104 can allow electrodes 102 and 104 to be flexible while withstanding the deflection associated with the touchscreen.

[0030] When a sufficient voltage is applied to electrodes 102 and/or 104, piezoelectric material 106 can expand in the H direction. The voltage must be sufficient to generate the piezoelectric effect. For example, a voltage of 20V can be sufficient, depending on the material used for piezoelectric material 106.

[0031] When the voltage is removed from electrodes 102 and 104, or when the voltage is less than the threshold voltage required to initiate the piezoelectric effect, piezoelectric material 106 returns to its original dimensions.

[0032] Piezoelectric actuator 100 can thus be made to vibrate by applying a control signal with an amplitude and frequency to one or both of electrodes 102 and 104, such that piezoelectric actuator 100 expands and contracts at that frequency.

[0033] In some embodiments, the voltage across piezoelectric material 106 can be generated by keeping one electrode at a constant voltage and applying a control signal to the other electrode. For example, 20V can be applied to electrode 102. The control signal can be a square wave with an amplitude between 0V and 20V, and a frequency in the sub-audible range. When the control signal is applied to electrode 104, piezoelectric actuator 100 vibrates at the frequency of the control signal. One skilled in the art will appreciate that the control signal is not limited to square waves, sub-audible frequencies or voltage amplitudes less than 20V, and that any type of wave, frequency, amplitude and combination thereof can be used without departing from the spirit of the present invention.

[0034] In other embodiments, control signals can be applied to both electrodes. The voltage across piezoelectric material 106 can be generated by applying a first control signal to one electrode and applying a second control signal to the other electrode. The first control signal can be, for example, a square wave with an amplitude between 0V and 20V, and a frequency in the sub-audible range. The second control signal can be a signal having the same amplitude and frequency as the first control signal, but 90 degrees out-of-phase with the first control signal. In one half-period, the first control signal is at 20V and the second control signal is at 0V. In the second half-period, the first control signal is at 0V and the second control signal is at 20V. In this embodiment, the piezoelectric material 106 can contract and expand more rapidly than in the embodiment described in the previous paragraph.

[0035] FIG. 2 shows grid 200, which is a simplified example of a plurality of piezoelectric actuators, wherein each of the piezoelectric actuators are the same as or similar to piezoelectric actuator 100 of FIG. 1. Each piezoelectric actuator can be individually-controlled. The piezoelectric actuators of grid 200 are shown as being arranged in rows and columns. In some embodiments, two or more piezoelectric actuators can be grouped together and controlled as a single entity. For example, two or more piezoelectric actuators can be grouped together to represent a virtual button. One skilled in the art would appreciate that the piezoelectric actuators can be grouped in any manner and collectively form any shape.

[0036] In some embodiments of the present invention, backplane 220 represents an electrically conductive material that functions as the top electrode, such as, e.g., electrode 104 of FIG. 1, of all the piezoelectric actuators in the grid. Similarly, electrodes 202, 204, 206, and 208, represent electrically conductive material that functions as the bottom electrode, such as, e.g., electrode 102 of FIG. 1. A voltage potential across a piezoelectric actuator's piezoelectric material can be created when the backplane 220 and the control electrode are different. When the voltage potential exceeds the threshold of the piezoelectric actuator's piezoelectric material (e.g., piezoelectric material 106 of FIG. 1), the piezoelectric material expands. For example, if the threshold voltage of piezoelectric material is 15V, the piezoelectric actuator can be activated when 10V is applied to backplane 220 and −10V is applied to its control electrode. A plurality of piezoelectric actuators can be activated by applying control signals to more than one control electrode. One skilled in the art would appreciate that the top electrode of each piezoelectric actuator can also be isolated from the top electrodes of other piezoelectric actuators so that both the top and bottom electrodes of a piezoelectric actuator are controlled individually.

[0037] The piezoelectric actuators of grid 200 are shown as being arranged in a pattern resembling the pixels of a visual display screen, but the piezoelectric actuators' dimensions can be independent from or related to the dimensions of the pixels in the display screen. For example, each piezoelectric actuator can have a larger, smaller or the same physical dimensions as a typical pixel in the display screen. Because a finger press on a touch screen typically measures 1 cm×1 cm, these piezoelectric actuators may be as large as 1 cm×1 cm. However, each piezoelectric actuator can be a fraction of that size (e.g., 1 mm×1 mm), which can enable a more precise, localized tactile response. The piezoelectric actuators may be as small as fabrication technology permits. One skilled in the art will appreciate that, despite the actuators shown in FIG. 2 having the same physical dimensions, the piezoelectric actuators can be any size, or combination of sizes without departing from the spirit of the present invention. For example, the piezoelectric actuators can be larger around the edges of the touchscreen and proportionately smaller towards the middle of the touchscreen. One skilled in the art would also appreciate that the space between piezoelectric actuators and/or the piezoelectric actuators' piezoelectric material can also be adjusted accordingly.

[0038] FIG. 3 shows exemplary voltage waveforms in the time domain that represent control signals for a particular piezoelectric actuator, such as piezoelectric actuator 210. For example, piezoelectric actuator 210 can be selectively activated by applying a steady voltage to backplane 220 and applying a control signal to control electrode 202 (which causes, e.g., a voltage difference above a preconfigured threshold). Backplane 220 is shown in FIG. 3 as being maintained at 20V by the electronic device. During the first half-period (i.e., between t0 and t1), control electrode 202 is shown at 20V, thereby creating a 0V potential difference across piezoelectric actuator 210. With a 0V potential difference, piezoelectric actuator 210 will remain at its original dimensions. During the second half-period (i.e., between t1 and t2), control electrode 202 is at 0V, thereby creating a 20V potential across piezoelectric actuator 210. With a 20V potential across piezoelectric actuator 210 (and assuming 20V is greater than the threshold voltage of the piezoelectric material of piezoelectric actuator 210), piezoelectric actuator 210 is activated and expands. When the next wave cycle begins at t3, the voltage potential returns to 0V and the piezoelectric actuator returns to its original dimensions. A user may feel a vibration when a piezoelectric actuator repetitively expands and contracts (i.e., returns to its original dimensions).