Next-Generation TouchSense® Vibration for Video Game Console Systems
A Note on Terminology

There are many terms used to describe the result of adding touch stimuli to the human-computer interface, including “full force feedback,” “haptics,” “rumble feedback,” “tactile feedback,” “touch-enabled,” “vibration,” “vibro-tactile,” and many more. Many parts of the industry have standardized on the term “force feedback” to describe a combination of vibro-tactile and kinesthetic outputs. This document deals mainly with vibro-tactile output alone, which the market often calls “rumble.”
Table of Contents

Introduction ............................................................................................................................ 1
  Reactions to Immersion’s Next-gen Technology................................................................. 1
TouchSense Technology Overview............................................................................................ 2
Next-generation System Components....................................................................................... 3
  A New Type of Actuator Design .......................................................................................... 3
  Middleware .......................................................................................................................... 4
  Immersion Studio for Gaming SDK .................................................................................... 5
Developing with Immersion Studio for Gaming ....................................................................... 7
Industry Transition ................................................................................................................ 8
  Technical Improvements without Trade-offs ................................................................ 10
Appendix A – Introduction to Immersion Studio for Gaming .................................................. 11
Appendix B – Periodic Effect Design Parameters ................................................................ 17

Figures*

Figure 1: Next-generation vibration architecture, one possible scenario ................................... 2
Figure 2: A wider range of effects ............................................................................................. 3
Figure 3: Stronger and shorter effects ...................................................................................... 3
Figure 4: More closely spaced and more in sync with onscreen events ................................... 4
Figure 5: Separating the rumble-creation and code-development pipelines .............................. 7
Figure 6: New game with Immersion middleware driving a legacy dual-motor rumble controller 8
Figure 7: Old game driving a next-generation vibration controller .......................................... 9
Figure 8: New game with Immersion middleware driving a next-generation vibration controller 9
Figure 9: Immersion Studio for Gaming project window ....................................................... 12
Figure 10: Immersion Studio for Gaming fire #1 effect creation ............................................ 13
Figure 11: Immersion Studio for Gaming fire #2 effect creation ............................................ 14
Figure 12: Immersion Studio for Gaming fire #3 effect creation ............................................ 15
Figure 13: Immersion Studio for Gaming MissileLauncher compound effect creation .............. 16
Figure 14: Immersion Studio for Gaming periodic effect parameters ..................................... 17
Figure 15: Square waveform ................................................................................................. 18
Figure 16: Sawtooth up waveform ........................................................................................ 18
Figure 17: Sawtooth down waveform ..................................................................................... 19
Figure 18: Sine waveform ..................................................................................................... 19
Figure 19: Triangle waveform .............................................................................................. 19

*All figures are conceptual and not meant to reflect an actual implementation for a specific console gaming system.
Introduction

On June 19, 2006, Immersion introduced its next-generation TouchSense® vibration (rumble) technology to match the realism expected of next-generation video game consoles. This innovation offers a much wider range of rumble effects and improved synchronization with audio and onscreen graphic events. The results can help games come even closer to simulating the physical world — meaning more realism, more fun, and more engaging game play.

As an example of the advancements offered by next-generation technology, imagine a next-gen off-road racing game. Gamers would not only be able to see every detail of the terrain — gravel, rocks, sand, mud — they would also be able to feel how the vehicle responds to these features — an experience more like driving in the real world. They could feel the sharp pop of shifting gears, and at the same time, the force of acceleration or deceleration. If they were also firing a machine gun, they could feel both the vehicle movement and the weapon’s repeating action. Or they could experience the vehicle movement and feel that they are being fired upon (taking damage).

With next-gen vibration, more subtlety is possible, such as the feeling of a nearby explosion that fades in intensity, which could now be felt along with fast, sharp machine gun fire hitting a nearby wall.

This paper explains the components of the new TouchSense technology and the technical and aesthetic improvements and advantages it offers. A suggested path for transitioning to TouchSense technology is also offered (page 8), which describes an implementation path that can occur at any stage of product lifecycle, even after a console model has launched.

Reactions to Immersion’s Next-gen Technology

Immersion Unveils Next-Gen Rumble Technology by Sid Shuman, Gamepro.com, June 16, 2006
“I personally experienced Immersion’s new rumbling technology yesterday, and I have to say that it’s a major, major step in the right direction. Not only are the rumbles stronger, they feel more detailed and crisp. A nearby explosion sends powerful shockwaves rippling through your hands; wielding a lightsaber produces a pleasant ‘humming’ sensation; and machinegun fire feels downright violent. It’s ten times better than the rumbling on the PS2 or Xbox 360.”

Immersion’s Magic Touch by Chris Boffo, Game Daily, June 19, 2006
“But this single, next-generation motor is not only capable of spinning in multiple directions, it can stop on a dime and is generally much stronger than its predecessors. The result is a richer, more intense experience that will further immerse us in these upcoming games.... The difference between this technology and previous controllers is akin to making the jump from the original Resident Evil on PS One to Resident Evil 4. It’s just in stark contrast to what I’ve been used to.”

“You’re probably asking yourself, “How can rumble be any better?” Fortunately for us, Immersion has shown us how. They have convinced us next-generation rumble is real and ready today... The realism and impressiveness created by Immersion’s new TouchSense technology is unlike anything you’ll ever feel. In fact, you have probably never even imagined how precise and advanced rumble can be.”

“In short, yes, this is a definite improvement over today’s available rumble, and the consumer would be best served if TouchSense became a standard feature.”
TouchSense Technology Overview

Just as sound and graphics fidelity has dramatically improved with advancements in those technologies, vibration feedback can also dramatically improve. With advancements in actuator technology, software, and development tools, it's now possible to produce a broader range of rumble effects that are both stronger and more subtle, crisper and more precise. Gamers secure a large step-change in quality of rumble feedback translating to more fun, realism, and engagement. And developers gain the satisfaction of producing higher quality games at lower production cost owing to higher efficiency tools.

Immersion's new TouchSense technology includes hardware and software elements that provide additional operating modes to widen the range of possible rumble effects. The technology can also emulate current dual-motor system performance for backward compatibility (Figure 1).

Immersion’s middleware is packaged into Immersion Studio® for Gaming SDK along with:

- Immersion Studio for Gaming authoring tool, and help, how-to, and API documentation
- TouchSense Vibration Effect Library files

The SDK is a single product aimed at both vibration content authors and code developers. Content authors will be most interested in the authoring tool, effects library, and effect design documentation. Code developers will appreciate the middleware package, API header files, and API documentation, which will support a quick vibration effect integration cycle.

Figure 1: Next-generation vibration architecture, one possible scenario
Next-generation TouchSense® Vibration for Video Game Console Systems

Next-generation System Components

Next-generation TouchSense technology includes:

- A new type of actuator design for the controller
- Middleware allowing design-once-deploy-everywhere functionality
- Immersion Studio for Gaming authoring tool

A New Type of Actuator Design

Next-generation TouchSense technology uses a new type of actuator design with:

- An eccentric (off-center) rotating mass (ERM), capable of bi-directional pulsing, spinning, and oscillating, which outputs a wider range of effects than a dual-motor system (Figure 2)
- Ability to output similar rumble effects as conventional ERM motors through spinning or pulsing (supplying backward compatibility for dual-motor games played on a console system with next-generation middleware)
- Ability to play multiple, superimposed vibrations
- Ability to output higher frequency vibrations
- Fast start and braking times, hence crisper, highly articulated, better synchronized effects

While current dual-motor systems generally use two unidirectional, spinning-mass motors to create complex vibrations within a certain range, Immersion’s next-generation TouchSense actuator uses bi-directional pulsing, spinning, and oscillating modes to produce effects that can be stronger, shorter in duration (Figure 3), crisper, more closely spaced, and more in sync with onscreen events.

Vibration pulses can be more closely spaced in time, increasing the range of playable effects and supplying greater realism. The actuator can use its oscillating mode to move quickly back and forth to more efficiently reach the desired strength in less time. Bi-directional pulsing can be used to abruptly stop a vibration. It enables...
effects to be more closely spaced so that gamers feel each distinct event, such as a combination of rapid punches in a boxing game or the staccato fire of a machine gun (Figure 4). Oscillating mode can be used to achieve even higher frequencies for rendering a wider variety of effects. These capabilities help achieve heightened realism and tighter synchronization of tactile effects with onscreen graphical and audio events.

![Figure 4: More closely spaced and more in sync with onscreen events](image)

In combination with the new actuator design, Immersion Studio for Gaming allows you to give gamers a greater range of effects than existing dual-motor technology. Two examples: (1) the stuttering jolts of firing an assault rifle, then the alarming click sensation produced from an empty chamber, (2) the initial accelerating surge of a light saber powering up, then the transition to a subtle hum, followed by the jolt of clashing it with your opponent’s weapon.

**Middleware**

TouchSense vibration technology includes proprietary peripheral device firmware, algorithms, and software that load in the console at runtime. The middleware components—which encompass over a decade of knowledge in the field of force feedback including for PC gaming and mobile phones (see Immersion’s TouchSense® System for Mobile Phones at [http://www.immersion.com/products/touchsense-tactile-feedback/5000-series/index.html](http://www.immersion.com/products/touchsense-tactile-feedback/5000-series/index.html)—interpret the programmed vibro-tactile effect and direct the actuator to faithfully produce it.

Immersion’s effect playback know-how is encapsulated in the middleware package, which is designed for platform-independent operation on the leading console systems. Although the architecture for next-generation TouchSense technology is defined and algorithms coded, porting the final version of the package to a particular game console system would require a license agreement with the console manufacturer. The description below outlines how the middleware package will work.

The two driving goals for the Immersion TouchSense middleware package are:

- Embrace a design-once-deploy-everywhere philosophy
- Cleave the vibration content creation (game asset) pipeline from the code development pipeline, bringing vibration content authoring in line with the trends in graphics and audio game asset development and management

Using Immersion’s TouchSense middleware solution, you need only know the assets by name (a simple text string) in order to load the effect definition file, store the assets in the system, and invoke vibration playback through a single call to one of Immersion’s API functions. This allows you to place vibration effect playback calls using preliminary assets, and it also gives vibration content artists the ability to design and preview effects without having to load them in-game. Both code developers and artists gain an independence that was not possible until now in vibration feedback content development.

Sometimes, the developer needs to get more involved in the in-game vibration effect design. There are situations where real-time vibration effect modulation is the preferred route to creating compelling sensations. Immersion
middleware acknowledges this by giving you interfaces to create simple effects and modulate many of their parameters over time. For example, a vibration's frequency could be mapped to the speed of a moving vehicle. You can invoke playback of a vibration effect, and then modulate its frequency at regular intervals to reflect the vehicle's current speed in the game. You can even choose to load an effect from an effect definition file, start playback, and then modulate one or more parameters over time.

Immersion's middleware handles the superimposition of effects so that developers don't have to. You can choose to either play effects in an interruptible fashion, with a priority scheme, or instruct the system to try to overlay as many rumble effects as the system can handle. The priority scheme is flexible enough to support both interruptible and overlay modes simultaneously, allowing for groups of vibration effects to be classified hierarchically, ensuring that important vibration events are never washed out by less important ones.

The middleware supports both next-gen advanced vibration and legacy dual-motor rumble. It also is broad and flexible enough to support future, not-yet-invented vibration systems. This is a major step in promoting a design-once-deploy-everywhere philosophy. Immersion's middleware algorithms allow effects authored for next-gen vibration to play with good results on legacy dual-motor systems.

We realize, however, that some authors may want to personally optimize content for both current and future vibration systems regardless of the sophistication of our algorithms. Content authors who want ultimate control over the sensations on both systems are able to use the Studio authoring tool to preview the sensations produced on both types of vibration systems and decide to what extent the effect definitions must be tweaked in order to produce what they feel is the best possible sensation on either vibration system.

Immersion will endeavor to make its middleware platform-independent, with the API offering similar interfaces, features, and performance on major gaming platforms. This makes porting to the major console platforms easier for both content authors and developers. The vibration assets are re-usable across the supported platforms.

**Immersion Studio for Gaming**

Immersion Studio for Gaming is an advanced, user-friendly Windows-based authoring tool optimized for fast and intuitive creation of rumble effects. It lets rumble designers easily create custom effects using a mouse and simple text entries. You can experience the effect immediately, iterate the design, and once satisfied, save the effect as an asset file, which can be played from the game. The tool is so easy to use that it promotes the idea of “creating, not coding” — allowing for rumble effect design to be assigned to someone who is more of an artist than a programmer and who develops expertise at conceiving of and applying engaging and realistic rumble effects to game action. (See also the Immersion white paper, *Best Practices for Use of Vibration Feedback in Video Console Games.*)

Using the Immersion design tool, you have increased ability to make game play feel more like the physical world, for example:

- Design spin-up / spin-down curves (right) — To closely simulate the feel of an engine revving up, accelerating, down shifting
- Layer, blend, and cross-modulate effects (below) — To feel the vibrating hum of a light saber, and layered upon it, the change in energy as it’s swung over and back, the static discharge when it strikes another weapon, and the sudden snap when the weapons separate
Exert fine control to produce clearly distinguishable rapid fire events—such as the firing of an automatic weapon, and a clear difference when firing an AK-47 or an M-16, for example.

The authoring tool is the vibration content author’s primary productivity tool. It promotes a design-once-deploy-everywhere philosophy and separates vibration content creation from code development, which will streamline and speed game production and enable more effective rumble effect design.

Immersion Studio allows you to deal in objects and inter-relationships like any modern programming language, freeing you from tedious low-level mechanics and letting you concentrate on integrating the rumble effects with graphics and sound. (See Appendix A—Introduction to Immersion Studio for Gaming, page 11.) You can finally focus on the art of creating even more compelling vibrations and synchronizing rumble effects to game sounds.

The tool’s graphical user interface elements make tweaking vibration effects a lot simpler. Fine-tuning specific parameters is handled through text entry areas, so you have immediate and fine-grained control over the outcome.

Designers can choose from a library of rumble effects developed by Immersion, key off an imported sound file, or create their own unique rumble effects.

Rumble effect design and integration is easy:

1. You design the rumble effects in the Studio application. You save the effect definitions in one or more asset files. These files become the primary point of contact between the artist and the code developer.

2. The code developer then uses Immersion’s API (part of the middleware package) to load the asset into memory and launch vibration effect playback by referencing particular effect definitions in the file. A couple of simple functions calls is all it takes to play back high-fidelity rumble effects.

Complex effects can be easily crafted by assembling a number of fundamental effect definitions and laying them out in a timeline. This method makes vibration creation for a magnificent 30-second explosion sequence much faster and easier. With the ability to program repetitions and view audio tracks within Studio, you can also quickly and easily create complex vibration tracks well synchronized with key audio sequences.

One of the authoring tool’s most powerful features is its ability to communicate with console peripherals. This gives the vibration content author the power to play and test effect designs and perfect them. (The preview capability may require access to a console development system, depending on the console’s overall architecture and the ease with which a vibration peripheral can interface with the Windows operating system.)
Developing with Immersion Studio for Gaming SDK

Immersion Studio for Gaming SDK offers the flexibility to design game effects using either a detailed or a conceptual approach. It supplies the ability to both make rumble effects more varied and interesting and to save development time. Offering a transformation in the way developers approach rumble effect design today, the tool supports enriching the content pipeline by allowing a streamlined and dedicated focus on a game’s touch stimuli (Figure 5).

Figure 5: Separating the rumble-creation and code-development pipelines
Industry Transition

You may be wondering whether this next-generation technology has missed the window for being included in next-generation console gaming systems. No, it hasn’t! It can be added at any time, and actually quite quickly and easily. In fact, there is precedent for providing a vibration feature after console system launch. After launching the PSOne system without force feedback in 1995, Sony introduced in 1997 (Japan) and 1998 (U.S.) the dual-motor controller that worked with the PSOne.

To allow the transition to advanced next-generation vibration, console makers would first need to provide support by way of forging a business arrangement with Immersion and then including the technology in their software development kits, console, and controllers. Immersion already has license agreements with most major third-party peripheral makers. We would provide them with reference designs and support to integrate the new technology into their gaming peripherals, which would be covered by existing license agreements.

The transition path to next-generation vibration also accommodates gamers. Backward compatibility is an important feature to them. Our next-generation technology will support playing both new and old tactile effects in games, and this will be transparent to the user, meaning they just load the game and start playing as always.

Following are three scenarios showing how our industry transition plan would work at various stages of adoption. Figure 6 below shows that, using Immersion’s middleware solution, rumble effects designed for next-gen systems can be played on existing dual-motor controllers — and with good results.

Figure 6: New game with Immersion middleware driving a legacy dual-motor rumble controller
Tactile effects designed with legacy dual-motor APIs will play on next-generation vibration controllers but will feel similar to effects experienced today, due to limitations of today's dual-motor APIs (Figure 7).

And tactile effects designed with next-gen technology and played on next-gen controllers will provide the best experience (Figure 8).
Technical Improvements without Trade-offs

In addition to providing a seamless transition that can be introduced at any time and that includes backward compatibility and a better gaming experience, new TouchSense technology provides additional advantages:

Motion-control and Tilt-sensing

Next-generation TouchSense technology will work with motion control and tilt sensing because the speed at which a user can move or tilt the controller is much slower than the frequencies generated by rumble feedback. It’s possible to differentiate these signals using filtering and other techniques.

Third-party Peripherals

The new actuator system can be implemented in third-party peripherals, but TouchSense software and control algorithms must first be loaded on the console. Next-generation game effects can then be played by first- or third-party peripherals that use the next-gen actuator and firmware.

Lower Cost

In addition, depending on the quality of the dual-motor system under comparison, the new actuator system can cost less. Elimination of the cost of one motor in a great many cases will offset a slightly more complex single actuator.

Wireless and Easy on Power

The new technology can be used in wireless controllers, and power consumption will not be greater than in existing dual-motor systems. In fact, in many cases, power consumption will be less.

Contact Immersion to discuss implementation of next-generation vibration technology:
touch@immersion.com.
Appendix A – Introduction to Immersion Studio for Gaming

Immersion Studio for Gaming can be used for creating effects for the most common gamepad technology today, the dual-motor controller. It can also be used for creating a much wider range of effects that exhibit more strength and more subtlety, playable using Immersion’s next-generation actuator technology.

Designing good rumble effects is not a trivial pursuit. Like a musical composer, the tactile effect designer has many choices to make in designing a rumble effect that elicits the desired tactile sensations — sensations that are designed to match well to the game’s graphic and sound events.

With current technology, this process could involve selecting predefined effects from a rumble library and calling a function to play it. If no pre-defined effects are satisfactory, the designer has to “manually” implement the rumble effect by calling low-level functions to directly drive the motors. This is challenging. How many spins of the motor do you need? How fast? Will the result match well to the game’s sound (which could be of a light saber cutting through steel, a car hitting road bumps at 70 mph, or the reload of an M-16 rifle)?

The following describes how to create a compound effect for a next-generation gamepad controller that simulates missile launcher operation including firing and attenuating reverberation as the missile accelerates into the distance. This design process would take about 10 minutes for users unfamiliar with the tool, about 2 to 3 minutes for experienced users.

If you are not familiar with periodic effect design parameters, you may want to review Appendix B, page 17, before reading this introduction to the design tool.

1. After installing its driver, attach the next-generation gamepad.
2. Open the Immersion Studio for Gaming application.
3. Open the File menu and pull down to “Select TouchSense Device.”
4. Select your gamepad device from the list of devices.

You’re now ready to begin designing.
5. Start a new effect project by opening the File menu and selecting the “New” option.
6. A new project window will open.
7. From the left effect Palette menu, double-click the Compound effect icon to open a compound file. In the same way, also open three Periodic effect files. These effect elements will be added to your project workspace.
8. Rename the compound effect MissileLauncher.
9. Rename the first periodic effect fire #1.
10. Rename the remaining two periodic effects fire #2 and fire #3.
First Effect

The goal of the first effect is to give the player a very strong kick, similar to what might be felt from the missile’s blast. To do this with a next-generation controller, we need to make an effect with a very high magnitude vibration, but we also want it to be crisp (distinctly finite) because after the missile leaves the launcher, we’ll want to play a different effect.

11. Double-click the fire #1 effect to open the effect editing window.

12. In the bottom right-hand corner of the edit window, click on the infinite icon and change the duration to 90 milliseconds by typing 0.09 in the duration field. Also set the attack time to 0. This will be our short blast of rumble to simulate the firing of the missile.

13. In the middle of the edit window, change the Magnitude field from 5000 to 10000, the strongest possible setting.

14. Change the period field to 0.171. This turns on the rumble at full magnitude for almost the whole effect but also gives a short negative pulse at the end. This negative pulse makes the effect much sharper than it would be on a current-generation, dual-motor controller. The final effect is shown above.

15. Close the fire #1 edit window.
Second Effect

For the second part of the effect, we want to create a vibration that gives the impression of a missile traveling away from the player. We will do this by creating a low strong vibration and play it along with a high-frequency fading buzz that we’ll create in the third effect.

![Figure 11: Immersion Studio for Gaming fire #2 effect creation](image)

16. Open fire #2 by double clicking on it.

17. Follow steps 12-14, but set the magnitude to 4500 and the duration to 0.4 s (400 milliseconds). Set the period to 0.760. As in step 14, a short negative pulse helps stop the next-gen actuator abruptly, rendering a much crisper effect than is possible with current dual-motor technology.

18. Close the fire #2 edit window.
Third Effect

This effect will provide the high-frequency fade of the missile. The next-generation actuator can play multiple effects with different frequencies, supporting this type of compound effect.

19. Double click on the fire #3 effect to open its edit window.

20. Follow steps 12–14, setting the duration to 0.4, the magnitude to 5000, and the period to 0.007. This creates a much higher frequency effect, as shown in the composition window above.

21. Set the fade time to 0.4. This will create an envelope that reduces the magnitude to 0 by the end of the effect.

22. Close the fire #3 edit window.

Now we will position the effects to make a compound effect for the MissleLauncher.
23. Drag each of your component effects, fire #1, fire #2, and fire #3, into your MissileLauncher Compound effect icon and double-click the icon to view your MissileLauncher compound effect.

24. Click on the seconds bar to set the timeline display to 1 second.

25. Drag each effect's graphic into position as shown in the figure above. Note that a slight pause after the fire #1 effect distinguishes between the missile launch and the trailing vibration of the missile's acceleration. From a design standpoint, by providing a clear separation between these two effects, you convey the extreme power of this weapon.

26. Press the green arrow play button (next to Compound in the screen above) to feel your completed effect.

27. Open the File menu and select “Save” to create an Immersion Force Resource (.IFR) file. From your game, you can now link to these effects at runtime by using Immersion’s middleware solution. The Immersion API allows your game to read Immersion Studio effect files and create Immersion TouchSense rumble effects. Since this is done at runtime, you can re-open the file at any time and tweak your saved effects without having to recompile your application.
Appendix B – Periodic Effect Design Parameters

Although the Immersion Studio for Gaming tool supports programming effects for virtually all types of game controllers — joysticks, steering wheels, dual motor gamepads, and our latest next-gen actuator — this paper discusses only the rumble effect used by gamepad controllers, which consists of repeating vibrational pulses. Immersion calls these effects periodics, which are defined in terms of six main parameters, all configurable from the main editing window.

Gamepad devices vary in their ability to play various effects, so although each interprets effects to best ability, effects will vary from device to device. Immersion next-generation technology has the ability to play stronger, more subtle, and a wider range of rumble effects with improved synchronization with audio and onscreen graphic events.

![Figure 14: Immersion Studio for Gaming periodic effect parameters](image)

**Duration**

Duration determines how long the entire periodic effect lasts.

**Envelope**

The envelope is an area that bounds the attack and fade portions of an effect and allows you to change the level of the effect over its duration (as opposed to changing individual cycles). If you are making a periodic to underscore the sound of a passing train, you might use an envelope to make the shaking increase from nothing as the train approaches, then decay as the train speeds off.
Both attack and fade portions have an associated level and time. In the attack portion, the force intensity or level builds to the effect’s highest magnitude over the attack time. In the fade portion, the level diminishes from the highest magnitude to the fade level over the fade time.

**Magnitude**

Magnitude is the vibration strength output. A high magnitude means a strong vibration, 10,000 being the highest setting. A magnitude below 100 may be too weak to be felt.

**Period**

The period controls the timing between vibration pulses. Shorter periods (higher frequencies) feel like buzzes. Longer periods (lower frequencies) feel like low reverberations or taps.

**Phase**

The phase of the waveform sets the point at which the effect begins. When set to 0, the vibration begins to play from 0 phase. When set to 180, it plays from the halfway point. Phase differences can only be felt for low-frequency periodic effects. When designing for a next-gen controller, setting the phase to include a negative segment of the waveform at the end of an effect will help provide a definite end (crispness).

**Waveform**

A periodic’s waveform is the shape of the repeated pulses. Shown in Figures 15–19 below are the five basic waveform varieties: square, sawtooth up, sawtooth down, sine, and triangle. The graphs display the vibration strength over time. The area above the horizontal line applies to the spinning force of the motor or actuator in one direction, the area below the horizontal line applies to the spinning force in the opposite direction. Waveform effects are more noticeable at lower frequencies, becoming increasingly difficult to distinguish as frequencies increase.

Square, the most intense of all of the waveforms, due to its abrupt transitions.

**Figure 15: Square waveform**

Sawtooth up waveform, where the vibration strength steadily rises and then suddenly drops after reaching its maximum.

**Figure 16: Sawtooth up waveform**
In a sawtooth down waveform, the vibration strength starts strong, then steadily drops to a minimum value, and the cycle repeats.

Figure 17: Sawtooth down waveform

The smoothest of the vibrations, the sine wave's vibration strength undulates gently over time.

Figure 18: Sine waveform

The triangle waveform is in between the square and the sine wave in terms of smoothness.

Figure 19: Triangle waveform