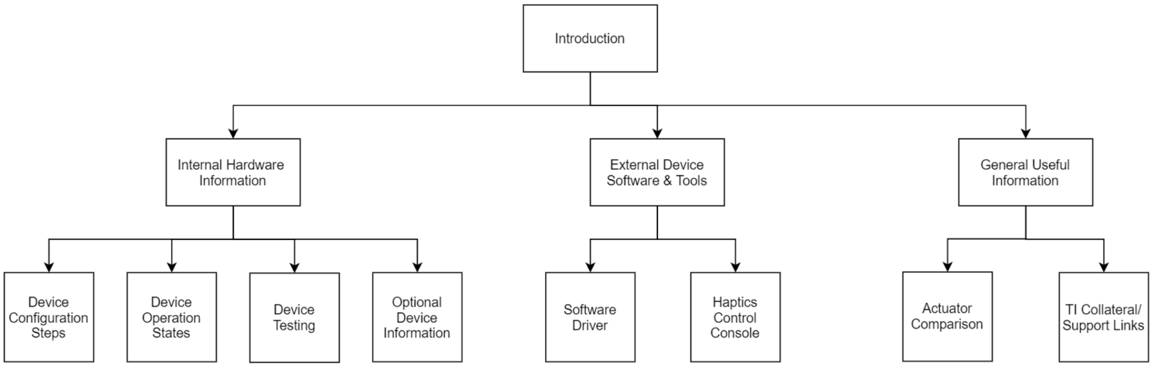
Application Report

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).


Introduction
Internal Hardware Information
External Device Software & Tools
General Useful Information
Device Configuration Steps
Device Operation States
Device Testing
Optional Device Information
Software Driver
Haptics Control Console
Actuator Comparison
TI Collateral/ Support Links

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.

Table of Contents

Copyright © 2020 Texas Instruments Incorporated

Trademarks

All other trademarks are the property of their respective owners.

Copyright © 2020 Texas Instruments Incorporated

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.

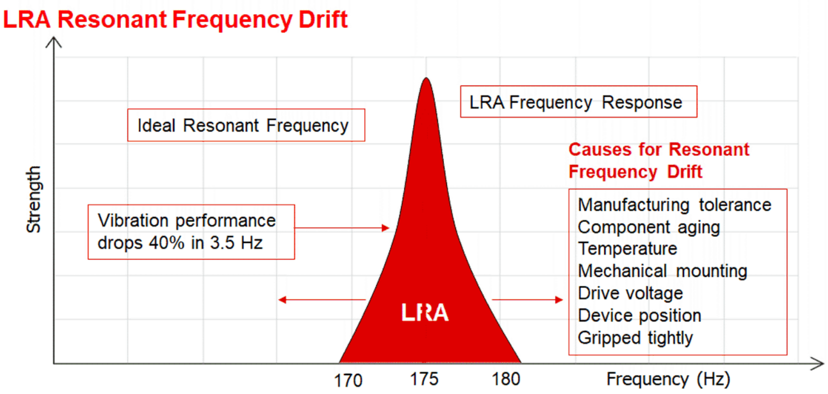


Figure 1-1. LRA Frequency Drift

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 genric 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 wavefroms 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, whcih will still allow user to use open-loop while still taking advantage of the smart loop powered auto-braking.

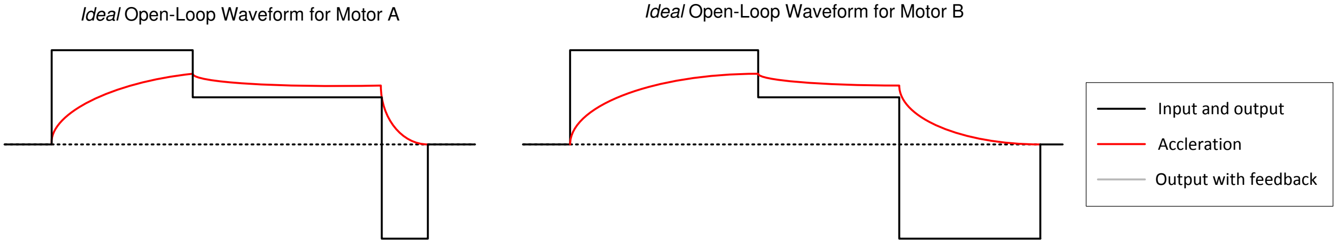


Figure 1-2. Actuator Waveform with Auto-Braking & Overdrive

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-

Copyright © 2020 Texas Instruments Incorporated

brake that is way to powerful, while the closed-loop mode modifies itself by adding overdrive and scaling down the auto-brake signifigantly. 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.

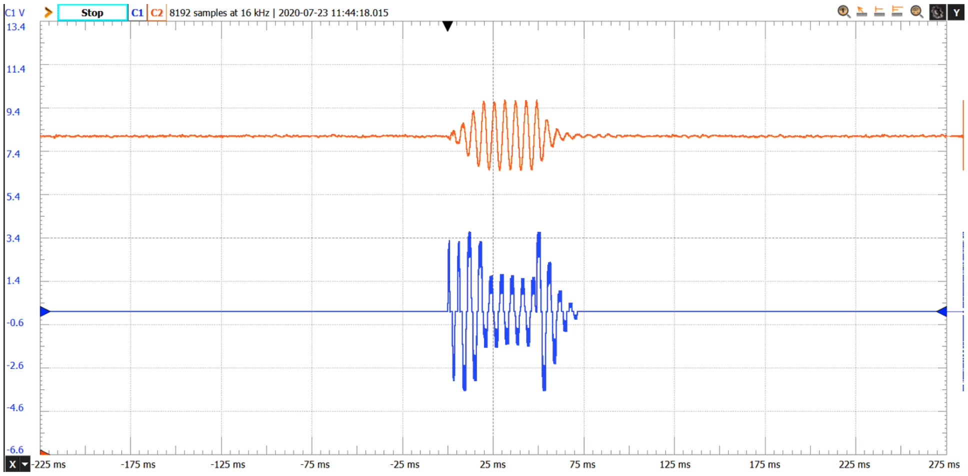


Figure 1-3. LRA Strong Click (80% Strength) Played in Closed-Loop Mode

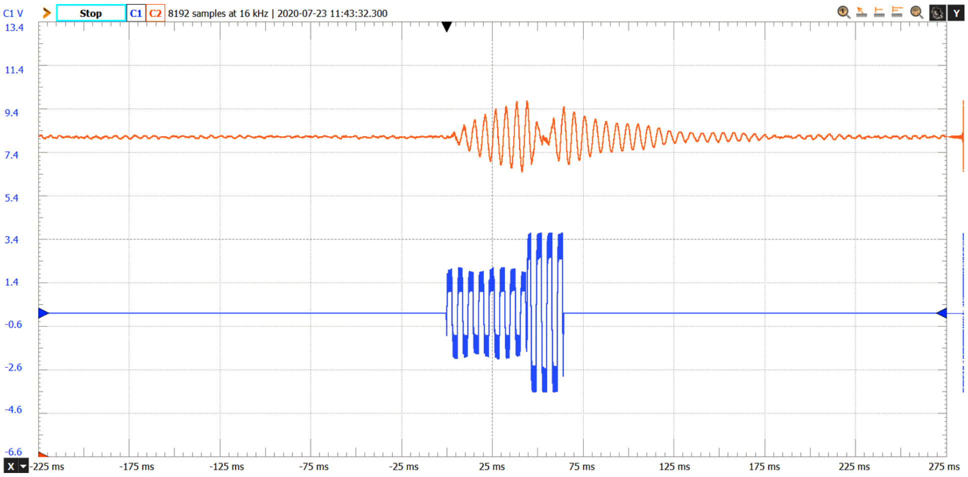


Figure 1-4. LRA Strong Click (80% Strength) Played in Open-Loop Mode with Auto-Braking Disabled

Copyright © 2020 Texas Instruments Incorporated

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

Copyright © 2020 Texas Instruments Incorporated

3 Device Overview

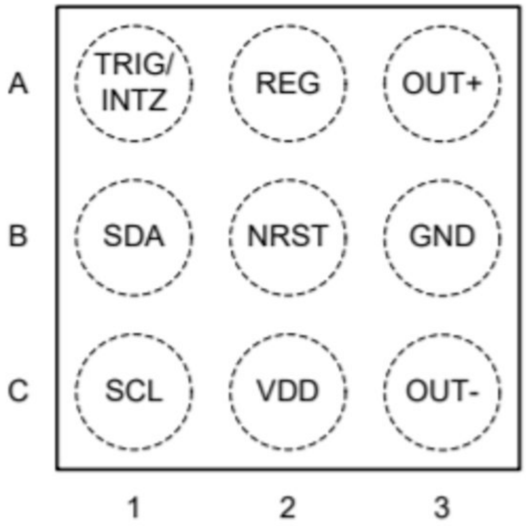
3.1 Actuator Selection

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-μF capacitor is required.
GND	B3	P	Supply ground
REG	A2	O	1.8 V regulator output. A 0.1-μF capacitor is required
OUT-	C3	O	Negative haptic driver differential output
OUT+	A3	O	Positive haptic driver differential output
SDA	B1	I/O	I^{2}C data
SCL	C1	I	I^{2}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. 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.

Copyright © 2020 Texas Instruments Incorporated

3.3 Functional Block Diagrams

A summary of the internal features and functions of the DRV2624 & DRV2625 can be visualized beaneath 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.

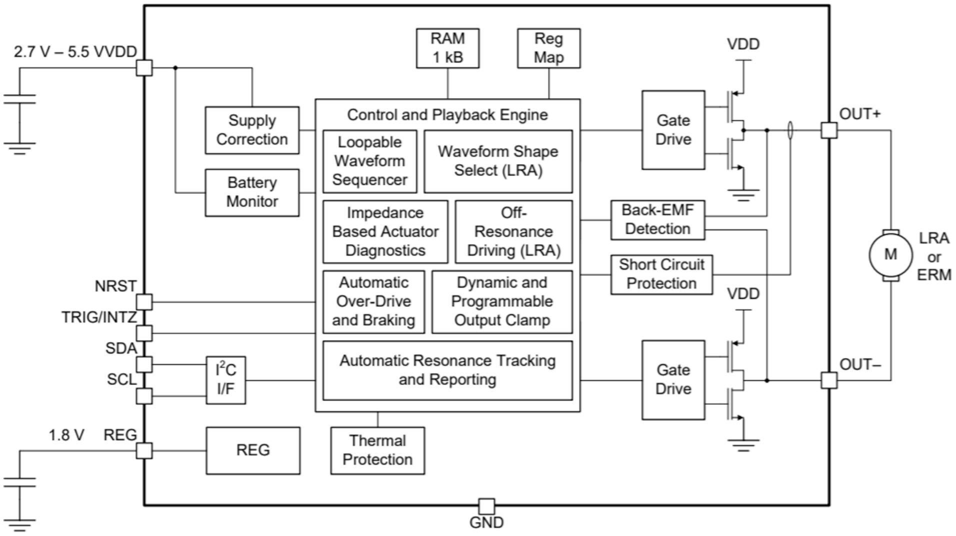

2.7 V – 5.5 VVDD
RAM 1 kB
Reg Map
VDD
Supply Correction
Control and Playback Engine
Loopable Waveform Sequencer
Waveform Shape Select (LRA)
Gate Drive
OUT+
Battery Monitor
Impedance Based Actuator Diagnostics
Off-Resonance Driving (LRA)
Back-EMF Detection
Short Circuit Protection
M
LRA or ERM
NRST
TRIG/INTZ
Automatic Over-Drive and Braking
Dynamic and Programmable Output Clamp
VDD
SDA
SCL
I2C I/F
Automatic Resonance Tracking and Reporting
Gate Drive
OUT–
1.8 V
REG
REG
Thermal Protection
GND

Figure 3-1. DRV2624 Block Diagram

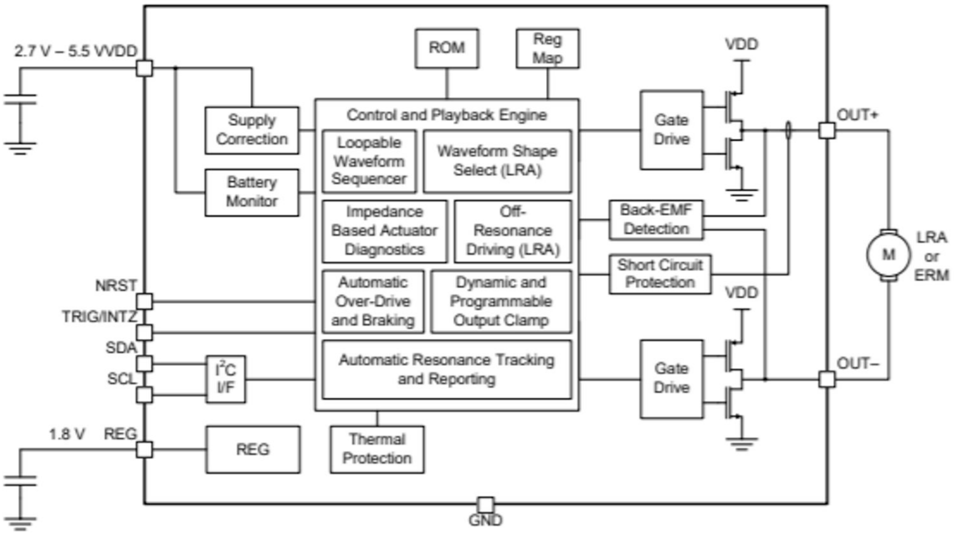

2.7 V – 5.5 VVDD
ROM
Reg Map
VDD
Supply Correction
Control and Playback Engine
Loopable Waveform Sequencer
Waveform Shape Select (LRA)
Gate Drive
OUT+
Battery Monitor
Impedance Based Actuator Diagnostics
Off-Resonance Driving (LRA)
Back-EMF Detection
Short Circuit Protection
M
LRA or ERM
NRST
TRIG/INTZ
Automatic Over-Drive and Braking
Dynamic and Programmable Output Clamp
VDD
SDA
SCL
I2C I/F
Automatic Resonance Tracking and Reporting
Gate Drive
OUT–
1.8 V
REG
REG
Thermal Protection
GND

Figure 3-2. DRV2625 Block Diagram

Copyright © 2020 Texas Instruments Incorporated

4 Device Configuration Steps

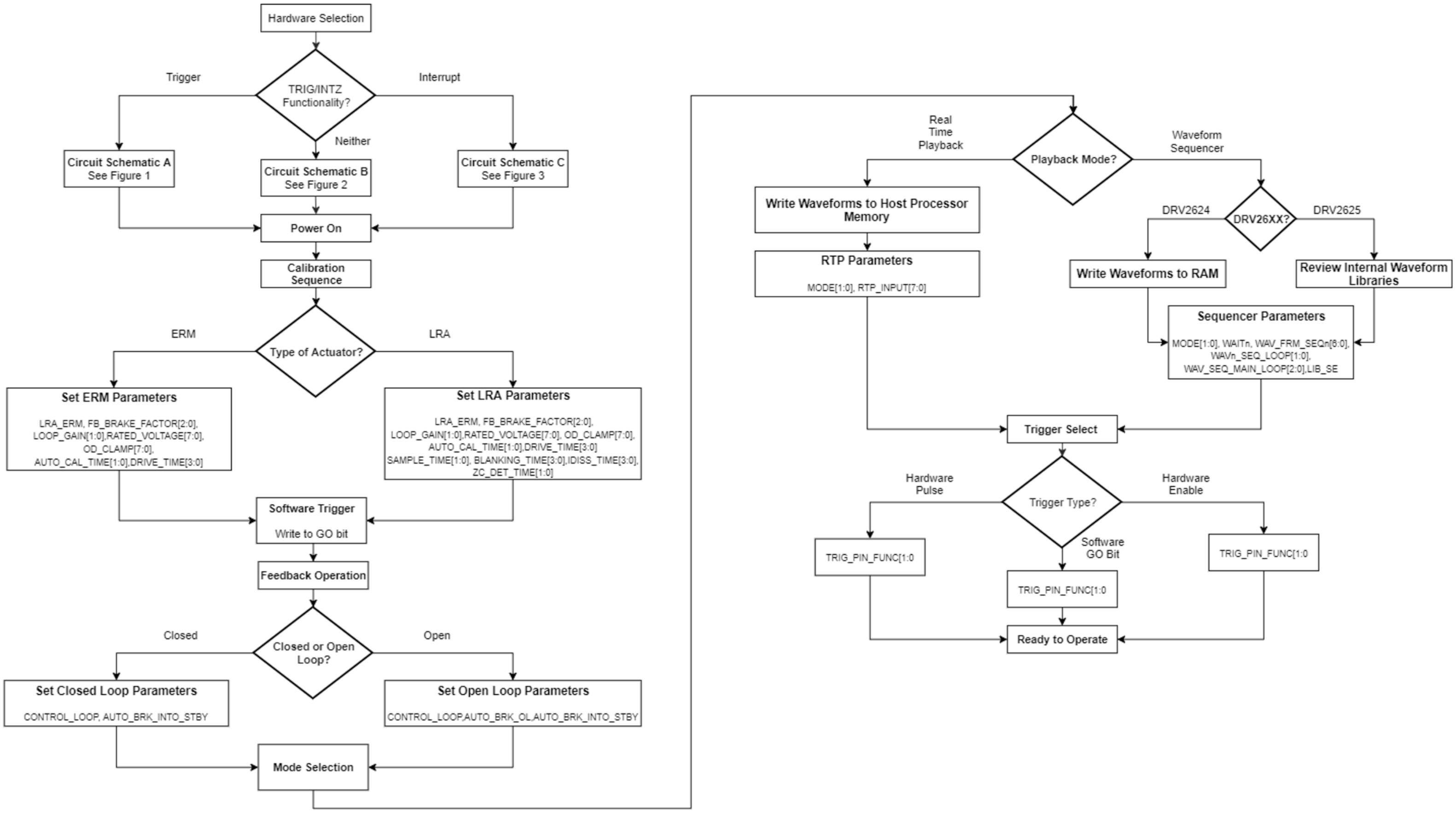


Figure 4-1. Initial Device Configuration Flowchart

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 interupt 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.

Copyright © 2020 Texas Instruments Incorporated

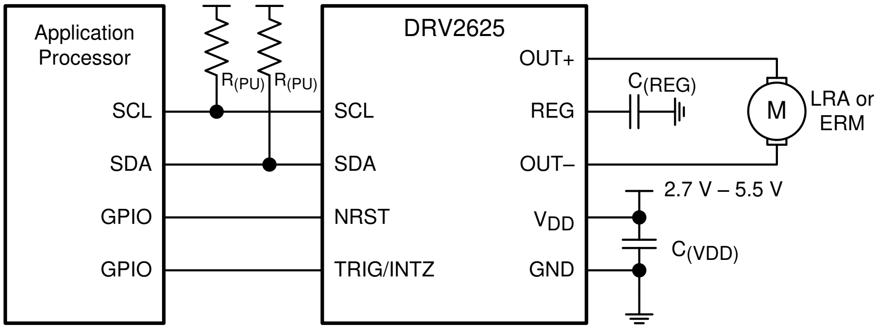


Figure 4-2. Processor Interface with Hardware Trigger

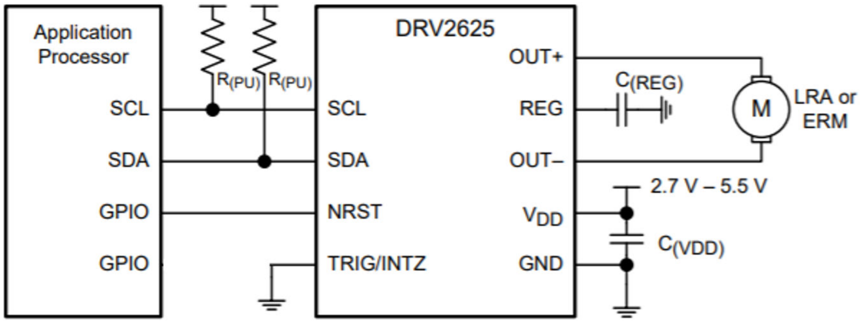


Figure 4-3. Processor Interface without Trigger

Table 4-1. Recommended External Components

COMPONENT	DESCRIPTION	SPECIFICATION	TYPICAL VALUE
$C_{(VDD)}$	Input capacitor	Capacitance	0.1 µF
$C_{(REG)}$	Regulator capacitor	Capacitance	0.1 µF
$R_{(PU)}$	Pull-up resistor	Resistance	2.2 kΩ

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 **I2**C 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

Copyright © 2020 Texas Instruments Incorporated

- 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**(LRA)** is the resonant frequency also given by the actuator datasheet and t**(SAMPLE_TIME)** is equal to 300 µs

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

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

- 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**(DRIVE_TIME)** = 4.2ms, t**(IDISS_TIME)** = .045 ms, and t**(BLANKING_TIME)** = .075 ms.

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

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

- 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:

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

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

(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.

Copyright © 2020 Texas Instruments Incorporated

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_INTO_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_INTO_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.

Copyright © 2020 Texas Instruments Incorporated

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 WAITn parameter which determines if the WAV_FRM_SEQn[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 WAVn_SEQ_LOOP[1:0] parameters to determine how many times each WAV_FRM_SEQn[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_SEQn 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 repeeat 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.

Copyright © 2020 Texas Instruments Incorporated

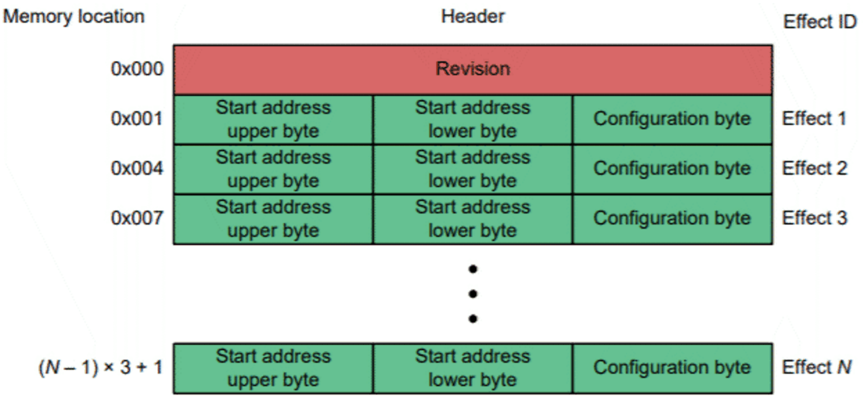


Figure 4-4. RAM Header Format

The configuration byte contains the following two parameters:

• The effect size contains the amount of bytes that define the waveform data and takes up the last 5 bits of the configuration byte. An effect size of 0 is an error state. Any odd-number effect size is an error state because the waveform data is defined as time-value (2 bytes). Therefore, the effect size must be an even number between 2 and 30.

• The WAVEFORM_REPEATS[2:0] bit is used to select the number of times the complete waveform is be played when it is called by the waveform sequencer and takes up the first three bits of the configuration byte. A value of 0 is no repeat and the waveform is played once. A value of 1 means 1 repeat and the waveform is played twice. A value of 7 means infinite repeat until the GO bit is cleared. During waveform design, ensure that the appropriate amount of drive time is at zero amplitude on the end of the waveform so that the waveform stored in the RAM is repeated smoothly.

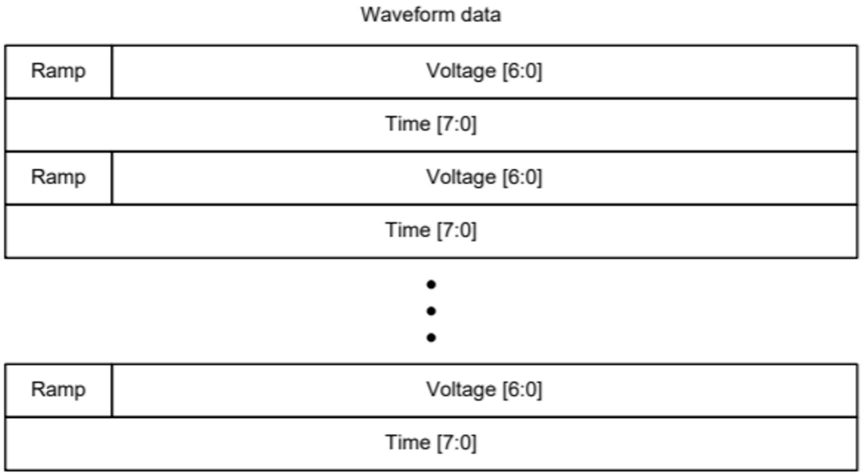


Figure 4-5. Waveform Data Structure

Data is stored as interleaved voltage-time pairs. Voltage in the voltage-time pair is a 7-bit signed number with range –63 to 63. The MSB of the voltage byte is reserved for the linear ramping mode. The Time value is the number of ticks that the Voltage will last. The size of the tick depends on the PLAYBACK_INTERVAL bit located in register 0x0D. If PLAYBACK_INTERVAL = 0 the absolute time is number of ticks × 5 ms. If PLAYBACK_INTERVAL = 1 the absolute time is number ticks × 1 ms. When the most significant bit of the Voltage byte is high, the engine interprets a linear interpolation between that voltage and the following voltage point. The following voltage point can either be a part of a regular voltage-time pair, or a subsequent ramp. The following lists the sequence of bytes:

1. Byte1 — Voltage1 (MSB High)

Copyright © 2020 Texas Instruments Incorporated

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 or When Triggered again	When Waveform Ends or When Triggered again	When Enable = 0
Parameter Set	GO Bit	None	None
Timing Diagram	Figure 4-6	Figure 4-7 Figure 4-8	Figure 4-9 Figure 4-10

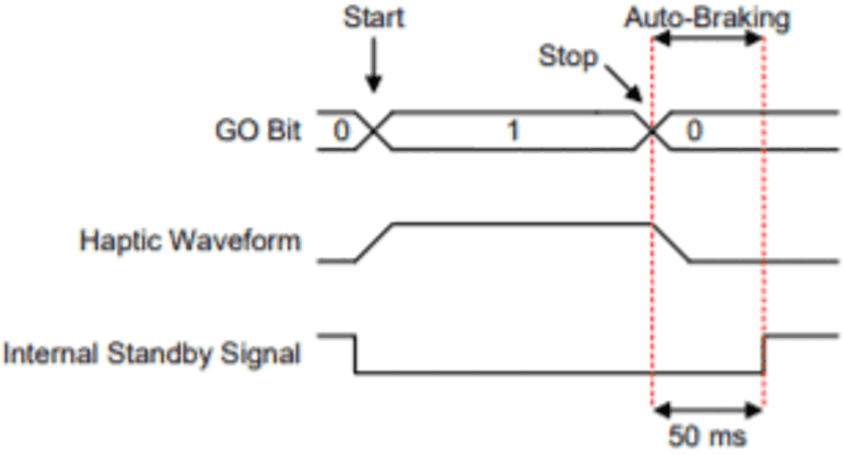


Figure 4-6. Software Trigger Functionality

Copyright © 2020 Texas Instruments Incorporated

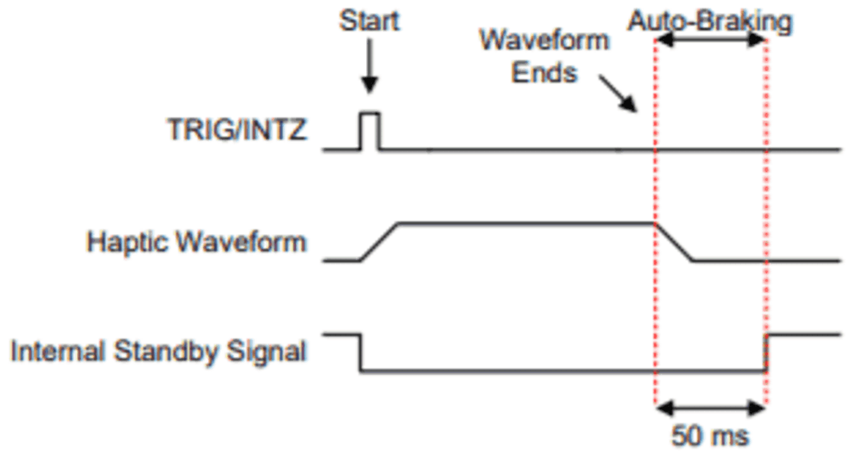


Figure 4-7. Trigger Pulse Functionality (Start Only)

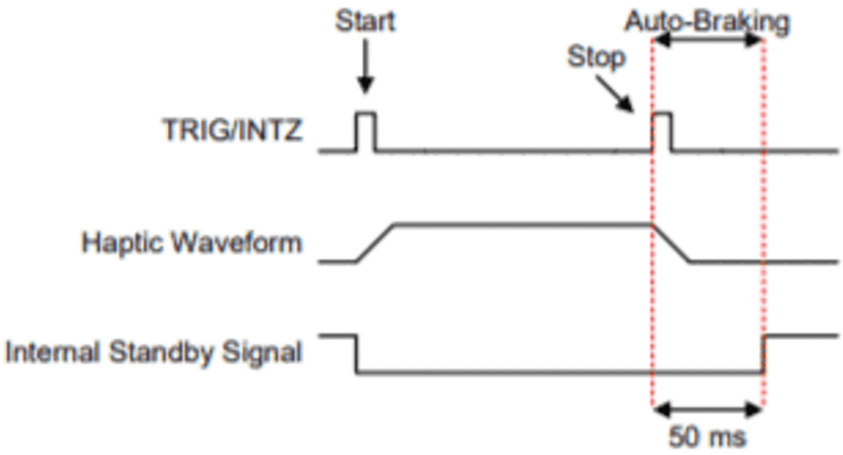


Figure 4-8. Trigger Pulse Functionality (Start & Stop)

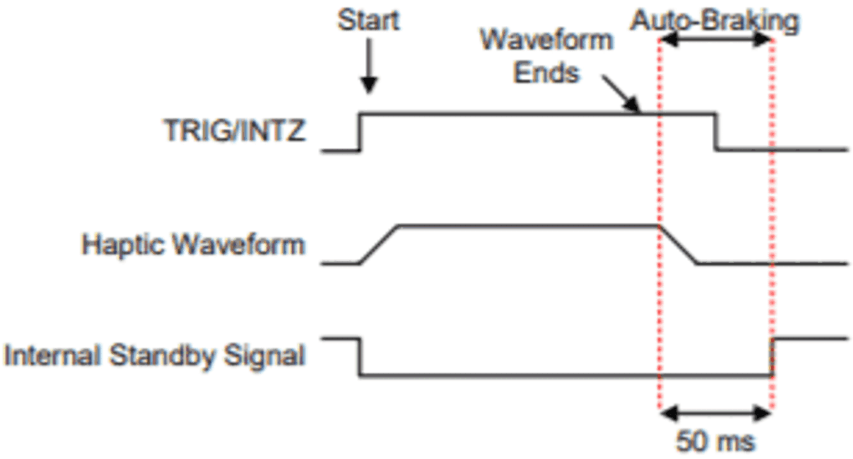


Figure 4-9. Trigger Enable Functionality

Copyright © 2020 Texas Instruments Incorporated

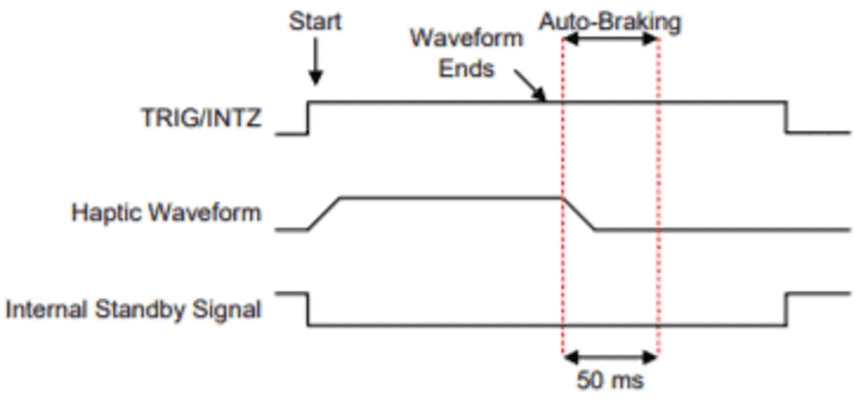


Figure 4-10. Trigger Enable Functionality (If Left On)

Copyright © 2020 Texas Instruments Incorporated

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.

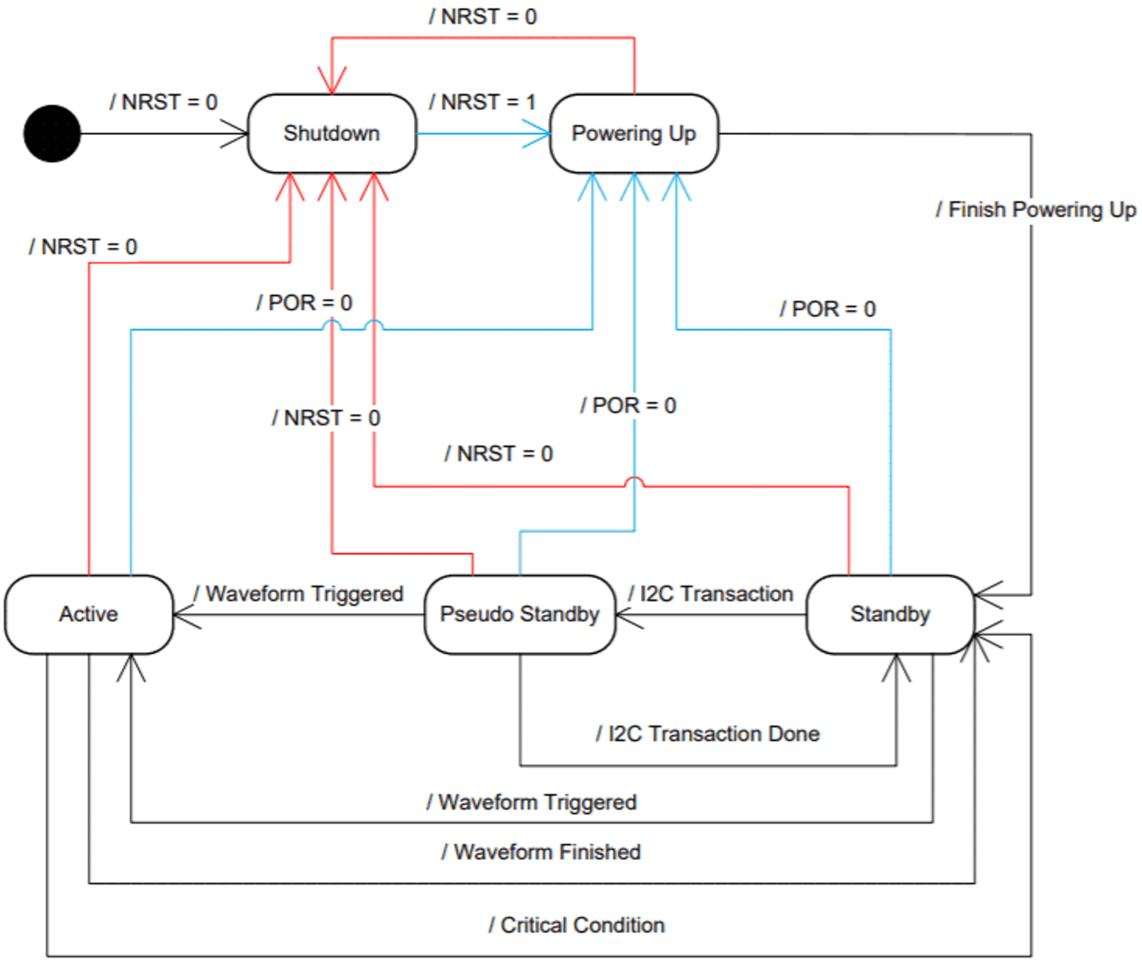


Figure 5-1. Power State Diagram

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

Copyright © 2020 Texas Instruments Incorporated

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.

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

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**st** voltage level the voltage clamp changes
BAT_LIFE_EXT_LVL2[7:0]	0x0B	2**nd** 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

Copyright © 2020 Texas Instruments Incorporated

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 MΩ on each channel and therefore have an approximately 1% loss in measured amplitude because of the voltage-divider effect with the filter.

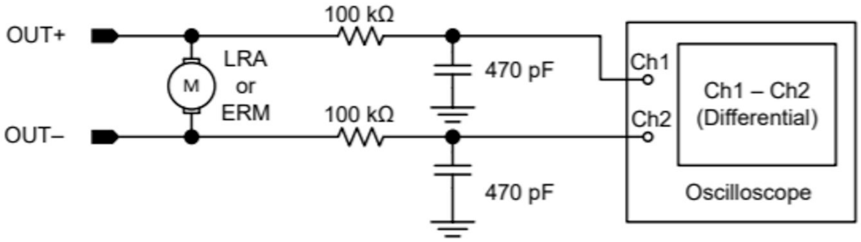


Figure 7-1. Output Recording Filter

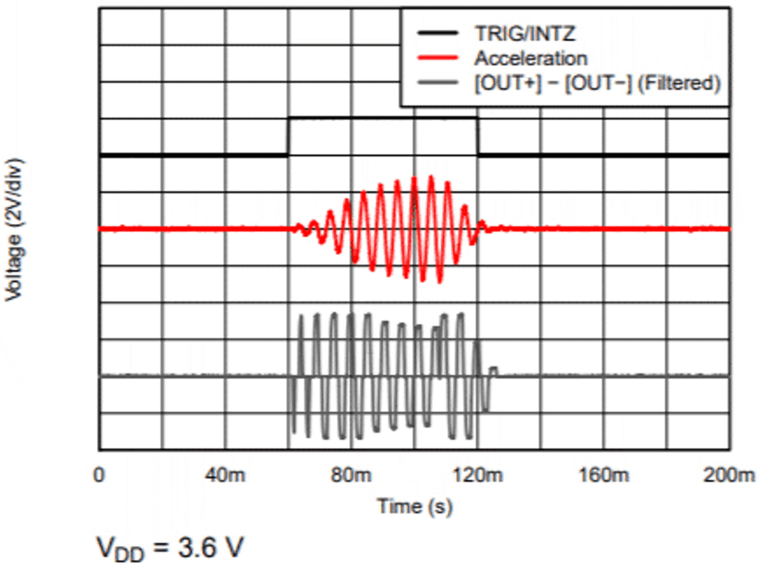


Figure 7-2. Waveform Recording Example of LRA

Copyright © 2020 Texas Instruments Incorporated

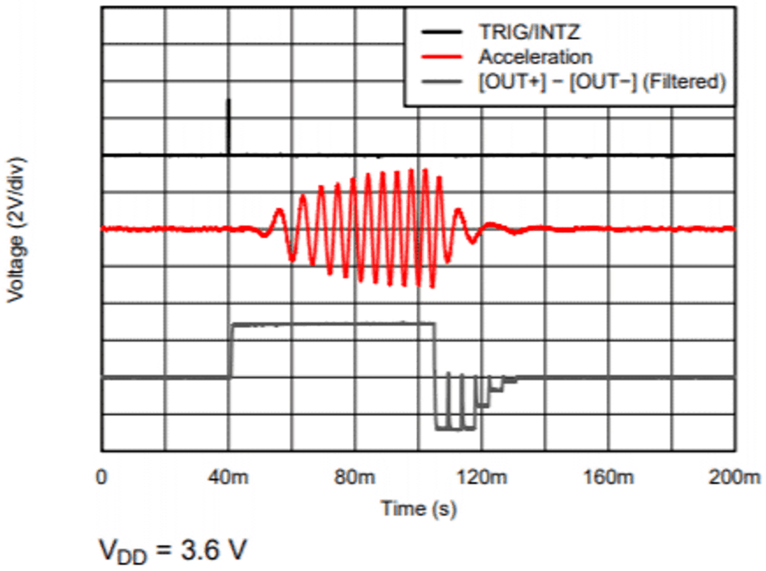


Figure 7-3. Waveform Recording Example of ERM

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.

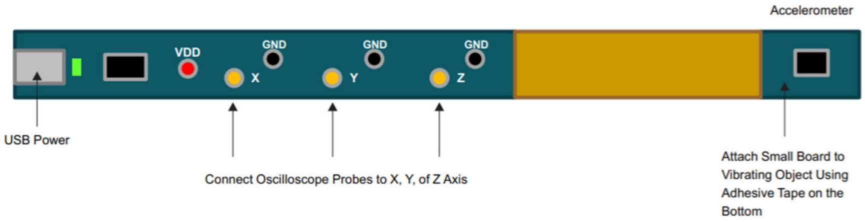

Accelerometer
VDD
GND
GND
GND
X
Y
Z
USB Power
Connect Oscilloscope Probes to X, Y, of Z Axis
Attach Small Board to Vibrating Object Using Adhesive Tape on the Bottom

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

Copyright © 2020 Texas Instruments Incorporated

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

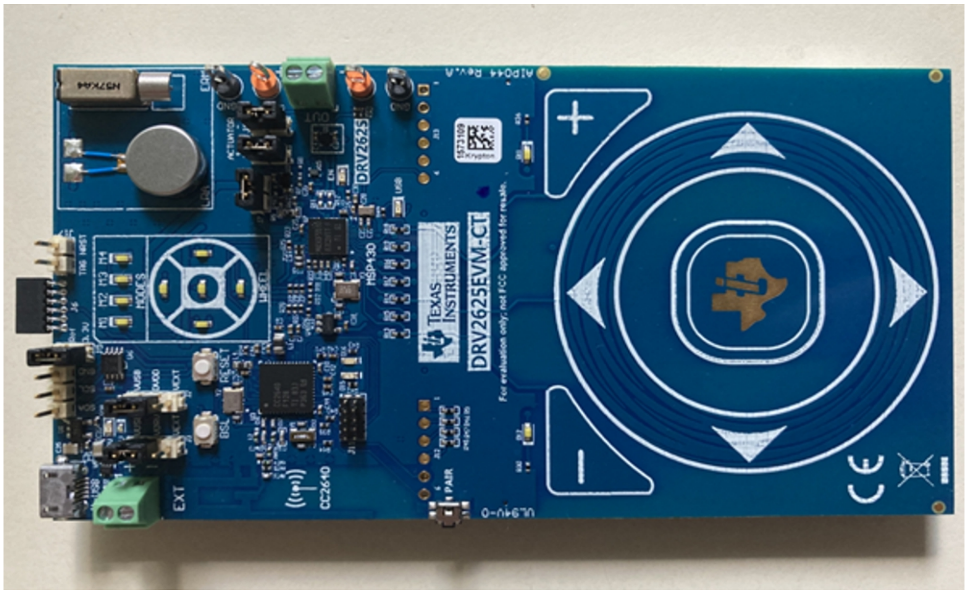
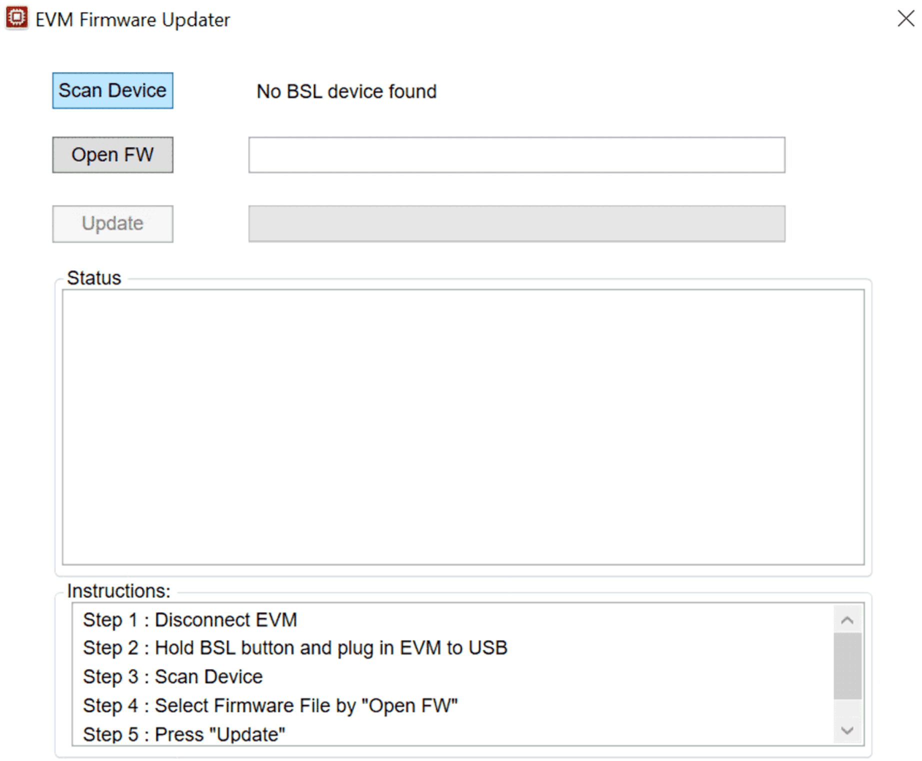


Figure 9-1. Picture of DRV2624 EVM

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.



No BSL device found

Status

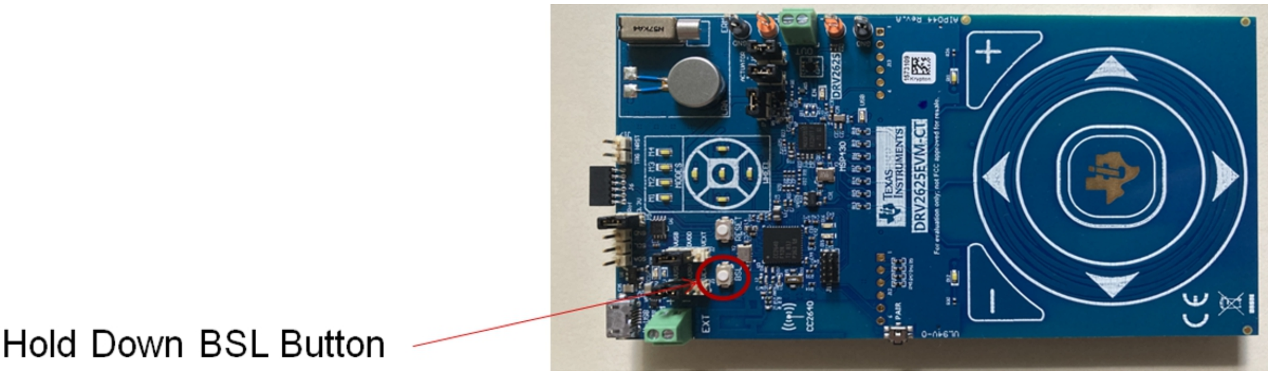
Instructions:

Step 1 : Disconnect EVM
Step 2 : Hold BSL button and plug in EVM to USB
Step 3 : Scan Device
Step 4 : Select Firmware File by "Open FW"
Step 5 : Press "Update"

Figure 9-2. Firmware Update Window

Copyright © 2020 Texas Instruments Incorporated

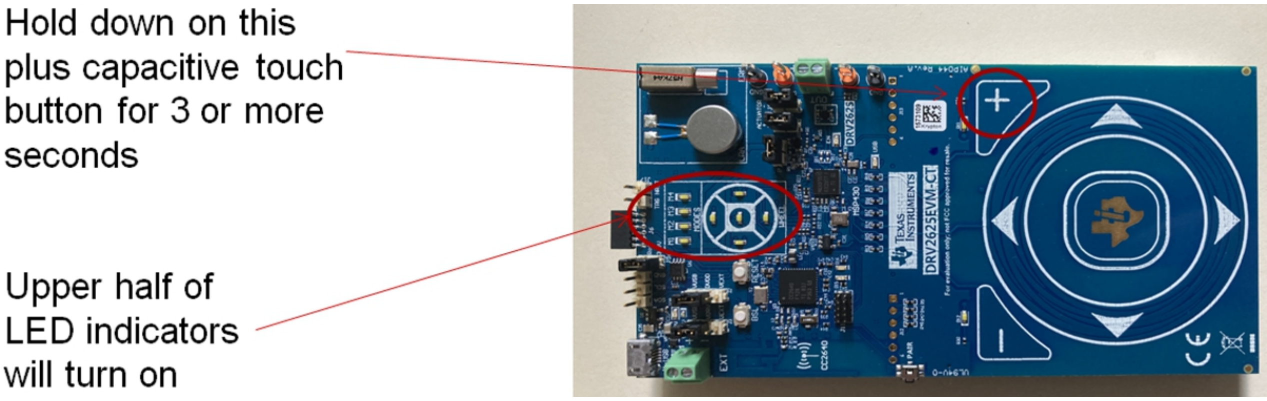
2. Follow the instructions on the bottom of the window, the BSL Button mentioned can be found where shown in the image below



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.



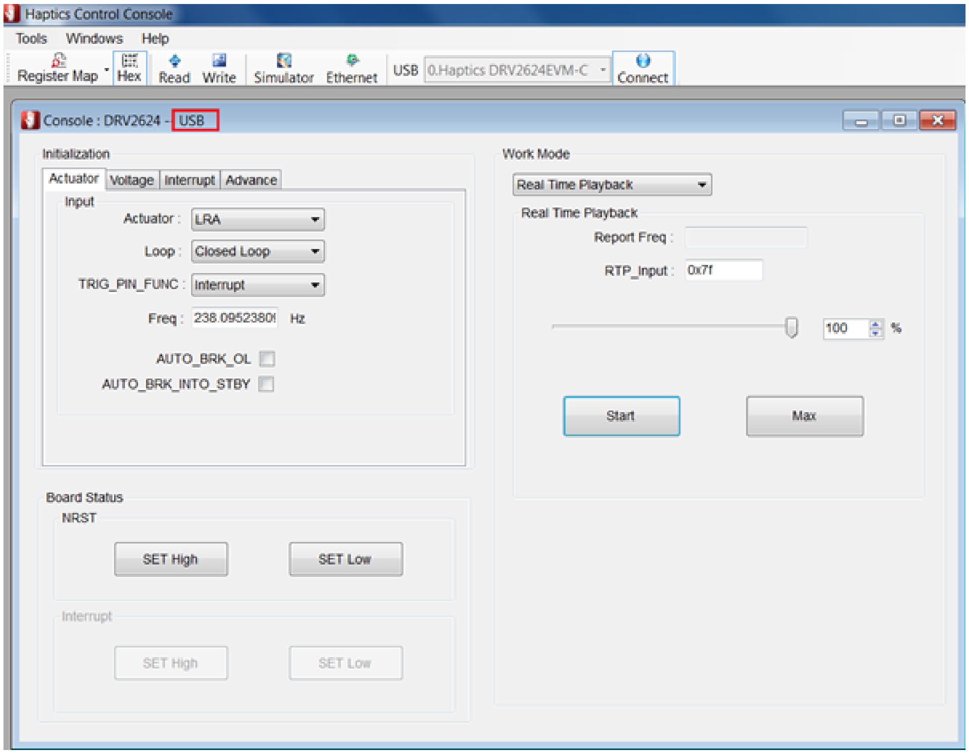
Hold down on this plus capacitive touch button for 3 or more seconds

Upper half of LED indicators will turn on

Figure 9-4. Putting Board into GUI Mode

Copyright © 2020 Texas Instruments Incorporated

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.



Actuator : LRA

Loop : Closed Loop

TRIG_PIN_FUNC : Interrupt

Freq : 238.0952380 Hz

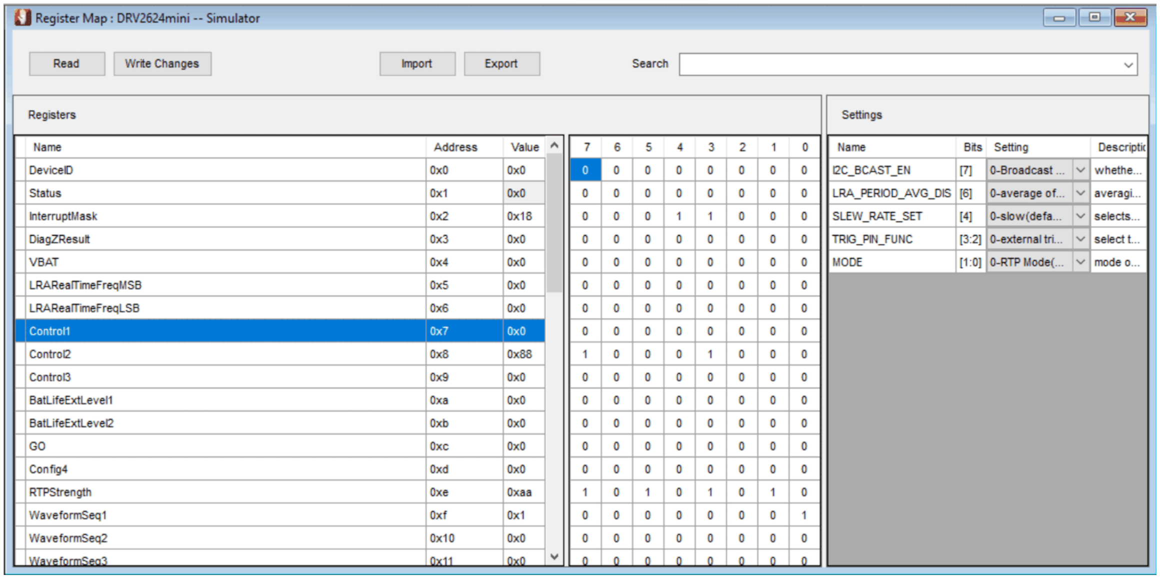
Work Mode: Real Time Playback

RTP_Input : 0x7f

100 %

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.



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

Name	Bits	Setting	Descriptic
I2C_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

Copyright © 2020 Texas Instruments Incorporated

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 representive mass for the vibrational waves to travel through just as it would in a real haptic feedback application.

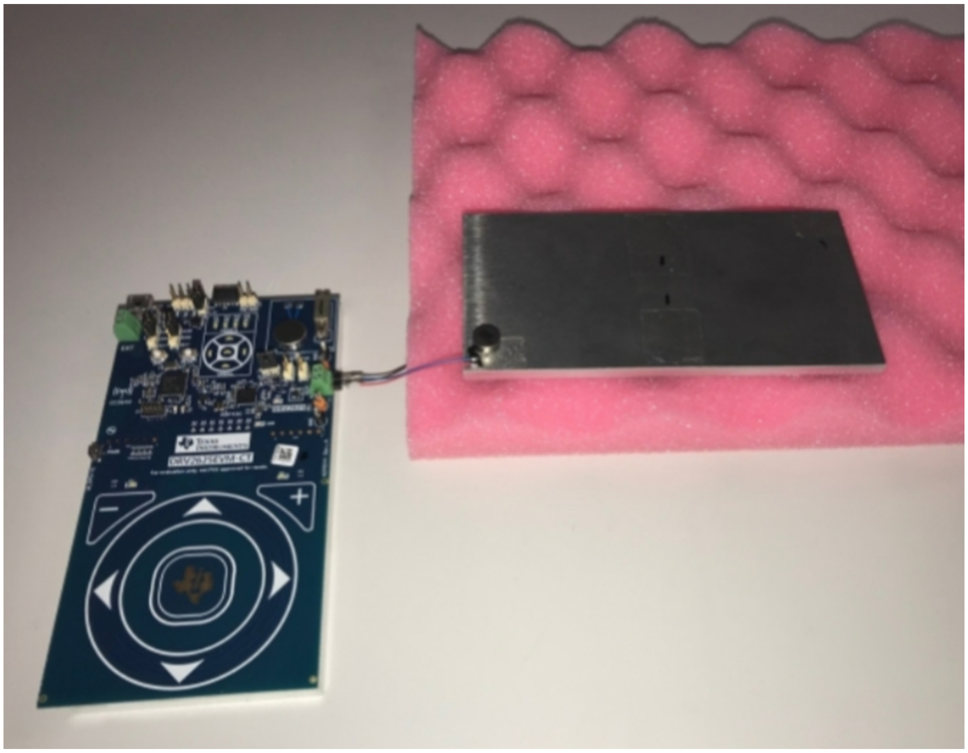
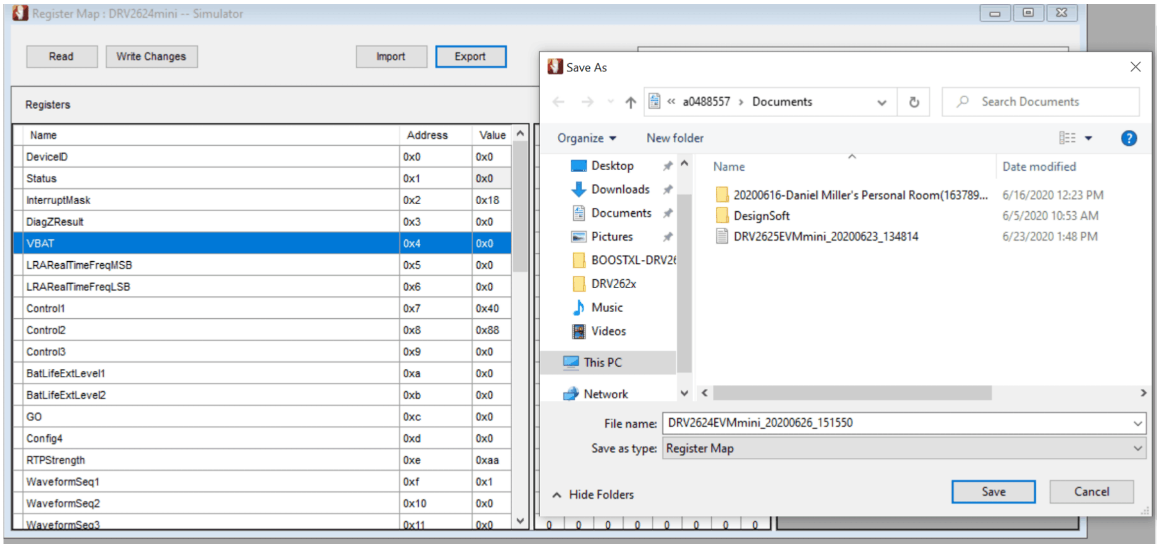


Figure 9-7. DRV2624 EVM with Proper Actuator Set-Up

Copyright © 2020 Texas Instruments Incorporated

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.



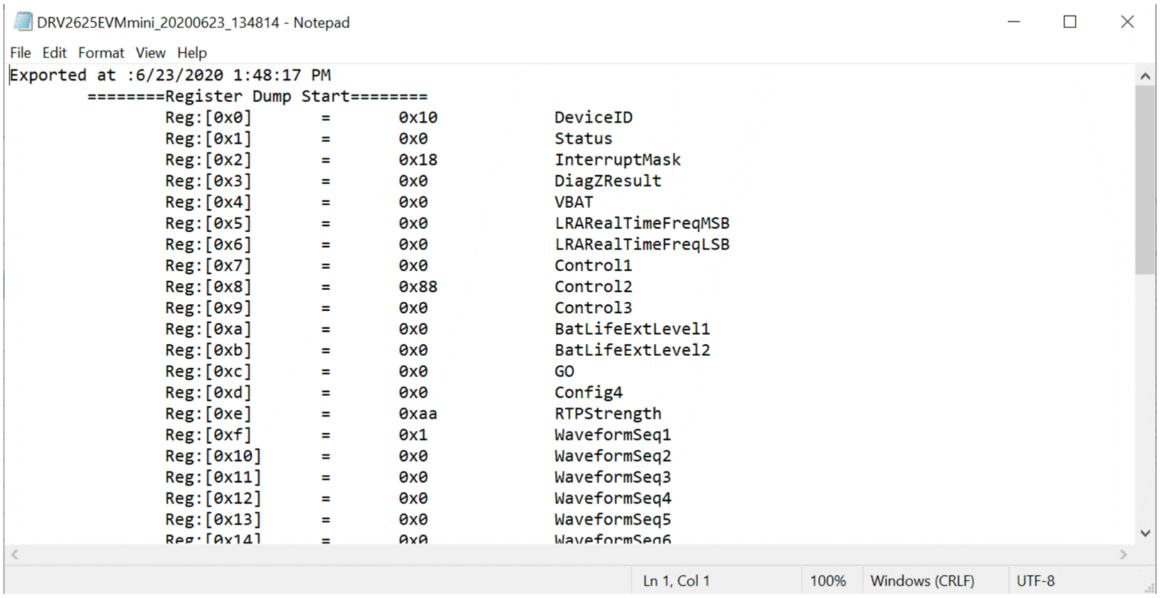
Name	Address	Value
DeviceID	0x0	0x0
Status	0x1	0x0
InterruptMask	0x2	0x18
DiagZResult	0x3	0x0
VBAT	0x4	0x0
LRARealTimeFreqMSB	0x5	0x0
LRARealTimeFreqLSB	0x6	0x0
Control1	0x7	0x40
Control2	0x8	0x88
Control3	0x9	0x0
BatLifeExtLevel1	0xa	0x0
BatLifeExtLevel2	0xb	0x0
GO	0xc	0x0
Config4	0xd	0x0
RTPStrength	0xe	0xaa
WaveformSeq1	0xf	0x1
WaveformSeq2	0x10	0x0
WaveformSeq3	0x11	0x0

Name	Date modified
20200616-Daniel Miller's Personal Room(163789...	6/16/2020 12:23 PM
DesignSoft	6/5/2020 10:53 AM
DRV2625EVMmini_20200623_134814	6/23/2020 1:48 PM

File name: DRV2624EVMmini_20200626_151550

Save as type: Register Map

Figure 9-8. Saving EVM Register Map


DRV2625EVMmini_20200623_134814 - Notepad
File Edit Format View Help
Ln 1, Col 1
100%
Windows (CRLF)
UTF-8

```
Exported at :6/23/2020 1:48:17 PM
        ========Register Dump Start========
                Reg:[0x0]       =       0x10            DeviceID
                Reg:[0x1]       =       0x0             Status
                Reg:[0x2]       =       0x18            InterruptMask
                Reg:[0x3]       =       0x0             DiagZResult
                Reg:[0x4]       =       0x0             VBAT
                Reg:[0x5]       =       0x0             LRARealTimeFreqMSB
                Reg:[0x6]       =       0x0             LRARealTimeFreqLSB
                Reg:[0x7]       =       0x0             Control1
                Reg:[0x8]       =       0x88            Control2
                Reg:[0x9]       =       0x0             Control3
                Reg:[0xa]       =       0x0             BatLifeExtLevel1
                Reg:[0xb]       =       0x0             BatLifeExtLevel2
                Reg:[0xc]       =       0x0             GO
                Reg:[0xd]       =       0x0             Config4
                Reg:[0xe]       =       0xaa            RTPStrength
                Reg:[0xf]       =       0x1             WaveformSeq1
                Reg:[0x10]      =       0x0             WaveformSeq2
                Reg:[0x11]      =       0x0             WaveformSeq3
                Reg:[0x12]      =       0x0             WaveformSeq4
                Reg:[0x13]      =       0x0             WaveformSeq5
                Reg:[0x14]      =       0x0             WaveformSeq6
```

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

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

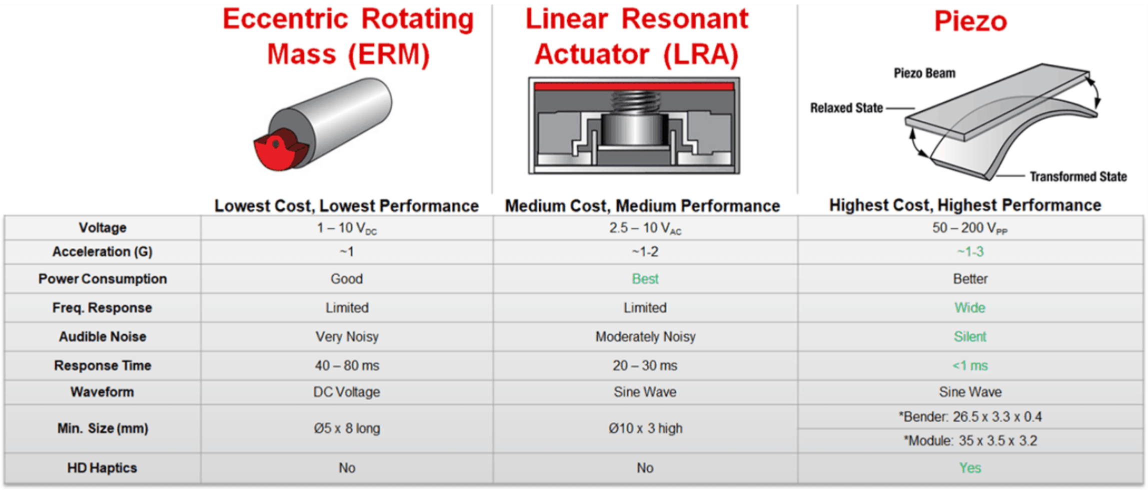
To order the DRV2625 EVM or find user guide: https://www.ti.com/tool/DRV2625EVM-CT

Copyright © 2020 Texas Instruments Incorporated

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.



	Eccentric Rotating Mass (ERM) Lowest Cost, Lowest Performance	Linear Resonant Actuator (LRA) Medium Cost, Medium Performance	Piezo Highest Cost, Highest Performance
Voltage	1 – 10 V_{DC}	2.5 – 10 V_{AC}	50 – 200 V_{PP}
Acceleration (G)	~1	~1-2	~1-3
Power Consumption	Good	Best	Better
Freq. Response	Limited	Limited	Wide
Audible Noise	Very Noisy	Moderately Noisy	Silent
Response Time	40 – 80 ms	20 – 30 ms	<1 ms
Waveform	DC Voltage	Sine Wave	Sine Wave
Min. Size (mm)	Ø5 x 8 long	Ø10 x 3 high	*Bender: 26.5 x 3.3 x 0.4 *Module: 35 x 3.5 x 3.2
HD Haptics	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

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

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

Copyright © 2020 Texas Instruments Incorporated

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2020, Texas Instruments Incorporated