User's Guide

DRV2625 ERM, LRA Haptic Driver Evaluation Kit

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ABSTRACT

The DRV2625 is a haptic driver designed for Linear Resonant Actuators (LRA) and Eccentric Rotating Mass (ERM) motors. It provides many features which help eliminate the design complexities of haptic motor control including reduced solution size, high efficiency output drive, closed-loop motor control, quick device startup, memory for waveform storage, and auto-resonance frequency tracking.

The DRV2625EVM-CT Evaluation Module (EVM) is a complete demo and evaluation platform for the DRV2625. The kit includes a microcontroller, linear actuator, eccentric rotating mass motor, and capacitive touch buttons which can be used to completely demonstrate and evaluate the DRV2625.

This document contains instructions to setup and operate the DRV2625EVM-CT in demo and evaluation mode.

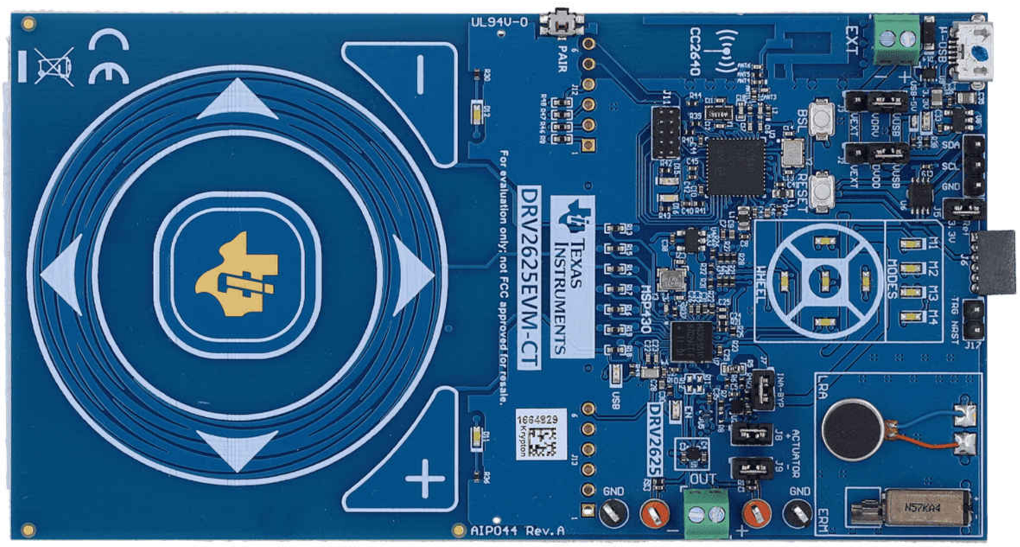

Figure 1-1. DRV2625EVM-CT Board

Evaluation Kit Contents:

- DRV2625EVM-CT demo and evaluation board
- Micro-USB cable
- Demonstration Firmware

Required for programming and advanced **configuration**:

- Code Composer Studio™ (CCS) or IAR Embedded Workbench IDE for MSP430
- MSP430 LaunchPad (MSP-EXP430G2), or MSP430-FET430UIF hardware programming tool
- DRV2625EVM-CT firmware available on ti.com

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1 Getting Started

The DRV2625 can be used as a demonstration or evaluation tool. When the DRV2625EVM-CT evaluation module is powered on for the first time, a demo application automatically starts. To power the board, connect the DRV2625EVM-CT to an available USB port on your computer using the included micro-USB cable. The demo begins with a board power-up sequence and then enters the demo effects mode. The four larger buttons on the wheel (1–4) can be used to sample haptic effects using both the ERM and LRA motor in the top right corner.

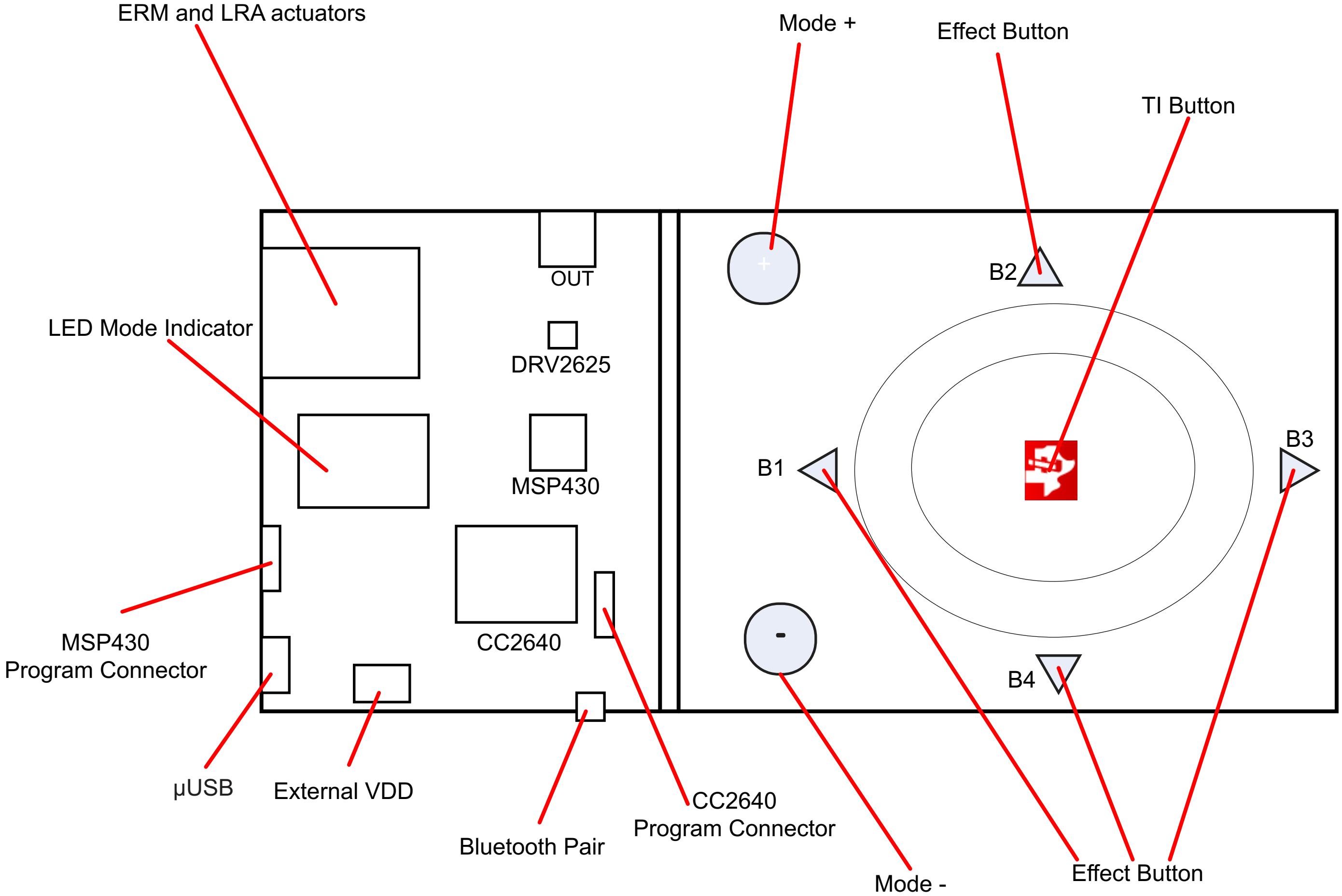

Figure 1-1. Board Diagram

1.1 Evaluation Module Operating Parameters

The following table lists the operating conditions for the DRV2625 on the evaluation module.

Table 1-1. Recommended Operating Conditions

Parameter	Specification
Supply voltage range	2.7 V to 5.5 V
Power-supply current rating	400 mA

1.2 Quick Start Board Setup

The DRV2625EVM-CT firmware contains haptic waveforms which showcase the features and benefits of the DRV2625. Follow the instructions below to begin the demo:

1. Out of the box, the jumpers are set to begin demo mode using USB power. The default jumper settings are found in the table below.

Table 1-2. Jumper Descriptions

Jumper	Default Position	Description
J3	Short pin 2-3	Powers using USB
J2	Short pin 2-3	USB power to DVDD
J5	Shorted	Level translator
J17	Open	Trigger/NRST for DRV2625
J7	Shorted	Bypass the I-Sense
J8	Shorted	Motor+ terminal
J9	Shorted	Motor- terminal
J4	Open	SDA/SCL connections to debug/Monitor advanced operations

2. Connect the included micro-USB cable to the USB connector on the DRV2625EVM-CT board.
3. Connect the other end of the USB cable to an available USB port on a computer, USB charger, or USB battery pack.
4. If the board is powered correctly, the LEDs will blink and the LRA and the ERM actuator will spin and stop at the start up.

2 DRV2625 Demonstration Program

The sections below provide a detailed description of the demo modes and effects.

2.1 Modes and Effects Table

The effects preloaded on the DRV2625EVM-CT are listed in Table 2-1. The modes are selected using the **+** and **–** mode buttons in the center of the board. The current mode is identified by the white LEDs directly above the mode buttons. Buttons B1–B4 trigger the effects listed in the description column and change based on the selected mode.

Table 2-1. Mode and Effects Table

Mode	Button	Description	Actuator	Waveform Location	Interface
Mode 0 LEDs Off	B1	Sharp Click	ERM	ROM	Internal Trigger (I^2C)
	B2	Sharp Click	LRA		
	B3	PulsingSharp	ERM		
	B4	PulsingSharp	LRA		
Mode 1 LED M1 On	B1	Soft Bump	ERM	ROM	Internal Trigger (I^2C)
	B2	Soft Bump	LRA		
	B3	Double Click	ERM		
	B4	Double Click	LRA		
Mode 2 LED M2 On	B1	Heartbeat x 3	ERM	ROM	Internal Trigger (I^2C)
	B2	Heartbeat x 3	LRA		
	B3	Buzz Alert 750 mS	LRA		
	B4	Buzz Alert 750 mS	ERM		
Mode 3 LED M3 On	B1	Closed Loop RTP 7F Buzz	LRA	ROM	RTP (I^2C)
	B2	Open Loop Pulsing with Auto Brake	LRA		RTP (I^2C)
	B3	Sine Wave Buzz RTP 7F	LRA		RTP (I^2C)
	B4	Open Loop Pulsing with no Auto Brake	LRA		RTP (I^2C)
Mode 4 LED M1 On	B1	RTP Strength change on position of the wheel	ERM and LRA	ROM	RTP (I^2C)
	B2				
	B3				
	B4				
	TI Button	Toggle ERM/LRA			Trigger One wire

2.2 Description of the Demo Modes

The following section highlights different features and benefits of using the DRV2625.

2.2.1 Mode Off – Haptics Effect Sequences

Below are a set of ERM and LRA Sharp Click waveforms. The four effects below show the difference between closed and open loop operation for both ERM and LRA.

In closed-loop operation for ERM's, the driver automatically overdrives and brakes the actuator. In open-loop, the waveform must be predefined with overdrive and braking.

For LRA's in closed-loop, the driver automatically tracks the resonant frequency, and overdrives and brakes the actuator. In open-loop, the waveform must be predefined with a static drive frequency, and overdrive and braking times.

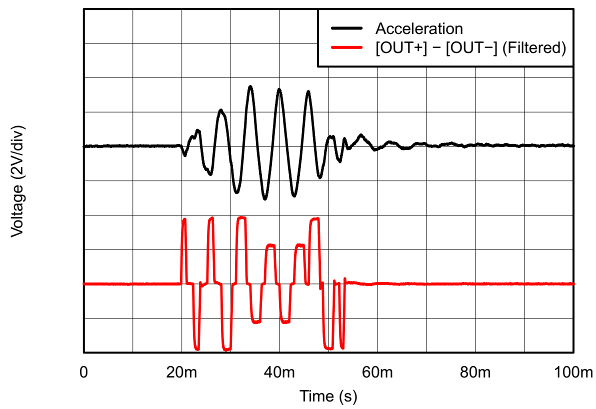

Figure 2-1. LRA Sharp Click Closed Loop Waveform

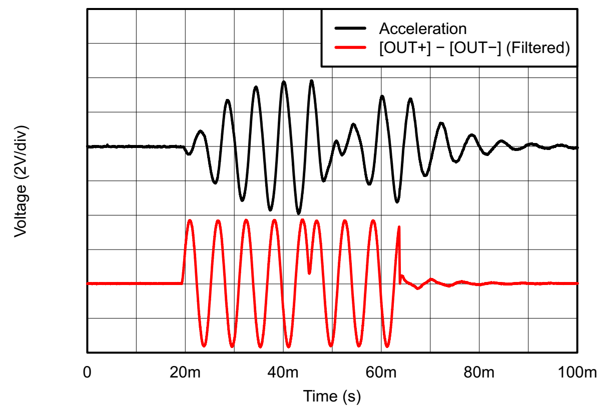

Figure 2-2. LRA Sharp Click Open Loop Waveform

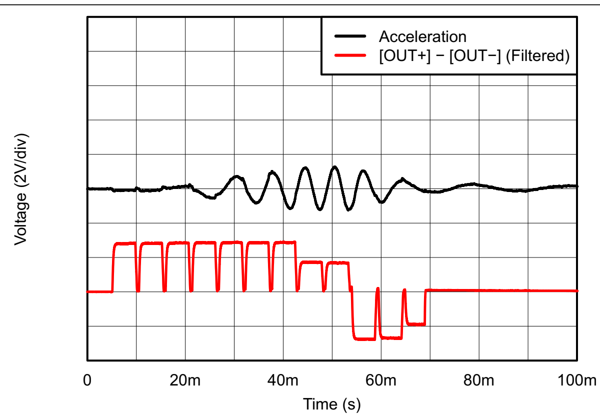

Figure 2-3. ERM Sharp Click Closed Loop Waveform

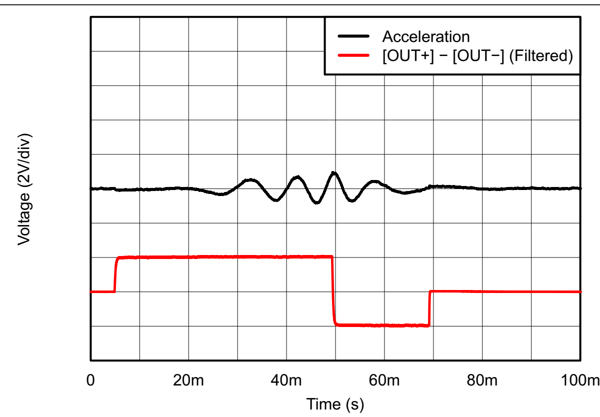

Figure 2-4. ERM Sharp Click Open Loop Waveform

2.2.2 Mode 4 – ERM Clicks

Mode 4 shows the difference in open-loop and closed-loop ERM clicks. In closed-loop the driver automatically overdrives and brakes the actuator. In open-loop, the waveform must be predefined with overdrive and braking. The image on the left shows a closed-loop waveform and the image on the right shows the same input waveform without closed-loop feedback enabled.

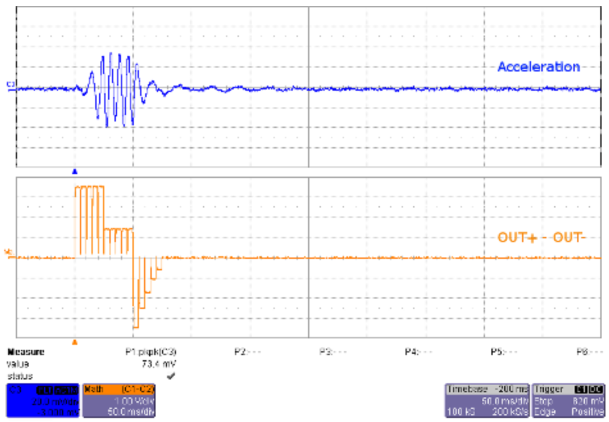

Figure 2-5. ERM Closed-Loop Click Waveform (Button 1)

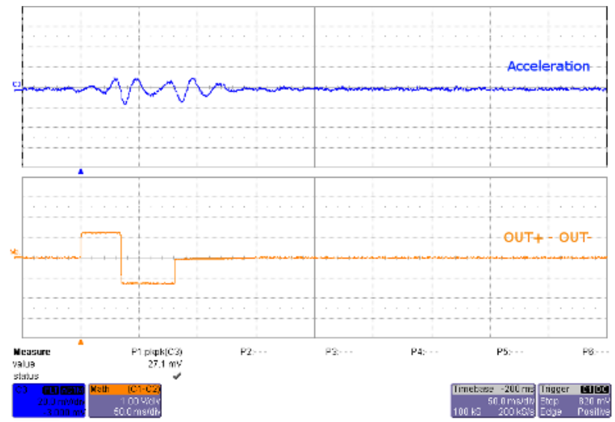

Figure 2-6. ERM Open-Loop Click Waveform (Button 4)

2.2.3 Automatic Braking in Open Loop

The DRV2625 offers automatic braking in open-loop operation for both ERM and LRA. See Figure 2-7 and Figure 2-8 below for two separate LRA waveforms that show the advantage of using closed-loop breaking out of open loop operation. Notice that the settling time of the waveform with automatic braking is 15 ms, significantly faster than the 40-ms time achieved without automatic braking enabled.

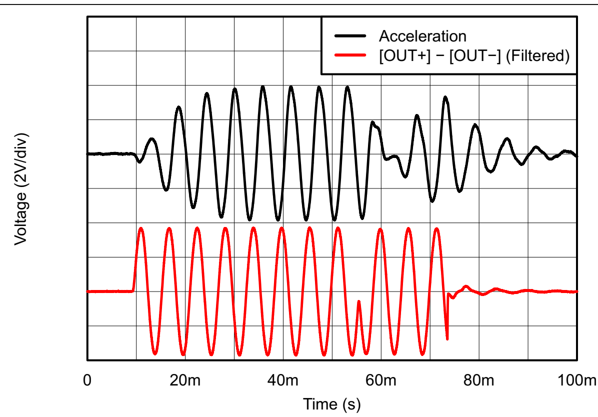

Figure 2-7. LRA Closed-Loop Click Waveform

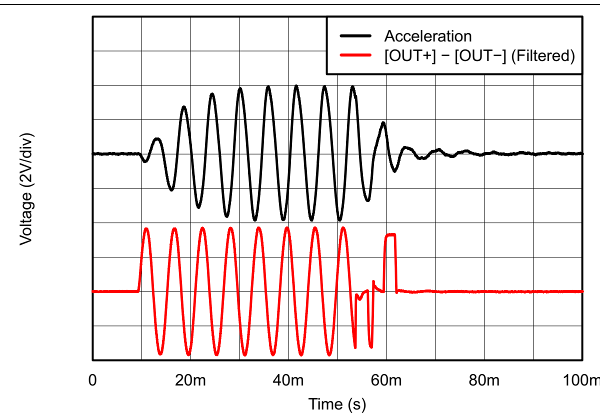

Figure 2-8. LRA Open-Loop Click Waveform

2.2.4 Auto-Resonance Tracking

Figure 2-9 and Figure 2-10 below showcase the advantages of the Smart Loop Architecture which includes auto-resonance tracking, automatic overdrive, and automatic braking. The two images below show the difference in acceleration between LRA auto-resonance ON and LRA auto-resonance OFF. Notice that the acceleration is higher when driven at the resonant frequency. The auto-resonance ON waveform has 1.32 G of acceleration and the auto-resonance OFF waveform has 0.92 G of acceleration. The auto-resonance ON waveform has 43% more acceleration.

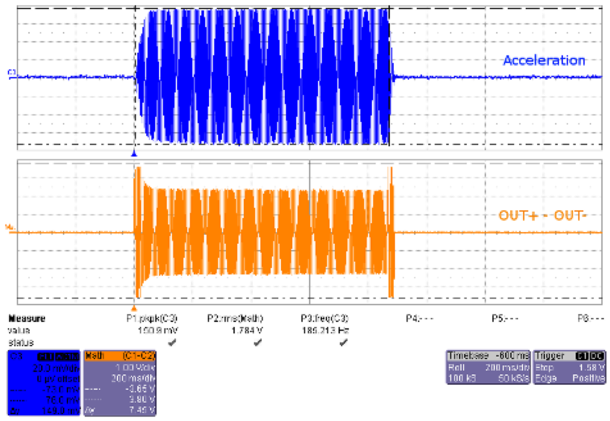

Figure 2-9. LRA Auto-Resonance ON Waveform (Button 1)

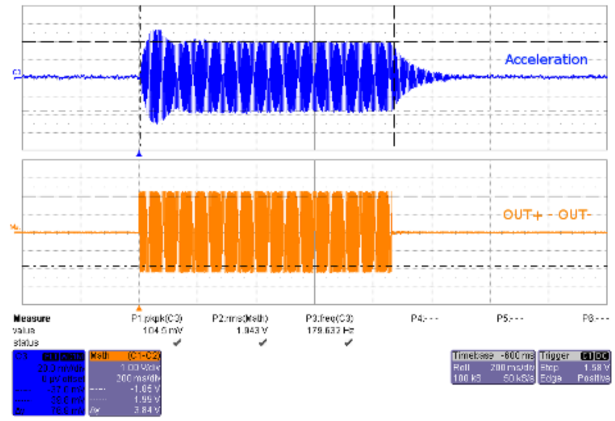

Figure 2-10. LRA Auto-Resonance OFF Waveform (Button 2)

The reason for higher acceleration can be seen in the acceleration versus frequency graph below. The LRA has a very narrow operating frequency range due to the properties of a spring-mass system. Furthermore, the resonance frequency drifts over various conditions such as temperature and drive voltage. With the Smart Loop auto-resonance feature, the DRV2625 dynamically tracks the exact resonant frequency to maximize the vibration force.

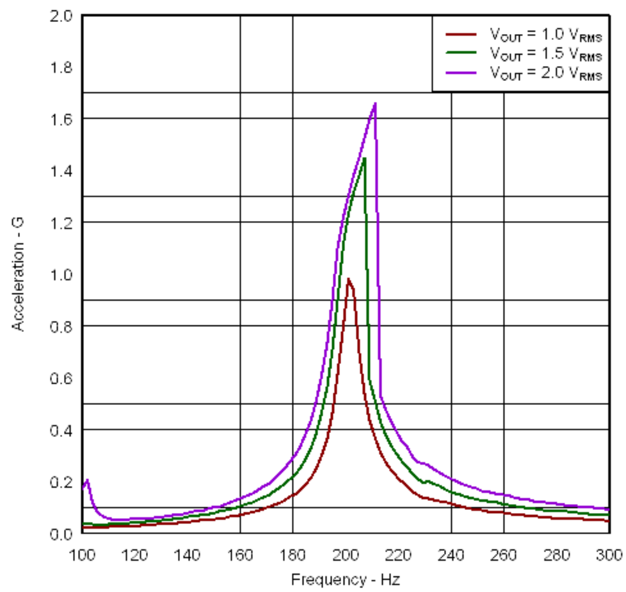

Figure 2-11. Acceleration Versus Frequency

2.3 ROM Library Mode

Access the ROM library effects by holding the **+** button until the mode LEDs flash and the colored LEDs flash ONCE.

Once in *Library Mode* the DRV2625 loaded ROM effects can be accessed in sequential order. For example, with all Mode LEDs off, B1 is waveform 1, B2 is waveform 2, and so on. Then when Mode LED M0 is on, B1 is waveform 5, B2 is waveform 6, and so on.

The equations for calculating the Mode and Button of an effect are:

Mode = RoundDown([Effect No.] / 4)

Button = ([Effect No.] – 1) % 4 + 1

% - modulo operator

To change between ERM and LRA:

1. Select mode 31 (11111'b) using the **+** or **–** buttons.
   - B1 – Press to select ERM
   - B2 – Press to select LRA
2. Then use the ROM effects as described above.

2.4 Waveform Library Effects List

Below is a description of the waveforms embedded in the DRV2625.

Table 2-2. Library Effect Overview

Effect ID	Waveform Name
1	Strong Click
2	Medium Click
3	Light Click
4	Tick
5	Bump
6	Strong Double Click
7	Medium Double Click
8	Light Double Click
9	Strong Triple Click
10	Buzz
11	Ramp Up
12	Ramp Down
13	Click + Bounce
14	Ramp Up + Click
15	Gallop Alert
16	Pulsing Alert

3 Additional Hardware Modes

Additional modes are available on the DRV2625EVM-CT providing increased board control and functionality.

3.1 Accessing GUI Mode

The DRV2625EVM-CT has the ability to be controlled via Haptics Control Console. In order to place the EVM into 'GUI Mode', hold down the (+) for approximately 3 seconds. The LED indicators will blink, and the right half of the LED's will remain on, indicating that the EVM is in GUI Mode.

3.2 Accessing Bluetooth Mode

The DRV2625EVM-CT Evaluation Module also features a mobile app for control over Bluetooth from an iOS app. In order to control the evaluation module via the mobile app, hold down the (-) for approximately 3 seconds. The LED indicators will blink, and the left half of the LED's will remain on, indicating that the EVM is in 'Bluetooth Mode'.

3.3 Haptics Control Console GUI

Haptics Control Console (HCC) allows the user to have control over the DRV2625 driver through a number of controls and features.

To control the DRV2625EVM-CT via HCC, connect the EVM to an available port on a computer using the included micro USB cable. Once the EVM is powered on, access GUI Mode by holding down the (+) for approximately 3 seconds as described in *Section 3.1*.

Open up the latest version of Haptics Control Console, and on the tool bar the USB tab will read out '2.Haptics DRV2625 EVM [version]'. Once the GUI has recognized the DRV2625EVM-CT, press 'Connect' to access the device Console.

Once connected the HCC provides the user flexibility to control the EVM functions through a GUI ‘Console’, and the ability to read and write to and from the DRV2625 through the ‘Register Map’ window as seen below inFigure 3-1 below.

Figure 3-1. Haptics Control Console

3.3.1 DRV2625 Console

The DRV2625 Console is divided into three sections Initialization, Work Mode, and Board Status, as seen below in Figure 3-2. Each section allows the user to control the device on the EVM through I2C writes and communication.

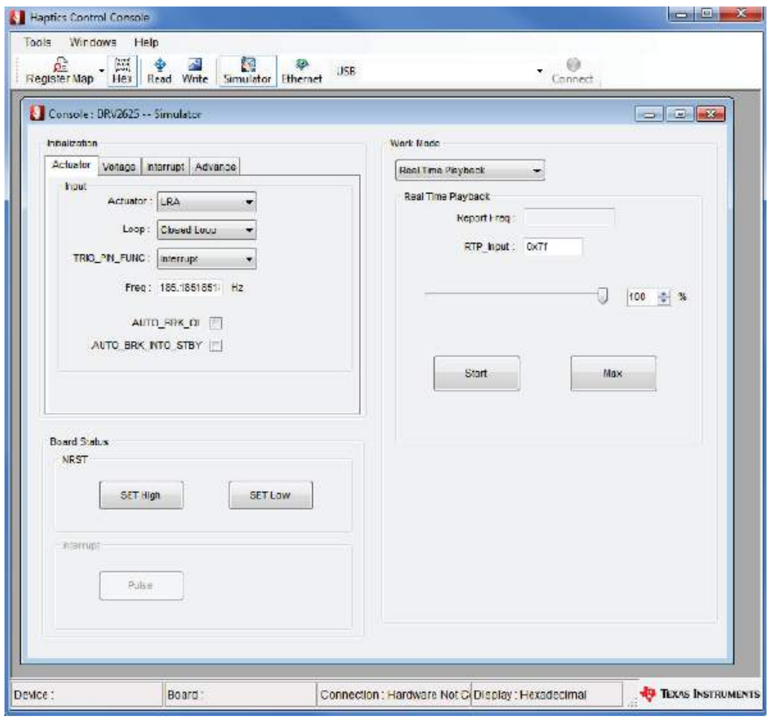

Figure 3-2. HCC DRV2625 Console

Please refer to the Haptics Control Console Users Guide for more detailed information on the device management features accessible through Haptics Control Console. The user’s guide can be found on www.ti.com.

4 Hardware Configuration

The DRV2625EVM-CT is very flexible and can be used to completely evaluate the DRV2625. The following sections list the various hardware configurations.

4.1 Input and Output Overview

The DRV2625EVM-CT allows complete evaluation of the DRV2625 though test points, jacks, and connectors. Table 4-1 gives a brief description of the hardware.

Table 4-1. Hardware Overview

Signal	Description	I/O
DRV TRIG	External input or monitor for DRV2625 IN/TRIG pin	Input/Output
NRST	External DRV2625 Shutdown control	Input
OUT+/OUT–	Filtered output test points for observation, connect to oscilloscope or measurement equipment	Output
USB	USB power (5 V)	Input
VBAT	External Supply Power (2.5 V – 5.5 V)	Input
SBW	MSP430 programming header	Input/Output
I^2C	DRV2625 and MSP430 I^2C bus	Input/Output

Hardware configuration details can be found in the following sections.

4.2 Power Supply Selection

The DRV2625EVM-CT can be powered by USB and an external power supply (VBAT). Jumpers J3 is used to select USB or VBAT for the DRV2625 and MSP430G2553, respectively. See Table 4-2 for possible configurations.

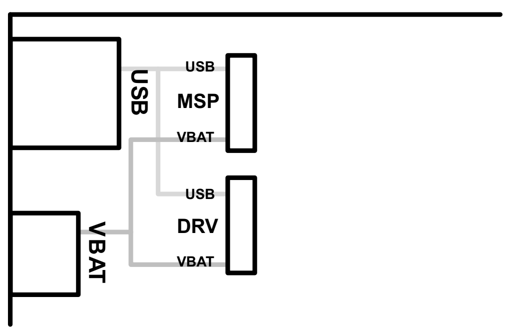

Figure 4-1. Power Jumper Selection

Table 4-2. Power Supply Configurations

Supply Configuration	DRV	MSP	DRV2625 Supply Voltage(1)
USB – Both	USB	USB	5 V
DRV2625 external supply, MSP430 USB	VBAT	USB	VBAT

(1) The DRV2625 supply must be on before operating the MSP430.

4.3 Using an External Actuator

The DRV2625EVM-CT can be used with an external actuator. Follow the instructions below to attach an actuator to the *OUT* terminal block.

1. Remove jumpers J8 and J9 which disconnects the on-board actuators from the DRV2625.
2. Attach the positive and negative leads of the actuator to the green *OUT* terminal block keeping in mind polarity.
3. Screw down the terminal block to secure the actuator leads.

Use the green terminal block when connecting an external actuator. The *OUT+* and *OUT–* test points have low-pass filters and should only be used for oscilloscope and bench measurements.

4.4 PWM Input

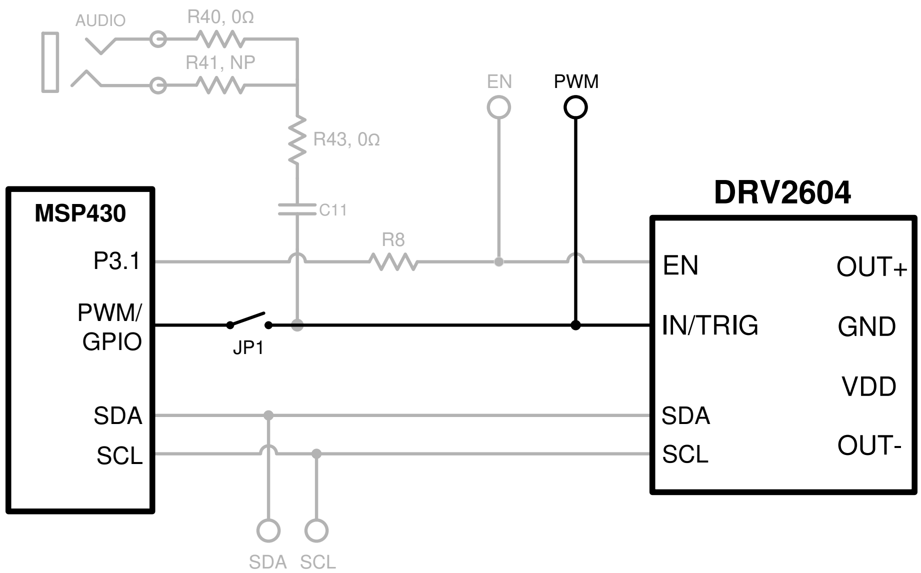

Figure 4-2. External PWM Input

Table 4-3. JP1 Options for PWM Input

JP1	PWM Source
Shorted	MSP430
Open	External PWM using PWM test point

To control the DRV2625 using PWM, follow the instructions below:

1. Enter Additional Hardware Modes.
2. Select Mode 2 (00010'b) using the increment mode button (**+**).
    - B1 – Disable Amplifier
    - B2 – ERM Mode
    - B3 – LRA Mode
    - B4 – No function
3. Choose either the on-board ERM or LRA using buttons B1 or B2.
4. Apply the PWM signal to the PWM test point at the top of the board.

4.5 External Trigger Control

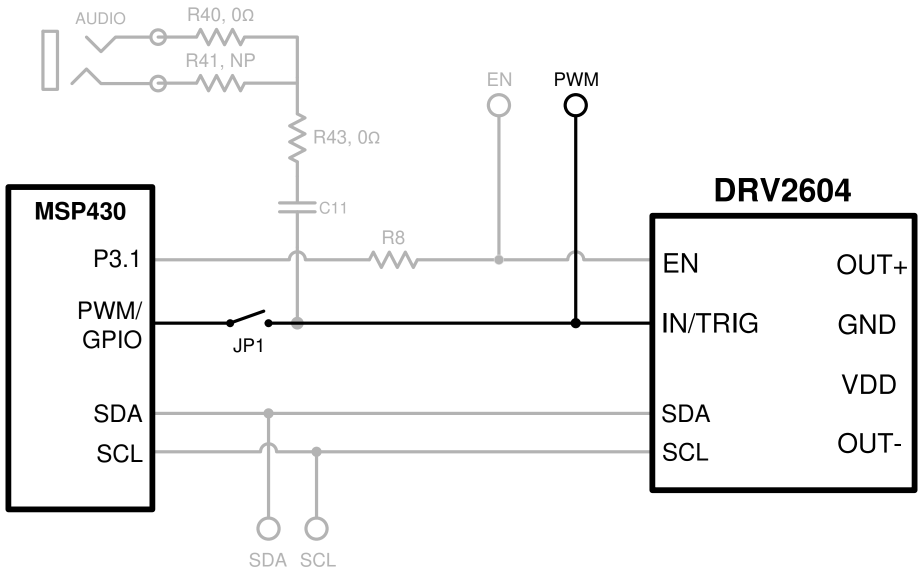

Figure 4-3. External Trigger Control

Table 4-4. JP1 Options for External Trigger Control

JP1	PWM Source
Shorted	MSP430
Open	External GPIO using PWM test point

The DRV2625 internal waveform sequencer can be triggered by controlling the IN/TRIG pin. There are two external trigger options: edge trigger and level trigger. See the data sheet for more information on these Input Trigger Modes.

In Mode 0 in the Additional Hardware Modes section, the DRV2625 can be set in external trigger mode and then triggered by using the trigger button control on button B4 or alternatively by applying an external trigger signal to the PWM test point.

4.5.1 MSP430 Trigger Control

1. Enter Additional Hardware Modes.
2. Select Mode 0 (00000'b) using the increment mode button (**+**).
   - B1 – Select the on-board ERM
   - B2 – Select the on-board LRA
   - B3 – Trigger Select (1 = Internal Trigger, 2 = Ext. Edge, 3 = Ext. Level)
   - B4 – Trigger the waveform sequence using the MSP430.
3. Fill the waveform sequencer with waveforms using the external I^2C port.
4. Choose either the on-board ERM or LRA using buttons B1 or B2.
5. Select either External Edge (2) or External Level (3) trigger using the B3 button. The trigger type appears in binary on the mode LEDs.
6. Apply the trigger signal to the IN/TRIG pin by pressing the B4 button.

4.5.2 External Source Trigger Control

1. Remove jumper JP1.
2. Enter Additional Hardware Modes.
3. Select Mode 0 (00000'b) using the increment mode button (**+**).
   - B1 – Select the on-board ERM
   - B2 – Select the on-board LRA
   - B3 – Trigger Select (1 = Internal Trigger, 2 = Ext. Edge, 3 = Ext. Level)
   - B4 – Trigger the waveform sequence using the MSP430.

4. Fill the waveform sequencer with waveforms using the external I^{2}C port.
5. Choose either the on-board ERM or LRA using buttons B1 or B2.
6. Select either External Edge (2) or External Level (3) trigger using the B3 button. The trigger type appears in binary on the mode LEDs.
7. Apply the external logic signal to the PWM test point to trigger the waveform.

4.6 External I^{2}C Input

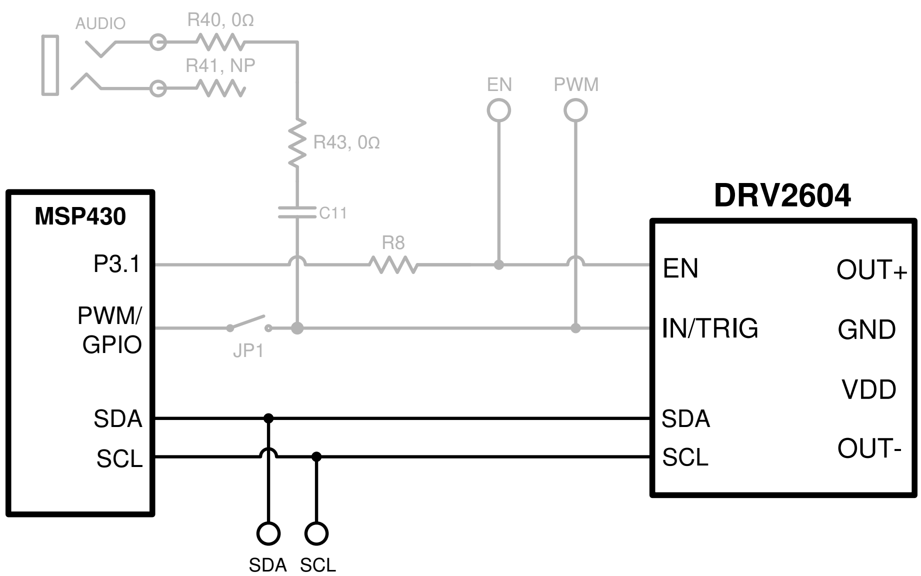

Figure 4-4. External I^{2}C Input

The DV2625 can be controlled by an external I^{2}C source. Attach the external controller to the I^{2}C header at the top of the board; be sure to connect SDA, SCL and GND from the external source.

4.6.1 External I^{2}C Control Initialization

I^{2}C communication is possible only when the EN pin is set high. To enable the DRV2625 and allow external I^{2}C control, follow the instructions below.

1. Enter Additional Hardware Modes.
2. Select Mode 0 (00000'b) using the increment mode button (**+**).
   - B1 – Select the on-board ERM
   - B2 – Select the on-board LRA
   - B3 – Trigger Select (1 = Internal Trigger, 2 = Ext. Edge, 3 = Ext. Level)
   - B4 – Trigger the waveform sequence using the MSP430.
3. Choose either the on-board ERM or LRA using buttons B1 or B2. Either button sets the EN pin high and turns on the *Active* LED.
4. Begin controlling the DRV2625 using the external I^{2}C source.

4.7 Analog Input

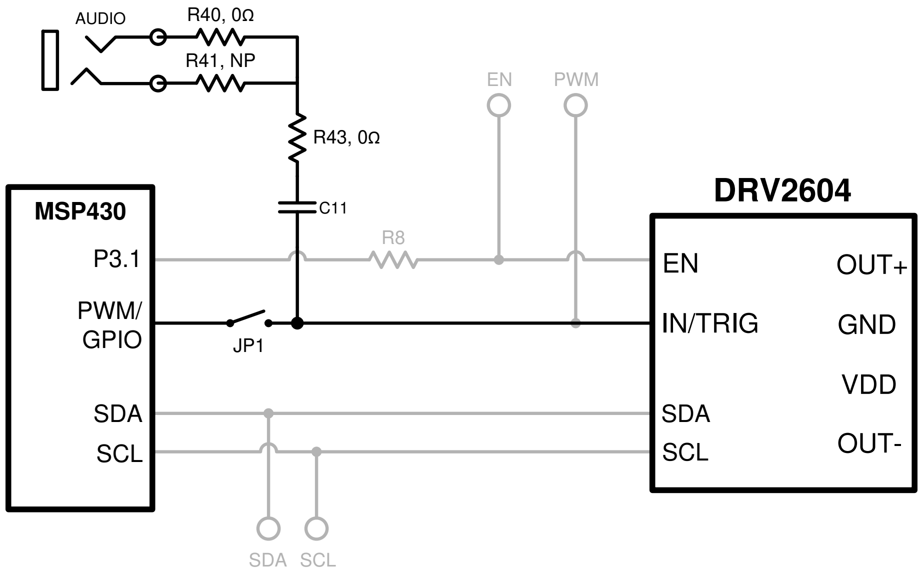

Figure 4-5. Analog Input

The analog input accepts an analog signal to control the envelope of the output waveform.

Use the following steps to use analog input mode:

1. Apply an analog signal (not PWM) to the AUDIO jack on the left side of the board. The tip of the inserted male 3.5 mm jack is applied to the IN/TRIG pin of the DRV2625. See Figure 4-5.
2. Enter Additional Hardware Modes.
3. Select Mode 5 (00101'b) using the increment mode button (**+**).
4. In Mode 5, choose button B1–B4, depending on the actuator and input coupling.
   - B1 – AC Coupling – ERM
   - B2 – DC Coupling – ERM
   - B3 – AC Coupling – LRA
   - B4 – DC Coupling – LRA
5. Enable the analog input signal.

5 Measurement and Analysis

The DRV2625 uses PWM modulation to create the output signal for both ERM and LRA actuators. To measure and observe the DRV2625 output waveform, connect an oscilloscope or other measurement equipment to the filtered output test points, *OUT+* and *OUT–*.

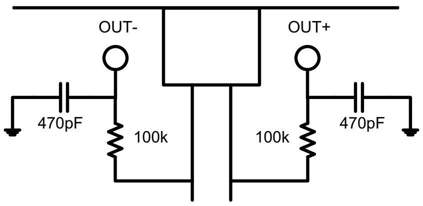

Figure 5-1. Terminal Block and Test Points

5.1 Using Low-Pass Filter to Record Waveforms

The DRV2625 drives LRA and ERM actuators using a 20-kHz PWM modulated waveform, but only the frequencies around the LRA resonant frequency or the ERM DC drive voltage are relevant to the haptic actuator vibration. The higher frequency switching content does not contribute to the vibration strength of the actuator and can make it difficult to interpret the modulated output waveform on an oscilloscope. The oscilloscope image on the left shows the DRV2625 unfiltered waveform and the image on the right shows a filtered version used for observation and measurement.

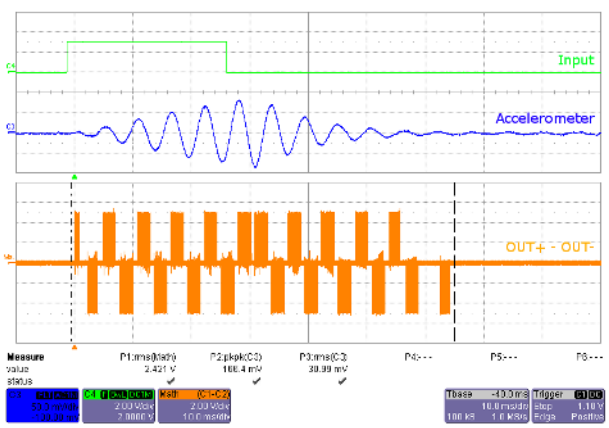

Figure 5-2. DRV2625 Unfiltered Waveform

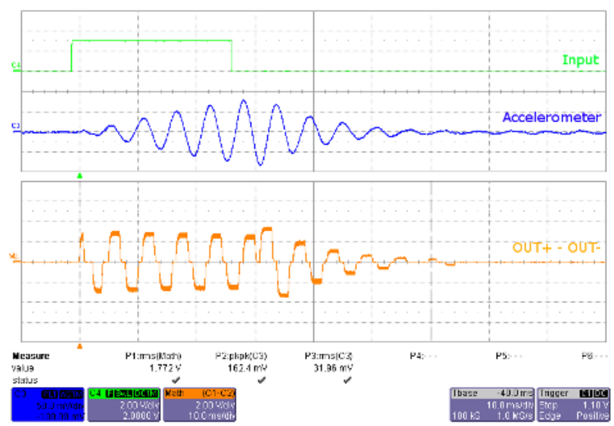

Figure 5-3. DRV2625 Filtered Waveform

If the DRV2625EVM-CT filter is not used, TI recommends using a 1st-order, low-pass filter with a cutoff between 1kHz and 3.5kHz . Below is a recommended output filter for use while measuring and characterizing the DRV2625 in the lab.

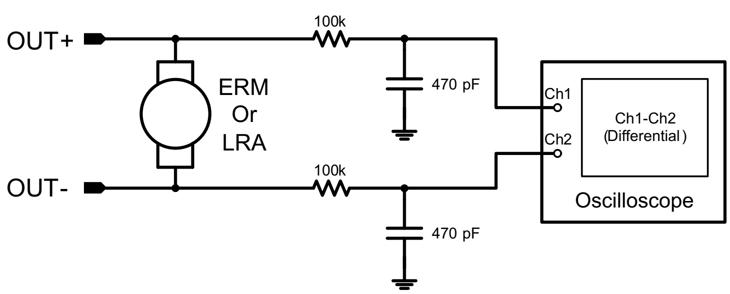

Figure 5-4. Measuring the DRV2625 Output Signal with an Analog Low-Pass Filter

6 Modifying or Reprogramming the Firmware

The MSP430 firmware on the DRV2625EVM-CT can be modified or reprogrammed to create new haptic effects or behaviors. Find the latest firmware source code and binaries on ti.com. Follow the instructions below to modify or reprogram the DRV2625EVM-CT.

1. Purchase one of the following MSP430F5510 compatible programmers:
   - MSP430 64-pin Target Development Board and MSP-FET(MSP-FETU64USB)
   - MSP-FET MCU Programmer and Debugger
2. Download and install Code Compose Studio (CCS) or IAR Embedded Workbench IDE.
3. Download the DRV2625EVM-CT source code and binaries from ti.com.
4. Connect the programmer to an available USB port.
5. Connect the programmer to the *J6* header on the DRV2625EVM-CT.
6. In CCS,
   a. Open the project file by selecting Project→Import Existing CCS Project.
   b. Select **Browse** and navigate to the DRV2625EVM-CT project folder, then press **OK**.
   c. Select the checkbox next to the DRV2625EVM-CT project in the *Discovered projects* window and then press **Finish**.
   d. Before compiling, navigate to Project→Properties→Build→MSP430 Compiler→Advanced Options→Language Options and make sure the checkbox for *Enable support for GCC extensions (–gcc)* is checked.
7. In IAR,
   a. Create a new MSP430 project in IAR,
   b. Select the MSP430F5510 device,
   c. Copy the files in the project folder downloaded from ti.com to the new project directory.

Figure 6-1 below shows the connection between the MSP430 Programmer and Debugger (MSP-FET) and the DRV2625EVM-CT.

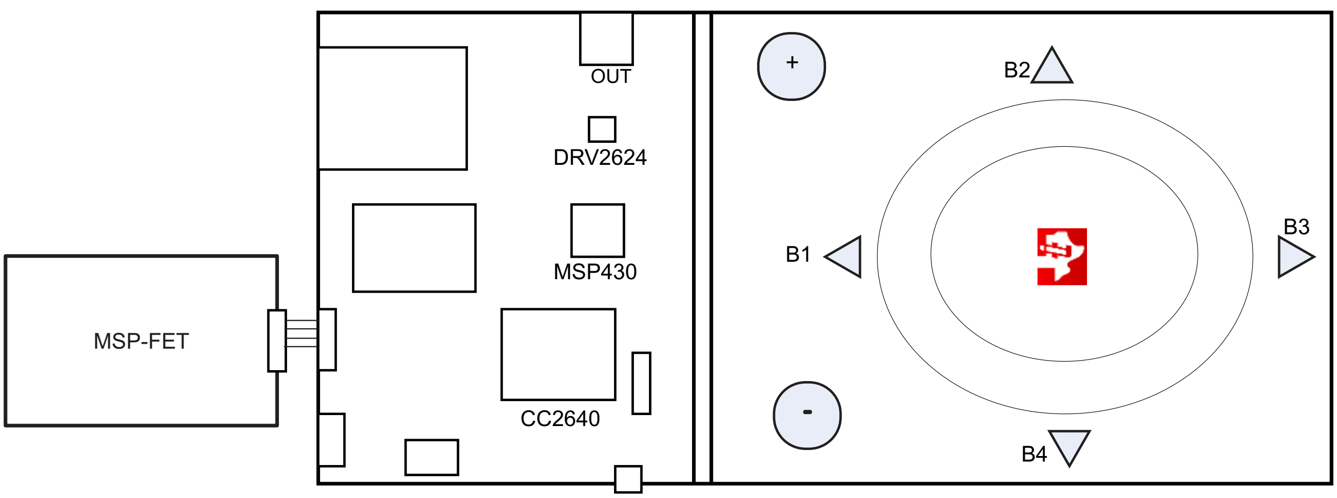

Figure 6-1. FET Programmer Connection

6.1 MSP430 Pin-Out

The DRV2625EVM-CT contains a MSP430G2553 low-cost microcontroller which controls the board and contains sample haptic effects. The pin-out for the microcontroller is found in Table 6-1.

Table 6-1. MSP430 Pin-Out

#	Label	Description
1	P1.1	Green LED
2	P1.2	Yellow LED
3	P1.3	Blue LED
4	P1.4	VREF+

Table 6-1. MSP430 Pin-Out (continued)

#	Label	Description
5	P1.5	Audio-to-Haptics
6	P3.1	Enable
7	P3.0	Actuator Mode Selection
8	NC	
9	P2.0	Button 1
10	P2.1	Button 2
11	P2.2	Button 3
12	P3.2	PWM
13	P3.3	WLED 0
14	P3.4	WLED 1
15	P2.3	Button 4
16	P2.4	+ Button
17	P2.5	– Button
18	P3.5	WLED 2
19	P3.6	WLED 3
20	P3.7	WLED 4
21	P1.6/SCL	I^2C Clock
22	P1.7/SDA	I^2C Data
23	SBWTDIO	Spy-Bi-Wire Data
24	SBWTCK	Spy-Bi-Wire Clock
25	P2.7	
26	P2.6	LRA/ERM Load Switch
27	AVSS	Analog Ground
28	DVSS	Digital Ground
29	AVCC	Analog Supply
30	DVCC	Digital Supply
31	P1.0	Red LED
32	NC	

7 Schematic

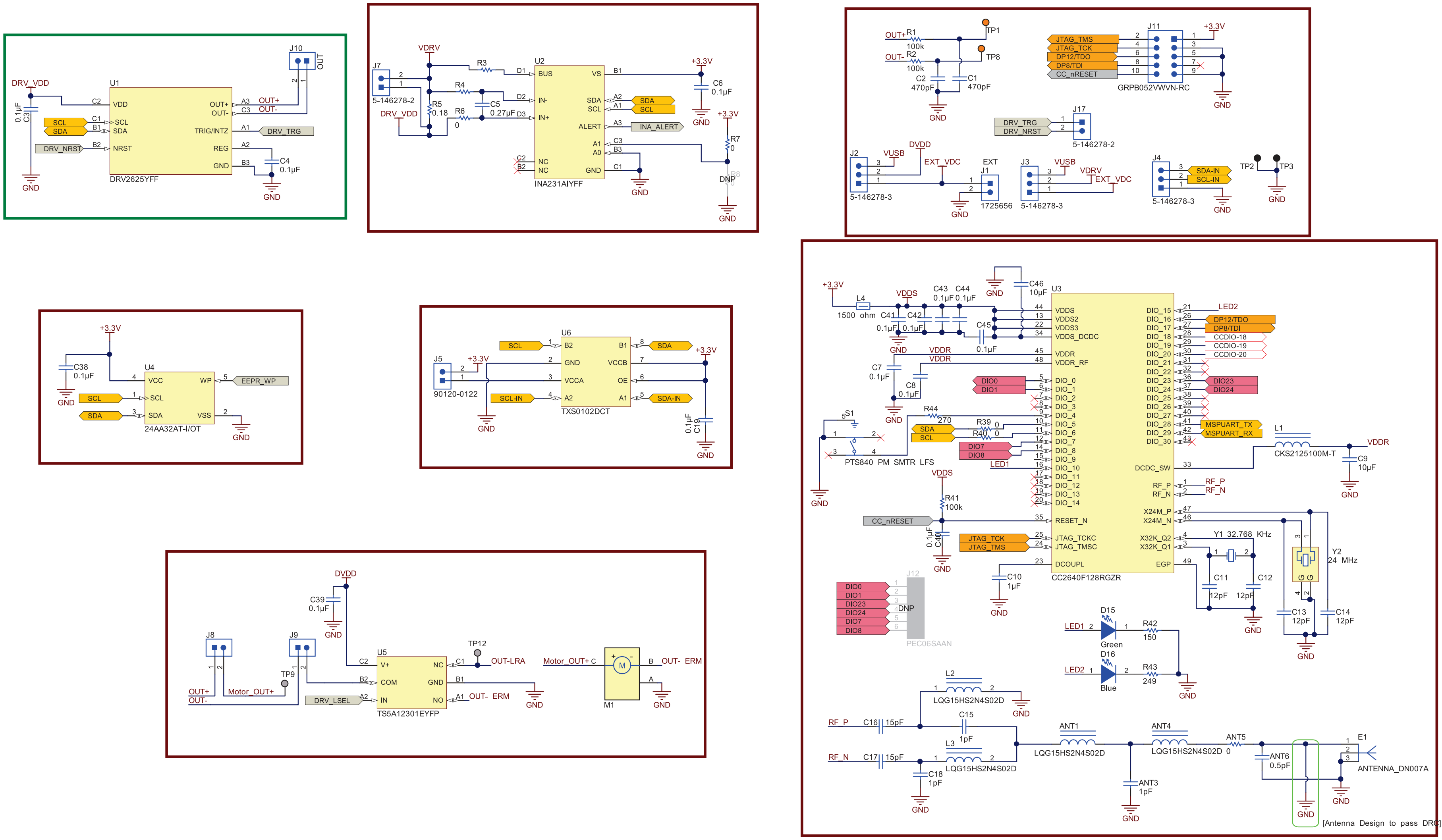

Figure 7-1. DRV2625EVM-CT Schematic Page 1

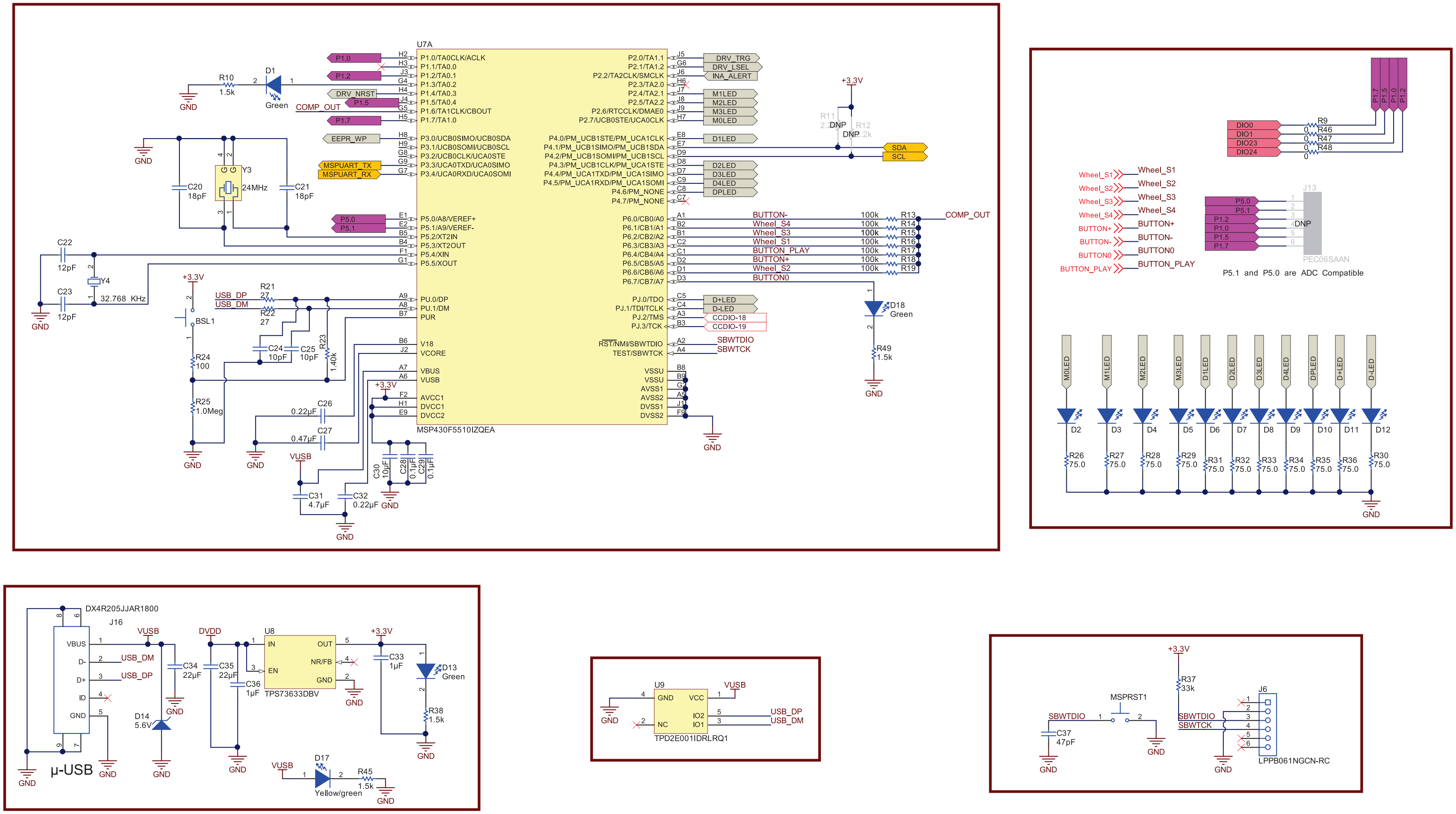

Figure 7-2. DRV2625EVM-CT Schematic Page 2

8 Layout

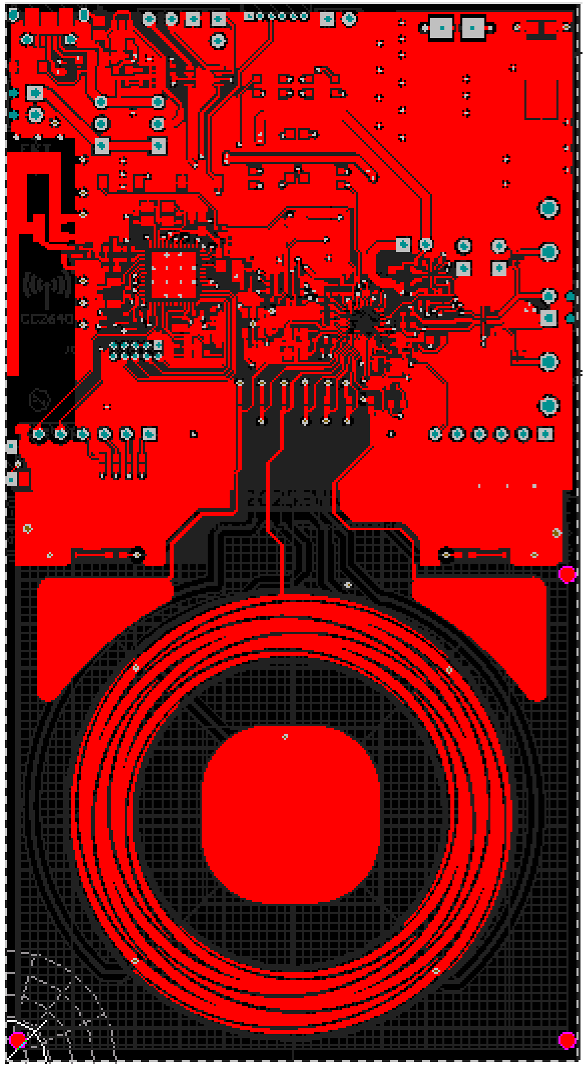

Figure 8-1. Top Layer

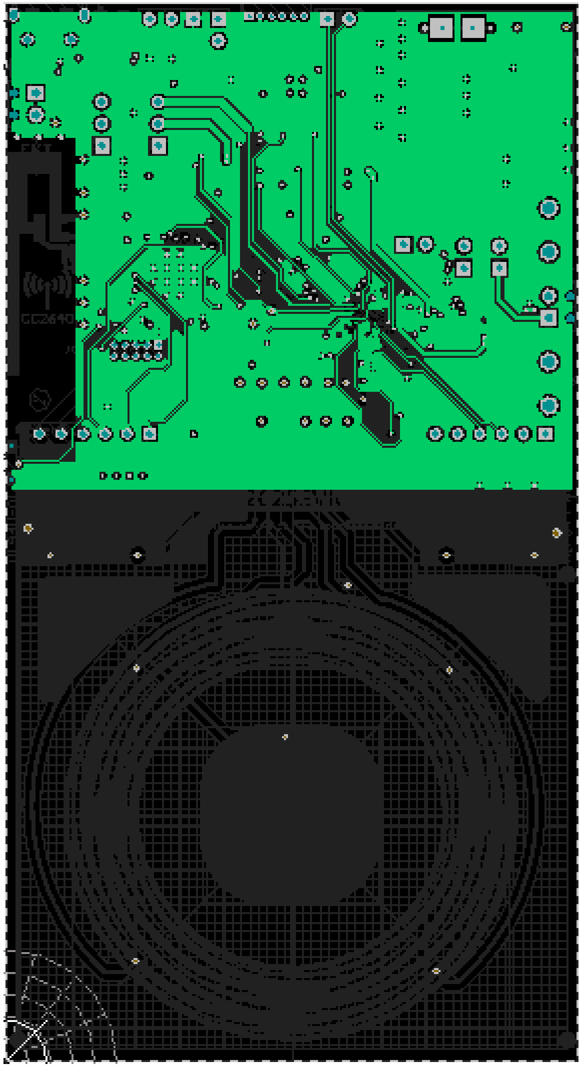

Figure 8-2. Layout Layer 2

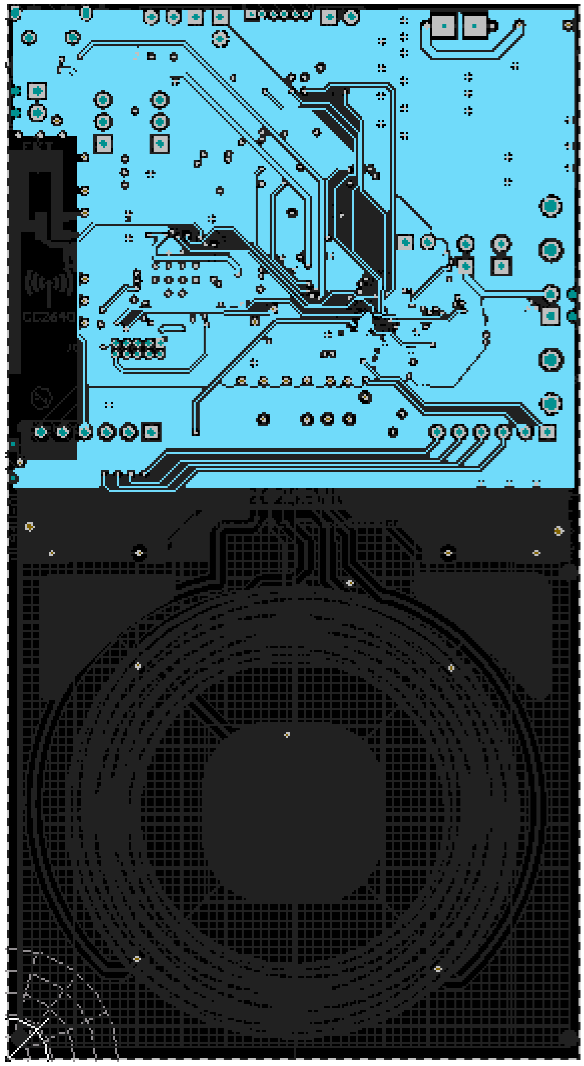

Figure 8-3. Layout Layer 3

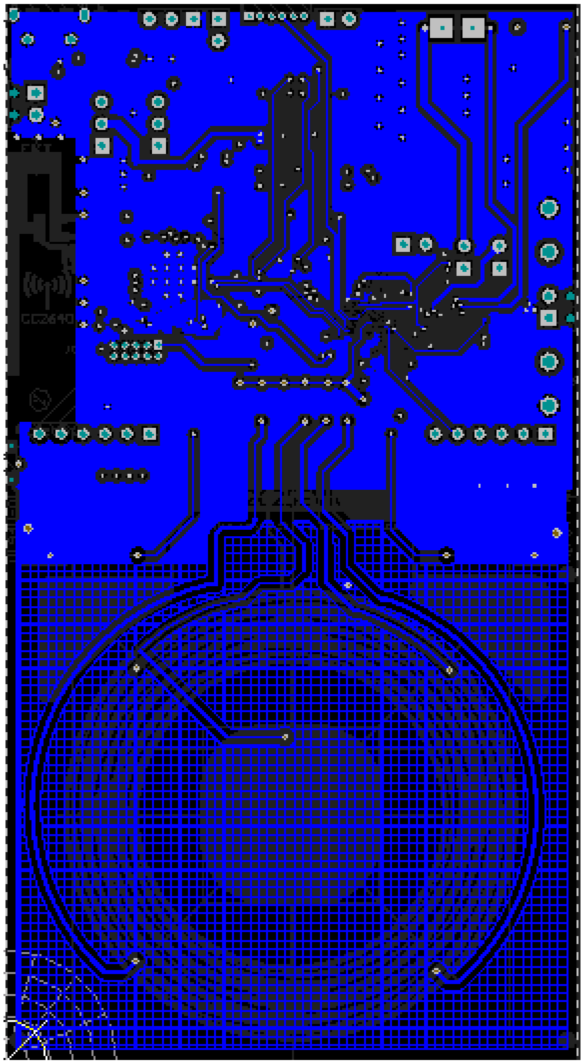

Figure 8-4. Layout Layer 4

9 Bill of Materials

Item #	Designator	Quantity	Value	Part Number	Manufacturer	Description	Package Reference
1	!PCB1	1		AIP044	Any	Printed Circuit Board	
2	ANT1, ANT4, L2, L3	4	2.4nH	LQG15HS2N4S02D	MuRata	Inductor, Multilayer, Air Core, 2.4 nH, 0.3 A, 0.15 ohm, SMD	0402 polarized
3	ANT3, C15, C18	3	1pF	GRM1555C1H1R0CA01D	MuRata	CAP, CERM, 1 pF, 50 V, +/- 5%, C0G/NP0, 0402	0402
4	ANT5, R3, R4, R6, R7, R9, R39, R40, R46, R47, R48	11	0	CRCW04020000Z0ED	Vishay-Dale	RES, 0, 5%, 0.063 W, 0402	0402
5	ANT6	1	0.5pF	GRM1555C1HR50BA01D	MuRata	CAP, CERM, 0.5 pF, 50 V, +/- 20%, C0G, 0402	0402
6	BSL1, MSPRST1	2		TL1015AF160QG	E-Switch	Switch, Tactile, SPST-NO, 0.05A, 12V, SMT	Switch, 4.4x2x2.9 mm
7	C1, C2	2	470pF	C1005C0G1H471J	TDK	CAP, CERM, 470 pF, 50 V, +/- 5%, C0G/NP0, 0402	0402
8	C3, C4, C19, C38, C39, C40, C41, C42, C43, C44, C45	11	0.1uF	GRM155R71C104KA88D	MuRata	CAP, CERM, 0.1 µF, 16 V, +/- 10%, X7R, 0402	0402
9	C5	1	0.27uF	GRM155R61A274KE15D	MuRata	CAP, CERM, 0.27 µF, 10 V, +/- 10%, X5R, 0402	0402
10	C6, C7, C8, C28, C29	5	0.1uF	GRM155R61C104KA88D	MuRata	CAP, CERM, 0.1uF, 16V, +/-10%, X5R, 0402	0402
11	C9, C30	2	10uF	GRM155R61A106ME44	MuRata	CAP, CERM, 10 µF, 10 V, +/- 20%, X5R, 0402	0402
12	C10, C33, C36	3	1uF	GRM155R61A105KE15D	MuRata	CAP, CERM, 1 µF, 10 V, +/- 10%, X5R, 0402, CAP, CERM, 1uF, 10V, +/-10%, X5R, 0402, CAP, CERM, 1 µF, 10 V, +/- 10%, X5R, 0402	0402
13	C11, C12, C13, C14, C22, C23	6	12pF	GRM1555C1H120JA01D	MuRata	CAP, CERM, 12 pF, 50 V, +/- 5%, C0G/NP0, 0402, CAP, CERM, 12 pF, 50 V, +/- 5%, C0G/NP0, 0402, CAP, CERM, 12 pF, 50 V, +/- 5%, C0G/NP0, 0402, CAP, CERM, 12 pF, 50 V, +/- 5%, C0G/NP0, 0402, CAP, CERM, 12pF, 50V, +/-5%, C0G/NP0, 0402, CAP, CERM, 12pF, 50V, +/-5%, C0G/NP0, 0402	0402
14	C16, C17	2	15pF	GRM1555C1H150JA01D	MuRata	CAP, CERM, 15 pF, 50 V, +/- 5%, C0G/NP0, 0402	0402
15	C20, C21	2	18pF	GRM1555C1H180JA01D	MuRata	CAP, CERM, 18pF, 50V, +/-5%, C0G/NP0, 0402	0402
16	C24, C25	2	10pF	GRM1555C1H100JA01D	MuRata	CAP, CERM, 10pF, 50V, +/-5%, C0G/NP0, 0402	0402
17	C26, C32	2	0.22uF	GRM155R71C224KA12D	MuRata	CAP, CERM, 0.22uF, 16V, +/-10%, X7R, 0402	0402
18	C27	1	0.47uF	GRM155R61C474KE01	MuRata	CAP, CERM, 0.47uF, 16V, +/-10%, X5R, 0402	0402
19	C31	1	4.7uF	GRM155R61A475M	MuRata	CAP, CERM, 4.7uF, 10V, +/-20%, X5R, 0402	0402
20	C34, C35	2	22uF	GRM21BR61C226ME44	MuRata	CAP, CERM, 22 µF, 16 V, +/- 20%, X5R, 0805	0805
21	C37	1	47pF	GRM1555C1E470JA01D	MuRata	CAP, CERM, 47pF, 25V, +/-5%, C0G/NP0, 0402	0402
22	C46	1	10uF	GRM155R61A106ME21D	MuRata	CAP, CERM, 10 µF, 10 V, +/- 20%, X5R, 0402	0402
23	D1, D13, D18	3	Green	LTST-C190GKT	Lite-On	LED, Green, SMD	1.6x0.8x0.8mm
24	D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12	11		SML312WBCW1	Rohm	LED, White, SMD	LED, 0603
25	D14	1	5.6V	MMSZ5232B-7-F	Diodes Inc.	Diode, Zener, 5.6V, 500 mW, SOD-123	SOD-123
26	D15	1	Green	150060VS75000	Wurth Elektronik eiSos	LED, Green, SMD	LED_0603
27	D16	1	Blue	LB Q39G-L2N2-35-1	OSRAM	LED, Blue, SMD	BLUE 0603 LED
28	D17	1	Yellow/green	SML-P12MTT86	Rohm	LED, Yellow/green, SMD	0402 LED
29	H1	1		ELV1036A	AAC	AAC1036 LRA Actuator	Used in PnP output
30	H2	1		TI-EVACASE-BLACK	Royal Case	TI Black EVA Case	Used in PnP output
31	H3	1		3-5-468MP	3M	TAPE TRANSFER ADHESIVE 3" X 5YD	Used in PnP output
32	H4	1		2-5-4466W	3M	TAPE POLY FOAM 2" x 5YD	Used in PnP output
33	H5	1			Heavy Metal	Metal Block (Custom Block, Heavy Metal, See metal block spec)	Used in PnP output

Item #	Designator	Quantity	Value	Part Number	Manufacturer	Description	Package Reference
34	J1, J10	2		1725656	Phoenix Contact	Terminal Block, 100mil, 2x1, 6A, 63V, TH	6.2x8.5x5.54 mm
35	J2, J3, J4	3		5-146278-3	TE Connectivity	Header, 100mil, 3x1, Tin, TH	Header, 3x1, 100mil, TH
36	J5	1		90120-0122	Molex	Header, 100mil, 2x1, Tin, TH	Header 2x1
37	J6	1		LPPB061NGCN-RC	Sullins Connector Solutions	Receptacle, 50mil, 6x1, Gold, R/A, TH	6x1 Receptacle
38	J7, J8, J9, J17	4		5-146278-2	TE Connectivity	Header, 100mil, 2x1, Tin, TH	Header, 2x1, 100mil, TH
39	J11	1		GRPB052VWVN-RC	Sullins Connector Solutions	Header, 50mil, 5x2, Gold, TH	Header, 5x2, 50mil
40	J16	1		DX4R205JJAR1800	JAE Electronics	Connector, Receptacle, Micro-USB Type AB, R/A, Bottom Mount SMT	Connector, USB Micro AB
41	L1	1	10uH	CKS2125100M-T	Taiyo Yuden	Inductor, Multilayer, Ferrite, 10 µH, 0.11 A, 0.52 ohm, SMD	0805
42	L4	1	1500 ohm	BLM18HE152SN1D	MuRata	Ferrite Bead, 1500 ohm @ 100 MHz, 0.5 A, 0603_950	0603_950
43	M1	1		BAL-3611	NIDEC SEIMITSU	Motor, SMT	15.1x4.55mm
44	R1, R2, R13, R14, R15, R16, R17, R18, R19	9	100k	CRCW0402100KJNED	Vishay-Dale	RES, 100 k, 5%, 0.063 W, 0402, RES, 100 k, 5%, 0.063 W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402	0402
45	R5	1	0.18	ERJ-3RSFR18V	Panasonic	RES, 0.18, 1%, 0.1 W, 0603	0603
46	R10, R38, R45, R49	4	1.5k	CRCW04021K50JNED	Vishay-Dale	RES, 1.5k ohm, 5%, 0.063W, 0402	0402
48	R23	1	1.40k	CRCW04021K40FKED	Vishay-Dale	RES, 1.40k ohm, 1%, 0.063W, 0402	0402
49	R24	1	100	CRCW0402100RJNED	Vishay-Dale	RES, 100 ohm, 5%, 0.063W, 0402	0402
50	R25	1	1.0Meg	CRCW04021M00JNED	Vishay-Dale	RES, 1.0Meg ohm, 5%, 0.063W, 0402	0402
51	R26, R27, R28, R29, R30, R31, R32, R33, R34, R35, R36	11	75.0	CRCW040275R0FKED	Vishay-Dale	RES, 75.0 ohm, 1%, 0.063W, 0402	0402
52	R37	1	33k	CRCW040233K0JNED	Vishay-Dale	RES, 33k ohm, 5%, 0.063W, 0402	0402
53	R41	1	100k	RG1005P-104-B-T5	Susumu Co Ltd	RES, 100 k, 0.1%, 0.063 W, 0402	0402
54	R42	1	150	CRCW0402150RJNED	Vishay-Dale	RES, 150, 5%, 0.063 W, 0402	0402
55	R43	1	249	CRCW0402249RFKED	Vishay-Dale	RES, 249 ohm, 1%, 0.063W, 0402	0402
56	R44	1	270	CRCW0402270RJNED	Vishay-Dale	RES, 270, 5%, 0.063 W, 0402	0402
57	S1	1		PTS840 PM SMTR LFS	C&K Components	SWITCH TACTILE SPST-NO 0.05A 12V, SMT	3.5x1.35x3.55mm
58	SH-J1, SH-J2, SH-J3, SH-J4, SH-J5, SH-J6	6	1x2	969102-0000-DA	3M	Shunt, 100mil, Gold plated, Black	Shunt
59	TP1, TP8	2	Orange	5013	Keystone	Test Point, Multipurpose, Orange, TH	Orange Multipurpose Testpoint
60	TP2, TP3	2	Black	5011	Keystone	Test Point, Multipurpose, Black, TH	Black Multipurpose Testpoint
61	U1	1		DRV2625YFF	Texas Instruments	DRV2625YFF, YFF0009AHAN	YFF0009AHAN
62	U2	1		NA231AIYFF	Texas Instruments	High- or Low-Side Measurement, Bidirectional CURRENT/ POWER MONITOR with 1.8-V I2C Interface, YFF0012AKAD	YFF0012AKAD
63	U3	1		CC2640F128RGZR	Texas Instruments	Ultra low-power ARM Cortex M3 2.4 GHz Radio MCU, Bluetooth Low Energy, RGZ0048A	RGZ0048A
64	U4	1		24AA32AT-I/OT	Microchip	32K I2C™ Serial EEPROM, SOT-23-5	SOT-23-5
65	U5	1		TS5A12301EYFP	Texas Instruments	IEC LEVEL 4 ESD-PROTECTED 0.75-O SPDT ANALOG SWITCH WITH 1.8-V COMPATIBLE INPUT LOGIC, YFP0006AAAA	YFP0006AAAA
66	U6	1		TXS0102DCT	Texas Instruments	2-BIT BIDIRECTIONAL VOLTAGE-LEVEL TRANSLATOR FOR OPEN-DRAIN AND PUSH-PULL APPLICATIONS, DCT0008A	DCT0008A

Item #	Designator	Quantity	Value	Part Number	Manufacturer	Description	Package Reference
67	U7	1		MSP430F5510IZQEA	Texas Instruments	25 MHz Mixed Signal Microcontroller with 32 KB Flash, 4096 B SRAM and 47 GPIOs, -40 to 85 degC, 80-pin BGA (ZQE), Green (RoHS & no Sb/Br)	ZQE0080A
68	U8	1		TPS73633DBV	Texas Instruments	Cap-Free, NMOS, 400mA Low-Dropout Regulator with Reverse Current Protection, DBV0005A	DBV0005A
69	U9	1		TPD2E001IDRLRQ1	Texas Instruments	Automotive Catalog Low-Capacitance + / - 15 kV ESD-Protection Array for High-Speed Data Inter, 2 Channels, -40 to +85 degC, 5-pin SOT (DRL), Green (RoHS & no Sb/Br)	DRL0005A
70	Y1	1		FC-135 32.7680KA-A3	Epson	Crystal, 32.768 KHz, 12.5 pF, SMD	SMD, 2-Leads, Body 3.2x1.5mm
71	Y2	1		TSX-3225 24.0000MF20G-AC3	Epson	Crystal, 24 MHz, 9 pF, SMD	SMD, 4-Leads, Body 2.65x3.35mm, Height 0.6mm
72	Y3	1		ABM8-24.000MHZ-B2-T	Abracon Corportation	Crystal, 24.000MHz, 18pF, SMD	3.2x0.8x2.5mm
73	Y4	1		FC-12M 32.7680KD-A3	Epson	Crystal, 32.768kHz, 12.5pF, SMD	Crystal 2.05x.6x1.2mm
74	FID1, FID2, FID3	0		N/A	N/A	Fiducial mark. There is nothing to buy or mount.	Fiducial
75	J12, J13	0		PEC06SAAN	Sullins Connector Solutions	Header, 100mil, 6x1, Tin, TH	TH, 6-Leads, Body 608x100mil, Pitch 100mil
76	R8	0	0	CRCW04020000Z0ED	Vishay-Dale	RES, 0, 5%, 0.063 W, 0402	0402
77	R11, R12	0	2.2k	CRCW04022K20JNED	Vishay-Dale	RES, 2.2k ohm, 5%, 0.063W, 0402	0402

10 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (December 2016) to Revision A (March 2017) **Page**

- Changed 'LRM' to 'LRA' in Actuator column of Mode 2 – B3 row in Table 2-1 7
- Changed 'ERA' to 'ERM' in Actuator column of Mode 2 – B4 in Table 2-1 7
- Deleted 'ROM Library Mode' and 'Waveform Library Effects List' sections.......... 11

Changes from Revision A (March 2017) to Revision B (December 2021) **Page**

- Updated front image.......... 1

11 Trademarks

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