Application Report

SLOA189–July 2014

DRV2605 Setup Guide

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ABSTRACT

The DRV2605 is an ERM and LRA driver that simplifies haptics integration for any application. This document provides instructions for configuring and operating the DRV2605.

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1 Initialization

This section describes the required steps for initializing the DRV2605.

1.1 Device Startup and Power

To start the device and begin an I^2C transaction:

1. Apply power to the VDD pin.
2. Set the ENABLE pin high or tie the ENABLE pin to VDD.
3. The device will perform a quick startup sequence (250 µs) and go into STANDBY mode.
4. Exit STANDBY mode by setting the STANDBY bit in register 0x01 to zero. A single write to register 0x01 can disable STANDBY and enable the device MODE.

Internal to the device, a startup sequence will occur every time power is applied. During the startup sequence the device will automatically set several internal registers. This power-up cycle takes less than 250 µs, once power is stable. After the initial 250 µs, the device is ready for operation and will default to the STANDBY state (STANDBY = 1).

If an attempt to send an I2C transaction to the device occurs prior to the device completing the internal startup sequence, the device will return a *nACK*. If a *nACK* occurs, retry the transaction until a successful *ACK* occurs.

1.2 Standby

The device has a low power mode that can be enabled or disabled by hardware or software. In order to control the actuator, the ENABLE pin must be high and the STANDBY bit (register 0x01, bit 6) must be low.

Table 1. Standby Control Settings

EN Pin	STANDBY Bit	Device State
High	0	Enabled
Low	X	Low-Power Mode
X	1	Low-Power Mode

If the ENABLE pin is low or the STANDBY bit is “1”, the device will enter a low power mode. When in the low power mode, the internal circuitry will be disabled and some registers will be inaccessible; however, data in the device registers and ROM will remain. To exit STANDBY, the ENABLE pin must be high and the STANDBY bit must be low.

To access registers via I2C, the ENABLE pin must be high. The ENABLE pin activates the internal clock to allow the device to act on I2C transactions. The device may ACK some I2C transactions if ENABLE is low; however, any updates will not be stored in the register as expected.

1.3 Device I2C Address

The DRV2605 is controlled by a series of I2C registers. To access these registers, first set the EN pin high and then use the 7-bit I2C address 0x5A. Table 2 shows the 7-bit address, the I2C read address, and the I2C write address.

Table 2. I2C Register Settings

	Hex	Binary
7-bit I2C Address	0x5A	101 1010
7-bit Address + Write Bit	0xB4	1011 0100
7-bit Address + Read Bit	0xB5	1011 0101

1.4 Rated and Overdrive Voltage

The rated and overdrive voltage registers set the full-scale and overdrive voltages used in the waveform data. For example, if the rated voltage is set to 3.3 V and a waveform calls for 100% output, then the output voltage will be 3.3 V. For the overdrive voltage, if the overdrive voltage is set to 4 V and the actuator is starting from zero acceleration or is in a transition from low acceleration to high acceleration, the driver will indicate overdrive and use 4 V.

1.4.1 ERM – Rated and Overdrive Voltages

1. Decide if closed-loop or open-loop mode will be used. If you are using the waveform libraries embedded in the DRV2605, use open-loop as the waveforms are tuned using open-loop mode. Closed-loop should be used for other modes.
2. For closed-loop, continue to step 3. For open-loop, skip to step 5.
3. **Closed-Loop Rated Voltage:** Set the RatedVoltage register (0x16) to the rated voltage specified in the actuator datasheet. Use the following equation to convert the voltage to the appropriate binary value:

$$\text{RatedVoltage (0x16)} = \frac{V_{\text{RatedVoltage}} \times 255}{5.36\text{ V}} \quad (1)$$

4. **Closed-Loop Overdrive Voltage:** Set the Overdrive Clamp (ODClamp) Voltage (0x17) to the actuator overdrive voltage specified in the actuator datasheet. Use the following equation to convert the voltage to the appropriate binary value.

$$V_{\text{peak}} = V_{\text{overdrive}} \times \frac{\text{DriveTime} + \text{IDissTime} + \text{BlankingTime}}{\text{DriveTime} - 300\ \mu\text{s}}$$

$$\text{ODClamp(0x17)} = \frac{V_{\text{peak}} \times 255}{5.44\text{ V}} \quad (2)$$

$V_{\text{overdrive}}$ – the maximum allowable DC voltage on the ERM

5. **Open-Loop Rated Voltage:** In open-loop mode, the rated voltage is not referenced by the control engine. Unlike closed-loop where 100% output equals the rated voltage, in open-loop mode, 100% output equals the overdrive voltage. A calculation for open-loop rated voltage is not necessary. Continue to step 6.
6. **Open-Loop Overdrive Voltage:** Set the Overdrive Clamp (ODClamp) Voltage (0x17) to the actuator overdrive voltage specified in the actuator datasheet. Use the following equation to convert the voltage to the appropriate binary value.

$$\text{ODClamp(0x17)} = \frac{V_{\text{overdrive}} \times 255}{5.6\text{ V}} \quad (3)$$

1.4.2 LRA — Rated and Overdrive Voltages

1. Convert the Rated Voltage from the LRA data sheet to an “average of the absolutes” voltage using the following equation. If the overdrive voltage is not listed, contact the actuator manufacturer or use the Rated Voltage.

$$V_{\text{avg\_abs}} = V_{\text{rms}} \times \sqrt{1 - (4 \times \text{SampleTime} + 300\ \mu\text{s}) f_{\text{LRA}}} \quad (4)$$

Default Values:

SampleTime = 300 µs
f_{LRA} = 175 Hz

2. Using the "average of the absolutes" voltage from the Equation 4, convert it to the appropriate binary value using Equation 5.

$$\text{RatedVoltage (0x16)} = \frac{V_{\text{avg\_abs}} \times 255}{5.3\text{ V}} \quad (5)$$

Insert the binary value into the Rated Voltage (0x16) register.

3. The overdrive voltage for an LRA is specified as a peak voltage. Use Equation 6 to convert the overdrive voltage to the appropriate binary value.

$$\text{ODClamp}(0x17) = \frac{V_{peak} \times 255}{5.6\ \text{V}} \tag{6}$$

Insert the binary value into the Overdrive Clamp Voltage (0x17) register.

1.5 *Setting the Control Registers*

Select the appropriate values for the Feedback, Control 1, Control 2, and Control 3 registers based on your actuator. See the DRV2605 datasheet (SLOS825) for a detailed description of each register.

Section 1.5.1 and Section 1.5.2 describe the recommendations for using the ERM and LRA libraries.

1.5.1 ERM Control Registers

The required register settings for the ERM libraries are shown in Table 3. All other registers can typically use default settings.

Table 3. Required ERM Registers

Register		Register Bits		
Name	**Address**	**Name**	**Bits**	**Setting**
Feedback Control	0x1A	nERM_LRA	[7]	0 - ERM (default)
Control 3	0x1D	ERM_OpenLoop	[5]	1 - Open Loop
Library Selection	0x03	LibrarySel	[2:0]	1 - TS2200C Library A - With Overdrive

1.5.2 LRA Control Registers

For LRA actuators, register settings are shown in Table 4. All other registers can typically use default settings.

Table 4. LRA Control Registers

Register		Register Bits		
Name	**Address**	**Name**	**Bits**	**Setting**
Feedback Control	0x1A	nERM_LRA	[7]	1 - LRA
Control 3	0x1D	LRA DriveMode	[2]	0 - Once per cycle (default)
		LRA_OpenLoop	[0]	0 - Auto Resonance On (default)
Library Selection	0x03	LibrarySel	[2:0]	6 - LRA Library

1.6 Examples

1.6.1 ERM Initialization

Table 5 is an example initialization for ERM using ERM Library 1. Most of the default settings were used in the Feedback Control, Control 1, Control 2, and Control 3 registers.

Table 5. ERM Initialization Example

Register			Parameter Selection		
Name	**Addr**	**Value (Hex)**	**Name**	**Bits**	**Setting**
Rated Voltage	0x16	90	RatedVoltage	[7:0]	3
Overdrive Clamp Voltage	0x17	A4	ODClamp	[7:0]	3.6
Feedback Control	0x1A	36	nERM_LRA	[7]	0 – ERM (default)
			FBBrakeFactor	[6:4]	3 – 4x (default)
			LoopGain	[3:2]	1 – Medium (default)
			BEMFGain	[1:0]	2 – 1.8x / 20x (default)
Auto-calibration Compensation Results	0x18	—	ACalComp	[7:0]	Write value obtained from auto-calibration
Auto-calibration Back-EMF Result	0x19	—	ACalBEMF	[7:0]	Write value obtained from auto-calibration
Control 1	0x1B	93	StartupBoost	[7]	1 – ON (default)
			AC_Couple	[5]	0 – DC Coupling / Digital Input Modes
			DriveTime	[4:0]	19
Control 2	0x1C	F5	BiDir_Input	[7]	1 – Bi-directional (default)
			BrakeStabilizer	[6]	0 – OFF (default)
			SampleTime	[5:4]	3 – 300 µs (default)
			BlankingTime	[3:2]	1 – 25 µs, 75 µs (default)
			IDissTime	[1:0]	1 – 25 µs, 75 µs (default)
Control 3	0x1D	80	NG_Thresh	[7:6]	2 – 4% (default)
			ERM_OpenLoop	[5]	0 – Closed Loop (default)
			SupplyCompDis	[4]	0 – ON (default)
			DataFormat_RTP	[3]	0 – Signed (default)
			LRADriveMode	[2]	0 – Once per cycle (default)
			nPWM_Analog	[1]	0– PWM Input (default)
			LRA_OpenLoop	[0]	0 – Auto Resonance On (default)
Library Selection	0x03	1	HiZ	[4]	0 – OFF (default)
			LibrarySel	[2:0]	1 – TS2200C Library A - With Overdrive
Mode	0x01	0	Dev_Reset	[7]	0 – OFF (default)
			STANDBY	[6]	0 – Device Ready
			Mode	[2:0]	0 – Internal Trigger (default)

1.6.2 LRA Initialization

Table 6 is an example of LRA initialization.

Table 6. LRA Initialization Example

Register			Parameter Selection		
Name	**Addr**	**Value (Hex)**	**Name**	**Bits**	**Setting**
Rated Voltage	0x16	53	RatedVoltage	[7:0]	2 Vrms
Overdrive Clamp Voltage	0x17	89	ODClamp	[7:0]	3 Vpeak
Feedback Control	0x1A	B6	nERM_LRA	[7]	1 – LRA
			FBBrakeFactor	[6:4]	3 – 4x (default)
			LoopGain	[3:2]	1 – Medium (default)
			BEMFGain	[1:0]	2 – 1.8x / 20x (default)
Auto-calibration Compensation Results	0x18	—	ACalComp	[7:0]	Write value obtained from auto-calibration
Auto-calibration Back-EMF Result	0x19	—	ACalBEMF	[7:0]	Write value obtained from auto-calibration
Control 1	0x1B	13	StartupBoost	[7]	0 – OFF
			AC_Couple	[5]	0 – DC Coupling / Digital Input Modes
			DriveTime	[4:0]	19
Control 2	0x1C	F5	BiDir_Input	[7]	1 – Bi-directional (default)
			BrakeStabilizer	[6]	0 – OFF (default)
			SampleTime	[5:4]	3 – 300 µs (default)
			BlankingTime	[3:2]	1 – 25 µs, 75 µs (default)
			IDissTime	[1:0]	1 – 25 µs, 75 µs (default)
Control 3	0x1D	80	NG_Thresh	[7:6]	2 – 4% (default)
			ERM_OpenLoop	[5]	0 – Closed Loop (default)
			SupplyCompDis	[4]	0 – ON (default)
			DataFormat_RTP	[3]	0 – Signed (default)
			LRADriveMode	[2]	0 – Once per cycle (default)
			nPWM_Analog	[1]	0 – PWM Input (default)
			LRA_OpenLoop	[0]	0 – Auto Resonance On (default)
Library Selection	0x03	6	HiZ	[4]	0 – OFF (default)
			LibrarySel	[2:0]	6 – LRA Library
Mode	0x01	0	Dev_Reset	[7]	0 – OFF (default)
			STANDBY	[6]	0 – Device Ready
			Mode	[2:0]	0 – Internal Trigger (default)

2 Auto-Calibration

Auto-calibration is a unique feature that allows the DRV2605 to tune the feedback and drive algorithm to any particular ERM or LRA. This allows for better control, response time, and acceleration.

Auto-calibration is not the same as the LRA auto-resonance function. Instead, auto-calibration is an algorithm that identifies and then tunes the driver based on the "amplitude" of the back-EMF. All ERM and LRAs vary slightly in construction and likewise will have unique back-EMF. Once auto-calibration is performed, the back-EMF of each ERM or LRA becomes normalized so it looks the same to the drive engine.

To perform auto-calibration:

1. Connect the actuator to the output pins and power the device.
2. Exit Standby mode.
3. Set the following registers to the appropriate values:
   - Rated Voltage (0x16)
   - Overdrive Voltage (0x17)
   - Feedback Control (0x1A) – Bits [1:0] can be left blank and will be populated by the auto-calibration engine
   - Control 1 (0x1B), Control 2 (0x1C), and Control 3 (0x1D)
   - Mode (0x01) – Set mode to Auto-Calibration
   - Auto-calibration Memory Interface (0x1E) – the auto-calibration time can be increased to improve calibration, but can be left as default for the initial calibration
4. Set the GO bit in register 0x0C to begin Auto-calibration.
5. Poll the GO bit until it changes to zero, indicating Auto-calibration has completed or wait until the actuator stops vibrating. It should take no more than 2 s.
6. Read the Diag_Results bit in the Status Register (0x00). Diag_Result should be set to “0” if Auto-calibration is successful. If “1”, then ensure the actuator is connected correctly and try again.
7. Read and save register values from ACalComp[7:0] (0x18), ACalBEMF[7:0] (0x19), and BEMFGain[1:0] of the Feedback Control Register (0x1A). These are the values returned by the Auto-calibration engine.
8. Auto-calibration is complete. Ensure that the performance of the actuator is acceptable and do one of the following:
   - Store the values on the host processor and reload into the registers after each power-cycle.
   - Repeat auto-calibration process at startup (from power cycle).
   - Permanently program the results in the non-volatile memory of the DRV2605. See the datasheet (SLOS825) for more information.

2.1 Auto-Calibration Verification

Verify auto-calibration was successful and the actuator is being driven correctly by comparing the following waveforms with the same waveforms taken using your actuator.

Click Waveforms

Verify the click waveforms look correct. Test clicks using the following effects:

Effect Number	Description	Figure
1	Strong Click – 100%	Figure 1
10	Double Click – 100%	Figure 2
12	Triple Click – 100%	Figure 3

Clicks are tested because they are a special category of effect; they are short in duration and typically do not reach maximum acceleration. When multiple clicks are put in a sequence it is important to make sure that the braking is working correctly.

The following list provides the key features to look for in the click waveforms:

- (OUT+) - (OUT–) should have three distinct segments; overdrive, sustain, and braking. These three components create the click feel.
- The acceleration waveform should rise with no distortion.
- Watch for repeating skipped sine wave half-cycles in the (OUT+) – (OUT–) waveform. You may see a few skipped half-cycles at the beginning and end of very low acceleration waveforms, which is expected.

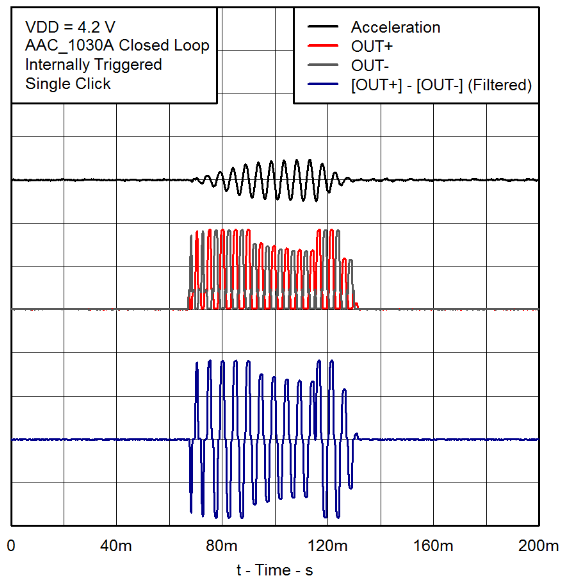


Figure 1. LRA - Single Click – Effect 1

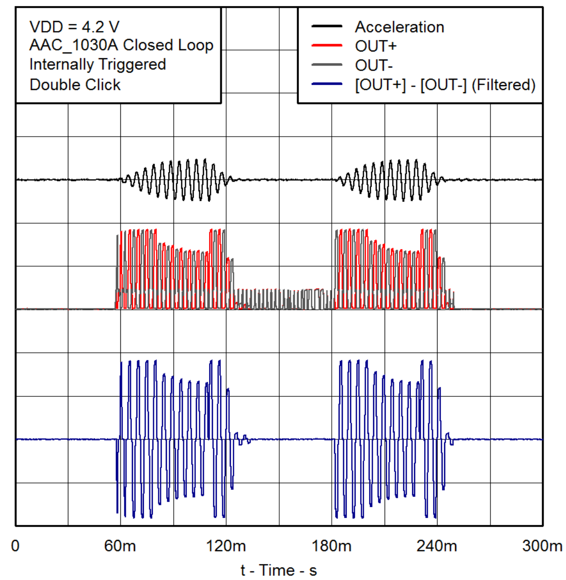


Figure 2. LRA – Double Click – Effect 10

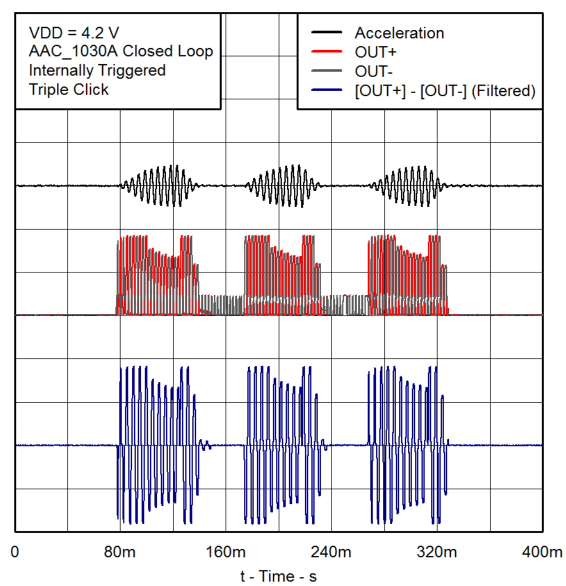


Figure 3. LRA – Triple Click – Effect 12

Buzz Waveform

The buzz effect is a staple of haptic vibration applications and often used as an alert. Test the buzz using the following effects:

Effect Number	Description	Figure
15	750 ms Alert	Figure 4
16	1000 ms Alert	Not Shown

The alert and buzz effects are best for testing steady-state response. The key features to look at are steady acceleration and steady output voltage. There should not be spikes or oscillations in the output or acceleration waveform.

Figure 4 shows a 750 ms buzz. The color distortion in the waveform is a result of oscilloscope aliasing.

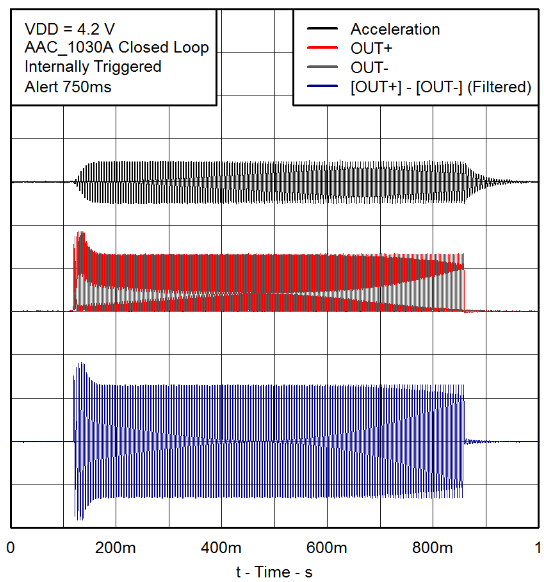


Figure 4. LRA – Alert 750 ms – 15

Ramp Waveforms

The ramp up and ramp down waveforms show how the actuator and driver interact during constantly changing peak output voltages. To test ramp effects, use the following:

Effect Number	Description	Figure
73	Transition Ramp Down Medium Smooth 2 – 100% to 0%	Figure 5

The key features to look for are skipping pulses in the ramp. At the beginning and end of the waveform in Figure 5 there will sometimes be a skipped pulse to overcome the coefficient of friction on the mass inside the LRA.

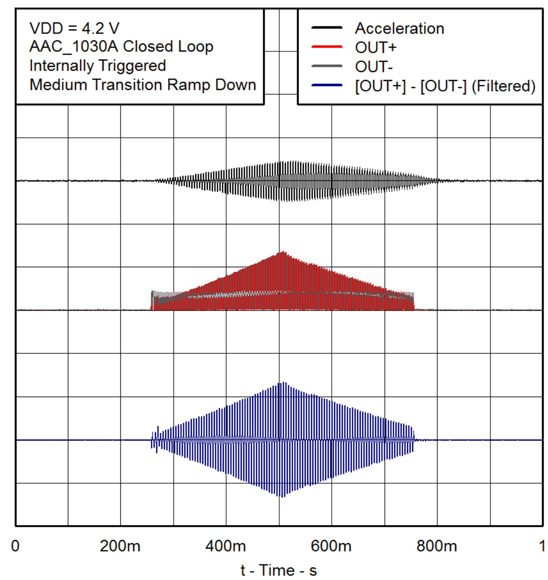


Figure 5. LRA – Transition Ramp Down Medium Smooth 2 – 100% to 0%

2.2 Examples

2.2.1 ERM Auto-Calibration

The example in Table 7 shows results of ERM Auto-Calibration.

Table 7. ERM Auto-Calibration Example

Register			Parameter Selection		
Name	**Addr**	**Value (Hex)**	**Name**	**Bits**	**Setting**
Rated Voltage	0x16	90	RatedVoltage	[7:0]	3
Overdrive Clamp Voltage	0x17	A4	ODClamp	[7:0]	3.6
Feedback Control	0x1A	36	nERM_LRA	[7]	0 – ERM (default)
			FBBrakeFactor	[6:4]	3 – 4x (default)
			LoopGain	[3:2]	1 – Medium (default)
			BEMFGain	[1:0]	2 – 1.8x / 20x (default)
Control 1	0x1B	13	StartupBoost	[7]	0 – OFF
			AC_Couple	[5]	0 – DC Coupling / Digital Input Modes
			DriveTime	[4:0]	19
Control 2	0x1C	F5	BiDir_Input	[7]	1 – Bi-directional (default)
			BrakeStabilizer	[6]	0 – OFF (default)
			SampleTime	[5:4]	3 – 300 µs (default)
			BlankingTime	[3:2]	1 – 25 µs, 75 µs (default)
			IDissTime	[1:0]	1 – 25 µs, 75 µs (default)
Control 3	0x1D	A0	NG_Thresh	[7:6]	2 – 4% (default)
			ERM_OpenLoop	[5]	1 – Open Loop
			SupplyCompDis	[4]	0 – ON (default)
			DataFormat_RTP	[3]	0 – Signed (default)
			LRADriveMode	[2]	0 – Once per cycle (default)
			nPWM_Analog	[1]	0– PWM Input (default)
			LRA_OpenLoop	[0]	0 – Auto Resonance On (default)
Mode	0x01	07	Dev_Reset	[7]	0 – OFF (default)
			STANDBY	[6]	0 – Device Ready
			Mode	[2:0]	7 – Auto Calibration
Auto-Calibration Memory Interface	0x1E	20	AutoCalTime	[5:4]	2 – 500 ms (default)
			OTP_Status	[2]	Read-Only
			OTP_Program	[0]	0 – OFF (default)
GO	0x0C	1	GO	[0]	1– ON
Poll Go bit for “0”					
Status	0x00	Read (0xA8)	DeviceID	[7:5]	Read – 101
			Diag_Result	[3]	Read – 1
			Feedback_Status	[2]	Read – 0 / 1
			OverTemp	[1]	Read – 0
			OC_Detect	[0]	Read – 0
Auto-calibration Compensation Results	0x18	Read	ACalComp	[7:0]	Read value and store
Auto-calibration Back-EMF Result	0x19	Read	ACalBEMF	[7:0]	Read value and store
Feedback Control	0x1A	Read	BEMFGain	[1:0]	Read bits [1:0] and store

2.2.2 LRA Auto-Calibration

The example shown in Table 8 runs auto-calibration on a 2 Vrms LRA actuator with overdrive set to 2.82 Vp (or 2 Vrms).

Table 8. LRA Auto-Calibration Example

Register			Parameter Selection		
Name	**Addr**	**Value (Hex)**	**Name**	**Bits**	**Setting**
Rated Voltage	0x16	53	RatedVoltage	[7:0]	2 Vrms
Overdrive Clamp Voltage	0x17	A0	ODClamp	[7:0]	2.82 Vpeak
Feedback Control	0x1A	B6	nERM_LRA	[7]	1 – LRA
			FBBrakeFactor	[6:4]	3 – 4x (default)
			LoopGain	[3:2]	1 – Medium (default)
			BEMFGain	[1:0]	2 – 1.8x / 20x (default)
Control 1	0x1B	93	StartupBoost	[7]	1 – ON (default)
			AC_Couple	[5]	0 – DC Coupling / Digital Input Modes
			DriveTime	[4:0]	19
Control 2	0x1C	F5	BiDir_Input	[7]	1 – Bi-directional (default)
			BrakeStabilizer	[6]	0 – OFF (default)
			SampleTime	[5:4]	3 – 300 µs (default)
			BlankingTime	[3:2]	1 – 25 µs, 75 µs (default)
			IDissTime	[1:0]	1 – 25 µs, 75 µs (default)
Control 3	0x1D	80	NG_Thresh	[7:6]	2 – 4% (default)
			ERM_OpenLoop	[5]	0 – Closed Loop (default)
			SupplyCompDis	[4]	0 – ON (default)
			DataFormat_RTP	[3]	0 – Signed (default)
			LRADriveMode	[2]	0 – Once per cycle (default)
			nPWM_Analog	[1]	0– PWM Input (default)
			LRA_OpenLoop	[0]	0 – Auto Resonance On (default)
Mode	0x01	07	Dev_Reset	[7]	0 – OFF (default)
			STANDBY	[6]	0 – Device Ready
			Mode	[2:0]	7 – Auto Calibration
Auto-Calibration Memory Interface	0x1E	20	AutoCalTime	[5:4]	2 – 500 ms (default)
			OTP_Status	[2]	Read-Only
			OTP_Program	[0]	0 – OFF (default)
GO	0x0C	01	GO	[0]	1– ON
Poll Go bit for “0”					
Status	0x00	Read (0xA8)	DeviceID	[7:5]	Read – 101
			Diag_Result	[3]	Read – 1
			Feedback_Status	[2]	Read – 0 / 1
			OverTemp	[1]	Read – 0
			OC_Detect	[0]	Read – 0
Auto-calibration Compensation Results	0x18	Read	ACalComp	[7:0]	Read value and store
Auto-calibration Back-EMF Result	0x19	Read	ACalBEMF	[7:0]	Read value and store
Feedback Control	0x1A	Read	BEMFGain	[1:0]	Read bits [1:0] and store

3 Waveform Library

The DRV2605 waveform library is stored in non-volatile memory (ROM). The waveforms can be played by inserting the desired effect ID into the waveform sequencer. When waveforms are placed in the waveform sequencer and the GO bit is set to "1", then the waveform or waveform sequence will begin playback. The trigger signal can either be controlled by I2C or an external GPIO.

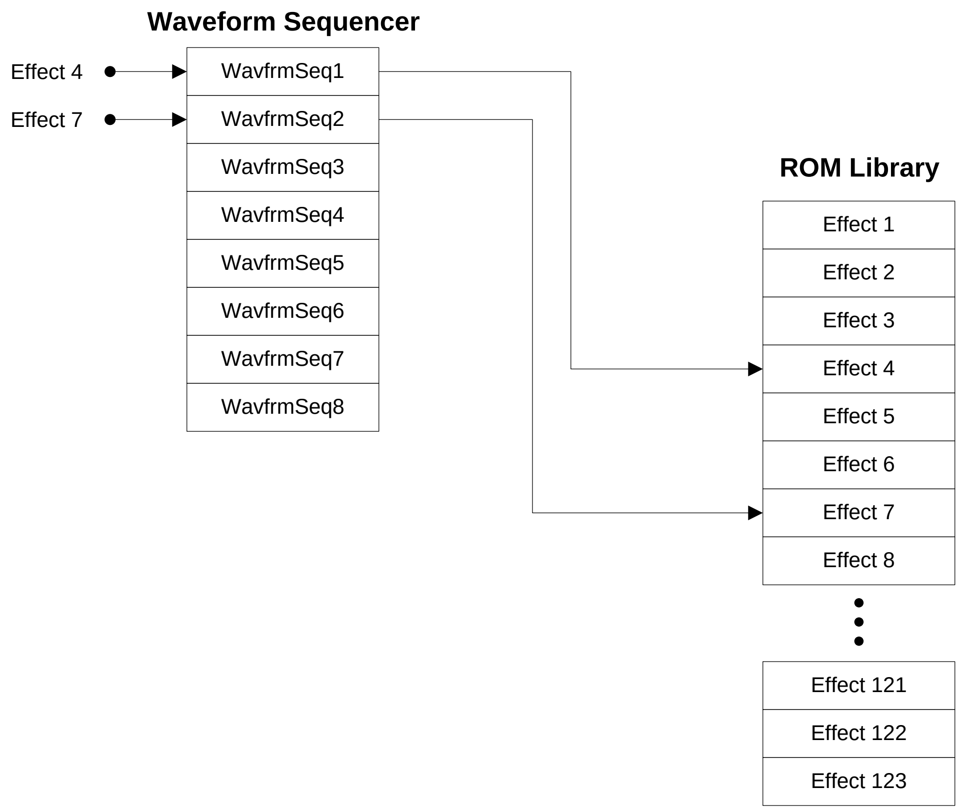


Figure 6. Waveform Sequencer and ROM Library

To play a waveform or waveform sequence:

1. Exit STANDBY mode by setting the EN pin HIGH and the STANDBY bit in register 0x01 to “0”.
2. Initialize the device to the appropriate settings (ERM/LRA, Open-Loop / Closed-loop, and so forth). Follow the steps in the Initialization section.
3. Select the trigger mode (0 = Internal Trigger, 1 = external edge trigger, 2 = external level trigger) in register 0x01.
4. Write the first waveform index number into the first Waveform Sequence Register (0x04).
5. Write additional waveforms into the subsequent waveform sequence registers as desired (0x05 – 0x0B).
6. If the sequence contains less than eight waveforms, then write the termination value 0x00 in the waveform sequence register following the last waveform.
7. To play the sequence, set the trigger high according to the trigger mode selected in step 3.
8. After the sequence has finished, place the device in STANDBY.

3.1 Select the Waveform Library

There are six ROM libraries in the DRV2605 and each contains 123 effects. Libraries 1–5 are for ERM motors and were designed to support various ERM motor types and characteristics. Library 6 is the LRA library and uses closed-loop feedback to auto-tune to any LRA actuator. The effects in each library were created to achieve the same feel, but the output will appear slightly different to account for differences in motor characteristics like startup time, acceleration, and brake time.

Figure 7. DRV2605 ROM Libraries

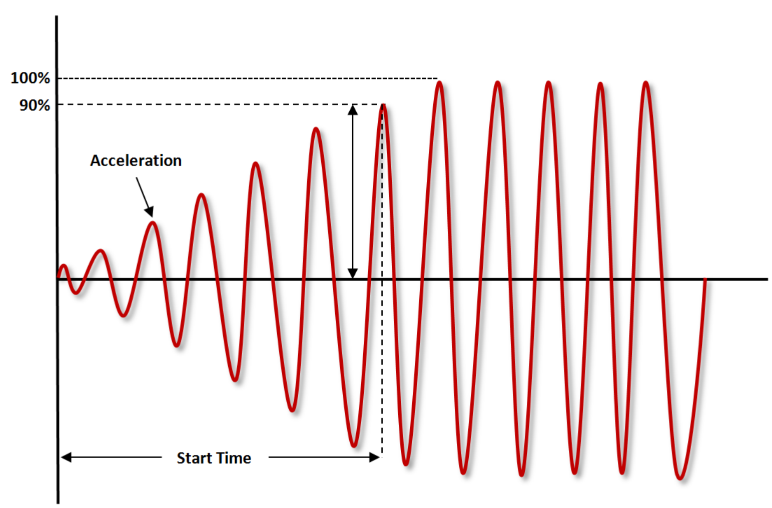
The ERM libraries can be chosen based on the startup and stop times of the actuator. Library A is for motors that have faster start and stop times and Library E is for ERMs that have slower start and stop times.

Table 9. DRV2605 ROM Library Actuator Properties

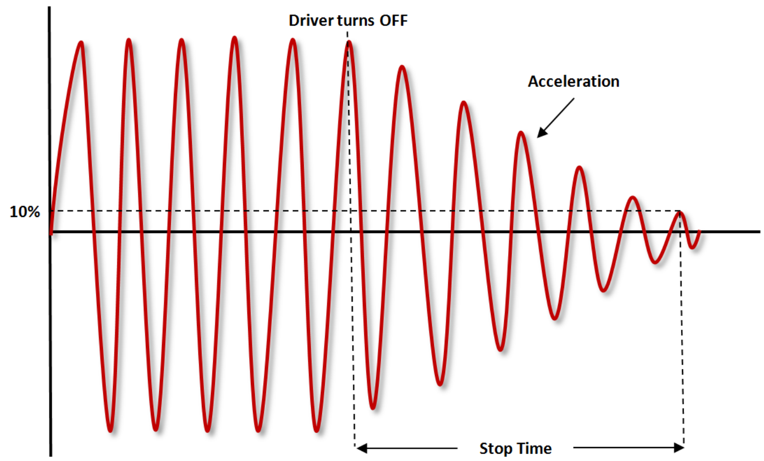
Number	Library	Actuator Properties	
		Start Time (ms)	Stop Time (ms)
1	Library A	40-60	20-40
2	Library B	40-60	5-15
3	Library C	60-80	10-20
4	Library D	100-140	15-25
5	Library E	>140	>30

Test the ERM to choose a library:

1. Mount the actuator on a similar size mass as the final application.
2. Mount an accelerometer to the mass.
3. Run the actuator at its Overdrive Voltage for 1 s.
4. **Measure the time from the waveform start to 90% of the maximum acceleration**.



5. **Run the actuator at the Overdrive voltage for 1 s and then the brake voltage for 1 s immediately after.**
6. Measure the time from the start of braking to 10% of the maximum acceleration.
7. Compare the measured times to Table 9.
8. Most actuators will use Library C or D.



Use the two measurements to select the most appropriate ERM waveform library from Table 9.

The following table lists three ROM library effects that can be used to measure the startup and braking of an ERM.

Effect Number	Description
15	750 ms Alert
16	1000 ms Alert
118	Long buzz for programmatic stopping – 100%

3.2 Examples

3.2.1 Play 3 Waveforms Using I²C

The sequence in Table 10 inserts effect 4, 7, and 5 into the sequence registers and triggers the playback using I²C. This sequence assumes the part was previously initialized.

Table 10. Sequence Registers with Effect 4, 7, and 5

Register			Parameter Selection		
Name	**Addr**	**Value (Hex)**	**Name**	**Bits**	**Setting**
Mode	0x01	0x00	Dev_Reset	[7]	0 – OFF (default)
			STANDBY	[6]	0 – Device Ready
			Mode	[2:0]	0 – Internal Trigger (default)
Waveform Sequencer	0x04	0x04	Wait + WavfrmSeq1	[7:0]	Write waveform identifier or wait time
	0x05	0x07	Wait + WavfrmSeq2	[7:0]	
	0x06	0x05	Wait + WavfrmSeq3	[7:0]	
	0x07	0x00	Wait + WavfrmSeq4	[7:0]	
	0x08	—	Wait + WavfrmSeq5	[7:0]	
	0x09	—	Wait + WavfrmSeq6	[7:0]	
	0x0A	—	Wait + WavfrmSeq7	[7:0]	
	0x0B	—	Wait + WavfrmSeq8	[7:0]	
GO	0x0C	0x01	GO	[0]	1 – ON

3.2.2 Play 5 Waveforms using External Trigger (GPIO) Mode

The sequence in Table 11 inserts five effects into the sequence registers and triggers the playback using the external trigger pin. This sequence assumes the part was previously initialized.

Table 11. Sequence Registers Playing 5 Waveforms

Register			Parameter Selection		
Name	**Addr**	**Value (Hex)**	**Name**	**Bits**	**Setting**
Mode	0x01	01	Dev_Reset	[7]	0 – OFF (default)
			STANDBY	[6]	0 – Device Ready
			Mode	[2:0]	0 – External Trigger (Edge Mode)
Waveform Sequencer	0x04	0x07	Wait + WavfrmSeq1	[7:0]	Write waveform identifier or wait time
	0x05	0x7B	Wait + WavfrmSeq2	[7:0]	
	0x06	0x10	Wait + WavfrmSeq3	[7:0]	
	0x07	0x01	Wait + WavfrmSeq4	[7:0]	
	0x08	0x02	Wait + WavfrmSeq5	[7:0]	
	0x09	0x00	Wait + WavfrmSeq6	[7:0]	
	0x0A	—	Wait + WavfrmSeq7	[7:0]	
	0x0B	—	Wait + WavfrmSeq8	[7:0]	
Apply a low to high edge to the IN/TRIG pin					

3.2.3 Play 3 Waveforms with Delay Using I²C

The sequence in Table 12 inserts the same three effects as Section 3.2.1 into the sequence registers, but separates them with a 40 ms delay. The delay can be used to create pauses between effects.

Table 12. Sequence Registers Playing 3 Waveforms with Delay Using I²C

Register			Parameter Selection		
Name	**Addr**	**Value (Hex)**	**Name**	**Bits**	**Setting**
Mode	0x01	0x00	Dev_Reset	[7]	0 – OFF (default)
			STANDBY	[6]	0 – Device Ready
			Mode	[2:0]	0 – Internal Trigger (default)
Waveform Sequencer	0x04	0x04	Wait + WavfrmSeq1	[7:0]	Write waveform identifier or wait time
	0x05	0x84	Wait + WavfrmSeq2	[7:0]	
	0x06	0x07	Wait + WavfrmSeq3	[7:0]	
	0x07	0x84	Wait + WavfrmSeq4	[7:0]	
	0x08	0x05	Wait + WavfrmSeq5	[7:0]	
	0x09	0x00	Wait + WavfrmSeq6	[7:0]	
	0x0A	—	Wait + WavfrmSeq7	[7:0]	
	0x0B	—	Wait + WavfrmSeq8	[7:0]	
GO	0x0C	0x01	GO	[0]	1 – ON

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