRGC	Mixed signal microcontroller, RGC0064B	RGC0064B	Texas Instruments
USB	1		1734035-2	Connector, receptacle, mini-USB type B, R/A, top mount SMT	USB mini type B	TE Connectivity
Y1	1		ABM8-24.000MHZ-B2-T	Crystal, 24-MHz, 18-pF, SMD	3.2 × 0.8 × 2.5-mm	Abracon Corporation
Y2	1		MS3V-T1R 32.768KHZ ±20PPM 12.5PF	Crystal, 32.768-kHz, 12.5-pF, SMD	1.4 × 1.4 × 5-mm SMD	MicrCrystal AG

STANDARD TERMS AND CONDITIONS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, or documentation (collectively, an "EVM" or "EVMs") to the User ("User") in accordance with the terms and conditions set forth herein. Acceptance of the EVM is expressly subject to the following terms and conditions.

- 1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM ("Software") shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms and conditions that accompany such Software
- 1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

- 2 *Limited Warranty and Related Remedies/Disclaimers:*

- 2.1 These terms and conditions do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.
- 2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for any defects that are caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI. Moreover, TI shall not be liable for any defects that result from User's design, specifications or instructions for such EVMs. Testing and other quality control techniques are used to the extent TI deems necessary or as mandated by government requirements. TI does not test all parameters of each EVM.
- 2.3 If any EVM fails to conform to the warranty set forth above, TI's sole liability shall be at its option to repair or replace such EVM, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

- 3 *Regulatory Notices:*

- 3.1 *United States*

3.1.1 *Notice applicable to EVMs not FCC-Approved:*

This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 Canada

3.2.1 For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

3.3 Japan

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/llds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/llds/ti_ja/general/eStore/notice_01.page

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan are NOT certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, User is required by Radio Law of Japan to follow the instructions below with respect to EVMs:

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】

本開発キットは技術基準適合証明を受けておりません。

本製品のご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。

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3.3.3 Notice for EVMs for Power Line Communication: Please see http://www.tij.co.jp/llds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。http://www.tij.co.jp/llds/ti_ja/general/eStore/notice_02.page

4 EVM Use Restrictions and Warnings:

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 Safety-Related Warnings and Restrictions:

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMS are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

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