*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.

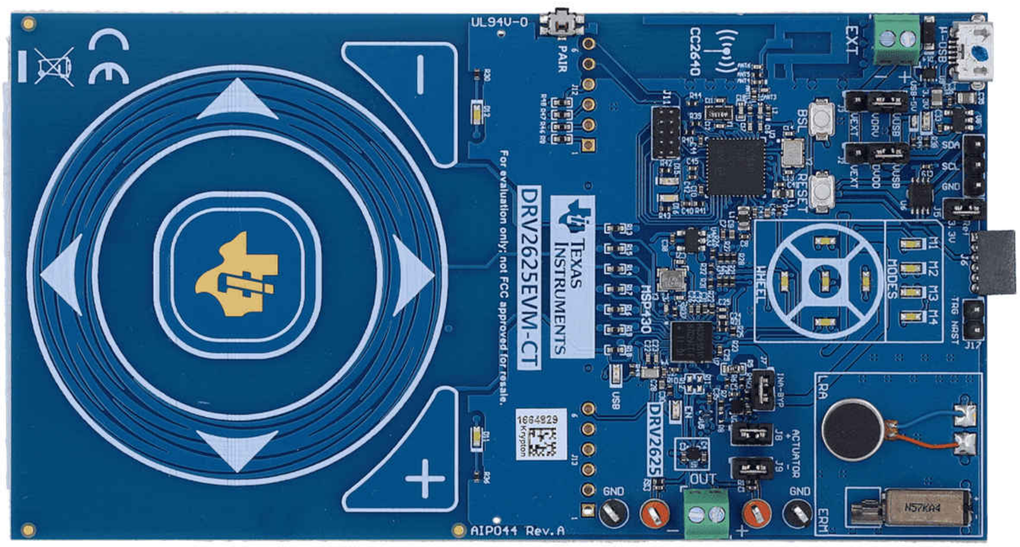


**Figure 1-1. DRV2625EVM-CT Board**

**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.

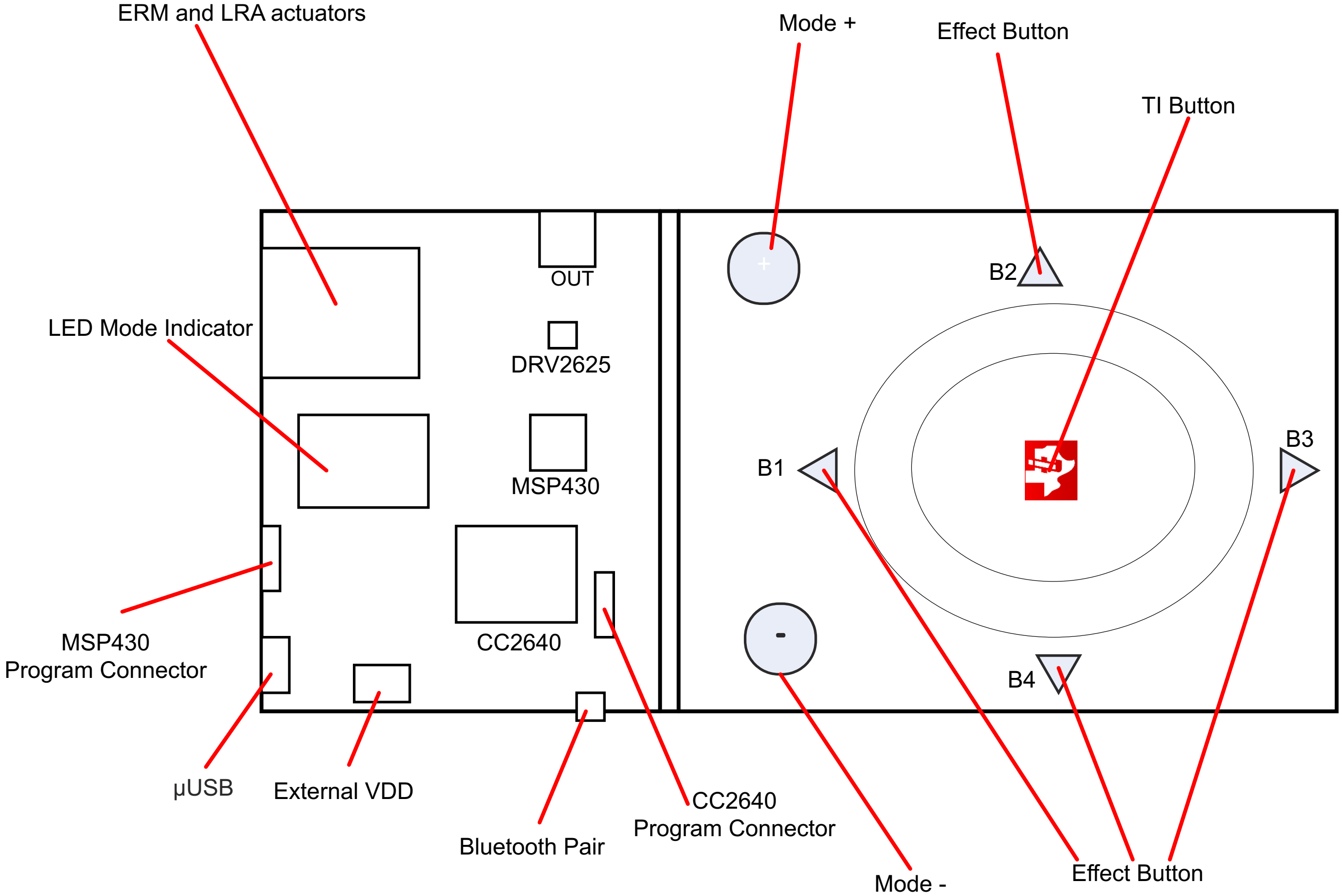


**Figure 1-1. Board Diagram**

## 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.

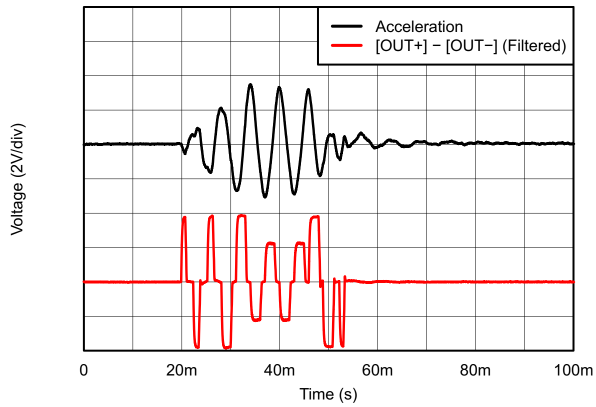


**Figure 2-1. LRA Sharp Click Closed Loop Waveform**

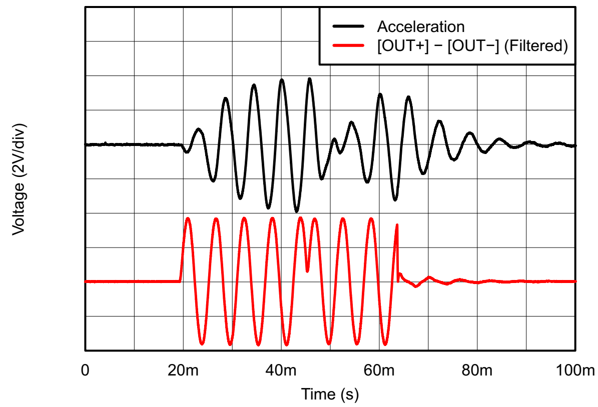


**Figure 2-2. LRA Sharp Click Open Loop Waveform**

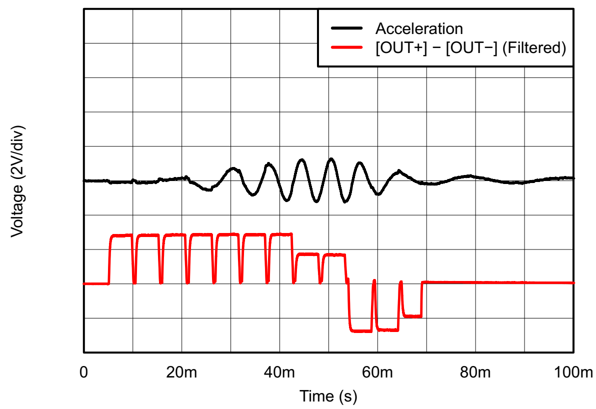


**Figure 2-3. ERM Sharp Click Closed Loop Waveform**

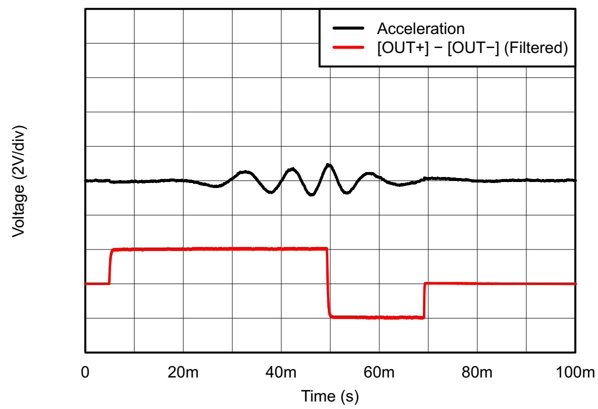


**Figure 2-4. ERM Sharp Click Open Loop Waveform**

### 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.

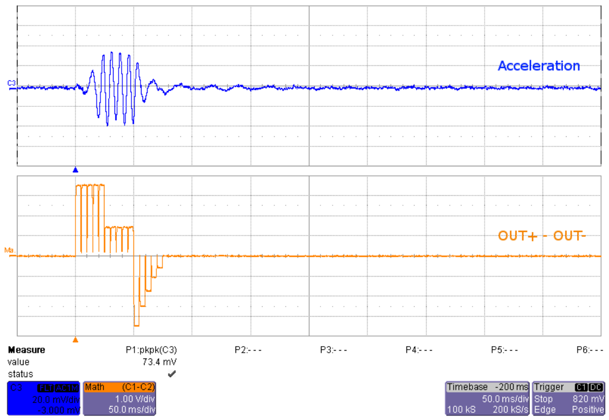


**Figure 2-5. ERM Closed-Loop Click Waveform (Button 1)**

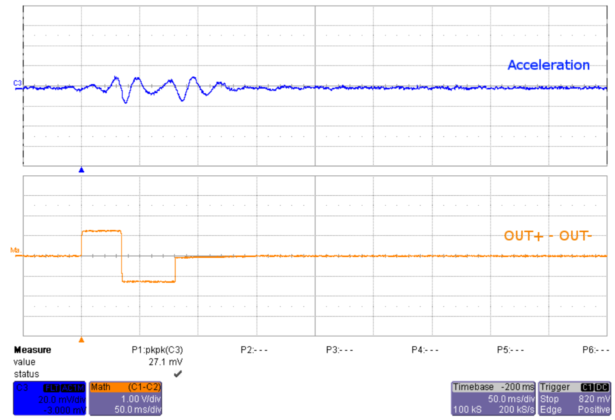


**Figure 2-6. ERM Open-Loop Click Waveform (Button 4)**

### 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.

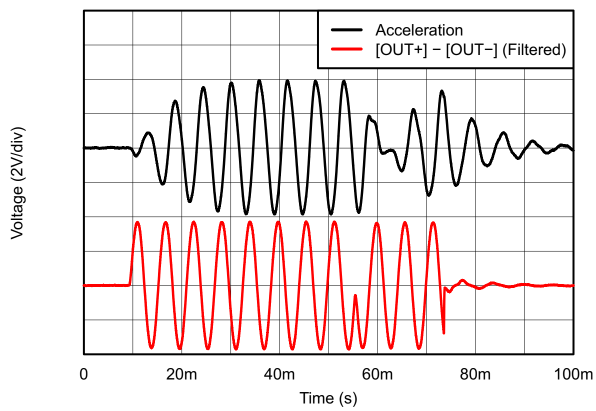


**Figure 2-7. LRA Closed-Loop Click Waveform**

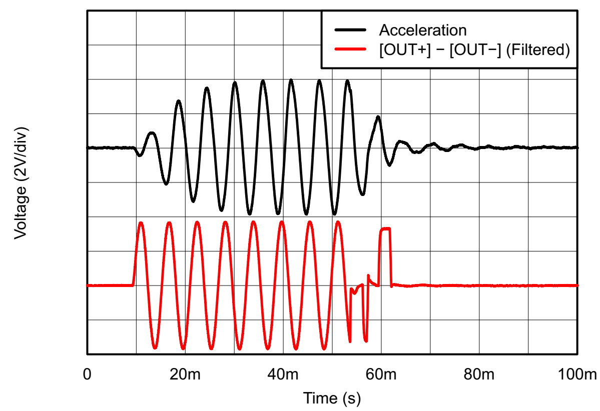


**Figure 2-8. LRA Open-Loop Click Waveform**

### 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.

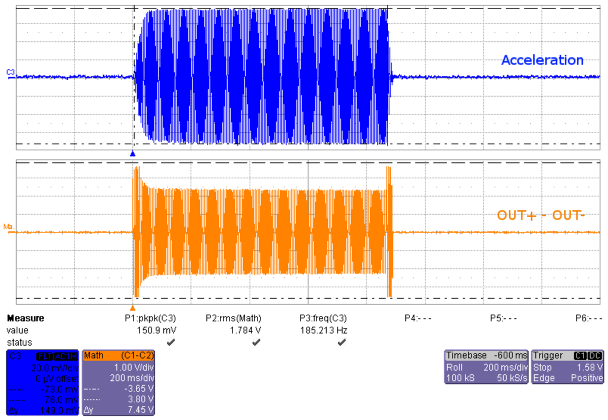


**Figure 2-9. LRA Auto-Resonance ON Waveform (Button 1)**

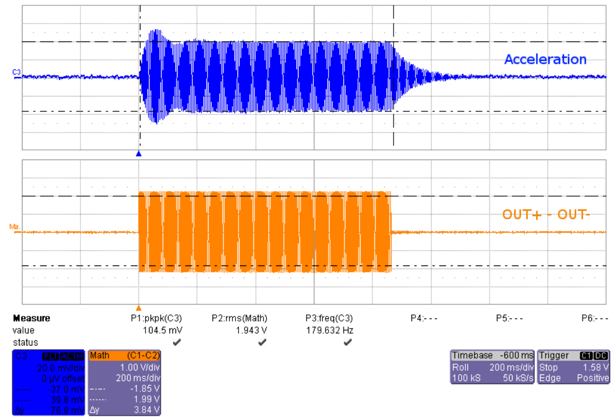


**Figure 2-10. LRA Auto-Resonance OFF Waveform (Button 2)**

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.

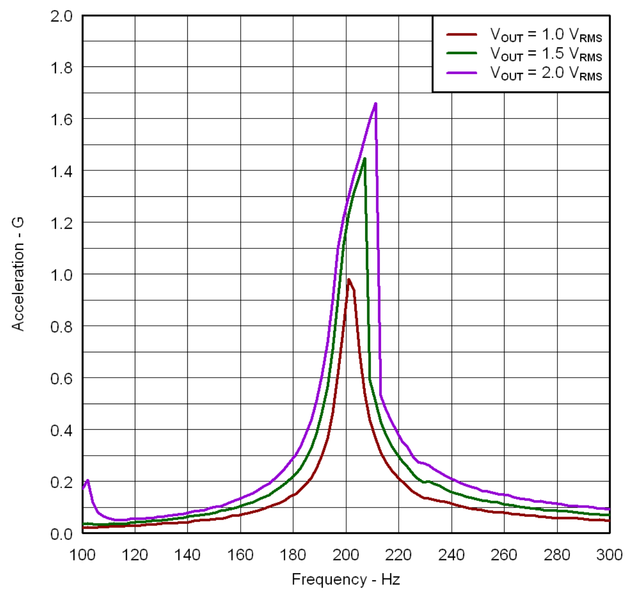


**Figure 2-11. Acceleration Versus Frequency**

## 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.

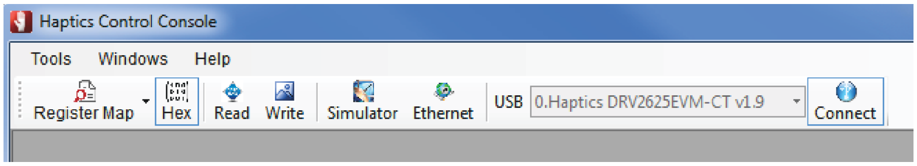


**Figure 3-1. Haptics Control Console**

### 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.

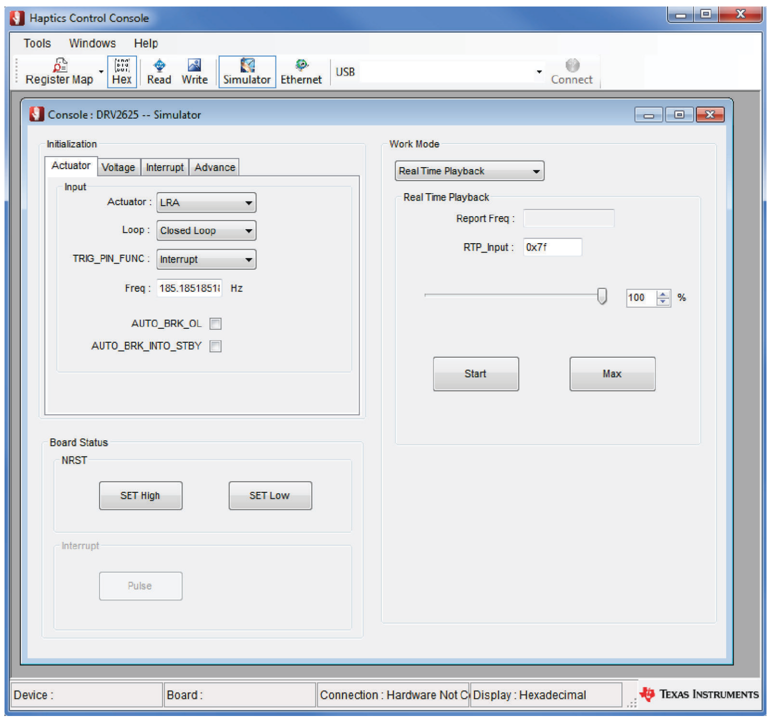


**Figure 3-2. HCC DRV2625 Console**

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.

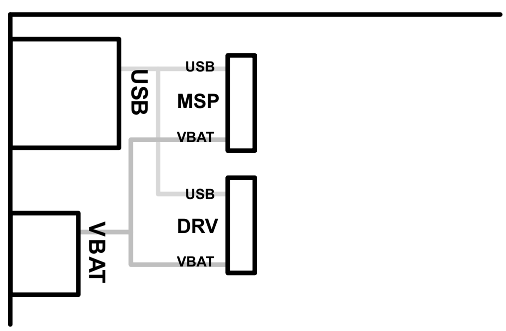


**Figure 4-1. Power Jumper Selection**

**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

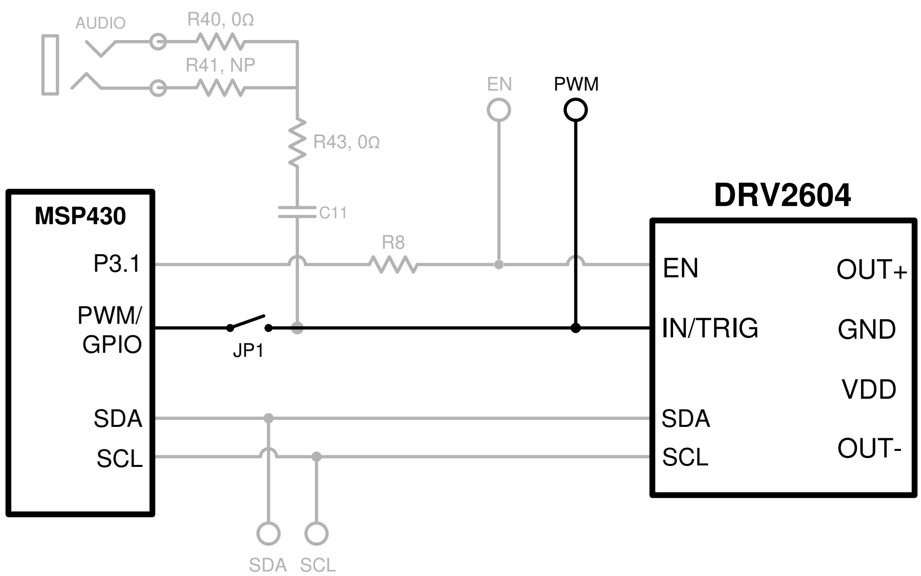


**Figure 4-2. External PWM Input**

**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

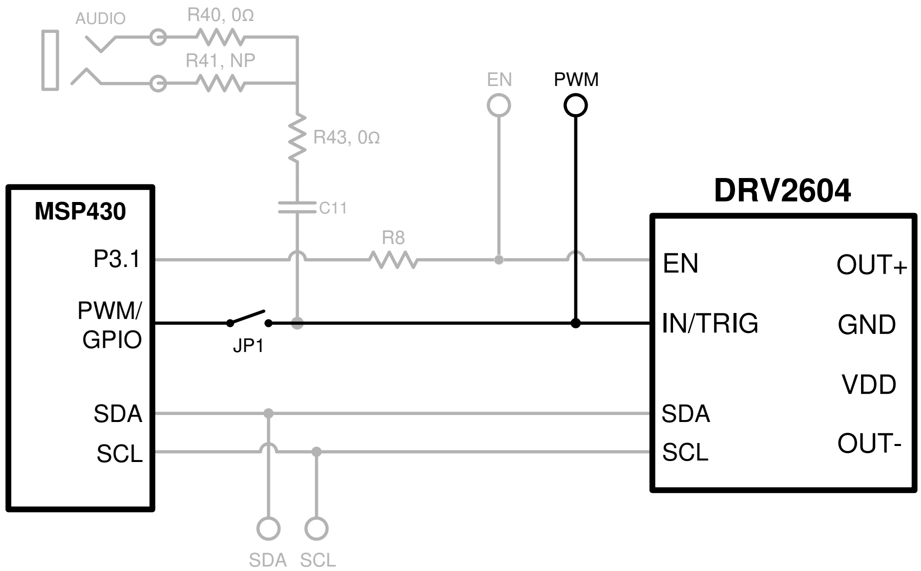


**Figure 4-3. External Trigger Control**

**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 I²C 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 I²C Input

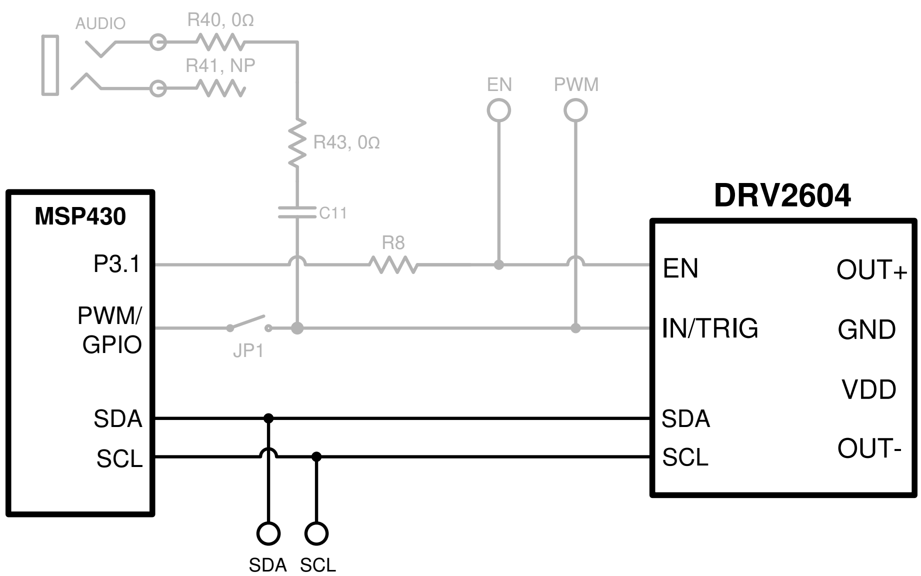


**Figure 4-4. External I²C Input**

The DV2625 can be controlled by an external I²C source. Attach the external controller to the I²C header at the top of the board; be sure to connect SDA, SCL and GND from the external source.

#### 4.6.1 External I²C Control Initialization

I²C communication is possible only when the EN pin is set high. To enable the DRV2625 and allow external I²C 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 I²C source.

## 4.7 Analog Input

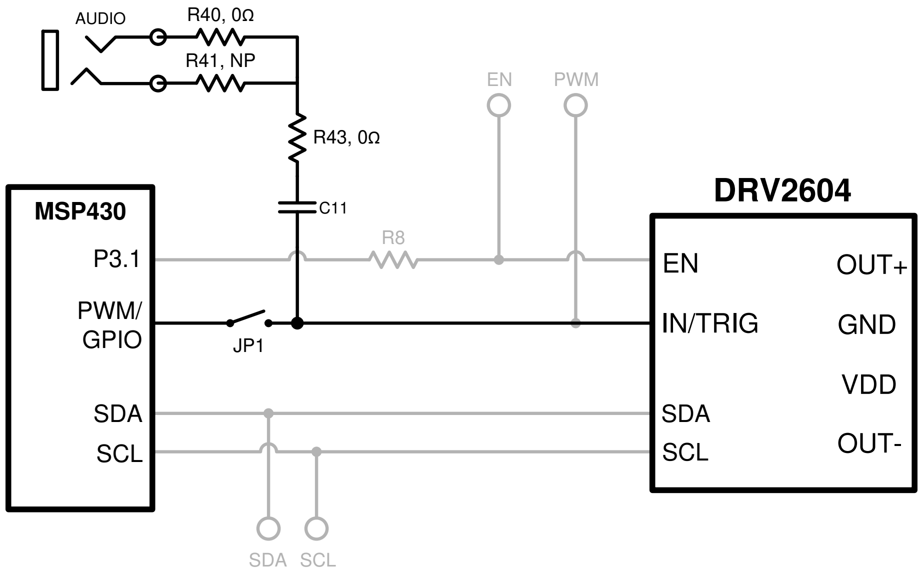


**Figure 4-5. Analog Input**

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–*.

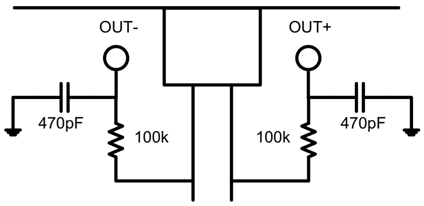


**Figure 5-1. Terminal Block and Test Points**

## 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.

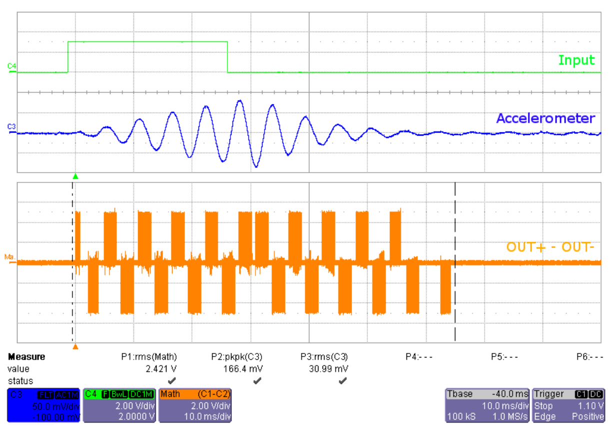


**Figure 5-2. DRV2625 Unfiltered Waveform**

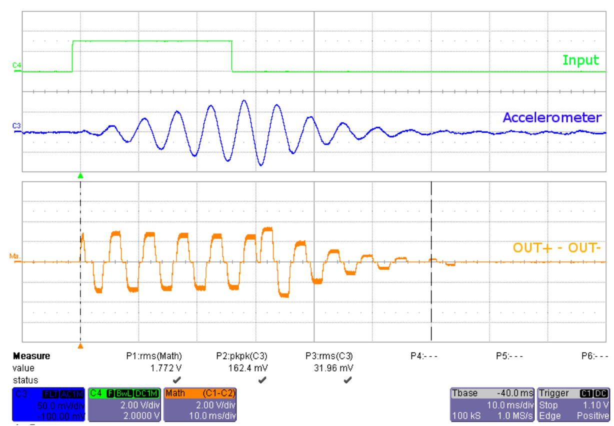


**Figure 5-3. DRV2625 Filtered Waveform**

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.

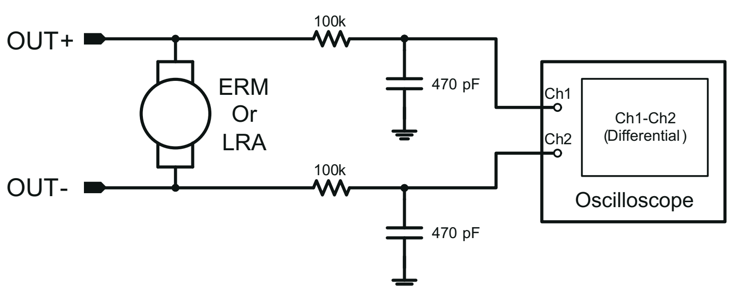


**Figure 5-4. Measuring the DRV2625 Output Signal with an Analog Low-Pass Filter**

# 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.

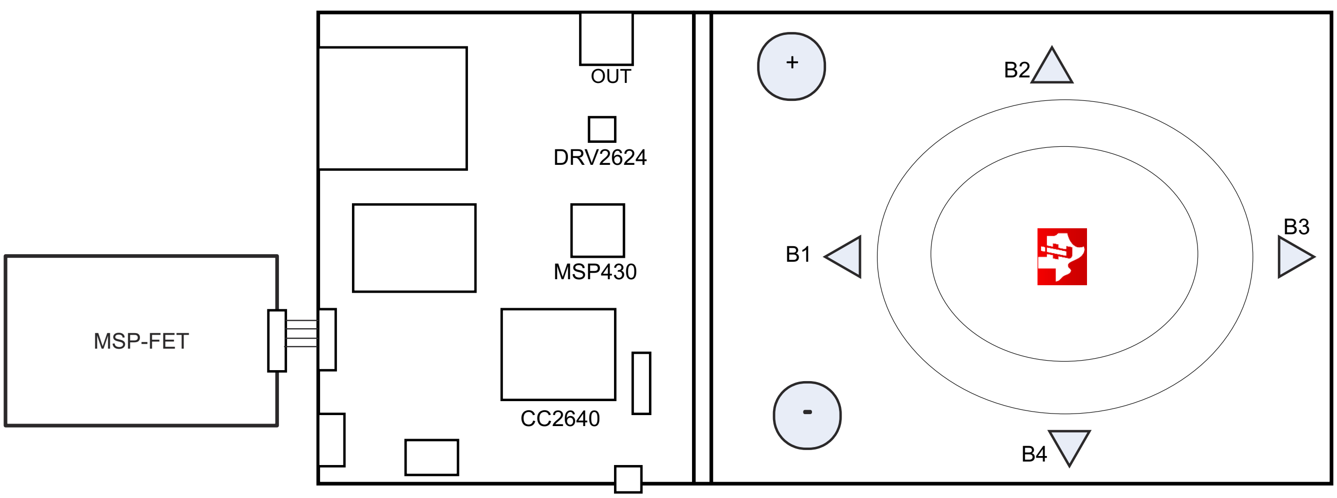


**Figure 6-1. FET Programmer Connection**

## 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

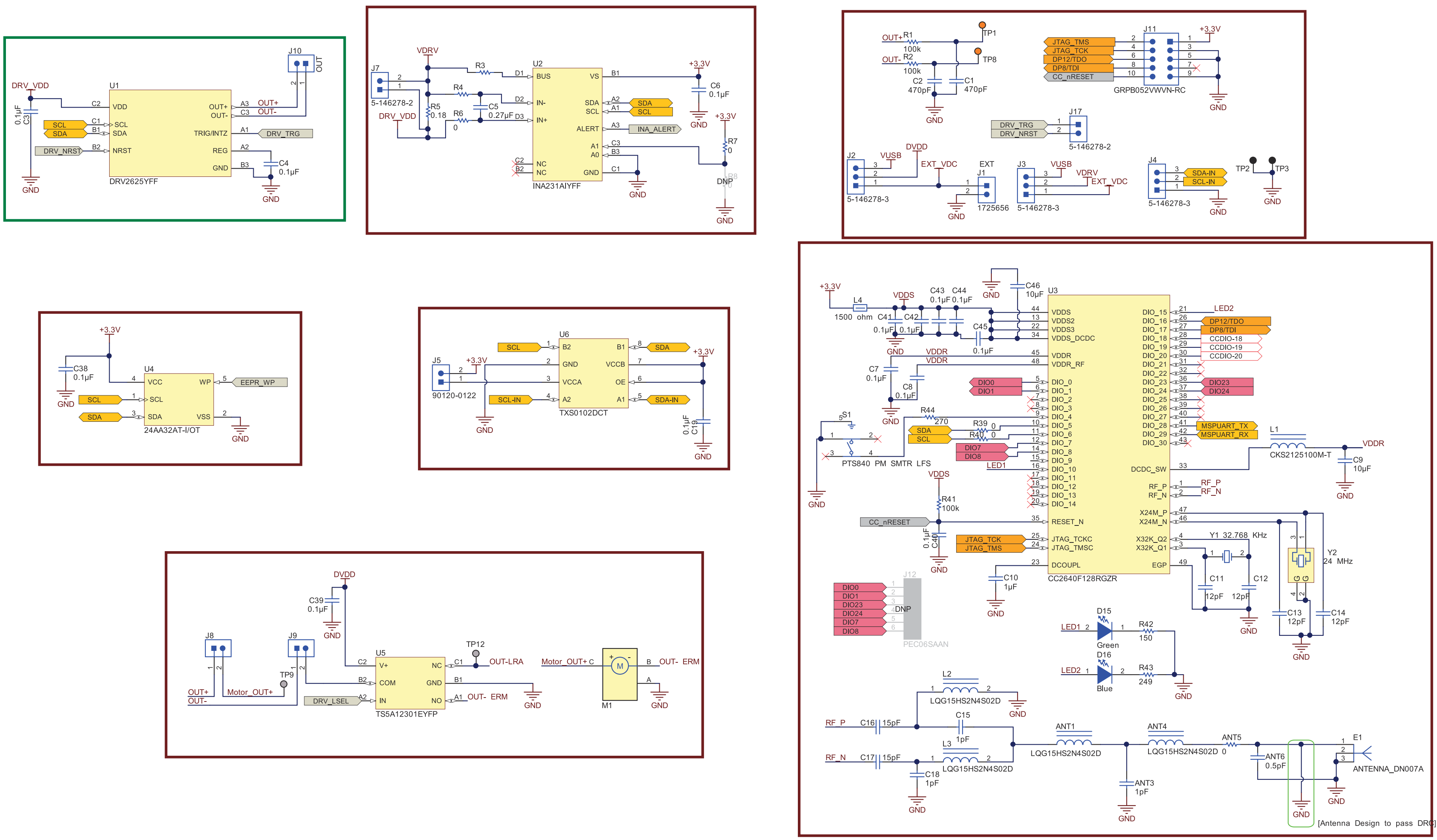


Figure 7-1. DRV2625EVM-CT Schematic Page 1

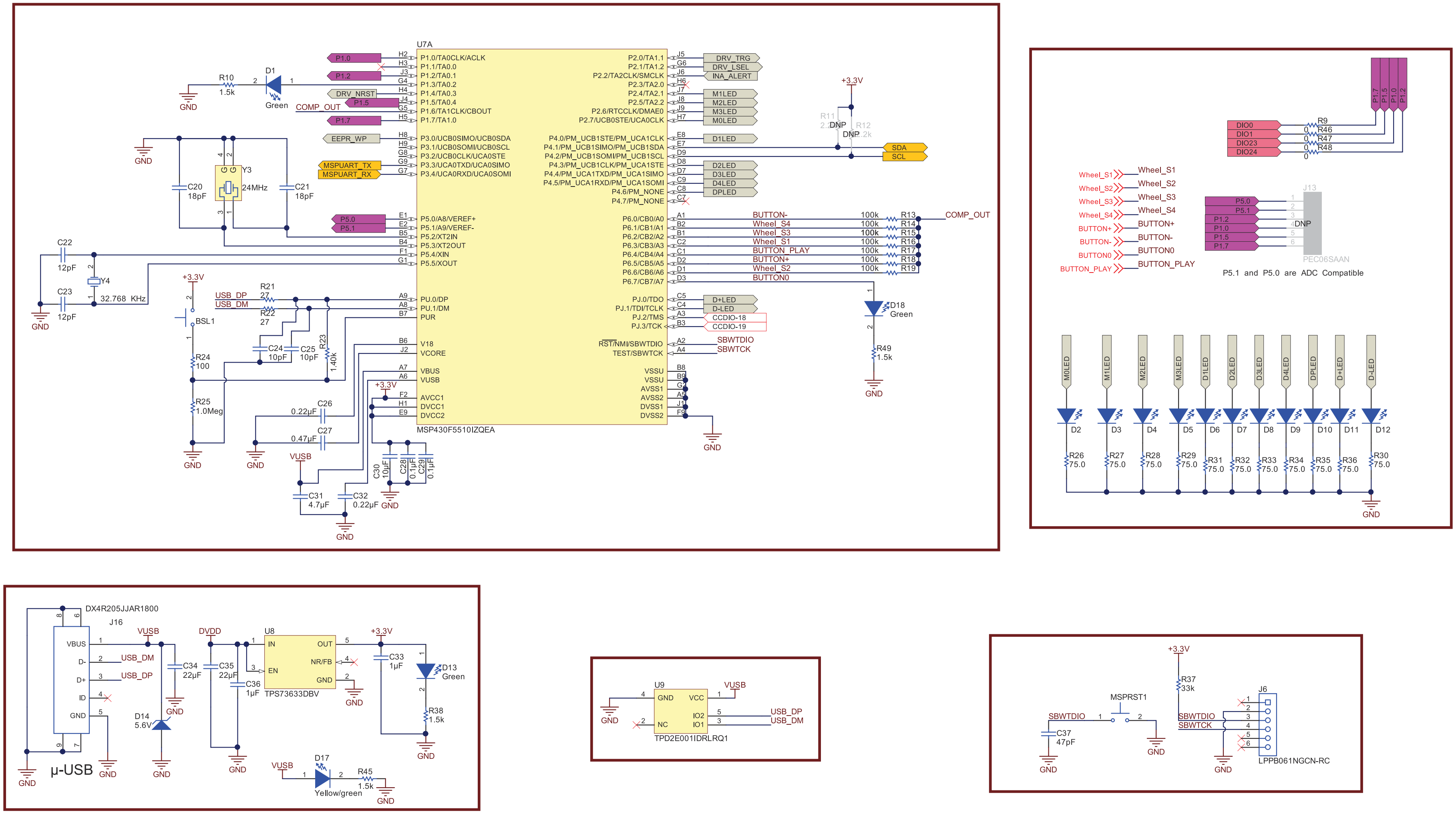


Figure 7-2. DRV2625EVM-CT Schematic Page 2

# 8 Layout

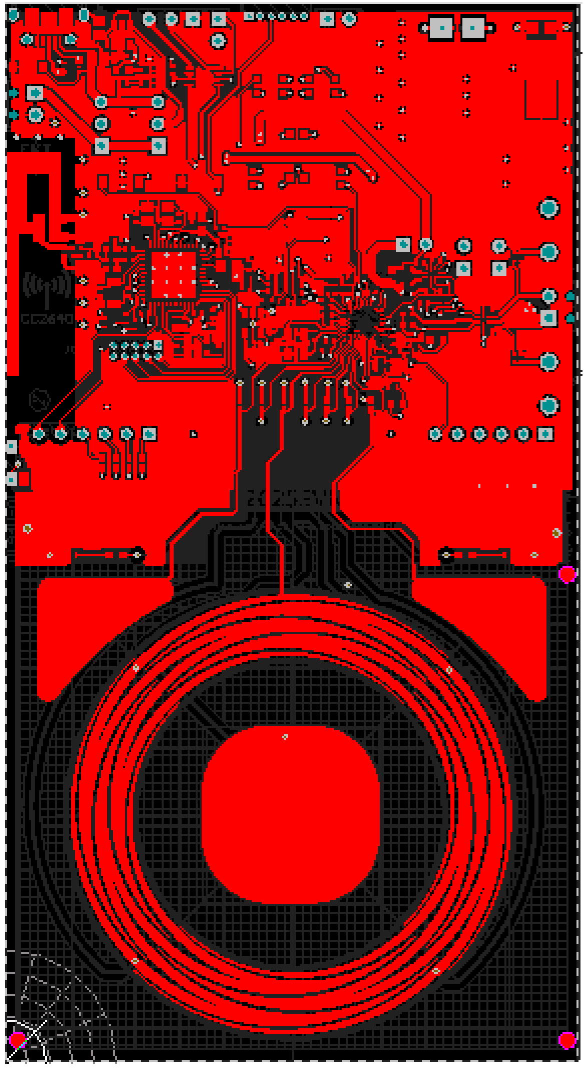

**Figure 8-1. Top Layer**

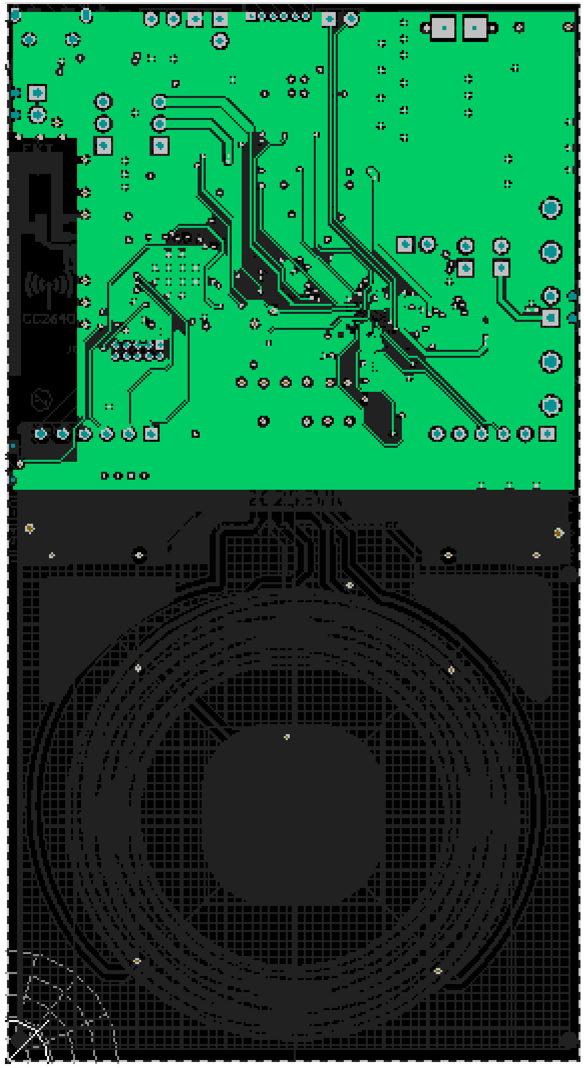

Figure 8-2. Layout Layer 2

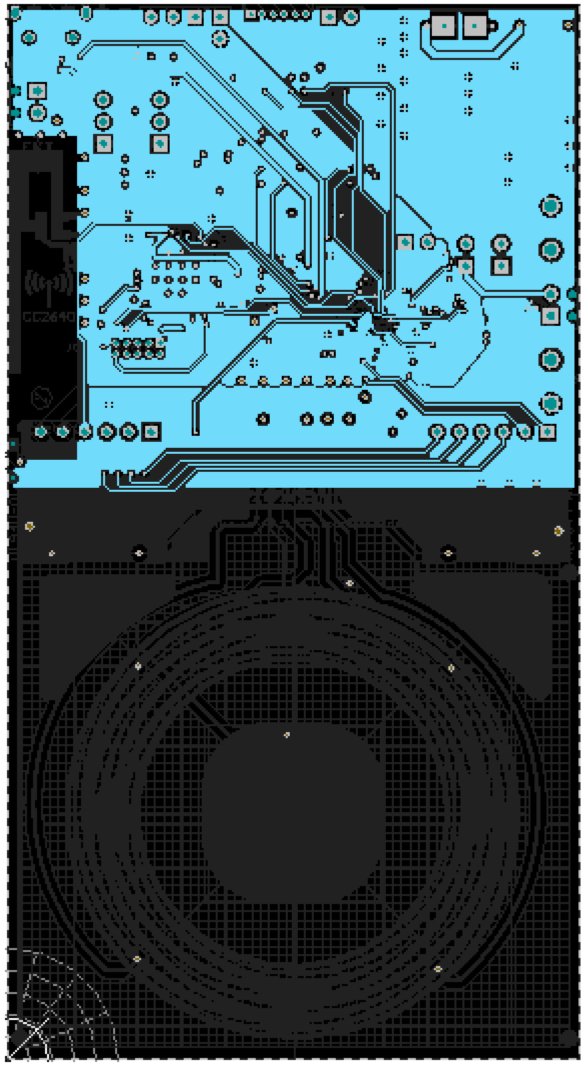

**Figure 8-3. Layout Layer 3**

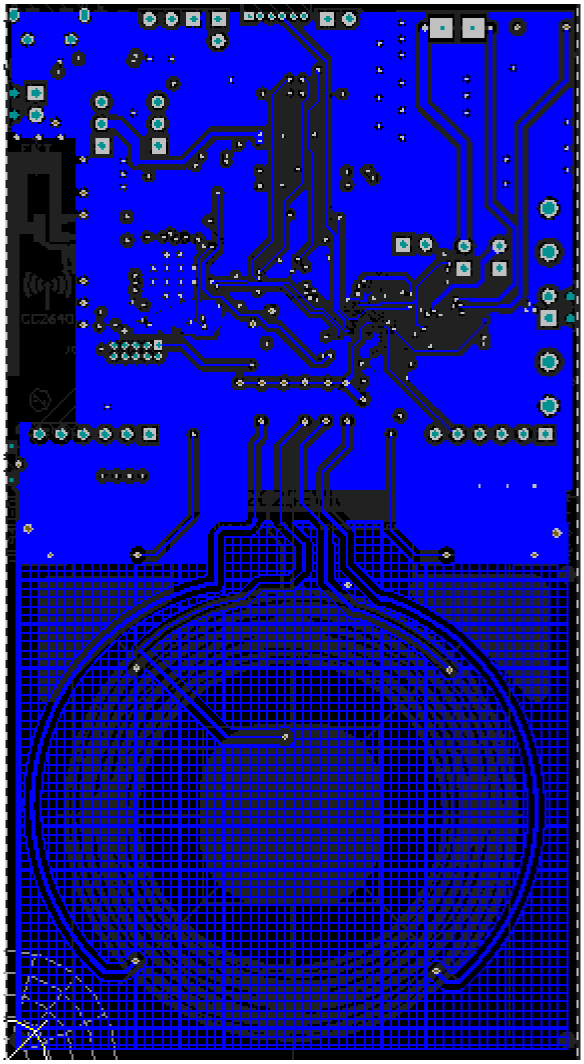

Figure 8-4. Layout Layer 4

# 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

Code Composer Studio™ is a trademark of TI.
All trademarks are the property of their respective owners.