[0021] As used herein, the term "operational mode" means a method or manner of functioning in a particular condition at a given time. For example, if a first electro-mechanical device is operating in a first resonant mode and a second electro-mechanical device is operating in a second resonant mode, the electro-mechanical transducer is operating collectively in, for example, a first operational mode. Alternatively, for example, if the first electro-mechanical device is operating in a third resonant mode, and the second electro-mechanical device is operating in a fourth resonant mode, the electro-mechanical transducer is operating collectively in a second operational mode. In another example, if the first electro-mechanical device is operating in a first resonant mode, and the second electro-mechanical device is not operating, the electro-mechanical transducer is operating collectively in a third operational mode. In other words, a given operation mode can be based on one electro-mechanical device operating in a resonant mode and another electro-mechanical device not being activated.

[0022] The term "resonant mode" means any mode of an electro-mechanical device operating in a frequency band centered around a resonant frequency. When an electro-mechanical device operates at or near a resonant frequency, several consequences occur. For example, when a transducer operates at or near a resonant frequency, the inertial term and the elastic terms substantially cancel. The power consumed by the actuator is then dedicated to balance dissipation (e.g. damping). If the dissipation is low, for example, in a cantilevered piezo-electric beam (i.e. a resonator with a high Q factor), the displacement is relatively large and limited by dissipative forces. In addition, if the mass that resonates is comparable to the mass of the structure to which the transducer is attached (e.g. case of a telephone), then the structure vibrates with a relatively large magnitude. Power lost during activation is in the dissipation. The remaining power is transmitted to the anatomy of the person with which the device is in contact.

[0023] The term "electro-mechanical device" as used herein, means an individual active component configured to provide haptic feedback. The term "active component" refers to a single component that provides a mechanical response to the application of an electrical signal. For example, for the embodiment illustrated in FIG. **5** and discussed below, a single length of, for example, piezoelectric material (for example, piezoelectric bar **410**) and the associated mass (for example, mass **412**) is referred to herein as the electro-mechanical device. In the example illustrated in FIG. **8** and discussed below, the electro-mechanical transducer includes only one electro-mechanical device.

[0024] The term "electro-mechanical transducer" means an apparatus having one or more electro-mechanical devices coupled to a mechanical ground. For example, in the illustrated in FIG. **5**, the electro-mechanical transducer includes all three lengths of piezoelectric material, each having a mass coupled thereto. In the embodiment illustrated in FIG. **8**, the electro-mechanical transducer includes piezoelectric bar **610** and the masses **620**, **630**, and **640**.

[0025] An embodiment of an electro-mechanical transducer is illustrated in FIG. **1**. An electro-mechanical transducer according to this embodiment includes a drive circuit **110** having an amplifier and includes an electro-mechanical transducer **120**. The electro-mechanical transducer **120** includes one or more electro-mechanical (E-M) devices **121**.

[0026] Drive **110** receives a haptic feedback signal and outputs a drive signal to electro-mechanical transducer **120**. The haptic feedback signal may be based on a command from a microprocessor within, for example, a computer or a portable communications device (not shown). The electro-mechanical transducer **120** is configured to selectively operate in one of multiple possible operational modes at a given time. The operational mode of the electro-mechanical transducer **120** at a given time will depend, for example, on the characteristics of the drive signal received from driver **10**. For a given operational mode, an electro-mechanical transducer can operate in multiple resonant modes as will be described in greater detail below. The one or more electro-mechanical devices **121** of electro-mechanical transducer **120** collectively output haptic feedback based on the drive signal, as illustrated in FIG. **7**.

[0027] FIG. **2** illustrates a piezoelectric bar in accordance with one embodiment. As described below in more detail, such a piezoelectric bar can be used as an electro-mechanical device within an electro-mechanical transducer.

[0028] The piezoelectric bar **200** is a bimorph piezoelectric device that is a two-layer bending motor having a length (L) **220** substantially larger than a width (W) **210**. In one embodiment, the piezoelectric bar **200** has a width (W) **210** of approximately 0.6 mm, a length (L) **220** of approximately 25 mm and a height (H) **230** of approximately 5 mm. Alternatively, the piezoelectric bar can have any suitable dimensions depending on the desired use.

[0029] When a voltage **240** from, for example, a drive source (not shown), is applied across the piezoelectric bar **200**, the piezoelectric bar **200** will flex. An appropriate level of voltage **240** to be applied to the piezoelectric bar **200** can be selected, based at least in part, on the material and the thickness of the material used to construct the piezoelectric bar **200**.

[0030] The piezoelectric bar **200** can be driven near a resonant frequency. When the piezoelectric bar **200** is driven near a resonant frequency, impedance transformation may be obtained. Impedance transformation results in large mechanical displacements as described above.

[0031] An electro-mechanical device **300** that can be used in combination with other electro-mechanical devices to construct an electro-mechanical transducer is illustrated as FIG. **3**. Multiple electro-mechanical devices **300** can be configured to operate in a selected operational mode from a set of possible operational modes, each operational mode having one or more resonant modes, as will be described in further detail with respect to FIG. **5**.

[0032] The electro-mechanical device **300** illustrated in FIG. **3** includes a piezoelectric bar **310** having mass **320** coupled to an end portion **325** of the piezoelectric bar **310**. A second end portion **335** of the piezoelectric bar **310** is coupled to a base member **330**. Base member **330** acts as a mechanical ground and is configured to remain stationary relative to the movement of the piezoelectric bar **310**.

[0033] The electro-mechanical device illustrated in FIG. **3** can operate as follows. A voltage **340** from a voltage source (not shown) can be applied to piezoelectric bar **310**. The piezoelectric bar can be, for example, a bimorph piezoelectric device as described above in connection with FIG. **2**. Voltage **340** causes piezoelectric bar **310** to flex in a first direction D_1. Voltage **340** can be modulated at a frequency, f_d, which is referred to herein as the drive frequency of the electro-mechanical device **300**. As described above, the frequency f_d can be selected such that the electro-mechanical device **300** operates near a resonant frequency the electro-mechanical device **300**. Frequency f_d is a function of the type of electro-mechanical device used in the electro-mechanical transducer, the dimensions of the electro-mechanical device (e.g., the length, width, height or thickness), and the position and weight of the masses in the electro-mechanical device.