High-definition haptics: Feel the difference!

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While most smartphone and tablet users already have experienced haptics, the term itself is mostly unknown to consumers. In its basic definition, "haptics" refers to the science of tactile feedback. The most basic form of haptics is when a cell phone vibrates, indicating either an incoming call or the arrival of a message in the phone's inbox. In these cases, the user's attention is grabbed by a tactile alert.

About one-third of smartphones include tactile feedback that extends beyond a vibration alert. A common example is the subtle vibrations a user feels when typing an email or texting. Each vibration confirms that a keystroke has registered. Users tend to commit fewer typing errors and have a more satisfactory experience when tactile feedback exists.

Enhancing the user experience with haptics

More and more mobile devices such as cell phones and tablets are now touch-enabled. Touch interface is so intuitive that toddlers can unlock a smartphone and click on the YouTube icon to view the playlist. However, touch screens have one major limitation in that there is no physical or mechanical feedback for user interactions or alerts. Well-designed haptics can significantly enhance the overall user experience of a touch-enabled mobile device.

Haptics has more usage than just serving as an alert or typing confirmation. Standard gestures like swipe to unlock, pinch to zoom, and push/pull to scroll could have their own haptic/tactile signatures. The feedback could increase as the user zooms in to the maximum enlargement of the view. Faster scrolling could provide faster tactile feedback. If this kind of context-sensitive feedback were combined with audiovisual feedback, the resulting consumer experience would be highly satisfactory and intuitive.

Haptics also brings in an element of fun. Many people play games on their mobile devices. Tactile feedback can be used to make the gaming experience significantly better. For example, in a first-person shooter game, the shooter could actually feel the weapons being fired. The user could feel crashes and bumps in a racing game, feel tension when releasing the string in the popular Angry Birds game, feel the guitar strings or piano keys, and so on. The possibilities are as endless as the game developer's imagination!

Inertial haptic actuators (ERMs/LRAs)

The standard haptics in a cell phone is due to a small motor called the eccentric rotating mass actuator (ERM). As the motor is driven with a voltage and starts to spin, a vibration is felt. A haptic driver chip drives this motor differentially, so the motor spins when a positive voltage is applied and brakes when reverse polarity, or a negative voltage, is applied. This works perfectly for vibration alerts. However, trying to use an ERM for other haptic applications, like gaming, quickly runs down the battery.

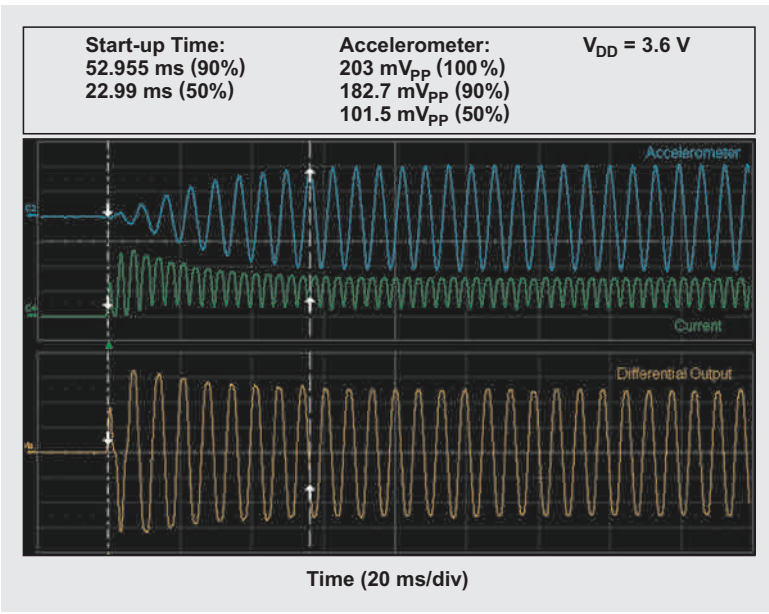
The ERM is inertial and needs overdrive to spin faster. Start-up time, defined as the time it takes for the motor to reach 90% of the rated acceleration, is usually in the range of 50 to 100 ms. Braking or stopping the motor involves a similar time frame. For a very simple haptic event like a click, the overhead is about 100 to 200 ms. If the application demands repeated haptic events, the latency associated with motor-based haptics may be undesirable.

Another aspect of the ERM is the buzzing or audible noise associated with the spinning motor. This is less of a concern if the haptic feedback is combined with audio feedback. However, in a silent conference room, everyone can hear the motor as someone types a message. The ERM also has few discernible haptic effects that can be generated by the user. The vibration frequency and amplitude are tied to a single control voltage.

Another type of inertial actuator, the linear resonant actuator (LRA), is used in some smartphones for haptics and vibration alerts. The LRA is of a different mechanical construction than the ERM. It consists of spring-mounted mass and vibrates in a linear motion. The LRA must be driven at a narrow resonant frequency. It also tends to have a slightly better start-up time than the ERM.

Depending on the manufacturer, start-up time varies from 40 to 60 ms (Figure 1). This offers a slight improvement over the ERM start-up time of between 50 and 100 ms. By modulating the resonance-carrier amplitude, it is possible to produce a variety of different haptic effects.

Figure 1. Typical start-up time of an LRA is 40 to 60 ms



High-definition haptics

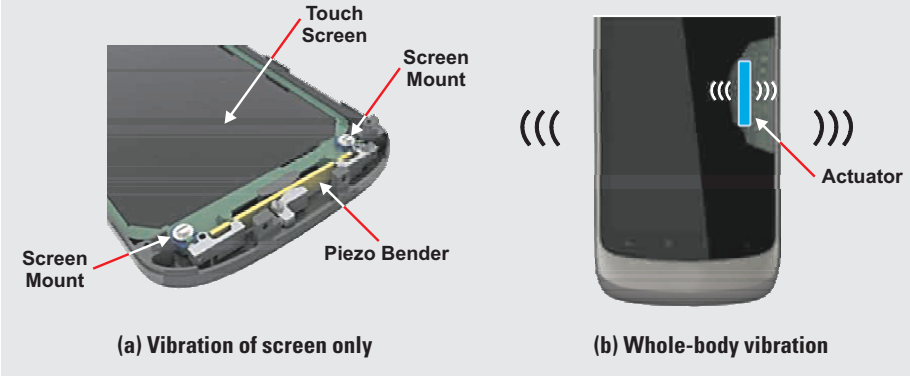
Just as high-definition (HD) TV offers higher resolutions than standard-definition TV to create a sharper and more discernible image, HD haptics lets users feel more discernible vibration effects than the buzz of inertial actuators. Piezoelectric (piezo) or ceramic haptic actuators are used to implement HD haptics and offer compelling differences from ERMs/LRAs).

Piezo actuators

When differential voltage is applied across both ends of a piezo actuator, it bends or deforms, generating a vibration. Piezo actuators need high voltage to deform. Depending on the manufacturer, voltage can vary from 50 to 150 V_{PP}. At higher voltages, the number of required piezo layers decreases; so at 150 V_{PP} the piezo actuator has approximately 4 layers, whereas at 50 V_{PP} there may be as many as 16 to 24 layers. At higher voltages, due to the reduced number of layers, the piezo actuator's capacitance is lower. In other words, less current is needed to drive lower-capacitance haptic actuators.

Piezo actuators are available as disks or as rectangular strips, also called benders. Piezo disks deform vertically and can be used for z-axis vibration. Piezo benders can be mounted directly to a "floating" touch screen to vibrate only the screen (Figure 2a). Piezo benders can also be mass mounted in a small module that can be mounted to the device's case or PCB to provide vibration for the whole device (Figure 2b). Piezo modules have become popular because mechanical integration is easy.

Figure 2. Form factors for piezo actuators



What makes piezo actuators HD?

Four key elements differentiate piezo actuators from iner-tial actuators:

1. *Faster start-up time:* Due to inherent mechanical properties of piezo actuators, start-up time is very fast—typically less than 15 ms, which is three to four times faster than ERMs. Compared to ERMs, the duration of the overall haptic event may be shortened by 70 ms. This is further illustrated in Figure 3.
2. *Higher bandwidth:* The higher bandwidth of piezo actuators, illustrated in Figure 4, provides a more detailed haptic palette with a greater number of effects.
3. *Lower audible noise:* Unlike ERMs, piezo actuators have no spinning mass to create mechanical noise.

Figure 3. Typical start-up time of a piezo module is ~14 ms

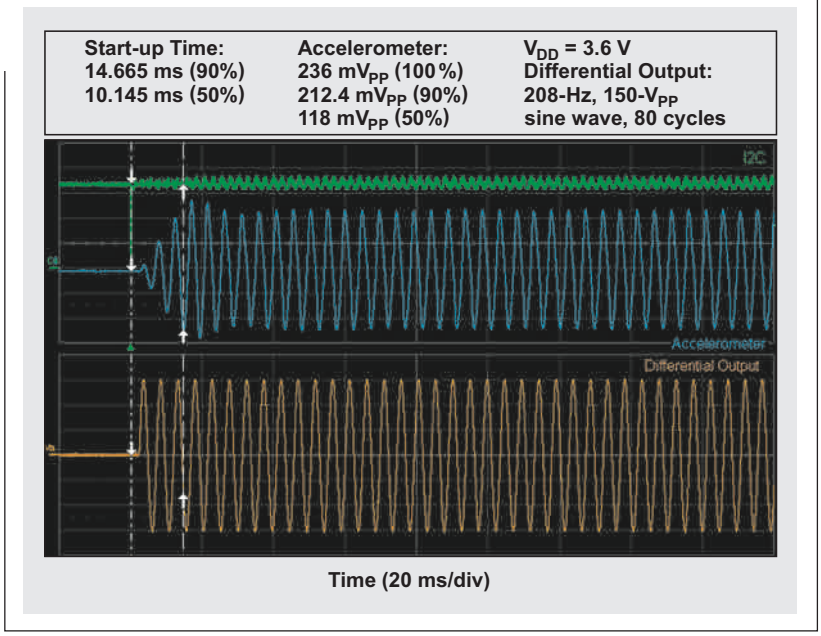
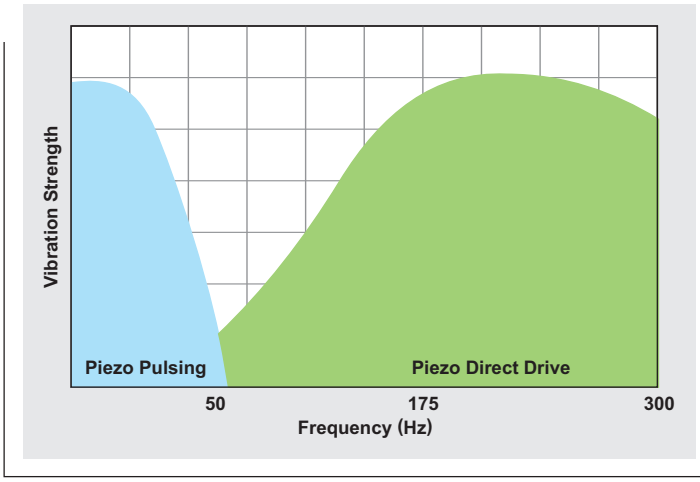


Figure 4. Higher bandwidth of piezo actuators (ideal model)



4. *Stronger vibration:* Piezo modules tend to generate higher vibration strengths. Figure 5 shows the acceleration characteristics of a commercially available piezo module, and Figure 6 shows the acceleration characteristics of a commercially available LRA. It can be seen that the piezo actuator generated a peak-to-peak acceleration of 3 G_{PP}, compared to less than 1.5 G_{PP} in the case of the LRA. This higher vibration strength implies that piezo modules are a great candidate for bigger-screen smartphones and tablets.

Current consumption of piezo actuators

Even though piezo actuators need higher voltage than standard inertial actuators, the actual current consumption is lower than that of ERMs and on a par with that of LRAs (see Table 1).

Conclusion

Piezo actuators deliver significant performance and cost advantages compared to inertial actuators. Their faster start-up time helps create sharp and crisp clicks for keyboard applications. Their higher band-width helps create more user-perceivable haptic effects that are critical for gaming applications. The stronger vibration strength of piezo actuators can be used to generate haptic feedback for bigger con-sumer devices like tablets and e-readers. Overall, piezo haptics offers compelling features to enhance the tactile feedback experience and helps improve the overall user experience of mobile devices.

Figure 5. Acceleration characteristics of a piezo module

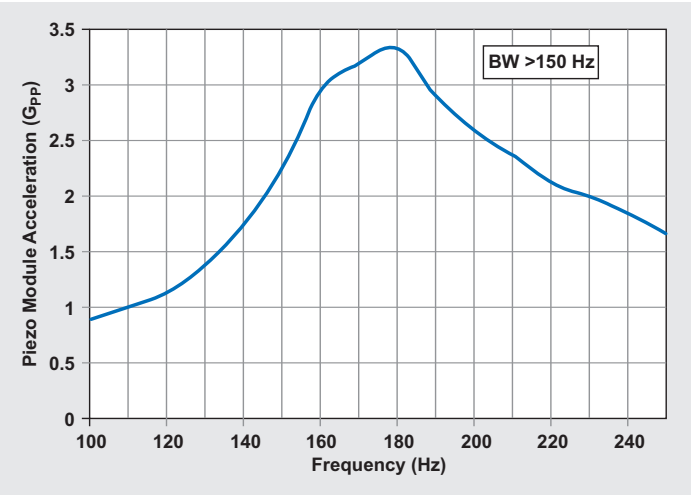


Figure 6. Acceleration characteristics of an LRA

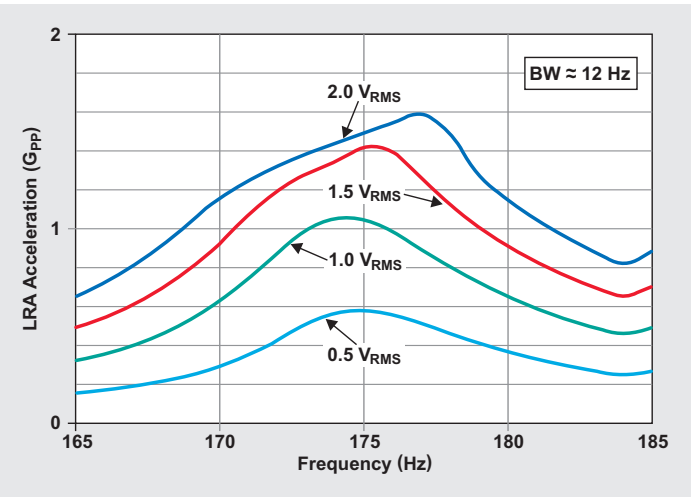


Table 1. Power consumption of haptic actuators

USAGE	PIEZO ACTUATOR (mAh)	LRA (mAh)	ERM (mAh)
Per 25 phone calls	2.685	1.497	3.540
Per 50 text messages	25.660	11.869	27.480
Per 4 hours of e-mail access	28.076	12.150	29.078
Crossword game (60 min)	1.094	0.487	1.150
DoodleJump game (30 min)	6.270	3.975	8.170
Shooting game (30 min)	24.976	37.777	61.558
Total power	88.761	67.755	130.975
Discharge percentage of 1200-mAh battery	7.4%	5.6%	10.9%