Using Vishay's IHPT® to Produce High Definition (HD) Tactile Feedback for Large Touch Displays and Human UI Devices

By Mariya Sachek

1. FEATURES

- High impulse vibrations for clear tactile feedback in noisy environments
- < 5 ms response time
- Wideband operating frequency 50 Hz to 500 Hz
- Low operating voltage range from 6 V_{p-p} to 16 V_{p-p}
- Operates on unipolar or bipolar pulses
- "Overdrive" voltages can be used to quickly reach peak acceleration
- Resonant point can be tuned by selecting the right combination of spring stiffness and mass
- Includes a license with Immersion® to produce haptics
- Four cases sizes to balance size, cost and force output for wide range of applications
- Turnable performance (resonant frequency, force, bandwidth, etc.)

2. GENERAL OVERVIEW

Description

The IHPT® haptic device employs principles of solenoid operation to produce high definition tactile feedback, achieving fast response times and high g acceleration. Intended for industrial, automotive, and consumer settings, it can enrich the user experience of human-machine interfaces such as touchscreens, button clusters, center consoles and can even be implemented as part of lane-keep assist or other automotive warning systems. Four distinct IHPT sizes are available for the best combination of size, cost and force output. The resonant frequency, force and other performance parameters can be tuned with careful selection of gap width, mass and the spring-return mechanism.

Construction

The device is a two-piece magnetic solenoid construction with mounting holes and is comprised of a stationary "U" core and moving "I-bar". An insulated copper winding is wrapped around the "U" core that terminates in flying leads that can be soldered or inserted into a terminal block on the circuit board.

Mounting

A typical haptic application has a stationary portion (e.g., frame) and a moving portion (e.g., touchscreen). The dynamic "I-bar" of the IHPT should be bolted to the moving mass and the static "U core" to the stationary element.

Mechanism

Driving current through the winding generates a magnetic field that produces an electromotive force that causes the two ends of the IHPT to come together, moving the mass, e.g., touchscreen, with it. The IHPT requires a return mechanism such as a spring or an elastic buffer that separates the moving and stationary components and brings the device back to center position.

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Driving Signal

The IHPT is designed to deliver high force output using low voltage drive levels from 8 V to 16 V. It can be driven with sinusoidal, rectangular and pulse waveforms to produce clicks and steady state vibrations. To power the device, an amplifier stage is needed. The IHPT can be driven with any solenoid-based driver, H-bridge topology, or even with rudimentary pulses generated by a simple MOSFET pulse circuit.

Advantages Over Other Technologies

Even though competing haptic technologies such as piezoelectric can produce high forces, they do so at small displacements, usually around 0.05 mm or less, which may be difficult for human touch to perceive even at the high forces produced by piezos. By contrast, the IHPT produces similar forces at displacements of 0.5 mm to 2 mm, making it easier to perceive through gloves and rugged environments.

3. SPECIFICATIONS

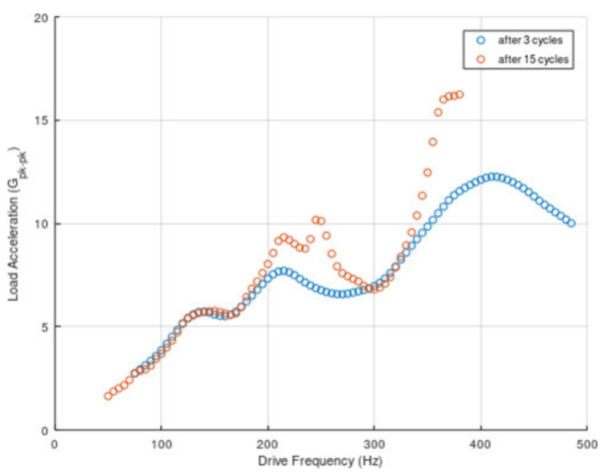

Fig. 1 - Peak to Peak Acceleration vs. Drive Frequency
(mass = 0.25 kg)

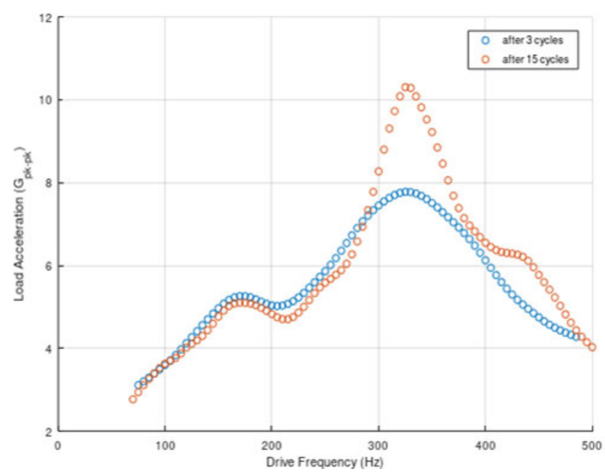

Fig. 3 - Peak to Peak Acceleration vs. Drive Frequency
(mass = 0.40 kg)

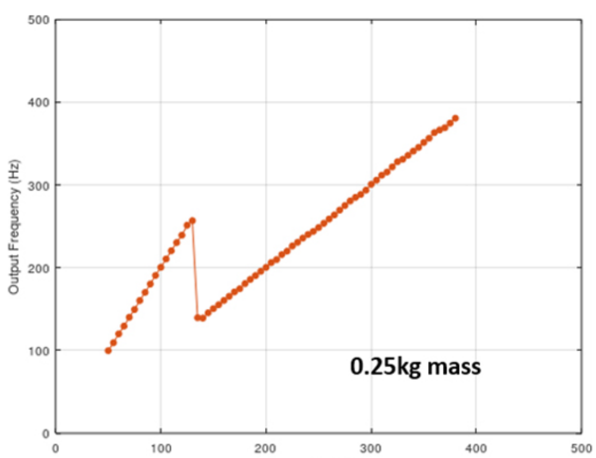

Fig. 2 - Frequency of Peak Energy vs. Input Frequency
(mass = 0.25 kg)

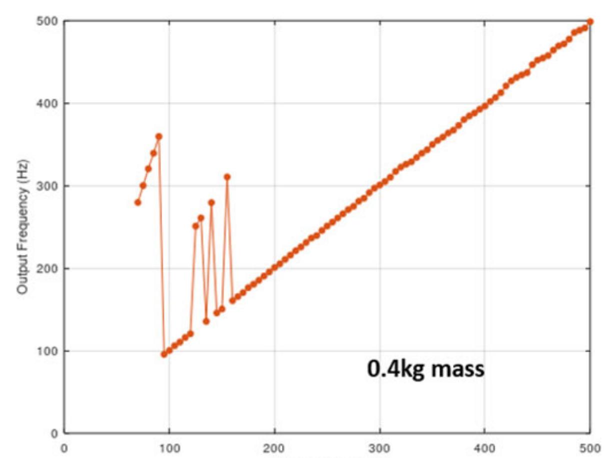

Fig. 4 - Frequency of Peak Energy vs. Input Frequency
(mass = 0.40 kg)

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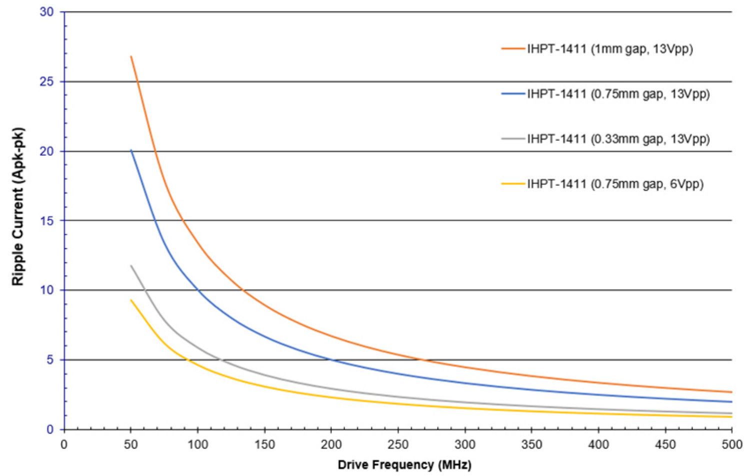

Fig. 5 - Current Draw vs. Frequency for Various Gap Settings
(sine wave excitation, 3 A_{DC} to 6.5 A_{DC} bias)

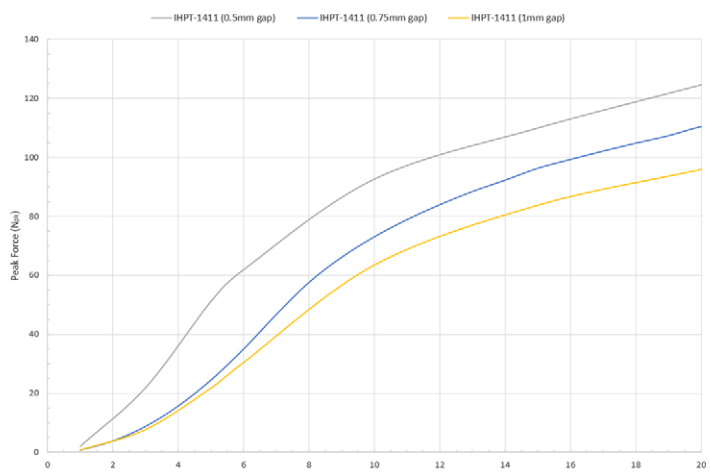

Fig. 6 - IHPT1411AFELR73AB0 (80 N) Peak Force Responce (typical)

APPLICATION NOTE

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4. APPLICATION NOTES

4.1. Driving Signal

The IHPT can be driven with sinusoidal, rectangular, pulse or arbitrary waveforms. Generally, a 50 % duty square wave produces the maximum force output for a given voltage peak amplitude. For proper operation, the peak to peak voltage swing of the input signal should be kept between 8 V_{pp} and 16 V_{pp}. The actuator is capable of generating short transient effects (for simulating clicks or button presses) or it can be used to generate steady state vibrations. An increase in the driving voltage will result in a proportional force increase to the power of 2.

To power the device, an amplifier stage is needed. The IHPT can be driven with any solenoid-based driver circuit, H-bridge topology, or even with rudimentary pulses with a simple MOSFET pulse circuit.

Driver boards and driver IC's are available through manufacturers such as TI which simplify the process of driving and evaluating such haptic devices. The user can either use the driving software provided with the board or they can feed their own arbitrary waveform into the board for amplification.

Driving board requirements:

- Should be capable of generating 16 V_{pk} waveforms
- 8 A continuous current output (13 A peak)

Short Transient Effects

Clicking effects typically require 1 to 3 cycles of a signal. The IHPT is capable of reaching its peak force output after 3 cycles.

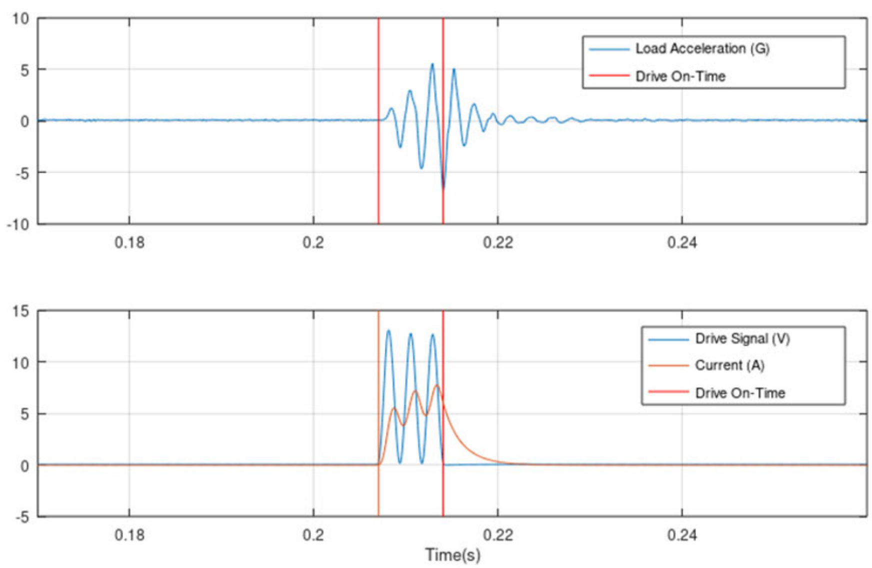

Fig. 7 - 420 Hz Signal (resonant frequency)

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Steady State Effects

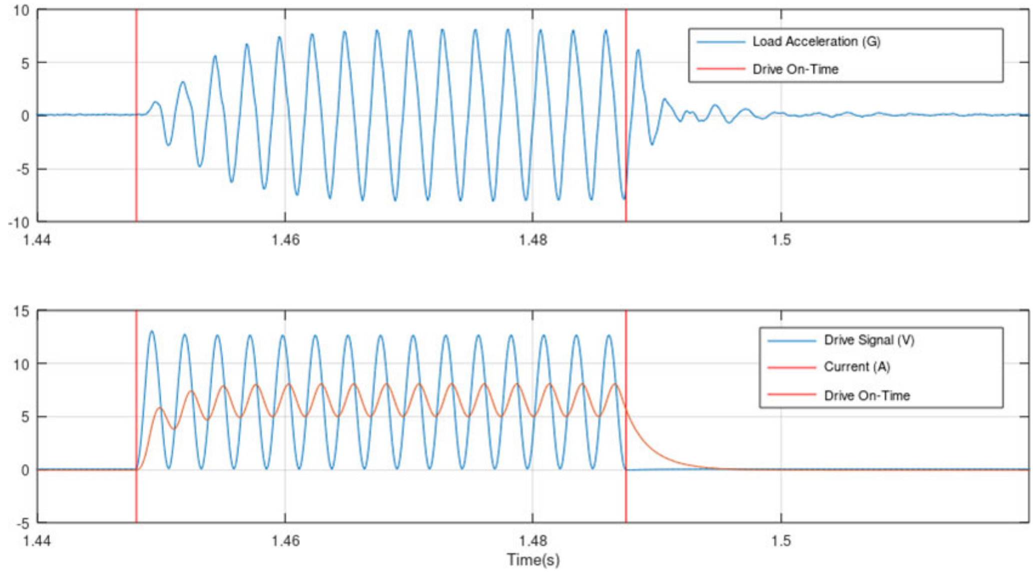

Fig. 8 - 380 Hz Signal (not resonance)

4.2. Frequency Response

Like many electromagnetic haptic actuators, the IHPT exhibits non-linear behavior across its operational bandwidth. The non-linearity is a result of beat frequencies produced by the resonance of the system and the sub-harmonic elements of other parallel components in that haptic system, such as the mass of the overall fixture the IHPT is mounted to. Securing the stationary "U" section to a sufficiently rigid mass or structure will mitigate these sub-harmonic element in the mechanical output response.

The designer has the option of using fully bipolar or fully unipolar driving signals. With a bipolar signal (i.e., no dc bias) the mechanical output frequency is doubled and acceleration strength is attenuated according to the IHPT's amplitude vs. frequency plot. This occurs because the solenoid properties of the IHPT behave like a mechanical rectifier. When a fully unipolar signal (i.e., with DC bias) is applied, the one to one frequency relationship is preserved, but this introduces DC losses into the system.

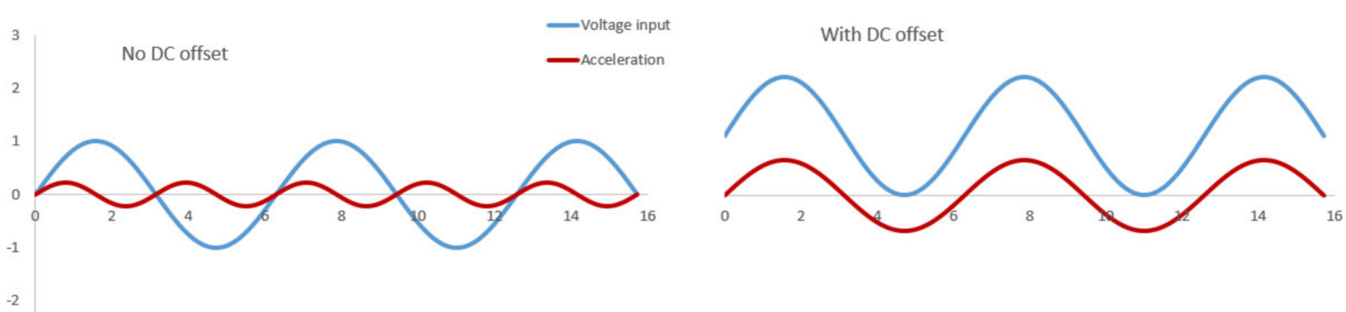

Fig. 9 - No DC Offset vs. With DC Offset

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4.3. Resonance

The most efficient mode of operation is at the resonance of the system. For the type of mass and mounting configurations the IHPT is designed for, this resonance point will typically fall between 150 Hz and 350 Hz. The resonant frequency f_0 (in Hz) is determined strictly by the mass m (in kg) and stiffness coefficient k (in N/m) of the spring or return mechanism according to the following:

$$f_0 = \frac{1}{2\pi\sqrt{m/k}}$$

The resonance of the actuator can be tuned to achieve the desired performance. To shift the resonant frequency to the right, a stiffer spring (higher k) or a smaller mass will shift the frequency response to the right. A heavier mass loads the system, shifting the resonant point to the left and lowers the acceleration output at the load. For example, increasing the mass from 0.25 kg to 0.5 kg would shift the peak frequency from 400 Hz to 280 Hz for a fixed k. This shift can be counteracted by selecting a stiffer spring with a higher k constant.

4.4. Braking Signal

When the power is shut off to the IHPT, the device and mass can sometimes continue to vibrate at the system's natural frequency. While this residual tail has been shown to be largely insignificant in many arrangements due to the inherent damping in the mounting, certain implementations can exaggerate this effect. In such cases, as well as applications that require very crisp feedback (e.g., short clicks or button press effects), a brake pulse can be used to counteract this undesired resonant output.

To construct an ideal brake signal, the following guidelines should be observed:

- Proper timing: the brake pulse should immediately follow the main driving signal and should be timed such that the IHPT halves are moving away from each other, which requires it to be -90° out of phase with the input signal (whereas with an LRA haptic actuator, a 180° phase shift is needed)
- Frequency selection: the braking signal needs to be at the resonant frequency of the system (not the frequency of the input signal) to properly counteract the unwanted resonance
- Repeated pulses: more than one brake pulse generally produces the best results
- "Overdrive" voltages at higher than the main drive signal can be considered for additional stopping power

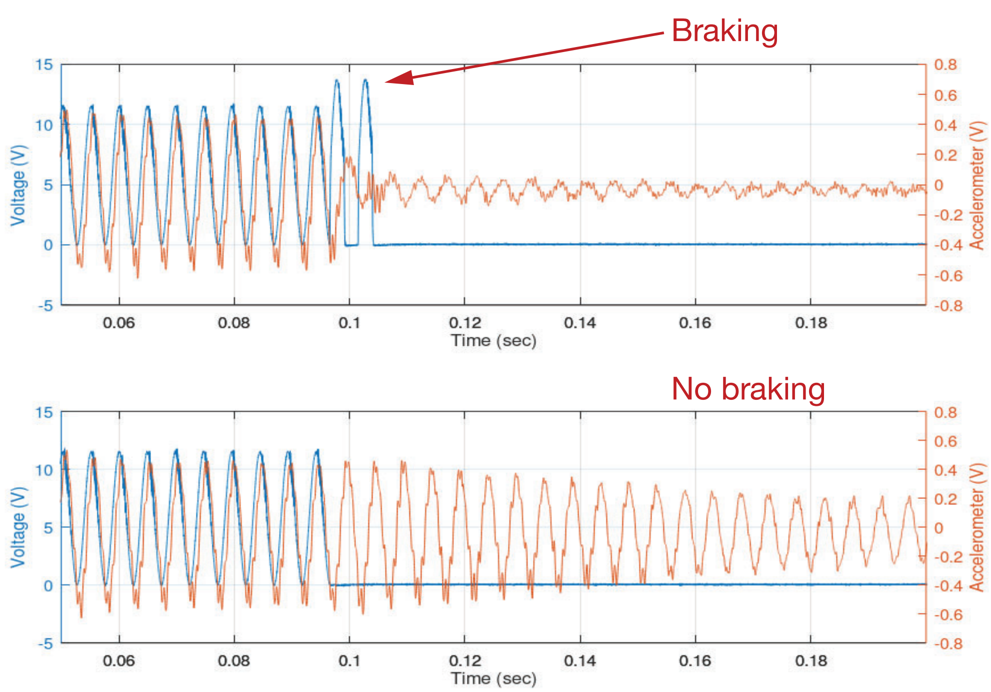

Fig. 10 - Braking vs. No Braking

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4.5. Mounting

Much like a DC solenoid, the two magnetic halves of the IHPT cannot repel, only attract, even when a negative polarity voltage waveform is applied. Because of this, the IHPT requires a return mechanism to achieve oscillation. Return mechanisms such as springs or elastic buffers can be used to return the IHPT to center position.

A typical haptic application has a stationary portion (e.g., frame) and a moving portion (e.g., touchscreen). The dynamic "I-bar" should be bolted to the moving mass and the static "U core" to the stationary element.

The IHPT can be mounted and secured into the haptic system in the following ways:

- Mounting holes in the IHPT allow it to be bolted in directly into the system
- Springs (coiled springs, leaf springs, etc.)
- Elastomeric rings
- Elastic buffers
- IHPC carrier which integrates return springs and mounting housing into one solution

Consideration needs to be made with regard to the stiffness of the springs and the elastomeric rings. A stiffer spring having a higher k constant will tend to shift the resonant frequency of the system upward. Similarly, a larger load mass will cause the resonance to shift to the lower end.

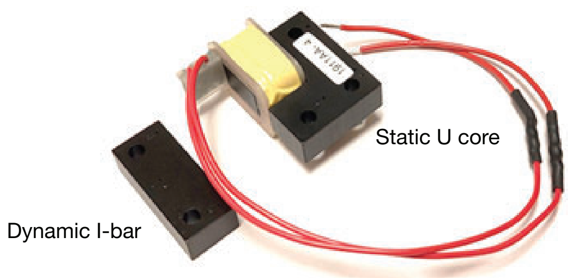

Fig. 11 - IHPT (unmounted)

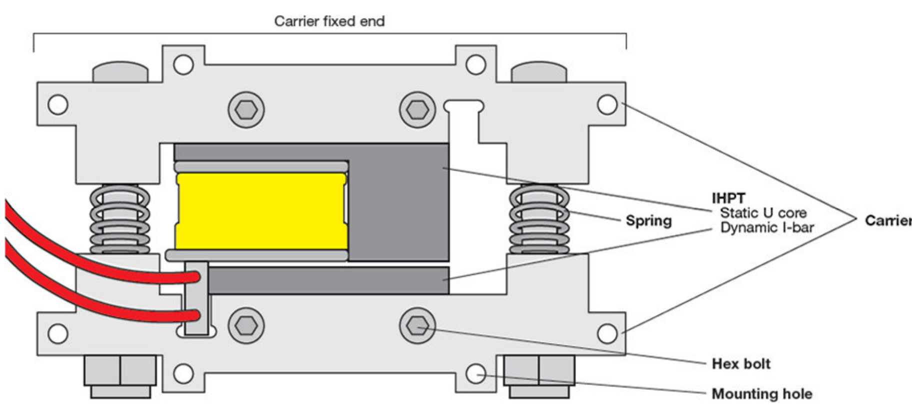

Fig. 12 - IHPT With Carrier

<u>Mass</u>

The IHPT is capable of actuating a mass of up to 2 kg.

<u>Gap Width</u>

For proper operation, the gap between the stationary "U" section and the moving "I-bar" should be initially set between 0.3 mm and 1 mm. A narrower gap drastically improves the already fast rise time and generates higher forces. A small gap would be ideal for a bipolar driving signal since the induced peak currents will not be as high as with a similar bipolar signal. If the driving signal is too high, it may cause the core halves to crash together. Too large of a gap will not produce sufficient force.

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5. TESTING AND MEASUREMENT

5.1. Reference Setup

Test Equipment and Materials

- IHPT1411AFELR73AB0 haptic solenoid device (gap set to 0.9 mm)
- Custom carrier and fixture for IHPT
- 0.25 kg to 1 kg mass
- DRV2511Q1EVM TI haptic solenoid driver evaluation kit (8 A peak current)
- Computer with the applicable software to run the TI board
- Arbitrary waveform generator (Agilent 33220A 20 MHz)
- DC power supply rail (set to 18 V_{DC})
- Oscilloscope (Keysight MSOX3014T, four channel)
- Current probe (Agilent N2781B 10 MHz/150 A_{RMS} AC/DC probe)
- Accelerometer (Kistler 8316A200, single-axis, 40 mV/g sensitivity)

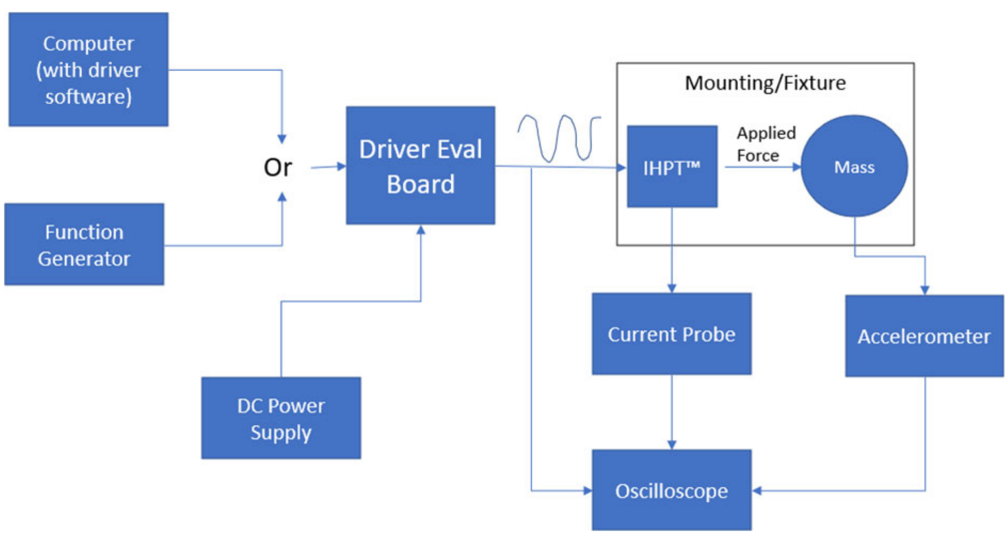

Fig. 13 - Functional Block Diagram of Test Setup

Simplified Electrical Application

TYPICAL APPLICATION