Application Report

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LRA Actuators: How to Move Them?

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ABSTRACT

This document describes from a high-level perspective the theory of operation for driving LRA actuators and compares typical open-loop and closed-loop solutions.

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1 Background

Linear resonant actuators (LRAs) are resonant systems that will produce vibration when exercised at or near its resonance frequency. All else being equal, an LRA will maximize the vibration strength when driven at its resonance frequency (see Figure 1). However, the resonance frequency may vary due to different factors, such as temperature, aging, the mass of the product to which the LRA is mounted, and in the case of a portable product, the manner in which the product is held. LRAs tend to have high-Q frequency response. Therefore, driving them with small offsets from the resonance frequency (typically 3 - 5 Hz) may result in a significant drop in vibration strength. Figure 2 and Figure 3 show an example that compares acceleration at resonance versus 4 Hz away.

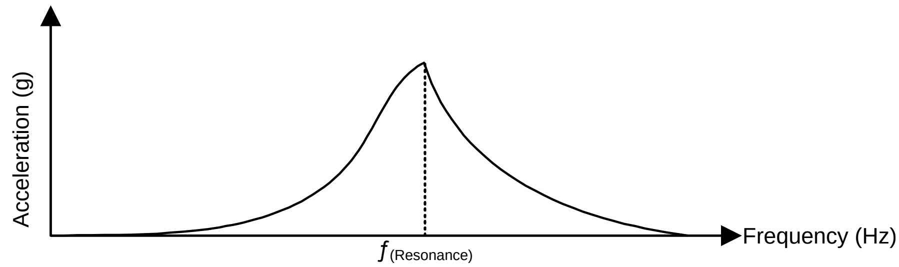

Figure 1. Typical LRA Acceleration Versus Frequency Response

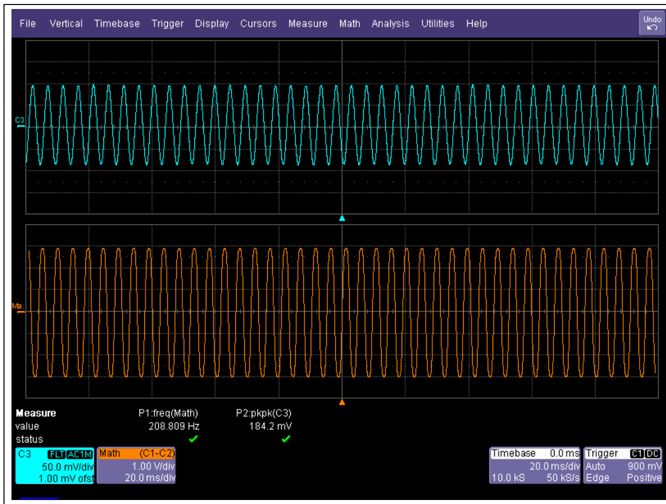

Figure 2. Acceleration at Resonance

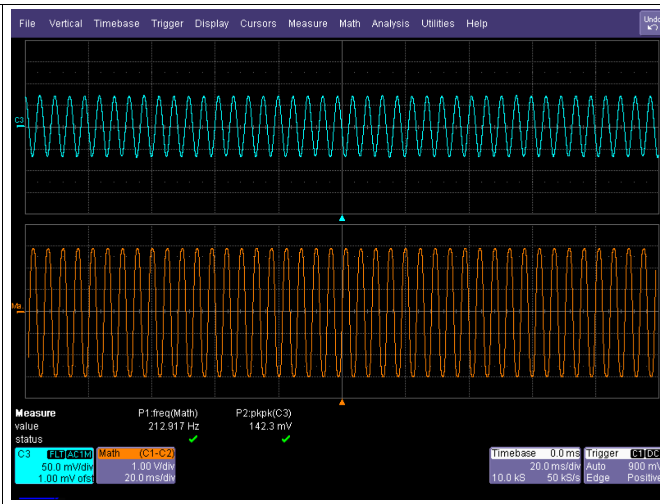

Figure 3. Acceleration Off-Resonance

2 Moving an LRA

In the simplest of terms, moving an LRA consists of:

- Injecting enough energy at or near the LRA's resonance frequency to overcome the static friction to get the mass moving
- Injecting the appropriate level of energy at or near the LRA's resonance frequency that results in the desired vibration level
- Injecting appropriate levels of energy at or near the LRA's resonance frequency with 180° phase shift in order to "brake" the actuator

Additionally, the actuator can be overdriven for a short period of time during the start or brake section of the waveform to reduce the time it takes to go from a rest position to the desired steady state and vice versa. Reducing the start-time and brake-time results in sharper, crisper effects. Refer to the data sheet of the actuator for safe and reliable overdrive voltage and duration.

3 Driving an LRA in Open-Loop

If the resonance frequency of an LRA is known, all that is needed to get it moving is to drive it at that frequency and with an amplitude high enough to overcome its static friction. Actuator manufacturers usually provide the typical resonance frequency of its actuators so this can be used as the starting point. The resonance frequency of a particular LRA model will usually have small part-to-part variations due to process and manufacturing variability; the more the part-to-part variations, the lower the part-to-part consistency of the vibration strength.

If braking is desired, the LRA can be driven at or near its resonance frequency with 180° phase shift in order to stop it. Careful manual tuning needs to be performed for each actuator and each amplitude level such that the LRA brakes optimally. If the braking signal is not strong enough or for long enough time, the LRA will under-brake, which translates to longer brake times. If the braking signal is too strong or for too long, the LRA will over-brake, which translates to the LRA moving in the opposite direction.

Figure 5 and Figure 7 show the advantages of having clean, sharp braking in a system. Figure 4 and Figure 6 show the effect of poor braking in the acceleration waveform.

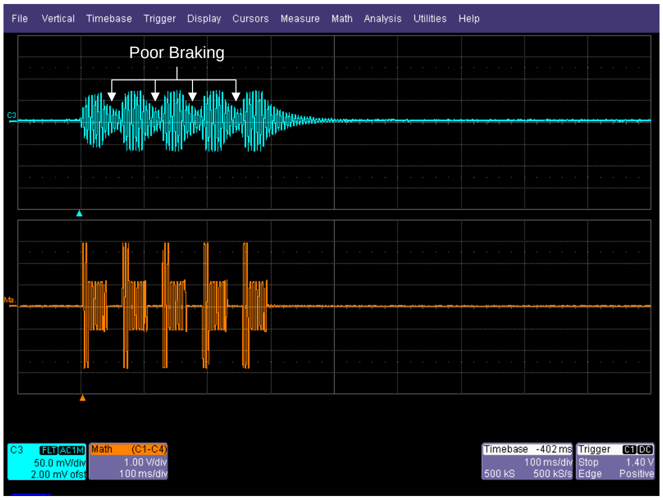

Figure 4. Pulsing Waveform in Open-Loop With Brake Problems

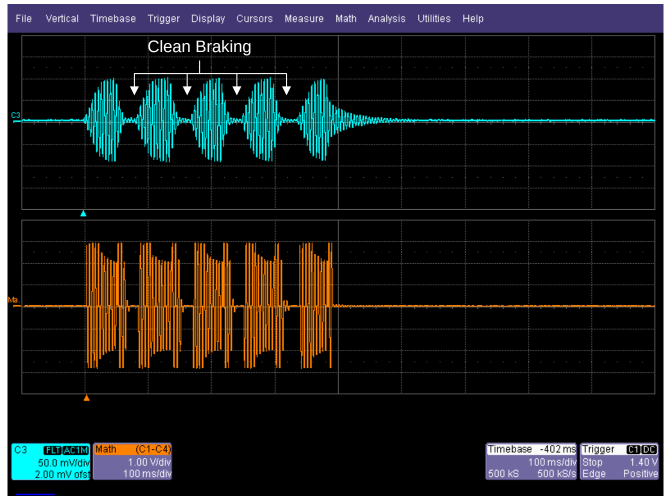

Figure 5. Pulsing Waveform in Closed-Loop

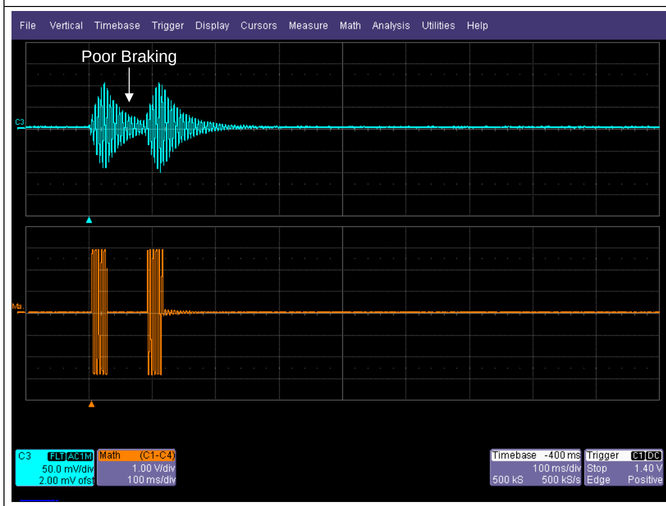

Figure 6. Double Click Waveform in Open-Loop With Brake Problems

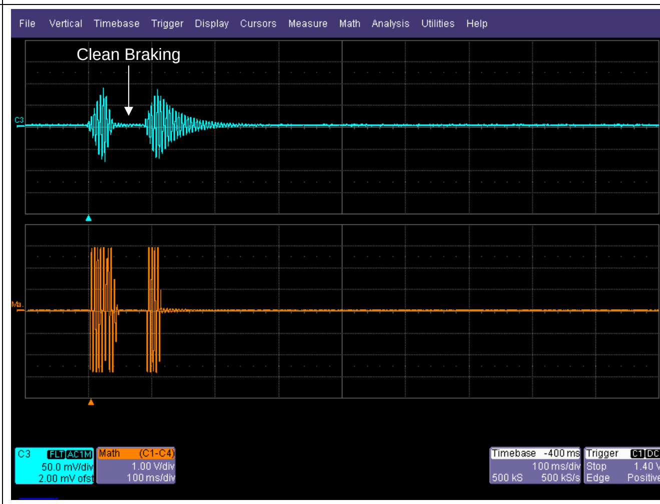

Figure 7. Double Click Waveform in Closed-Loop

If overdriving is desired, careful manual tuning must be performed for each amplitude level such that the LRA overdrives optimally. If the overdrive signal is not strong enough or for long enough time, the LRA will under-overdrive, which translates to longer start-times and brake-times. If the overdrive signal is too strong or for too long, the LRA will over-overdrive, which translates to the LRA moving beyond its desired level of strength, potentially causing a "bump" in the haptic feel. The optimal overdrive signal can be defined as the one that minimizes start-time and brake-time but is not perceptible in the acceleration waveform. Figure 8 shows a buzz waveform with an open-loop driver and no braking. This waveform highlights the effect that over-overdriving will have in acceleration. For comparison purposes, Figure 9 shows a buzz waveform with a closed-loop driver and no braking.

Note that if overdrive and braking are used in an open-loop system, the manual tuning information must be contained in the LRA's driving signal, which means that for different actuators, different driving signals must be used.

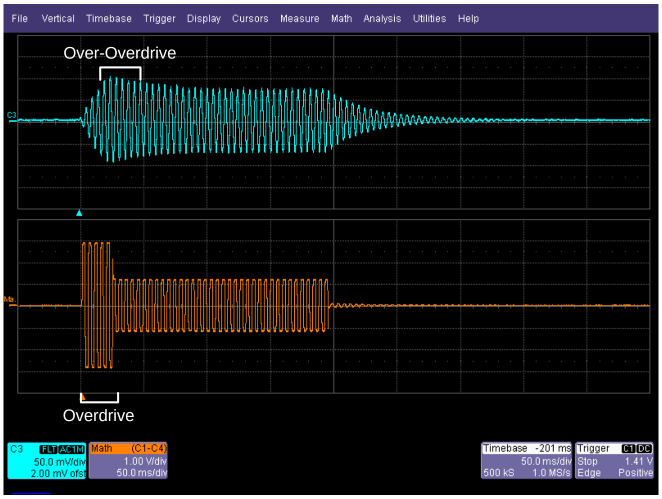

Figure 8. Buzz Waveform in Open-Loop With Over-Overdrive Problems

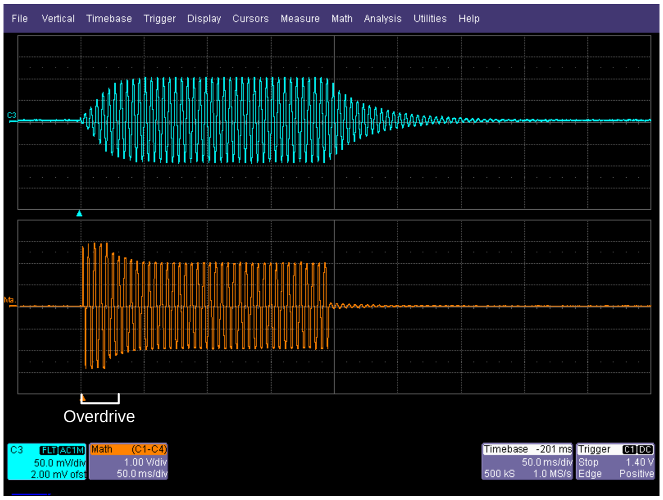

Figure 9. Buzz Waveform in Closed-Loop

4 Driving an LRA in Closed-Loop

There are many types of closed-loop systems that can be implemented to control an LRA. A resonance tracking closed-loop system for LRA (auto-resonance), constantly monitors the resonance frequency of the LRA and adjusts the driving frequency to track it, maximizing the vibration strength for a given driving voltage. Such an engine is present in devices such as the DRV2603, DRV2605, and DRV2605L. A level tracking closed-loop system, once calibrated, regulates the output vibration strength to the desired level, irrespective of variations of the resonance frequency. Such an engine is present in devices such as the DRV2605 and DRV2605L.

A closed loop system that implements resonance tracking and level tracking loops have the advantage of automatically driving at the resonance frequency, and automatically performing overdrive and braking at optimum levels, removing the need for tedious manual tuning. An example of a closed-loop driving signal and the feedback signal is shown in Figure 10.

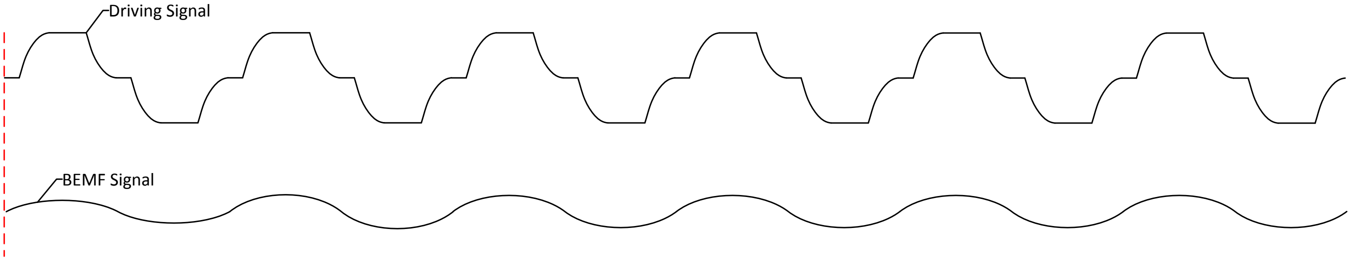

Figure 10. Closed-Loop Driving Signal With BEMF Feedback Signal

A weakness present in some closed-loop systems arises when the actuator exhibits too high of a static friction for the desired levels of energy transfer, causing the actuator to not move. Since a closed loop system relies on monitoring the actuator's movement in order to synchronize the driving signal's frequency, a non-moving actuator can cause such a system to malfunction (since the feedback signal is not valid). An example of such a scenario is when an LRA gets frozen. Advanced closed-loop drivers such as the DRV2605L employ proprietary algorithms [(1)] to get around this limitation by driving a signal at a default frequency if the driver fails to synchronize, and then automatically synchronize once the actuator starts moving, such that features like auto-resonance and automatic overdrive and braking are available. An example of a closed-loop driving signal with the feedback signal implementing the re-synchronisation feature is shown in Figure 11.

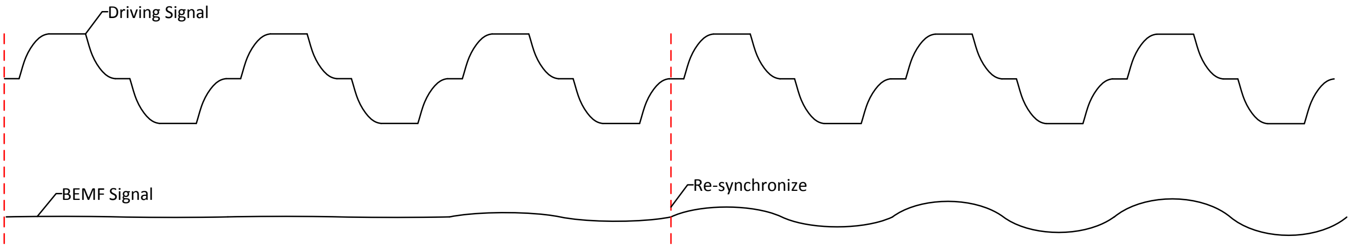

Figure 11. Closed-Loop Driving Signal With BEMF Feedback Signal and Re-Synchronisation Feature

(1) Patent pending control algorithm

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