

# Application Report

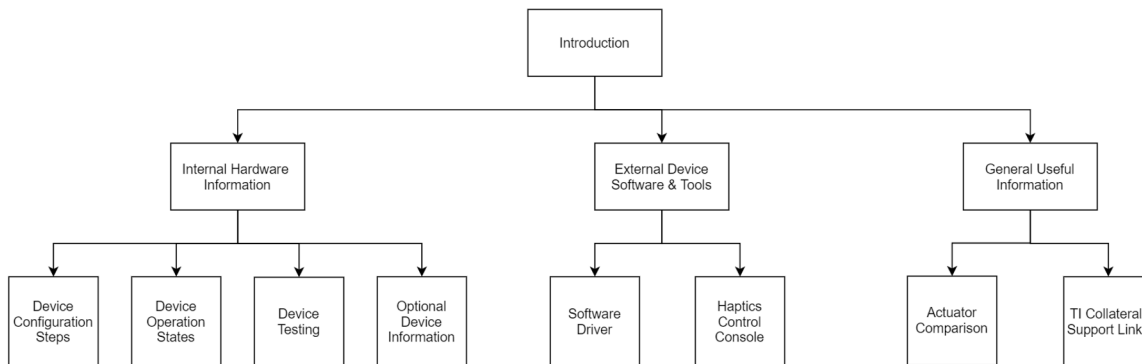
## DRV2624 & DRV2625 Quick Start Guide



Carson Allen

### Abstract

This document provides a guide on properly configuring the [DRV2624](#) & [DRV2625](#) and selecting the correct mode of operation in order to drive a Linear Resonant Actuator (LRA) or Eccentric Rotating Mass (ERM).



The flowchart above is a breakdown of how this quick start guide is sectionalized. Going from left to right we first go through the internal device details of setting all necessary registers, which includes how the device switches between modes, how the device can be recorded from, and all other additional features within the device. Next we talk about external software and tools available to use when integrating the device into a system and determining the best mode for its application. This guide then wraps up with an explanation of the different types of haptic actuators and links for other supporting documentation.

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## 1 Introduction

The DRV2624 & DRV2625 are a pair of low power haptic drivers that utilize closed-loop architecture to ensure crisp and consistent haptic effects across a large variety of LRA and ERM models. Closed-loop feedback allows for resonant tracking along with proper auto-braking and overdrive. While ERMs benefit from the auto-braking and overdrive, they do not have resonant frequencies making the main benefits of the closed-loop architecture for LRAs. Driving a LRA at its resonant frequency is crucial to achieve peak acceleration and max vibration, but this frequency differs between actuators and changes over the time of usage, making it traditionally difficult to achieve max effect. Furthermore, there is very little margin of error in doing so with as little as 3 Hz leeway before acceleration amplitude drops rapidly from its resonant peak. The DRV2624 & DRV2625 solve that by using their closed-loop design to lock on and track the exact resonance frequency over the course of the actuator’s usage to adjust for any change.

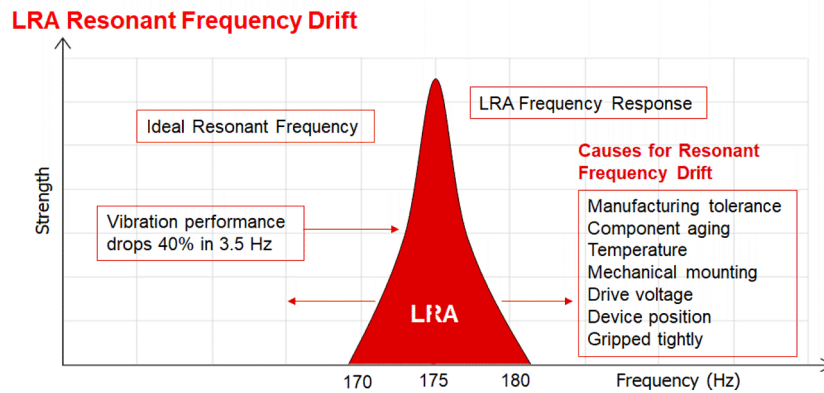


Figure 1-1. LRA Frequency Drift

Auto-braking and overdrive allows the DRV2624 & DRV2625 to quickly accelerate the connected actuator to desired amplitude and quickly bring it to rest, made possible by the closed-loop’s ability to track actuator acceleration. In the figure below, we can see the necessity of these features that take advantage of the smart closed-loop architecture. Both waveforms are optimal for two different actuators to demonstrate the same haptic effect. With closed-loop feedback a single generic waveform can have its overdrive and autobraking times customized in real-time to produce these waveforms, whereas in complete open-loop mode these overdrive and auto-braking times would need to be saved in the waveforms themselves, requiring every different ERM to have its own custom waveform saved in memory. An option to switch to closed-loop for auto-braking is available for open loop mode, which will still allow user to use open-loop while still taking advantage of the smart loop powered auto-braking.

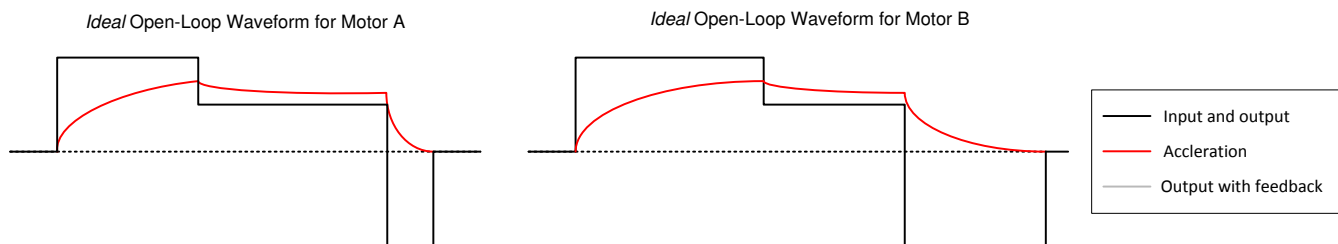
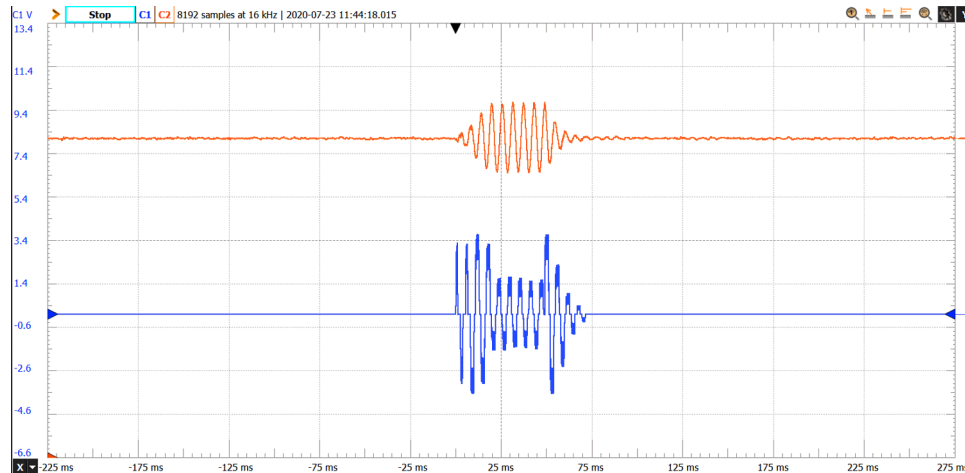


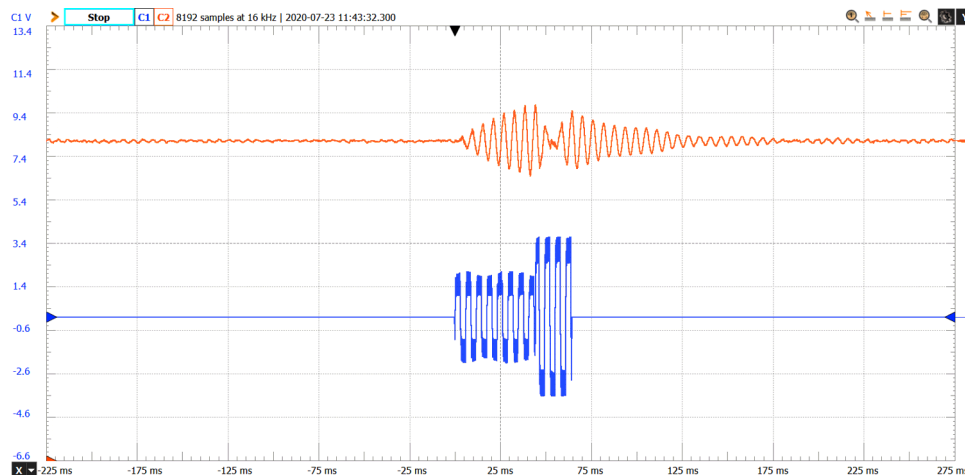
Figure 1-2. Actuator Waveform with Auto-Braking & Overdrive

An Example of how crucial these are for a proper haptic feedback can be seen in the waveform recordings from the DRV2625 below. Both waveforms are playing the Strong Click (80% Strength) from the LRA library off the DRV2625 ROM. The only difference is the first waveform recording is in closed-loop mode while the second waveform recording is in complete open-loop mode. In each recording, the top waveform is the acceleration, amplitude of about 1G, measured via the DRV-ACC16 accelerometer tool, while the bottom waveform is the output of the device itself. We can clearly see that the open-loop completely lacks overdrive and has an auto-

brake that is way to powerful, while the closed-loop mode modifies itself by adding overdrive and scaling down the auto-brake significantly. The result is a crisp strong click effect that is expected, instead of the slow-rising and too long-lasting complete open-loop result that leads to a completely distorted effect. Also note that the open-loop can be modified to switch to closed-loop for auto-braking in order to maintain open-loop functionality but with smooth braking of the closed-loop like in the first figure.



**Figure 1-3. LRA Strong Click (80% Strength) Played in Closed-Loop Mode**



**Figure 1-4. LRA Strong Click (80% Strength) Played in Open-Loop Mode with Auto-Braking Disabled**

## 2 Materials Needed

- DRV2624 or DRV2625 Chip or EVM Board
- 2.6 V to 5.5 V Power Supply
- Host Microprocessor
- Required Resistors and Capacitors in [Figure 4-2](#)
- LRA or ERM
- Haptics Control Console Software

## 3 Device Overview

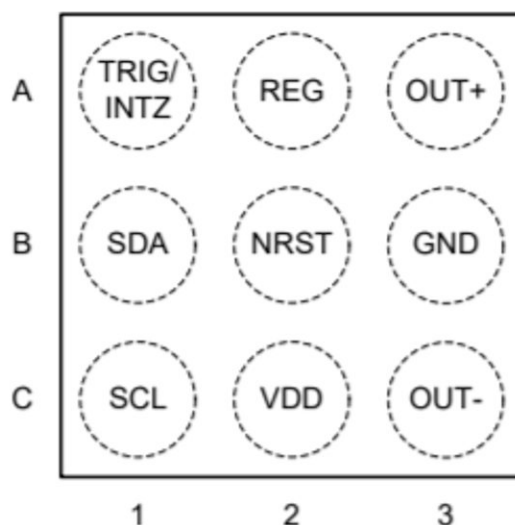
### 3.1 Actuator Selection

One of the most important steps is selecting an actuator that can be supported by the DRV2624 & DRV2625. Both ERMs and LRAs are supported but parameters including resonant frequency and rated voltage must be considered.

- LRA resonant frequency range: 45 - 300 Hz
- Minimum load impedance: 8 ohms
- Maximum load capacitance: 100 pF
- Supply voltage range: 2.7 – 5.5 V

### 3.2 Pin Configuration and Functions

Below is the pinout and corresponding pin descriptions for the 9-Pin YFF package of both the DRV2624 & DRV2625.



| PIN       |     | I/O | DESCRIPTION  |
|-----------|-----|-----|--|
| NAME      | NO. |     |  |
| VDD       | C2  | P   | Supply input (2.7 V to 5.5 V). A 0.1- $\mu$ F capacitor is required.   |
| GND       | B3  | P   | Supply ground  |
| REG       | A2  | O   | 1.8 V regulator output. A 0.1- $\mu$ F capacitor is required   |
| OUT-      | C3  | O   | Negative haptic driver differential output   |
| OUT+      | A3  | O   | Positive haptic driver differential output   |
| SDA       | B1  | I/O | I <sup>2</sup> C data  |
| SCL       | C1  | I   | I <sup>2</sup> C clock   |
| TRIG/INTZ | A1  | I/O | Multi-mode pin. Selectable as input trigger (pulse) or input enable. This pin has an internal pull-down.<br>If pin is not used, it should be connected to ground.  |
| NRST      | B2  | I   | Device reset pin (shutdown mode). If pin is not used, it should be connected to VDD (no internal pull-up or pull-down). This ball should be at the center to allow for people to avoid vias if they need to. This way the user can short the NRST to the VDD and have a no-via layout. |

### 3.3 Functional Block Diagrams

A summary of the internal features and functions of the DRV2624 & DRV2625 can be visualized beneath in the form of functional block diagrams. Within the Control and Playback Engine block it can be seen all the components that make these devices smart and make them more than just motor drivers. The only distinction between the nearly identical block diagrams is the type of memory onboard the device located in the top middle of the schematic.

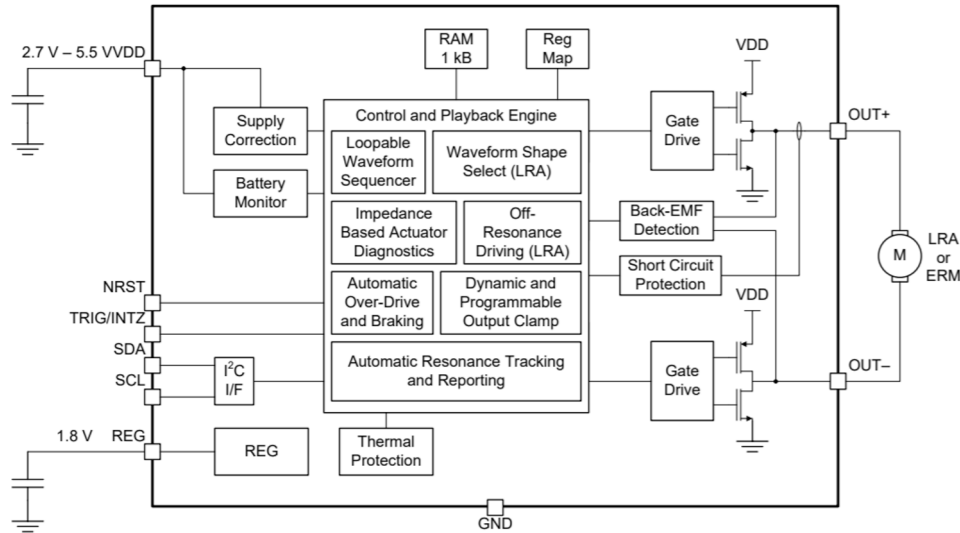


Figure 3-1. DRV2624 Block Diagram

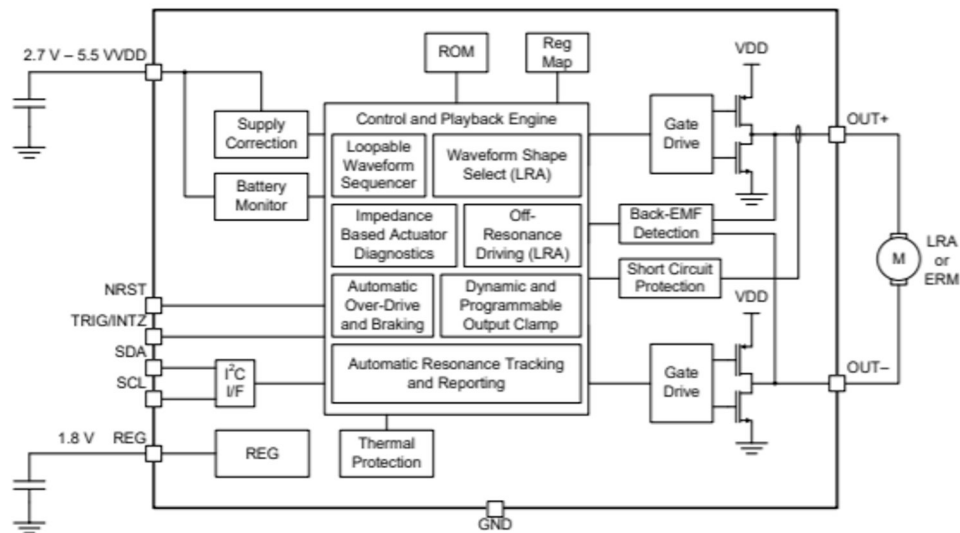
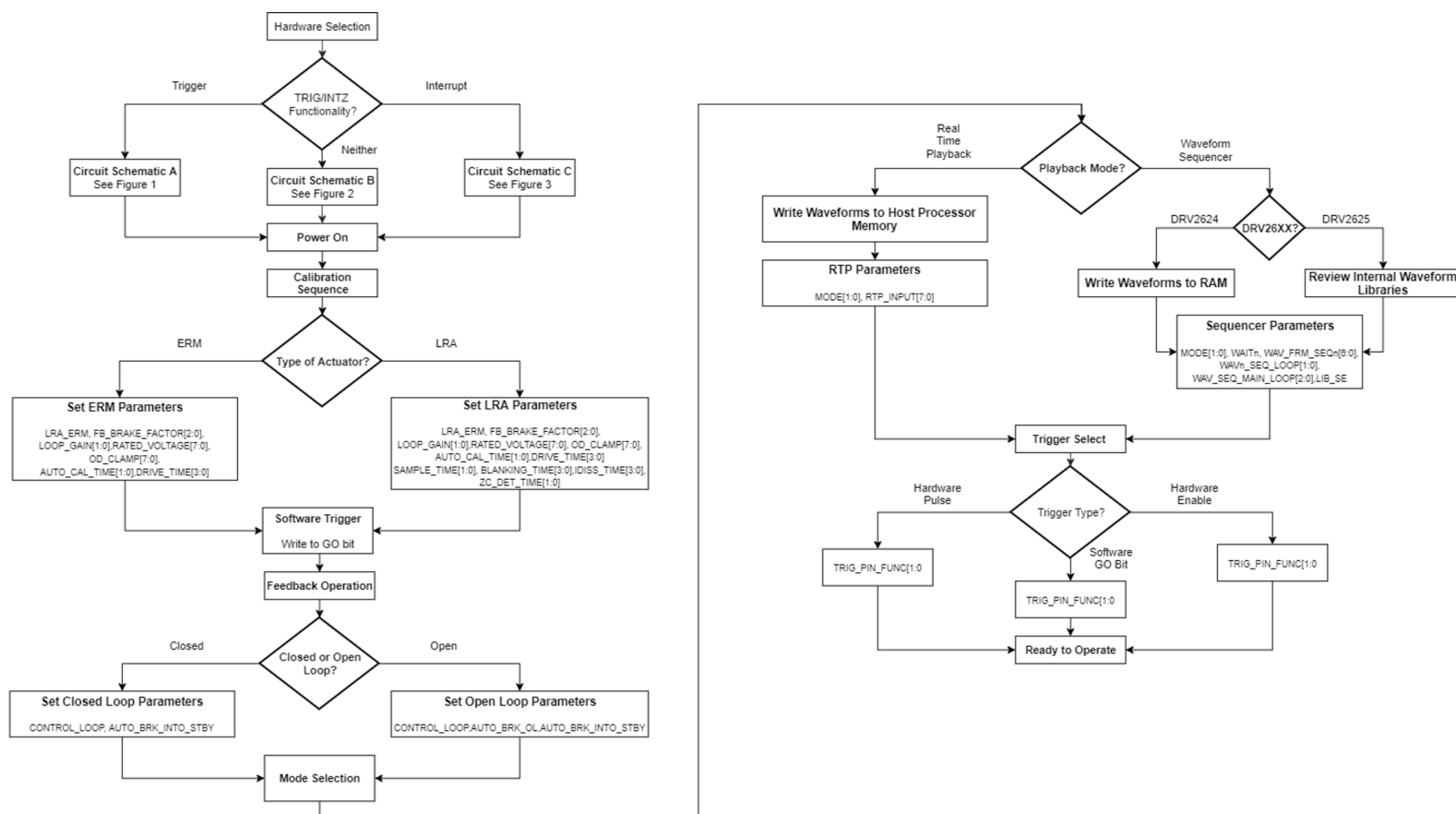


Figure 3-2. DRV2625 Block Diagram

## 4 Device Configuration Steps



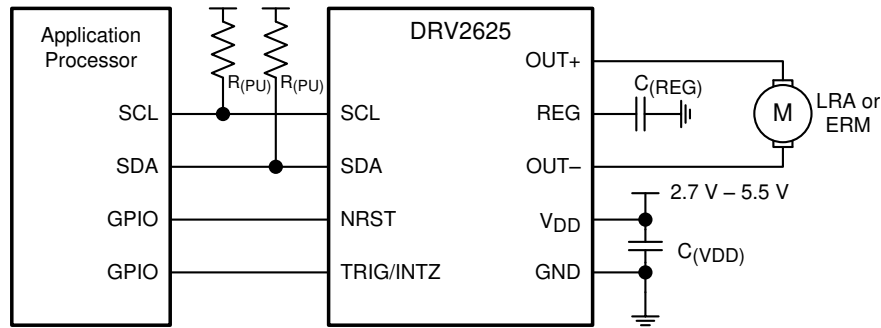
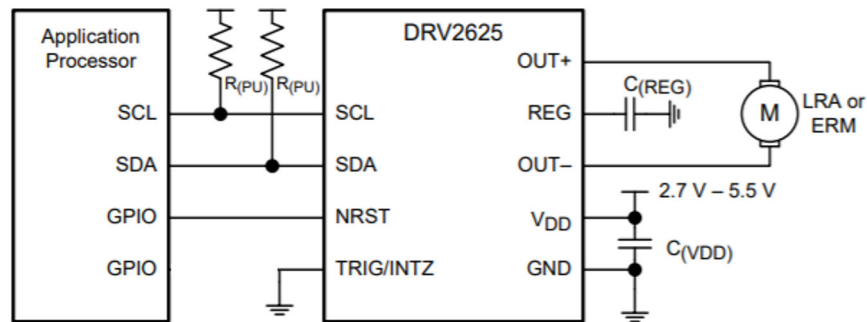
**Figure 4-1. Initial Device Configuration Flowchart**

Figure 4-1 above is a breakdown of the upcoming sections that cover circuit configuration, auto-calibration configuration, feedback mode selection, playback mode options, and finally how to trigger the device to play. This will also serve as a refresher once the following sections have already been read. The interrupt option in the flowchart is not mentioned in this document and should be referred to in the individual data sheets for more information.

### 4.1 Circuit Configuration

The proper DRV2624 & DRV2625 circuit schematic to use when connecting to a host processor completely depends on the decision regarding what type of trigger wants to be used. If a pulse trigger or enable trigger is desired, simply connect a wire between a GPIO port of the host processor and the TRIG/INTZ pin on the device, see Figure 4-2. If only the software trigger will be used, the pin should be connected to ground, see Figure 4-3. Another requirement in the device hookup is including capacitors to ground at the VREG and VDD pins and having pull-up resistors on the SCL and SDA connections. Resistor and capacitor values are listed in Table 4-1.




**Figure 4-2. Processor Interface with Hardware Trigger**

**Figure 4-3. Processor Interface without Trigger**
**Table 4-1. Recommended External Components**

| COMPONENT   | DESCRIPTION         | SPECIFICATION | TYPICAL VALUE  |
|-------------|---------------------|---------------|----------------|
| $C_{(VDD)}$ | Input capacitor     | Capacitance   | 0.1 $\mu$ F    |
| $C_{(REG)}$ | Regulator capacitor | Capacitance   | 0.1 $\mu$ F    |
| $R_{(PU)}$  | Pull-up resistor    | Resistance    | 2.2 k $\Omega$ |

**Note:** Capacitors mentioned above should have a voltage rating of 10V or higher

## 4.2 Power On

### Powering Up

1. Supply 2.7 – 5.5 V to the VDD and have the GND pin connected to a common ground
2. Wait least 1 ms before the DRV2625 device accepts I2C commands.
3. Assert the NRST pin (logic high). The NRST pin can be asserted any time during or after the wait period.
4. Write the MODE[1:0] parameter in Register 0x07 to value 0x00 to remove the device from standby

## 4.3 Auto-Calibration

The auto-calibration routine is necessary for both ERMs and LRAs to adjust for possible resistive losses and EMF-magnitude compensation. This calibration is not part of the power up sequence and must be triggered by the programmer to be executed. A number of parameters must be inputted to the proper registers before the routine can start. Step by step instructions below will guide what these parameters should be set to and how to start the auto-calibration.

1. Write a value of 0x03 to the MODE[1:0] parameter in Register 0x07 to set the auto-calibration routine.
2. Populate the input parameters required by the auto-calibration engine:
  - (a) The following are input parameters required for the user to set for an accurate auto-calibration

- LRA\_ERM in Register 0x08 — Set to 1 for LRA or to 0 for ERM.
- RATED\_VOLTAGE[7:0] in Register 0x1F — The inputted value is determined by the equation below where the voltages on the left side of the equations are the rated voltages that can be found in the datasheet of the actuator that is being used with the driver.  $f(\text{LRA})$  is the resonant frequency also given by the actuator datasheet and  $t(\text{SAMPLE\_TIME})$  is equal to 300  $\mu\text{s}$

$$V_{(\text{ERM-CL\_AV})} = 21.88 \times 10^{-3} \text{ RATED\_VOLTAGE}[7:0] \quad (1)$$

$$V_{(\text{LRA-CL\_RMS})} = \frac{20.58 \times 10^{-3} \times \text{RATED\_VOLTAGE}[7:0]}{\sqrt{1 - (4 \times t_{(\text{SAMPLE\_TIME})} + 300 \times 10^{-6}) \times f_{(\text{LRA})}}} \quad (2)$$

- OD\_CLAMP[7:0] in 0x02 — The inputted value is determined by the equation below and the maximum voltage of the actuator that can be found in the datasheet of the actuator that is being used with the driver. With  $t(\text{DRIVE\_TIME}) = 4.2\text{ms}$ ,  $t(\text{IDISS\_TIME}) = .045\text{ms}$ , and  $t(\text{BLANKING\_TIME}) = .075\text{ms}$ .

$$V_{(\text{ERM-OL\_AV})} = 21.59 \times 10^{-3} \text{ OD\_CLAMP}[7:0] \quad (3)$$

$$V_{(\text{LRA-OL\_RMS})} = 21.32 \times 10^{-3} \times \text{OD\_CLAMP}[7:0] \times \sqrt{1 - f_{(\text{LRA})} \times 800 \times 10^{-6}} \quad (4)$$

- DRIVE\_TIME[3:0] in Register 0x07 — The inputted value will depend on the period of the LRA that is being used with the driver. The period is based on the frequency in the LRA data sheet. Use the following two equations to calculate the correct value to write:

$$\text{DriveTime (ms)} \approx 0.5 \times \text{LRA Period} \quad (5)$$

$$\text{DriveTime (ms)} = 0.5 + \text{DRIVE\_TIME}[3:0] * 0.1 \quad (6)$$

(b) The following are also input parameters but do not require modification as the defaults work for the majority of actuators. More info on these parameters can be found later on under optional device features.

- SAMPLE\_TIME[1:0] — Default value of 3 is valid for most actuators.
- FB\_BRAKE\_FACTOR[2:0] — Default value of 3, which is valid for most actuators.
- AUTO\_CAL\_TIME[1:0] — Default value of 3 is valid for most actuators.
- LOOP\_GAIN[1:0] — Default value of 2 is valid for most actuators.
- BLANKING\_TIME[3:0] — Default value of 1 is valid for most actuators.
- IDISS\_TIME[3:0] — Default value of 1 is valid for most actuators.
- ZC\_DET\_TIME[1:0] — Default value of 0 is valid for most actuators.

3. Write a 1 to the GO bit in Register 0x0C to start the auto-calibration process. When auto calibration is complete, the GO bit automatically clears. The auto-calibration results are written in parameters A\_CAL\_BEMF[7:0], A\_CAL\_COMP[7:0], and BEMF\_GAIN[1:0] located in register 0x21, 0x22, and 0x23, respectively.

4. Check the status of the DIAG\_RESULT bit in Register 0x01 to ensure that the auto-calibration routine is complete without faults.

5. Evaluate system performance with the auto-calibrated settings. Note that the evaluation should occur during the final assembly of the device because the auto-calibration process can affect actuator performance and behavior. If any adjustment is required, the inputs can be modified and this sequence can be repeated. If the performance is satisfactory, the user can do any of the following:

(a) Repeat the calibration process upon subsequent power ups.

(b) Store the auto-calibration results in host processor memory and rewrite them to the DRV2624 or DRV2625 device upon subsequent power ups. The device retains these settings when in STANDBY mode or when the EN pin is low.

## 4.4 Closed-Loop vs Open-Loop

Although the DRV2624 & DRV2625 has most its advantages from its closed loop architecture, the drivers can be used in both closed-loop and open-loop modes. The most significant difference is the resonance tracking engine is unavailable in open-loop. Overdrive will still be in effect in open-loop but timing is based off the waveform and ODT and not automatically adjusted like in closed-loop. Auto-braking is not enabled by default for open-loop but can be by setting `AUTO_BRK_OL`, in which case the system switches over to closed-loop when braking is initialized. ERMs are normally driven via open-loop, as they do not benefit from the auto-resonance tracking engine, and LRAs are normally driven closed-loop as resonant tracking is crucial for optimal operation. If open-loop is selected for an LRA, the LRA is driven according to the open-loop frequency set in the `OL_LRA_PERIOD` parameter. For setting the device to the proper mode follow the steps below.

### For Closed-Loop:

1. Leave the `CONTROL_LOOP` bit in Register 0x08 set as 0
2. Set the `AUTO_BRK_INT0_STBY` bit in Register 0x08 to 1 to enable auto-braking

### For Open-Loop:

1. Set the `CONTROL_LOOP` bit in Register 0x08 to 1
2. Set the `AUTO_BRK_INT0_STBY` bit in Register 0x08 to 1 to enable auto-braking
3. Set the `AUTO_BRK_OL` bit in Register 0x08 to 1 to enable auto-braking in open-loop operation
4. Set the `OL_LRA_PERIOD[9:0]` in Registers 0x05 & 0x06 to establish driving frequency for an attached LRA in open-loop

## 4.5 Playback Mode

The actual method in which the DRV2624 & DRV2625 play a waveform or series of waveforms when in an active state is determined by the playback mode. The two playback modes available are the Real Time Playback (RTP) mode and the Waveform Sequencer mode.

RTP mode works off the host processor streaming digital amplitude values to be played by the device. Each value sent from the processor is stored in a single register and the device outputs a waveform at the amplitude corresponding to that value until the next value sent from the processor is written to that register. This allows for direct control over the waveform shape and haptic effect by the host processor.

The Waveform Sequencer mode works by calling waveforms from the internal memory of the device. Waveform identifiers are placed in a series of eight register which call and play the data from memory when triggered to do so. Each waveform called can be manipulated to have a delay or repeat several times, giving a lot of flexibility when playing combinations of different waveforms. Waveform identifiers for the DRV2624 depends on the users programming of the waveform data onto its RAM, while for the DRV2625 the identifiers and waveform data is preloaded onto its ROM and a table of this information is available on page 67 of the DRV2625 datasheet.

**NOTE: Although the waveform libraries on the DRV2625 are provided by Immersion, there is no licensing or purchasing required by the user of the device to use these libraries.**

### RTP Mode:

1. Set the `MODE[1:0]` parameter to 0x00 in Register to 0x07 to select RTP mode operation
2. Write the desired drive amplitude to the real-time playback input parameter `RTP_INPUT[7:0]` in Register 0x0E. This is an 8-bit signed number where max voltage set by value 0x7F corresponds to the voltage set by the `OC_CLAMP` parameter
3. Trigger the waveform using the desired trigger method (GO bit, or external trigger). Trigger method will be set in a later section.
4. Continue writing to the `RTP_INPUT[7:0]` to change the amplitude and control the waveform.
5. Send a stop trigger using the desired trigger method (GO bit, or external trigger). Trigger method will be set in a later section.

6. Device will automatically go into standby upon completion of the playback

#### Waveform Sequencer:

1. Set the MODE[1:0] parameter in Register 0x07 to 1 to select Waveform Sequencer mode operation
2. Figure out what waveforms will be played by either looking at the ROM library table on page 67 in the [DRV2625 datasheet](#) or the user-programmed RAM if the DRV2624 is being used.

**NOTE: Although the waveform libraries on the DRV 2625 are provided by Immersion, there is no licensing or purchasing required by the user of the device to use these libraries.**

3. Identify the waveform indexes to be played and populate them in bits 7:0 of the eight waveform sequencer registers. The first bit in each register is the WAIT<sub>n</sub> parameter which determines if the WAV\_FRM\_SEQ<sub>n</sub>[6:0] will hold a waveform identifier index if written to 0 or hold a time delay value if written to 1. These registers take up Registers 0x0F to 0x16.
4. Manage the 8 WAV<sub>n</sub>\_SEQ\_LOOP[1:0] parameters to determine how many times each WAV\_FRM\_SEQ<sub>n</sub>[6:0] will play its effect. Keep set as 0 to have each effect looped only one. Set as 1, 2, or 3 to be replayed that many times respectively before moving to the next waveform in the following WAV\_FRM\_SEQ<sub>n</sub> register. These are located in Registers 0x17 & 0x18.
5. Set the WAV\_SEQ\_MAN\_LOOP[2:0] parameter in Register 0x19 to however many times you want the whole playback of waveform sequencers to repeat before going back to stand by. Set from 0 to 6 for 0 to 6 times looped or to 7 for infinite looping.
6. Trigger the waveform using the desired trigger method (GO bit, or external trigger).
7. Device will automatically go into standby upon completion of the playback

More details about these registers can be found in register descriptions section of the DRV2624 & DRV2625 datasheets

### **4.6 Writing to RAM (DRV2624 Only)**

The DRV2624 device contains 1 kB of integrated RAM to store customer waveforms. The waveforms are represented as amplitude-time pairs. Using the waveform sequencer, the waveforms can be recalled, sequenced, and played through the I2C or an external GPIO trigger.

A library consists of a revision byte (should be set to 0), a header section, and the waveform data content. The library header defines the data boundaries for each effect ID in the data field, and the waveform data contains a sequence of amplitude-time pairs that define the effects.

The header block consists of N-boundary definition blocks of 3 bytes each. N is the number of effects stored in the RAM (N cannot exceed 127). Each of the boundary definition blocks contain the start address (2 bytes) and a configuration byte. The start address contains the location in the memory where the waveform data associated with this effect begins.

The position of the effect pointer in the header becomes the effect ID. The first effect boundary definition points to the ID for effect 1, the second definition points to the ID for effect 2, and so on. The resulting effect ID is the effect ID that is used in the waveform sequencer.



2. Byte2 — Time1
3. Byte3 — Voltage2
4. Byte4 — Time2

The engine creates a linear interpolation between Voltage1 and Voltage2 over the time period Time1, where Time1 is a number of 5-ms ticks. The start value for the ramp is the 7-bit value contained in Voltage1. The end amplitude is the 7-bit value contained in Voltage2. The MSB in Voltage2 can indicate a following voltage-time pair or the starting point in a subsequent ramp.

To access the RAM in order to write the previously described data you must follow these steps:

1. Write the desired start address in the RAM\_ADDR[15:0] in Registers 0xFD & 0xFE
2. Write the desired first byte of data into the RAM\_DATA[7:0] parameter in Register 0xFF, the RAM\_ADDR[15:0] will increment after a write to this register.
3. Write the next byte to the RAM\_DATA[7:0] and repeat until all data is stored.

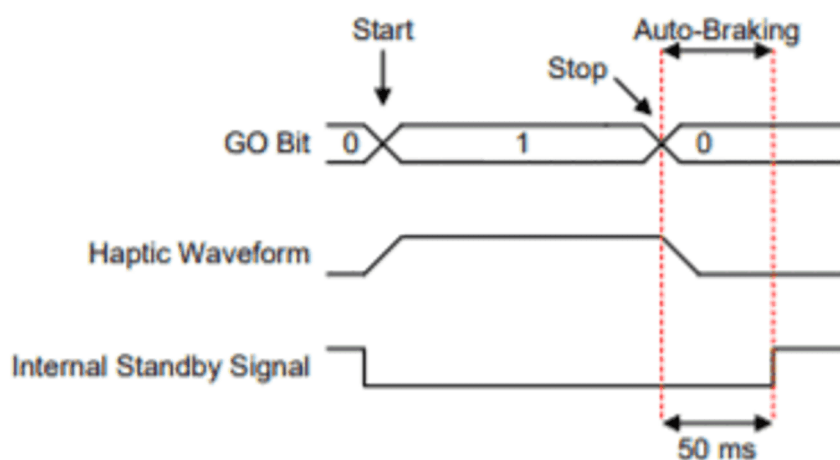
## 4.7 Trigger Selection

### Trigger Selection

The last necessary step before being able to play waveforms from the DRV2624 & DRV2625 is to set the trigger type. Back in the circuit configuration section it should have been determined whether the trigger would be hardware or software. [Table 4-2](#) is a chart with accompanying timing diagrams that compares the two different types of hardware trigger and the software trigger options.

**Table 4-2. Trigger Type Comparison**

| Trigger Type               | Software Trigger                              | Pulse Trigger   | Enable   |
|----------------------------|---|---|--|
| TRIG/INTZ Connection       | Grounded/ or GPIO                             | GPIO  | GPIO   |
| Software Trigger Available | Yes   | Yes   | No   |
| Goes back to Standby       | When Waveform Ends<br>or When Triggered again | When Waveform Ends<br>or When Triggered again         | When Enable = 0  |
| Parameter Set              | GO Bit  | None  | None   |
| Timing Diagram             | <a href="#">Figure 4-6</a>                    | <a href="#">Figure 4-7</a> <a href="#">Figure 4-8</a> | <a href="#">Figure 4-9</a> <a href="#">Figure 4-10</a> |



**Figure 4-6. Software Trigger Functionality**

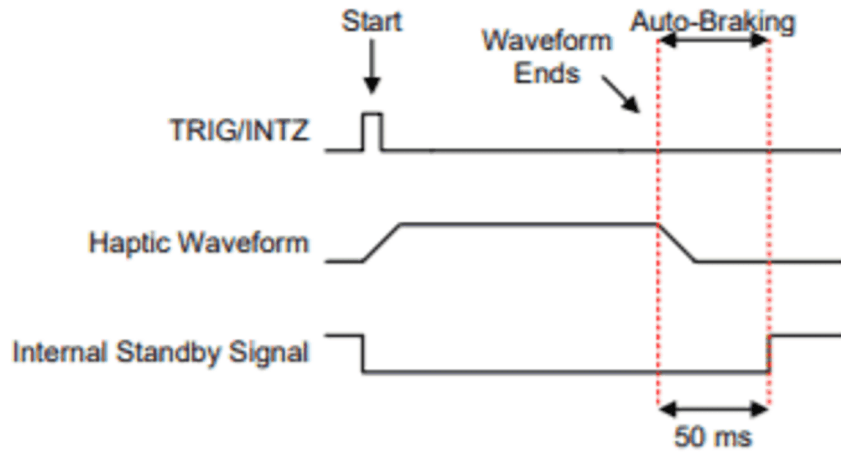


Figure 4-7. Trigger Pulse Functionality (Start Only)

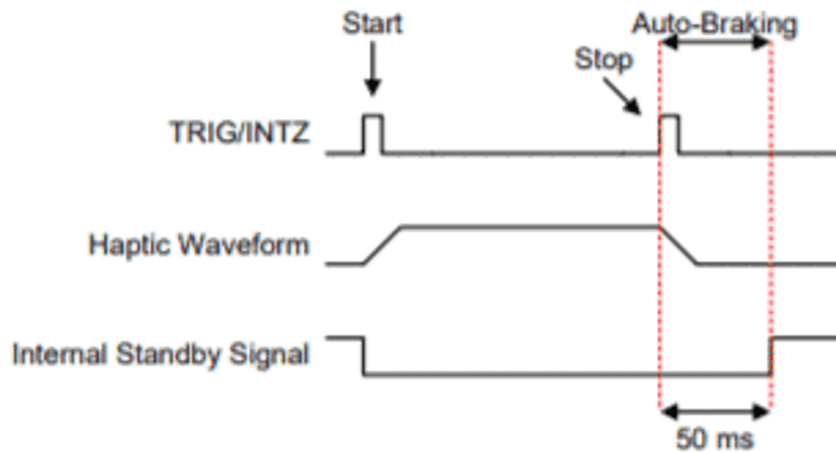


Figure 4-8. Trigger Pulse Functionality (Start & Stop)

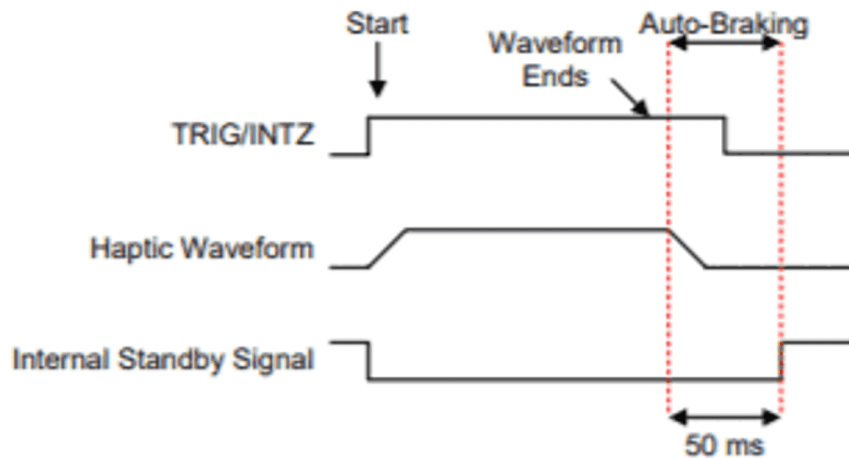


Figure 4-9. Trigger Enable Functionality

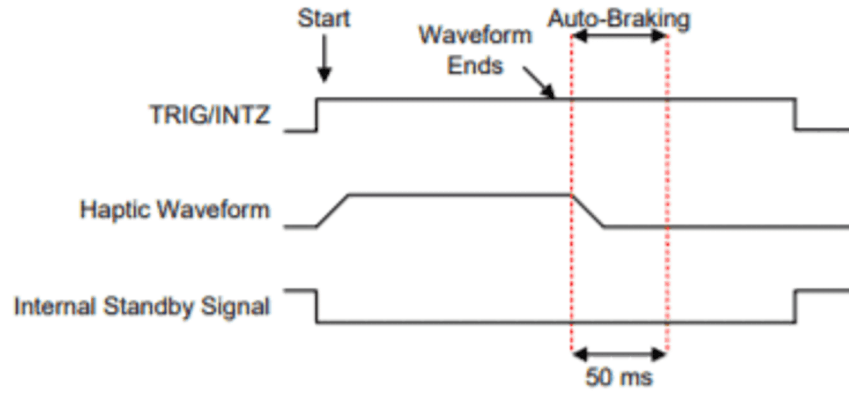


Figure 4-10. Trigger Enable Functionality (If Left On)



## 5 Operation States

The DRV2624 & DRV2625 devices have multiple power states to optimize power consumption. In the event of a critical condition, the device goes immediately into the standby state. Figure 5-1 shows the transitions into and out of each state. The device goes into active mode only when it must run a process. When the device gets into active mode, the first thing done is to check for critical conditions (such as overcurrent, thermal shutdown or UVLO). If a critical condition is present, the device sets the appropriate flag in Register 0x01, and immediately goes into standby. If no critical condition is present, the device runs the routine and when finished returns to the standby state. If a critical condition happens during a routine execution, the routine is aborted immediately and the device sets the appropriate flag in Register 0x01, and immediately goes into standby. If a stop trigger is received while a routine is being executed, the routine will be stopped and the device will go into standby state.

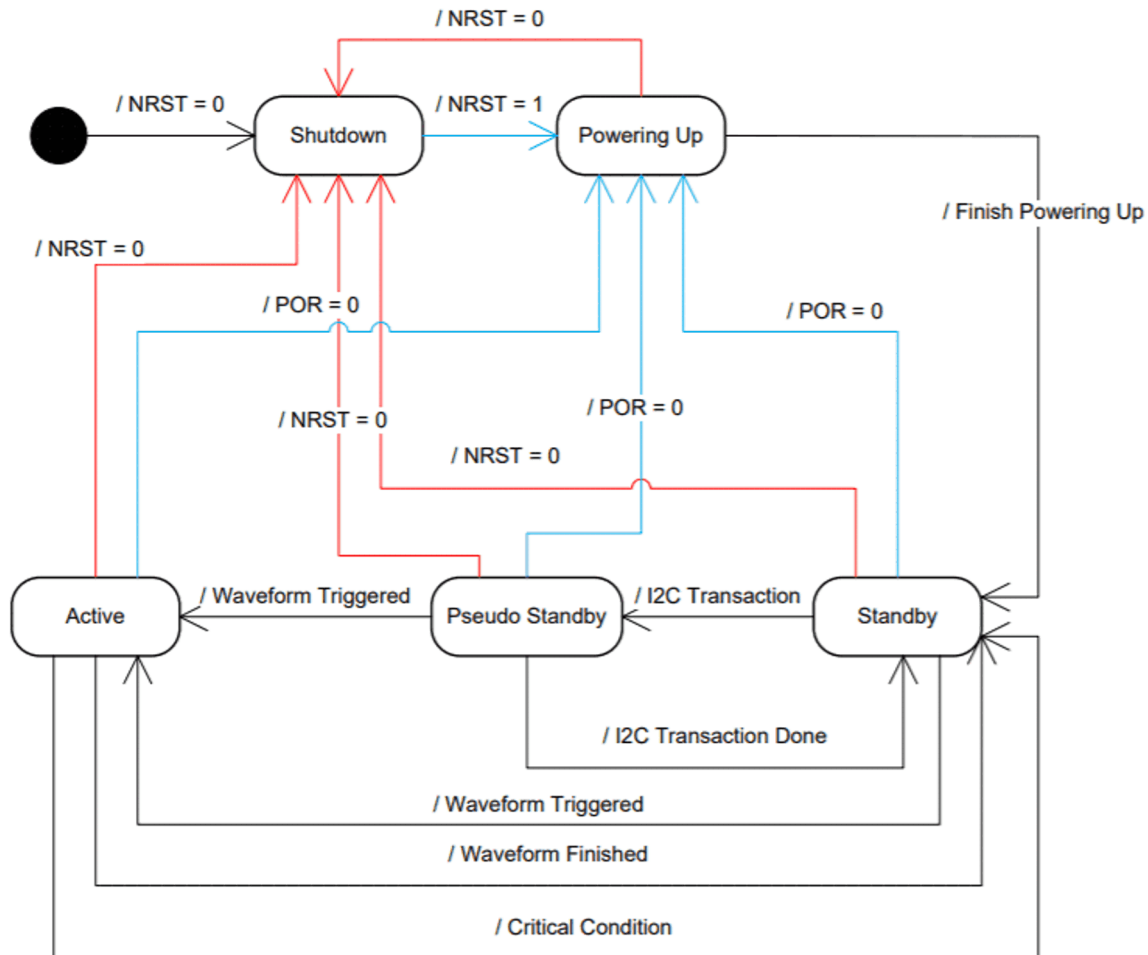


Figure 5-1. Power State Diagram

## 6 Optional Features

This section offers details into the optional steps and parameters that do not necessarily need to be set for basic operation of the DRV2624 & DRV2625 devices. These features and steps may be useful for more advanced users or for those who are trying to troubleshoot problems encountered in driving their specific ERM or LRA.

### 6.1 Diagnostics Routine

The DRV2624 & DRV2625 also features a diagnostics routine to read the impedance of a connected actuator and detect proper functionality. During the first part of the routine a small injection of current will flow through the output to detect the impedance between the the OUT+ and OUT- pin, the result of this measurement will be

stored in the DIAG\_Z\_RESULT. Failure to complete part one of the routine will result in the DIAG\_RESULT bit being set high. Part two of the diagnostics routine has the device play a waveform to the output and sample the back-EMF as it would in normal operation, if any critical condition or invalid back-EMF response is detected the DIAG\_RESULT will be set high.

Steps to run Diagnostics Routine:

1. Set the MODE[1:0] parameter in register 0x07 to 2 for Diagnostic Routine mode
2. Trigger the process just as for any other routine either through software trigger (GO bit) or hardware trigger (pulse or enable functionality).
3. Check DIAG\_RESULT bit in register 0x01, being high indicates a problem with the actuator connection or a critical condition occurred and the routine was aborted.
4. Check DIAG\_Z\_RESULT[7:0] in register 0x03 and CURRENT\_K in register 0x30 to calculate the actuator impedance using the equation below if desired.

$$R_{(\text{act})} = 478.43 \cdot \frac{\text{DIAG\_Z\_RESULT}[7:0]}{719 + 4 \cdot \text{CURRENT\_K}[7:0]} \quad (7)$$

## 6.2 Optional Parameters

**Table 6-1. Optional Parameters Descriptions and Locations**

| Parameter Name           | Register    | Brief Description  |
|--------------------------|-------------|--|
| PROCESS_DONE             | 0x01        | Bit set when a process finishes                          |
| UVLO                     | 0x01        | Set when VDD drops past a threshold                      |
| OVER_TEMP                | 0x01        | Set when temperature rise over a threshold               |
| OC_DETECT                | 0x01        | Set when over-current is detected                        |
| VBAT[7:0]                | 0x04        | Holds supply voltage value                               |
| LRA_PERIOD[9:0]          | 0x05 & 0x06 | Measured LRA period value                                |
| I2C_BCAST_EN             | 0x07        | Sets Device to Broadcast mode                            |
| LRA_PERIOD_AVG_DIS       | 0x07        | Sets how to average read LRA frequency                   |
| LINEREG_COMP_SEL[1:0]    | 0x07        | Compensates for LDO shifting                             |
| HYBRID_LOOP              | 0x08        | Set into hybrid loop mode                                |
| INPUT_SLOPE_CHECK        | 0x08        | Alternate hybrid mode                                    |
| BAT_LIFE_EXT_LVL_EN[1:0] | 0x09        | Enables battery life extender functionality              |
| UVLO_THRES[2:0]          | 0x09        | Change level of VDD drop threshold                       |
| BAT_LIFE_EXT_LVL1[7:0]   | 0x0A        | 1 <sup>st</sup> voltage level the voltage clamp changes  |
| BAT_LIFE_EXT_LVL2[7:0]   | 0x0B        | 2 <sup>nd</sup> voltage level the voltage clamp changes  |
| DIG_MEM_GAIN[1:0]        | 0x0D        | Scales the stored waveform amplitudes                    |
| ODT[7:0]                 | 0x1A        | Adds time offset to overdrive portion of waveforms       |
| SPT[7:0]                 | 0x1B        | Adds time offset to positive sustain level of waveforms  |
| SNT[7:0]                 | 0x1C        | Adds time offset to negative sustain level of waveforms  |
| BRT[7:0]                 | 0x1D        | Adds time offset to braking portion of waveforms         |
| NG_THRESH                | 0x23        | Sets noise threshold of device                           |
| FB_BRAKE_FACTOR[2:0]     | 0x23        | Controls braking gain ratio                              |
| LOOP_GAIN[1:0]           | 0x23        | Controls how quickly back-EMF is matched with output     |
| RATED_VOLTAGE_CLAMP[7:0] | 0x24        | Controls max of steady-state voltage                     |
| OD_CLAMP_LVL1[7:0]       | 0x25        | Over writes OC_Clamp if VDD goes below BAT_LIFE_EXT_LVL1 |

**Table 6-1. Optional Parameters Descriptions and Locations (continued)**

|                    |      |   |
|--------------------|------|---|
| OD_CLAMP_LVL2[7:0] | 0x26 | Over writes OC_Clamp if VDD goes below BAT_LIFE_EXT_LVL2                      |
| LRA_MIN_FREQ_SEL   | 0x27 | Select minimum LRA frequency supported  |
| LRA_RESYNC_FORMAT  | 0x27 | Sets resync method of device  |
| BLANKING_TIME[3:0] | 0x28 | Time given for back-EMF to settle   |
| IDISS_TIME[3:0]    | 0x28 | Time for inductor current to discharge  |
| OD_CLAMP_TIME[1:0] | 0x29 | Sets max overdrive time   |
| SAMPLE_TIME[1:0]   | 0x29 | Time to wait after zero-crossing to sample back-EMF                           |
| ZC_DET_TIME[1:0]   | 0x29 | Zero-crossing detection time  |
| AUTO_CAL_TIME[1:0] | 0x2A | Set time of auto-calibration routine  |
| LRA_AUTO_OPEN_LOOP | 0x2C | Controls if device switches to open loop if no impedance is present at output |
| AUTO_OL_CNT[1:0]   | 0x2C | Amount of time to sense output impedance                                      |
| LRA_WAVE_SHAPE     | 0x2C | Controls output wave shape in open loop mode                                  |

### 6.3 Advanced Parameter Modification Example

Below is an example of modifying an advanced parameter mentioned in the previous table, in order to show the utility of doing such a thing for advanced user and for those that are troubleshooting.

Let's look at FB\_BRAKE\_FACTOR[2:0] in register 0x23. Below is the parameter description from the DRV datasheet

**Table 6-2. Brake Factor Parameter Description**

| FIELD                | TYPE | DEFAULT | DESCRIPTION   |   |
|----------------------|------|---------|---|---|
| FB_BRAKE_FACTOR[2:0] | R/W  | 3       | Selects the feedback gain ratio between braking gain and driving gain. In general, it is recommended to add additional feedback gain while braking so that the actuator will brake as quickly as possible. Large ratios give less stable operation than lower ones. The advanced user may choose to optimize this register. Otherwise, the default value should give good performance for most actuators. This value should be set prior to running auto calibration. |   |
|                      |      |         | 0   | 1.  |
|                      |      |         | 1   | 2.  |
|                      |      |         | 2   | 3.  |
|                      |      |         | 3   | 4.  |
|                      |      |         | 4   | 6.  |
|                      |      |         | 5   | 8.  |
|                      |      |         | 6   | 16.   |
|                      |      |         | 7   | Removes feedback during braking (braking disabled). |

As you may see in the description, it is recommended that the default value of 3 will likely give good performance. Changing this value to be greater or less could work better for the exact actuator attached to the device, but it may also cause instability. So this parameter and the others listed in the prior table should be left as is unless a more advanced user of this chip wishes for optimization of device performance and has the background to know how to correctly change these registers.

All register maps and descriptions can be found starting on page 36 of the [DRV2624 datasheet](#) and on page 34 of the [DRV2625 datasheet](#).

## 7 Waveform Measurements and Recordings

To capture the graphs like the ones displayed in the figures below, the following first-order RC-filter setup was used. The filter should be used when viewing output signals on an oscilloscope because output PWM modulation is present in all modes and will appear very differently. Ensure that effective impedance of the filter is not too low because the closed-loop and auto resonance tracking features can be affected. Therefore, TI recommends that this exact filter be used for output measurement. Most oscilloscopes have an input impedance of 1 M $\Omega$  on each channel and therefore have an approximately 1% loss in measured amplitude because of the voltage-divider effect with the filter.

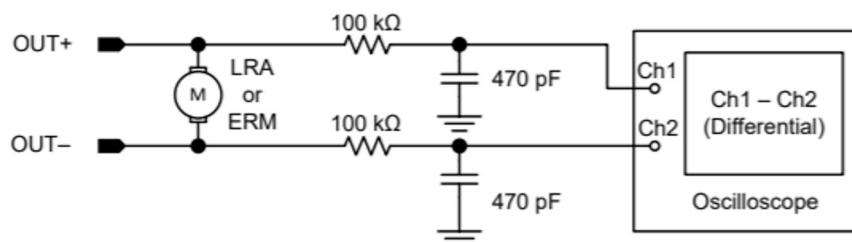


Figure 7-1. Output Recording Filter

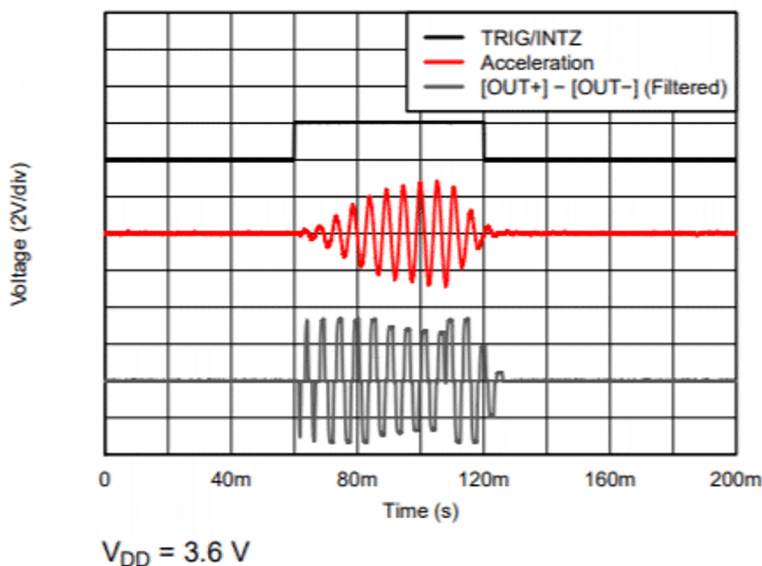


Figure 7-2. Waveform Recording Example of LRA

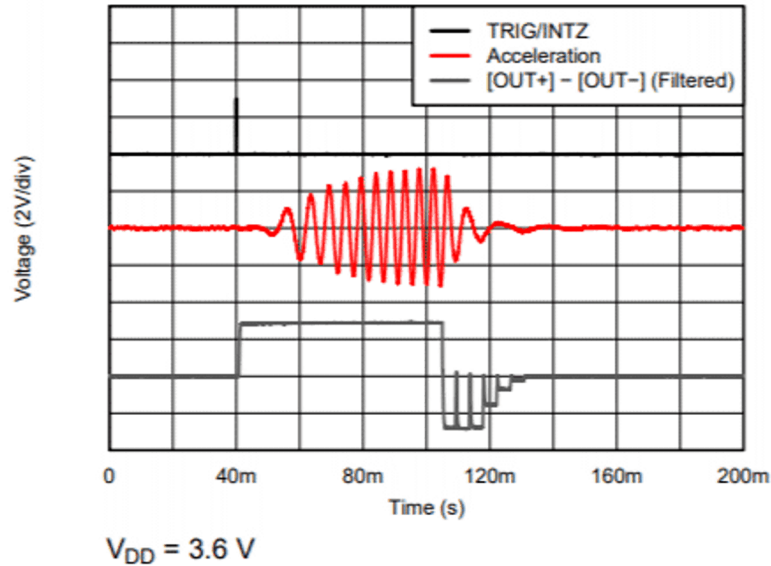


Figure 7-3. Waveform Recording Example of ERM

To capture the acceleration waveforms presents in the recordings above, it is necessary to use the DRV-ACC16-EVM accelerometer measurement tool. Relatively simple to use, it just requires sticking the accelerometer portion of the tool to the actuator attached to DRV2624 or DRV2625 and connecting an oscilloscope probe to the pin that corresponds to the axis that you want to measure the acceleration of. The device also requires power via a USB connection. Layout of the tool can be seen below.

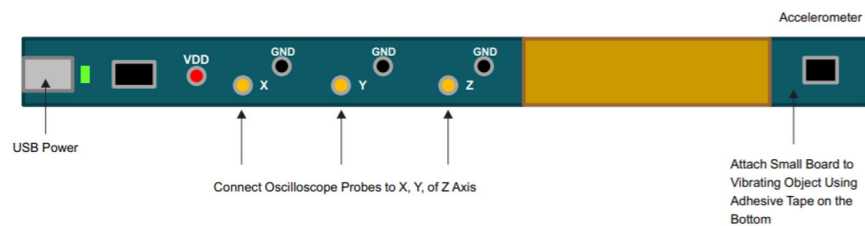


Figure 7-4. DRV-ACC16-EVM Board Layout

For purchasing of this tool see: <https://www.ti.com/tool/DRV-ACC16-EVM>

For more example waveform recordings for different haptic effects see pages 7 & 8 of the DRV2624 or DRV2625 datasheet.

## 8 Software Drivers

When using the DRV2624 & DRV2625 within a system, a driver library may be available depending on the choice of host processor. Below you will find links to driver libraries for Android processors and TI MSP430 processors

DRV2624 Driver Library: <https://git.ti.com/cgit/drv262xsw-android/drv2624-android-driver/>

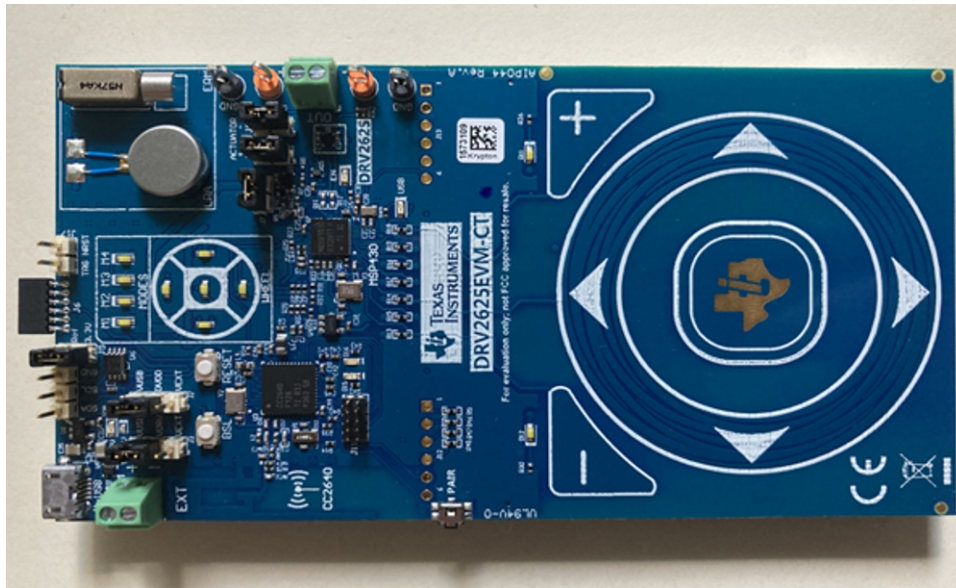
DRV2625 Driver Library: <https://git.ti.com/cgit/drv262xsw-android/drv2625-android-driver/>

TI MSP430 Demo Code Containing Driver Libraries: <https://e2e.ti.com/support/tools/ccs/f/81/p/913801/3381194?tisearch=e2e-sitesearch&keymatch=DRV2625#3381194>

## 9 Haptics Control Console

Before integrating either the DRV2624 & DRV2625 it is often useful to use the evaluation modules for either of these two chips in combination with our Haptics Control Console. The EVM as pictured below, features either the

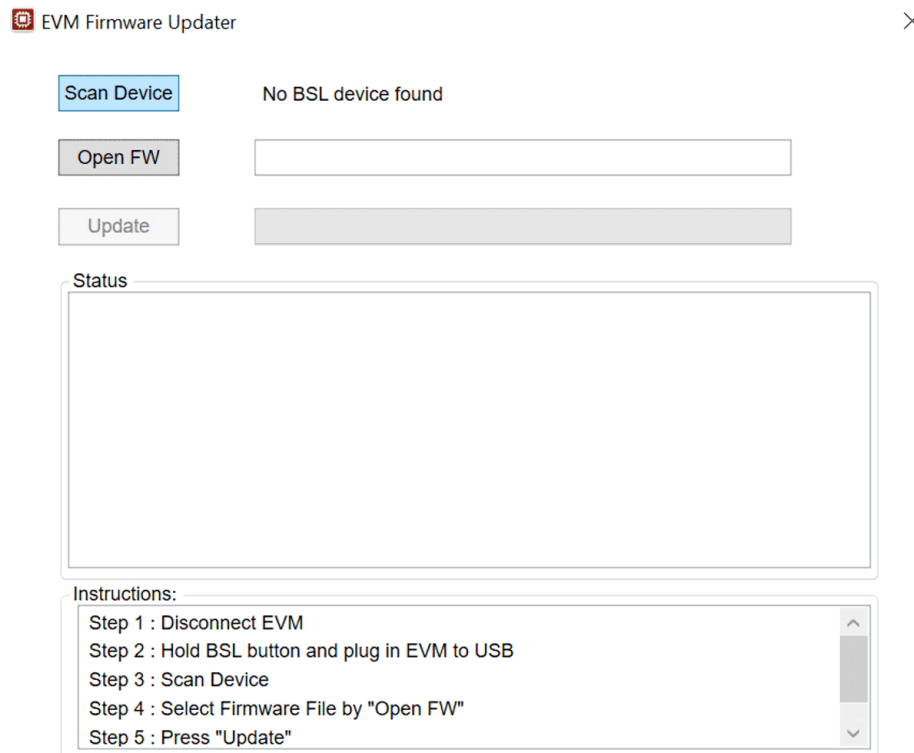
DRV2624 or DRV2625 with onboard actuators and a USB port for connection to a PC so the Haptics Control Console can program the board.



**Figure 9-1. Picture of DRV2624 EVM**

To get started with using the Haptics Control Console:

1. Open up the program and go to the top left under Help ⇒ Firmware Update then the window pictured below will pop-up.



**Figure 9-2. Firmware Update Window**

2. Follow the instructions on the bottom of the window, the BSL Button mentioned can be found where shown in the image below

Hold Down BSL Button

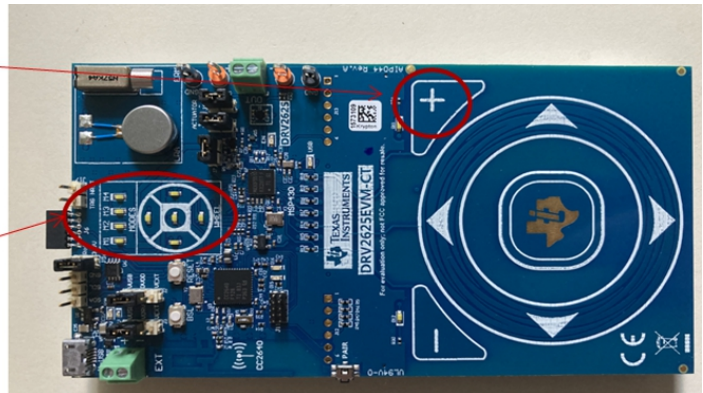


**Figure 9-3. Location of BSL Button**

3. Once the Firmware Update is complete exit the window and go back to the board and hold down the plus capacitive touch button for atleast 3 seconds or until the TOP half of LEDs light up. This will put the board into GUI mode.

Hold down on this plus capacitive touch button for 3 or more seconds

Upper half of LED indicators will turn on



**Figure 9-4. Putting Board into GUI Mode**

4. Once in GUI mode go to the top middle and hit connect, the Console window will open up as seen below, letting you easily configure the system use drop down lists to select actuator type, loop mode, playback mode, etc., without having to directly write the bits to the registers.

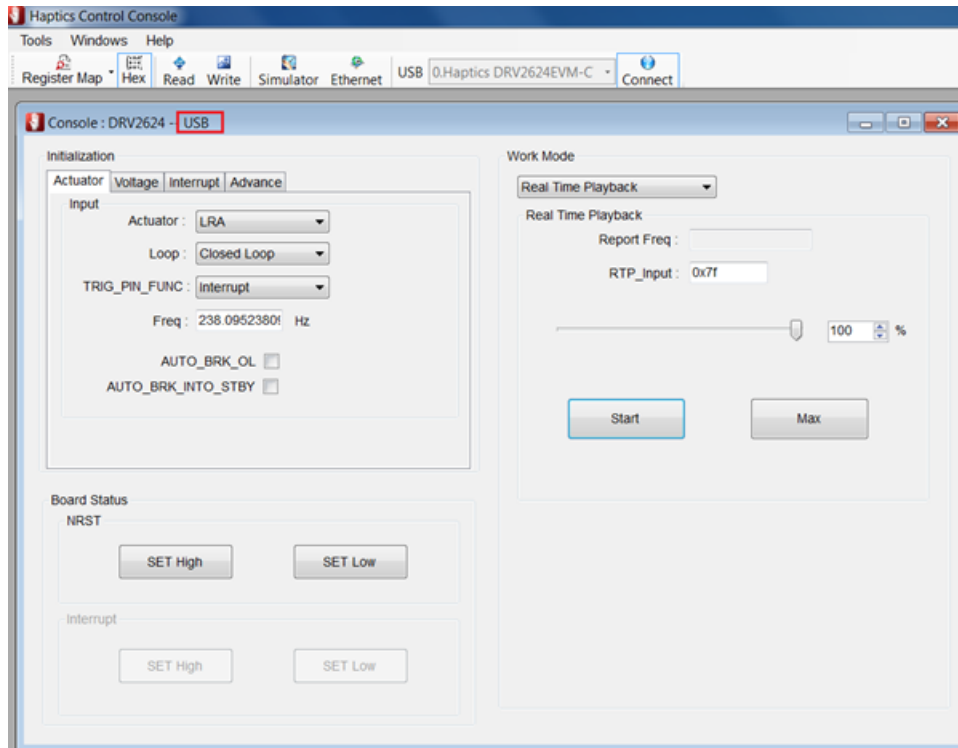
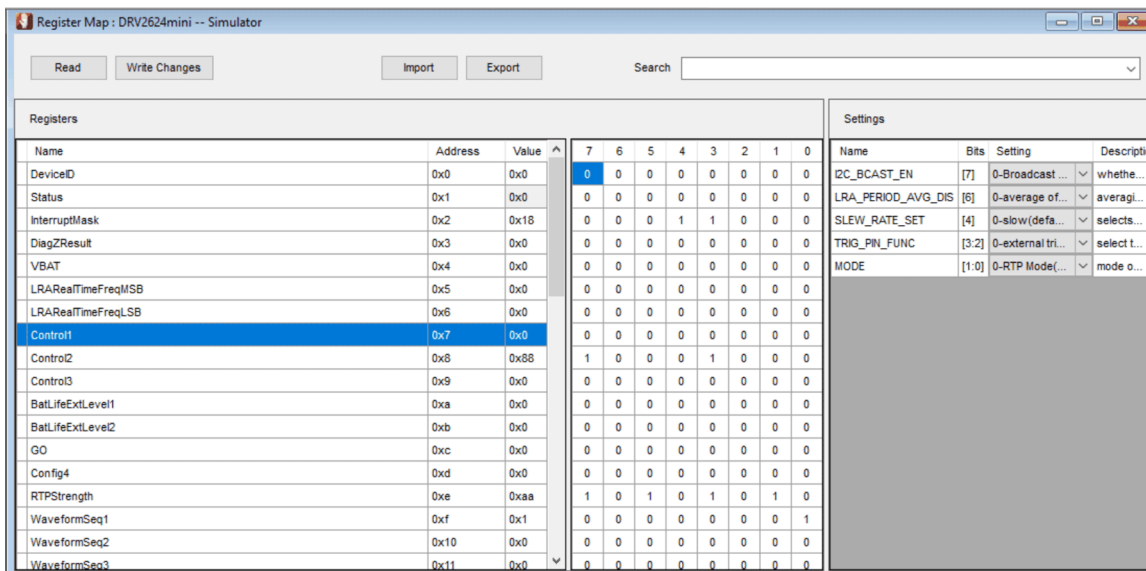


Figure 9-5. DRV2624 Console Window

5. Alternatively the register map window can be opened by going to the top left selecting Tools ⇨ Register Map ⇨ DRV2624. Here we can change each register bit by bit, including descriptions of what parameters are in each register with drop down list detailing the different parameter settings.



The screenshot shows the 'Register Map : DRV2624mini -- Simulator' window. It features a table of registers and a settings panel on the right.

| Name               | Address | Value | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------------------|---------|-------|---|---|---|---|---|---|---|---|
| DeviceID           | 0x0     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Status             | 0x1     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| InterruptMask      | 0x2     | 0x18  | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| DiagZResult        | 0x3     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| VBAT               | 0x4     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LRARealTimeFreqMSB | 0x5     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LRARealTimeFreqLSB | 0x6     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Control1           | 0x7     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Control2           | 0x8     | 0x88  | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Control3           | 0x9     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BatLifeExtLevel1   | 0xa     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BatLifeExtLevel2   | 0xb     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GO                 | 0xc     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Config4            | 0xd     | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RTPStrength        | 0xe     | 0xaa  | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 |
| WaveformSeq1       | 0xf     | 0x1   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| WaveformSeq2       | 0x10    | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WaveformSeq3       | 0x11    | 0x0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

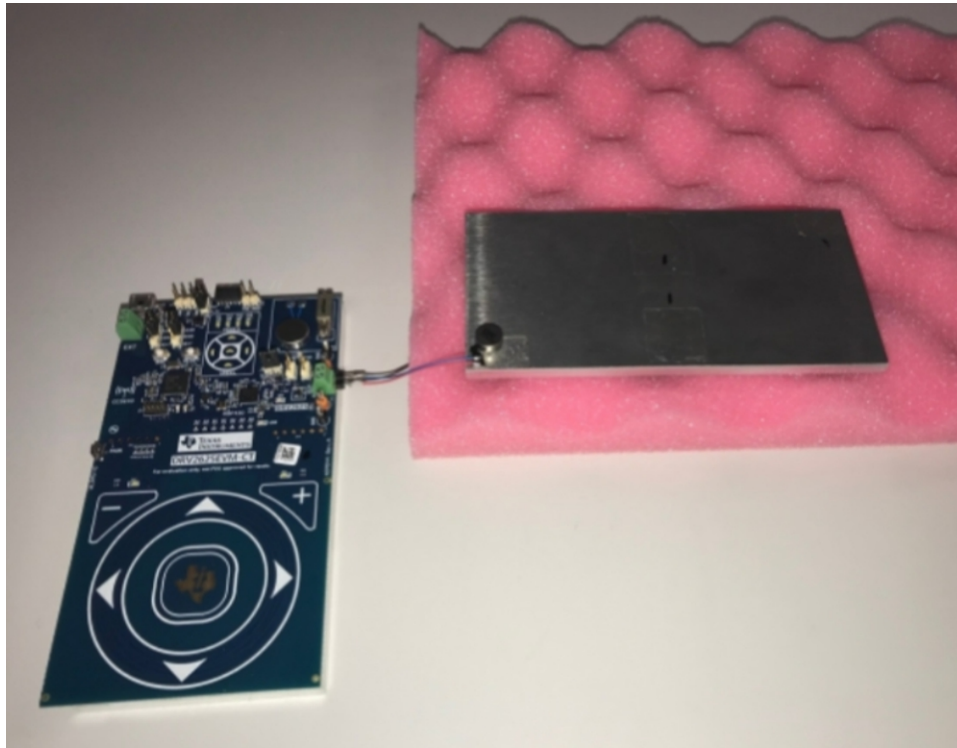
The 'Settings' panel on the right includes:

| Name               | Bits  | Setting           | Description |
|--------------------|-------|-------------------|-------------|
| ICZ_BCAST_EN       | [7]   | 0-Broadcast...    | whethe...   |
| LRA_PERIOD_AVG_DIS | [6]   | 0-average of...   | averagi...  |
| SLEW_RATE_SET      | [4]   | 0-slow(defa...    | selects...  |
| TRIG_PIN_FUNC      | [3-2] | 0-external tri... | select t... |
| MODE               | [1:0] | 0-RTP Mode(...)   | mode o...   |

Figure 9-6. DRV2624 Editable Register Map

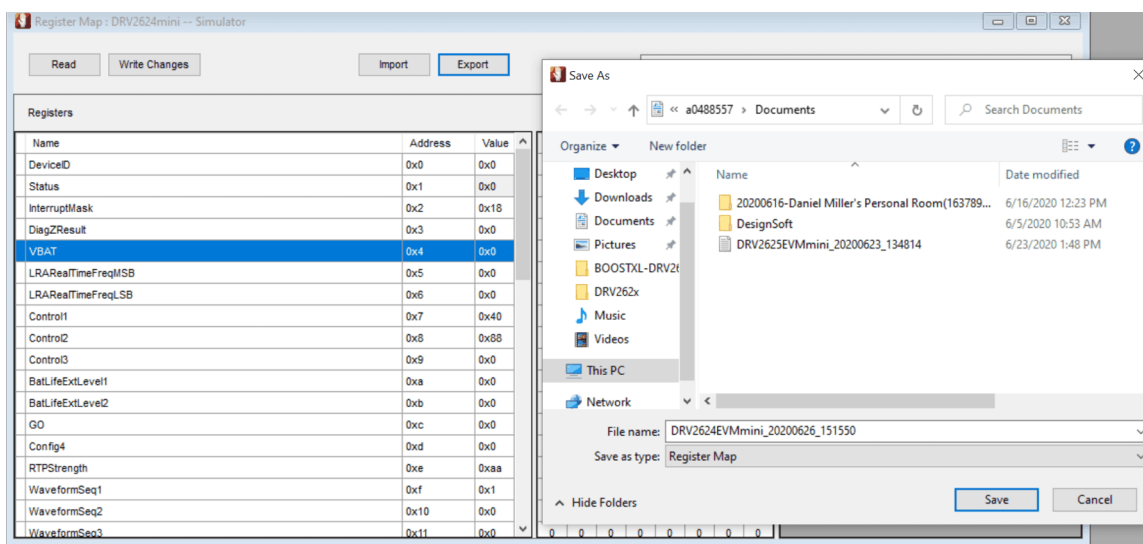


6. Once programmed, the EVM can be triggered and the attached actuator can be felt or recorded from using the DRV-ACC16-EVM. Note when using the EVM the set up below is recommended, where the actuator is placed on a small slab of metal as a representative mass for the vibrational waves to travel through just as it would in a real haptic feedback application.

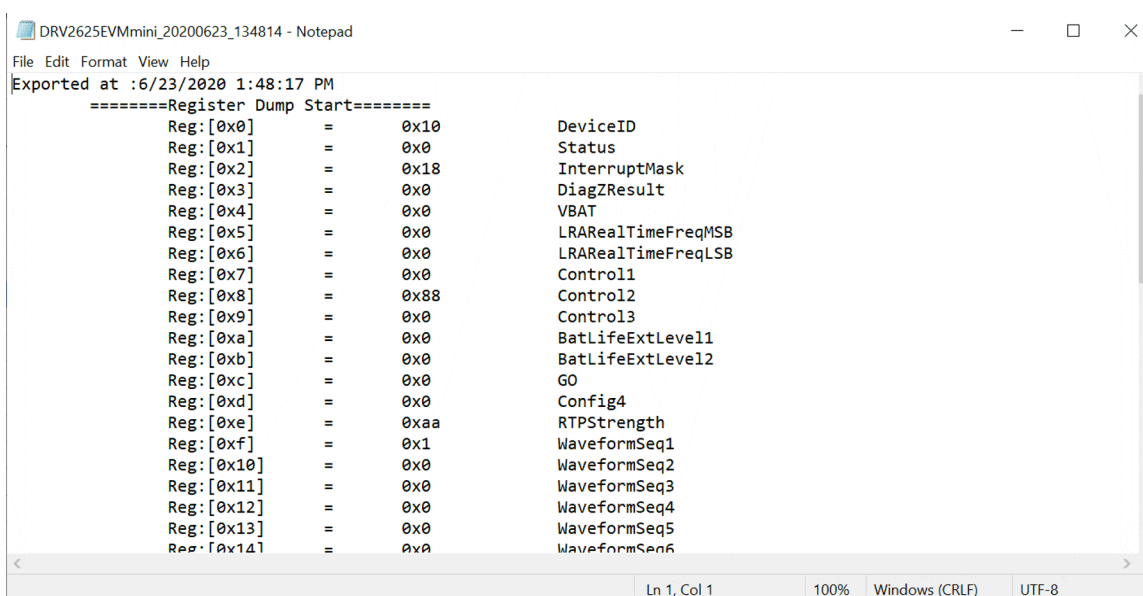


**Figure 9-7. DRV2624 EVM with Proper Actuator Set-Up**

7. These register settings can easily be shared with other by using the Export button, this allows you to save a text file that gives a list of all register values.



**Figure 9-8. Saving EVM Register Map**



**Figure 9-9. Saved Register Map in Text File**

To download the Haptics Control Console: <https://www.ti.com/tool/HAPTICS-CONSOLE>

To see the Haptics Control Console User Guide: [https://www.ti.com/lit/ug/slou502a/slou502a.pdf?ts=1593457824491&ref\\_url=https%253A%252F%252Fwww.google.com%252F](https://www.ti.com/lit/ug/slou502a/slou502a.pdf?ts=1593457824491&ref_url=https%253A%252F%252Fwww.google.com%252F)

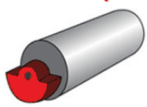
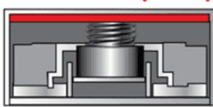

To order the DRV2624 EVM or find user guide: <https://www.ti.com/tool/DRV2624EVM-CT>

To order the DRV2625 EVM or find user guide: <https://www.ti.com/tool/DRV2625EVM-CT>

## 10 General Information

### 10.1 Types of Actuators

The actuator decision is based on many factors including cost, form factor, vibration strength, power consumption requirements, haptic sharpness requirements, reliability, and audible noise performance. The actuator selection is one of the most important design considerations of a haptic system and therefore the actuator should be the first component to consider when designing the system. The following sections list the basics of ERM, LRA, and Piezo actuators.

|                          | <b>Eccentric Rotating Mass (ERM)</b>  | <b>Linear Resonant Actuator (LRA)</b>   | <b>Piezo</b>  |
|--------------------------|---|---|---|
|                          |  |  |  |
|                          | <b>Lowest Cost, Lowest Performance</b>  | <b>Medium Cost, Medium Performance</b>  | <b>Highest Cost, Highest Performance</b>  |
| <b>Voltage</b>           | 1 – 10 V <sub>DC</sub>  | 2.5 – 10 V <sub>AC</sub>  | 50 – 200 V <sub>PP</sub>  |
| <b>Acceleration (G)</b>  | ~1  | ~1-2  | ~1-3  |
| <b>Power Consumption</b> | Good  | Best  | Better  |
| <b>Freq. Response</b>    | Limited   | Limited   | Wide  |
| <b>Audible Noise</b>     | Very Noisy  | Moderately Noisy  | Silent  |
| <b>Response Time</b>     | 40 – 80 ms  | 20 – 30 ms  | <1 ms   |
| <b>Waveform</b>          | DC Voltage  | Sine Wave   | Sine Wave   |
| <b>Min. Size (mm)</b>    | Ø5 x 8 long   | Ø10 x 3 high  | *Bender: 26.5 x 3.3 x 0.4<br>*Module: 35 x 3.5 x 3.2                                |
| <b>HD Haptics</b>        | No  | No  | Yes   |

**Figure 10-1. Types of Haptic Actuators**

### 10.2 Additional Links

DRV2624 Product Page: <https://www.ti.com/product/DRV2624?keyMatch=DRV2624&tisearch=Search-EN-everything&usecase=GPN>

DRV2625 Product Page: <https://www.ti.com/product/DRV2625?keyMatch=DRV2625&tisearch=Search-EN-everything&usecase=GPN>

DRV2624 Datasheet: [https://www.ti.com/lit/ds/symlink/drv2624.pdf?ts=1593457927091&ref\\_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FDRV2624](https://www.ti.com/lit/ds/symlink/drv2624.pdf?ts=1593457927091&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FDRV2624)

DRV2625 Datasheet: <https://www.ti.com/lit/ds/symlink/drv2625.pdf?ts=1593441315898>

Understanding I2C Communication: [https://www.ti.com/lit/an/slva704/slva704.pdf?ts=1593027093519&ref\\_url=https%253A%252F%252Fwww.google.com%252F](https://www.ti.com/lit/an/slva704/slva704.pdf?ts=1593027093519&ref_url=https%253A%252F%252Fwww.google.com%252F)

DRV2625 BoosterPack for a TI LaunchPad: <https://www.ti.com/tool/BOOSTXL-DRV2625>

Haptic Drivers Energy Consumption: <https://www.ti.com/lit/an/sloa194/sloa194.pdf>

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