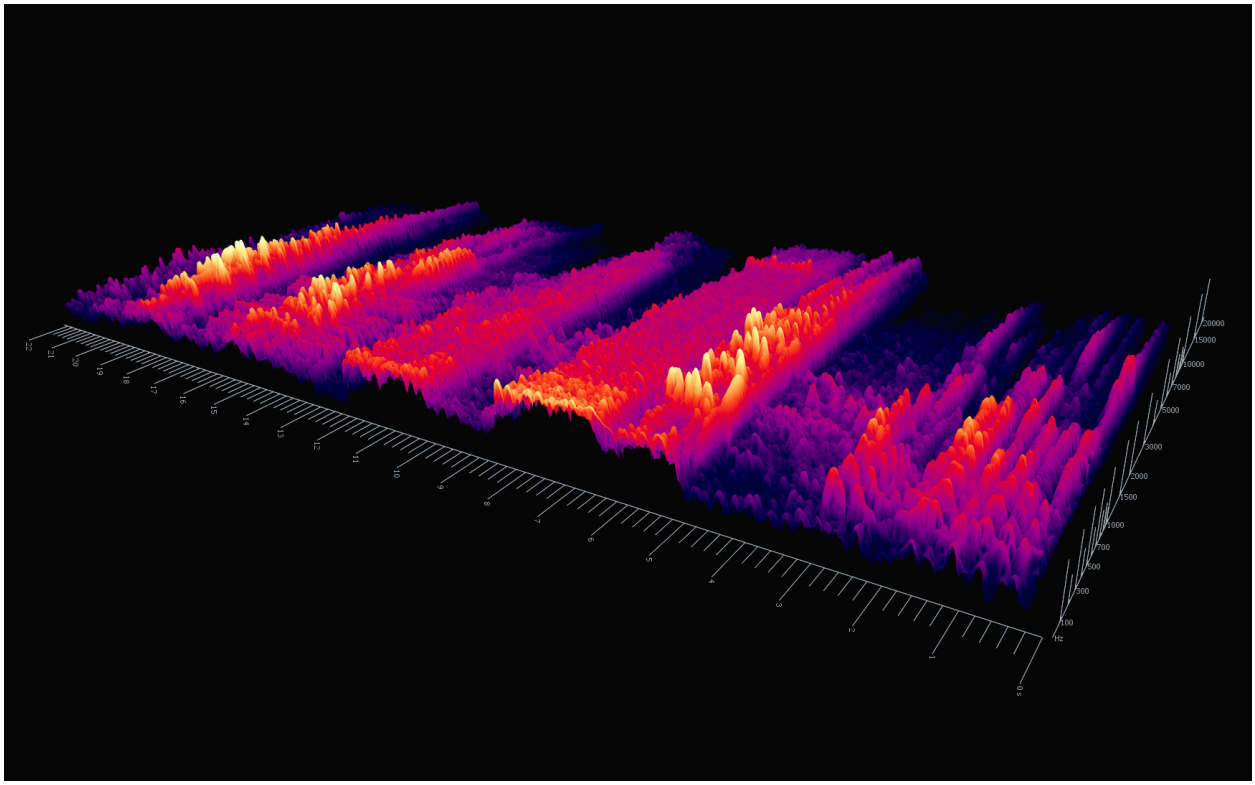
Why Digital Signal Processing Is the Key Requirement for HD Haptics

Deliver realistic experiences that enhance product differentiation with Lofelt Wave



Haptic technologies offer tremendous potential for delivering immersive experiences for games, movies, music and more. By supplementing audio-visual content with tactile vibrations, haptic technologies can enhance sensory stimulation and increase user engagement.

Many hardware platform vendors have integrated basic haptics into their products. Using simple actuators, they have created game controllers that produce low rumbles or smartphones that generate buzzing alerts. But next-generation high-definition (HD) haptics requires more than hardware alone. Incorporating software into haptic systems is critical for overcoming limitations of hardware-only solutions.

Software-based digital signal processing (DSP), running as firmware on embedded processors, optimizes signals used by the actuators to produce vibrotactile feedback. With the right engine, software-based DSP can maximize hardware capabilities for delivering lifelike experiences.

Lofelt is pioneering the integration of software and hardware for haptics. By combining real-time, audio-driven DSP with wideband actuators, Lofelt Wave™ technology offers an end-to-end haptic system that surpasses results provided by hardware-only solutions and delivers natural, realistic experiences that enhance product differentiation.

Optimizing haptic signals with real-time DSP

Overcome the limitations of hardware-only solutions.

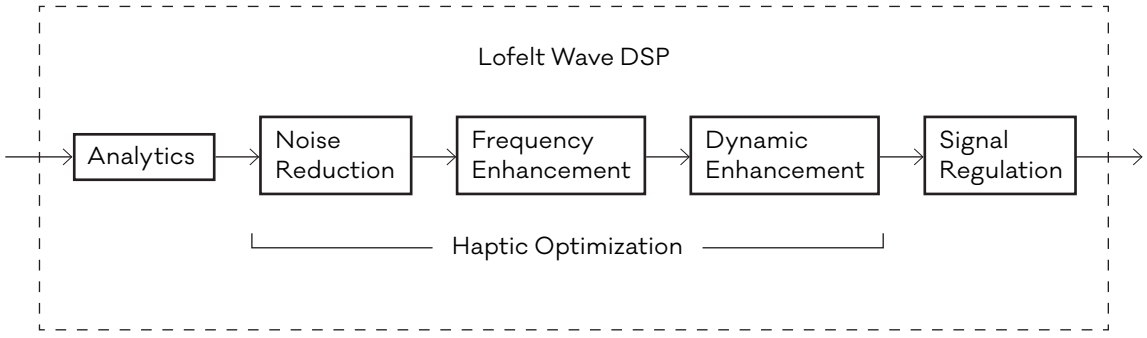
Hardware-only solutions are unable to capitalize on the full potential of using audio input to generate haptics. Some simply translate the amplitude of sound into the vibration frequency of an actuator. Others solely boost bass audio to produce low-frequency vibrations. These solutions cannot compensate for variations in background noise levels, equalization or dynamics among content. They are unable to tune incoming audio frequencies specifically for human mechanoreceptors or adjust dynamics to intensify vibrotactile feedback.

The Lofelt Wave DSP engine offers a real-time, software-based signal flow that optimizes audio for haptics. Drawing from advanced audio technologies, the engine comprises multiple, integrated components:

- **Analytics:** Collects and analyzes key data on the incoming audio signal – including peak volume, average level over time and audio transients – and passes information along to other components.
- **Noise reduction:** Helps ensure only important audio events are translated into haptics.
- **Frequency enhancement:** Tunes incoming frequencies for human tactile senses.
- **Dynamic enhancement:** Helps deliver consistent tactile experiences and can boost the impact of certain audio events.
- **Signal regulation:** Prepares the signal for the unique characteristics of the actuator and its hardware environment.

This signal flow operates in real time, delivering extremely low latency between audio events and haptic feedback. The DSP engine keeps latency below 6 ms – easily within the range needed for delivering heightened realism.[1]

Envisioning the future of haptics
To explore the requirements for delivering realistic user experiences through HD haptics, read the white paper, Elevating Haptic Technology with Lofelt Wave.



Lofelt Wave DSP incorporates analytics, noise reduction, frequency enhancement, dynamics enhancement and signal regulation components for real-time signal flow optimization.

[1] The overall latency of the end-to-end experience is dependent on the other devices and technologies employed. For example, a wireless game controller might introduce additional latency through the wireless connection.

Boosting the impact of haptics with adaptive noise reduction

Translate only the most important audio events into haptic vibrations.

Audio content might include sounds that should not be translated into haptic feedback. Let's say you want to provide an immersive experience for watching sporting events. The broadcast audio signal from a soccer match contains not only the sounds of the ball being kicked but also the noise of the crowd and commentary from announcers. At the instant when the ball is kicked, you want to ensure that a vibration from the kick is strongly felt and not drowned out by a constant rumble of a cheering crowd.

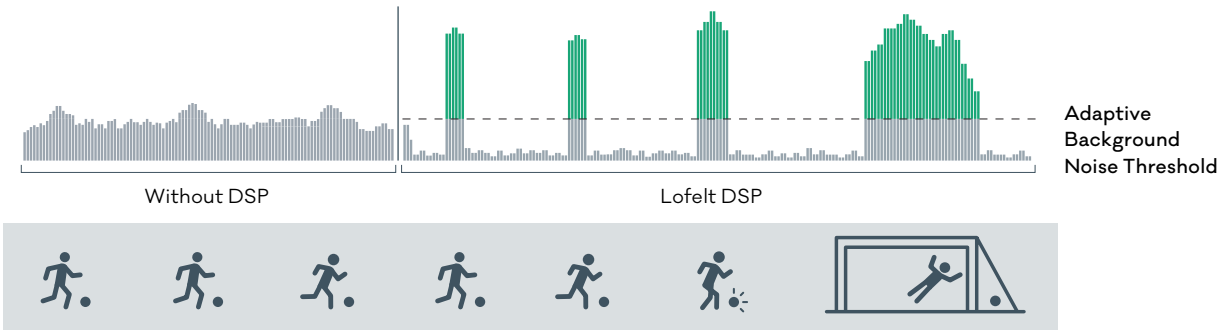
With hardware-only solutions, you cannot easily filter out the unwanted sound. Noisy games, movies, sporting events, music and other content will cause the actuator to vibrate continuously, diminishing the overall impact of the haptic experience.

Lofelt Wave DSP uses the analysis of incoming audio content to apply noise reduction to background sounds. Reducing the background helps ensure that only important aspects of the signal are used for generating tactile vibrations. The DSP engine leaves background content in the audio domain without vibrating the actuator. By applying noise reduction, you can deliver haptic experiences designed for maximum impact.

Providing user-selectable profiles
User testing has shown that most people prefer a subtle haptic experience while listening to music; slightly more dynamic haptics when watching movies; and more intense, immersive haptics while playing games. Lofelt Wave DSP provides distinct, user-selectable onboard profiles for gaming, music and movies – with no hardware changes required. The desktop-based Lofelt Wave Control application allows parameter adjustments for fine-tuning and constructing custom profiles. You can modify DSP parameters to create a signature haptic character that helps differentiate your brand.

	Gaming	**Movies**	**Music**
Desired haptic experience	Intense	Dynamic	Subtle
Frequency/dynamic enhancement	Max	Medium	Minimum
Noise reduction	Max	Medium	Off

Users can switch among profiles to accommodate different content.



Noise reduction enhances the impact of key events while preventing background noise from vibrating the actuator.

Tuning haptics for human physiology with frequency enhancement

Enrich the frequencies that will have the greatest tactile impact.

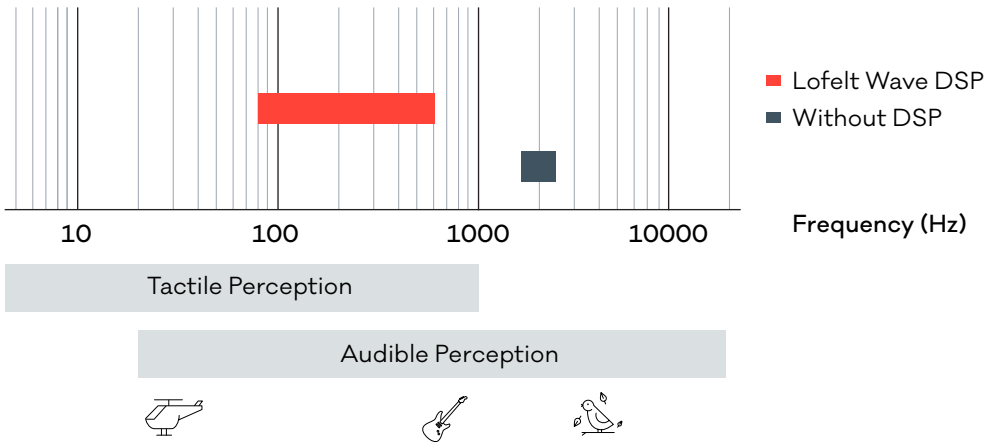
Audio content from games, movies and music typically contains a broad range of frequencies – but not all of those frequencies are the ones required for creating haptic experiences. For example, a hammer hitting an anvil in a video game might generate a sound that peaks at 2000 Hz. However, the human mechanoreceptors responsible for signaling pressure and transient events (such as the hammer hitting the anvil) are stimulated by lower-frequency vibrations, ranging from 40 to 1000 Hz.

Hardware-only solutions are unable to dynamically optimize incoming audio frequencies for human mechanoreceptors. With a hardware solution, the anvil strike might simply vibrate an actuator at the peak audio frequency of 2000 Hz, failing to deliver the same tactile impact as a lower-frequency vibration.

The frequency enhancement component of the Lofelt Wave DSP engine boosts frequencies in the right range for those human mechanoreceptors. The result is a more natural tactile response to the event.

Lofelt Wave DSP further enriches frequencies with advanced physical modeling. The engine uses the incoming audio to excite a physical model of a musical instrument. The physical model responds to the incoming sound according to the sound's envelope – it responds differently to a percussive clap than to a vocalized melody. This process creates natural sympathetic resonances that can subtly enhance the haptic signal.

The audio signal also activates a sine wave at a frequency that will have a meaningful haptic impact. The sine wave is combined with the original signal and the results from the physical modeling to create a very nuanced and natural haptic signal.



An example of audio events at 2000 Hz being processed into the key haptic sensitivity frequency range.

Ensuring consistency and increasing engagement with dynamics enhancement and analytics

Accommodate variations in audio volume.

The sound level of audio content can vary dramatically among games, movies and music. The level can even change significantly within a single title. Some games feature continuously high-volume soundtracks. Others might begin in a subdued environment and then ramp up action with a loud soundtrack and exciting events.

Without software processing, a system that uses audio as input for haptics cannot easily compensate for volume variations in audio content. Two equally exciting action-adventure games could generate very different haptic results. For the user, shifting from one game to the next could produce a jarring experience.

Lofelt Wave DSP automatically compensates for dynamic discrepancies in signals. The DSP engine continuously analyzes the peak volume, average volume and transients of incoming audio. Changes in intensity are then leveled out to avoid dramatic shifts in haptic feedback for a consistent feeling. By continuously analyzing incoming audio, the DSP engine becomes an adaptive, closed-loop system that can even adjust to changes within a game, movie or piece of music.

The dynamic enhancement component of the DSP engine can also augment the dynamics of audio content. It can boost the haptic impact of certain audible events and actions to provide an even more engaging user experience.

Image taken from Limbo video game

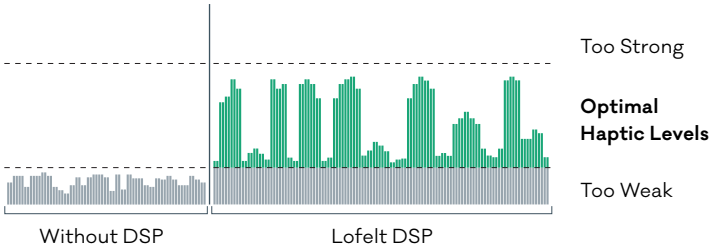
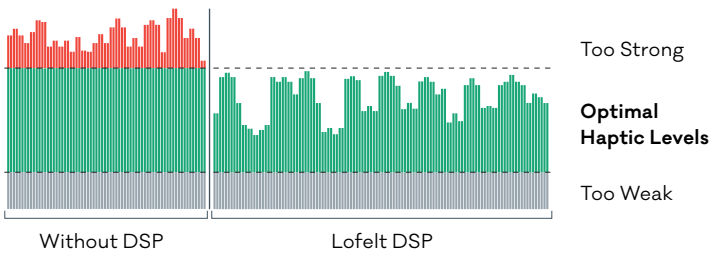


Image taken from Eve Valkyrie video game



Protecting actuators and future-proofing your design

Address hardware issues without costly, time-consuming redesign.

Without optimizing audio signals for actuators, hardware-only haptic solutions leave actuators vulnerable to damage and fatigue. Driving an actuator at too high of an amplitude could cause the component to wear out. You might be faced with frustrated customers and costly warranty repairs or replacements.

Hardware-only solutions also have difficulty addressing unexpected issues relating to the actuator's physical characteristics and its interactions with other hardware elements. The actuator's mass, frequency response range, maximum displacement and resonance all can interfere with the intended haptic results. Hardware-based solutions that simply translate motor-on messages into vibrations lack the flexibility to handle these issues without a redesign. You might need to test different actuators or fine-tune other aspects of the physical environment, which could add costs and delay your launch.

Lofelt Wave DSP automatically optimizes the signal for the actuator tolerance and attached mass, and keeps the actuator displacement within the hardware specification. You can deliver a consistent, balanced user experience while increasing the lifetime of actuators.

With Lofelt Wave DSP, you can also adjust for unexpected hardware issues without a costly, time-consuming redesign. You can tweak DSP parameter settings to compensate for physical characteristics and interactions so you can deliver an optimal experience. Even if issues arise late in the development cycle, you can make modifications easily with firmware updates.

Lofelt Wave DSP also enables you to make aftermarket upgrades. You can respond to marketplace trends and introduce new, differentiating features once your product is on the shelves – without undertaking a new hardware launch.

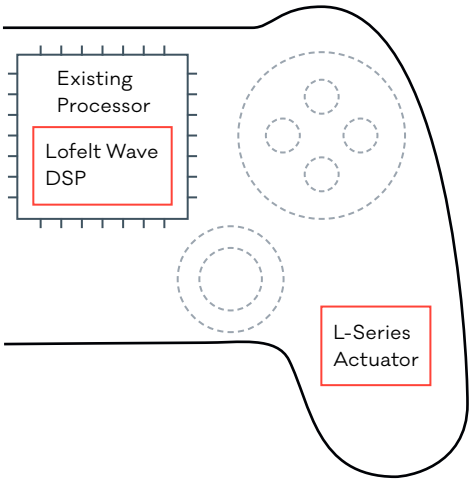
Considering implementation options for Lofelt Wave DSP

Run firmware on a discrete or existing processor.

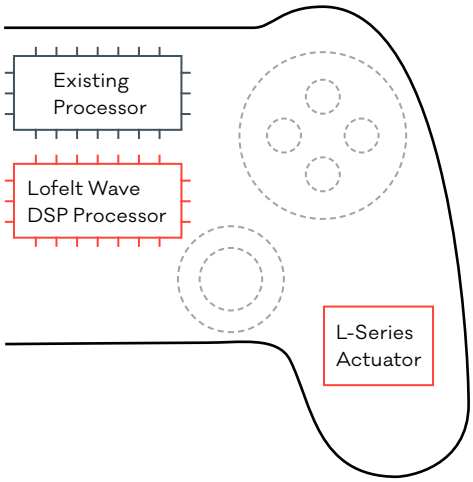
Lofelt Wave DSP was designed for maximum efficiency. Because it does not require tremendous processing performance, it can be implemented in a wide array of processors – including off-the-shelf, ultra-low-power embedded Arm®-based processors. The processor you choose needs only to meet a set of minimum requirements. The DSP processor can be embedded in a controller or headset without adding significant weight or engineering complexity. You also have the choice to run Lofelt Wave DSP on your hardware platform's existing processor if there are sufficient processing resources. Doing so enables you to consolidate hardware components, reducing space, weight, power and costs.

Accelerating time to market with end-to-end haptics
Lofelt Wave DSP is part of the comprehensive, end-to-end Lofelt Wave haptic system, which also incorporates wide-band hardware actuators. With an end-to-end system, you can eliminate the lengthy – and costly – work of developing firmware, testing actuators and integrating components. Lofelt also offers extensive resources to help further speed product integration and accelerate time to market.

1. Existing Processor



2. Standalone Processor



Lofelt Wave DSP can run on the hardware platform's existing processor or a standalone processor.

Maximizing the value of HD haptics with Lofelt Wave

Integrating software processing into your haptics system can help elevate haptics beyond notification-like buzzes and low-end rumbles. You can provide a more engaging, consistent user experience while gaining the flexibility for modifying that experience without redesigning your hardware.

Lofelt Wave technology is leading the way in the integration of software and hardware for haptics. Using advanced digital audio technologies, Lofelt Wave DSP can help deliver extremely natural, realistic experiences that enable you to better differentiate your products in a highly competitive marketplace. By providing an end-to-end haptic system, Lofelt Wave reduces the time and complexity of haptics integration, allowing you to achieve a rapid return on investment.

Ready to learn more about Lofelt Wave? Contact us at lofelt.com/contact to receive spec sheets, schedule an in-person demo and discuss ways we can work together. Also, you can request an evaluation kit for your own prototyping.

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