Application Note

Benefits of Auto-Resonance Tracking

ABSTRACT

The DRV2603, DRV2604, and DRV2605 (DRV260x devices) as well as the DRV2624 and DRV2625 (DRV262x devices) are linear resonant actuator (LRA) and eccentric rotating mass motor (ERM) haptic drivers with unique features to ease haptic design and system-level challenges. For LRA's, these drivers feature a unique auto-resonance tracking engine which automatically tracks and generates the LRA resonant frequency. DRV262X device family is an optimized version of DRV260X device family, without PWM or Analog control. However the DRV262x do come with additional configurable settings and diagnostic tools.

This application note discusses the benefits of auto-resonance tracking in the DRV2605 and DRV2625 including vibration strength, response time, and efficiency. These benefits are also applicable to the DRV2603, DRV2604, and DRV2624.

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1 Introduction

The DRV260x and DRV262x families of devices use a unique LRA control algorithm called auto-resonance tracking. Auto-resonance tracking uses the back-EMF of an LRA to detect and track the resonance frequency. The DRV260x and DRV262x devices then uses this resonance frequency information to drive the LRA in closed loop. Auto-resonance provides numerous benefits and eases the integration of LRAs:

- Stronger and more consistent vibrations across actuators
- Lower power consumption while driving at resonance
- The ability to overdrive and brake an LRA and achieve better response time

Figure 1-1 shows the input and output signals in an auto-resonance tracking system.

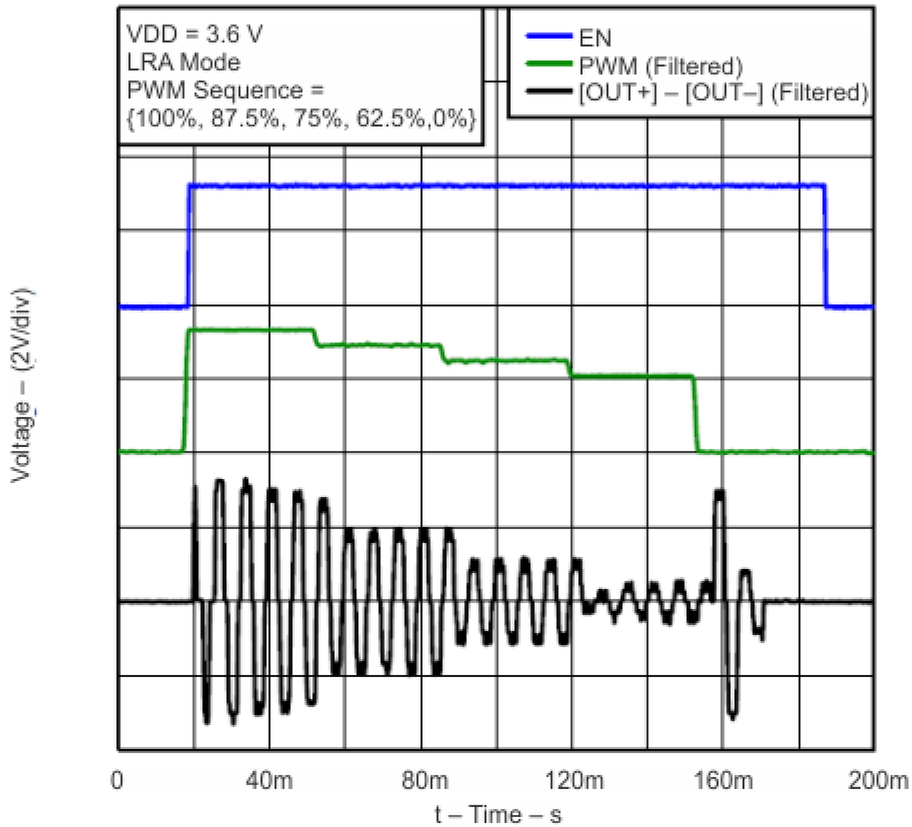

Figure 1-1. LRA Auto-Resonance Detection

The green waveform is the (PWM) input to the DRV2605 and is a filtered PWM-modulated DC signal representing the waveform envelope or amplitude of the output waveform. The black line represents the sine wave output generated by the DRV2605 with the detected resonant frequency. The DRV2625 does not have a PWM input but the same functionality is achieved using the Real Time Playback (RTP) registers of the device, where instead of setting a physical voltage level on a pin you would set a voltage level via an 8-bit value using I^2C.

2 How Auto-Resonance Tracking Works

Auto-resonance tracking takes advantage of the back-EMF generated by an LRA to determine the resonant frequency. TI has characterized this back-EMF to determine how best to control the LRA frequency, vibration strength, and start and stop time.

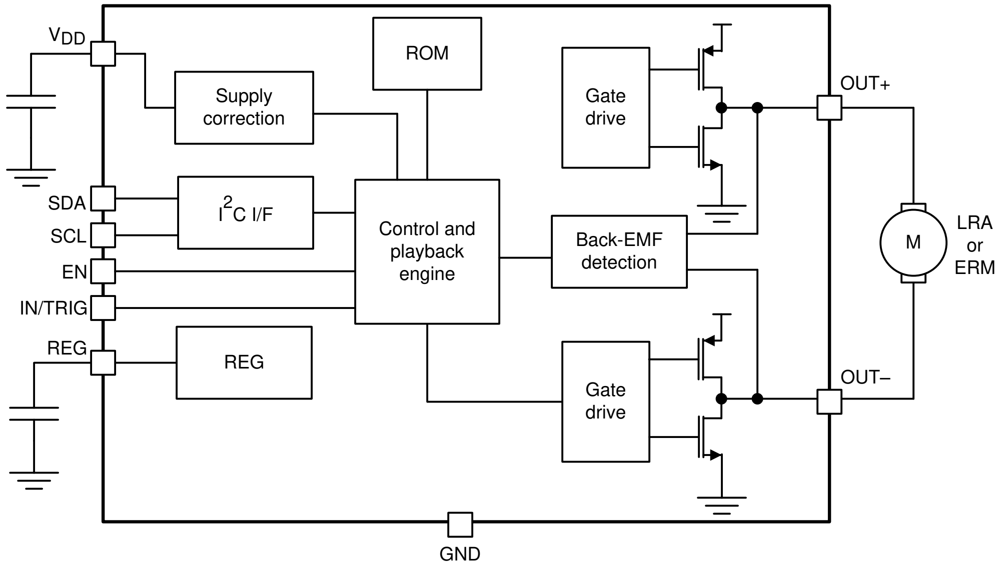

Figure 2-1. DRV2605 Block Diagram

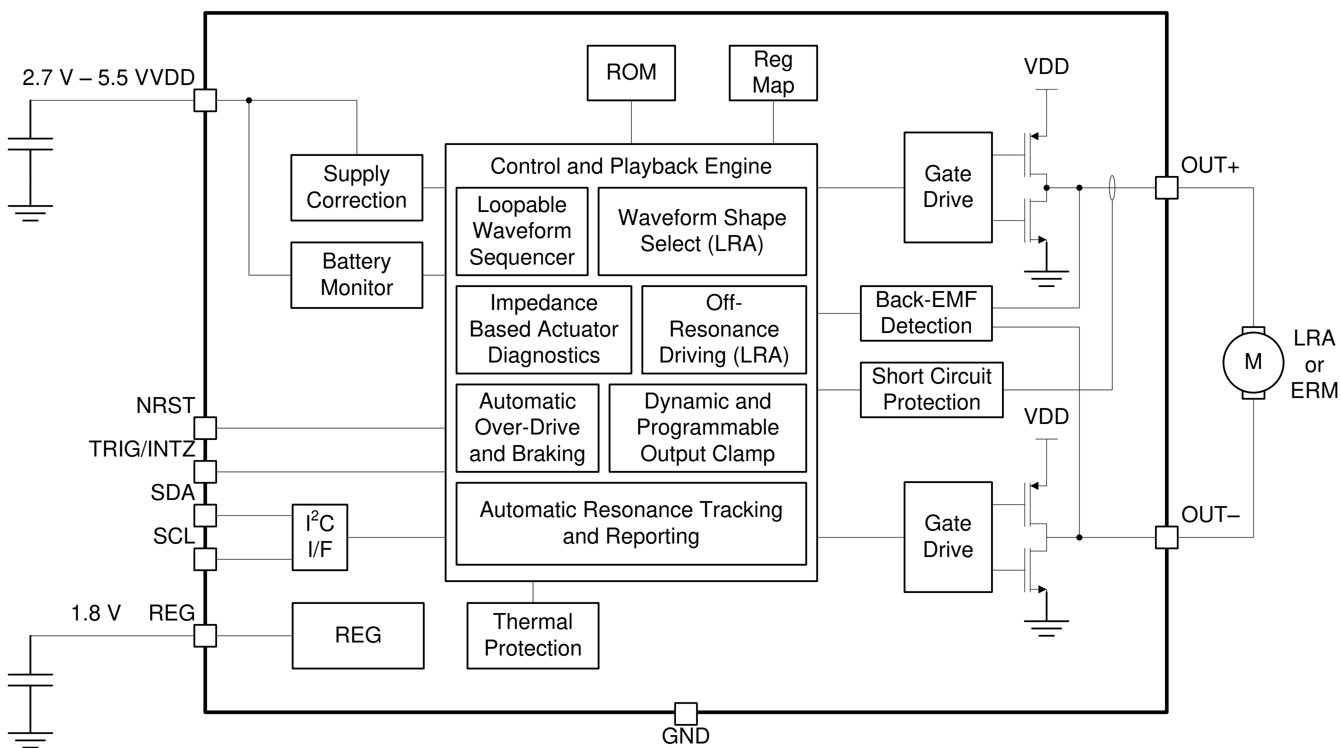

Figure 2-2. DRV2625 Block Diagram

Auto-resonance tracking makes use of the electro-mechanical properties of an LRA. Inside the LRA, the back-EMF changes as the magnet moves closer or further away from the drive electrodes. This back-EMF signal is sensed on the output pins by the DRV2605 and DRV2625 every cycle and sent to the auto-resonance engine. The auto-resonance engine then determines the frequency.

If the frequency is too high, the DRV2605 and DRV2625 will reduce the output frequency, and if the frequency is too low, the DRV2605 and DRV2625 will increase the output frequency. This dynamic tracking will ensure more consistent vibration. Consistent vibration is much harder to achieve with a non-auto-resonance drivers, because the LRA resonant frequency can constantly vary as a result of manufacturing tolerances and environmental factors. Having real-time tracking of the resonant frequency is important to keep a strong, consistent vibration. DRV2604 and DRV2624 Behave identically with the exception of having internal RAM vs ROM which does not impact the auto-resonance feature.

3 Auto-Resonance Vibration Strength

Linear resonant actuators have a very narrow resonant frequency, as shown in Figure 3-1. The narrow resonance is a result of the resonance behavior of the spring and mass inside the LRA. An LRA will have a resonance at one frequency with a steep drop on either side.

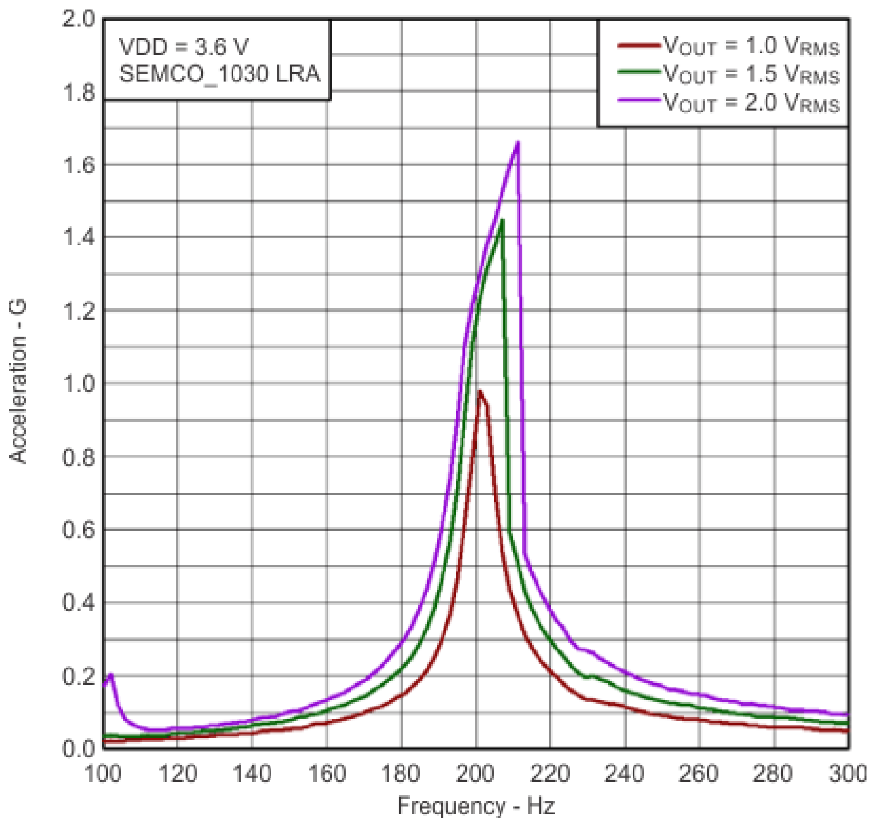

Figure 3-1. Resonant Frequency of Linear Resonant Actuators

The graph in Figure 3-1 shows acceleration versus frequency using three different driver output voltages. As the voltage increases, likewise the acceleration, the resonance frequency shifts making it impossible to predetermine the resonance frequency of an LRA.

Auto-resonance will ensure vibration performance across all actuators, no matter the resonance frequency. TI's auto-resonance algorithm dynamically determines the resonance frequency as the actuator is vibrating.

Figure 3-2 depicts the lab results of 21 actuators driven by the DRV2605 (blue dots) and the DRV8601 without auto-resonance (orange dots). The 21 actuators have data sheet specified resonant frequencies of 230Hz, but are separated into 7 frequency groups based on their actual resonant frequency at maximum acceleration. The orange dots are driven at 230Hz and the blue dots are driven by the auto-resonance tracking algorithm. From the graph, the DRV2605 shows consistent acceleration across actuators, while the orange has mixed results due to the constant drive frequency (230 Hz). The graph shows that auto-resonance provides consistent acceleration across actuators. DRV2625 has same characterization but can act over a broader range of frequencies (45Hz-300Hz)

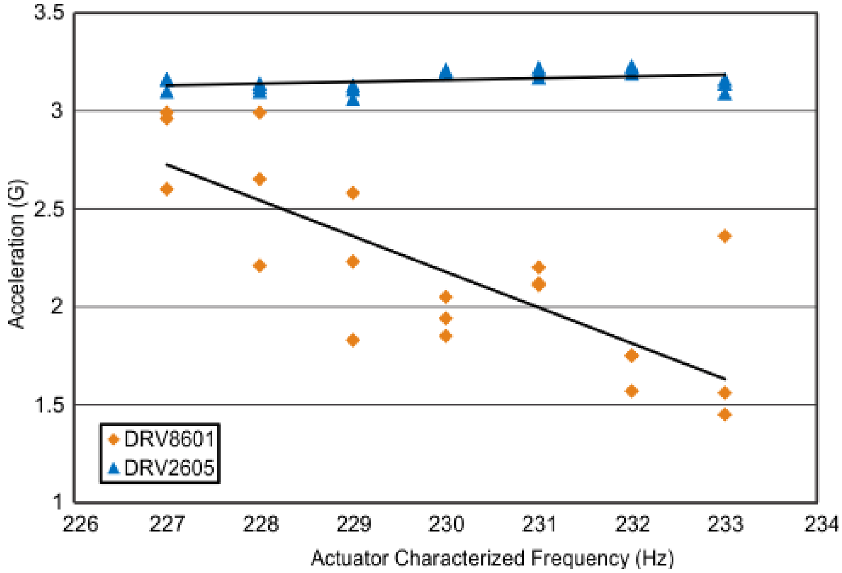

Figure 3-2. Acceleration Performance of the DRV2605 versus DRV8601

4 Auto-Resonance Efficiency

An LRA is a spring-mass system and thus must be driven at the resonance frequency to maximize efficiency. Similar to an electrical circuit at resonance, the LRA will reuse energy in the system when vibrating at resonance. Driving at a frequency a few hertz off resonance while trying to achieve the same performance as resonance operation will cause the mechanical spring force to oppose the magnetic force of the driver, resulting in wasted energy.

The DRV2605 or DRV2625 with auto-resonance detection can ensure that the actuator is driven efficiently. We measure efficiency using two metrics:

1. The common electric metric of power in watts
2. The normalized watts per g, which is the power in watts, mentioned above, divided by the acceleration produce by the actuator.

Output power for the 21 actuators in the previous section were measured and resulted in large efficiency improvements when driven by the DRV2605. Table 4-1 shows the percentage difference in efficiency for the 21 actuators. The improvement is a result of auto-resonance tracking. While measured with DRV2605, the DRV2604, DRV2624, and DRV2625 would be able to replicate similar results if not identical.

Table 4-1. Efficiency Improvements with Auto-Resonance

	No Auto-Resonance (Output ~230 Hz)			Auto-Resonance			Efficiency Improvement		
	Power (mW)	Acceleration (Grms)	mW / G	Power (mW)	Acceleration (Grms)	mW / G	Acceleration Improvement	Power Improvement	Power / G Improvement
1	143.9	2.96	48.62	121.9	3.16	38.57	6.8%	15.3%	20.7%
2	149.6	2.99	50.02	116.5	3.16	36.86	5.7%	22.1%	26.3%
3	148.3	2.6	57.02	123.9	3.1	39.97	19.2%	16.4%	29.9%
4	145.3	2.99	48.60	113.1	3.1	36.48	3.7%	22.2%	24.9%
5	147.9	2.21	66.91	116.1	3.12	37.21	41.2%	21.5%	44.4%
6	147.6	2.65	55.69	120.9	3.14	38.49	18.5%	18.1%	30.9%
7	151.8	2.23	68.09	117.9	3.13	37.68	40.4%	22.3%	44.7%
8	148.4	1.83	81.07	121.6	3.06	39.72	67.2%	18.1%	51.0%
9	148.7	2.58	57.62	123.1	3.11	39.59	20.5%	17.2%	31.3%
10	146.7	2.05	71.55	114.0	3.19	35.73	55.6%	22.3%	50.1%
11	149.3	1.94	76.94	111.9	3.2	34.97	64.9%	25.0%	54.5%
12	148.1	1.85	80.06	120.8	3.21	37.65	73.5%	18.4%	53.0%
13	153.2	2.2	69.65	118.3	3.2	36.97	45.5%	22.8%	46.9%
14	145.8	2.11	69.08	116.9	3.22	36.31	52.6%	19.8%	47.4%
15	144.3	2.12	68.05	120.6	3.17	38.05	49.5%	16.4%	44.1%
16	144.3	1.75	82.44	116.3	3.19	36.47	82.3%	19.4%	55.8%
17	149.9	1.75	85.68	116.3	3.23	36.00	84.6%	22.4%	58.0%
18	148.7	1.57	94.73	118.2	3.22	36.70	105.1%	20.6%	61.3%
19	148.9	1.45	102.68	116.0	3.16	36.69	117.9%	22.1%	64.3%
20	148.3	2.36	62.85	112.0	3.09	36.25	30.9%	24.5%	42.3%
21	148.2	1.56	95.01	110.2	3.14	35.09	101.3%	25.7%	63.1%
AVG	148.0	2.2	71.1	117.4	3.2	37.2	51.8%	20.6%	45.0%

5 Auto-Resonance Braking

LRA braking is a unique feature only available on the TI auto-resonance drivers. An LRA must be driven at the resonant frequency to obtain the best vibration and startup performance. Likewise, to brake an LRA, it must also be driven using the resonant frequency, except 180 degrees out-of-phase.

Figure 5-1 shows a click waveform that is driven at resonance for 4 1/2 cycles. Braking is then applied using a 180 degree out-of-phase sine-wave. In addition to applying the inverse phase waveform, the DRV2605 and DRV2625 also tracks the acceleration of the LRA and adjusts the output voltage according to the level of the acceleration. This ensures the LRA stops quickly and does not begin vibrating again.

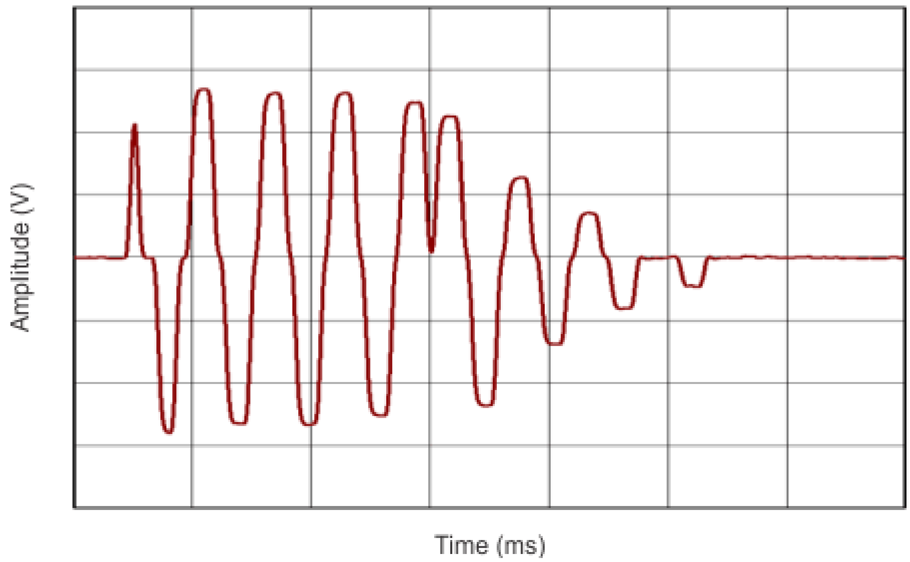

Figure 5-1. Auto-Resonance Braking

Figure 5-2 and Figure 5-3 compare the stop time of an LRA with braking and an LRA without braking. Notice the orange output waveform in Figure 5-3 reverses phase at the falling edge of the input signal. This active braking allows the LRA to stop 75 ms quicker than the waveform in Figure 5-2 that does not brake. This translates qualitatively into a "sharper" or "crisper" click.

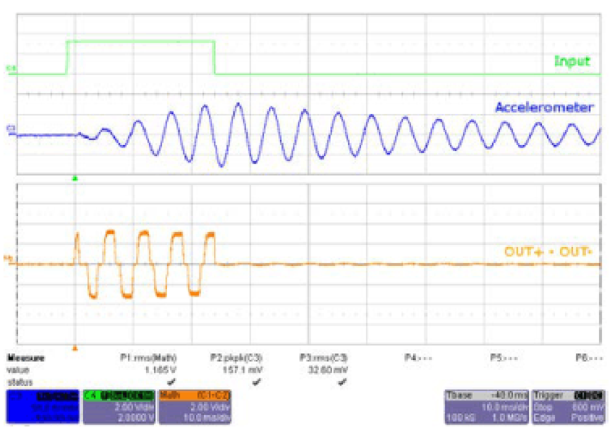

Figure 5-2. Click without Braking

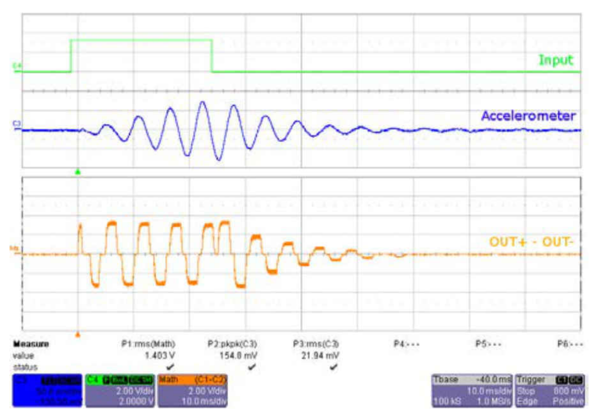

Figure 5-3. Click with Braking

6 How to Measure Auto-Resonance

The question that often arises is “How can I measure the auto-resonance frequency?” Measuring the frequency is quite easy. To see what frequency the DRV260x or DRV262x family of devices is driving, measure the filtered PWM-modulated output waveform or alternatively in both families of devices a register holding a LRA_PERIOD byte can be translated using a mathematical formula provided in the data sheet to tell users what the given output frequency is operating at. But filtering the output waveform will allow users to see the underlining sine or square wave. See the DRV2605EVM-CT User’s Guide or DRV2625EVM-CT User's Guide for more information on filtering.

Measuring the output frequency can be clear, but *How do I know that the DRV260x or DRV262x drivers are driving at the resonant frequency?* The answer is, *Users can see if device output frequency matches LRA's data sheet value but the exact resonant frequency cannot be determined entirely empirically because of the many environmental factors.* It is easier to answer a different question: *Is the performance better with auto-resonance tracking?* The answer is *yes*. Auto-resonance dynamically tracks the LRA frequency to improve acceleration, efficiency, and braking time.

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (October 2013) to Revision A (November 2021)	Page
• Added *and DRV2625* throughout publication	1
• Added general references to DRV2604 and DRV2624 throughout publication	1
• Updated block diagram	3
• Added *DRV2604 and DRV2624 Behave identically with the exception of having internal RAM vs ROM which does not impact the auto-resonance feature.*	4
• Added *DRV2625 has same characterization but can act over a broader range of frequencies (45Hz-300Hz).*	4
• Updated the *See the DRV2605EVM-CT User’s Guide or DRV2625EVM-CT User's Guide for more information.*	8
• Updated *The exact resonant frequency cannot be determined empirically, because of the many environmental factors.* to *Users can see if device output frequency matches LRA's data sheet value but the exact resonant frequency cannot be determined entirely empirically because of the many environmental factors.*	8

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