when manipulated by the user. Such input devices include buttons and can include additional, dials, switches, scroll wheels, or other controls or mechanisms. Power supply **186** can optionally be included in device **12** coupled to actuator interface **182** and/or actuator assembly **54** to provide electrical power to the actuator, or be provided as a separate component. Alternatively, power can be drawn from a power supply separate from device **12**, or power can be received across a bus such as USB or a wireless link. Also, received power can be stored and regulated by mouse **12** and thus used when needed to drive actuator assembly **54** or used in a supplementary fashion.

Enhancing Tactile Sensations

[**0062**] The present invention includes several methods for enhancing the feel of tactile sensations, especially those sensations provided by inertial haptic feedback mechanisms, such as the actuator assembly **100** of **FIG. 3**, rotational eccentric masses, or the like.

[**0063**] When using an inertial actuator assembly such as assembly **100** shown in **FIG. 3**, some limitations on the strength of tactile sensations become evident. One limitation is that there tends to be limited power available to drive the actuator in most consumer applications, such as mice, gamepads, remote controls, etc. Some mouse embodiments, for example, draw power from the communication bus, such as USB. The limited power means that the inertial mass will not be able to swing through its full amplitude motion across a wide range of driving frequencies.

[**0064**] Another limitation is the limited range of motion of the inertial mass in assembly **100**, i.e. the moving actuator is only moved a certain distance before it encounters physical limits to its travel. Even if sufficient power is available to drive the actuator, the assembly **100** relies on the acceleration of an inertial mass to impart forces upon the user. These accelerations are strong when the mass is driven by a high frequency periodic signal because the mass is driven back and forth very quickly, undergoing significant accelerations and decelerations during a given time period. But when driving the inertial mass at a low frequency, the sensation to the user is weak even if enough power is available to drive the mass. This is because the inertial mass has a very limited range of motion within which to accelerate the mass. A low frequency periodic drive signal will impart much weaker inertial forces upon the user because the inertial mass is pressed against one of the limit stops during much of the signal time. This limited range of motion may be desirable in other aspects of the assembly design, e.g. a low profile so it will fit in small devices, but it detracts from the strength of the low frequency tactile sensations.

[**0065**] The methods described herein combine a higher frequency with a desired low frequency to provide a resulting signal that produces greater strength tactile sensations output to the user. The term "combining" is intended to include both the pulse bursts embodiment, in which higher frequency bursts are output at a low frequency, as well as the other embodiments which add and/or multiply high frequency and low frequency signals or components thereof.

[**0066**] Pulse Bursts

[**0067**] One method of the present invention provides "pulse bursts" at particular portions of a low frequency waveform to generate higher strength tactile sensations.

[**0068**] **FIG. 5***a* is a graph **200** illustrating a standard drive signal **202** for the actuator assembly **100**. Drive signal **202** is a periodic signal having a lower frequency in the available frequency range, e.g. 5 Hz in a discernible range of 0-200 Hz. The positive signals of the waveform drive the inertial mass in one direction, while the negative signals of the waveform drive the inertial mass in the opposite direction. Signal **202** is shown as a square wave as an example, but can be any other type of repeating, periodic waveform, such as a sine wave, triangle wave, sawtooth-shaped wave, etc.

[**0069**] The strength of the tactile sensation resulting from the waveform **202** would be quite weak, because the inertial mass is pressed against the limits of its range of motion during most of the cycle time. The inertial mass is moved to its opposite position in its range in only the first portion of each flat portion of the waveform, so that it is not moving for the rest of each flat portion.

[**0070**] **FIG. 5***b* is a graph **210** illustrating a drive waveform **212** of the present invention which conveys the sensation of a low frequency waveform while allows the moving inertial mass to impart more inertial energy to the user. The waveform **212** is intended to convey the same low frequency of the waveform **202** shown in **FIG. 5***a*. To accomplish this, waveform **212** includes a high frequency "burst"**214** periodically output to convey the desired frequency of the waveform **202**. Each burst **214** is a number of oscillations of the inertial mass at the high frequency, and each burst conveys a "pulse" to the user. The bursts are output periodically to convey the desired lower frequency. For example, each burst **214** can be output at approximately the same point in time each rising or falling edge of the waveform **202** occurs, as shown in **FIG. 5***b*. This would provide a pulse to the user twice per period of the low frequency waveform. Alternatively, each burst **214** can be output at approximately each rising edge of the waveform **202**; this would convey a pulse to the user once per period of the low frequency waveform (the pulses can alternatively be output at falling edges of waveform **202**). Either of these methods can be used, and the choice of one or the other may depend on what the designer expects, e.g., a specified 5 Hz low frequency could mean 10 pulses or 5 pulses per second, based on the method used. In any case, the bursts are effectively output at the rate of a desired low frequency.

[**0071**] The bursts allow a low frequency sensation to be conveyed to the user at a much higher strength than if no bursts were used. The bursts can be at a high enough frequency that the user cannot distinguish them as oscillations; the user preferably only feels a single pulse. Furthermore, the bursts should be at a high enough frequency to provide high strength sensations to the user. For example, the frequency of each burst can be 40 Hz. The frequency of the bursts can be retrieved from memory by the processor forming the controlling waveform. The burst frequency can also optionally be specified by a user and communicated over the communication link.

[**0072**] The length of each burst can vary in different embodiments. Four changes of direction of the inertial mass are shown in the example of **FIG. 4***b*; in other embodiments, more or less changes of direction can be performed. The bursts should have a significant portion of the waveform separating them, or else the user may not be able to distinguish one burst from another, and therefore would feel