

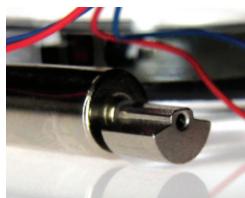
Integration Guide

Haptic Feedback & Vibration Alerting for Handheld Products



Since its invention in the early 90's, simple vibration feedback has alerted billions of people and grabbed their attention. Now its successor, haptic feedback can convey operator information and radically improve user interfaces.

Both techniques are designed into thousands of devices every year. This is our guide for how to design the best attention-grabbing vibration alerts, and build the most tactile haptic user interfaces.



In the early 90's, the market of miniature vibration motors was built around pagers, but soon vibration alerting was added to mobile / cell phones, where it remains an essential feature. Today's equipment consumers and designers are expecting vibration alerting and haptic feedback to be present as added value features.

Precision Microdrives is the market leading manufacturer of vibration alert products. Our mission is to support customers through design with best practice advice, and deliver our products 'On time & To Spec' from 1+ prototypes to 100k+ volume production.

This booklet will guide you through the best ways to add haptic feedback or vibration alerting to your product. See our website www.precisionmicrodrives.com for more in-depth application notes on these and more topics.

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Haptic Feedback vs Vibration Alerting



Vibration Profile



SMS!



Advanced vibration patterns to convey information, simulate clicks & button presses with predefined haptic waveforms.

Simple vibration patterns to notify users of an event. Strong vibrations to catch operator's attention.



Conveys Information



Discrete



Enhanced Experience



Simple & Inexpensive



Discrete



Effective Alert

- Telecommunications
- Auto Dashboards
- Capacitive Touch
- Touchscreens
- Control Sticks
- Videogames



- Scanners and Detectors
- Safety Equipment
- Electronic Tools
- Pagers
- Meters
- GPS



LRA / ERM

\$1.50



Haptics Driver

\$0.70 ~ \$1.20



Host Microcontroller
Budgetary pricing for 10k pcs



Motor IC / MOSFET

\$0.20 ~ \$0.70



ERM / LRA

\$1.25

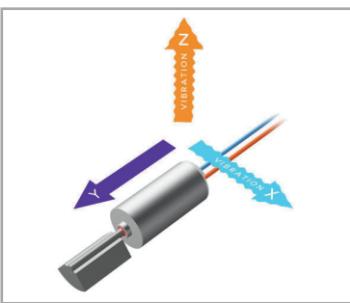
\$2.20 ~ \$2.70

\$1.45 ~ \$1.95

Low Cost



A Video Game Controller with 'Dual Shock'



ERMs Vibrate in Two Axes

Frequency

$$f_{vibration} = \frac{(\text{Motor RPM})}{60}$$

Force

$$F_{vibration} = m \times r \times \omega^2$$

m = the mass of eccentric weight

r = mass' offset distance

ω = speed of the motor (rads⁻¹)

$$\omega = 2\pi f$$

Introduction to Vibration Motors

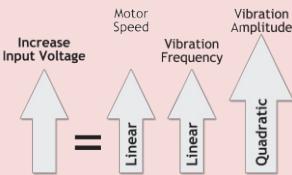
The vibrations used in haptic feedback and vibration alerting can be generated by two different electromechanical devices. These are known as Eccentric Rotating Mass motors and Linear Resonant Actuators. The term 'vibration motor' or 'pager motor' usually refers to the ERM type. Piezo based vibration motors are based on different technology, but are not manufactured commercially yet.

What is an ERM Vibration Motor?

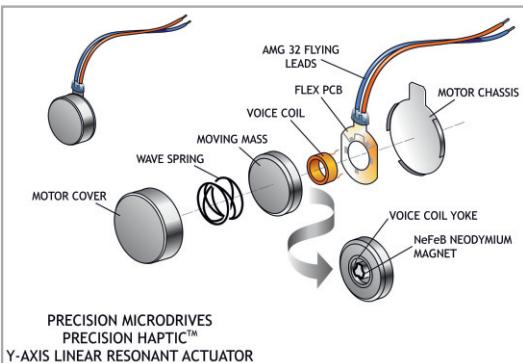
The term 'Eccentric Rotating Mass' refers to how the vibrations are created. These are normal DC motors, with a small eccentric / offset weight attached to the shaft, and an unbalanced force is created when they rotate. This unbalanced force displaces the motor, as well as whatever the motor is attached / secured to. It's the high speed displacement that is known as 'vibration'.

Characteristics of ERM Motors

The rotating eccentric mass generates a centrifugal force on the motor body which causes vibration in two axes. This force is governed by the formula left. A larger eccentric mass with a bigger offset from the shaft will produce more force and hence more vibration amplitude. [Increasing the voltage supplied to the motor will increase its speed](#), and therefore the frequency of the vibration, with a linear relationship. Furthermore, increasing the motor speed will also increase the vibration amplitude with a quadratic relationship, which can be very useful if bursts of high vs low amplitude vibration are required. With ERM's it is not possible to independently vary frequency and amplitude; they remain interrelated. ERM motors can be driven simply with plain DC or PWM drive signals (we cover this later).



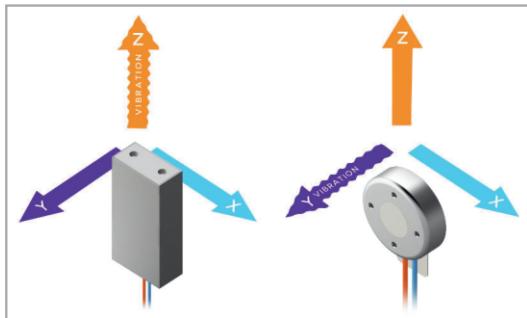
Vibration Motor Relationships



Precision Microdrives Y-axis LRA Linear Vibrator Motor

What is an LRA Motor?

LRA stands for Linear Resonant Actuator. It is comprised of a magnetic mass on a spring and a voice coil. When a current flows through the voice coil, a force is generated due to the magnetic field. This force causes the mass to displace. The repeated displacement of the mass produces a varying force which is felt as vibration.



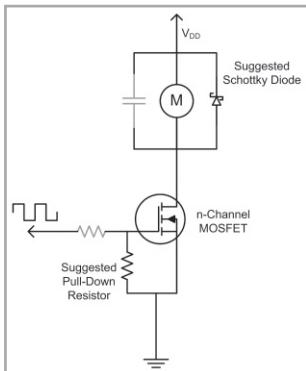
Linear Resonant Actuators Only Vibrate in One Axis

Characteristics of an LRA Motor

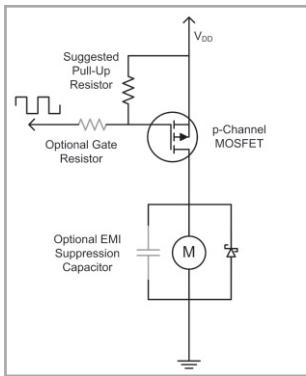
The mass is restricted to move in two opposite directions, creating vibration in one axis. Changing the direction of the current through the voice coil causes the mass to be driven in opposite directions, therefore LRAs are driven by AC signals. The frequency of this signal

must match the 'resonant frequency' of the LRA, to produce any useful vibration amplitude. Increasing the drive voltage, increases the amplitude linearly, whilst frequency remains fixed to the frequency of the drive signal. The easiest drive method is to use a dedicated driver chip. The LRA's small size limits its maximum vibration amplitude, but motor lifetime and haptic response time is better than ERMs.

Feature	ERM	LRA
Vibration Strength	Low to High	Low (Touchscreen / Handhelds)
Vibration Frequency	Varies with Voltage	Fixed (Typically ~ 150 - 200 Hz)
Vibration Direction	Two Axes	One Axis
Device Near Lifetime	150 ~ 1500 Hours	Better
Efficiency	Average	Better
Drive Signal	DC Voltage / PWM	Sine Wave / PWM
Haptic Performance	Good	Better
Device Cost	Low	Higher



N-type Driver Circuit



P-type Driver Circuit

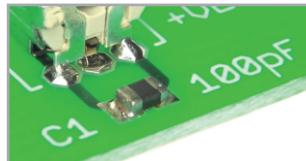
Introduction to Driving ERMs and LRAs

ERM vibration motors require a DC drive signal to operate while LRAs require an AC drive signal. Drive signals must respect both the minimum start voltage and a maximum operating voltage, shown in datasheets. Motors can be connected directly to an appropriate power source (e.g. a battery), but cannot be driven directly from microcontrollers due to limited current. Most often, vibration motors are controlled from a microcontroller via a driver circuit.

Discrete Driver Circuits for ERMs

Discrete drivers circuits for ERMs use transistors as a switch to connect the motor to a DC power source. This allows the motor to be controlled by a low power signal from a microcontroller or digital logic / sensors. It also supports Pulse Width Modulation for varying the vibration amplitude and advanced signalling. MOSFETs are preferred to BJTs because of their higher efficiency and better compatibility with lower battery voltages (1.5 ~ 4 V). Either N-type or P-type transistors can be used; typically a P-type is used with 1.5 V or lower supplies due to their lower typical gate-source voltage drop. Optionally a schottky diode can be added to protect the

transistor against high back-EMF voltages, but this is often only required for motors > 12mm diameter. This type of driver will typically cost \$0.1 USD ~ \$0.2 USD per unit.

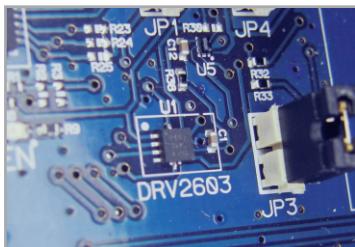


Ceramic Caps Filter EMI

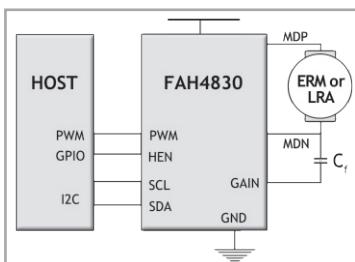
EMI Considerations for Vibration Motors

Electromagnetic Interference (EMI) is the radiation of electromagnetic noise. This noise can affect control signals and other electronics which produces errors and reduces performance. The DC motors used in ERMs are a common source of EMI due to commutator arcing.

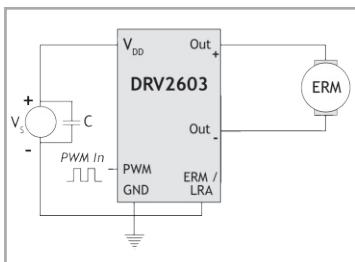
A few simple components can reduce EMI and protect delicate circuitry such as RF circuits. The level of EMI reduction is a design choice. The most common solutions are a decoupling ceramic capacitor across the motor terminals though better performance can be achieved with an X2Y ceramic filter instead.



Texas Instrument DRV2603 Evaluation Module



FAH4830 Example Circuit



DRV2603 Example Circuit

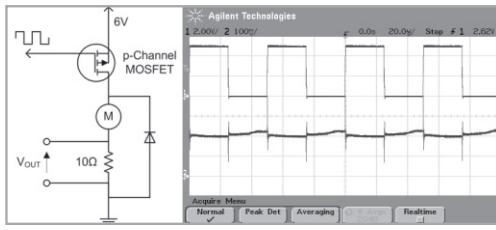
Motor Driver Integrated Circuits

Single integrated circuit chips for driving ERM motors are freely available. They can reduce circuit complexity and simplify the process of adding advanced features. For example they can be controlled by digital signals or serial buses and have a wide range of input and output voltages. Some can drive the motor in both directions, enabling advanced vibration patterns, and most come with built-in motor protection. The latest driver ICs from TI and Fairchild (left) drive both ERMs and LRAs for haptic feedback.

LRA Driver Integrated Circuits

LRAs require an AC signal. To generate this from a DC source (such as a battery) a dedicated LRA driver chip is required. These take a mixture of digital PWM or I2C signals from a microcontroller to control the LRA. The resonant frequency of an LRA can shift depending on the target mass, operating environment, and age. The latest driver ICs have an auto-resonance feature to solve this problem and offer active braking to improve haptic feedback performance. Haptic processors handle advanced features automatically, and libraries internally store predefined effects.

Supplier (Chip)	DRV2603 (Texas Instruments)	DRV2605 (Texas Instruments)	FAH4830 (Fairchild)	Analog Devices (ADUX1001i)
Input Voltage	2.5 - 5.2 V	2.5 - 5.2 V	2.7 - 5.5 V	2.3 - 4.8 V
Output Voltage	3.3 V (ERM) OR 2 V _{RMS} (LRA)	3.3 V (ERM) OR 2 V _{RMS} (LRA)	3.6 V	
Output Current	400 mA (max)	400 mA (max)	500 mA (max)	
Active Breaking	Yes	Yes	Yes	Yes
PWM	Yes (10 - 250 kHz)	No	Yes (10 - 50 kHz)	Yes (and I ² C)
Auto-Resonance (LRA only)	Yes	Yes	No	Yes
Device Cost	\$0.70 USD / 1ku	\$0.70 USD / 1ku	\$0.70 USD / 1ku	
Haptics Processor	Yes	Yes	Yes	Yes
Haptics Library	No	Yes	No	No



Example of motor driven by a PWM signal

pattern of vibration via Pulse Coding.

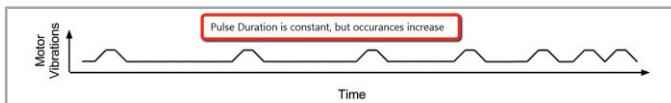
A Pulse Width Modulated (PWM) signal is a string of high frequency (typically 20 kHz) pulses, where the period that the pulses are 'On' vs 'Off' (duty cycle) can be varied. When the pulses are averaged (e.g. filtered by the inductance of a motor winding), a voltage is produced that is proportional to the duty cycle which allows easy variation in vibration amplitudes from motors.

Pulse Coding (PC) represents a string of low frequency pulses (typically 2~5 Hz) which are not filtered. The 'On' vs 'Off' time and number of repetitions of the resulting pulses of vibration are used to encode information.

Using PWM with Vibration Motors

Altering the duty cycle and hence motor voltage, allows us to vary vibration amplitude and frequency. The PWM signal is fed from the microprocessor into either a MOSFET or IC driver which is connected to the motor. Driver ICs can also use PWM signals to produce more advanced haptic effects and PWM is the most universal control input for LRA driver ICs.

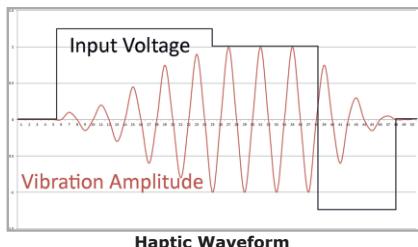
Advanced Vibration Alerting



Vibration Pulse Occurrence Modulation

- Amplitude Modulation - uses PWM to vary the amplitude, e.g. with Sine, Triangle, or Sawtooth envelopes. Used a lot in massagers to create vibration patterns.
- Pulse Duration Coding- uses PC to vary pulse length to encode simple messages (e.g. SMS in Morse on earlier Nokia phones).
- Pulse Occurrence Coding - uses PC to vary pulse frequency to indicate proximity to an event, e.g. a reverse parking sensor vibrating a steering wheel.

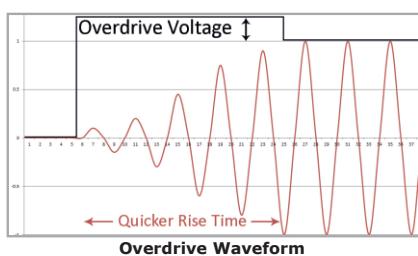
There are 3 types of advanced vibration alerting:



What Are Haptic Waveforms?

Haptic feedback implements advanced vibration patterns to transmit accurate, varied information to the user. Beyond a simple on/off, the vibration amplitude, frequency, and overall waveform can be manipulated by the drive signal.

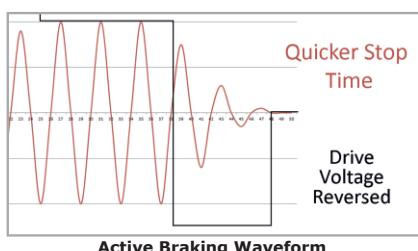
To create these complex vibration waveforms, the haptic performance of the actuators need to be improved. This can be achieved using the techniques below, some drivers implement these automatically.



Overdrive

Increases the responsiveness of the device by increasing the acceleration of the actuator. This means a reduce time to maximum vibration strength and to the minimum level for human skin (0.04 G). Overdrive also enables waveforms that require a quick jump in vibration intensity, such as 'clicks'.

It is achieved by applying a voltage above the actuator's Rated Voltage, close to the Maximum Operating Voltage, for a short period of time. This high voltage produces a greater force in the magnetic field, thereby increasing the acceleration of the motor or LRA's internal mass.



Active Braking

Quickly stops the actuator from vibrating for a 'crisper' experience. Vibrations can occur even after the drive signal has stopped, due to momentum in the actuator. This is particularly true for LRAs, causing the vibrations appear to fade away instead of stop.

By reversing the applied voltage (ERMs) or switching the AC signal 180° out of phase (LRAs), users will feel the vibrations stop much quicker. Critical for implementing waveforms with multiple peaks, such as differentiating between effects like single and double clicks.

Haptic Feedback Evaluation

Test Vibration Alerting and Haptic Feedback

With 4 different actuators varying in vibration amplitude and frequency

Experience ERMs and LRAs

In addition to the eccentric rotating mass motors, linear resonant actuators are present in both the grip and the controller

Precision Haptic™ Range

Features our best haptic feedback actuators for high end performance, all available in 1+ quantities online at precisionmicrodrives.com

Metal Base & Rubber Cover

Motors and PCB are mounted securely in the metal base, with a detachable rubber cover providing access to components inside the grip



on Kit

123 Different Effects with 6 Different Libraries

Test fully licensed and royalty-free haptic effects for ERMs and LRAs

Industry Leading Hardware

Texas Instruments' DRV2605 haptic controller powers all Precision Microdrives actuators, based on Arduino Uno R3 development boards

Test External Actuators

For the next step in prototyping, use test points to connect your own external actuator and drive it using the DRV2605 through the Arduino

Customise Software

Learn about haptic feedback with demos and tutorials, or develop prototypes in Engineering Mode with open-source editable software



Our Haptic Feedback Evaluation Kit gives users the opportunity to evaluate advanced haptic feedback and vibration alerting in handheld products. The kit demonstrates how products can benefit from vibration features and highlights some of the design considerations.

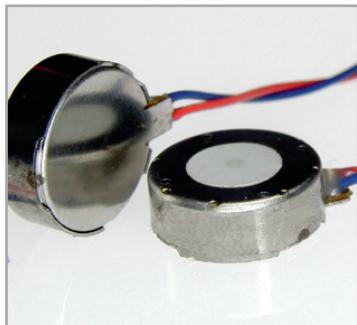
In addition, the design process is aided by offering an external actuator connection. This enables designers to compare performance with the haptic grip for further analysis whilst simplifying testing analysing one component at a time.

**Order online at
Precisionmicrodrives.com**

Introducing the Precision Haptic™ Range

Engineered and manufactured especially for haptic feedback applications, these actuators offer the best solution for haptic products.

Each has been tested to the Imerrssions TS2000 criteria and are certified for use with their specially licensed software and drivers, including industry leading chips from TI, Fairchild, and Analog Devices - see page 7 for more details.



Precision Haptic Linear Resonant Actuator, C10-100

Precision Haptic™ LRAs

Our LRAs offer light directional vibrations with excellent response times. They are perfect for use in touchscreen and smaller handheld devices.

With an improved efficiency over their ERM counterparts and a longer lifetime they are an attractive option for battery powered devices, or for those looking to take advantage of their quick reactions in high-end haptic feedback devices.

The C10-100 is a Y-axis LRA, vibrating prependicular to the mounting plane. Pages 10 & 11 shows how to take advantage of vibration directions for improved performance. Look for haptic drivers with auto-resonance detection for the best LRA experience.



Precision Haptic Eccentric Rotating Mass Vibration Motor, 308,102

Precision Haptic™ ERMs

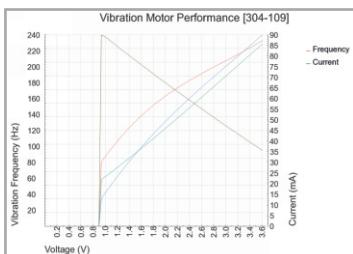
The ERMs found in the Precision Haptic™ range are specially designed to improve the haptic performance compared to standard ERMs.

They are less expensive than the LRA counterparts and produce vibrations in two axes due to their rotational behaviour. This means they are more suited for applications where users grasp the product, such as control joysticks or steering wheels.

Although larger in size, both the 306-109 and 308-102 are over twice as strong as the C10-100, and the 305-000 provides a lighter, low frequency ERM alternative. Ensure the haptic driver can meet the overdrive voltage to enable haptic waveforms.

Key Features

Body Diameter:	10 mm
Body Length:	3.6 mm
Typical Operating Current:	69 mA RMS
Typical Vibration Amplitude:	1.4 G
Typical Normalised Amplitude:	1.4 G
Rated Voltage:	2 V RMS
Rated Resonant Frequency:	175 Hz
Lead Length:	100 mm

Example of the Key Features Table, in LRA Vibration Motor Datasheet**Typical Vibration Motor Performance, 304-109 (Vibration Motor)**

datasheets have detailed vibration performance graphs. The relative strengths of vibration motors can be compared by using the published normalised vibration amplitude figures, which account for the differences in inertial loads during testing.

Haptic Feedback Specifications

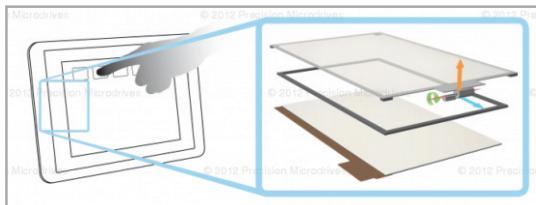
PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Typical Lag Time	At rated voltage using the inertial test load	18 ms	
Typical Rise Time	At rated voltage using the inertial test load	27 ms	
Typical Stop Time	At rated voltage using the inertial test load	24 ms	
Typical Active Brake Time	Time taken from steady-state to 0.04 G under inverse polarity at max. voltage	17 ms	

Typical Haptic Characteristics, 304-109 (Vibration Motor)

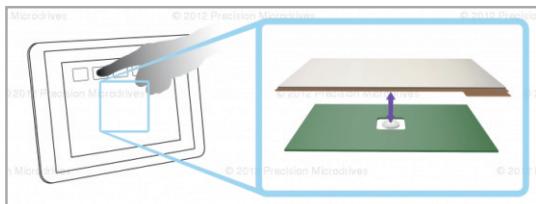
be upgraded to include haptic response graphs. Numeric specifications are based on:

Lag-time	The time from start to a vibration amplitude of 0.04G (limit of human feeling).
Rise-time	The time from start to 50% of the rated vibration amplitude.
Stop-time	The time from when the applied voltage is removed to when the vibration amplitude falls below 0.04G.
Active-brake time	The time from when a reverse (brake) voltage is applied, to when the vibration amplitude falls below 0.04G.

All vibration motor datasheets have a haptics performance section. This is currently based on numeric haptic constants, but will soon



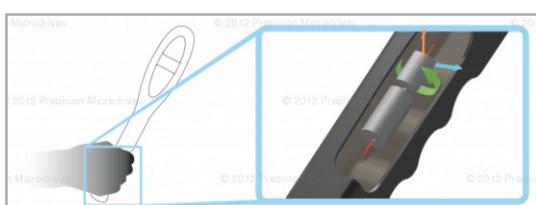
ERM in Touchscreen Example



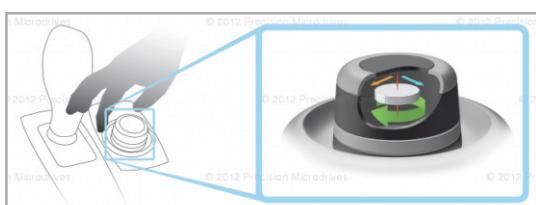
Linear Resonant Actuator in Touchscreen Example



ERM in Control Joystick Example



ERM in Security Scanner Example



Coin Vibration Motor in Jog Dial / Shuttle Wheel Example

Touchscreen

User's fingertips press into the touchscreen, so for vibrations to be returned towards the user, a cylindrical ERM or LRA should be used. Coin vibration motors are not suitable as they vibrate in directions perpendicular to the pressed force of the finger. An LRA will vibrate directly into the user finger and can be mounted directly behind the screen. ERMs are best mounted at the side.

Control Sticks

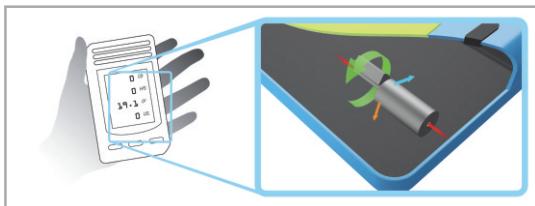
For gaming or as an industrial control stick, joysticks are best fitted with a cylindrical ERM to vibrate towards the users grasp at all times. These are easily fitted inside the main section of the stick.

Security Scanner

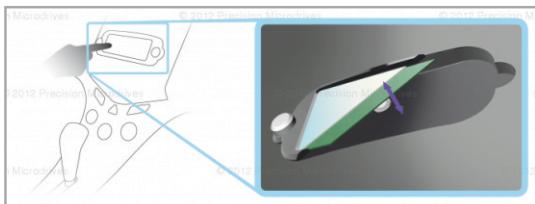
Discreet security scanners can have audible alerts replaced with vibration alerting by inserting a cylindrical ERM. Similar to our joystick example, the force is directed outwards to the users grasp.

Jog Dials

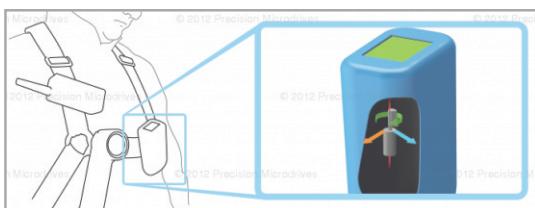
High end cars and consumer electronics can add haptic feedback to their dials. The low profile of coin motors coupled with vibrations in two axes make them an ideal choice.



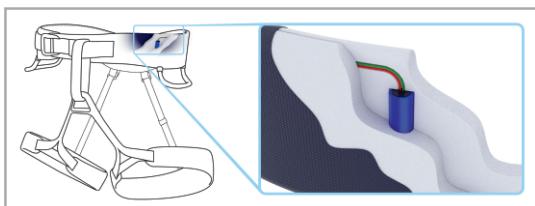
Handheld Gas Monitor Example



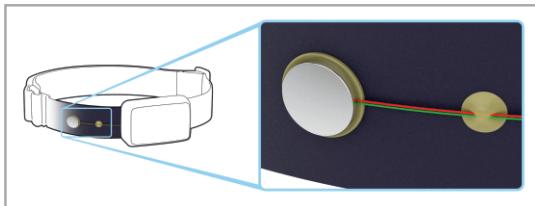
Linear Resonant Actuator in Car Dashboard Panels Example



ERM in Body Worn Vibration Alerting Pack



Vibration Motor in Secured Foam Housing



Vibration Motor Secured with Adhesive

Handheld Instruments

Like mobile phones, handheld instruments with haptics are designed to vibrate all over, so placement of the vibration source is flexible, depending on other design constraints.

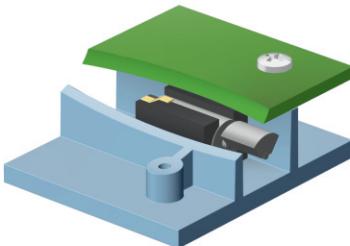
Auto Dashboard

New cars have dashboards with capacitive touch buttons and haptic feedback. LRAs produce crisp tactile feedback on small panels; larger panels require an ERM. Touch surfaces are often suspended within the dashboard chassis so the haptic vibrations are isolated.

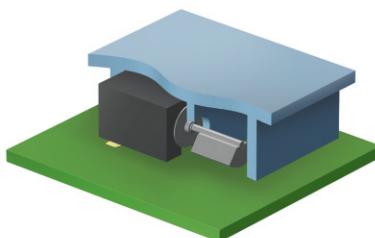
Body Worn Vibration Alerts

For applications in noisy or distracting environments, vibration alerting is a great alternative to lights and beeps. By mounting them on the body, the users hands can be kept free to work. These are often used where protective or thick clothing is required, so the motor needs to be strong enough to overcome the damping of soft materials. This can be aided by ensuring the vibrations are directed towards the user. Typically motors range from larger ERMs in gas detectors, to smaller low profile coin motors in wrist watches.

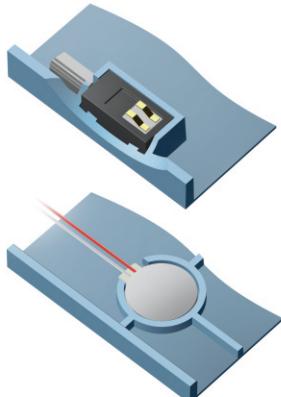
PCB Enclosures



The PCB is used to secure the spring pad connected motor in the moulded receptacle

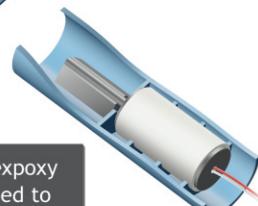


Structural Ribs

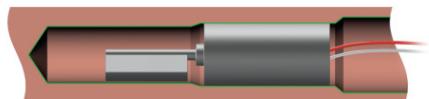


Structural ribs improve an enclosure's stiffness, secure the motor, and help transfer vibration through the enclosure

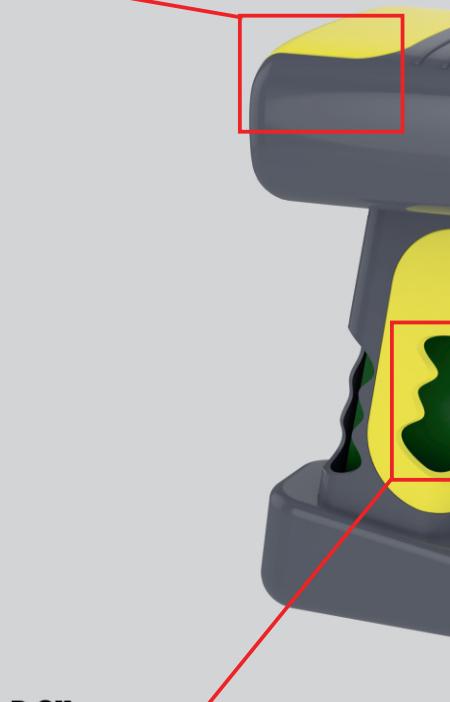
Hotmelt or viscous epoxy adhesives can be used to further secure the motor in place, but be careful not to glue the moving parts



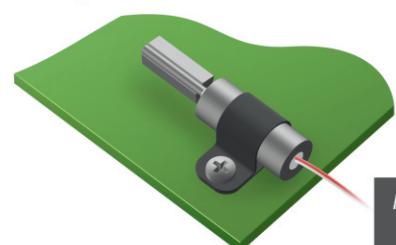
Push Fit



An interference push fit is a simple way to mount an ERM vibration motor



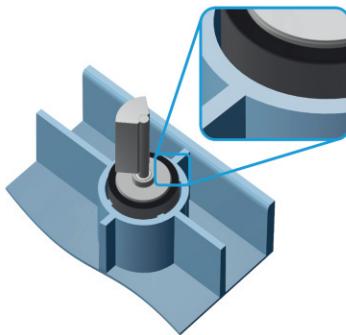
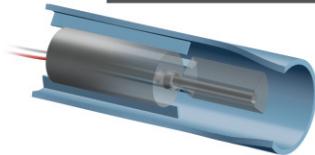
P-Clip



Metal P-clip
for

Foam / Silicone Wraps

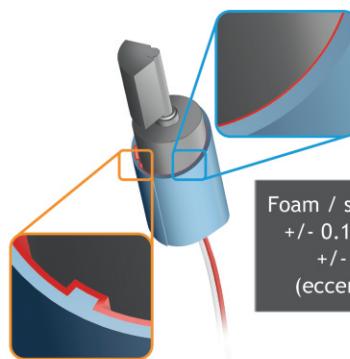
Often ribs are used for the interference fit



Use thin foam or silicone pads & wraps to dampen noise and reduce unwanted audible harmonic vibrations

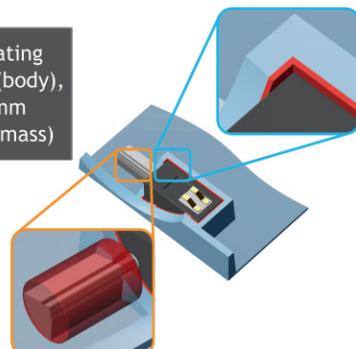
Tolerance

Recommended gaps and tolerances

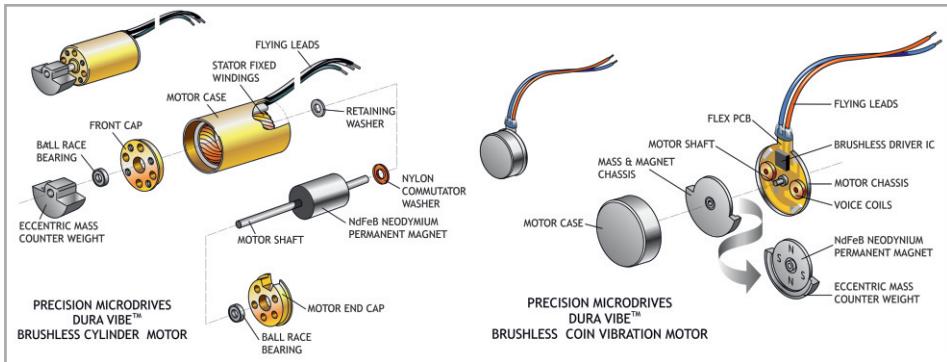


Foam / silicone wraps
+/- 0.1mm (body),
+/- 0.25mm
(eccentric mass)

Plastic mating
+/- 0.5mm (body),
+/- 0.1mm
(eccentric mass)



Clips are a low cost and simple method securing motors to PCB or enclosures



Exploded Brushless Vibration Motors

Motor Brush Lifetime

Vibration motors have a finite life. For brushed vibration motors this is linked to wear of the brushes and commutator mechanism. Typically a brushed vibration motor can have a Mean Time To Failure (MTTF) of 100 to 2000 hours. Beyond this lifetime, brushless designs are required.

Long Life & ATEX

Whereas brushed motors have moving coils (armature) in a fixed magnets, brushless motors have fixed coils (stators) and a rotating magnet. Brushless motors have no commutator mechanism, so the direction of the current in the stator coils is changed electronically to keep the motor shaft rotating in the same direction. Since there are no brushes to wear out, the brushless motors have much longer lifetimes (MTTFs of 5000+ hours). Furthermore, since there is no DC arcing as the motor rotates (common on brushed motor), brushless vibration motors are ideal for vibration alerting in ATEX environments. When a weight is attached to the shaft, the motion and hence vibration characteristics remain identical to brushed motors.

Driving Brushless Vibration Motors

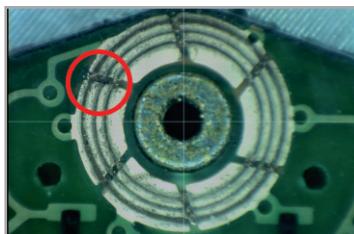
To drive a brushless motor, the current to the stator coils needs to be varied in a specific way, which means brushless motors need a special driver IC. Some brushless vibration motors like the coin type already have an internal driver IC, whilst others require an external one. More details available in our [Application Bulletin 18](#), online.

Implementing true haptic feedback with low latency start and stop times is not practical with brushless vibration motors because the start algorithms take too long to get the motor running. However, brushless vibration motors can be used with the advanced vibration alerting techniques, found on page 8.



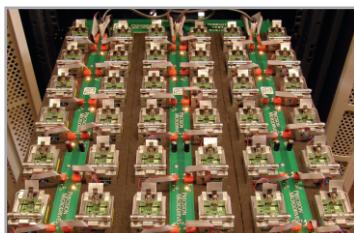
A vibration motor end cap with damaged and burnt metal brushes

short circuit will occur. Alternatively, metal fatigue in the brushes might occur first, in which case a snapped brush will cause the failed motor to go open circuit. In either case, the motor will no longer run.



Worn coin motor commutator where worn metal fragments have caused a short circuit

useful as the average amount of hours until a motor fails. The distribution of failures is also very important, and relevant parameters to are shown on the datasheets. Please consult our application notes online, for more information.



Recently tested 307-001 7mm Pico Vibe motor produced a MTTF of approximately 1,800 hours

using Weibull Analysis. If there haven't been enough failures in the period to obtain a reasonable confidence level, we continue the test for another 720 hours.

Vibration Motor Failures

There are two vibration motor failure modes; overheating, which is very rare, and much more commonly, mechanical wear of the commutator mechanism. As the brushes (typically highly conductive metal alloys) move over the copper commutator, small metal particles from both parts are produced through mechanical attrition, and these tend to fill gaps between commutator segments. Eventually, with enough build up, a

Measuring Motor Failure Rates

Precision Microdrives is leading the industry in vibration motor lifetime testing. Product lifetime and failure rates are determined through a statistical processes. For more popular vibration motors, we provide Mean Time To Failure (MTTF) and Failure In Time (FIT) analysis on the datasheet. These measurements show the same information in different ways, but the MTTF is most

useful as the average amount of hours until a motor fails. The distribution of failures is also very important, and relevant parameters to are shown on the datasheets. Please consult our application notes online, for more information.

Our Longevity Testing Methods

No vibration motor lifetime testing machines were commercially available, so we built our own. Our motor longevity testing machine tests 48 motors of the same model simultaneously. Each motor is attached to a sled that has its own accelerometer to monitor its performance and a server records all the data. After 720 hours (28 days), the data is analysed and MTTF and FIT rates are calculated

Precision Microdrives

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