# DRV2604L ERM, LRA Haptic Driver Evaluation Kit

The DRV2604L 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 DRV2604LEVM-CT Evaluation Module (EVM) is a complete demo and evaluation platform for the DRV2604L. 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 DRV2604L.

This document contains instructions to setup and operate the DRV2604LEVM-CT in demo and evaluation mode.

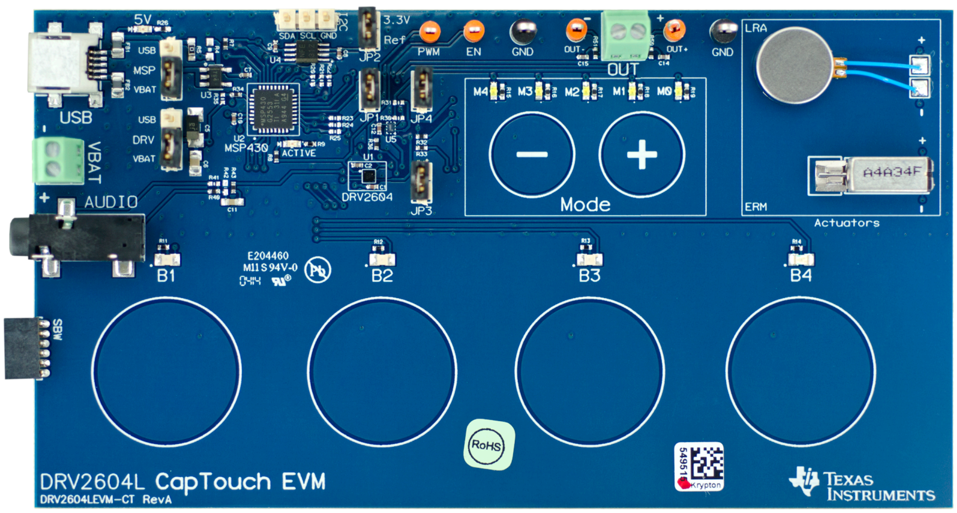


**Figure 1. DRV2604LEVM-CT Board**

**Evaluation Kit Contents:**

- DRV2604LEVM-CT demo and evaluation board
- Mini-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
- DRV2604LEVM-CT firmware available on ti.com

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# 1 Getting Started

The DRV2604L can be used as a demonstration or evaluation tool. When the DRV2604LEVM-CT evaluation module is powered on for the first time, a demo application automatically starts. To power the board, connect the DRV2604LEVM-CT to an available USB port on your computer using the included mini-USB cable. The demo begins with a board power-up sequence and then enters the demo effects mode. The four larger buttons (B1–B4) can be used to sample haptic effects using both the ERM and LRA motor in the top right corner. The two smaller mode buttons (**–**, **+**) are used to change between the different banks of effects. See the DRV2604L Demonstration Program section for a more detailed description of the demo application.

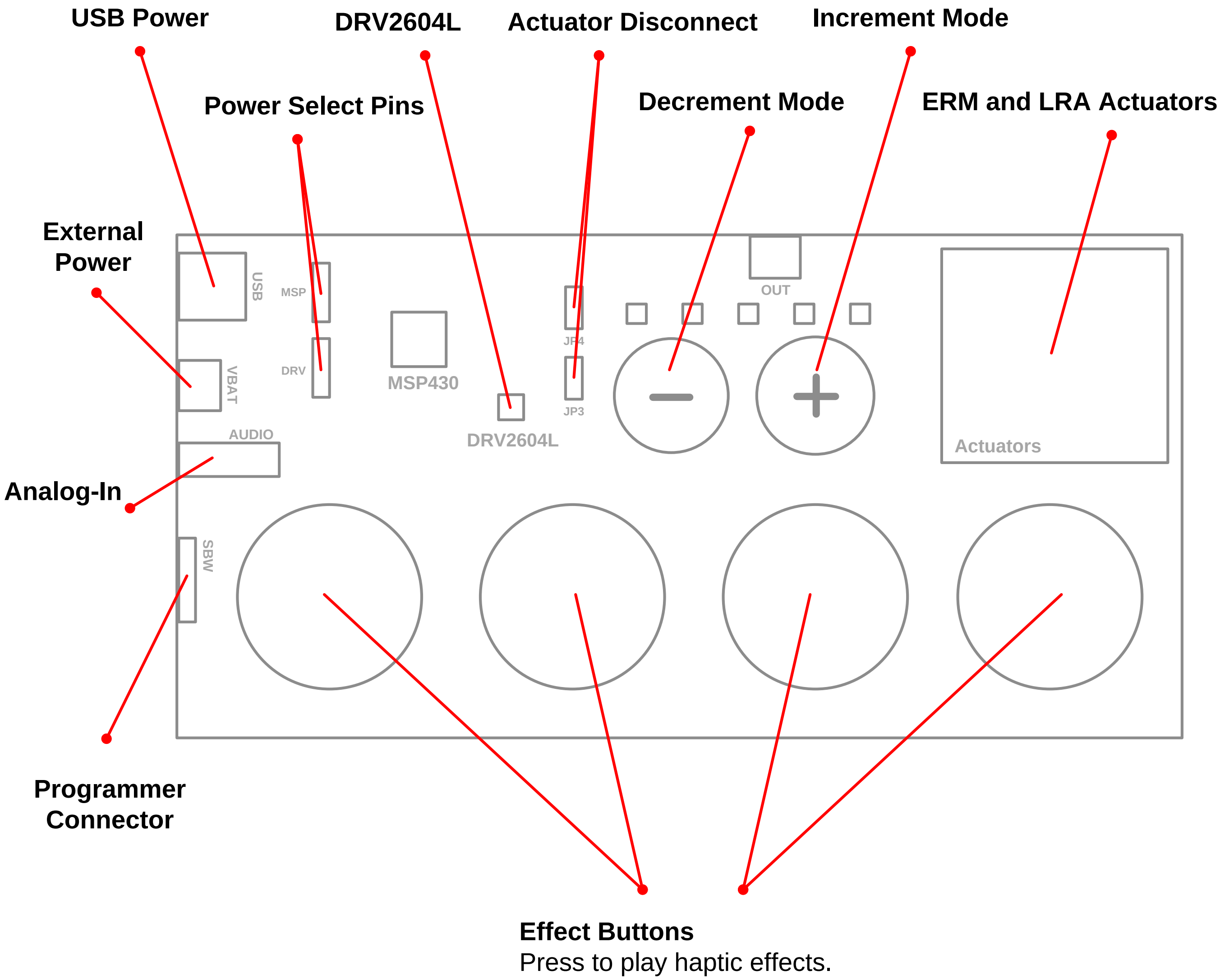


**Figure 2. Board Diagram**

Code Composer Studio is a trademark of Texas Instruments.

### 1.1 Evaluation Module Operating Parameters

The following table lists the operating conditions for the DRV2604L on the evaluation module.

| Parameter | Specification |
|---|---|
| Supply voltage range | 2.5 V to 5. 5 V |
| Power-supply current rating | 400 mA |

### 1.2 Quick Start Board Setup

The DRV2604LEVM-CT firmware contains haptic waveforms which showcase the features and benefits of the DRV2604L. 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.

| Jumper | Default Position | Description |
|---|---|---|
| JP1 | Shorted | Connect MSP430 GPIO/PWM output to DRV2604L IN/TRIG |
| JP2 | Shorted | 3.3 V reference for $I^2C$ |
| JP3, JP4 | Shorted | Connect on-board actuators to DRV2604L |
| MSP | USB to MSP | Select USB (5 V) or VBAT power for the MSP430 |
| DRV | USB to DRV | Select USB (5 V) or VBAT power for the DRV2604L |

2. Connect the included mini-USB cable to the USB connector on the DRV2604LEVM-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 four colored LEDs will turn on, the four mode LEDs will flash, and the LRA and ERM will perform auto-calibration, indicating the board has been successfully initialized.

## 2 DRV2604L Demonstration Program

The DRV2604LEVM-CT contains a microcontroller and embedded software to control the DRV2604L. There are three sets of modes accessible by pressing and holding the “+” button. Follow the instructions in the following sections to access the effects in each set.

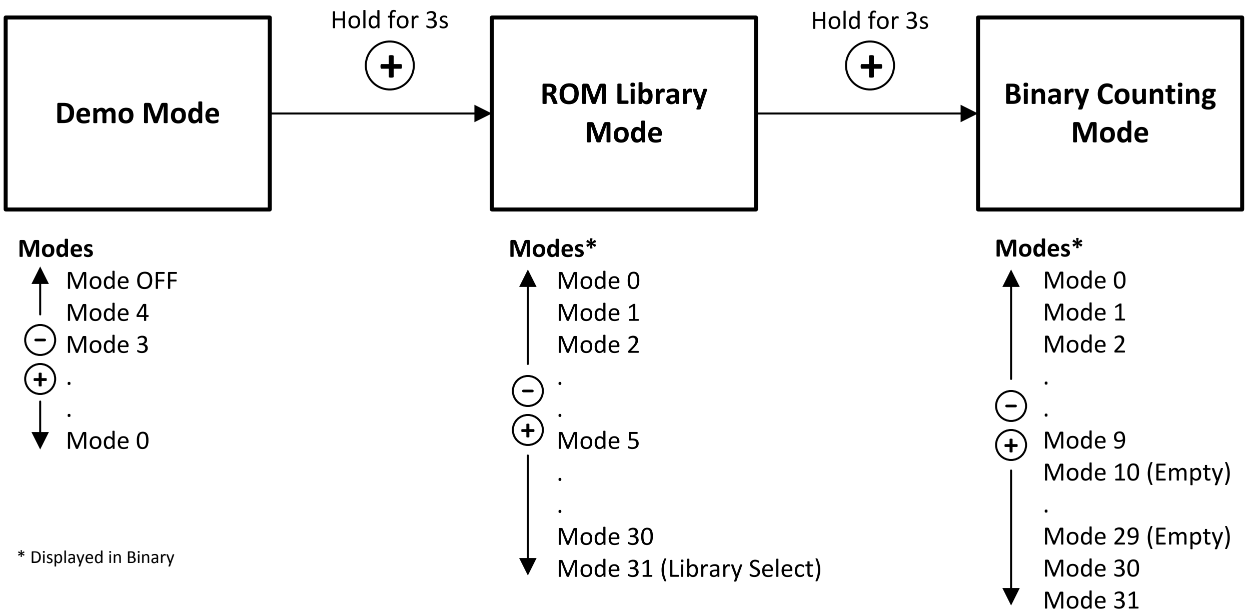


**Figure 3. DRV2604LEVM-CT Mode Sets**

## 2.1 Modes and Effects Table

The effects preloaded on the DRV2604LEVM-CT are listed in Table 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 1. Mode and Effects Table**

| Mode | Button | Description | Actuator | Waveform Location | Interface |
|---|---|---|---|---|---|
| **Mode Off**<br>LEDs Off | B1 | Click + Bounce | ERM | RAM | Internal Trigger (I$^2$C) |
| | B2 | Ramp Up + Click | LRA | | |
| | B3 | Gallop Alert | ERM | | |
| | B4 | Pulsing Alert | LRA | | |
| **Mode 4**<br>LED M4 On | B1 | Strong Click | ERM | RAM | Ext. Level Trig. |
| | B2 | Bump + Release | | | Internal Trigger |
| | B3 | Double Strong Click | | | Ext. Edge Trig. |
| | B4 | Click (Open Loop) | | µController | PWM |
| **Mode 3**<br>LED M3 On | B1 | Strong Click | LRA | RAM | Ext. Level Trig. |
| | B2 | Single-Cycle Click | | | Internal Trigger |
| | B3 | Single-Cycle Click with braking | | | Internal Trigger |
| | B4 | Click (Open Loop) | | µController | PWM |
| **Mode 2**<br>LED M2 On | B1 | Buzz Auto-Resonance ON | LRA | µController | RTP (I$^2$C) |
| | B2 | Buzz Auto-Resonance OFF | | | PWM |
| | B3 | Buzz Alert | ERM | | |
| | B4 | Scroll Wheel | LRA | | RTP (I$^2$C) |
| **Mode 1**<br>LED M1 On | B1 | Click with braking | ERM and LRA | RAM | Internal Trigger (I$^2$C) |
| | B2 | Click without braking | | | |
| | B3 | Click with braking (Open Loop) | | | |
| | B4 | Selects ERM or LRA | | | |
| **Mode 0**<br>LED M0 On | B1 | Auto-Calibration | ERM | Internal Routine | Internal Trigger (I$^2$C) |
| | B2 | Auto-Calibration | LRA | | |
| | B3 | Click | ERM/LRA | RAM | |
| | B4 | Buzz | | | |

## 2.2 Description of the Demo Modes

The following sections describe each demo mode in more detail.

### 2.2.1 Mode Off – Haptics Effect Sequences

Mode Off is a set of haptic sequences that combine a series of haptic effects. The two effects below show combinations of clicks and ramps.

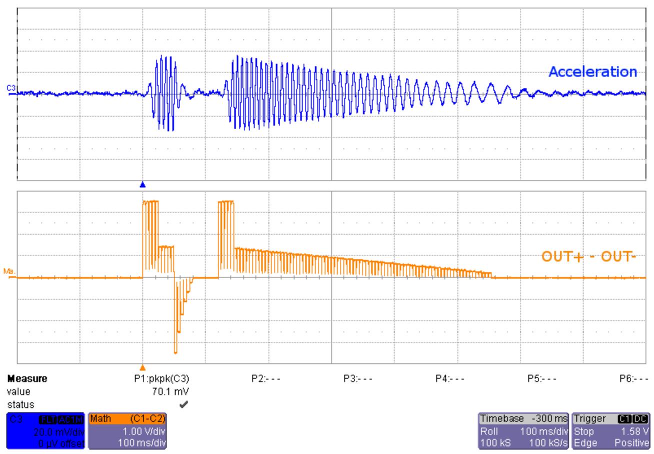


**Figure 4. ERM Click and Bounce Waveform (Button 1)**

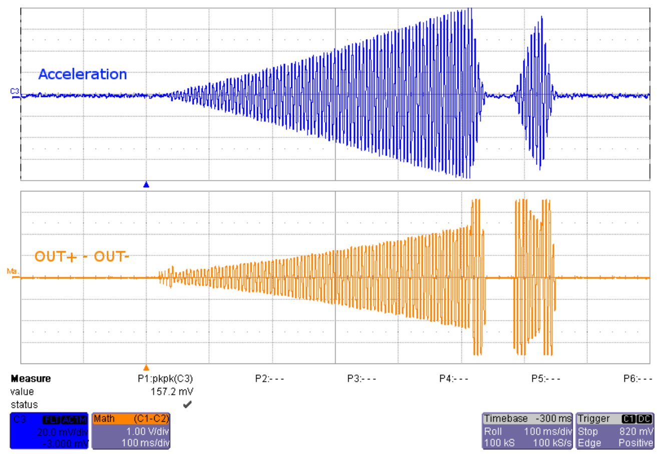


**Figure 5. LRA Ramp-Up and Click Waveform (Button 2)**

### 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.

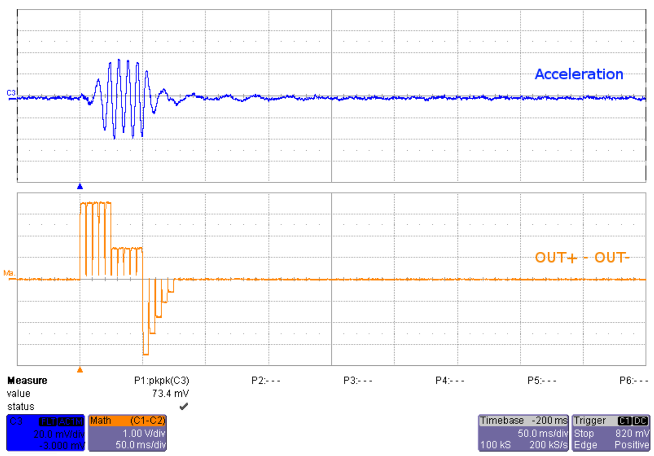


**Figure 6. ERM Closed-Loop Click Waveform (Button 1)**

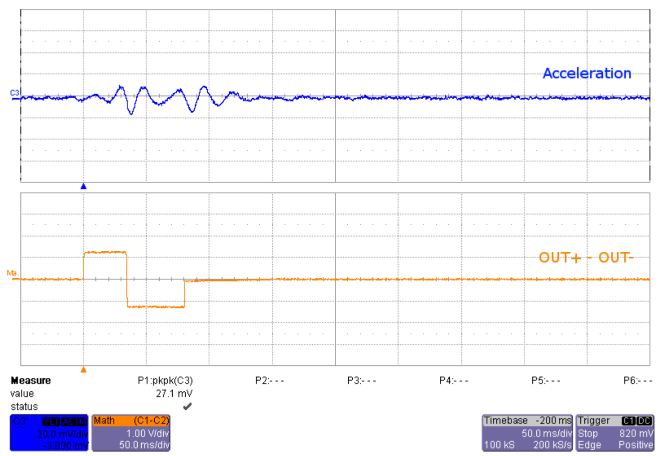


**Figure 7. ERM Open-Loop Click Waveform (Button 4)**

### 2.2.3 Mode 3 – LRA Clicks

Mode 3 shows what the waveforms look like with and without braking and how closed-loop and open-loop mode affects the acceleration profile. Figure 8 and Figure 9 demonstrate single-cycle clicks. 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 10 shows a closed-loop waveform (with overdrive and braking) while Figure 11 shows open-loop mode that does not have overdrive or braking. Overdrive and braking allows the waveform to feel more crisp.

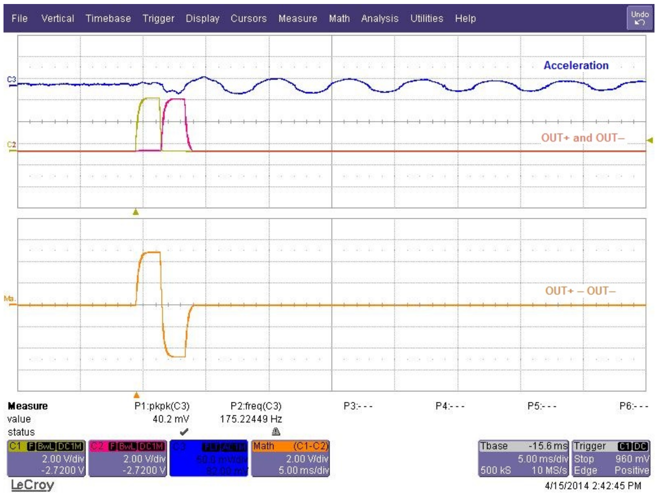


Figure 8. LRA Single-Cycle Click (Button 2)

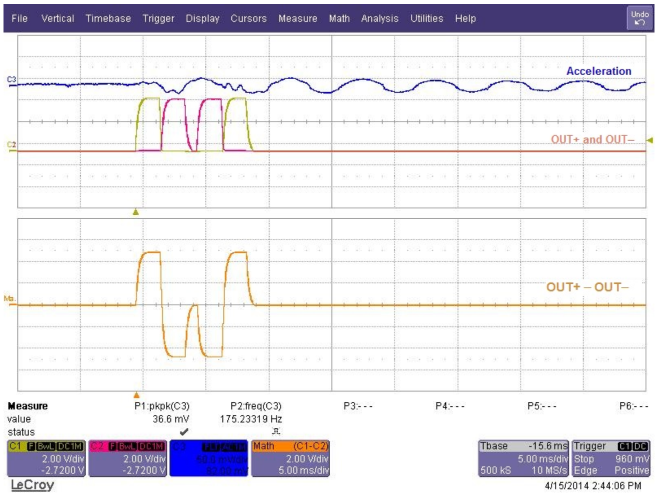


Figure 9. LRA Single-Cycle with Braking (Button 3)

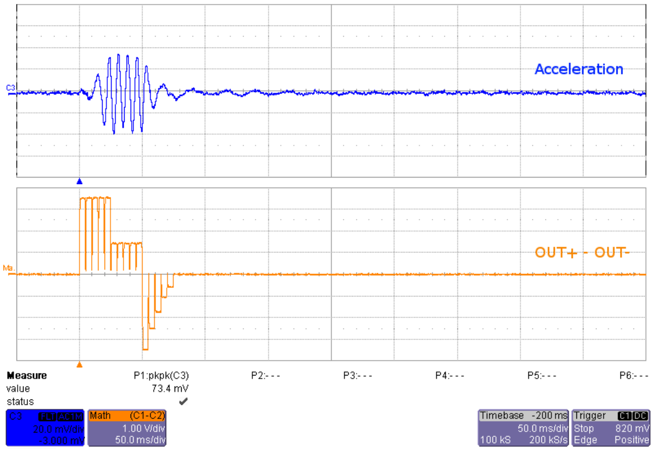


Figure 10. LRA Closed-Loop Click Waveform (Button 1)

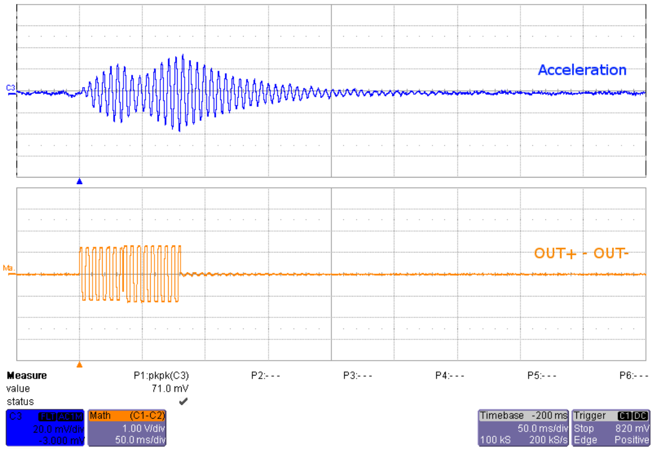


Figure 11. LRA Open-Loop Click Waveform (Button 4)

### 2.2.4 Mode 2 – Alerts and Scroll Wheel

Mode 2 showcases 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.

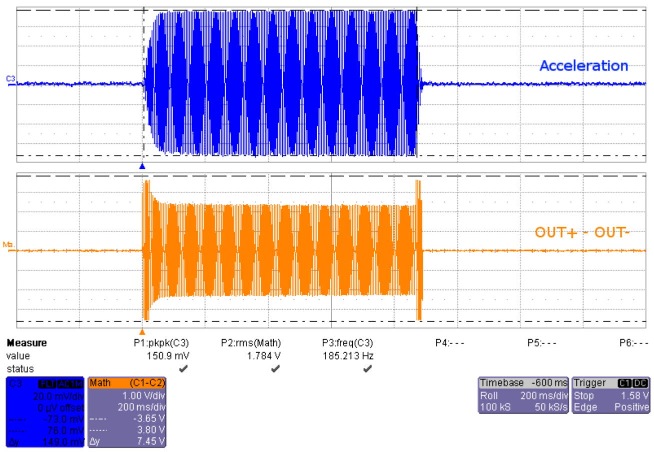


**Figure 12. LRA Auto-Resonance ON Waveform (Button 1)**

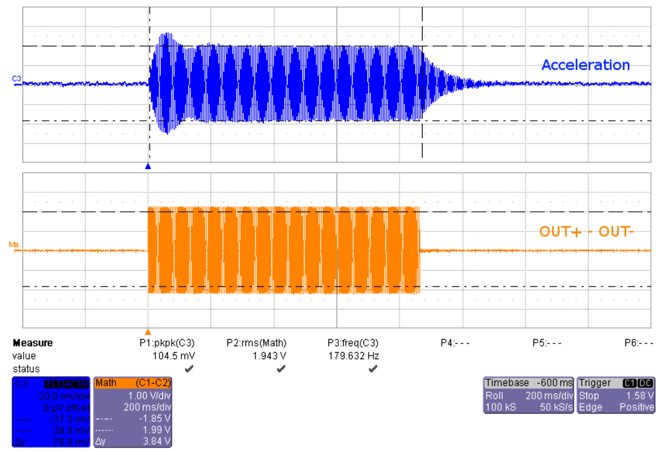


**Figure 13. LRA Auto-Resonance OFF Waveform (Button 2)**

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 DRV2604L dynamically tracks the exact resonant frequency to maximize the vibration force.

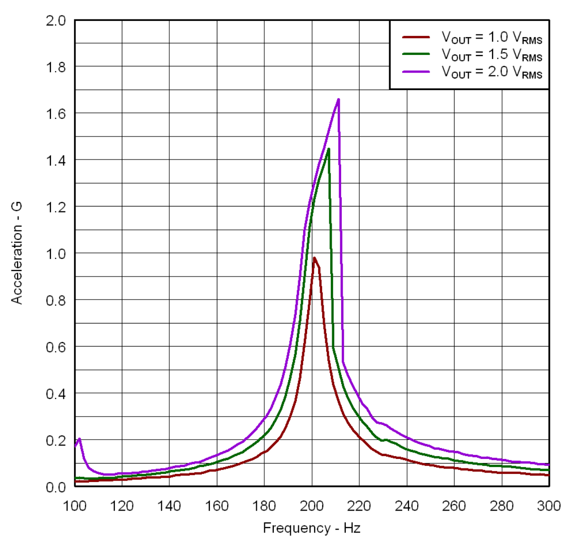


**Figure 14. Acceleration Versus Frequency**

Button 4 uses a series of clicks to create a scroll wheel effect. See the oscilloscope capture in Figure 15.

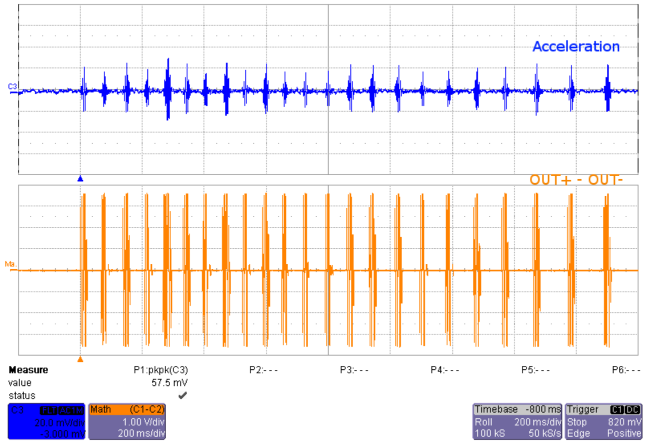


**Figure 15. LRA Scroll Wheel Effect Waveform (Button 4)**

### 2.2.5 Mode 1 – Click Waveforms

Mode 1 shows the advantages and disadvantages of the click waveform in the different modes of operation. Button 1 plays the click waveform with braking in auto-resonance. Button 2 plays the click waveform with no braking in auto-resonance. It is apparent that braking allows the waveform to dampen faster so there is no excessive oscillations at the end of the waveform. Button 3 plays the click with braking but in open loop. Braking is not supported in open loop, thus there is no reverse operation of the actuator shown in the graph.

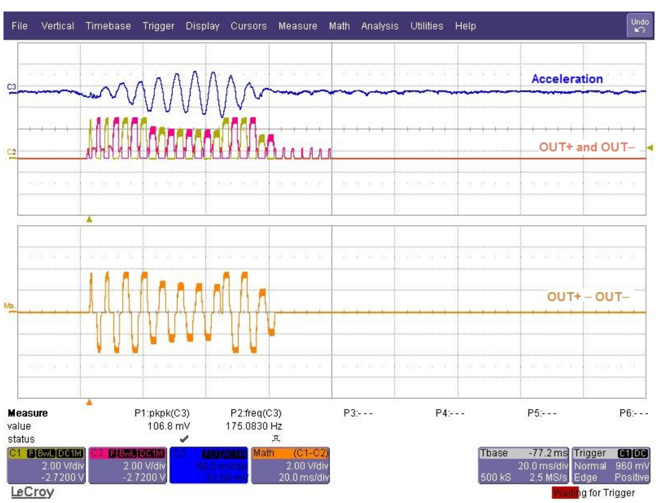


**Figure 16. LRA Click with Braking in Open Loop (Button 3)**

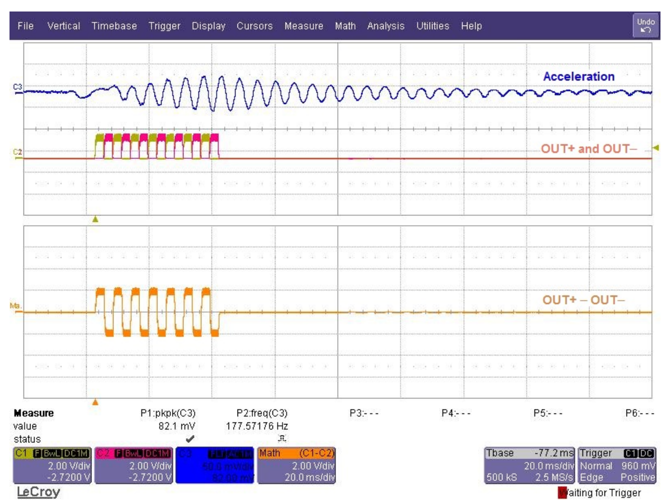


**Figure 17. LRA Click with Braking in Auto Resonance (Button 1)**

### 2.2.6 Mode 0 – Auto-Calibration

Auto-calibration is a DRV2604L-embedded routine that detects the characteristics and behavior of an actuator and adjusts the drive waveform automatically.

Perform auto-calibration using the following steps:

1. Connect an actuator to the green output terminal (OUT) or use the on-board actuators
2. For an ERM actuator, run the ERM auto-calibration by pressing button B1
3. For an LRA actuator, run the LRA auto-calibration by pressing button B2

4. Read the auto-calibration register values using $I^2C$
5. Test using buttons B3 and B4

### 2.3 RAM Library Mode

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

Once in *Library Mode* the DRV2604L loaded RAM 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 RAM effects as described above.

### 2.4 Waveform Library Effects List

Table 2 lists the descriptions of the waveforms embedded in the DRV2604L.

**Table 2. Waveform Effects**

| 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 | Gallop Alert |
| 14 | Pulsing Alert |
| 15 | Test Click with Braking |
| 16 | Test Buzz with Braking |
| 17 | Life Test Buzz with Braking |
| 18 | Life Test Continuous Buzz |
| 19 | ERM OL 1 ms Interval Click |
| 20 | LRA OL 1 ms Interval Click |
| 21 | ERM/LRA Click for 5 ms playback interval |
| 22 | ERM/LRA Click for 1 ms playback interval |

# 3 Additional Hardware Modes

Additional modes are available on the DRV2604LEVM-CT providing increased board control and functionality. The additional modes are not available in *demo* mode, but can be accessed by switching to *binary counting mode*. In *binary counting mode* the mode LEDs count in binary (32 modes) rather than in *demo* mode format (only 6 modes including off).

## 3.1 Enter Binary Counting Mode

To enter *binary counting mode* and access the additional modes:

1. Press and hold the increment mode button (**+**) for approximately 3 seconds until the mode LEDs flash and the colored LEDs flash once.
2. Press and hold the increment mode button (**+**) one more time until the mode LEDs flash and the colored LEDs flash twice.
3. Select from the *binary counting mode* using the **+** and **–** buttons.

## 3.2 Exit Binary Counting Mode

To exit *binary counting mode* and return to *demo* mode:

1. Press and hold the decrement mode button (**–**) for approximately 3 seconds.
2. Release the button when the actuator buzzes and mode LEDs flash.
3. Select from the *demo* modes using the **+** and **–** buttons.

## 3.3 Binary Counting Modes

Table 3 lists the modes available in *binary counting mode*.

**Table 3. Binary Counting Modes**

| Mode | Button | Description | Notes |
|---|---|---|---|
| **Mode 0**<br>External $I^2C$ Mode<br>LEDs: 00000 | B1 | Set ERM Output | Use this mode to control the DRV2604L using an external I2C Master. Press B1 or B2 to choose between the ERM or LRA. Press B3 to choose the trigger type. (1 - Internal, 2 - Ext. Edge, 3 - Ext. Level). Press B4 to trigger the waveform sequencer. |
| | B2 | Set LRA Output | |
| | B3 | Choose Trigger | |
| | B4 | Trigger Button | |
| **Mode 1**<br>Auto-Calibration & Diagnostics<br>LEDs: 00001 | B1 | ERM Auto-Calibration | Run the auto-calibration. The new auto-calibration results are used for all board effects. 1 flash = successful, 3 flashes = error. |
| | B2 | LRA Auto-Calibration | |
| | B3 | ERM Diagnostics | Run diagnostics. 1 flash = successful, 3 flashes = error. The status register bits [3:0] are displayed on the mode LEDs [3:0] when complete. |
| | B4 | LRA Diagnostics | |
| **Mode 2**<br>External PWM<br>LEDs: 00010 | B1 | Disable PWM Mode | External PWM - disconnect MSP430 PWM using JP1. Connect external PWM signal to the "PWM" testpoint at the top of the board. Select actuator using buttons B2 and B3. |
| | B2 | Set ERM Output | |
| | B3 | Set LRA Output | |
| | B4 | - | |
| **Mode 3**<br>External PWM and Enable<br>LEDs: 00011 | B1 | Return to normal mode | External PWM and Enable - disconnect MSP430 PWM using JP1. Connect external PWM signal to the "PWM" testpoint at the top of the board. Connect an external enable signal to the "EN" testpoint. Select actuator using buttons B2 and B3. Press B1 before switching modes. |
| | B2 | Set ERM Output | |
| | B3 | Set LRA Output | |
| | B4 | - | |
| **Mode 4**<br>Analog Input<br>LEDs: 00100 | B1 | AC Coupling - ERM | Analog Input - apply an external analog signal for AC coupling on the "Audio" jack. Apply a DC coupled signal to the "PWM" testpoint. |
| | B2 | DC Coupling - ERM | |
| | B3 | AC Coupling - LRA | |
| | B4 | DC Coupling - LRA | |
| **Mode 5**<br>Auto-resonance OFF frequency adjust<br>LEDs: 00101 | B1 | Alert (Auto-resonance On) | Vary the auto-resonance OFF (open-loop) output frequency and see the change in vibration force over frequency. Hold B3 or B4 for quick frequency adjustment. Compare B2 (auto-resonance off) with B1 (auto-resonance on). |
| | B2 | Alert (Auto-resonance Off) | |
| | B3 | Decrease output frequency | |
| | B4 | Increase output frequency | |
| **Mode 6**<br>Life Test (RTP) 2s ON, 1s OFF<br>LEDs: 00110 | B1 | Begin Life Test | Life Test using RTP (2 seconds on, 1 second off) - life test repeats infinite times and board must be powered down to stop. Increment / Decrement amplitude using B3 and B4. Test new amplitude using B2. Choose actuator using buttons B1 and B2 in Mode 0 or Mode 1. |
| | B2 | Test Buzz | |
| | B3 | Decrease output voltage (–1) | |
| | B4 | Increase output voltage (+1) | |
| **Mode 7**<br>Life Test (RTP) Infinite Buzz<br>LEDs: 00111 | B1 | Begin Life Test | Life Test using RTP (Infinite Buzz) - board must be powered down to stop buzz. Increment / Decrement amplitude using B3 and B4. Test new amplitude using B2 before beginning life test. Choose actuator using buttons B1 and B2 in Mode 0 or Mode 1. |
| | B2 | Test Buzz | |
| | B3 | Decrease output voltage (–1) | |
| | B4 | Increase output voltage (+1) | |
| **Mode 8**<br>Life Test (PWM) 2s ON, 1s OFF<br>LEDs: 01000 | B1 | Begin Life Test | Life Test using PWM (2 seconds on, 1 second off) - life test repeats infinite times and board must be powered down to stop. Increment / Decrement amplitude using B3 and B4. Test new amplitude using B2. Choose actuator using buttons B1 and B2 in Mode 0 or Mode 1. |
| | B2 | Test Buzz | |
| | B3 | Decrease output voltage (–1) | |
| | B4 | Increase output voltage (+1) | |
| **Mode 9**<br>Recorder<br>LEDs: 01001 | B1 | Start/Stop Recording | Recorder - use this mode to create a single amplitude pattern. Start by pressing the record button (B1). Then use B2 to create the pattern by tapping the button. When finished press the play back button (B3). |
| | B2 | Create Pattern | |
| | B3 | Start/Stop Play Back | |
| | B4 | - | |
| **Mode 10**<br>Life Test (RAM) Infinite Buzz<br>LEDs: 01010 | B1 | Life Test Infinite Buzz | Life Test (RAM Mode) - Increment / Decrement amplitude using B3 and B4. B1 - Start/Stop Infinite Buzz Life Test. B2 - Start/Stop 2s ON, 1s OFF life test. Choose actuator using buttons B1 and B2 in Mode 0 or Mode 1. |
| | B2 | Life Test 2 s ON, 1 s OFF | |
| | B3 | Decrease output voltage (–1) | |
| | B4 | Increase output voltage (+1) | |
| **Mode 11**<br>Frequency Sweep<br>LEDs: 01011 | B1 | Infinite Buzz at Frequency | Frequency Sweep (ROM Mode) - Increment/Decrement the frequency using B3 and B4. B1 - Start/stop infinite buzz at chosen frequency. B2 - Start/Stop infinite buzz using auto-resonance. Frequency range: (50 Hz - 300 Hz) |
| | B2 | Infinite Buzz at Resonance | |
| | B3 | Decrease Frequency (–1) | |
| | B4 | Increase Frequency (+1) | |
| **Mode 12**<br>2nd Cycle Test<br>LEDs: 01100 | B1 | Never Transition to Open Loop | 2nd Cycle Test - closed-loop drive to a resistive load on the output. B1 plays a buzz alert with OL drive disabled. B2 plays an infinite buzz with the automatic transition to open loop drive enabled (when back-EMF not detected). Demonstrates DRV2604L improved algorithm to sync |
| | B2 | Auto-transition to OL Drive | |
| | B3 | | |
| | B4 | | |

**Table 3. Binary Counting Modes (continued)**

| Mode | Button | Description | Notes |
|---|---|---|---|
| **Mode 13**<br>RAM Playback Interval<br>LEDs: 01101 | B1 | 5 ms playback interval enabled | Playback Interval - demonstrates the 1 ms or 5 ms playback interval. Affects waveform by multiplying the time data either by 1 ms or 5 ms. B1 - 5 ms mode enabled, B2 - 1 ms mode enabled, B3 - selects between ERM or LRA |
| | B2 | 1 ms playback interval enabled | |
| | B3 | Selects ERM or LRA | |
| | B4 | | |
| **Mode 30**<br>Actuator Break-in<br>LEDs: 11110 | B1 | Begin Actuator Break-in | Actuator Break-in - used to break in new actuators |
| | B2 | | |
| | B3 | | |
| | B4 | | |
| **Mode 31**<br>About the Board<br>LEDs: 11111 | B1 | Device ID | About the Board - the value will appear on the mode LEDs in binary. DRV2604L Device ID = 00100 |
| | B2 | Silicon Revision | |
| | B3 | Code Revision | |
| | B4 | | |

# 4 Hardware Configuration

The DRV2604LEVM-CT is very flexible and can be used to completely evaluate the DRV2604L. The following sections list the various hardware configurations.

## *4.1 Input and Output Overview*

The DRV2604LEVM-CT allows complete evaluation of the DRV2604L though test points, jacks, and connectors. Table 4 gives a brief description of the hardware.

**Table 4. Hardware Overview**

| Signal | Description | I/O |
|---|---|---|
| PWM | External input to DRV2604L IN/TRIG pin | Input/Observe |
| EN | External DRV2604L enable control | Input/Observe |
| OUT+/OUT– | Filtered output test points for observation, connect to oscilloscope or measurement equipment | Output |
| OUT | Unfiltered output terminal block, connect to actuator | Output |
| USB | USB power (5 V) | Input |
| VBAT | External Supply Power (2.5 V–5.5 V) | Input |
| SBW | MSP430 programming header | Input/Output |
| $I^2C$ | DRV2604L and MSP430 $I^2C$ bus | Input/Output |
| Audio | The audio jack is connected to the IN/TRIG pin of the DRV2604L. When the DRV2604L is in analog input mode, an analog signal from this jack controls the amplitude envelope of the output waveform. | Input |

Hardware configuration details can be found in the following sections.

### 4.2 Power Supply Selection

The DRV2604LEVM-CT can be powered by USB or an external power supply (VBAT). Jumpers DRV and MSP are used to select USB or VBAT for the DRV2604L and MSP430G2553, respectively. See the following table for possible configurations.

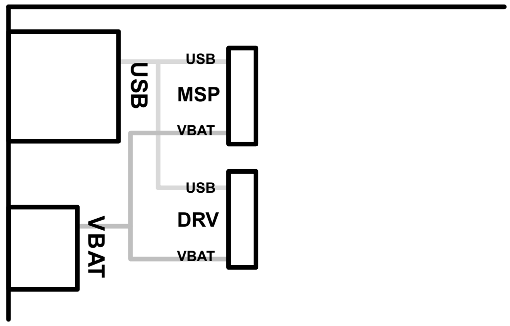


**Figure 18. Power Jumper Selection**

| Supply Configuration | DRV | MSP | DRV2604L Supply Voltage[1] |
|---|---|---|---|
| USB – Both | USB | USB | 5 V |
| DRV2604L external supply, MSP430 USB | VBAT | USB | VBAT |
| External supply – both | VBAT | VBAT | VBAT |
| USB with 3.3-V LDO[2] – both | USB | USB | 3.3 V (R4 = Short, R5 = Open) |

(1) The DRV2604L supply must be on before operating the MSP430.
(2) If a 3.3-V DRV2604L supply voltage is preferred while using the USB as the power source, remove R5 and add a 0-Ω resistor across R4.

### 4.3 Using an External Actuator

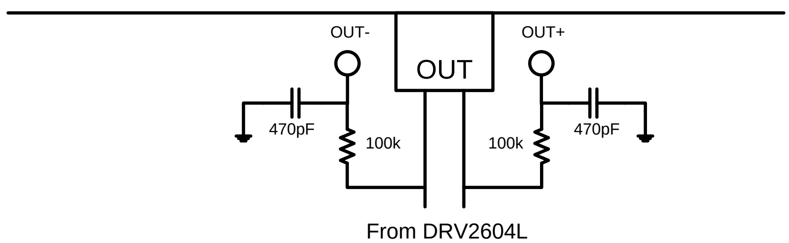


**Figure 19. Terminal Block and Test Points**

The DRV2604LEVM-CT can be used with an external actuator. Follow the instructions below to attach an actuator to the *OUT* terminal block.

1. Remove jumpers JP3 and JP4, which disconnects the on-board actuators from the DRV2604L.
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.

It is important to 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

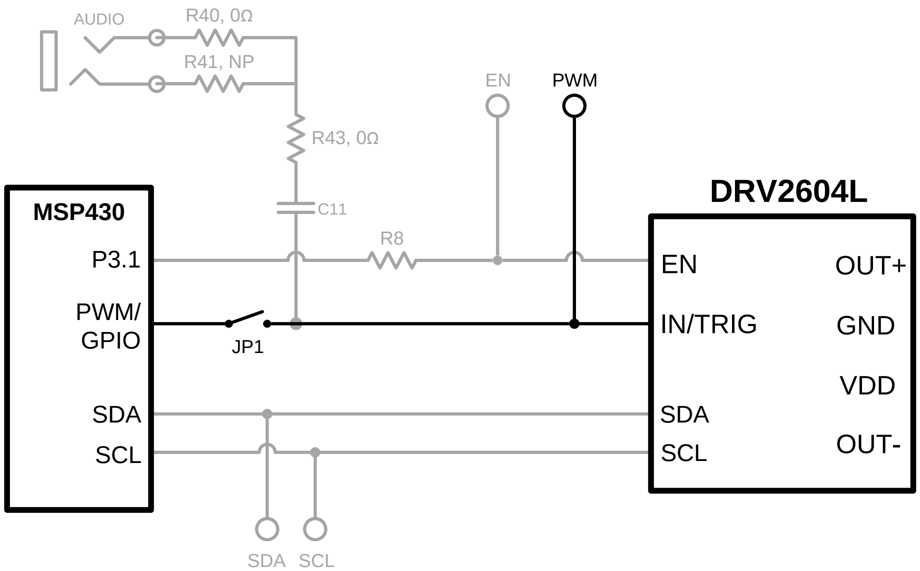


**Figure 20. External PWM Input**

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

To control the DRV2604L 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

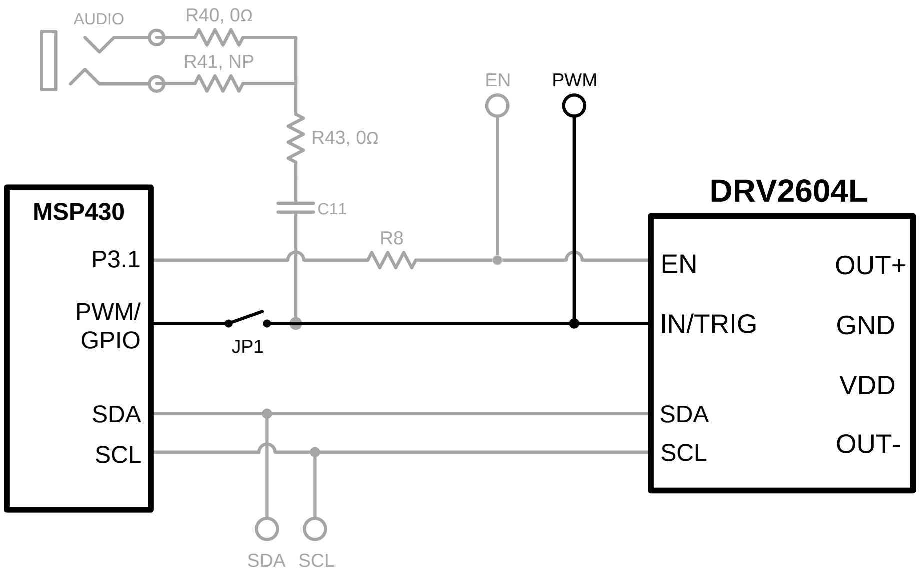


**Figure 21. External Trigger Control**

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

The DRV2604L 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 DRV2604L 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

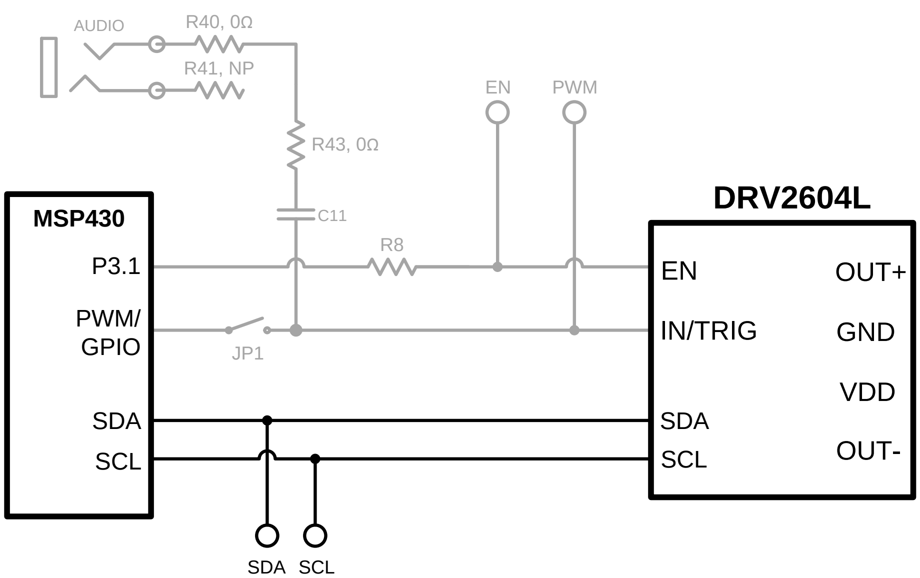


**Figure 22. External I²C Input**

The DV2604 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.

I²C communication is possible only when the EN pin is set high. To enable the DRV2604L 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 DRV2604L using the external I²C source.

### 4.7 Analog Input

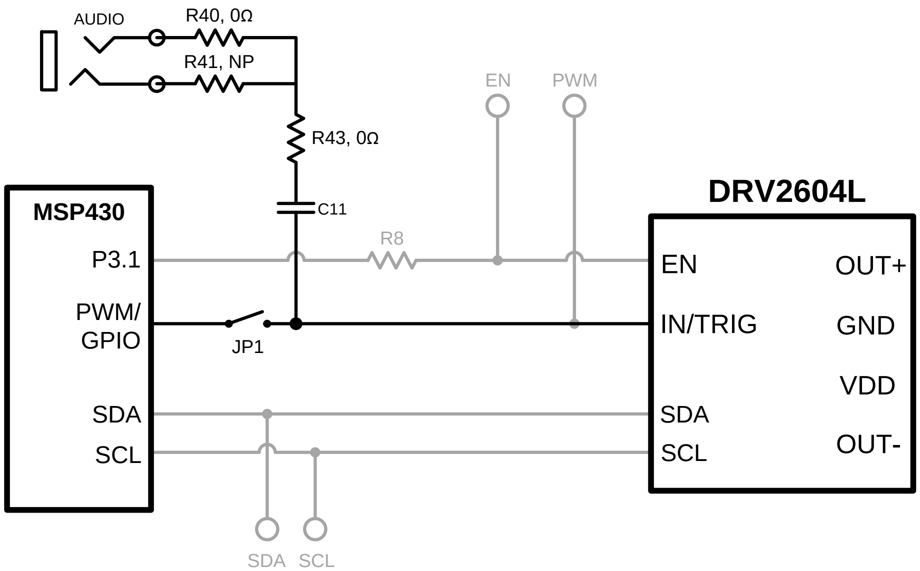


**Figure 23. Analog Input**

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 DRV2604L. See Figure 23.
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 DRV2604L uses PWM modulation to create the output signal for both ERM and LRA actuators. To measure and observe the DRV2604L output waveform, connect an oscilloscope or other measurement equipment to the filtered output test points, *OUT+* and *OUT–*.

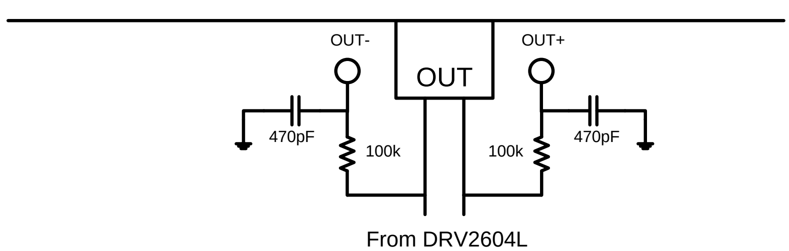


**Figure 24. Terminal Block and Test Points**

The DRV2604L 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 DRV2604L unfiltered waveform and the image on the right shows a filtered version used for observation and measurement.

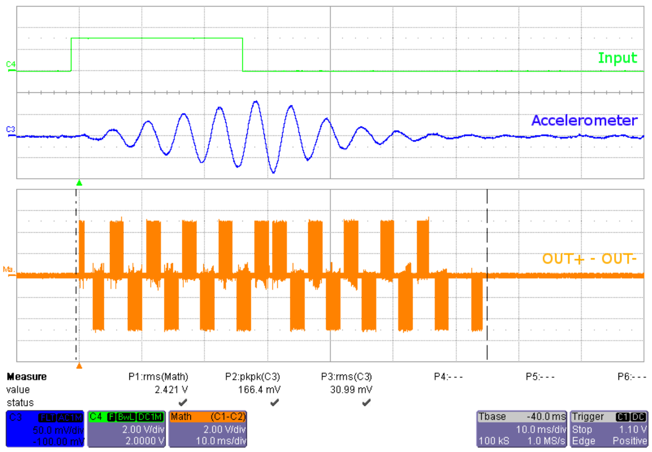


**Figure 25. DRV2604L Unfiltered Waveform**

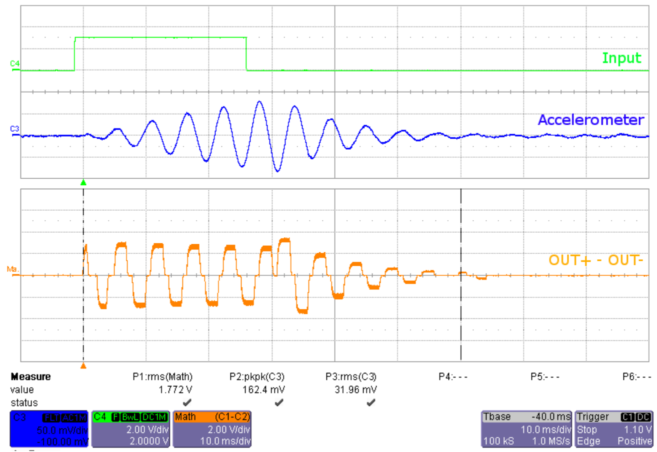


**Figure 26. DRV2604L Filtered Waveform**

If the DRV2604LEVM-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 DRV2604L in the lab.

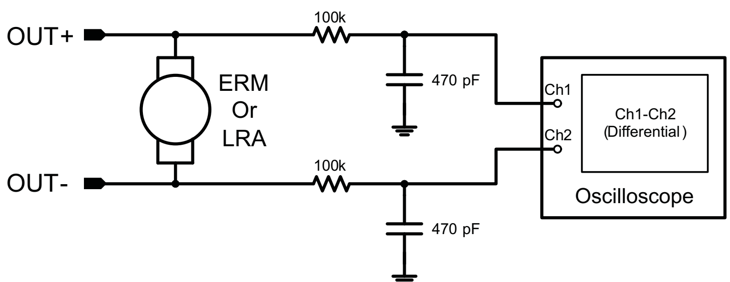


**Figure 27. Measuring the DRV2604L Output Signal with an Analog Low-Pass Filter**

## 6 Modifying or Reprogramming the Firmware

The MSP430 firmware on the DRV2604LEVM-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 DRV2604LEVM-CT.

1. Purchase one of the following MSP430G2553 compatible programmers:
   - LaunchPad (MSP-EXP430G2) – requires the additional purchase of a header for J4 (recommended)
     - Digi-Key: ED8650-ND
     - Mouser: 575-500201
   - MSP430-FET430UIF – requires a JTAG to Spy-Bi-Wire adapter (MSP-JTAGSBW if available)
2. Download and install Code Compose Studio (CCS) or IAR Embedded Workbench IDE.
3. Download the DRV2604LEVM-CT source code and binaries from ti.com.
4. Connect the programmer to an available USB port.
5. Connect the programmer to the *SBW* header on the DRV2604LEVM-CT.
6. In CCS,
   (a) Open the project file by selecting Project→Import Existing CCS Project.
   (b) Select **Browse** and navigate to the DRV2604LEVM-CT project folder, then press **OK**.
   (c) Select the checkbox next to the DRV2604LEVM-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 MSP430G2553 device,
   (c) Copy the files in the project folder downloaded from ti.com to the new project directory.

Figure 28 shows the connection between the MSP430 LaunchPad (MSP-EXP430G2) and the DRV2604LEVM-CT.

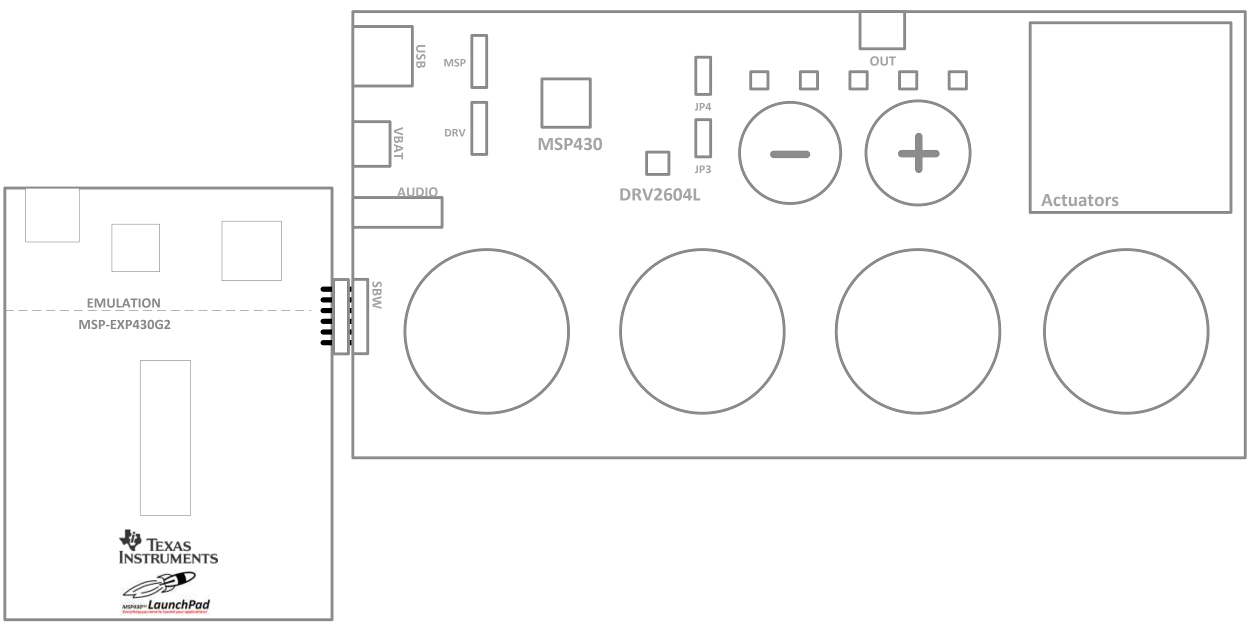


**Figure 28. LaunchPad Programmer Connection**

### 6.1 MSP430 Pin-Out

The DRV2604LEVM-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 5.

**Table 5. MSP430 Pin-Out**

| # | Label | Description |
|---|---|---|
| 1 | P1.1 | Green LED |
| 2 | P1.2 | Yellow LED |
| 3 | P1.3 | Blue LED |
| 4 | P1.4 | VREF+ |
| 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 29 shows the schematic for this EVM.

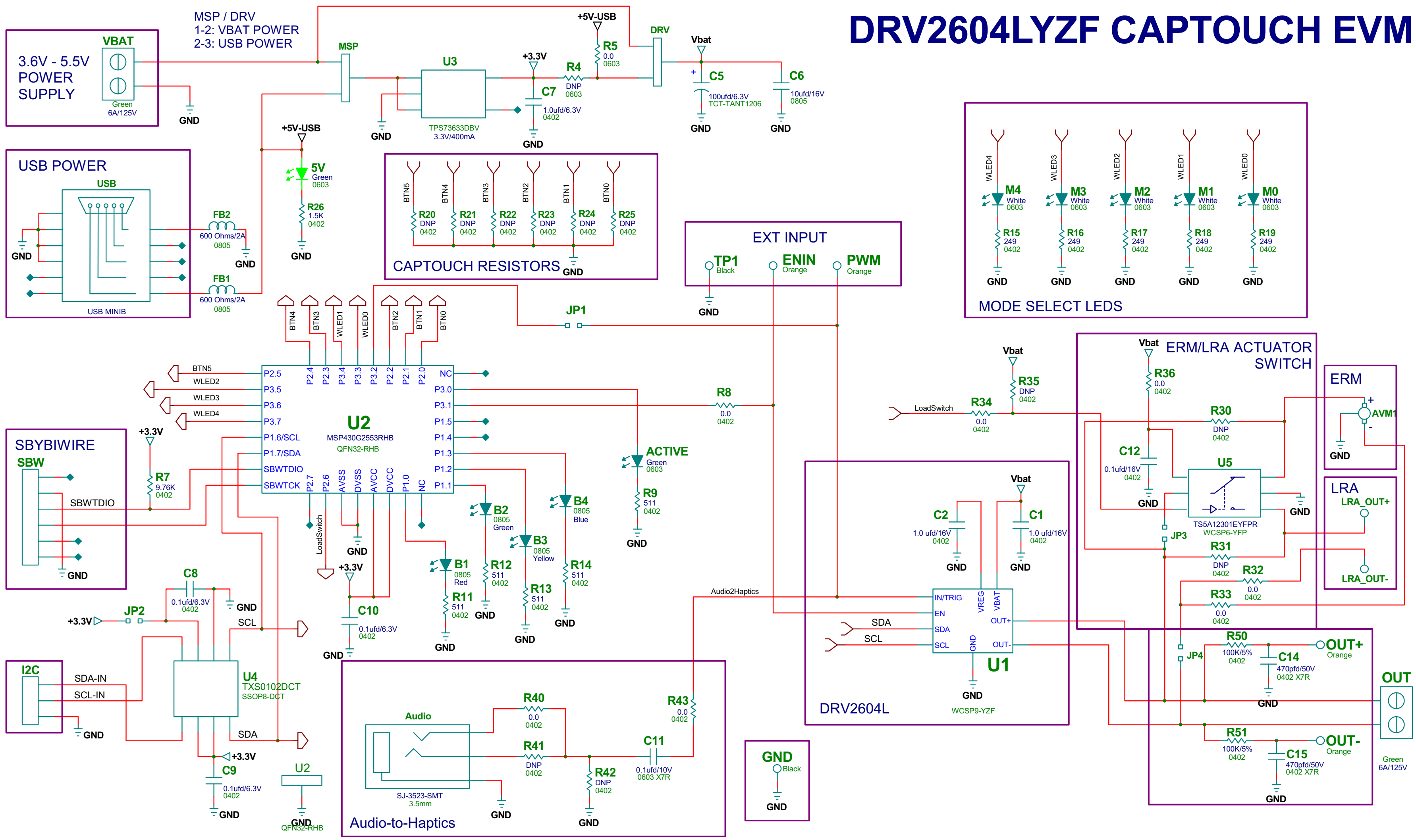


**Figure 29. DRV2604LEVM-CT Schematic**

# 8 Layout

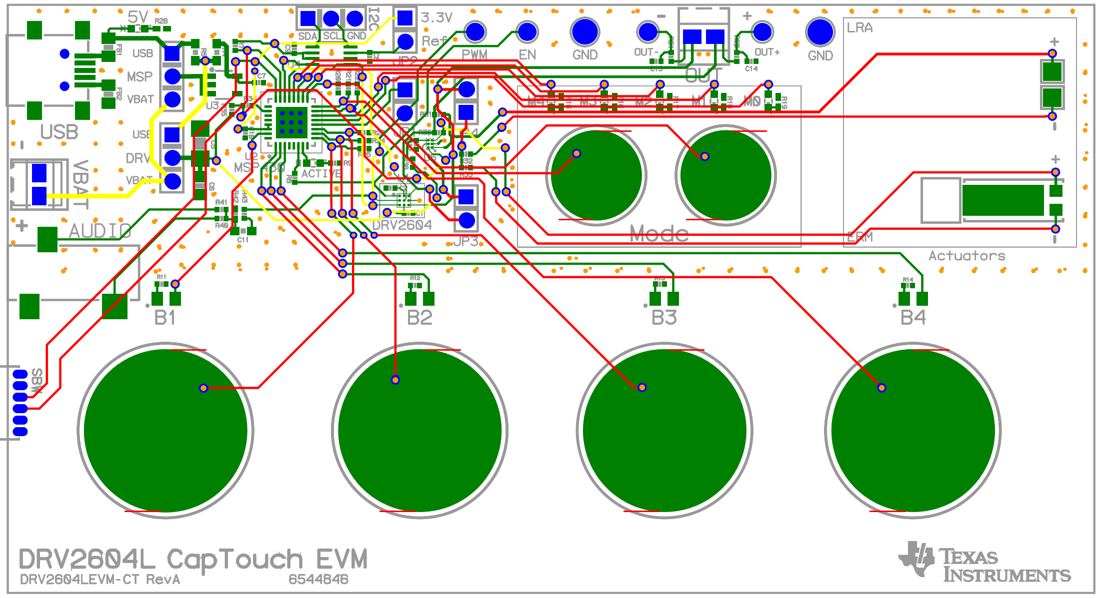


**Figure 30. X-Ray Top View**

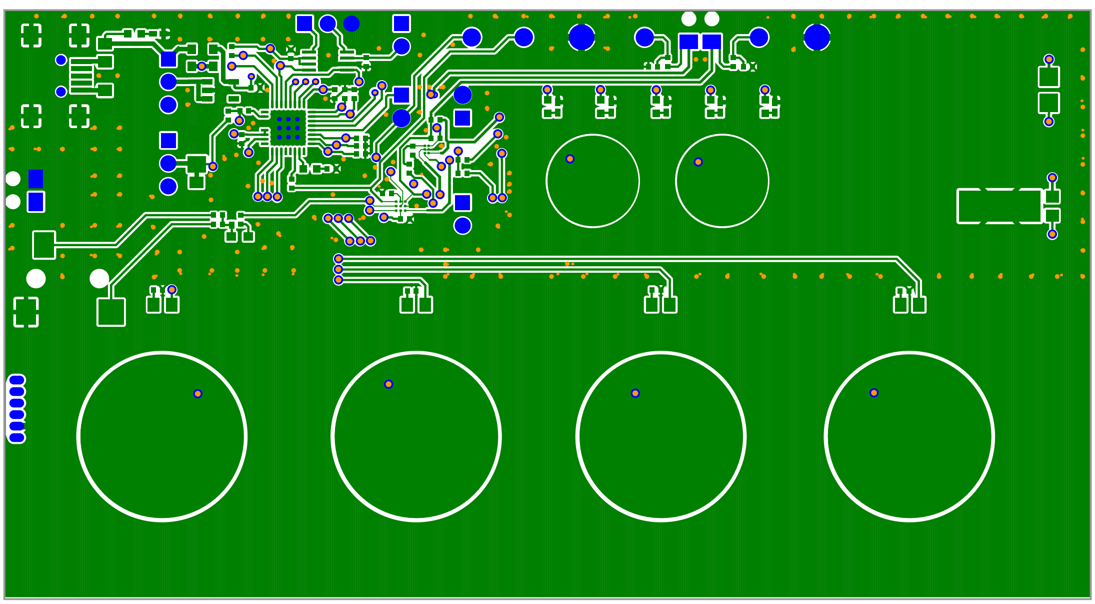

**Figure 31. Top Copper**

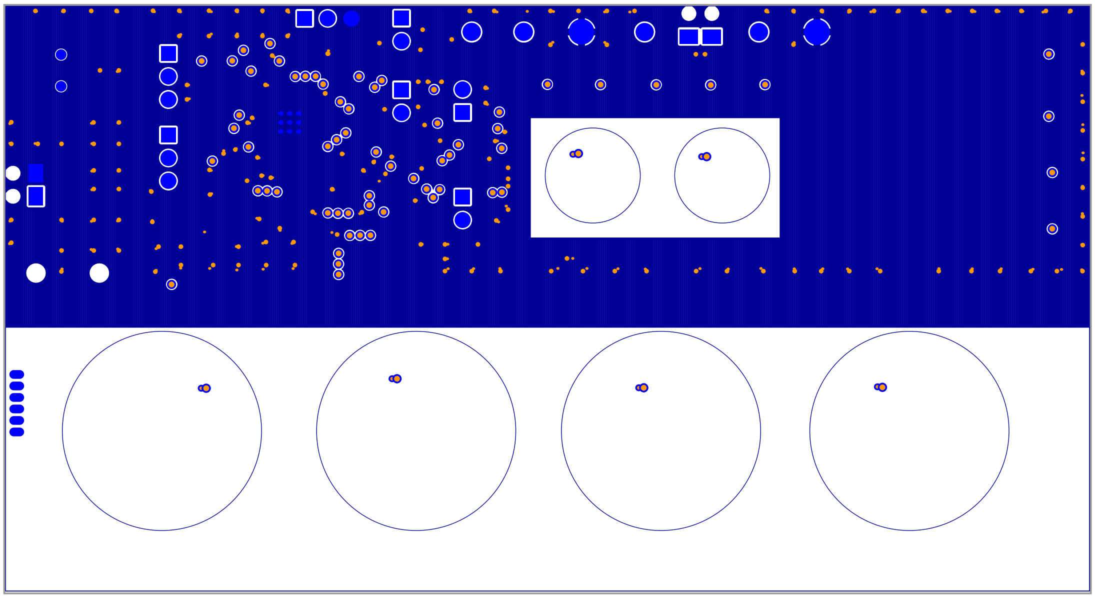

Figure 32. Layer 2 Copper

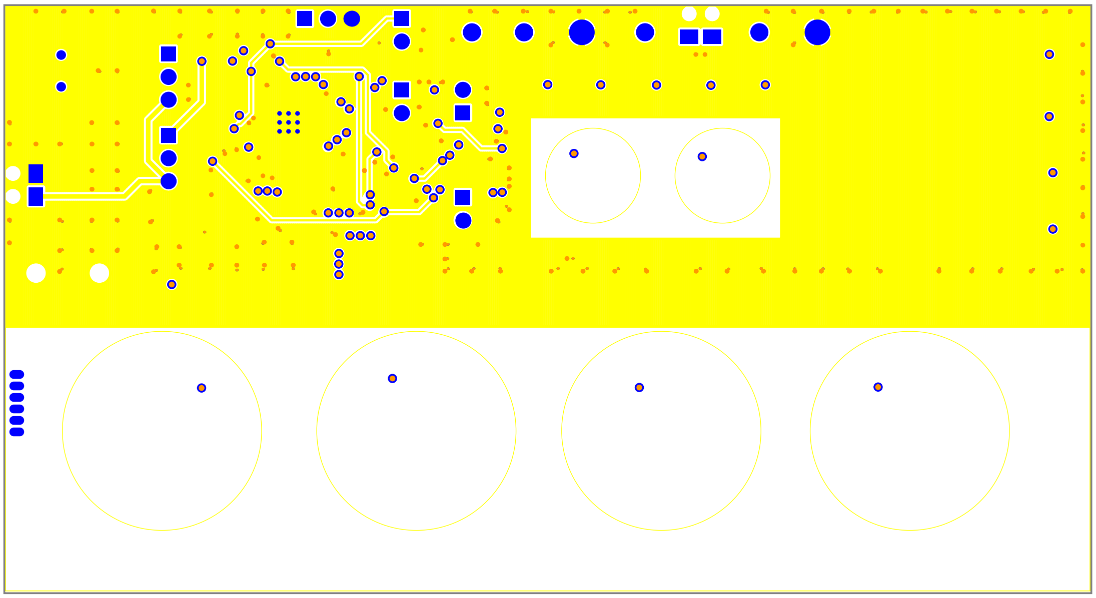

Figure 33. Layer 3 Copper

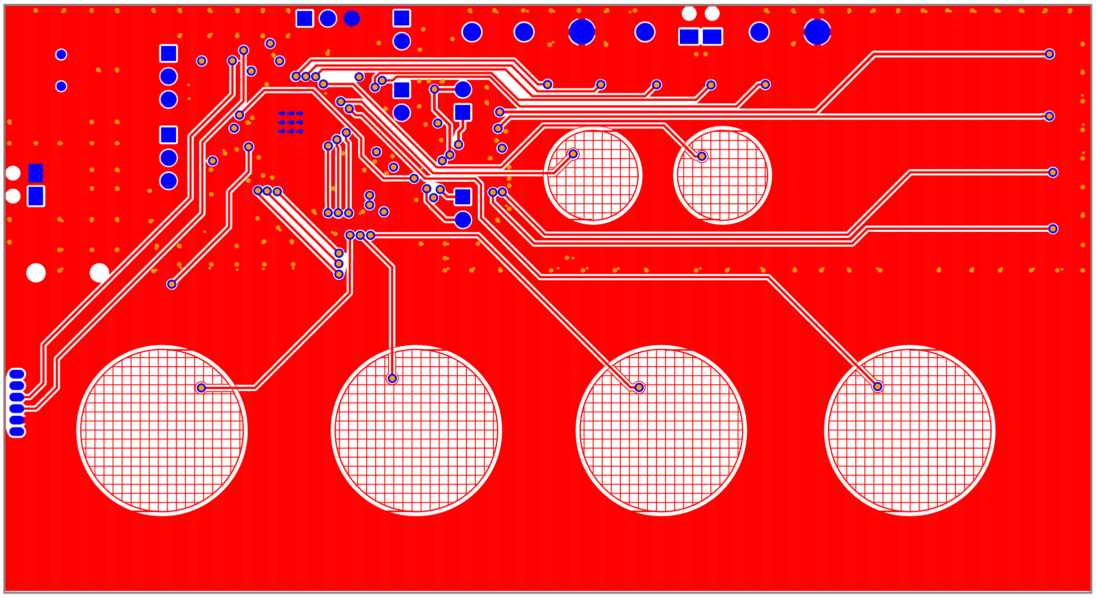

**Figure 34. Bottom Copper**

# 9 Bill of Materials

Table 6 lists the bill of materials.

**Table 6. Bill of Materials**

| Item | MFR Part Number | QTY | Ref Designators | Vendor Part Number | Description | MFR |
|---|---|---|---|---|---|---|
| | | | **Semiconductors** | | | |
| 1 | DRV2604LYZF | 1 | U1 | DRV2604LYZF | HAPTIC DRIVER AUTO DETECT FOR LRA AND ERM WCSP9-YZF ROHS | TEXAS INSTRUMENTS |
| 2 | TXS0102DCTR | 1 | U4 | 296-21978-1 | 2-BIT BIDIR LEVEL TRANSLATOR SSOP8-DCT ROHS | TEXAS INSTRUMENTS |
| 3 | MSP430G2553IRHB32T | 1 | U2 | 595-P430G2553IRHB32T | MIXED SIGNAL MICRO 16KB FLASH 512B RAM QFN32-RHB ROHS | TEXAS INSTRUMENTS |
| 4 | TPS73633MDBVREP | 1 | U3 | 296-21283-1 | VOLT REG 3.3V 400MA LDO CAP FREE NMOS SOT23-DBV5 ROHS | TEXAS INSTRUMENTS |
| 5 | TS5A12301EYFPR | 1 | U5 | 296-23757-1-ND | IEC LEVEL 4 ESD-PROTECTED 0.75-OHM ANALOG SWITCH WCSP6-YFP ROHS | TEXAS INSTRUMENTS |
| 6 | LTST-C190KGKT | 2 | 5V,ACTIVE | 160-1435-1-ND | LED,GREEN,2.0V,SMD0603,ROHS | LITE-ON INC. |
| 7 | LNJ037X8ARA | 5 | M0,M1,M2,M3,M4 | LNJ037X8ARACT-ND | LED, WHITE 2.9V SMD0805 ROHS | PANASONIC |
| 8 | SML-LXT0805SRW-TR | 1 | B1 | 67-1555-1 | LED, RED 2.0V SMD0805 ROHS | LUMEX OPTO |
| 9 | SML-LXT0805GW-TR | 1 | B2 | 67-1553-1 | LED, GREEN 2.0V SMD0805 ROHS | LUMEX OPTO |
| 10 | SML-LXT0805YW-TR | 1 | B3 | 67-1554-1 | LED, YELLOW 2.0V SMD0805 ROHS | LUMEX OPTO |
| 11 | LTST-C171TBKT | 1 | B4 | 160-1645-1-ND | LED, BLUE 3.3V SMD0805 ROHS | LITE-ON INC. |
| | | | **Capacitors** | | | |
| 12 | C1005X5R1C105K050BC | 2 | C1,C2 | 445-4978-1-ND | CAP SMD0402 CERM 1.0UFD 16V 10% X5R ROHS | TDK CORP |
| 13 | C1005X5R0J104K | 3 | C8,C9,C10 | 445-1266-1 | CAP SMD0402 CERM 0.1UFD 6.3V 10% X5R ROHS | TDK CORP |
| 14 | 0805YD106KAT2A | 1 | C6 | 478-5165-1 | CAP SMD0805 CERM 10UFD 16V X5R 10% ROHS | AVX |
| 15 | GRM155R60J105KE19D | 1 | C7 | 490-1320-1 | CAP SMD0402 CERM 1.0UFD 6.3V X5R 10% ROHS | MURATA |
| 16 | C1005X5R0J104K | 1 | C11 | 445-1266-1 | CAP SMD0402 CERM 0.1UFD 6.3V 10% X5R ROHS | TDK CORP |
| 17 | C0402C471K5RACTU | 2 | C14,C15 | 399-1025-1 | CAP SMD0402 CERM 470PFD 50V 10% X7R ROHS | KEMET |
| 18 | TCTAL0J107M8R | 1 | C5 | 511-1498-1-ND | CAP TANT1206 100UFD 6.3V 20% TCT SERIES ROHS | ROHM |
| | | | **Resistors** | | | |
| 19 | ERJ-2RKF9761X | 1 | R7 | P9.76KLCT-ND | RESISTOR SMD0402 THICK FILM 9.76K OHMS 1/10W 1% ROHS | PANASONIC |
| 20 | RMCF0402ZT0R00 | 5 | R8,R32,R33,R34,R36 | RMCF0402ZT0R00CT | ZERO OHM JUMPER SMT 0402 0 OHM 1/16W,5% ROHS | STACKPOLE ELECTRONICS |
| 21 | RC0402FR-07511RL | 5 | R9,R11,R12,R13,R14 | 311-511LRCT-ND | RESISTOR SMD0402 THICK FILM 511 OHMS 1% 1/16W ROHS | YAGEO |
| 22 | ERJ-2GEJ152 | 1 | R26 | | RESISTOR,SMT,0402,THICK FILM,5%,1/16W,1.5K | Panasonic |
| 23 | RMCF0603ZT0R00 | 1 | R5 | RMCF0603ZT0R00CT-ND | RESISTOR SMD0603 ZERO OHMS 1/10W ROHS | STACKPOLE ELECTRONICS |
| 24 | ERJ-2RKF2490X | 5 | R15,R16,R17,R18,R19 | P249LTR-ND | RESISTOR,SMT,0402,249 OHM,1%,1/16W | Panasonic |
| 25 | CRCW04020000Z0ED | 2 | R40,R43 | 541-0.0JCT | ZERO OHM JUMPER SMT 0402 0 OHM 1/16W,5% ROHS | VISHAY |
| 26 | ERJ-2GEJ104 | 2 | R50,R51 | P100KJCT | RESISTOR SMD0402 THICK FILM 100K OHMS 1/16W 5% ROHS | PANASONIC |

**Table 6. Bill of Materials (continued)**

| Item | MFR Part Number | QTY | Ref Designators | Vendor Part Number | Description | MFR |
|---|---|---|---|---|---|---|
| | | | | | **Ferrite Beads** | |
| 27 | MPZ2012S601A | 2 | FB1,FB2 | 445-2206-1 | FERRITE BEAD SMD0805 600 Ohms 2A ROHS | TDK |
| | | | | | **Headers, Jacks, and Shunts** | |
| 28 | LPPB061NGCN-RC | 1 | SBW | S9010E-06 | HEADER THRU FEMALE 1X6-RA 50LS GOLD ROHS | SULLINS |
| 29 | PBC03SAAN | 3 | DRV,I2C,MSP | S1011E-03-ND | HEADER THRU MALE 3 PIN 100LS GOLD ROHS | SULLINS |
| 30 | PBC02SAAN | 1 | JP2 | S1011E-02 | HEADER THRU MALE 2 PIN 100LS GOLD ROHS | SULLINS |
| 31 | PBC02SAAN | 3 | JP1,JP3,JP4 | | HEADER THRU MALE 2 PIN 100LS GOLD ROHS | SULLINS |
| 32 | UX60-MB-5ST | 1 | USB | H2959CT | JACK USB MINIB SMT-RA 5PIN ROHS | HIROSE |
| 33 | SJ-3523-SMT | 1 | Audio | CP-3523SJCT-ND | JACK AUDIO-STEREO MINI(3.5MM ,3-COND SMT-RA ROHS | CUI STACK |
| 34 | SPC02SYAN | 6 | MSP (2-3), DRV (2-3), JP1, JP2, JP3, JP4 | S9001-ND | SHUNT BLACK AU FLASH 0.100LS CLOSED TOP ROHS | SULLINS |
| 35 | 1725656 | 2 | OUT,VBAT | 277-1273 | TERMINAL BLOCK MPT COMBICON 2PIN 6A/125V GREEN 100LS ROHS | PHOENIX CONTACT |
| | | | | | **Test Points and Switches** | |
| 36 | 5011 | 2 | GND,TP1 ((Solder so that color ring is secured) | 5011K | PC TESTPOINT BLACK 063 HOLE ROHS | KEYSTONE ELECTRONICS |
| 37 | 5003 | 4 | PWM,ENIN, OUT+, OUT– (Solder so that color ring is secured) | 5003K | PC TESTPOINT, ORANGE, ROHS | KEYSTONE ELECTRONICS |
| 38 | NRS-2574 | 1 | AVM1 | NRS-2574 | ACTUATOR VIBRATION MOTOR 1,3V 9000 RPM ROHS | SANYO |
| 39 | ELV1036A | 1 | - | - | ACTUATOR - LINEAR VIBRATOR, 2VRMS | AAC |
| 40 | - | 1 | - | - | Metal Block (Custom Block, Heavy Metal, See metal block spec) | Heavy Metal |
| 41 | 3-5-468MP | 1 | - | 3M9724-ND | TAPE TRANSFER ADHESIVE 3" X 5YD | 3M |
| 42 | 2-5-4466W | 1 | - | 3M9962-ND | TAPE POLY FOAM 2" x 5YD | 3M |
| | | | | | **Components not Assembled** | |
| 43 | TestPoint_SMD-Square_2.0mm | 2 | LRA_OUT+, LRA_OUT– | | TESTPOINT SMD SQUARE 2.0mm | |
| 44 | R0402_DNP | 9 | R20,R21,R22,R23,R24,R25,R30,R31,R35 | | R0402_DNP | |
| 45 | R0603_DNP | 1 | R4 | RMCF0603ZT0R00CT-ND | R0603_DNP | STACKPOLE ELECTRONICS |
| 46 | R0402_DNP | 1 | R41 | P4.99KLCT-ND | R0402_DNP | PANASONIC |
| 47 | R0402_DNP | 1 | R42 | 541-0.0JCT | R0402_DNP | VISHAY |

## Revision History

| Changes from Original (May 2014) to A Revision | Page |
| --- | --- |
| • Changed C1 and C2 designator value to 1.0 μF in schematic. | 23 |
| • Changed contents of item 12 in BOM. | 27 |

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7. Should any EVM not meet the specifications indicated in the user's guide or other documentation accompanying such EVM, the EVM may be returned to TI within 30 days from the date of delivery for a full refund. THE FOREGOING LIMITED WARRANTY IS THE EXCLUSIVE WARRANTY MADE BY TI TO USER AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE. TI SHALL NOT BE LIABLE TO USER FOR ANY INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES RELATED TO THE HANDLING OR USE OF ANY EVM.
8. No license is granted under any patent right or other intellectual property right of TI covering or relating to any machine, process, or combination in which EVMs might be or are used. TI currently deals with a variety of customers, and therefore TI's arrangement with the user is not exclusive. TI assumes no liability for applications assistance, customer product design, software performance, or infringement of patents or services with respect to the handling or use of EVMs.
9. User assumes sole responsibility to determine whether EVMs may be subject to any applicable federal, state, or local laws and regulatory requirements (including but not limited to U.S. Food and Drug Administration regulations, if applicable) related to its handling and use of EVMs and, if applicable, compliance in all respects with such laws and regulations.
10. User has sole responsibility to ensure the safety of any activities to be conducted by it and its employees, affiliates, contractors or designees, with respect to handling and using EVMs. Further, user is responsible to ensure that any interfaces (electronic and/or mechanical) between EVMs 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.
11. User shall employ reasonable safeguards to ensure that user's use of EVMs will not result in any property damage, injury or death, even if EVMs should fail to perform as described or expected.
12. User shall be solely responsible for proper disposal and recycling of EVMs consistent with all applicable federal, state, and local requirements.

**Certain Instructions.** User shall operate EVMs within TI's recommended specifications and environmental considerations per the user's guide, accompanying documentation, and any other applicable requirements. Exceeding the specified ratings (including but not limited to input and output voltage, current, power, and environmental ranges) for EVMs may cause property damage, personal injury or death. If there are questions concerning these ratings, 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 result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the applicable EVM user's 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, some circuit components may have case temperatures greater than 60°C as long as the input and output are maintained at a normal ambient operating temperature. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors which can be identified using EVMs' schematics located in the applicable EVM user's guide. When placing measurement probes near EVMs during normal operation, please be aware that EVMs may become very warm. As with all electronic evaluation tools, only qualified personnel knowledgeable in electronic measurement and diagnostics normally found in development environments should use EVMs.

**Agreement to Defend, Indemnify and Hold Harmless.** User agrees to defend, indemnify, and hold TI, its directors, officers, employees, agents, representatives, affiliates, licensors and their representatives harmless from and against any and all claims, damages, losses, expenses, costs and liabilities (collectively, "Claims") arising out of, or in connection with, any handling and/or use of EVMs. User's indemnity shall apply whether Claims arise under law of tort or contract or any other legal theory, and even if EVMs fail to perform as described or expected.

**Safety-Critical or Life-Critical Applications.** If user intends to use EVMs in evaluations of safety critical applications (such as life support), and a failure of a TI product considered for purchase by user for use in user's product would reasonably be expected to cause severe personal injury or death such as devices which are classified as FDA Class III or similar classification, then user must specifically notify TI of such intent and enter into a separate Assurance and Indemnity Agreement.

# RADIO FREQUENCY REGULATORY COMPLIANCE INFORMATION FOR EVALUATION MODULES

Texas Instruments Incorporated (TI) evaluation boards, kits, and/or modules (EVMs) and/or accompanying hardware that is marketed, sold, or loaned to users may or may not be subject to radio frequency regulations in specific countries.

**General Statement for EVMs Not Including a Radio**

For EVMs not including a radio and not subject to the U.S. Federal Communications Commission (FCC) or Industry Canada (IC) regulations, TI intends EVMs to be used only for engineering development, demonstration, or evaluation purposes. EVMs are not finished products typically fit for general consumer use. EVMs may nonetheless generate, use, or radiate radio frequency energy, but have not been tested for compliance with the limits of computing devices pursuant to part 15 of FCC or the ICES-003 rules. Operation of such EVMs may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be required to correct this interference.

**General Statement for EVMs including a radio**

*User Power/Frequency Use Obligations*: For EVMs including a radio, the radio included in such EVMs is intended for development and/or professional use only in legally allocated frequency and power limits. Any use of radio frequencies and/or power availability in such EVMs and their development application(s) must comply with local laws governing radio spectrum allocation and power limits for such EVMs. It is the user's sole responsibility to only operate this radio in legally acceptable frequency space and within legally mandated power limitations. Any exceptions to this are strictly prohibited and unauthorized by TI unless user has obtained appropriate experimental and/or development licenses from local regulatory authorities, which is the sole responsibility of the user, including its acceptable authorization.

**U.S. Federal Communications Commission Compliance**

**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 could void the user's authority to operate the equipment.

**FCC Interference Statement for Class A EVM devices**

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 its own expense.

**FCC Interference Statement for Class B EVM devices**

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.

**Industry Canada Compliance (English)**

**For EVMs Annotated as IC – INDUSTRY CANADA Compliant:**

This Class A or B digital apparatus complies with Canadian ICES-003.

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

**Concerning EVMs Including Radio Transmitters**

This device complies with Industry Canada licence-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.

**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.

**Canada Industry Canada Compliance (French)**

Cet appareil numérique de la classe A ou B est conforme à la norme NMB-003 du Canada

Les changements ou les modifications pas expressément approuvés par la partie responsable de la conformité ont pu vider l'autorité de l'utilisateur pour actionner l'équipement.

**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.

**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.



## Important 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.

http://www.tij.co.jp

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東京都新宿区西新宿６丁目２４番１号

西新宿三井ビル

http://www.tij.co.jp

Texas Instruments Japan Limited

(address) 24-1, Nishi-Shinjuku 6 chome, Shinjuku-ku, Tokyo, Japan

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In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265