relatively high frequency; in some embodiments, it is preferably near a frequency which the actuator assembly **100** efficiently outputs strong sensations, e.g. at or near a resonance frequency of the mechanical system.

[**0087**] **FIG. 7** shows a waveform **258** which is the sum of the two signals **254** and **256** shown in **FIG. 6**. Waveform **258** provides a high frequency waveform at amplitudes that vary according to the low frequency, so that the user perceives the low frequency as "riding on" the high carrier frequency. The high frequency oscillations allow the actuator assembly to output strong tactile sensations, while the low frequency motion provides an oscillation perceived by the user at the desired low frequency. As in the embodiment of **FIGS. 5***b* and **5***c*, a threshold low frequency can be established, where if the desired frequency is under the threshold frequency, the high frequency signal is added to the desired signal, and where if the desired frequency is over the threshold frequency, which only the desired signal is used to drive the actuator assembly, since it is of sufficient frequency to be output as a strong sensation.

[**0088**] As in the resonance pulse burst embodiment described above, the adding can be performed only for desired frequency outputs that are below a predetermined threshold frequency. Below the threshold frequency, the waveform is too low a frequency to be felt by the user at a compelling magnitude, so the waveform is added to a high frequency waveform. Above the threshold frequency, the waveform is output at a sufficiently high magnitude to be easily felt by the user when it is directly output without summing.

[**0089**] One disadvantage that can occur with some embodiments of haptic feedback devices is that the summed waveform **258** may reach a saturation point and thus cause a reduction in magnitude of the output tactile sensations as the waveform goes above or below the saturation points of the output that are dictated by the limits to motion of an inertial mass and/or by other components in the actuator assembly or drive electronics. For example, if high frequency oscillations are to be modified by a low frequency oscillation by simply adding the high and low frequency signals, then the inertial mass may be biased toward one end of its range, where it has less room to oscillate. This, in turn, dampens the amplitude of the resulting combined tactile sensation, so that the user feels a much reduced sensation. For example, **FIG. 7** illustrates saturation levels **260** where the output waveforms may be clipped in a particular embodiment. This has occurred because the low frequency portion of the waveform has shifted the high frequency signal to one extreme of the range of motion of the inertial mass; the inertial mass no longer oscillates about its origin position, but rather near an extreme, which limits the motion of the mass in that direction and prevents the full magnitude of the tactile sensation. This can cause the tactile sensation to feel uneven or weak to the user. One solution to this is to normalize the output so that it exists within the range of the actuator assembly. For example, the amplitude of the composite waveform **258** can be reduced by the amount x%, where $x=A_1\%+A_2\%-100\%$. In other words, waveform **258** would be re-scaled such that its maximum amplitude would not exceed 100% if the sum of amplitudes would exceed 100% without re-scaling.

[**0090**] A different problem that may occur using the adding technique of **FIG. 7** is that, when outputting sensations of different desired frequencies, there may be an abrupt change in the output of the device when outputting a sensation below the threshold frequency, where the desired frequency signal is added to the high frequency signal, and changing that sensing to one having a frequency above the threshold frequency, at which point the desired frequency signal is output directly. For example, a particular tactile effects may be desired in which the output frequency is varied from low to high or vice versa, e.g. the frequency of the sensation is swept between two values. If this sweep crosses the threshold frequency, then the method for outputting the sensation changes from the adding method to a direct output method. This change is not smooth, and can be perceived by the user as a change in frequency and amplitude content, thus destroying much of the fidelity of the effect. Thus, the adding method does not easily allow for smooth blending between frequency regions.

[**0091**] Filtering and Sum of Products Method

[**0092**] A different embodiment of the present invention mitigates some of the problems encountered in the adding method of **FIG. 7**. The filtering embodiment addresses the problem of driving inertial actuators in certain applications without losing the low frequency content. The method filters each effect with a low and high frequency filter and uses the low frequency signal as an envelope to modulate the high frequency signal, thus using multiplication of signals rather than using the direct addition described above. It is a filtering technique in the sense that it transforms a set of frequency and amplitude components into another set of frequency and amplitude components that is an equivalent representation of the haptic information content. The transformed set of frequency and amplitude components is more ideally matched to the output characteristics of the haptic transducer.

[**0093**] This approach is a time domain, real-time filter technique. A simplified sum of products method could also be implemented that saves significant firmware overhead and produces a result that is very close to the sum of products method. The simplified method could therefore (in some embodiments) can be implemented in firmware, e.g. running on a local microprocessor or other processor on the interface device. One representation of multiple effects is taken and transformed into an equivalent representation of the set of effects that takes into account the characteristics of the inertial actuator assembly. This can be described as a signal transformation or filter process. The process operates on the magnitude, frequency and phase information from commanded force effect(s) and re-combines the effect parameters to create an equivalent set of magnitude, frequency and phase parameters for the output signals and signal envelopes that are then synthesized in real time.

[**0094**] The process calculates gain or weighting terms for each effect using a low-pass and a high-pass filter function with a corner frequency that is implementation-dependent. In the simplified sum of products method, a weighted sum of the low-passed effect(s) combine to create a single envelope signal that then modulates the weighted sum of the high passed effect(s). In the standard sum of products method, a weighted sum of the low passed effects excluding one effect is multiplied by the high pass weighted copy of the excluded effect to yield an envelope modulated effect. The sum of all such effects multiplied by their modulation