Application Note

Haptic Energy Consumption

ABSTRACT

Many electronic products must interact with the user or operator to communicate. For the last 40 years, the main communication methods in electronics have been audible or visual feedback; their main language of communication is sound and light. Today, haptic feedback has become another way for electronics to communicate with human beings, using their sense of touch. Haptics can be used in consumer, industrial, and automotive applications, such as a smartphone, tablet, mouse, ATM machine, and automotive infotainment systems.

A smartphone, smart-watch, and fitness tracker are all portable battery-powered systems that can use haptics. Many engineers may be concerned with the energy consumption of haptics in battery critical applications. The DRV260x, DRV262x ERM/LRA Driver Families and the DRV2667 Piezo Driver enhance the user experience with haptics, while at the same time minimizing energy consumption.

This document introduces three types of actuator technologies, explains how to measure energy consumption, and compares each type of actuator.

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1 Introduction

Haptics provide mechanical feedback through the use of vibrations to simulate specific events, surfaces, and effects. It can simulate different surfaces and effects by varying frequency, amplitude, duration, and direction of a vibration.

Figure 1-1 illustrates three types of actuators, Eccentric Rotating Mass (ERM), Linear Resonant Actuator (LRA), and Piezo Actuator.

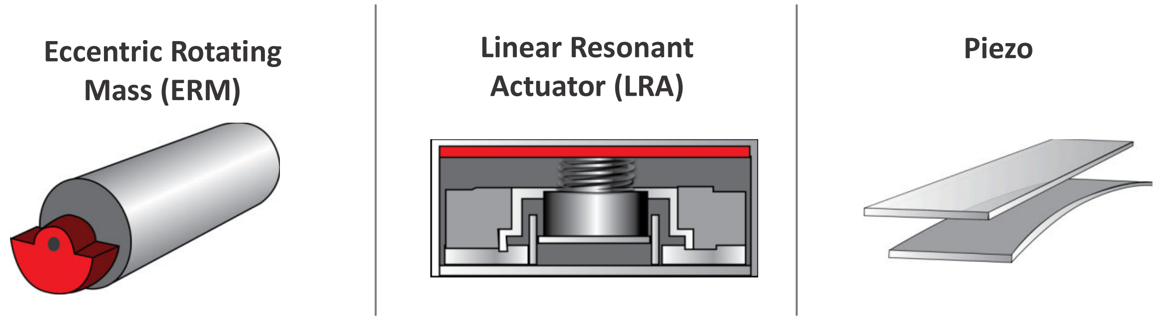


Figure 1-1. Three Types of Actuators

1.1 Eccentric Rotating Mass

An ERM is a DC motor with an off-center mass that spins to create vibrations. When the ERM rotates, the off-center mass results in a centripetal force; this kind of centripetal force causes displacement of the motor. People perceive this displacement as a vibration. The ERM vibrates because of rotation forces so there is acceleration on two axes (X, Y, or Z axis). This creates losses in unintentional axes in some applications.

Advantages:

- Easy to drive
- Low cost
- Flexible form factor (bar or coin)

Disadvantages:

- Slow response
- Acceleration is correlated with angular frequency(ERM)
- High energy consumption

1.2 Linear Resonant Actuator

An LRA is a spring-mass system that vibrates in a linear motion. Inside, there is a coil suspended by springs and when voltage is applied, the coil generates a magnetic field. The coil interacts with the magnet and mass, whereas the magnetic field varies with the applied drive signal, the magnet and mass move up and down creating force. This movement is perceived as a vibration.

Noticeable vibrations only occur at the resonant frequency due to the spring constant. Linear actuators must be driven within a narrow band (±2 Hz) around the resonant frequency; otherwise it results in a drop-off of acceleration (see Figure 1-2). Due to manufacturing tolerance, component aging, temperature and mechanical mounting, the LRA's exact resonant frequency varies. The DRV260x and DRV262x Drivers with auto-resonance function can detect the resonant frequency, helping increase acceleration performance.

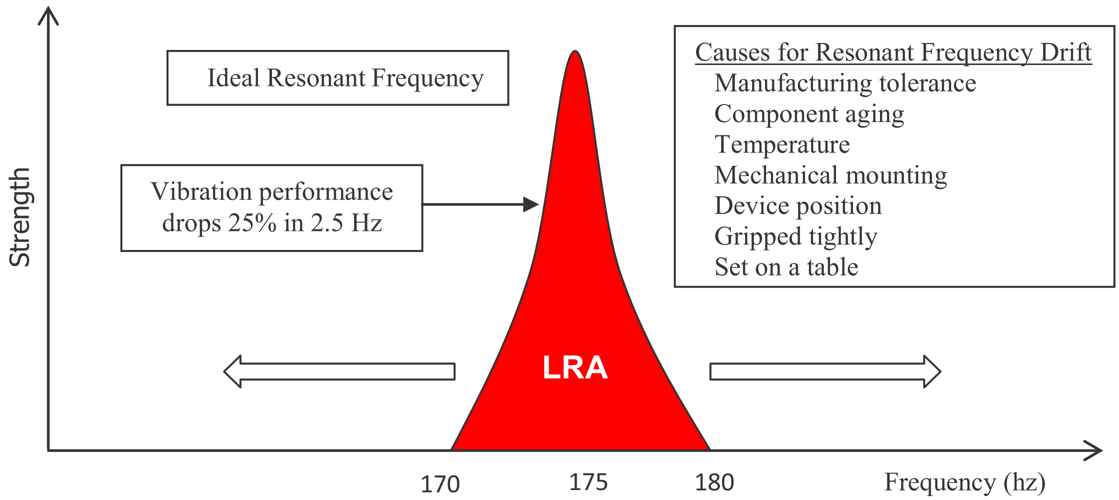


Figure 1-2. LRA Resonant Frequency Drift

The LRA acceleration occurs in one axis because it vibrates in an up and down motion. This benefits an LRA to create more vibration strength and have more energy saving

Advantages:

- Faster response time than ERM
- Larger acceleration
- Higher efficiency

Disadvantages:

- Resonant frequency drift reduces acceleration
- Difficult to drive

1.3 Piezo Actuator

Piezoelectric materials are a type of materials that will deform (move) when a voltage is applied. Piezo haptic actuators enable precise actuation for high-definition haptics which corresponds to a faster start-up time, a higher bandwidth of drive voltage, lower audible noise, and stronger vibrations compared with ERMs and LRAs.

Piezo actuators come in two types: single-layer or multi-layer. The single-layer Piezo requires higher voltage to move some distance because Piezo actuators are capacitive loads. Multi-layer Piezo requires lower voltages but higher current. The DRV2667 can drive Piezo actuators up to 200 Vpp.

Piezo actuators vibrate when a voltage is applied, which causes a deformation in the Piezo material. The deformation in the material creates a flexing motion, which results in acceleration in one direction. Overall, Piezo actuators have stronger acceleration, faster response times, and lower energy consumption.

Advantages:

- Quick response time
- Wide frequency bandwidth
- Larger acceleration
- Higher efficiency
- Lower audible noise
- Available in a variety of shapes and sizes
- Flexible mounting options

Disadvantages:

- Needs higher voltages to drive
- More expensive compared to LRA and ERM

Table 1-1 shows a comparison of ERM, LRA and Piezo actuator.

Table 1-1. Actuator Comparisons

Attribute	ERM	LRA	Low Layer Count Piezo	High Layer Count Piezo
Performance	Good	Better	Best	Best
Acceleration (g)	~1	~1-2	~3-5	~3-5
Audible Noise	Very Noisy	Moderate Noise	Silent	Silent
Response Time	~50 ms	~30 ms	0.5 ms	0.5 ms
Energy Consumption	High	Low	Lower	Lower
High-Definition Haptics	No	No	Yes	Yes
Cost	$	$$	$$	$$$

2 How to Measure Energy

In this document, we evaluated the AAC 1036C LRA, Sanyo NRS2574I ERM, and SEMCO PHAT423535XX Piezo module. All the graphs were taken on the DRV2604EVM-CT and DRV2667EVM-CT. There is no significant difference in resulting energy consumption between DRV260x and DRV262x driver families. Below is the legend for the oscilloscope channels:

C1: The wave of OUT+

C2: The wave of OUT–

Math: The wave of C1-C2

C3: Acceleration

C4: Mean current

Energy consumption is very important for portable applications, especially for wearable products like smart watches, bands, and fitness trackers. This section explains how to measure energy consumption and compares the energy advantages of each actuator.

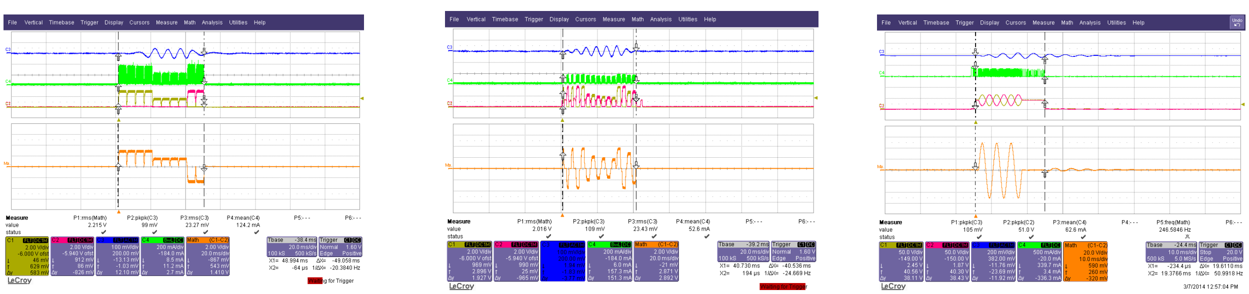
There are three ways to measure the energy in haptics.

- Current Consumption
- Energy Consumption
- Current versus Acceleration

The following sections explore these different methods:

2.1 Current Consumption

This section compares the average current consumption of ERM, LRA, and Piezo. This is useful when comparing the instantaneous current consumption of each actuator. It can also show the maximum number of clicks for battery-powered products.



(a) ERM (b) LRA (C) Piezo

Figure 2-1. Click Current Consumption Measurements

Figure 2-1 shows the click waveforms of ERM, LRA, and Piezo actuators. The mean current measurement of the waveform shows the energy consumption of each type of actuator. Keeping peak acceleration constant around 0.9 g, the ERM consumes 124 mA, the LRA consumes 51.3 mA, and the Piezo consumes 62.6 mA.

For a 1200-mAh battery, we can use the current consumption to calculate the maximum number of clicks. Use the ERM values from Table 2-1 to calculate an example:

Table 2-1. Click Current Consumption Data

Click	Mean Current (mA-per click)	Time Window (ms)	MAX Acceleration (g)	MAX Number of Clicks (1200-mAh Battery)
ERM	124	50	0.868	696774
LRA	52.6	40	0.956	2053232
Piezo	62.6	19.61	0.921	3570076

Conclusion

- Comparing ERM and LRA, the LRA consumes half the current of the ERM at the same acceleration.
- The current consumption of a Piezo click is close to the consumption of an LRA click and is lower than the consumption of an ERM click.
- For the Piezo, the maximum number of clicks is five times greater than the ERM. As for the LRA, the maximum number of clicks is three times greater than the ERM.

2.2 Energy Consumption

This section describes the energy consumption during each haptic event. The energy consumption for clicks, buzzes, and alerts can be measured in µA-hour and mA-hour.

For the ERM in Figure 2-1, the click duration is 50 ms. The energy consumption of the ERM click can be calculated using the following equation:

Using the previous equation, the energy consumption of an LRA click is 0.57 µAh and for Piezo, the energy consumption is 0.34 µAh.

Table 2-2. Click Energy Consumption Data

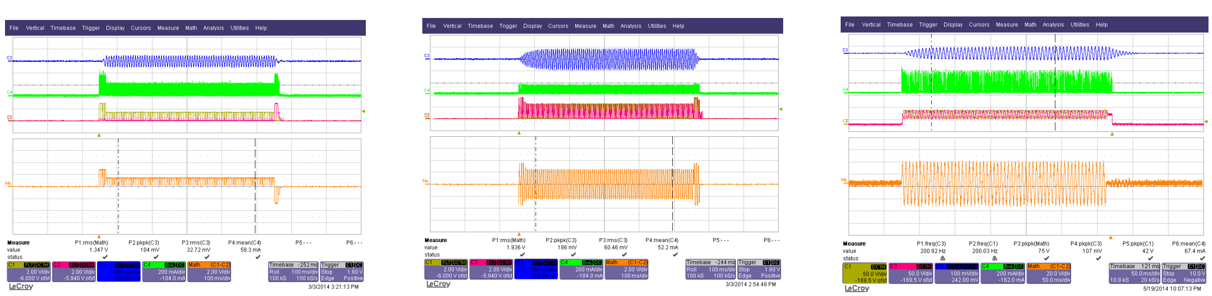
Click	VDD (V)	Mean Current (mA)	Time Window (ms)	Energy (µAh per Click)
ERM	5	124	50	1.72
LRA	5	52.6	40	0.58
Piezo	5	62.6	19.61	0.34

Conclusion

- Compared with the ERM, the LRA offers 67% energy savings per click. The LRA has the best efficiency and is better for applications concerned with battery life.
- The Piezo has quick response time which creates the shortest effects. The short duration of the Piezo click and the quick response time helps contribute to energy savings.

2.3 Current Versus Acceleration

There is another parameter that measures the ratio of the current to the acceleration. It shows which actuator provides the best acceleration but consumes the least amount of current. This method is used for a continuous and constant acceleration effect.



(a) ERM (b) LRA (C) Piezo

Figure 2-2. Buzz Energy Consumption Measurements

Figure 2-2 shows the energy consumption for the ERM, LRA, and Piezo during a buzz effect. A buzz waveform is a continuous waveform with constant acceleration. The actuators are compared with different acceleration forces by using a new energy metric called “mA/g”, which is the current per unit of acceleration. This metric normalizes the current per unit of acceleration.

Table 2-3. Buzz Energy Consumption Data

Buzz	Mean Current (mA)	Acceleration (g)	Energy (mA/g)
ERM	58.3	0.91	62.1
LRA	52.2	1.63	32.0

Table 2-3. Buzz Energy Consumption Data (continued)

Buzz	Mean Current (mA)	Acceleration (g)	Energy (mA/g)
Piezo	67.4	0.93	72.4

Conclusion

- The LRA consumes the least current per g, which means it is the best actuator for long duration effects.
- The ERM and Piezo nearly consume the same current per g in the long time effects.

See Section 5 for the energy consumption of a click tested on more kinds of actuators. The data is evaluated on the DRV2603EVM-CT. However, there is no significant difference when testing on the DRV2604EVM-CT, and therefore still representative of both DRV260x and DRV262x driver families.

3 Energy Consumption Comparisons for ERM, LRA and Piezo

In this section, we summarize more energy consumption data for the ERM, LRA, and Piezo with different types of haptic effects.

Table 3-1. Energy Consumption Comparisons Data

	Piezo			LRA			ERM		
Effect	**Duration (ms)**	**Consumption (µAh)**	**Accelerate (g)**	**Duration (ms)**	**Consumption (µAh)**	**Accelerate (g)**	**Duration (ms)**	**Consumption (µAh)**	**Accelerate (g)**
Bump	13.3	0.31	0.96	40	0.30	0.93	39	1.14	0.89
Click	19.61	0.34	0.921	51.3	0.57	0.903	50	1.72	0.90
Pulse	48	0.90	0.91	91	0.68	0.95	94	1.72	0.92
Alert	60	1.18	0.92	75	0.47	0.91	78.70	2.00	0.96
Buzz	609	11.4	0.90	752	3.38	1.00	609	11.41	0.93

Figure 3-1 converts this data to a bar graph:

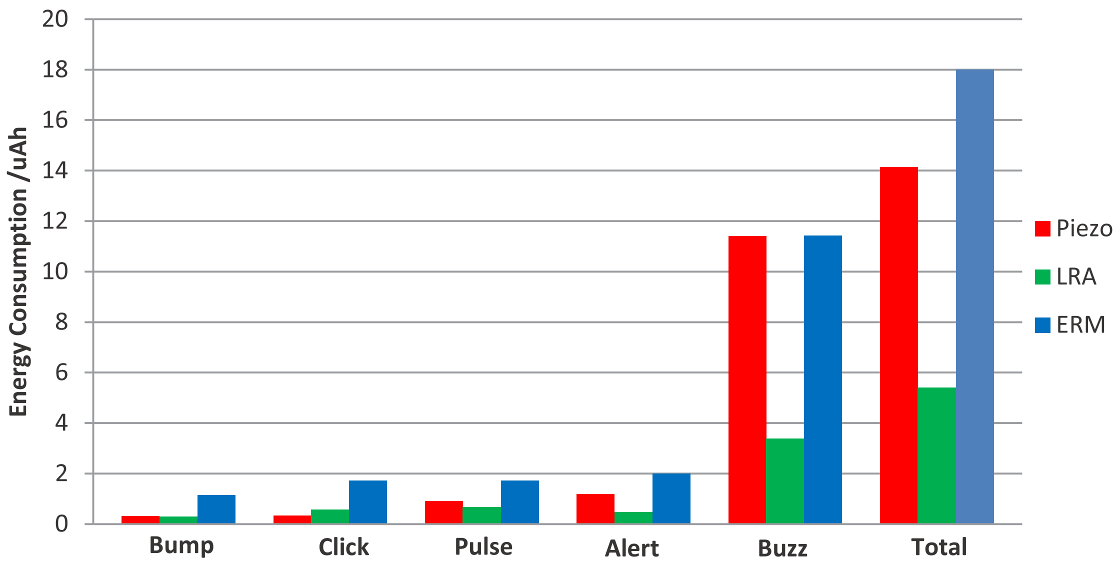


Figure 3-1. Energy Consumption of Piezo, LRA, and ERM

Table 3-1 and Figure 3-1 illustrate the following conclusions:

- The Piezo consumes the least amount of energy on short effects compared to the other actuators
- When playing longer, constant-acceleration effects, Piezo consumes the same amount of energy as ERM
- The LRA can save 60%-80% energy compared to ERM

The actuator is loaded with a 100 g metal mass to simulate a smartphone. Section 6Appendix B shows the test condition, and Appendix C shows how to use the effects data in Table 3-2 to calculate each scenario for a smartphone.

Table 3-2. Phone Scenarios

	Energy Consumption (uAh)		
Usage	**Piezo**	**LRA**	**ERM**
Phone Call (1x)	140.2	46.31	154.22
15x	2103	694.62	2313.54
Text Message (1x)	72.74	115.87	352.40
15x	1091.04	1737.96	5286
Reply to an Email	106.74	172.86	524.6
5x	533.68	864.32	2623
Reminder (1x)	125.84	38.5	134.18

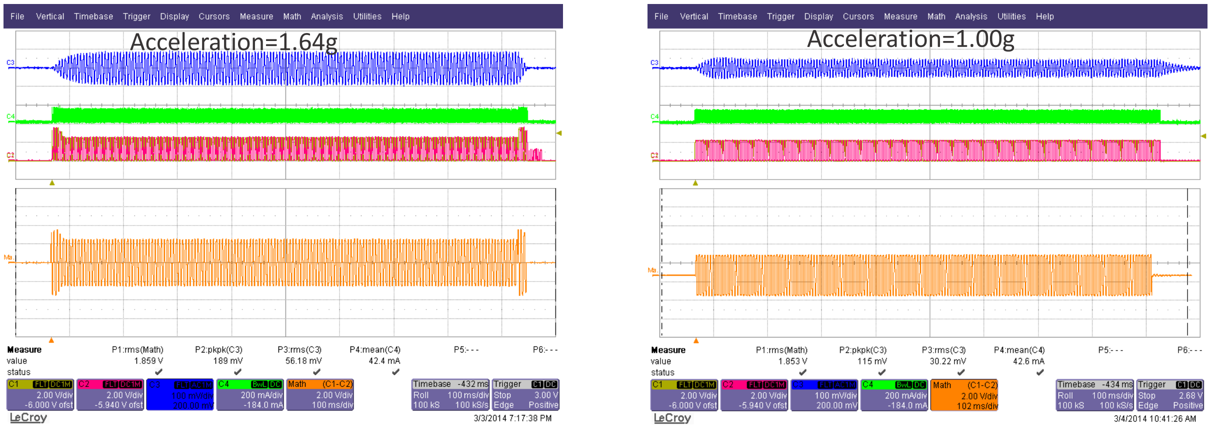
Table 3-2. Phone Scenarios (continued)

	Energy Consumption (uAh)		
Usage	**Piezo**	**LRA**	**ERM**
10x	1258.4	385	1341.8
Games - 60 minutes	2628	2235.40	6979.30
Social Media 60 - minutes	2624.69	2242.46	7087.40
Standby	240	45.6	45.6
Total	15204.41	11744.05	36760.8
Total/1200 mAh Battery (%)	1.267	0.979	3.06

It is very clear that LRA and Piezo have big energy advantages for portable applications. For the smartphone application, an ERM consumes nearly two times more energy than LRA and Piezo. The battery of a smart-watch is usually much smaller, so the proportion of total energy consumption of haptics is more significant. In this case, the energy savings of TI haptics solution is more significant.

4 Energy Consumption Advantage of DRV260x and DRV262x Drivers

The DRV260x and DRV262x drivers are a series of haptic drivers for ERM and LRA actuators. They contain many features that help reduce energy consumption for LRA actuators. One important feature is the auto-resonance tracking engine. Auto-resonance tracks the resonant frequency of an LRA in real time. If the resonant frequency shifts in the middle of a waveform for any reason, the engine will track the frequency cycle to cycle to maximize the actuator acceleration. By vibrating at the resonance frequency, the driver needs less energy per “g” of acceleration, which means instant energy savings.



(a)Auto Resonant on (b) Auto Resonant off

Figure 4-1. Buzz Waveform With Auto Resonant on/off

Table 4-1. Auto Resonance on and off Data

	Acceleration (g)	Start Time (ms)	Stop Time (ms)	f (Hz)	Energy (mA/g)
Resonance on	1.64	56.0	14.5	175	28.4
Resonance off	1.00	51.7	71.6	185	51.8

Table 4-1 shows that acceleration is much larger and power consumption is much lower when auto-resonance is on. With auto-resonance on, the DRV2605 adapts to the changing LRA resonant frequency which is centered around 175 Hz. However, the driver no longer tracks the frequency when auto-resonance is off. That is why stronger acceleration is achieved when auto-resonance is on. The same holds true for all DRV260x and DRV262x devices.

Auto-resonance also improves the startup speed and stop speed of the actuators.

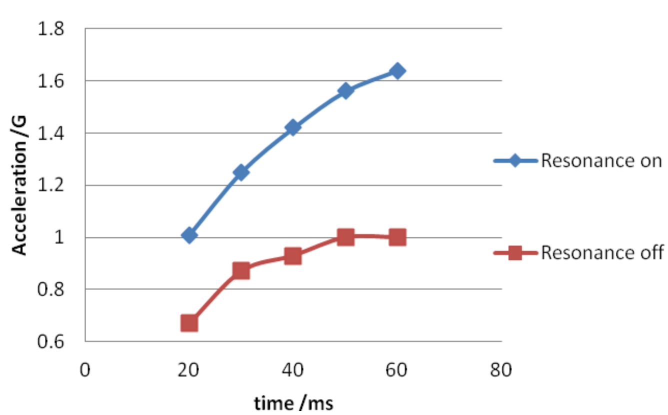


Figure 4-2. Startup Speed

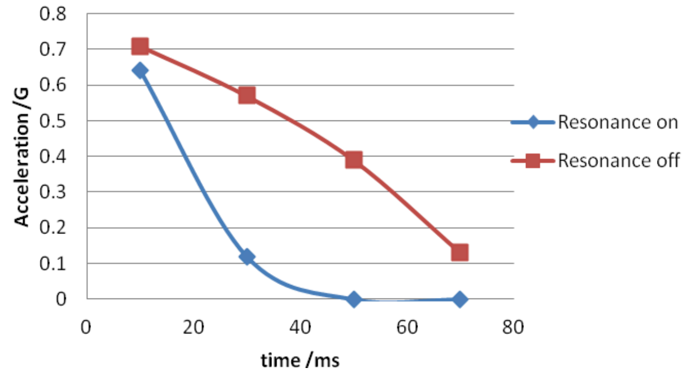


Figure 4-3. Stop Speed

Table 4-1 shows that the start time with auto-resonance on is longer; however, this is a result of the higher acceleration due to auto-resonance. The auto-resonance engine can help actuators start and stop more quickly and reach the same acceleration in less time, just as Figure 4-2 and Figure 4-3 show. In Table 4-1 when auto-resonance is on, the actuator just needs slightly more time to produce a larger acceleration force.

5 Appendix A Energy Consumption of Actuators

Table 5-1 shows energy consumption of more actuators of different manufactures, including AAC, SEMCO, Copal, AWA, and Sanyo.

Table 5-1. Actuator Energy Consumption Data

Actuators	Duration (ms)	Acceleration (g)	Full-Scale Click (µAh per click)
LRA – AAC ELV1411	50	0.941	0.680
LRA – Partron (Rectangle)	50	0.466	0.531
LRA – Partron (Round)	50	0.557	0.458
LRA – LG Innotek	50	1.32	0.412
LRA – AAC ELV1036A	50	0.914	0.541
LRA – SEMCO 1030	50	0.846	0.521
LRA – SEMCO 1036	50	0.795	0.414
LRA – Copal AA7	45	0.631	0.633
ERM – Sanyo NRS2574I	45	1.103	1.819
ERM – Sanyo BMR3565	45	0.541	1.284
ERM – AWA GS-2717	45	0.580	0.718
ERM – Sanyo BNK3266	45	0.550	1.342
Piezo – SEMCO	16.5	0.904	0.782
Piezo – AAC	16.5	0.543	0.680

6 Appendix B. Test Setup Picture

Figure 6-1 illustrates a haptic energy consumption test setup.

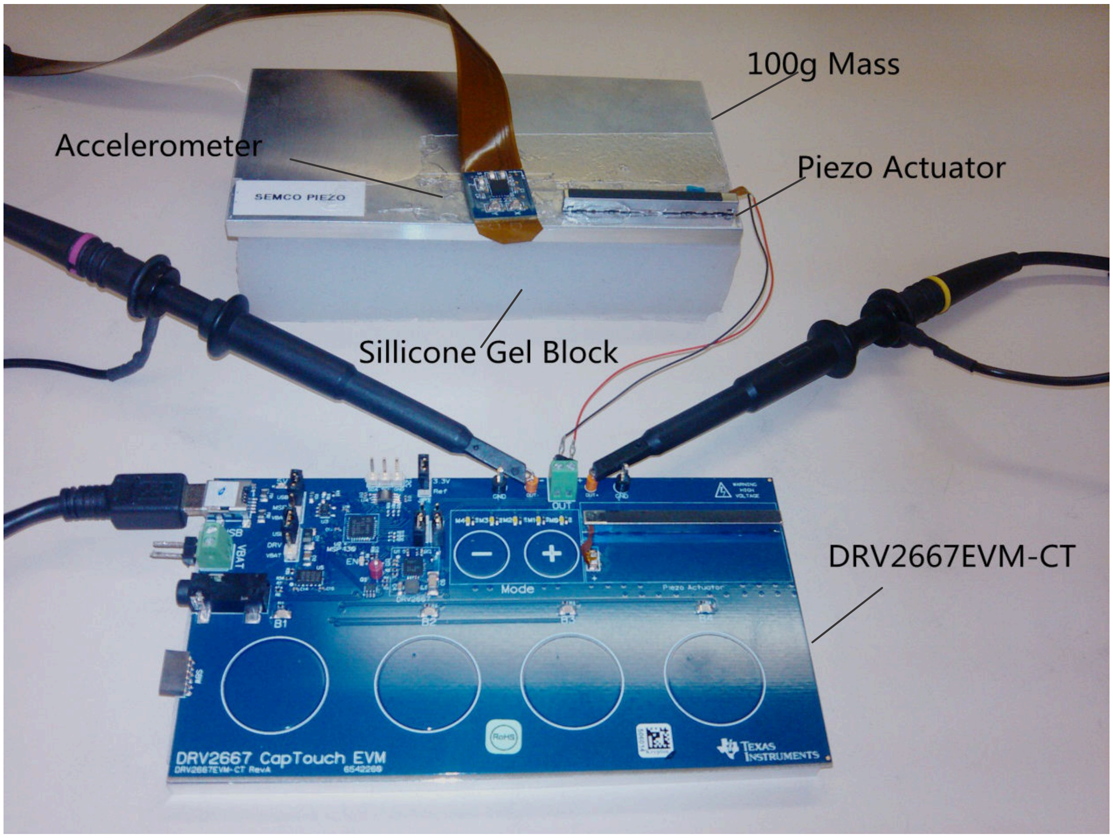


Figure 6-1. Test Setup Illustration

7 Appendix C. Energy Consumption Calculation for Smartphone Scenarios

This section shows how to use the data of Figure 3-1 to calculate the smartphone scenarios.

1. Phone call-15 times a day
   - Dial phone numbers: Assume the user dials 10 numbers in each phone call. There are a total of 150 clicks.
   - Receive phone calls: Assume each phone call received has 12 buzzes, every 2 buzz combines a ringing. There are a total of 180 buzz effects.
2. Text Message-15 times a day
   - Write a text message: Assume 40 words in each text message, each word combines 5 characters. There are a total of 3000 clicks.
   - Receive a text message: Assume there are 4 alerts when receiving a text message. There are 60 alerts in total.
3. Email-5 times a day
   - Reply to an email: Assume there are 60 words in each email, each word combines 5 characters. There are a total of 1500 clicks.
   - Receive an email: Assume each text message received has 4 alerts. There are 20 alerts in total.
4. Reminding-10 times a day
   Assume each reminder consists of 10 alerts and 10 buzzes.
5. Games-60 minutes a day
   Different games use different effects, so just assume they include the following effects in 10 minutes and games are played for one hour each day.
   - Bump: 100 times
   - Click: 500 times
   - Pulse: 200 times
   - Alert: 150 times
   - Buzz: 20 times
6. Social media- 60 minutes a day
   Assume there are the following effects in 10 minutes, and then interpolate the data for 60 minutes.
   - Bump: 70 times
   - Click: 400 times
   - Pulse: 80 times
   - Alert: 60 times
   - Buzz: 12 times
7. Other- 60 minutes a day, including search, web, news, clock
   Assume there are following effects and people consumed the total time of one hour on these actions.
   - Bump: 720 times
   - Click: 2400 times
   - Pulse: 360 times
   - Alert: 312 times
   - Buzz: 78 times

Standby energy consumption

The typical DRV260x driver standby current is 1.9 μA while the typical for the DRV262x driver is 1.55 μA , and the DRV2667 (Piezo driver) standby current is 10 μA. For one day the energy consumption of ERM and LRA drivers is 45.6 μAh or 37.2 μAh for DRV260x or DRV262x respectively, and Piezo driver is 240 μAh.

8 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (May 2014) to Revision A (January 2022)	Page
• Updated "haptics drivers" references	1
• Updated general device references to "DRV260x and DRV262x"	1

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