

Elevating Haptic Technology with Lofelt Wave

Delivering realistic user experiences with
an audio-driven end-to-end haptic system



From gamers and movie fans to music enthusiasts and virtual reality (VR) early adopters, consumers today are demanding greater realism in their multimedia experiences. Even people operating a computer mouse or using a tablet on an automobile dashboard increasingly expect to receive more than visual and audio cues: they want to feel realistic tactile responses.

Haptic technologies offer a compelling way to augment audiovisual technologies by generating sensations felt through the skin.

Yet initial haptic technologies have been primarily limited to simple vibrating notifications – they are a poor match for the stunning sound and images generated by more mature audiovisual systems.

Lofelt Wave™ technology is a comprehensive, end-to-end haptic system that uses an innovative real-time, audio-driven approach to overcome the limitations of other haptic technologies. By combining wideband hardware and advanced firmware with deep engineering expertise, Lofelt Wave delivers natural, realistic sensory experiences across a broad array of use cases.

Understanding the basic physiology of touch

Producing a realistic user experience requires an understanding of tactile perception.

We gain important information about our surroundings through haptic feedback. We perceive motion (kinesthetic feedback) through our muscles, joints and tendons. And we sense pressure, temperature, texture and vibrations (tactile or cutaneous feedback) through a variety of mechanoreceptors located in the skin.

Most haptic technologies developed for touch-based smartphones and tablets, gaming, music listening and similar use cases focus on providing tactile feedback through vibrations. Depending on their frequency, those vibrations stimulate one or more types of mechanoreceptors embedded in the skin, providing different kinds of information. For example, low-frequency vibrations (between 5 and 200 Hz) stimulate mechanoreceptors located near the surface of the skin, which help us recognize textured objects with small bumps and ridges. Higher-frequency vibrations (from 40 to 1,000 Hz) stimulate mechanoreceptors located deeper in the skin that indicate when we're encountering pressure or experiencing transient events, such as a collision.¹

In haptic technologies, vibrations are typically created using some form of actuator.

Integrating small actuators into systems such as gaming headsets or touch-based tablets enables manufacturers to produce sensory experiences by engaging the human haptic system.

In the real world, we often experience haptic and audio vibrations together. A single event can generate haptic and audio vibrations across a wide range of frequencies and amplitudes – and those frequencies and amplitudes change over time. For example, an explosion generates high-amplitude broadband signals - high frequencies audible through the air, and low frequency vibrotactile signals felt through the ground. The amplitude of the haptic vibration may fade quickly, while acoustic reflections mean the audible part fades at a different rate.

Similarly, whether we're listening to a symphony or riding a motorcycle, we experience complex, dynamic waveforms that comprise multiple frequencies stretching across the audio and haptic spectrums. Creating a realistic experience, then, requires more than implementing a single-frequency actuator and programming it to vibrate at a particular intensity for a certain length of time.

¹ For the ways in which auditory and tactile perception work together in the experience of music, see Merchel, S. (2014). *Auditory-Tactile Music Perception* (ISBN:978-3-8440-3161-4), Shaker Verlag, Germany.

Defining requirements for delivering a realistic experience

Haptic technologies must satisfy several key requirements to deliver immediate, realistic experiences.

Wideband vibration frequencies: Real-world events produce complex, multi-frequency haptic and audio vibrations. But many current types of vibration actuators and motors have a limited frequency range. Some can only produce one or two fixed frequencies. Few can produce vibration frequencies below 100 Hz, though there is important information that can be transmitted at lower frequencies. Producing realistic, natural tactile feedback requires haptic technologies that can draw from complex, dynamic, full-spectrum audio waveforms and enhance those waveforms by producing vibrations across a full haptic frequency spectrum.

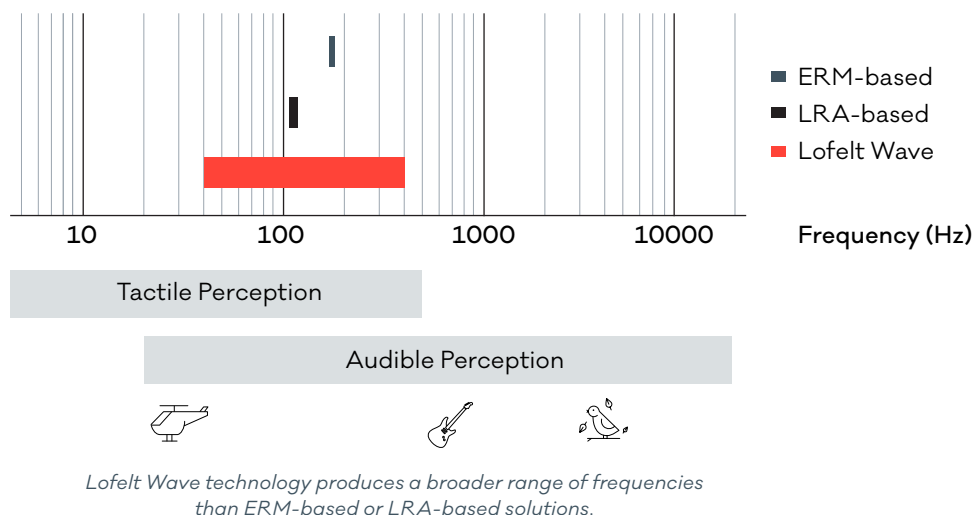
Separation of amplitude and frequency: Some vibration-based haptic technologies use actuators or motors that are unable to separate amplitude and frequency. With those technologies, if you want to increase the amplitude (to generate a more powerful sensation), you also have to increase the frequency of the actuator or motor. Enhancing realism requires technology that disentangles amplitude and frequency. You should be able to create powerful – or subtle – sensations across a full frequency range.

Low latency: Audio, visual and tactile cues must be tightly synchronized.

In gaming, for example, players must see, hear and feel an explosion simultaneously for it to be perceived as real. Extensive research and user feedback has shown that the latency between a sound and a vibration should be lower than 12 ms to maintain the illusion they are related.²

Signal optimization: To maximize the impact of the sensory effect and to optimize the use of the hardware, haptic technologies should optimize the signal they use to create vibrations. They should remove any extraneous noise from the signal – including any resonant peaks or other undesirable audible artifacts created by the device – to produce vibrations that are tailored for the frequency range of the human haptic system.

Lofelt Wave technology takes a unique approach to providing tactile feedback that meets these requirements for delivering highly realistic user experiences. Advanced firmware with innovative digital signal processing (DSP) produces an extreme low-latency signal flow while optimizing the signal for human haptics. Wideband frequency actuators that separate amplitude from frequency generate vibrations covering a full frequency and dynamic range.



² See Merchel, S. (2014). *Auditory-Tactile Music Perception* (ISBN:978-3-8440-3161-4), Shaker Verlag, Germany.

Providing a real-time, end-to-end signal flow

Lofelt Wave encompasses multiple technologies that together enable an end-to-end signal flow from the original source media to the user.

To deliver the most immediate, realistic experience, Lofelt has designed a real-time signal flow that can provide extreme low latency of less than 6ms.³ Academic research, feedback from gamers and musicians using digital audio technology, plus Lofelt's own in-house testing, all have shown that users need latency to be less than 12 ms to feel the connection between the vibrations and other audiovisual cues.

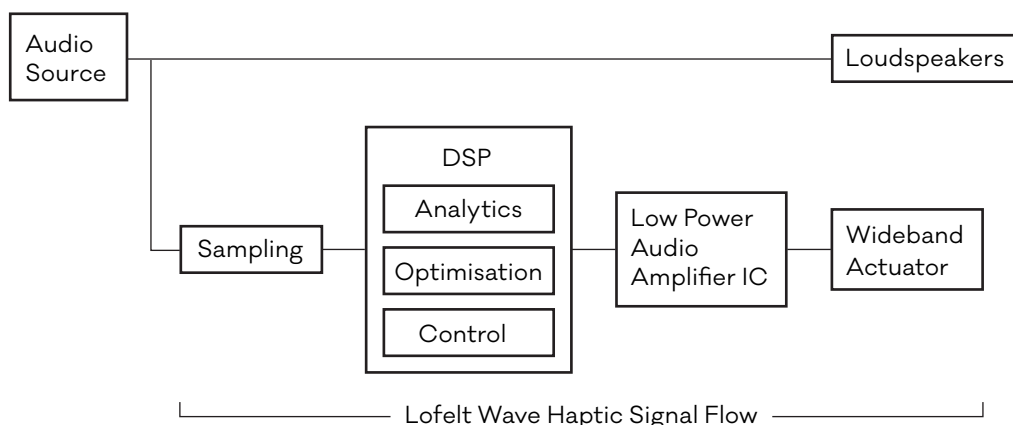
A wireless gaming headset that uses Lofelt Wave offers an example of a typical signal path. The headset receives digital audio information wirelessly and decodes it into stereo audio. The Lofelt technology then taps into the stereo audio, which is digitally sampled by the Lofelt Wave DSP running on an embedded processor.

The Lofelt Wave DSP analyzes the digital information and refines the signal to deliver the best possible haptic experience. As part of the process, the DSP reduces extraneous background noise in the signal and optimizes the signal frequency to match the body's perceptible tactile range.

Adaptive algorithms operate as a closed-loop system. The Lofelt Wave DSP continuously analyzes the audio and uses the results to modify haptic processing parameters, creating a consistent user experience even as the audio environment changes.

At the same time, built-in displacement protection helps maximize the lifespan of the actuators. This capability ensures that the actuators are not pushed past their physical limitations, which could cause damage and reduce their lifespan.

After optimizing the signal, the DSP translates the signal back into the analog domain, generating two audio signals for the left and right sides of the headset. The analog signals pass through low-power integrated-circuit (IC) amplifiers, which provide sufficient power to drive the actuators. The actuators then translate this audio information into vibrations that are perceived in a way that enhances the depth of the experience by complementing and reinforcing audiovisual content.



Lofelt Wave provides a real-time end-to-end signal flow from the original audio source to the user.

³ 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.

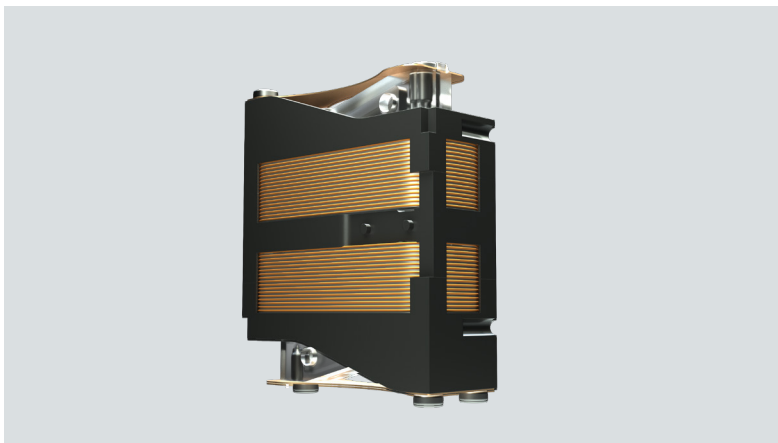
Generating dynamic, wideband vibrations

Lofelt Wave incorporates hardware technology designed to enhance tactile perception.

Lofelt Wave actuators produce a full spectrum of vibration frequencies, including sub-audible frequencies that are essential in generating a realistic experience. These actuators offer a continuous frequency range, allowing you to generate smooth frequency sweeps from high to low or vice versa. You can even reproduce vibrational polyphony, creating a low rumble and layering higher frequency vibrations on top.

With Lofelt Wave actuators, you can control frequency and amplitude separately – unlike with other haptic technologies. You can produce low frequencies that are powerful, subtle or anywhere in between.

Lofelt Wave actuators also operate efficiently. If you attempt to simulate a variety of frequencies using a single-frequency actuator, for example, the actuator will consume a lot of energy – and battery life will suffer. Because Lofelt Wave actuators are designed to operate over a wide frequency range, it can do so much more efficiently than an actuator that is being pushed beyond its fixed frequency.



Lofelt L5 Actuator

Eccentric rotating mass (ERM) motors

ERM motors spin an offset mass in a circle, creating a vibration. To deliver more power, you speed up the motor, which also raises the vibration frequency. ERM motors cannot reproduce complex waveforms or provide accurate, timely feedback for audiovisual cues since it might take 100 ms for a motor to start vibrating. Because there is no way to disentangle frequency and amplitude, ERM motors cannot create nuanced sensations.

Linear resonant actuators (LRAs)

LRAs operate like loudspeakers, except that they move a mass back and forth instead of pushing air. Each LRA has a fixed resonant frequency and lets you adjust its amplitude independently. This single-frequency design is a significant limitation. Though you can try to simulate different frequencies – for example, by turning the actuator on and off at different rates – the result is not very realistic. Dual-frequency LRAs help overcome the inability to alter frequencies. But these actuators still only deliver a very limited experience.

Piezo actuators and electro-active polymer actuators (EAPs)

Piezo actuators and EAPs are available in small form factors that enable them to be embedded into tablets and smartphones. However, both require high voltage to drive them, which can present product design challenges. And while piezo actuators and EAPs can work well for finger-tip touch surfaces, they are inadequate for creating the more robust vibrations needed for other devices, such as headphones or game controllers.

Why Lofelt?

There are other companies developing haptic technologies, but Lofelt offers several unique capabilities that help produce strongly differentiated products and outstanding user experiences.

Audio heritage

Most haptic technology companies are essentially motor manufacturers looking for ways to sell small motors. By contrast, the Lofelt executive team has a deep background in audio and music technology. That background has helped Lofelt develop audio-driven haptic technologies that deliver realistic, natural experiences.

End-to-end haptic system

Lofelt Wave is a comprehensive, end-to-end haptic system that combines wideband hardware actuators with adaptive firmware and deep expertise. By working with Lofelt, organizations have the option to avoid the time-consuming, costly process of developing their own firmware. With extensive integration and development resources, Lofelt can also streamline key processes and accelerate time to market.

The end-to-end system from Lofelt can be integrated into other products efficiently, without requiring excessive additional components. For example, Lofelt Wave firmware can be embedded anywhere, such as in headphones, smartphones or automotive display systems.

Patent-pending technologies

Lofelt Wave incorporates multiple patent-pending technologies, including:

- **Real-time audio-to-haptics software:** Advanced DSP algorithms convert audio to the optimal wideband haptic signal with extremely low latency.
- **Real-time analytics software:** Lofelt Wave technology includes an adaptive closed-loop system that helps ensure a consistent user experience even when the audio environment changes.
- **Wideband actuators:** With a compact design, these wideband actuators provide true wideband performance in the frequency range that delivers the greatest haptic impact.

Validated concept and user feedback

Lofelt Wave technology has been validated through extensive in-house prototyping with headphones, game controllers and other devices. Prototyping allows Lofelt engineers to identify and address any issues that might arise in real product integration, saving you time and money. For example, through prototyping, Lofelt can determine whether actuator frequencies will need to be adjusted once embedded into a headset to compensate for the mass of the device. Consequently, Lofelt engineers developed a tuning parameter in the firmware that allows you to modify the resonant frequency easily.

Lofelt also conducts user testing with prototypes. User testing generates valuable feedback for product development and can help preempt user-related issues down the road.

Product differentiation

Choosing Lofelt Wave technology lets you differentiate your products and gain a competitive edge. You can brand your products to highlight this innovative haptic technology, underscoring how it delivers a heightened sense of realism.

Manufacturing partnerships

While several small companies are developing interesting technology concepts, not all can actually deliver manufactured products. Lofelt has partnered with reliable, tier 1 manufacturers who have supplied industry-leading technology vendors. These manufacturers are well prepared to deliver Lofelt Wave actuators at scale.

Broad expertise

Unlike other vendors, Lofelt is not focused solely on manufacturing actuators. The Lofelt team has expertise in several fields that are critical for producing a realistic experience through multiple, integrated technologies. Lofelt employs mechanical, electrical and software engineers as well as physicists and user experience testers – all of whom contribute to the continued development of Lofelt Wave.

Supporting a wide array of use cases

Lofelt Wave technology can support diverse use cases, including gaming, music, movies, VR and more.

Gaming

Actuators can be integrated into gaming headsets to augment the stereo sound of games, enhancing the realism of on-screen events and providing a more engaging experience. Lofelt technology can also be integrated with game controllers. While some controllers already use rudimentary haptic technologies, which provide notification-like rumbles or buzzes, Lofelt Wave technology offers much more realistic feedback. Integrating Lofelt Wave into headphones and controllers also provides gamers heightened awareness of their in-game surroundings by presenting an additional dimension of feedback that is separated from other audiovisual cues.

Movies and videos

Incorporating Lofelt Wave technology into headphones helps place viewers in the middle of the cinematic landscape. With Lofelt wideband actuators, viewers not only hear but also feel deep bass.

Music listening

Lofelt Wave technology enables users to feel deep, resonant bass that music fans generally experience only in live concerts. They can sense those low frequencies without cranking up their headphones or boosting the bass, both of which can damage hearing and generate audio distortion.

VR

As VR headsets gain popularity and become less expensive, there will be increasing demand for haptic technology that can complement the audiovisual experiences those headsets deliver. Headsets and VR controllers that incorporate Lofelt Wave technology with wideband actuators can contribute to much more immersive experiences than other, more limited haptic technologies, which produce single-frequency or dual-frequency buzzy notifications.

Touch-based screens and input devices

Lofelt Wave technology can also help simulate textures, opening new possibilities for integrating haptics with touch-based screens and input devices. You could, for example, put an actuator in a stylus. When a user moves the stylus over a rough surface in the virtual environment, he or she would feel the tiny ridges through the stylus. Similarly, you could place actuators in computer mice or other input devices, enabling users to sense textures that appear on screen.

The increasing use of touch-based, tablet-like screens inside vehicles presents another key opportunity for integrating haptics. You could provide haptic responses when a driver presses a button, adjusts a dial or flips a switch. Lofelt Wave technology creates much more realistic tactile experiences than other haptic technologies, which generate simple buzzes. Drivers – whose eyes are supposed to remain on the road – are given reinforcement to visual feedback that could help enhance safety.

Continue your exploration of Lofelt Wave

Haptic technologies can provide an important complement to audio and visual technologies, creating a highly engaging user experience. Until now, however, most haptic technologies have lagged far behind their audio and visual counterparts, delivering only simple notification-like vibrations.

Lofelt Wave elevates haptic technology to match the high-quality sound and visuals that can be produced by a diverse array of devices. The result is an incredibly natural, realistic experience for users.

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.