Application Note

Integrating the TI DRV2605L for Audio-to-Haptic Feedback in a Gaming Handheld

ABSTRACT

This application note presents a practical method to add immersive haptic feedback to a gaming handheld using the Texas Instruments DRV2605L haptic driver in the Audio-to-Haptic mode. In modern handhelds, game audio is abundant even when explicit haptic events are absent – the DRV2605L exploits this by automatically converting audio signals into vibration drive for an Linear Resonant Actuator (LRA) in real time. This application note describe the advantages of the Audio-to-Haptic mode (such as closed-loop resonance tracking), the hardware configuration used to evaluate this, and waveform results demonstrating the LRA's response at various audio frequencies and amplitudes. This application note also detail how to seamlessly switch between *audio-driven haptics* and manual haptic control (using the DRV2605L's real-time playback or effect library modes) during game play. Our tests confirm that the DRV2605L produces meaningful tactile effects from game audio with minimal latency, and transitions smoothly when the system overrides with specific haptic cues. This document provides guidelines for integrating the DRV2605L into a handheld device, including configuration tips and scope captures of the haptic output. The approach requires only modest hardware additions (the DRV2605L driver and an LRA) yet significantly enhances user immersion by leveraging existing audio content for haptic feedback.

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1 Introduction

Modern gaming handhelds strive to deliver immersive tactile feedback. Typically, rumble or vibration events are triggered directly by the game software (for example, a predefined vibration pattern when an on-screen explosion occurs). If a game does not explicitly provide such haptic cues, some devices attempt to derive vibration feedback from the audio output. One common approach is to use an Audio Processing Object (APO) in the sound pipeline along with an embedded microcontroller algorithm to drive a vibration motor based on audio. This **APO+EC** method can monitor the game's sound for bass or impact cues and activate the haptic motor accordingly. However, relying on audio alone has limitations: if the audio lacks obvious low-frequency components (explosions, deep hits, and so on.), the vibration feedback can feel weak or nonexistent. There can also be noticeable latency and inconsistent intensity when using only the audio stream to generate haptics.

To address these gaps, the TI DRV2605L haptic driver's Audio-to-Haptic mode is implemented in a gaming handheld context. In Audio-to-Haptic mode, the DRV2605L continuously monitors an analog audio input (such as the game's headphone output) and automatically drives an LRA based on the audio's frequency and amplitude characteristics. Low-frequency audio content (bass beats, explosions, environment noise) is intelligently converted into vibration patterns, meaning even if the game doesn't program any rumble, the background audio produces a tactile effect. The conversion algorithm (licensed from Immersion's TouchSense®) makes sure these vibrations feel natural and in sync with the audio rather than just random buzzing.

In our implementation, the handheld's audio codec outputs left and right audio channels, each fed both to speakers (or headphones) and to a DRV2605L configured in audio-to-vibe mode. An embedded controller (EC) on the device can also interface with each DRV2605L through I²C for configuration and to trigger specific haptic effects when needed. Figure 1-1 illustrates the dual-input haptic configuration: the audio path (green lines) and the EC control path (blue lines) both influence the DRV2605L haptic drivers.

Codec and EC-based left or right channel routing to dual DRV2605L drivers for haptic feedback in a gaming handheld. Each DRV2605L can receive an analog audio input (green) and I²C control signals (blue) from the embedded processor, supporting synchronized audio-driven and direct haptic feedback.

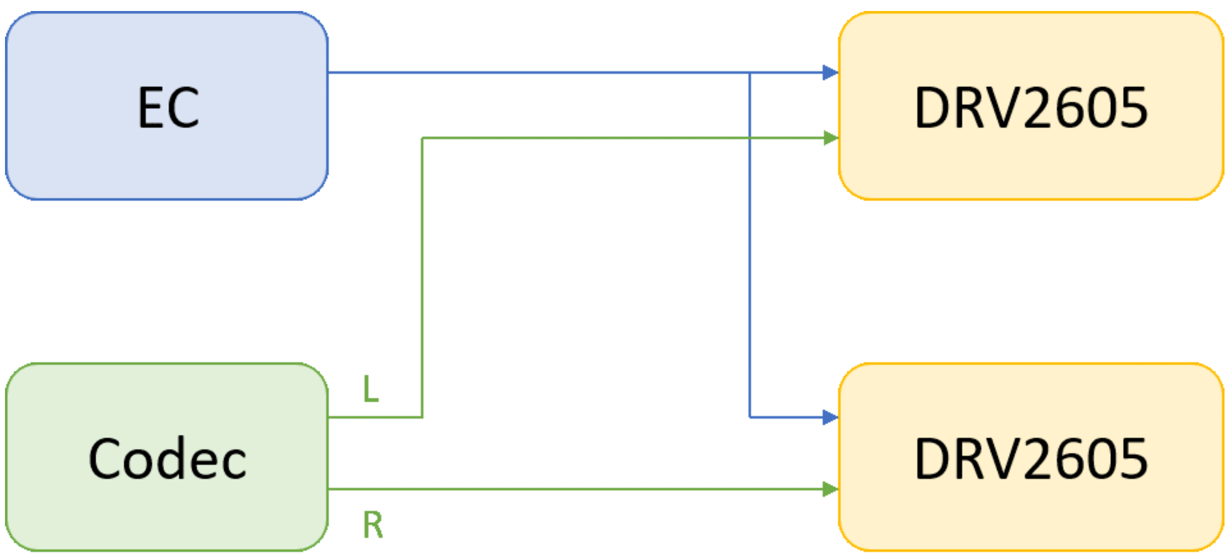

Figure 1-1. Dual DRV2605L Haptic Routing Through Codec and EC

This document is structured as follows:

- An overview the DRV2605L's Audio-to-Haptic mode and the benefits
- Description of the hardware test setup and key configuration steps for using Audio-to-Haptic.
- Waveform results from lab tests are presented to analyze the LRA's response at different audio frequencies and volumes.
- Sharing the behavior when *switching modes* – for example, toggling between audio-driven haptics and manual playback mode – and how to make sure of smooth transitions.
- Recommendations for integrating these modes in a product design

2 DRV2605L Audio-to-Haptic Mode Overview and Advantages

The DRV2605L is a specialized haptic driver for both Linear Resonant Actuators (LRAs) and Eccentric Rotating Mass motors (ERMs). This includes a closed-loop control architecture and an internal library of haptic effects. This document focuses on the Audio-to-Haptic capability, a feature that *automatically converts an audio input signal into meaningful tactile effects*. Key advantages of using the DRV2605L Audio-to-Haptic mode include:

- **Automatic Audio Conversion to Haptics:** In Audio-to-Haptic mode, the DRV2605L continuously monitors an analog audio input and generates a corresponding drive output on the LRA. Low-frequency components in the audio (for example, a 50–200Hz bass rhythm or an impact sound) are detected and translated into vibration. This happens in real time, so even if a game does not explicitly issue a rumble command, the *audio produces a tactile response*. The conversion algorithm is tuned so that the vibrations feel relevant to the content – sharp transient sounds create crisp taps, while sustained low tones create a buzzing or rumble – rather than a one-size-fits-all buzz.
- **Resonance Tracking and Smart-Loop™ Closed-Loop Control:** The DRV2605L employs a closed-loop control system with *automatic resonance tracking* for LRAs. An LRA has a natural resonant frequency (typically about 170–200Hz); driving this at resonance maximizes efficiency and vibrational strength, but the resonant frequency can shift slightly with temperature, aging, or if the device is not exactly mounted. The DRV2605L's Smart-Loop™ algorithm constantly adjusts to stay on the LRA's resonance and applies active braking when needed. This yields more consistent acceleration and faster rise/fall times for vibrations. In practice, closed-loop control prevents the LRA from *ringing* or overshooting when the audio signal stops, and makes sure each pulse is crisp. (By contrast, an open-loop drive can let the LRA ring and take longer to settle.)
- **Built-In Vibration Effect Library:** Aside from Audio-to-Haptic mode, the DRV2605L contains an internal ROM library of over 100 predefined haptic waveforms and effects (licensed from Immersion). While not the focus of this note, this library can be very useful when games do provide specific haptic events – the host processor can trigger library waveforms through I²C (for example, playing a *double click* vibration or an explosion rumble). Having this library on-chip means developers don't need to craft custom vibration waveforms for common effects. This design primarily used Audio-to-Haptic for automatic background feedback, but the *library effects* are available for on-demand events (like a game menu selection or a special in-game action). Later in the document demonstrates switching between Audio-to-Haptic and a library effect.

Note that the DRV2605L's Audio-to-Haptic engine drives the LRA designed for tactile feel, which does not always exactly mimic the input audio waveform. The goal is to maximize the vibration relevance rather than literally reproducing the audio frequencies (especially since an LRA cannot respond well to very high frequencies). The device effectively extracts the amplitude envelope of the audio and drives the LRA at the resonant frequency, modulating the intensity. This makes sure of strong feedback even if the audio frequency is above or below the LRA's designed for range.

To illustrate the benefit of the closed-loop Smart-Loop control, Figure 2-1 shows a scope capture of an *open-loop drive* scenario. Here, a built-in library waveform (a *double-click* effect) was played to an LRA with the driver's closed-loop features disabled. The upper trace shows the driver's raw PWM output to the LRA, and the lower trace shows the actual voltage across the LRA. Without adaptive control, the LRA's response is not tightly controlled – you can observe some variation in amplitude and a slower damping of the vibration after each pulse. Enabling the DRV2605L's Smart-Loop closed-loop mode makes these pulses more consistent and sharply delineated (not shown in this figure, but observed in our testing).

Open-loop LRA drive waveform for a *double-click* haptic effect (using the DRV2605L's internal library).The upper waveform (yellow/magenta) is the differential output from the driver, and the lower waveform (red) is the resulting voltage across the LRA. Without closed-loop damping and resonance control, the LRA motion shows slight overshoot and inconsistent amplitude between pulses.

Figure 2-1. Open-Loop LRA Waveform for Double-Click Effect

In summary, the DRV2605L's Audio-to-Haptic mode simplifies the addition of ambient haptics by leveraging existing audio, while the closed-loop control and effect library makes sure that the vibrations are high-quality and that specific tactile events can still be played as needed.

3 Hardware Test Setup and Configuration

To evaluate the Audio-to-Haptic performance, a test bench was set up using the DRV2605L and a representative LRA actuator. The hardware consisted of a TI DRV2605LEVM-MD evaluation module (which includes the DRV2605L driver and an LRA on a small board) connected to a host controller. In a real product, the host can be an application processor or microcontroller in the hand-held console. Audio was fed into the DRV2605L and the LRA's vibration output was observed under various conditions. Key aspects of the setup and configuration included:

- **Audio Input and Coupling:** An audio codec or signal generator provided an analog audio signal into the DRV2605L's IN pin. The input was AC-coupled through a 1μF capacitor in series (as recommended) to block any DC offset and allow the AC audio through. The DRV2605L's input impedance (about 100kΩ) and the 1μF capacitor form a high-pass filter with a cutoff around 1.6Hz, which easily passes the audio frequencies of interest but filters out DC. The audio signal amplitude was kept within the DRV2605L's acceptable range (no more than about 1.8V_peak-to-peak). In practice, our *100% volume* test level corresponded to 1.0VRMS (about 2.8Vp-p), and then scaled down from there for lower percentages. The DRV2605L's built-in noise gate was left at the default setting, which ignores any audio below a few millivolts – this prevents background hiss or very faint sounds from accidentally triggering the actuator when silence is expected.
- **I²C Control and Mode Configuration:** The host controller was connected to the DRV2605L's I²C interface (SCL, SDA). Through I²C commands, the DRV2605L's registers were configured for Audio-to-Haptic mode. Important register settings included selecting Mode 0x04 *(Audio-to-Vibe)*, enabling *LRA drive* (as opposed to ERM mode), and enabling *analog input with AC-coupling* (this involved setting the DRV2605L's control registers: for example, AC_COUPLE = 1 and N_PWM_ANALOG = 1 in the appropriate control registers). The rated voltage and overdrive clamp were also set for the LRA, but the auto-calibration (described next) can adjust those if needed. Figure 3-1 shows a simplified schematic of the setup, highlighting the connections between the host (application processor), the DRV2605L, and the LRA.
- **Auto-Calibration:** Before using Audio-to-Haptic mode, the DRV2605L's auto-calibration routine for the LRA was run. This is a one-time (or infrequent) step that helps the driver measure the LRA's resonant frequency, rated drive voltage, and other parameters. To do this, the DRV2605L was put in calibration mode (Mode register = 0x07) and the GO bit was toggled through I²C. The driver briefly drives the LRA and measures the response. After a few hundred milliseconds, a status bit indicated the calibration was complete and successful. Auto-calibration set the designed for drive parameters (like the effective resistance and back-EMF constants of the LRA) so that closed-loop control can be accurate for our specific actuator. Calibration was important for the first use of a new LRA; once calibrated, the values were stored in registers and used for subsequent Audio-to-Haptic operation.
- **Measurement Instruments:** To observe the haptic behavior, a digital oscilloscope (Rigol DS series) with multiple probes was used. One differential probe was connected across the LRA terminals to monitor the *voltage being applied to the LRA* by the DRV2605L (this differential voltage correlates with the force output of the LRA). Another channel was connected to the audio input signal so the relationship between the audio and the resulting vibration drive can be seen. For evaluating mode switching, the oscilloscope was set to a slower time base (hundreds of milliseconds per division) to capture the moments when modes were toggled. For capturing steady-state waveforms (like the LRA response at a given frequency and amplitude), a faster time base (microseconds to milliseconds scale) was used to see the details of the PWM waveform and the envelope.

The DRV2605L is interfaced to an application processor through I²C (SCL, SDA lines with pull-up resistors). The analog audio input is fed through a coupling capacitor C(IN) into the IN/TRIG pin (with the option to short this to ground if not used). The DRV2605L drives the LRA (or ERM) with a differential output (OUT+ and OUT–); supply decoupling capacitors (C(REG), C(VDD)) are shown for the regulator and supply rails. The EN pin can be used to enable/disable the driver (tie high for always on). The 1μF input capacitor creates a high-pass filter (about 1.6Hz cutoff) with the IN pin impedance, allowing low-frequency audio to pass while blocking DC.

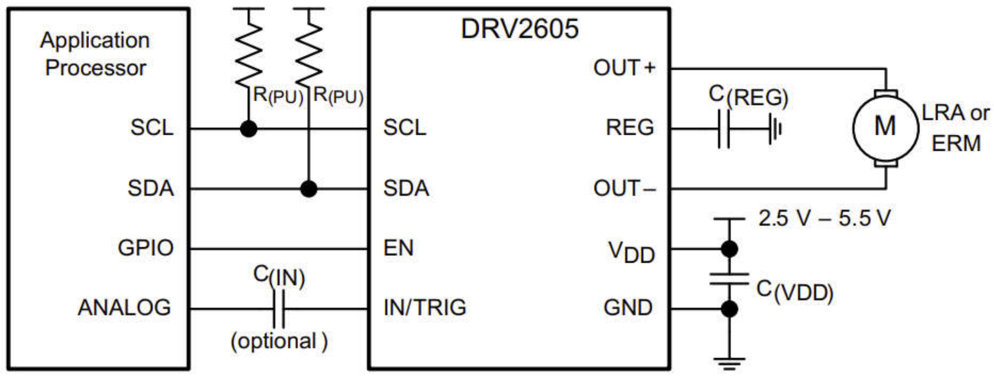

Figure 3-1. Hardware Setup for Testing Audio-to-Haptic Mode

Using this setup, two main sets of experiments were conducted:

1. **Steady-State Audio-to-Haptic Performance:** Driving the LRA in Audio-to-Haptic mode at various audio frequencies and amplitudes, to characterize how the LRA responds.
2. **Mode Switching Tests:** Toggling the DRV2605L between Audio-to-Haptic mode and real-time playback mode under different conditions (with and without audio present) to make sure smooth transitions. In the next section, waveform results for the first set of tests (Audio-to-Haptic mode performance) are presented.

Initial I²C Configuration

Before operating the DRV2605L, an initial configuration must be applied through the **DRV2605LEVM-MD GUI**. Follow these steps:

1. Open **DRV2605LEVM-MD GUI** and connect the EVM through USB.
2. Select **Import Settings** and load the provided configuration file (initial table.txt).

The following register settings are essential for proper initialization:

Table 3-1. Installation Register Settings

Register	Value	Description
0x01	0x04	Mode (Audio-to-Haptic)
0x03	0x06	Library Selection
0x04	0x06	Waveform Sequencer 1
0x0C	0x00	GO
0x11	0x00	Audio-to-Vibe Control
0x12	0x02	ATH Minimum Input Level
0x13	0x8D	ATH Maximum Input Level
0x14	0x4C	ATH Minimum Output Drive
0x15	0xFF	ATH Maximum Output Drive
0x16	0x2C	Rated Voltage
0x17	0x2C	Overdrive Clamp Voltage
0x1A	0xB6	Feedback Control (LRA Closed Loop)
0x1B	0xBB	Control1 (AC coupling enabled)
0x1C	0xF5	Control2
0x1D	0xA3	Control3 (Analog Input enabled)
0x1E	0x20	Control4
0x1F	0x80	Control5
0x20	0x3F	LRA Open Loop Period

These settings make sure of optimized performance, proper calibration, and mode configuration for Audio-to-Haptic functionality.

Mode-Switching Procedure

After initialization, the DRV2605L can switch between **Audio-to-Haptic mode** and the built-in **library mode** dynamically. Use the following I²C commands through GUI's Register Write feature or microcontroller I²C script:

- **Switch to Audio-to-Haptic Mode**:

Write Register 0x01 = 0x04

- **Switch to Built-in Library Mode (Gaming mode)**:

Write Register 0x01 = 0x00

Write Register 0x0C = 0x01 //Trigger vibration event

To make sure of smooth operation and avoid continuous triggering, follow this timing recommendation:

- Wait approximately **20ms** after triggering the vibration event. If no further events occur:

Write Register 0x01 = 0x04 // Return to Audio-to-Haptic mode

This timing makes sure the device transitions smoothly back to continuous audio-derived haptic feedback when explicit events cease.

GUI Usage (DRV2605LEVM-MD)

1. Open the **DRV2605LEVM-MD GUI** after connecting the evaluation board.
2. Import the provided initial configuration (initial table.txt) using the GUI's **Import Settings** button.
3. To switch modes manually:
   - Use the **Write** option in GUI:
     - Enter Reg= 0x01, Val = 0x04 for **Audio-to-Haptic mode**.
     - Enter Reg= 0x01, Val = 0x00 for **Built-in Library mode**.
   - Confirm and execute by clicking the **Write** button.

This provides a straightforward way to confirm proper DRV2605L operation and quickly evaluate haptic feedback performance under different modes.

Example I²C Script for Automated Testing

For quick and automated testing, you can implement the following script through your host microcontroller (pseudo-code example):

```
// Initialize DRV2605L (load settings from initial table)

I2C_Write(0x5A, 0x01, 0x04); // ATH mode by default

// When gaming event occurs (user presses button or game triggers event)

I2C_Write(0x5A, 0x01, 0x00); // Library mode

I2C_Write(0x5A, 0x0C, 0x01); // Trigger haptic event

Delay(20ms); // Allow the event vibration to complete

// If no further events, revert back to ATH

I2C_Write(0x5A, 0x01, 0x04); // Audio-to-Haptic mode
```

This script can be integrated into gaming handheld firmware for effective and seamless haptic experience control.

4 Waveform Test Results and Analysis (Audio-to-Haptic Mode)

First, the DRV2605L's output in Audio-to-Haptic (A-V) mode was examined using controlled audio inputs. The goal was to see how effectively the driver converts different frequency audio signals into LRA vibrations, and how the vibration amplitude scales with audio amplitude. Three test tones were used – 100Hz, 200Hz, and 300Hz – which represent audio content below, at, and above the typical LRA resonant frequency (about 180Hz). These can be thought of as a low bass rumble (100Hz), a near-resonance buzz (200Hz), and a higher-pitched hum (300Hz). Each tone was tested at four amplitude levels: 25%, 50%, 75%, and 100% (where 100% corresponds to the system volume being set to maximum). For example, 25% corresponds to setting the system volume to 25, 50% to volume level 50, and so on. This configuration allows us to observe the linearity of the DRV2605L's output at different input volume levels and determine whether any saturation occurs in the vibration response.

For each test, the audio was played in A-V mode and the steady-state waveforms of the LRA drive (differential output) and the audio input were captured. The oscilloscope screen shots (Figure 4-1 through Figure 4-12) show the results. In all these figures, the blue trace (labeled C2) is the audio input voltage, and the magenta or yellow traces (C1 and C3, or the mathematical difference M3) represent the differential voltage across the LRA as driven by the DRV2605L. Essentially, the colored PWM wave on each graph is the driver output, and the envelope or amplitude corresponds to the vibration strength. The measured amplitude of the audio input for each case (in millivolts RMS) is indicated in the figure captions for reference.

100Hz Input (Below Resonance): At 100Hz, the LRA is being driven below the resonant frequency. The vibration is expected to be weaker for a given voltage compared to at resonance, but the DRV2605L can still drive proportionally to the audio amplitude.

DRV2605L output for a 100Hz sine wave input at 25% volume (2.1mV). At this low audio level, the differential voltage applied to the LRA is small, resulting in a very slight vibration. The waveform shows the PWM pulses (pink or yellow) at the driver output; the amplitude of these pulses is low, just enough to produce a barely perceptible buzz.

Figure 4-1. 100Hz Input at 25% Volume – Minimal Vibration

DRV2605L output for 100Hz input at 50% volume (7.1mV). With a moderate audio level, the driver delivers a higher voltage to the LRA (roughly double the amplitude of the 25% case). The LRA's vibration is now noticeable. The scope trace shows a clear 100Hz envelope in the LRA's drive voltage (blue trace oscillating at 100Hz, and PWM output following that envelope). The vibration amplitude has roughly doubled from the 25% case, indicating an approximately linear response in this range.

Figure 4-2. 100Hz Input at 50% Volume – Noticeable Vibration

DRV2605L output for 100Hz input at 75% volume (14.1mV). At this higher audio level, the driver's output PWM swings are larger, driving the LRA with greater force. The vibration is strong and still follows the 100Hz audio waveform envelope.

Figure 4-3. 100Hz Input at 75% Volume – Strong Vibration

DRV2605L output for 100Hz input at 100% volume (21.8mV). With maximum audio input, the driver outputs the full-scale differential voltage (yellow or magenta PWM traces). The LRA receives a strong 100Hz-driven vibration. The driver successfully drives the LRA without clipping.

Figure 4-4. 100Hz Input at 100% Volume – Full-Scale Vibration

200Hz Input (Near Resonance): 200Hz is in the vicinity of our test LRA's resonant frequency. The LRA is expected to respond most strongly around this frequency, achieving larger vibration for less input voltage.

DRV2605L output for a 200Hz sine wave input at 25% volume (2.1mV). There is no PWM output on M3 trace.

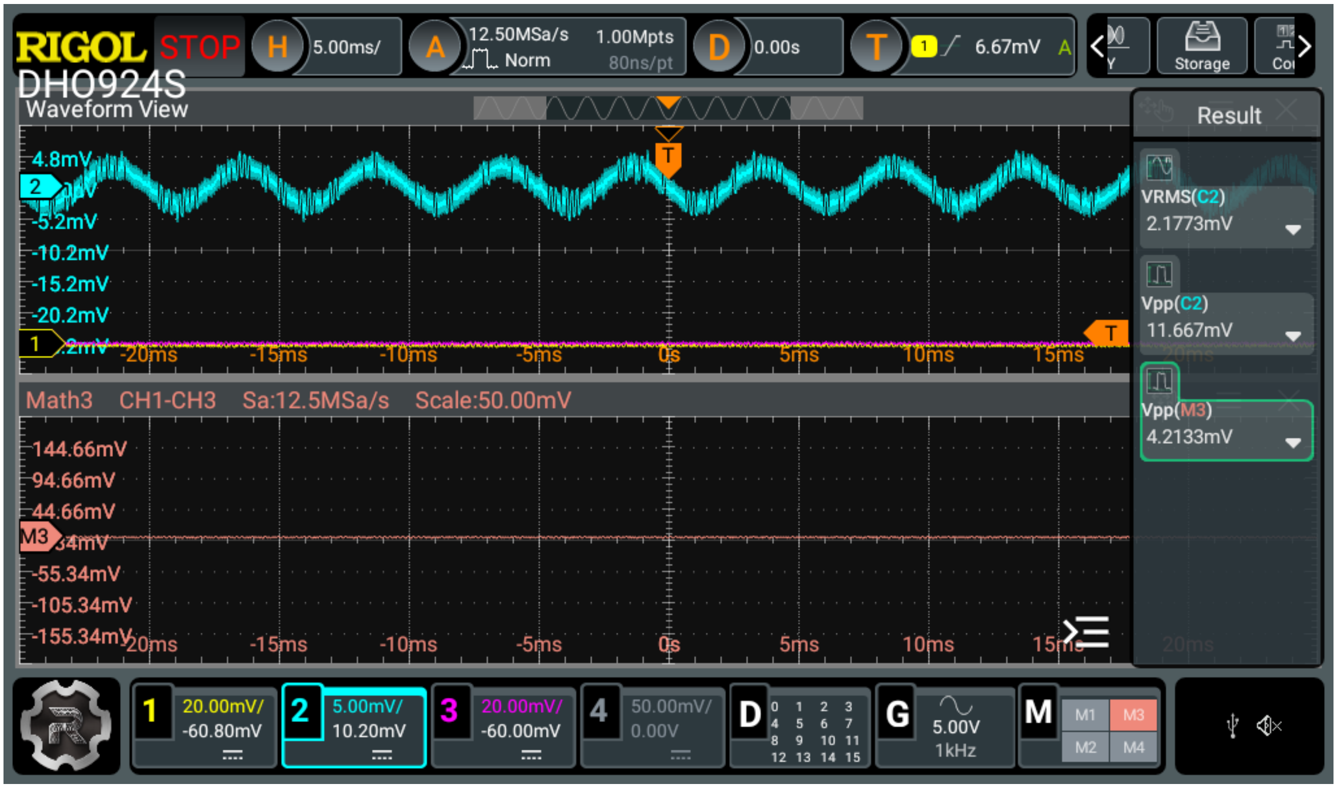

Figure 4-5. 200Hz Input at 25% Volume – No PWM Output

DRV2605L output for 200Hz input at 50% volume (7.1mV). With a half-scale audio input at resonance, the LRA drive (yellow or magenta) is more pronounced. The blue trace indicates the 200Hz audio waveform.

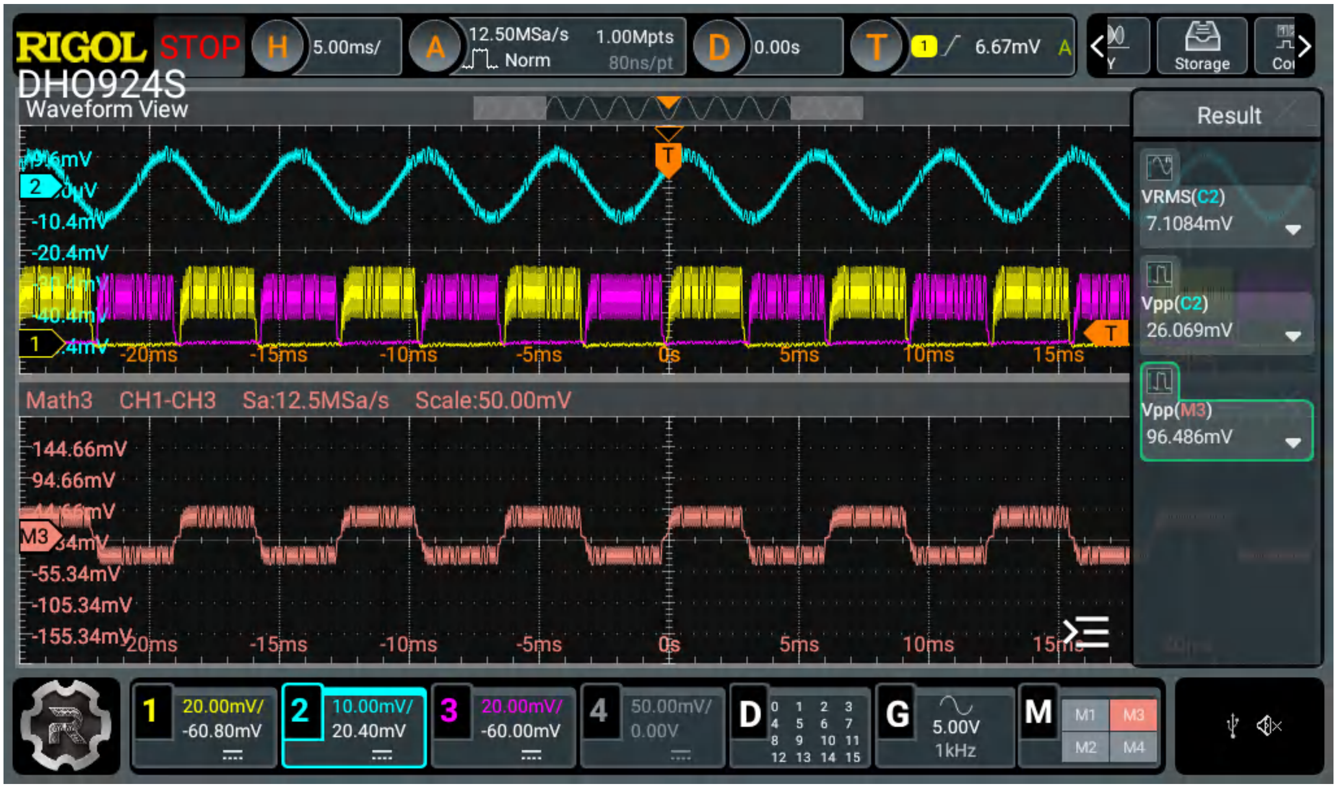

Figure 4-6. 200Hz Input at 50% Volume – Moderate Vibration

DRV2605L output for 200Hz input at 75% volume (14.1mV). At 75% audio level, the output waveform shows large PWM swings.

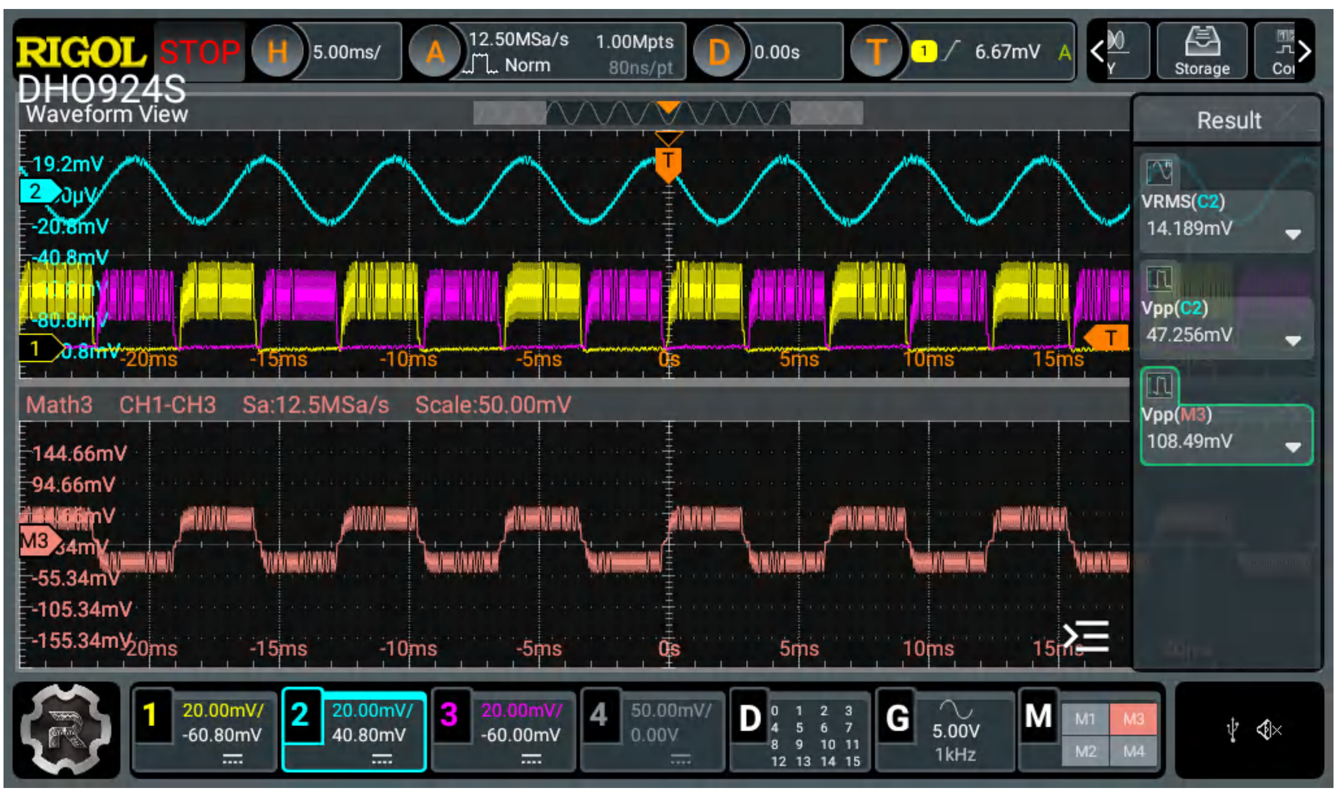

Figure 4-7. 200Hz Input at 75% Volume – High PWM Activity

DRV2605L output for 200Hz input at 100% volume (21.8mV). Full-scale input at resonance drives the LRA at maximum intensity. The output waveform (magenta or yellow) exhibits the highest amplitude pulses observed, and the blue trace confirms the 200Hz audio is continuous. The LRA's movement is at the peak – this corresponds to a very strong vibration (a deep buzz).

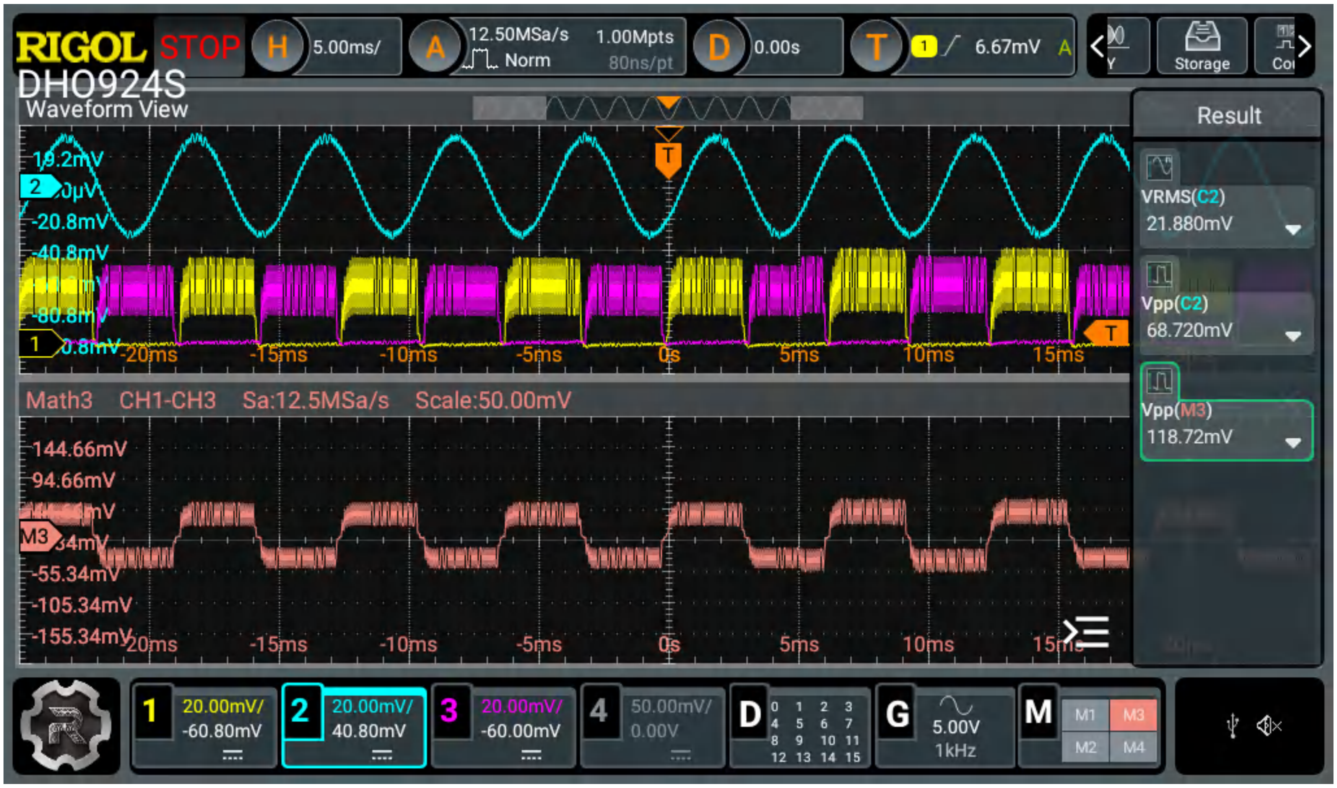

Figure 4-8. 200Hz Input at 100% Volume – Maximum Vibration

At resonance, the DRV2605L's closed-loop control was especially valuable. As the LRA's motion intensified, the back-EMF from the LRA also increases (LRAs generate a voltage as the LRA move).

300Hz Input (Above Resonance): 300Hz is higher frequency. In this regime, the driver is pushing the LRA less stronger, so the vibration output is expected to drop off.

DRV2605L output for a 300Hz input at 25% volume (2.1mV). At a quarter volume, the audio is a 300Hz tone, but the LRA's differential voltage (M3, red trace) is zero.

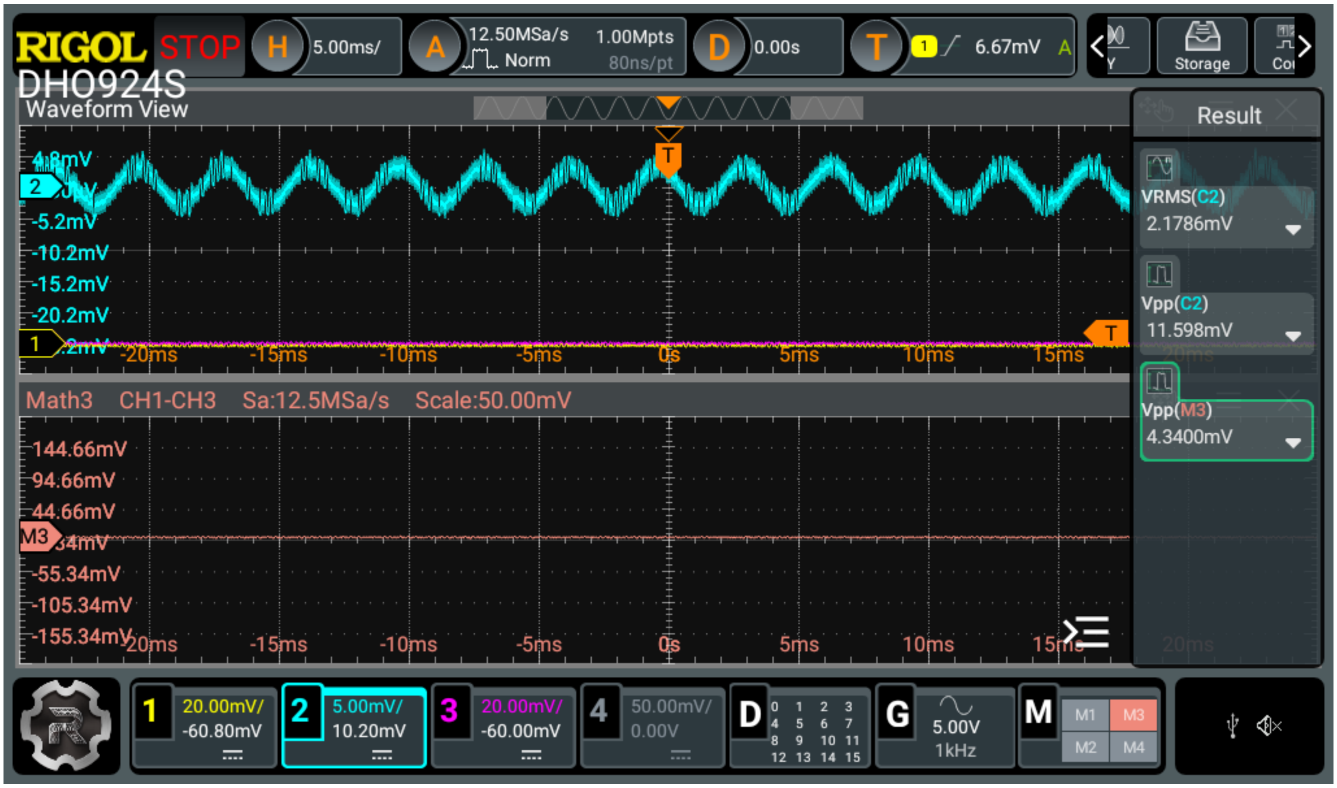

Figure 4-9. 300Hz Input at 25% Volume – No Vibration

DRV2605L output for 300Hz input at 50% volume (7.0mV). With a moderate 300Hz input, the driver again outputs has no vibration.

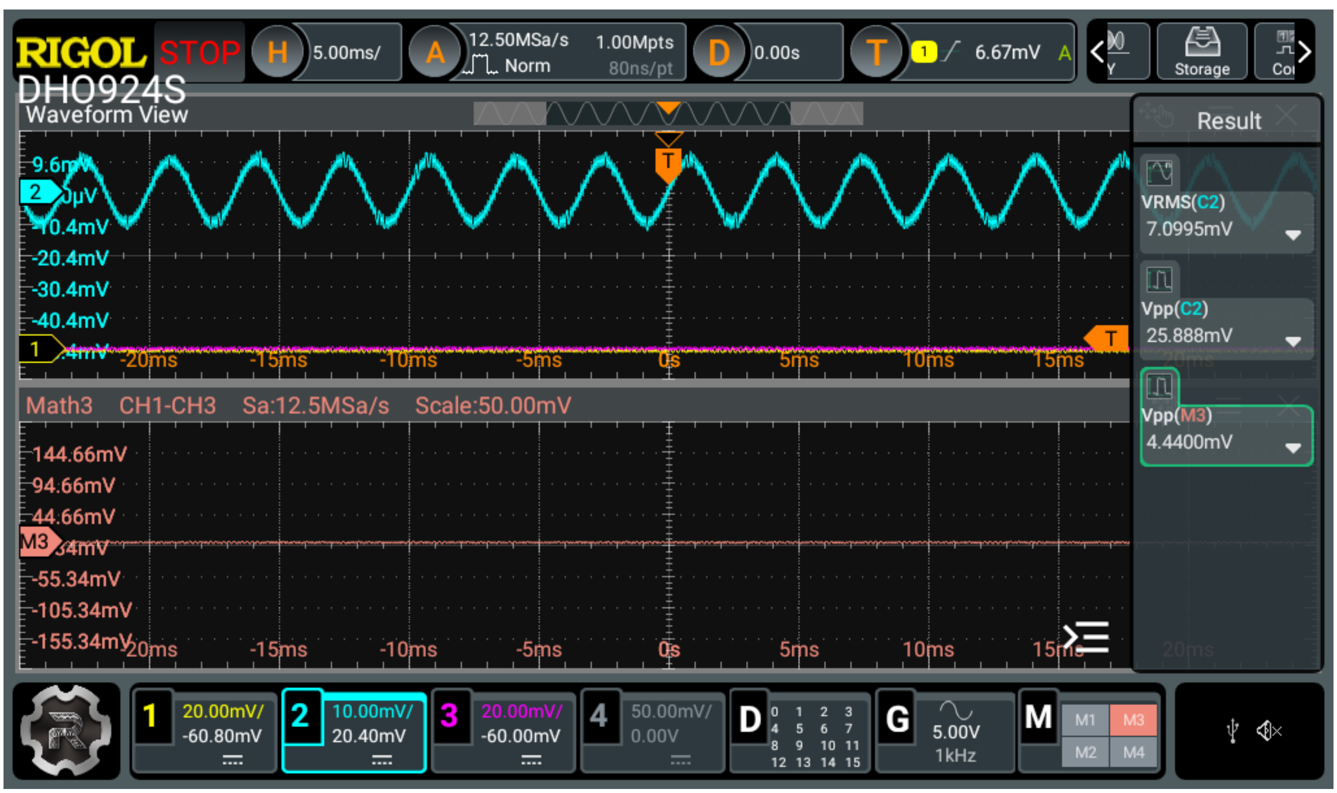

Figure 4-10. 300Hz Input at 50% Volume – No Vibration

Indeed, at 300Hz, the vibrations were quite weak. The DRV2605L appears to handle the input by converting this into a lower-frequency vibration but at an amplitude that reflects the difficulty of a 300Hz excitation. As the amplitude was increased:

DRV2605L output for 300Hz input at 75% volume (14.1mV). At 75% volume, the scope shows substantial PWM activity. The LRA does vibrate, but the vibration feels softer than the equivalent 75% at 200Hz. The output waveform is well-behaved (no erratic behavior), indicating the driver is in control – the driver simply cannot create as strong a vibration at that frequency.

Figure 4-11. 300Hz Input at 75% Volume – Soft Vibration

DRV2605L output for 300Hz input at 100% volume (21.0mV). With maximum audio amplitude at 300Hz, the driver outputs as much as the driver can. The scope shows a high-frequency content in the audio (blue) but the LRA drive (magenta or yellow) manifests as an amplitude-modulated waveform primarily at the LRA's resonance. The resulting vibration is present and roughly correlates to the audio's intensity, but this is noticeably weaker than the 100Hz or 200Hz full-volume cases.

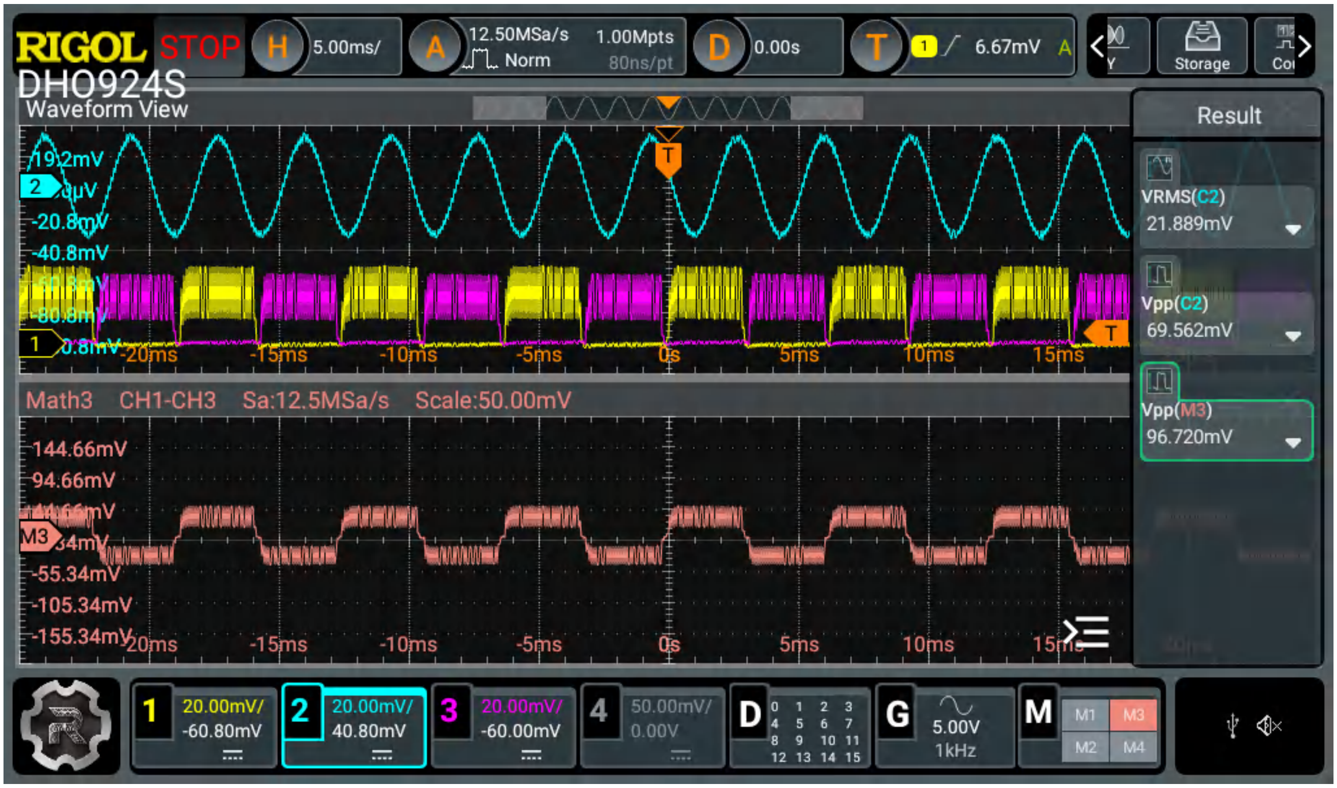

Figure 4-12. 300Hz Input at 100% Volume – Weak Vibration Response

Higher frequency, some tactile feedback is still generated – the control makes sure the waveforms remained clean in all cases (no unintended distortion or prolonged ringing). Note that very short audio bursts (less than approximately 10–20ms) do not produce much tactile sensation if below the human tactile threshold. The DRV2605L's algorithm likely incorporates filtering that can ignore extremely brief blips of audio to avoid spurious ticks.

Overall, these steady-state tests demonstrated that the DRV2605L effectively converts audio input into LRA vibrations, especially around the LRA's resonant frequency. The device provided a roughly proportional vibration response to the audio amplitude up the limits, with maintaining stability.

5 Mode Switching Behavior (Audio-to-Haptic vs. Real-Time Playback)

After characterizing the Audio-to-Haptic mode alone, the behavior when switching between Audio-to-Haptic (A-V) mode and manual drive modes was examined. In many applications, the system can normally run in Audio-to-Haptic mode for ambient feedback, but then temporarily switch to a direct haptic mode (like real-time playback or playing a library effect) when a specific event occurs that has a dedicated rumble pattern. The DRV2605L supports on-the-fly mode switching through the Mode register, but this is important to manage the transition to avoid any undesirable artifacts (like a momentary jolt or a pause in vibration).

Several scenarios were tested: switching from A-V mode to Real-Time Playback (RTP) mode, and vice versa, under conditions with and without ongoing audio input. The key observations were:

Understanding the Modes: In Audio-to-Haptic (A-V) mode, the DRV2605L autonomously drives the LRA from the audio input – no explicit I²C commands are needed to generate vibrations, as long as audio is present. In Real-Time Playback (RTP) mode, the DRV2605L instead takes direct commands: the host writes an 8-bit value to the RTP input register (0x02) at any time to specify the desired drive strength (effectively commanding the PWM output on the LRA). RTP mode is useful for generating arbitrary waveforms or playing back effects under host control. There is also a Waveform Sequencer/Library mode where the host can trigger predefined effect sequences (by writing to registers 0x04–0x0B for sequence and setting mode 0x00), but that is conceptually similar to RTP for the purpose of switching (the driver isn't using the audio input in that case).

- **Switching from A-V to RTP with No Audio Present:** If the audio input is silent at the time of switching to A-V mode, then effectively nothing happens (the driver goes into audio mode but since there is no audio, this outputs nothing). When the system switches from A-V to RTP mode, if no manual drive command is given, the vibration remains off. This scenario is trivial as there is no conflict – as soon as audio starts or an RTP value is written, the corresponding output takes effect.
- **Switching from A-V to RTP with Ongoing Audio:** This is a more interesting case. Imagine the device is in A-V mode with some continuous background audio, and then the system wants to take over and play a specific haptic effect through RTP or the library. In A-V mode, the DRV2605L is actively driving the LRA based on audio. At the moment of switching to RTP mode, if the driver immediately stops driving (because no RTP value is set yet), the LRA can abruptly halt, potentially causing a discontinuity. To avoid a sudden stop, the transition must be handled carefully.

For example, Figure 5-1 captures a scenario where the device was initially in RTP mode (with no vibration output commanded), and we switched to Audio-to-Haptic mode while a 100Hz audio tone at 50% volume was already playing into the DRV2605L. The top half of the scope trace shows the blue audio waveform continuing through the switch. The bottom (red) trace is the LRA output. You can see that once A-V mode is enabled (around the switch moment), the output starts oscillating and within 1 cycle reaches the expected amplitude for that audio input. This confirms the device smoothly began audio-driven operation (with just a minor initial dip due to the algorithm's settling).

Scope capture of switching from RTP mode to Audio-to-Haptic mode while a 100Hz audio tone is playing. Time 0 on the horizontal axis is the moment of mode switch. The blue trace (CH2) is the audio input (14.2mV RMS, about 50% volume) which is continuous before and after the switch. The magenta/yellow traces (LRA differential output) were flat during RTP mode (no drive commanded), then begin oscillating once Audio-to-Haptic mode engages. A brief amplitude ramp-up is observed immediately after t=0, as the DRV2605L's audio algorithm takes over. By about 40–50ms after the switch, the vibration output has reached steady-state, matching the audio's amplitude. The transition is smooth, with no large spikes or discontinuities.

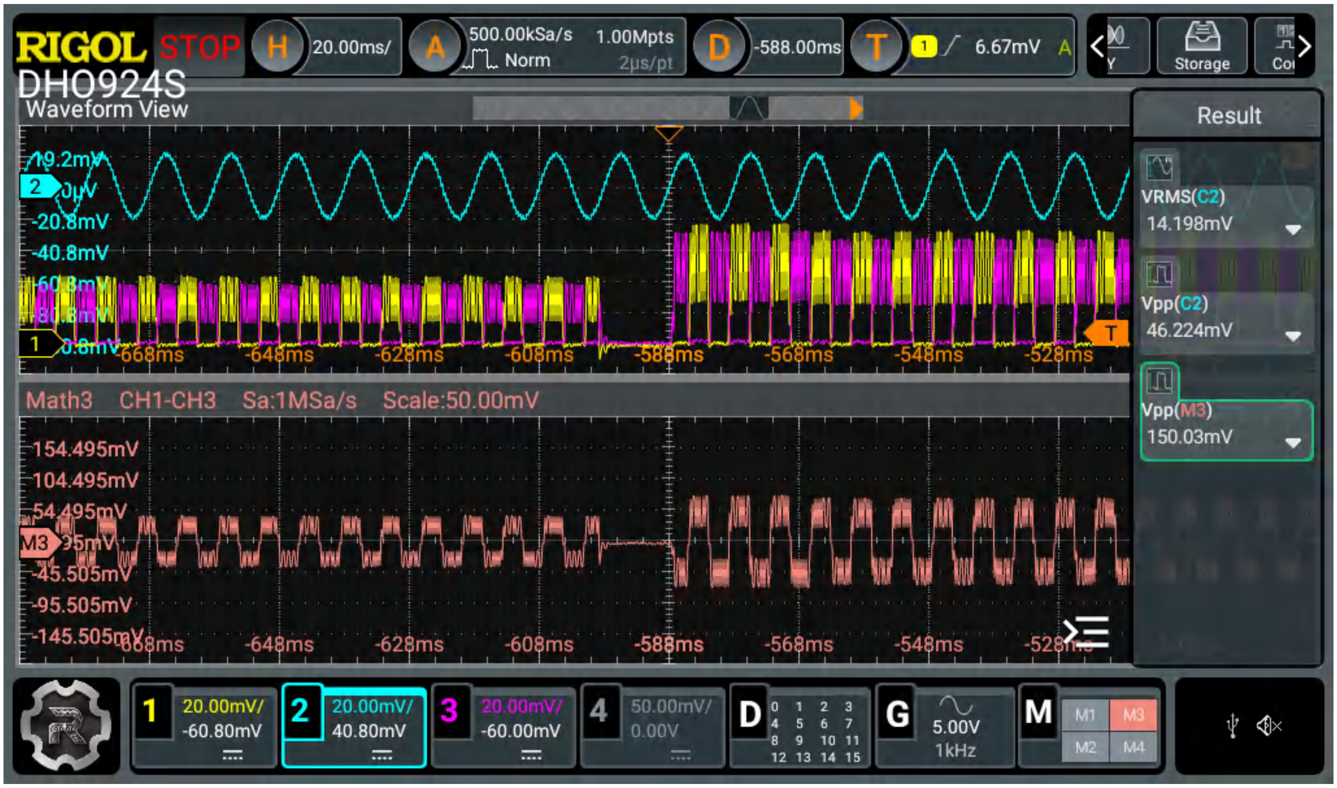

Figure 5-1. Switching From RTP Mode to Audio-to-Haptic Mode While a 100Hz Audio Tone is Playing

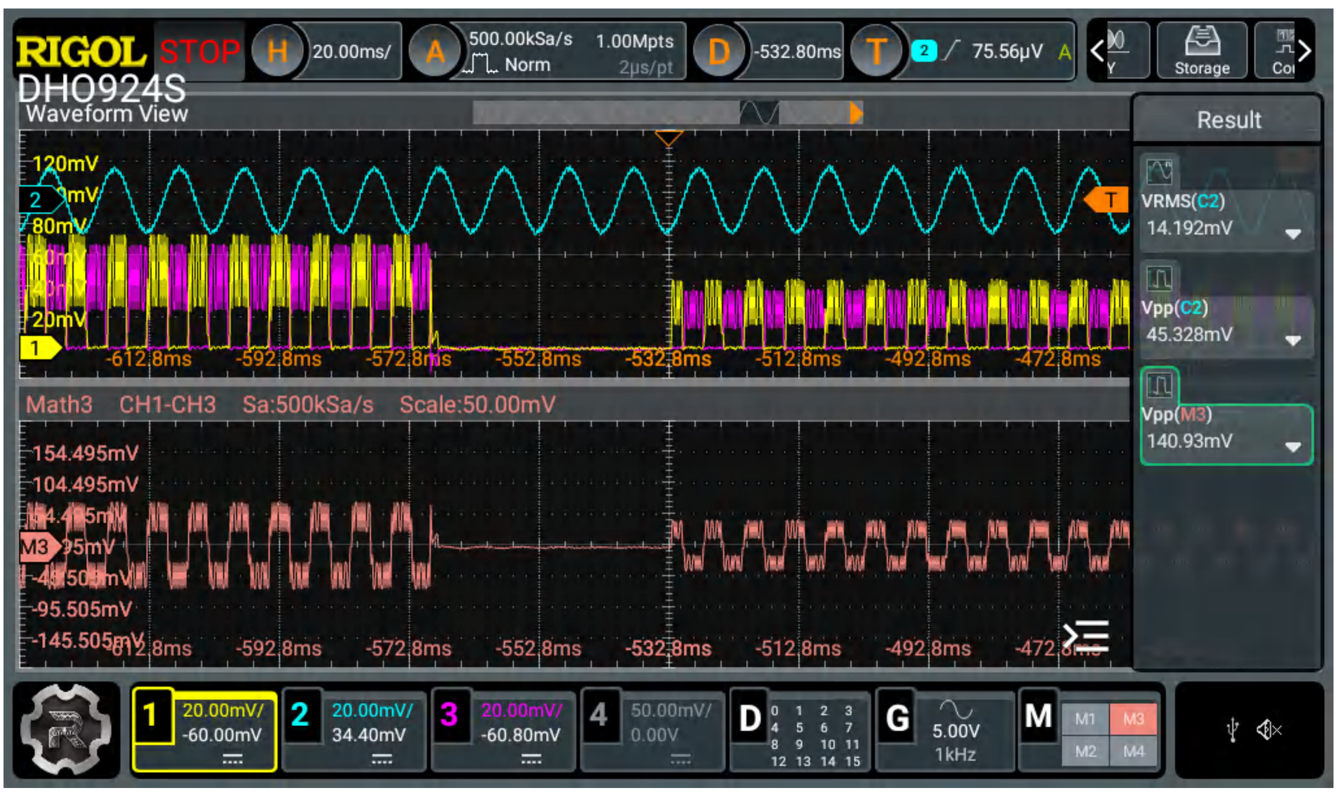

Figure 5-2. Switching From Audio-to-Haptic Mode to RTP Mode, Using the Technique of Zeroing the Drive at Switch-over

In summary, to achieve glitch-free transitions between automatic audio haptics and manual control, the host needs to manage the RTP register value at switch time (either matching the current level or setting this to zero for an intentional pause) and be mindful of the short mode-switch delay. With these practices, the DRV2605L can seamlessly hand over control without the user feeling any discontinuity in vibration.

6 Integrating and Switching Modes in DRV2605L: Audio-to-Haptic and Built-in Library Mode

Based on the above exploration, integrating the Audio-to-Haptic mode alongside the DRV2605L's other modes requires considering a few factors:

1. **Initial Device Configuration:** On startup, the DRV2605L can be auto-calibrated (if using a new LRA or if conditions have changed significantly) and then put into Audio-to-Haptic mode (Mode 0x04). Meanwhile, the host needs to be ready to switch modes through I²C when needed. This is also useful to configure the DRV2605L's control registers (such as the noise gate and filters) appropriately for the expected audio. In this design, default values worked well, but those registers allow customization of how the audio is filtered and scaled.
2. **Switching to Manual Mode:** When a specific haptic effect is desired (for example, a weapon recoil or an explosion the game explicitly knows about), the system can override the audio-driven vibrations by switching the DRV2605L to a manual mode. For instance, to play a ROM library effect, the device can be put in Waveform Sequencer mode (Mode 0x00) and the desired effect index loaded into the waveform sequencer registers. Alternatively, for a custom effect, Real-Time Playback mode (Mode 0x05) can be used and the host can stream the waveform by writing to the RTP register.
3. **Returning to Audio Mode:** After the event haptic is done (the effect completes or the custom command finishes), switch the mode back to 0x04 (Audio-to-Haptic) so that ongoing game audio resumes control. If audio was continuously playing in the background, the vibrations can kick back in automatically. Testing confirmed that this approach works well. The DRV2605L can robustly switch between modes and the tactile effect to the user is that there is always something driving the haptic motor – either the game's audio or the game's explicit haptic commands. Using the library effects is convenient because these are tuned waveforms for common events (like clicks, double clicks, ramping buzzes, and so on). One can, for example, use audio-to-vibe for general atmosphere, but when the player fires a weapon or there is an explosion that the game explicitly triggers, a stronger library effect can be used (while perhaps momentarily muting the audio input to the DRV2605L if needed, though this was often not even necessary to mute – switching modes automatically ignores the audio).

An important recommendation is to coordinate the audio and haptic events if possible. If a game event comes with a sound (like an explosion sound effect) and a library effect is also triggered for this, consider muting or lowering the audio feed into the DRV2605L at that moment to avoid double-driving the LRA. In practice, since the approach above actually switches modes, the audio input is not used when the library effect is playing, so no conflict arises. However, if one were using multiple DRV2605L drivers (for example, one for continuous audio haptics and another for event effects), make sure the audio-driven driver is not vibrating at the same time as the explicit effect driver to prevent overlapping vibrations. In the single-driver approach described, this situation is avoided.

To further streamline development, TI's PC GUI (USB-based console) was used to experiment with mode switching and to tune parameters before coding them. This is strongly recommended: using the EVM or a similar tool for initial development can accelerate understanding and provide a more engaging development process. For example, the GUI can quickly toggle modes and adjust settings without recompiling firmware, making this easier to fine-tune the behavior.

This tool provides register map and buttons to configure the DRV2605L's settings as shown in Figure 6-1.

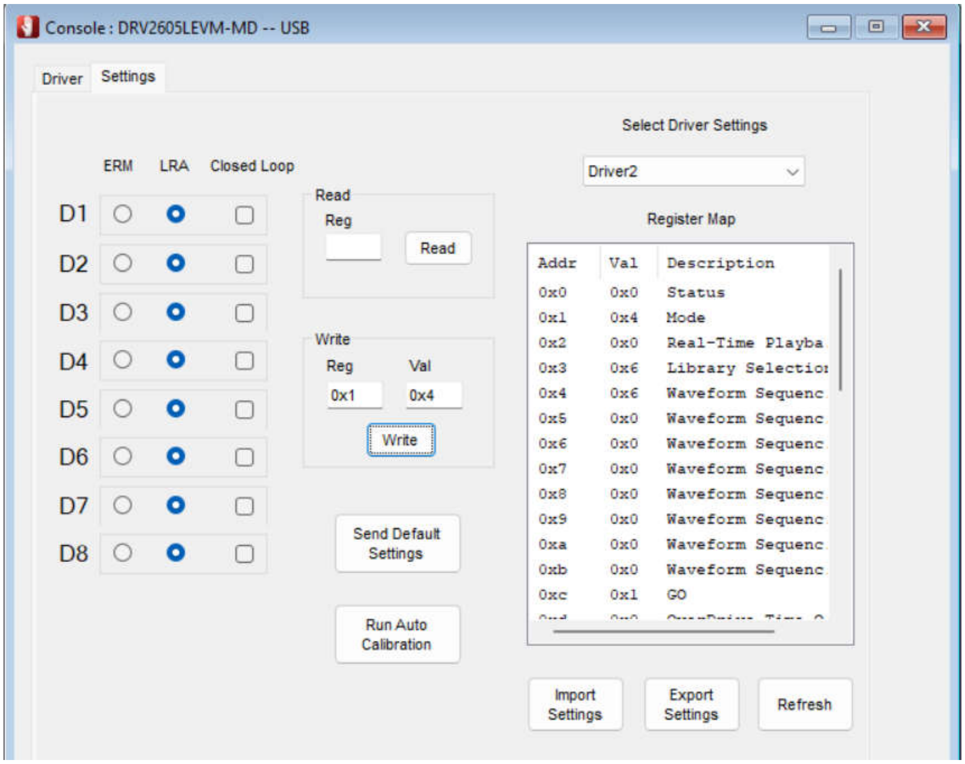

Figure 6-1. DRV2605LEVM-MD Console GUI (USB kit) Used in Development

7 Observations and Recommendations on Mode Switching

From these experiences, some key lessons were learned. Key observations and recommendations for implementing this include:

- **Use Closed-Loop (LRA) Mode:** Always configure the DRV2605L for closed-loop LRA drive when using an LRA. The Smart-Loop control is crucial for good performance. Tests in open-loop mode showed weaker and less consistent vibration. Closed-loop makes sure the LRA is driven at resonance and stops quickly when commanded to 0, which is especially helpful during mode switches (no residual shaking).
- **Minimize Mode Switches:** Mode switching needs to be infrequent and deliberate. Allow a delay of a few milliseconds for the DRV2605L to settle when switching modes. If mode changes are too frequent (for example, rapidly toggling between audio and manual modes), the LRA does not have time to stabilize, leading to sub-designed results. In practice, even switching once per game event is usually fine – just avoid unnecessary rapid toggling.
- **Group Haptic Actions:** This is generally recommended to keep the noise gate at default (approximately few mV threshold) to prevent unintended vibrations from very low-level audio. When planning haptic feedback, group haptic actions where possible. For example, if a cutscene with no gameplay is running, use audio-to-haptic for background music; when the cutscene ends and gameplay resumes with explicit events, switch to manual mode for those. Clustering mode switches around logical segments of gameplay avoids constant toggling and makes the haptics more predictable.
- **Use Auto-Calibration Appropriately:** Make sure the accuracy of the driver's closed-loop parameters. In this design, once calibrated, recalibration on every boot was not needed (the values can be stored, or the values remain in the driver unless power is removed). However, performing auto-calibration at least once (or occasionally, if environmental conditions change) is a good practice to maintain designed for performance. This was verified that leaving the device uncalibrated can result in subpar feedback, so calibration is advisable.
- **Monitor Status Flags:** During testing, the status register (which includes fault flags) was monitored to make sure no fault conditions were being triggered – none were in these tests. The recommendation is to incorporate such monitoring in the final design, especially when driving an LRA hard, to catch any overcurrent or other fault conditions.

By incorporating the above recommendations – particularly the careful handling of transitions – engineers can achieve seamless integration of Audio-to-Haptic and manual haptic control on a gaming handheld device. The approach harnesses the existing audio output of games to generate immersive vibrations in real time, while still allowing explicit haptic effects on demand. The DRV2605L provides a powerful method by automatically transforming audio signals into tactile feedback, and the closed-loop control keeps those vibrations crisp and on-point. Tests across various audio frequencies and volumes illustrated that the device effectively converts audio input into meaningful vibrations – especially around the LRA's resonant frequency where the feedback was strongest. Also, when specific events demanded unique haptic responses, the system can temporarily switch modes and deliver the desired effect without jarring the user or introducing latency.

Looking beyond this specific test scenario, the concept of Audio-to-Haptic feedback has broad applicability. Any consumer device with an audio output can potentially leverage this technology to enhance user experience. For example, a VR controller can use Audio-to-Haptic to generate environmental vibrations (wind, distant explosions) from game audio for added immersion. A home theater chair or wearable vest can convert a movie or game's audio soundtrack into vibrations for a simple *4D* experience. The DRV2605L, with the small size and flexibility, is well-designed to these applications. In the future, one can imagine devices like smart phones, tablets, or car entertainment systems using audio-driven haptics to enrich content without requiring developers to explicitly code haptic tracks for every piece of media.

8 Summary and Future Applications

This application note demonstrated how to integrate and use the TI DRV2605L haptic driver in Audio-to-Haptic mode on a gaming handheld device. Our approach was to harness the existing audio output of games to generate immersive vibrations in real time, while still allowing explicit haptic effects on demand. The DRV2605L provides a powerful design by automatically transforming audio signals into tactile feedback, and the closed-loop control makes sure those vibrations are crisp and on-point. Our tests across various audio frequencies and volumes illustrated that the device effectively converts audio input into meaningful vibrations – especially around the LRA's resonant frequency where the feedback was strongest. The experiment also showed that the device can smoothly transition between audio-driven haptics and direct command-driven haptics (RTP or library mode), which is crucial for practical use in games that have a mix of ambient and scripted haptic events. The provided control scheme (including I^2C commands and mode-switch strategy) can serve as a reference for engineers to replicate and fine-tune projects.

Looking beyond our specific test scenario, the concept of Audio-to-Haptic feedback has broad applicability. Any consumer device with an audio output can potentially leverage this technology to enhance user experience. For example, a VR controller can use Audio-to-Haptic to generate environmental vibrations (wind, distant explosions) from the game audio, while still using specific haptic cues for direct interactions. Similarly, a gaming chair or wearable vest can convert a movie or game's audio soundtrack into vibrations for a simple *4D* experience. The DRV2605L, with the small size and flexibility, is well-designed to these applications. Nevertheless, even with current technology, implementing the DRV2605L as described can significantly bridge the gap when explicit haptic content is lacking, enriching the user's immersive experience with minimal software overhead.

In conclusion, integrating the DRV2605L into a gaming handheld for Audio-to-Haptic feedback is a feasible and effective design. This provides continuous, context-aware rumble by utilizing the game's own audio, requires modest hardware changes, and is highly configurable to match the desired feel. By following the guidelines and examples provided in this note, engineers and field application teams can accelerate development and deliver a more engaging product. The combination of real-time audio-driven haptics and on-demand custom effects – all enabled by the DRV2605L – opens up a new dimension of interactive feedback for gamers and beyond.

9 References

1. Texas Instruments, *MSP430FR573x Mixed-Signal Microcontrollers*, data sheet.
2. Texas Instruments, *DRV2605L ERM and LRA Haptic Driver Evaluation Kit*, data sheet.
3. National Library of Medicine, *Temporal Summation in Vibrotactile Sensitivity*, R T Verrillo, 1965