

TACHAMMER™

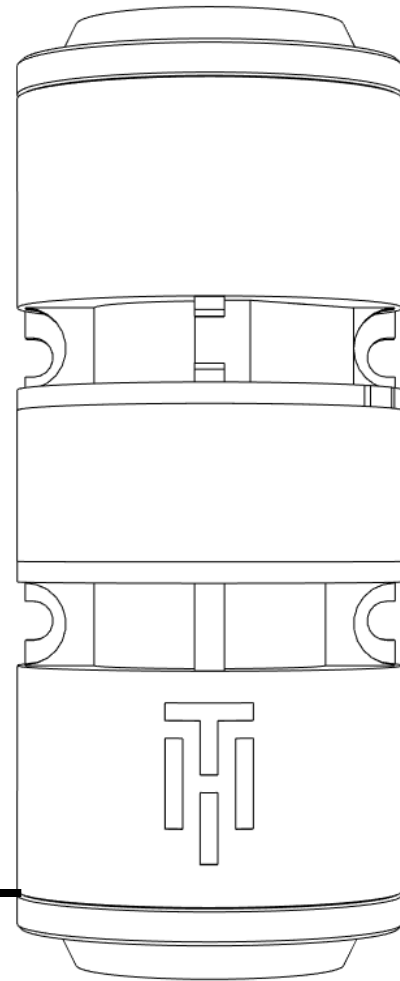
DRAKE

LMR Vibrotactile Haptic Motor

*Wideband, high definition (HD)
voice coil actuator for electronic devices*

Product: TacHammer Drake (LF/LFi/ MF/HF)
Product ID: TH-D-952395 (LF/LFi/ MF/HF)

Revised: May 12, 2023



FEATURES:

- Ultrawide operating frequency of 5-300Hz
- 19 G peak acceleration
- High displacement (3mm)
- High operating efficiency: <2 μ Amp-hour / click
- Operating voltage: 1 - 7 Vp-p
- Wide compatibility with drive electronics
- Robust mechanism (one moving part)
- Multimodal haptic generation:
Pulses, Vibrations, Waveforms, Audio, Impact

LINEAR MAGNETIC RAM (LMR)
CLASS HAPTIC ACTUATOR

HAPTIC PLAYBACK:

PULSES | VIBRATIONS |
WAVEFORMS | AUDIO |
IMPACT



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1 LMR Technology

1.1 LMR Technology Features

1. Wide Frequency Response
 - a. Response over a larger frequency range
 - b. Ideal for wideband applications like audio-to-haptics
2. High Displacement
 - a. Ideal for haptic translation through materials, housings and clothing
3. Power Efficient,
 - a. Battery powered, portable electronics
 - b. Efficient click energy for tap and click haptic effects
4. High Dynamic Range
 - a. (Low stiction) *low force to move hammer from resting place*
 - i. Allows minimum threshold for barely noticeable detection
 - b. [chart that shows minimum threshold of detection vs voltage levels]
5. Linear frequency tracking
 - a. Great audio-to-haptics response
6. (voice coil?) - Low Drive Requirements
 - a. Compatible with a wide range of Driver ICs, PMICs and MOSFETs
 - b. Simple to drive and operate

1.2 Operating Principles

Mechanism

The TacHammer™ haptic actuator is a LMR type voice coil actuator with magnetic suspension. Applying a positive or negative current to the terminals moves an internal mass (ram).

Rest Position and Damping

When no voltage is applied, the ram returns to a resting position in the actuator housing. This rest position is maintained by the magnetic field of a magnetic array. When the hammer returns to its rest position, a small haptic may be felt depending on the prior position and velocity of the hammer. This return haptic can be damped by applying a canceling waveform, or by connecting (shorting) the positive and negative terminals.

Passive Damping

Damping can also be used to prevent unintended motion of the hammer when subjected to vigorous shaking. Passive damping can be achieved without needing a continuous power source by connecting (shorting) the positive and negative terminals.

Note: use of solid-stage amplifiers may introduce damping in the haptic system.

Drive Signals



TacHammer can be driven by simple, individual electronic pulses, pre-built waveforms, continuous waveforms (square, sine or arbitrary), audio signals, or a blend. Amplification and amplitude modulation can be accomplished by varying the input voltage or using PWM. See section **4.1** for drive signal details.



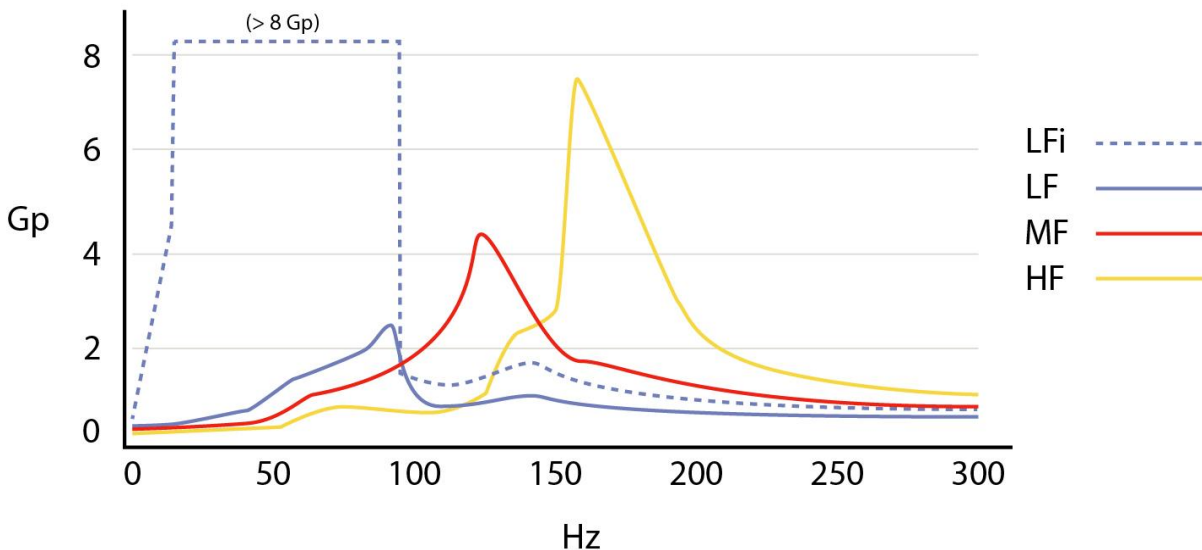
2 Specifications

2.1 Variant Overview

| PARAMETER | LFi (Impact) | LF | MF | HF | UNIT |
|--|--------------|-------|-------|-------|--------|
| Peak Acceleration | 19 | 2.5 | 4.5 | 7.5 | G |
| Peak Acceleration Frequency (Resonance) ¹ | 65 | 95 | 130 | 160 | Hz |
| RMS Acceleration at Peak Acceleration Frequency ² | 13.4 | 1.7 | 3.18 | 4.45 | Grms |
| RMS Current at Peak Acceleration Frequency ² | 174 | 170 | 222 | 145 | mA |
| RMS Power at Peak Acceleration Frequency ^{2,3} | 242 | 231 | 394 | 168 | mW |
| Acceleration Efficiency ² | 108 | 26 | 11.4 | 56 | G/W |
| Click Energy ⁴ | .95 | .3 | .61 | .87 | μAh |
| Latency ⁵ | ~10 | ~10 | ~10 | ~10 | ms |
| Rise Time ⁵ | >5 | >5 | >5 | >5 | ms |
| Fall Time ⁵ | >5 | >5 | >5 | >5 | ms |
| Noise at Peak Acceleration Frequency ⁶ | <65 | <45 | <45 | <45 | dba |
| Operating Life ⁷ | 120M+ | 120M+ | 120M+ | 120M+ | cycles |

2.1.1 Variant Overview - Frequency Response

TacHammer Drake Frequency Response



2.2 Drake-LF Performance Specification

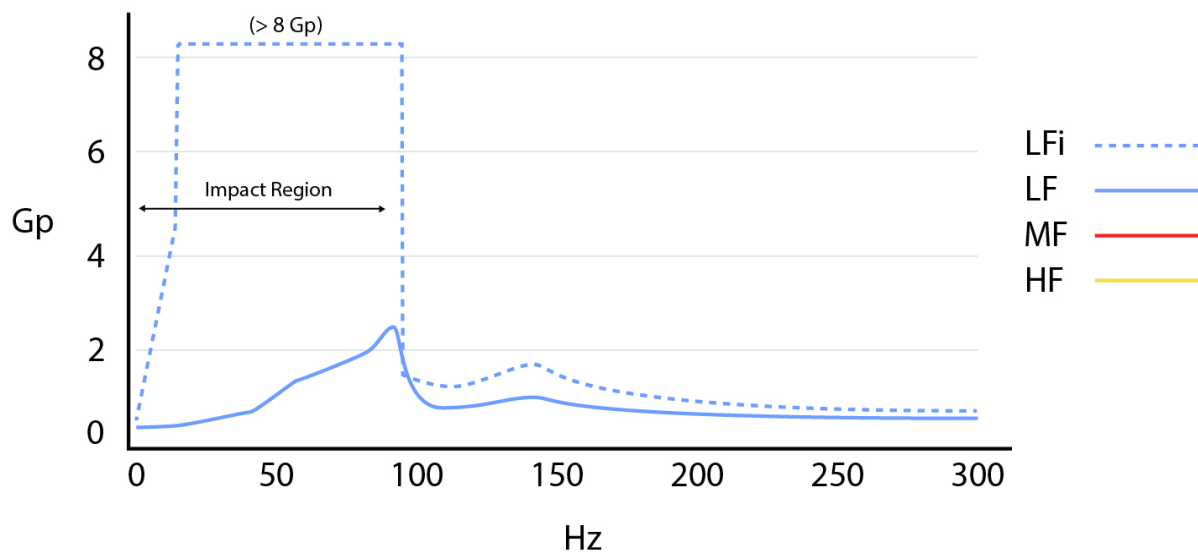
General Operating Performance

When attached to a 100g mass

| PARAMETER | LF Impact (LFI) | LF Vibration | UNIT |
|--|-----------------|--------------|--------|
| Peak Acceleration | 19 | 2.5 | G |
| Peak Acceleration Frequency (Resonance) ¹ | 65 | 95 | Hz |
| RMS Acceleration at Peak Acceleration Frequency ² | 13.4 | 1.7 | Grms |
| RMS Current at Peak Acceleration Frequency ² | 174 | 170 | mA |
| RMS Power at Peak Acceleration Frequency ^{2,3} | 242 | 231 | mW |
| Acceleration Efficiency ² | 108 | 26 | G/W |
| Click Energy ⁴ | .95 | .3 | μAh |
| Latency ⁵ | ~10 | ~10 | ms |
| Rise Time ⁵ | >5 | >5 | ms |
| Fall Time ⁵ | >5 | >5 | ms |
| Noise at Peak Acceleration Frequency ⁶ | <65 | <45 | dbA |
| Operating Life ⁷ | 120M+ | 120M+ | cycles |

2.2.2 Drake LF & LFI Frequency Response

TacHammer Drake Frequency Response



2.3 MF Variant Performance Specification

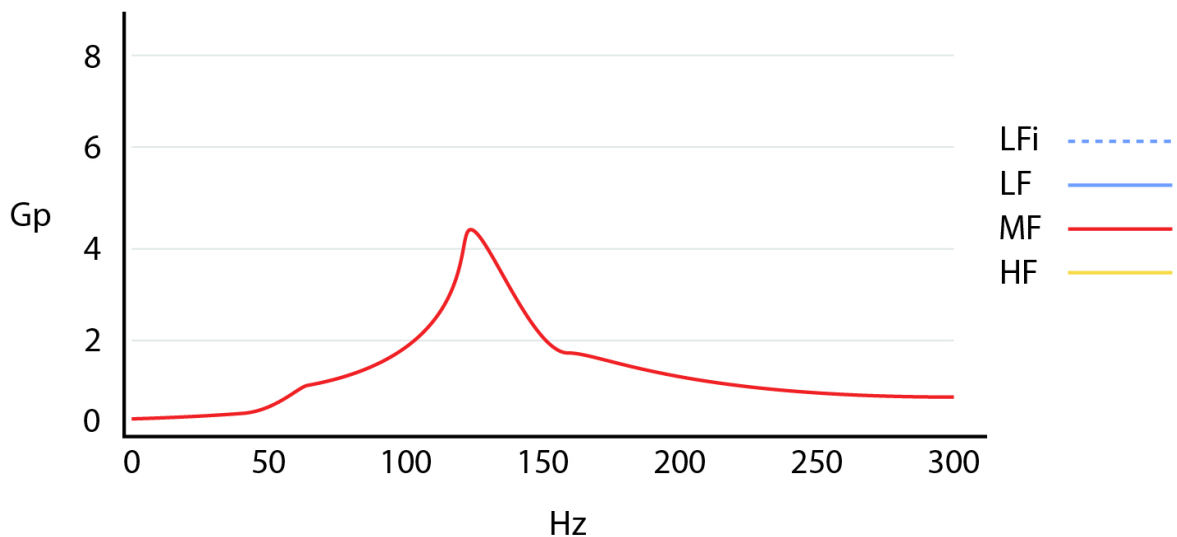
General Operating Performance

When attached to a 100g mass

| PARAMETER | Drake-MF | UNIT |
|--|----------|--------|
| Peak Acceleration | 4.5 | G |
| Peak Acceleration Frequency (Resonance) ¹ | 130 | Hz |
| RMS Acceleration at Peak Acceleration Frequency ² | 3.18 | Grms |
| RMS Current at Peak Acceleration Frequency ² | 222 | mA |
| RMS Power at Peak Acceleration Frequency ^{2,3} | 394 | mW |
| Acceleration Efficiency ² | 11.4 | G/W |
| Click Energy ⁴ | .61 | μAh |
| Latency ⁵ | ~10 | ms |
| Rise Time ⁵ | >5 | ms |
| Fall Time ⁵ | >5 | ms |
| Noise at Peak Acceleration Frequency ⁶ | <45 | dbA |
| Operating Life ⁷ | 120M+ | cycles |

2.3.2 Drake-MF Frequency Response

TacHammer Drake Frequency Response



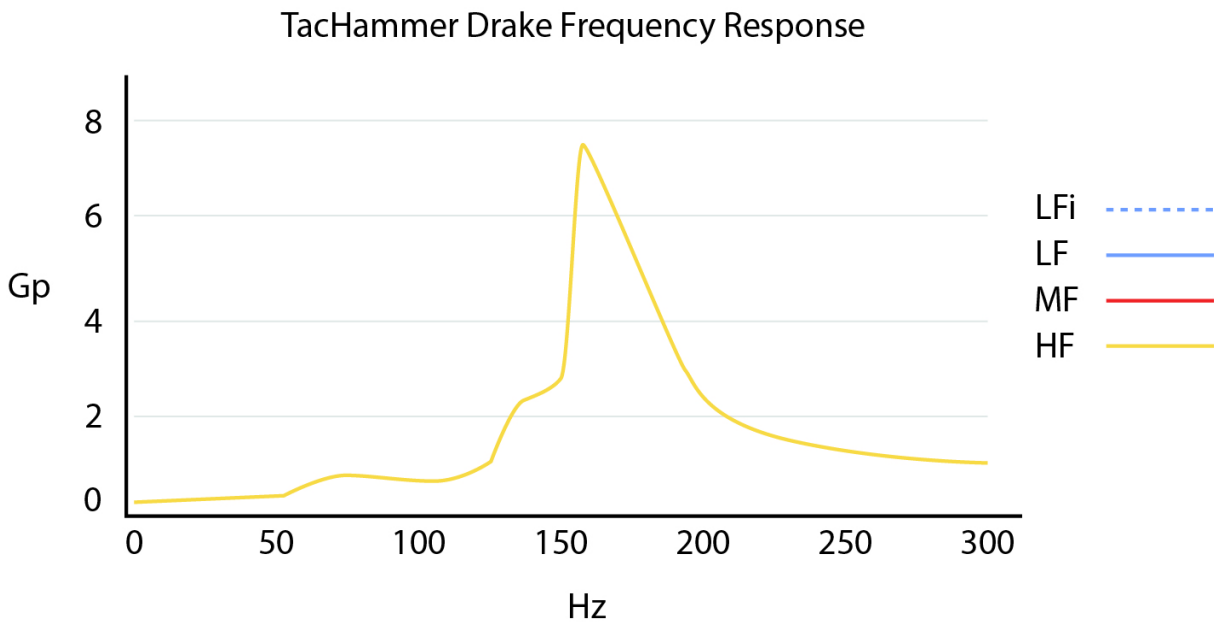
2.4 HF Variant Performance Specification

General Operating Performance

When attached to a 100g mass

| PARAMETER | Drake-HF | UNIT |
|--|----------|--------|
| Peak Acceleration | 7.5 | G |
| Peak Acceleration Frequency (Resonance) ¹ | 160 | Hz |
| RMS Acceleration at Peak Acceleration Frequency ² | 4.45 | Grms |
| RMS Current at Peak Acceleration Frequency ² | 145 | mA |
| RMS Power at Peak Acceleration Frequency ^{2,3} | 168 | mW |
| Acceleration Efficiency ² | 56 | G/W |
| Click Energy ⁴ | .87 | μAh |
| Latency ⁵ | ~10 | ms |
| Rise Time ⁵ | >5 | ms |
| Fall Time ⁵ | >5 | ms |
| Noise at Peak Acceleration Frequency ⁶ | <45 | dbA |
| Operating Life ⁷ | 120M+ | cycles |

2.4.2 Drake-HF Frequency Response



2.5 Drive Condition and Measurement Notes

1. Resonance is defined as the frequency that yields the highest peak acceleration at 3.3V
2. Measured at +/- 3.3V, 100g jig, at peak acceleration frequency. mass driven towards accelerometer
3. Power calculated $P = I_{rms}^2 * Resistance$
4. Click Energy defined as the energy to perform a single click.

$$ClickEnergy = \frac{I_{instantaneous} * PulseWidth}{3600}$$

Calculated as:

5. See section 4.2 *Response Time Note* for additional details
Impact measured at: 3.3V, 100g mass, 1Hz, 7.8ms pulse width
Traditional measured at: 3.3V, 100g mass, 1Hz, 7.8ms pulse width
6. Measured from 10cm
7. 1 Cycle is defined as one complete movement of the actuator from rest to rest. Tested at 3.3Vp, 50Hz@40% duty cycle



2.6 Recommended Operating Conditions

| PARAMETER | MIN | MAX | UNIT |
|-----------------------|-----|-----|------|
| Operating Voltage | .5 | 7 | Vp-p |
| Operating Temperature | -20 | 80 | °C |

The actuator can be driven at higher voltages up to 10V+ for short periods of time as long as the coil temperature does not exceed 80°C.

2.7 Electrical Characteristics

| PARAMETER | MIN | TYP | MAX | UNIT |
|-----------------------------|------|------|------|------|
| Coil Resistance (DC) @ 20°C | 7.6 | 8 | 8.4 | Ω |
| Impedance @ 100hz, 1V (LFI) | 8.23 | 8.66 | 9.09 | Ω |
| Impedance @ 100hz, 1V (LF) | 7.70 | 8.11 | 8.52 | Ω |
| Impedance @ 100hz, 1V (MFI) | 7.57 | 7.97 | 8.37 | Ω |
| Impedance @ 100hz, 1V (HFI) | 7.71 | 8.12 | 8.53 | Ω |

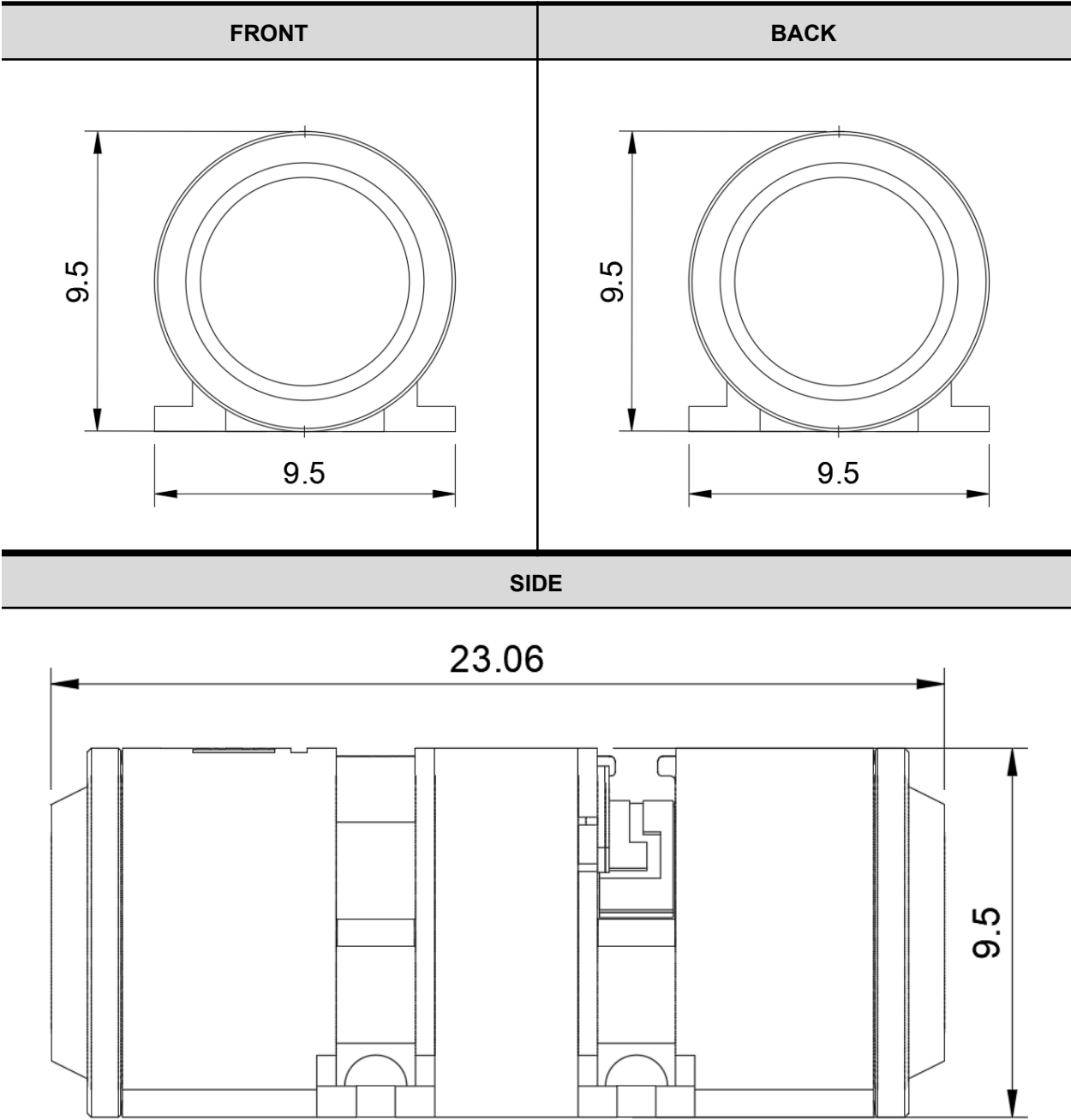
2.8 Mechanical Characteristics

| PARAMETER | SPECIFICATION |
|----------------|----------------------------|
| Dimensions | 9.5 mm x 9.5 mm x 23.06 mm |
| Total Weight | 8.56 grams |
| Connector Type | Flying Lead |



2.9 Product Dimension Specification

*All dimensions in mm



3 Application Notes

3.1 Driving Signal

TacHammer can be driven with various types of electrical inputs without requiring specialized electronics. For basic applications

3.1.1 Single Impulse Haptics

Single haptics such as a single Tick or Pulse can be generated with a short DC pulse. Positive (+V) voltage drives the hammer towards the impact end to generate sharp “ticks”. Negative (-V) voltage drives the hammer towards the hammer into a repelling magnetic field to generate blunt “pulses”.

The following table lists the recommended duration for the respective haptic.



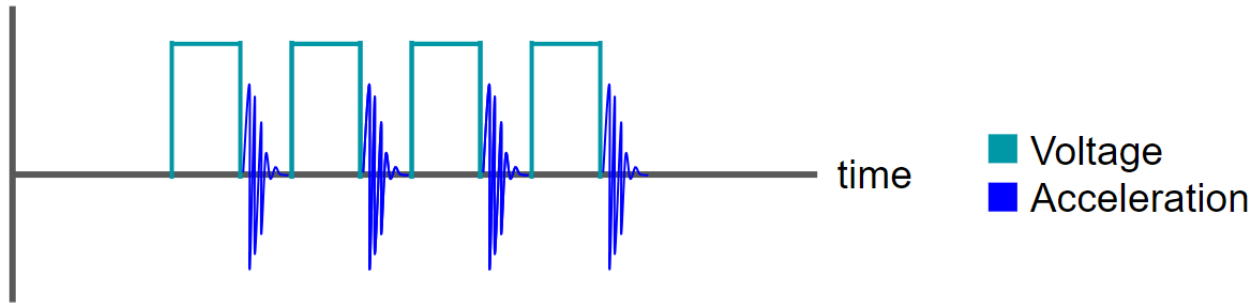
| HAPTIC | DURATION | UNIT |
|------------|----------|------|
| Tick (+V) | 8.6 | ms |
| Pulse (-V) | 5.2 | ms |

Varying the pulse width and/or applying pulse-width-modulation provides for further modulation of the haptic strength. Note: when using PWM, be sure to use non-audible frequencies and/or low-pass filtering to avoid generating unwanted noise.

3.1.2 Repeated Haptics (Vibrations)

For repeated haptics such as vibrations, TacHammer is optimally driven with square wave inputs. Arbitrary waveforms using PWM and/or sine waves can also be used to generate continuous haptic playback. Note: it is often not required to run at maximum duty cycle to generate peak acceleration amplitudes. A reduced duty cycle can save power without impacting performance.





3.1.3 LRA Drive Signal compatibility

TacHammer can be driven using LRA signals. While compatible, playback using LRA signals may result in slightly reduced performance. For best results, shift the LRA drive signal frequency closer to the TacHammer's f_0 (which is typically a lower frequency) or use audio waveforms. Using a closed-loop LRA driver IC can help modify the LRA input signal to be optimized for higher output on the TacHammer.

3.1.4 Arbitrary and Audio waveform

TacHammer can be used to playback audio waveforms typically used for driving speakers. For best results, signal amplification can be used via dedicated haptic ICs, audio ICs (PWM, Class-D, or Analog), or discrete components (h-bridge).

3.1.5 Drive Signal conditioning

Low Pass Filtering can be used to eliminate audible sound generation. LPF can be accomplished using ICs, discrete components, or software signal processing (DSP).

Resonance shifting can be achieved by applying a DC offset signal to the input waveform. A positive offset will LOWER the unit resonance, and a negative offset will raise the unit resonance. **WARNING:** using a DC offset will accelerate temperature rise in the coil. Be careful not to overheat the coil or the unit may prematurely fail.

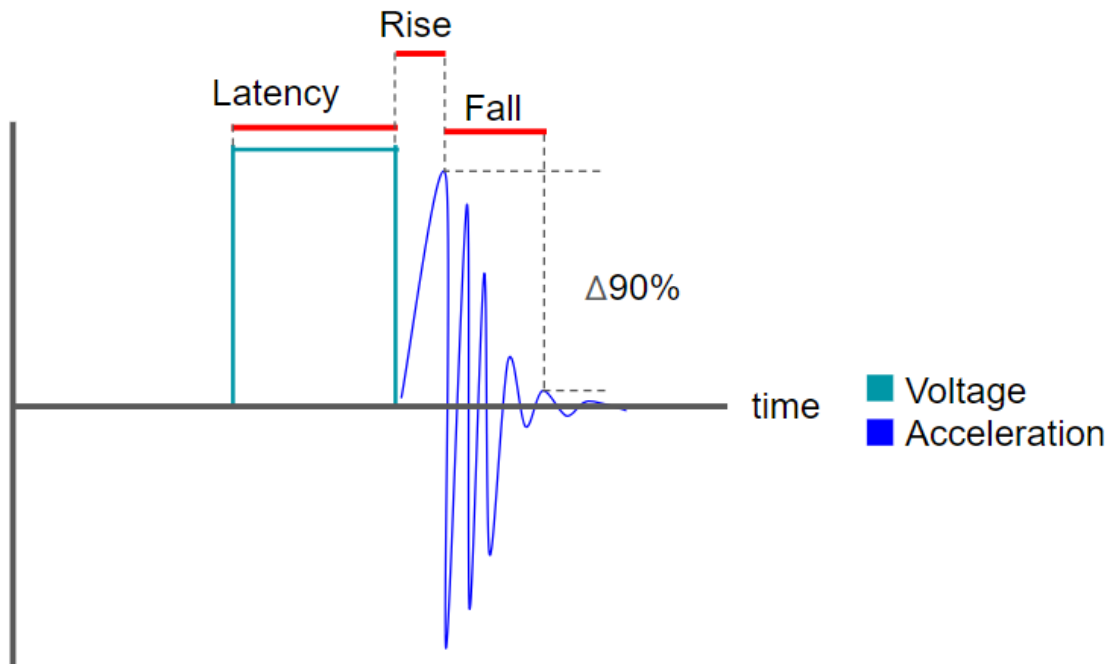
3.1.6 Non-Linear Magnetic Suspension Design

The TacHammer has a non-linear force profile, which is one of the primary differences between the TacHammer and existing haptic technologies. This nonlinearity allows the TacHammer to have a wide operating frequency range and quick response time primarily due to its low stiction at rest.

This means that you can create effective click effects with very low power consumption, respond well to audio drive signals, and create very subtle haptic effects that would otherwise be difficult to produce on legacy technologies. Additionally, the nonlinearity removes the requirement for expensive drive ICs, making the overall solution cost lower than other HD haptic motors.



3.2 Response Time Note



Note: Above image is a representation of the driving signal and corresponding acceleration waveform for a single impact haptic.

3.3 Compatible Driving Hardware

TacHammer Drake (all models) are responsive to a diverse range of drive signals and can be driven by a variety of amplifiers including:

- **Class D Amplifiers**

Examples:

PAM8403 - Diodes Incorporated

BH3541F - ROHM Semiconductors

- **Dedicated Haptic Driver ICs**

Examples:

DRV2605 - TI

DA7281 - Dialog Semiconductor

AW8623DNR - Awinic IC

- **H-Bridge Motor Controllers**

Examples:

DRV8833 - TI

Discrete Component H-Bridge

- **PMICs**

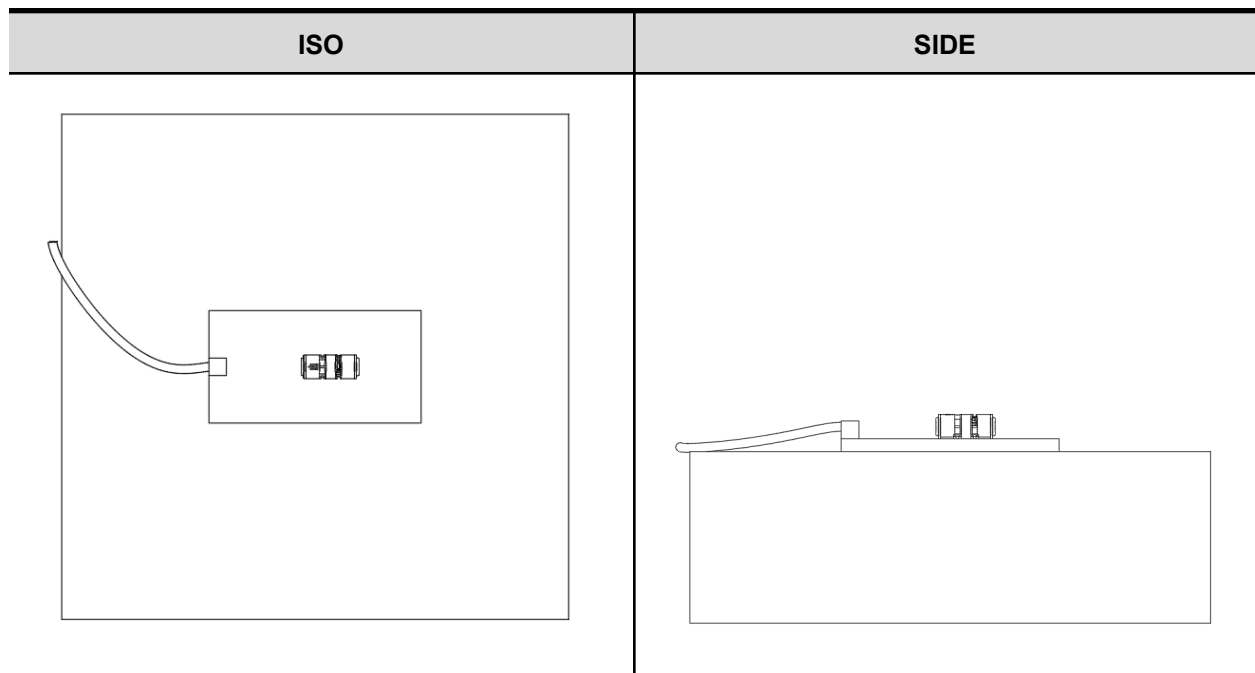


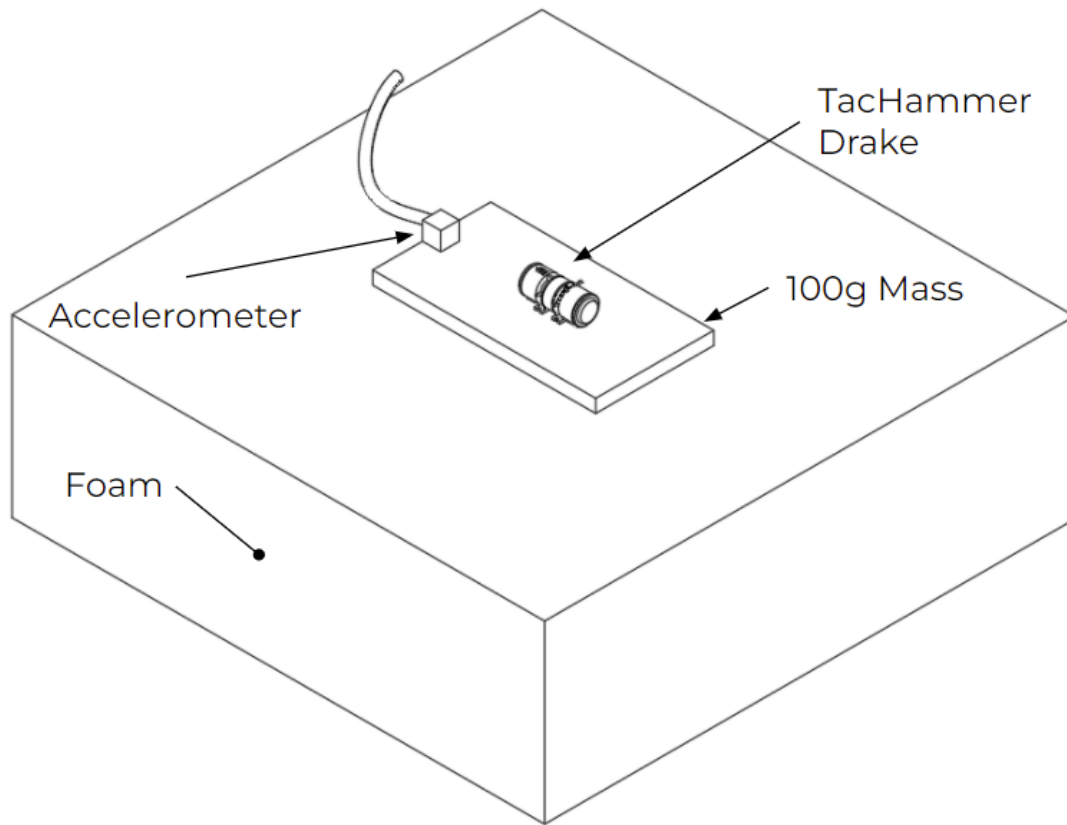
3.4 Measurement Method

3.4.1 Test Equipment

| FUNCTION | MANUFACTURER | MODEL NUMBER |
|------------------|--------------|-------------------|
| Accelerometer | Dytran | 7523A3 |
| Power Supply | Agilent | 6632B |
| Signal Generator | Rigol | DG1022 |
| Signal Amplifier | Rigol | PA1011 |
| Oscilloscope | Lecroy | Waverunner 204MXI |

3.4.2 Test Fixture Setup





The TacHammer unit is mounted to a 100g mass and placed on top of a foam block. An accelerometer is mounted along the axis of the TacHammer 3cm away from the TacHammer. Measurements are taken as the maximum vector amplitude from reading in 3-axes.

4 Standard Test Conditions

4.1 Test Environment

- The standard measurement environment is $25^{\circ}\text{C} \pm 3^{\circ}\text{C}$ & $65\% \text{ RH} \pm 20\% \text{ RH}$ unless otherwise marked
- All temperatures $< 0^{\circ}\text{C}$ are $+0^{\circ}\text{C}/-3^{\circ}\text{C}$ standard unless otherwise marked
- All temperatures $> 0^{\circ}\text{C}$ are $+3^{\circ}\text{C}/-0^{\circ}\text{C}$ standard unless otherwise marked

4.2 Reliability Tests and Criteria

This section contains a detailed list of tests and success criteria

| TEST NAME | TEST DESCRIPTION | TEST STANDARD | SUCCESS CRITERIA |
|---|---|---------------|---|
| Drop Test | Drop JIG : 200g including the Actuator and assembly screws. Drop from 1.0m in specified drop buck onto 6 face. Actuator is not powered. | | Performance specifications within 20% of original (after 4hours of recovery after test) |
| Life Test - Impact | $25^{\circ}\text{C}/50\%\text{RH}$. The life test cycle, 1s on, 1s off, 200 Hours | | Performance specifications within 20% of original (after 4hours of recovery after test) |
| Life Test - Non-Impact | $25^{\circ}\text{C}/50\%\text{RH}$. The life test cycle, 1s on, 1s off, silent mode, 200 Hours | | Performance specifications within 20% of original (after 4hours of recovery after test) |
| High Temperature Storage | 85°C , 96 hours. Actuator is not powered. | EIA-364-17 | Performance specifications within 20% of original (after 4hours of recovery after test) |
| Low Temperature Storage | -40°C , 96 hours. Actuator is not powered. | EIA-364-17 | Performance specifications within 20% of original (after 4hours of recovery after test) |
| High Temperature and Humidity Life Test | $85^{\circ}\text{C}/95\%$. The life test cycle, 1s on, 1s off, 40 Hours. | EIA-364-17 | Performance specifications within 20% of original (after 4hours of recovery after test) |
| Low Temperature Life Test | -40°C . The life test cycle, 1s on, 1s off, 72 Hours. | EIA-364-17 | Performance specifications within 20% of original (after 4hours of recovery after test) |
| Long Life Test | $25^{\circ}\text{C}/50\%\text{RH}$. The life test cycle, 1s on, 1s off, 600 Hours | | Performance specifications within 20% of original (after 4hours of recovery after test) |
| Thermal Shock Test | 5 cycles of -40°C for 30 minutes then $+85^{\circ}\text{C}$ for 30 minutes. The life test cycle, 1s on, 1s off, 5 temperature cycles. | EIA-364-32 | Performance specifications within 20% of original (after 4hours of recovery after test) |



| | | | |
|--|---|--------------|---|
| Salt Spray Test | 35°C and 5% salt solution concentration. The life test cycle, 1s on, 1s off, 8 Hours. | EIA-364-26 | Performance specifications within 20% of original (after 4hours of recovery after test) |
| Non-Operating Random Vibration Test | JIG:200g including the Actuator and assembly screws. 3 axes, 10 minutes per axis, 6 g, 10-2000Hz. Actuator is not powered. | EIA -364-28 | Performance specifications within 20% of original (after 4hours of recovery after test) |
| Shock Test | JIG: 180g including the Actuator and assembly screws. Half sine shock plus,+X/-X/+Y/-Y/+Z/-Z axis,each axis 3 times,500G,Actuator is not powered. | EIA -364-27B | Performance specifications within 20% of original (after 4hours of recovery after test) |
| Solderability Test | Subject connector to the solder pot Temperature:245±5°C.3~5 sec. | EIA-364-52 | Performance specifications within 20%of original (after 4hours of recovery after test) |

