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(54) **METHOD AND APPARATUS FOR FINGER POSITION TRACKING AND HAPTIC DISPLAY USING CONDUCTIVE ISLANDS**

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(51) **Int. Cl.**

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| <b>G06F 3/041</b> | (2006.01) |
| <b>G06F 3/044</b> | (2006.01) |
| <b>G09B 21/00</b> | (2006.01) |

(52) **U.S. Cl.**

CPC ..... **G06F 3/016** (2013.01); **G06F 3/044** (2013.01); **G06F 3/0416** (2013.01); **G09B 21/003** (2013.01)

(58) **Field of Classification Search**

CPC ..... G06F 3/016; G06F 3/0416; G06F 3/044; G09B 21/003

See application file for complete search history.

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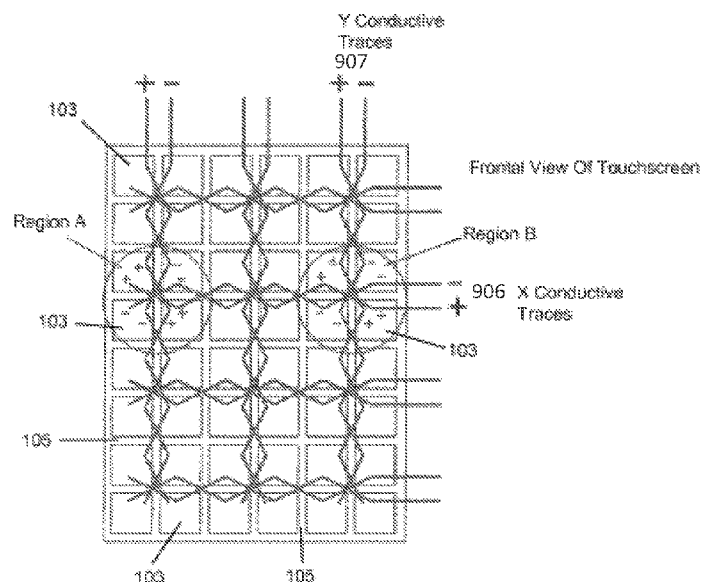
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(57) **ABSTRACT**

A touchscreen includes conductive islands that are capacitively coupled to conductive traces, where they may be used to provide capacitive sensing of the position of one or more fingers in contact with a touchscreen and/or to exert haptic forces on one or more fingers in contact with a touchscreen.

**17 Claims, 10 Drawing Sheets**



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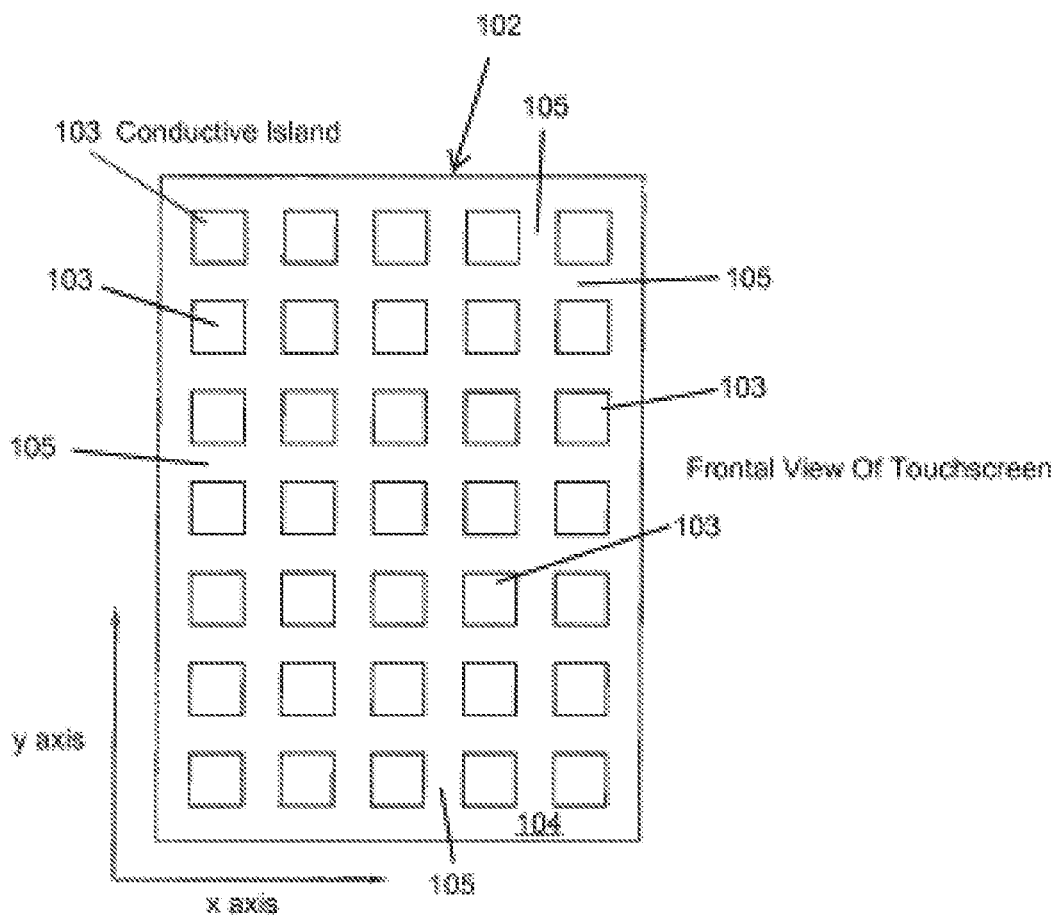


FIG. 1A

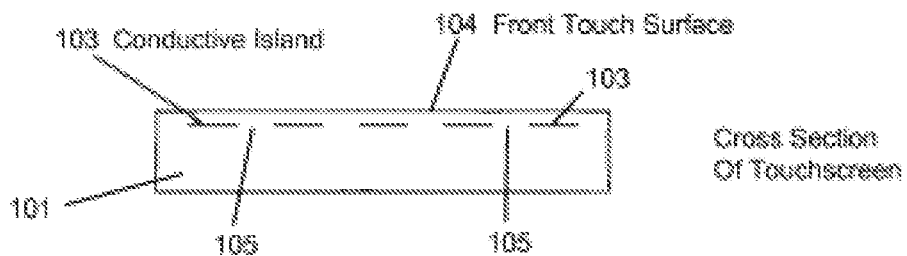


FIG. 1B

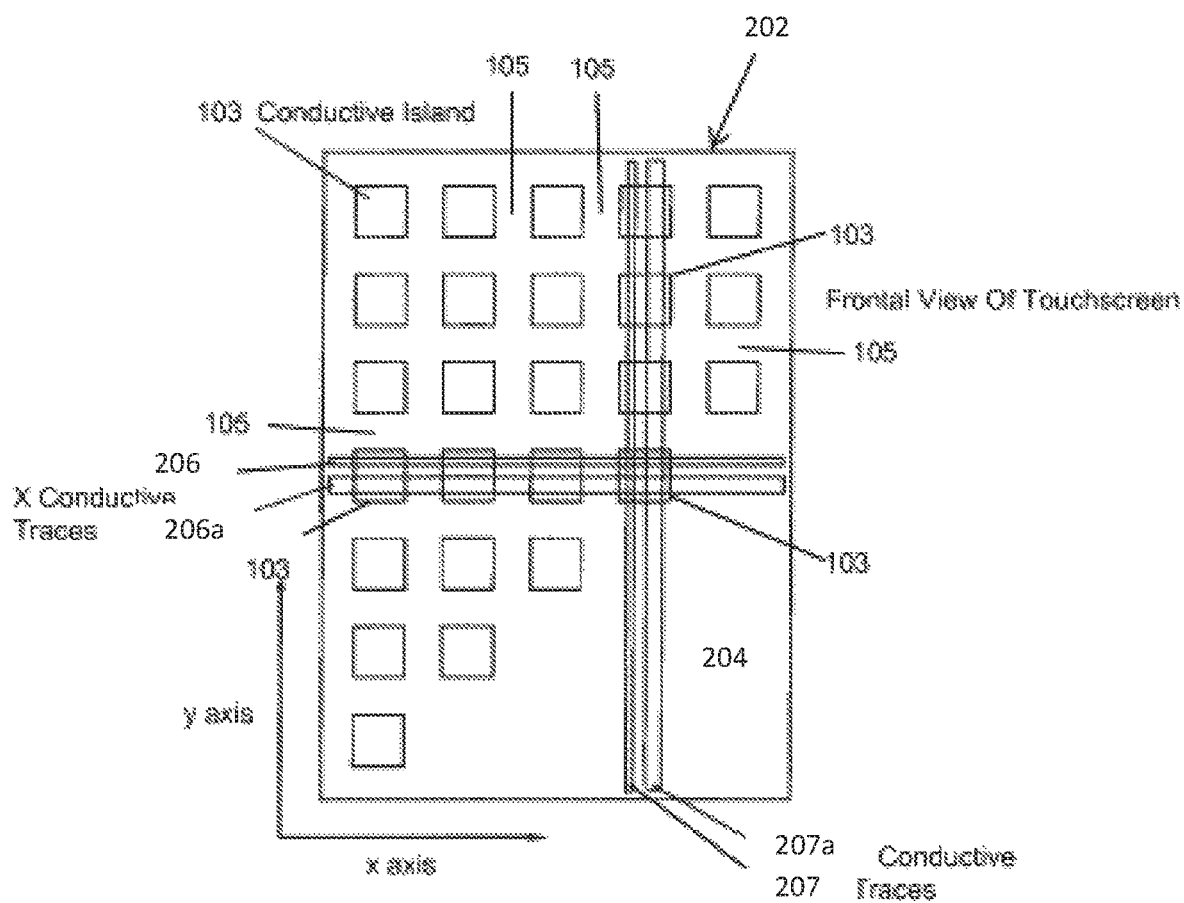


FIG. 2A

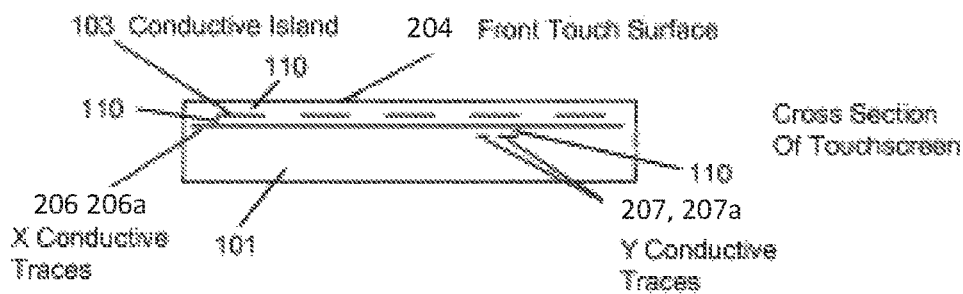


FIG. 2B

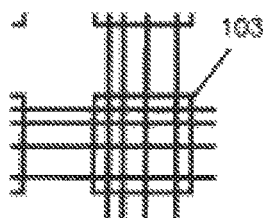


FIG. 2C

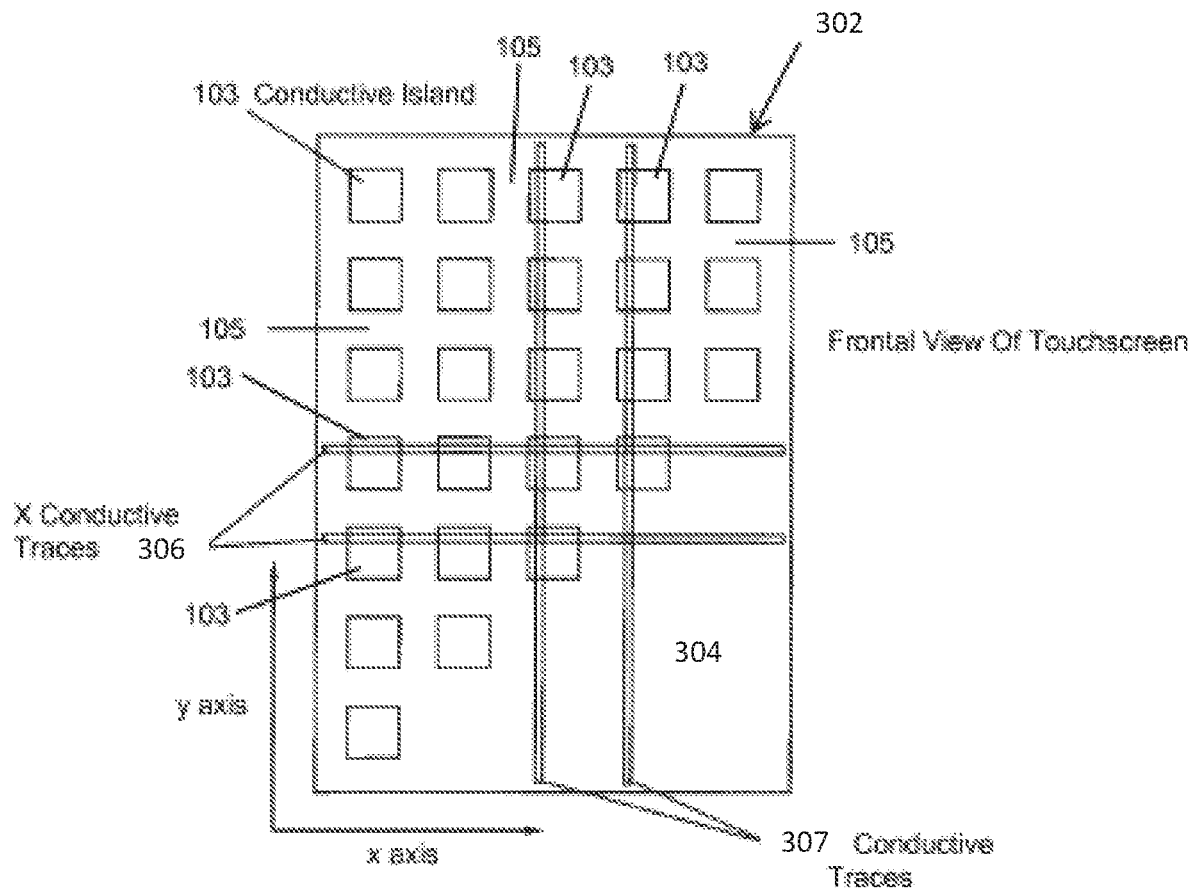


FIG. 3A

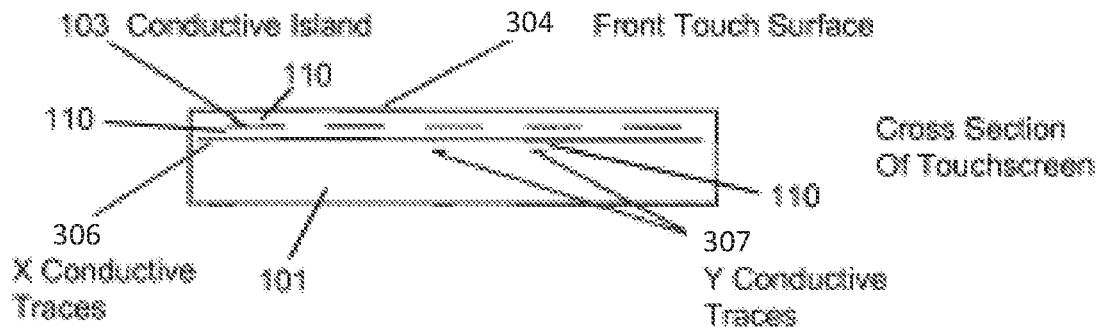


FIG. 3B

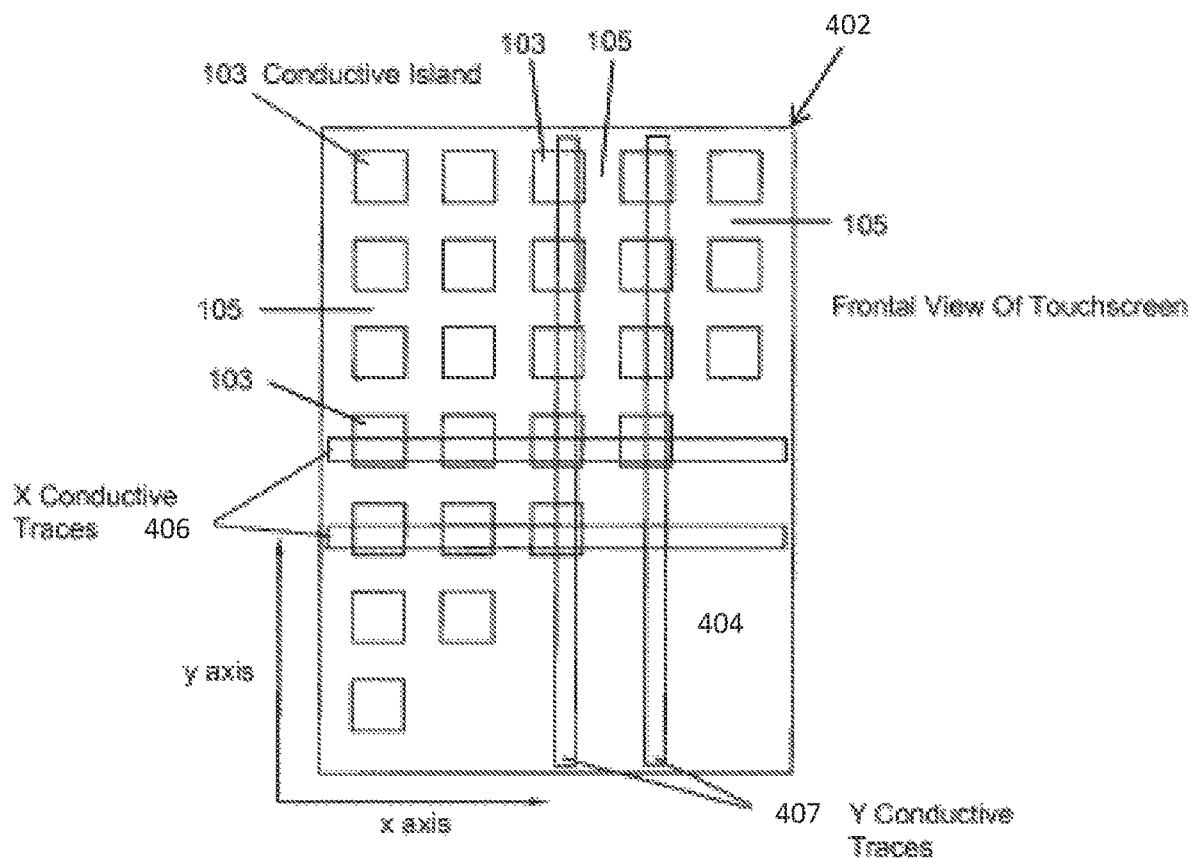


FIG. 4A

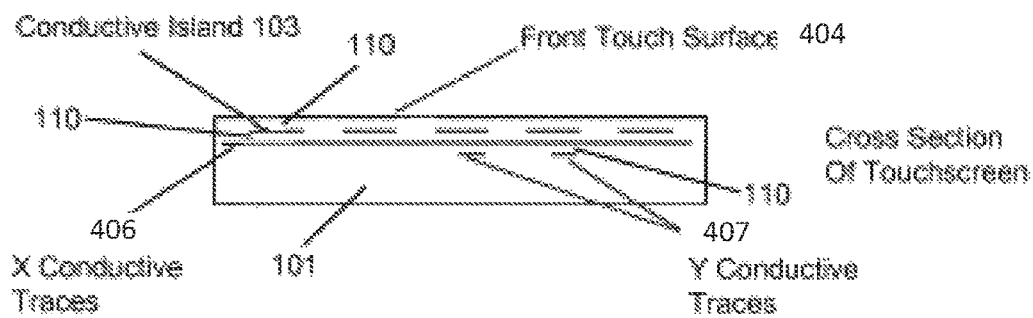


FIG. 4B

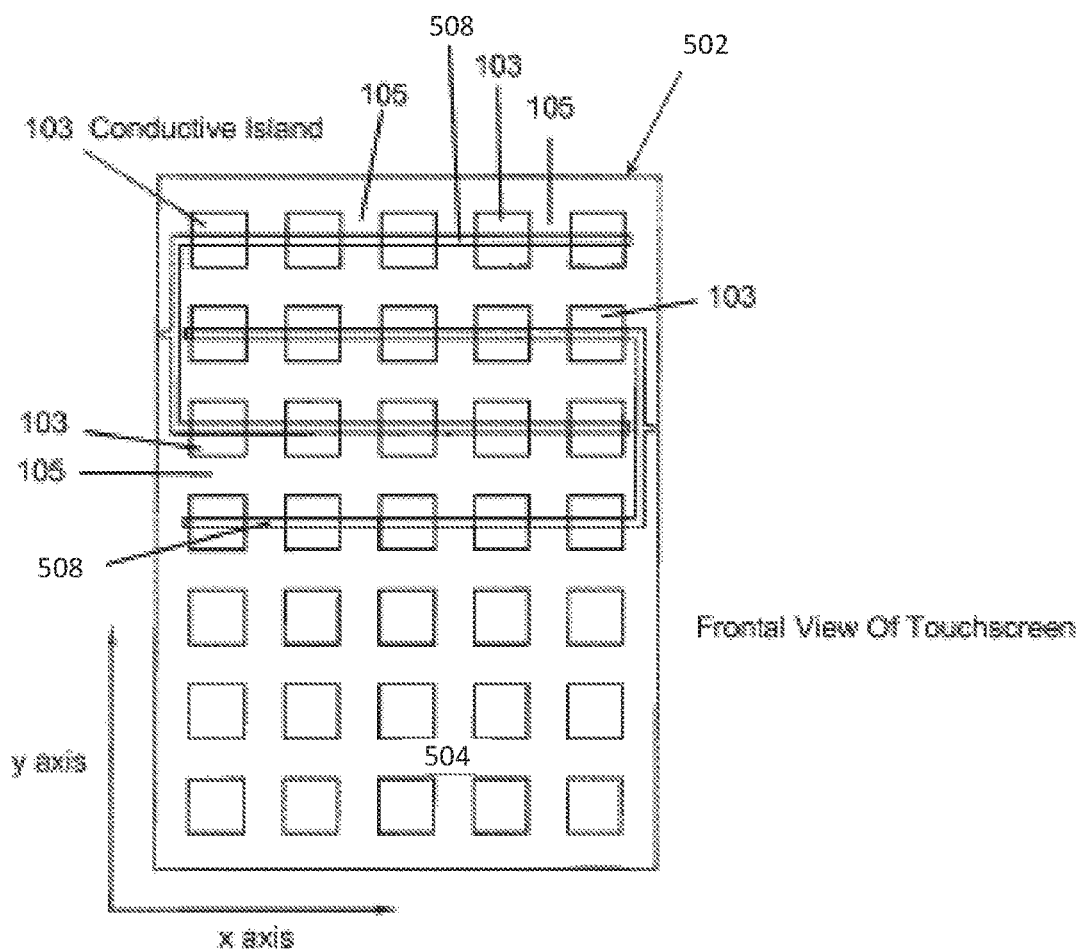


FIG. 5A

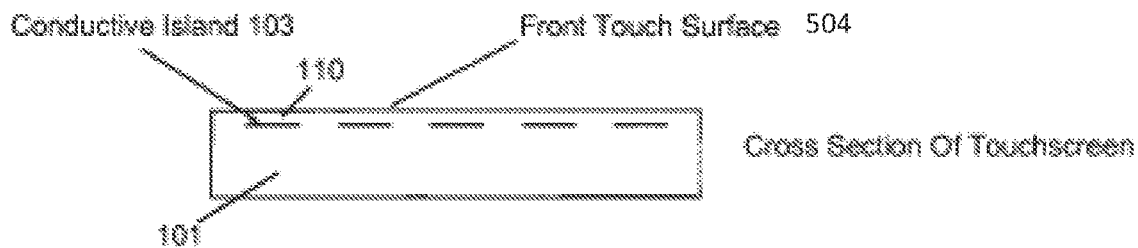


FIG. 5B

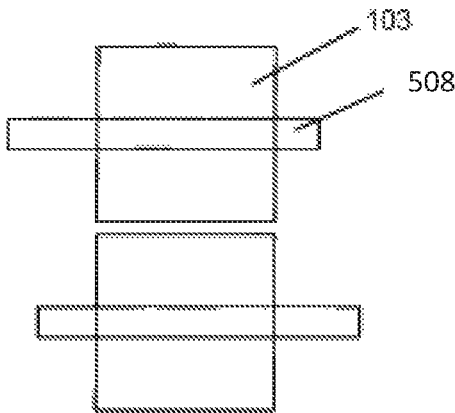


FIG. 5C

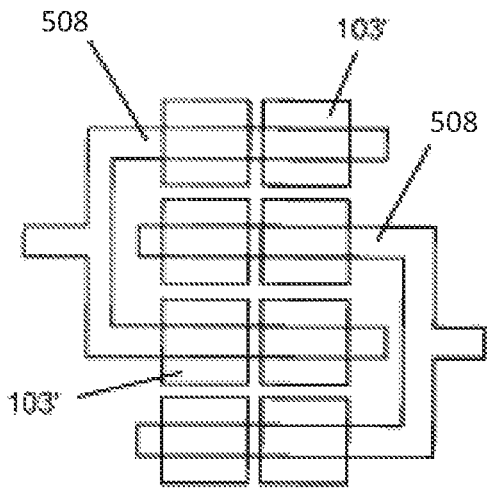


FIG. 5D



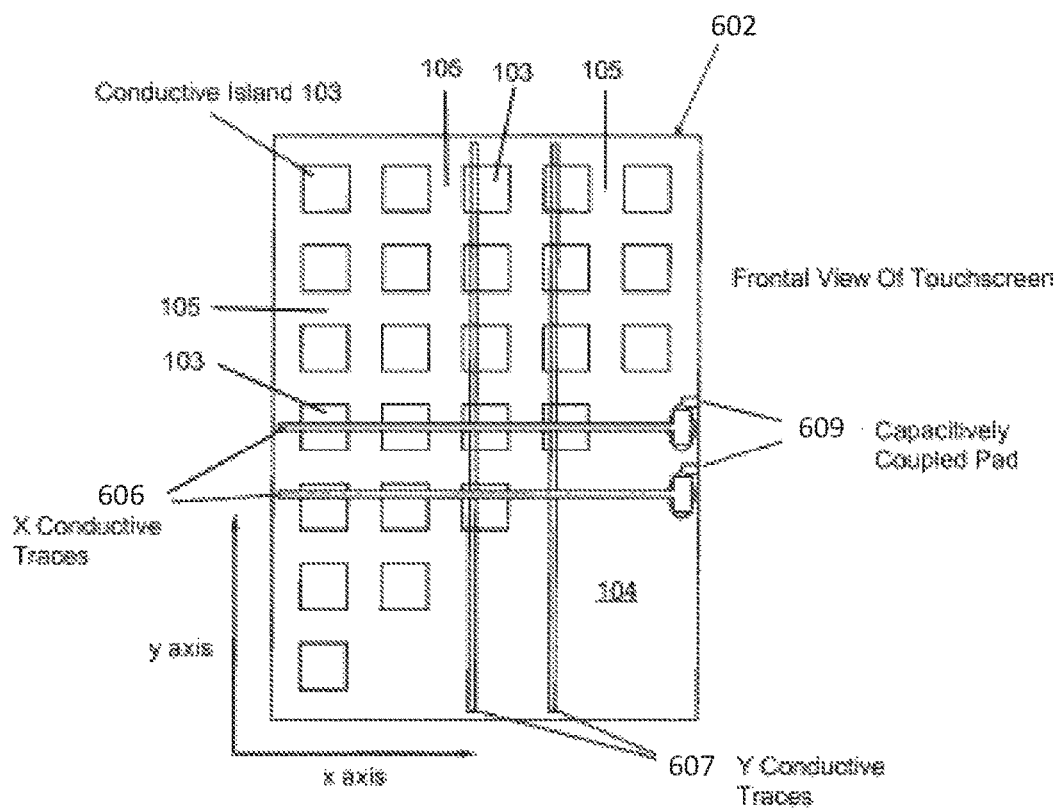


FIG. 6A

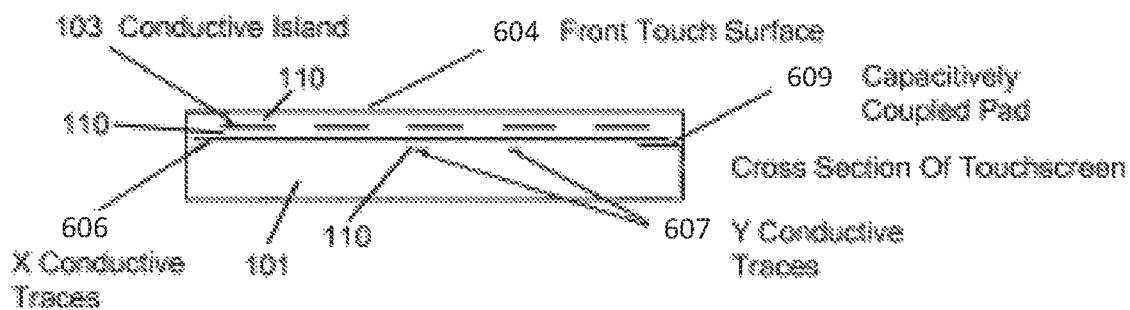


FIG. 6B

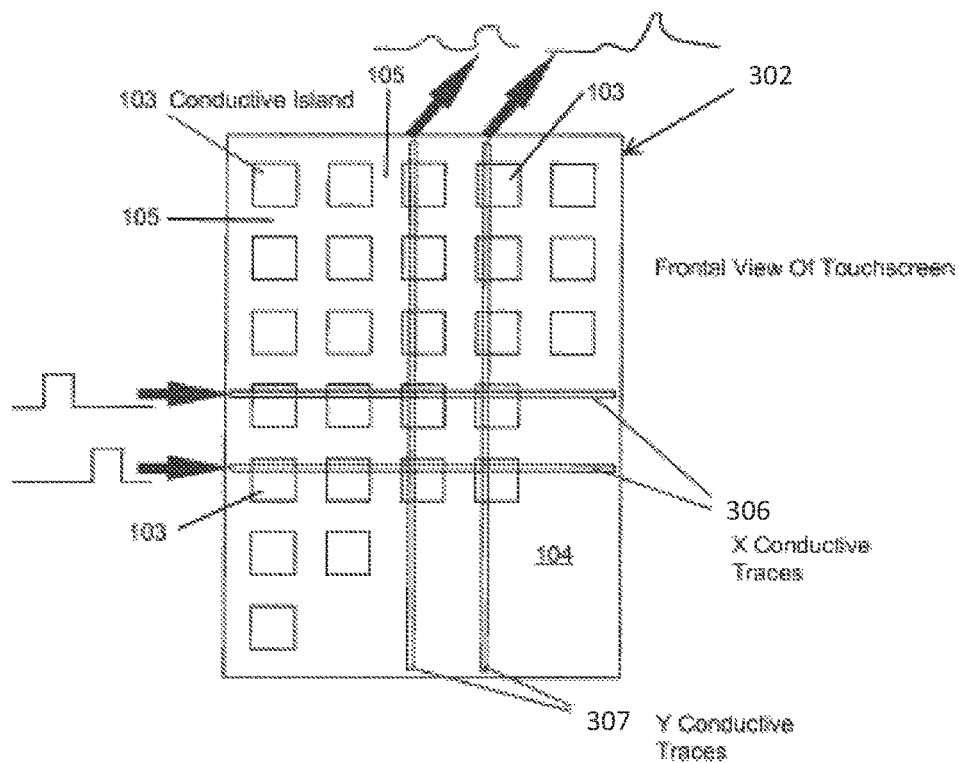


FIG. 7

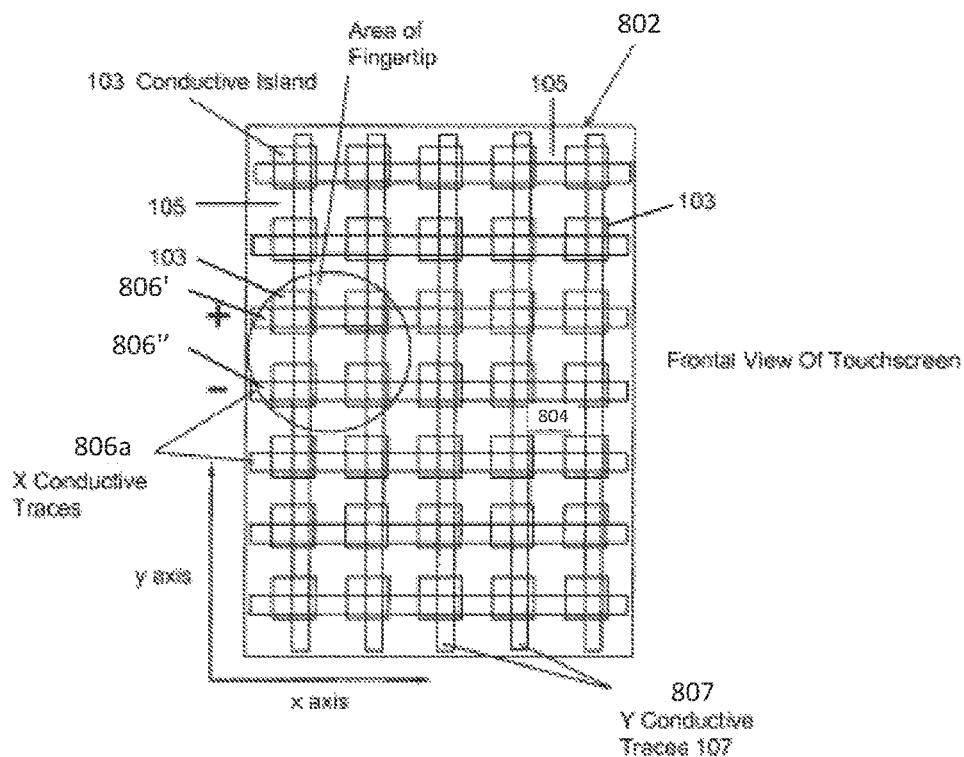


FIG. 8A

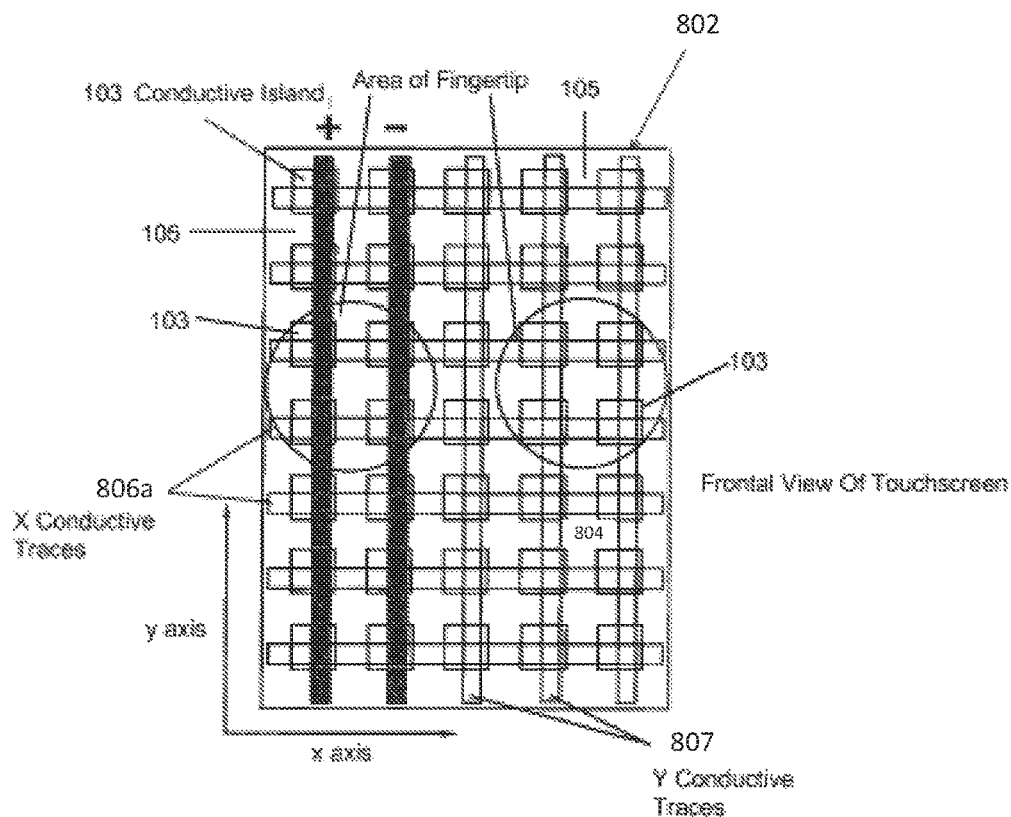


FIG. 8B

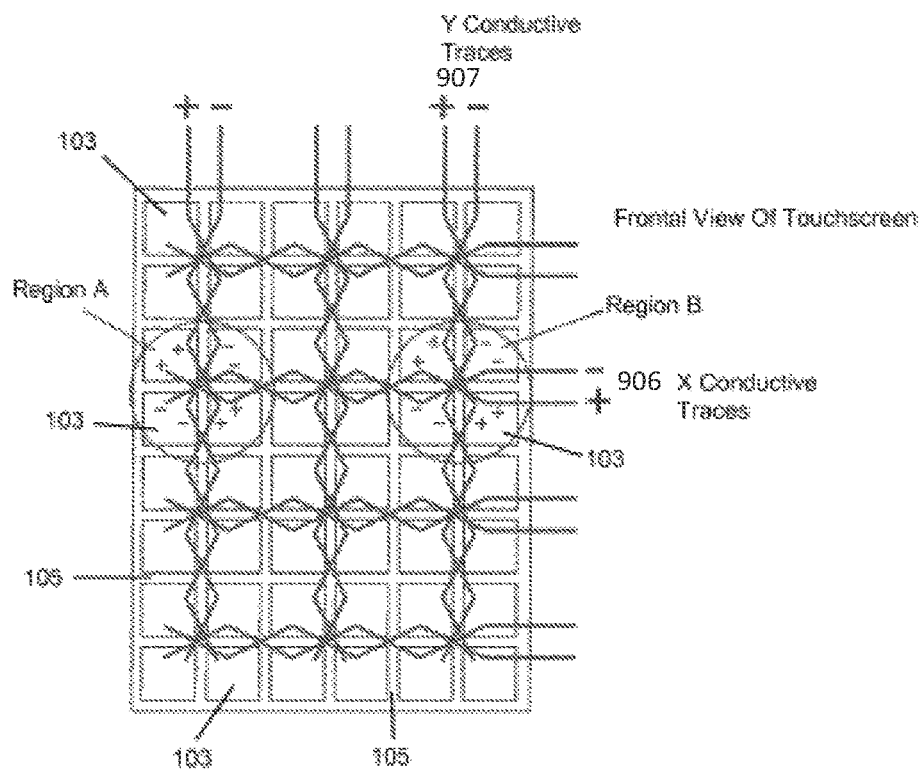


FIG. 9A

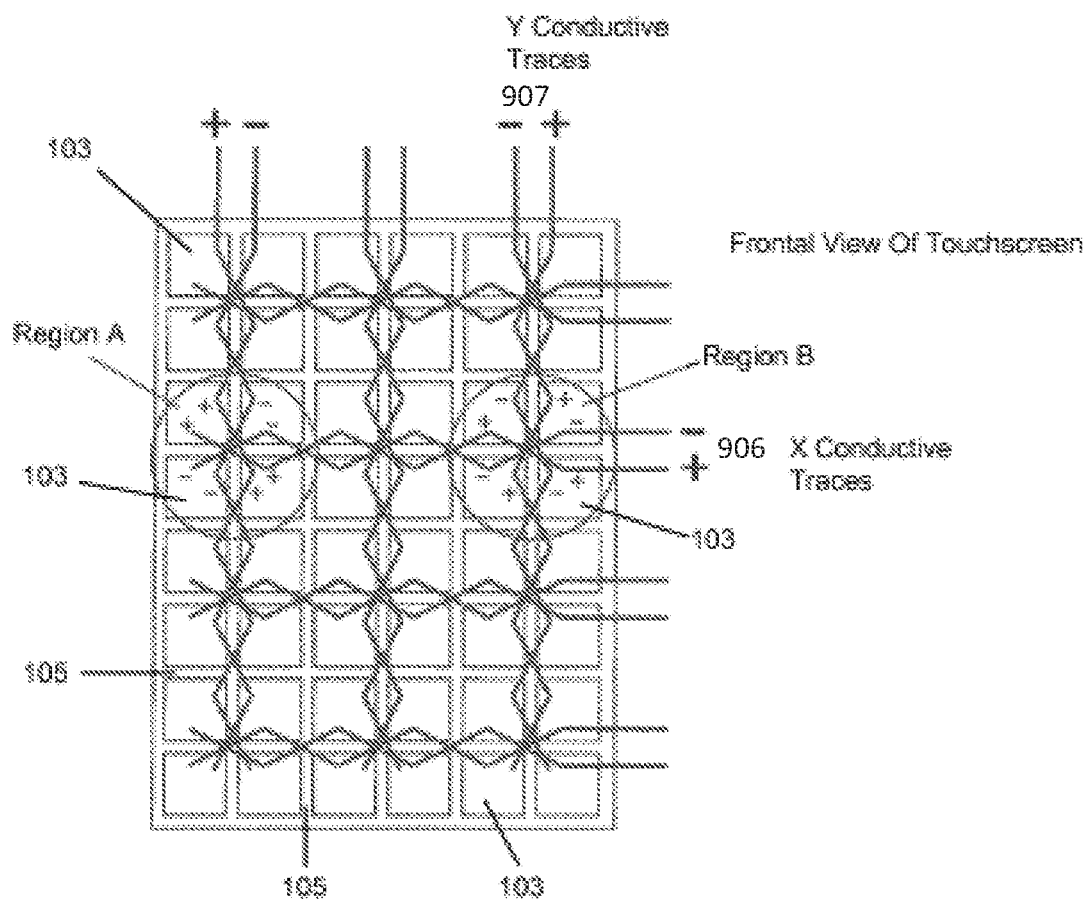


FIG. 9B

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## METHOD AND APPARATUS FOR FINGER POSITION TRACKING AND HAPTIC DISPLAY USING CONDUCTIVE ISLANDS

### RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application No. 62/173,732, titled "Method and Apparatus For Finger Position Tracking and Haptic Display Using conductive Islands," filed on Jun. 10, 2015.

### CONTRACTUAL ORIGIN OF THE INVENTION

This invention was made with government support under grant numbers IIS-0964075 and IIS-1302422 awarded by the National Science Foundation. The government has certain rights in the invention.

### FIELD OF THE INVENTION

The present disclosure generally relates to the field of haptics, and more particularly to touchscreens that include conductive islands that are capacitively coupled to conductive traces.

### BACKGROUND

Touchscreens have become ubiquitous for computer interface, and are used in mobile phones, tablets, laptop computers, bank kiosks, and many other applications and devices. Touchscreens are able to detect the location of a user's finger in contact with the screen. The detected location then can be used by a computer program to respond to the user's command as expressed by his or her touch, such as to move a graphical object that is visible on the screen or to select a button or menu item.

Usually the touch sensitive screen is transparent and is combined with a visual display so that the user may imagine that he or she is touching or pointing to the objects that are visually portrayed. There are two flows of information involved: visual information from a computer to the user, and touch information from the user to a computer.

Less common is the other direction of conveyance of touch information, in which the user can employ his or her sense of touch to receive information from a computer. This could support the user's perception of edges or textures, or even apparent bumps or depressions of the surface.

The facility to convey touch information to the user is called haptics. A contemporary form of haptics is accomplished by producing vibrations of a handheld device. A user may imagine the vibrations to be originating in his or her interaction with icons or other graphical features portrayed on a visual display. Going beyond vibrational haptics, the term surface haptic display refers to touchscreens in which forces can be generated by the screen and exerted on the user's fingertip at the point that it contacts the screen.

If a touchscreen can separately detect the location of more than one finger in contact with the screen at the same time, this is known as "multitouch." If a surface haptic display can produce different forces on more than one finger in contact with the screen at the same time, this is known as "multi-haptics."

A challenge for surface haptic display is to find ways for a touchscreen, which is usually made of glass, to be able to exert forces on a fingertip that is touching it. The forces must be under software control. Further, the mechanism of force production must not interfere with detection of the location

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of a fingertip that is touching the screen. Additionally the mechanism of force production should be reasonably transparent, so that a visual display under the touchscreen is not obscured.

One way of accomplishing surface haptic display is to use electrostatic attraction to create forces on a user's fingertip. Transparent electrodes, such as indium tin oxide (ITO), are placed beneath the surface of a touchscreen, which typically is made of glass. The electrodes are charged to a potential relative to that of a user's finger. The electrostatic attraction between the electrode and the user's fingertip increases the contact force between fingertip and glass, and therefore, also increases the frictional force that the user must overcome to move his or her finger across the glass. The user perceives the increased frictional force, which can be modulated under software control to represent icons, textures, edges, and other haptic effects. The force of electrostatic attraction depends on many factors including the potential difference (voltage), surface area, distance between surfaces attracted, frequency of alternation of the sign of the voltage, and the dielectric constant of the material between them.

An object of the disclosure is to provide capacitive sensing of the position of one or more fingers in contact with a touchscreen and/or to exert haptic forces on one or more fingers in contact with a touchscreen.

### SUMMARY

This disclosure provides description of constructions and methods of making touchscreens that include conductive islands that are capacitively coupled to conductive traces. The purpose and advantages of the invention will be set forth in and apparent from the description and drawings that follow, as well as will be learned by practice of the claimed subject matter.

One embodiment of the present disclosure includes a touchscreen comprising a front surface having a plurality of conductive islands positioned at a depth in close proximity to the front surface, and wherein the conductive islands are substantially electrically isolated from one another.

Another embodiment includes a plurality of conductive traces, each conductive trace being substantially capacitively coupled to at least two of the conductive islands.

In another embodiment, a plurality of the conductive traces are electrically connected.

In another embodiment, the plurality of conductive traces is positioned above the conductive islands.

In another embodiment, the plurality of conductive traces are each positioned below the conductive islands.

In another embodiment, a capacitive coupling connects a plurality of the conductive traces to additional electronics.

In another embodiment, a location of a fingertip in contact with the touchscreen is determined by measuring a mutual capacitance of a plurality of the conductive traces.

In another embodiment, an attractive electrostatic force on a fingertip is created when the fingertip touches the touchscreen, by charging at least one of the conductive islands that is close to the fingertip, via a capacitive coupling of the at least one conductive island to at least one conductive trace that is in proximity to the at least one conductive island.

In another embodiment, the attractive electrostatic force on a fingertip is diminished, by a reduction in the charge on at least one conductive island that is close to the fingertip, via a capacitive coupling of the at least one conductive island to a second conductive trace that also is in proximity to the at least one conductive island.

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In another embodiment, conductive traces pass through an array of the conductive islands in a zigzag pattern.

Another embodiment of the present disclosure includes a method of determining a touch location in a touchscreen, the method including the steps of forming a plurality of conductive islands in a front surface at a depth in close proximity to the front surface substantially electrically isolating the conductive islands from one another.

Another embodiment includes the step of forming a plurality of conductive traces, each conductive trace being substantially capacitively coupled to at least two of the conductive islands.

In another embodiment, a plurality of the conductive traces are electrically connected.

In another embodiment, the plurality of conductive traces is positioned above the conductive islands.

In another embodiment, the plurality of conductive traces are each positioned below the conductive islands

In another embodiment, a capacitive coupling connects a plurality of the conductive traces to additional electronics.

In another embodiment, a location of a fingertip in contact with the touchscreen is determined by measuring a mutual capacitance of a plurality of the conductive traces.

In another embodiment, an attractive electrostatic force on a fingertip is created when the fingertip touches the touchscreen, by charging at least one of the conductive islands that is close to the fingertip, via a capacitive coupling of the at least one conductive island to at least one conductive trace that is in proximity to the at least one conductive island.

In another embodiment, the attractive electrostatic force on a fingertip is diminished, by a reduction in the charge on at least one conductive island that is close to the fingertip, via a capacitive coupling of the at least one conductive island to a second conductive trace that also is in proximity to the at least one conductive island.

In another embodiment, conductive traces pass through an array of the conductive islands in a zigzag pattern.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and provided for purposes of explanation only, and are not restrictive of the subject matter claimed. The terms finger and fingertip are used interchangeably herein to refer to a portion of a user's body that may engage or contact a touchscreen and it will be appreciated that they are used generically to represent any portion of a user's body. Further features and objects of the present disclosure will become more fully apparent in the following description of the preferred embodiments and from the appended claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In describing the preferred embodiments, reference is made to the accompanying drawing figures wherein like parts have like reference numerals, and wherein:

FIG. 1 A shows a frontal view of a touchscreen having conductive islands.

FIG. 1B shows a cross-sectional view of a the touchscreen in FIG. 1A;

FIG. 2A shows a frontal view of a touchscreen including representative conductive traces that are substantially capacitively coupled to respective conductive islands;

FIG. 2B shows a cross-sectional view of the touch screen of FIG. 2A;

FIG. 2C is a close up schematic illustration of a frontal view of one of the conductive islands shown in FIG. 2A;

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FIG. 3A shows a frontal view of a touchscreen having conductive islands and representative conductive traces that are substantially capacitively coupled to respective conductive islands and wherein some of the conductive traces cross paths;

FIG. 3B shows a cross-sectional view of the touch screen of FIG. 3A;

FIG. 4A shows a frontal view of a touchscreen having conductive islands and representative conductive traces that are substantially capacitively coupled to respective conductive islands and wherein some of the conductive traces cross paths;

FIG. 4B shows a cross-sectional view of the touch screen of FIG. 4A;

FIG. 5A shows a frontal view of a touchscreen having conductive islands and alternative representative conductive traces that are substantially capacitively coupled to respective conductive islands;

FIG. 5B shows a cross-sectional view of the touch screen of FIG. 5A;

FIGS. 5C and 5D show close up schematic illustrations of a frontal view of relatively larger conductive islands from FIG. 5A that are substantially capacitively coupled to the alternative conductive traces, and a frontal view of relatively smaller conductive islands that are substantially capacitively coupled to still further alternative conductive traces;

FIG. 6A shows a frontal view of a touchscreen having conductive islands and representative conductive traces that are substantially capacitively coupled to respective conductive islands and wherein some of the conductive traces cross paths and are capacitively coupled to conductive pads on the exterior surface of the substrate of the touchscreen;

FIG. 6B shows a cross-sectional view of the touch screen of FIG. 6A;

FIG. 7 shows a frontal view of a touchscreen having conductive islands and representative conductive traces that are substantially capacitively coupled to respective conductive islands and wherein some of the conductive traces cross paths, and further representing that the respective X conductive traces may be energized with a square wave pulse and that the Y conductive traces receive a charge from the X conductive traces;

FIG. 8A shows a schematic illustration of a frontal view of another example touchscreen having conductive islands and representative conductive traces that are substantially capacitively coupled to respective conductive islands and wherein some of the conductive traces cross path and having some negative charged conductive traces and other positive charged conductive traces;

FIG. 8B shows another embodiment of the touchscreen of FIG. 8A with an alternative method of charging some of the conductive traces to present different haptic sensations to two fingers;

FIG. 9A shows a frontal view of a touchscreen having conductive islands and representative conductive traces that pass through the array of conductive islands in a zigzag pattern and that are substantially capacitively coupled to respective conductive islands, and further wherein some of the conductive traces cross paths and some charged conductive traces are charged negative and other conductive traces are charged positive;

FIG. 9B shows another embodiment of the touchscreen of FIG. 9A with an alternative way of charging some of the conductive traces that would change the electrostatic attraction of the front surface of the touchscreen to a finger.

It should be understood that the drawings are not to scale. While some details of a touchscreen device, including

details of fastening means and other plan and section views of the particular components, have not been included, such details are considered to be within the comprehension of those of skill in the art in light of the present disclosure. It also should be understood that the present invention is not limited to the example embodiments illustrated.

#### DETAILED DESCRIPTION

The present disclosure generally provides touchscreens having a front surface and a plurality of conductive islands positioned at a depth that is in close proximity to the front surface, and wherein the conductive islands are substantially electrically isolated from one another.

FIG. 1A shows a frontal view of a touchscreen **102** that includes a substrate **101**. FIG. 1B shows a cross-sectional view of the touchscreen **102**. In one embodiment, the depth of conductive islands **103** within the touchscreen is such that they are in close proximity to the front (touched) surface **104** of the touchscreen **102**, at a depth of 5  $\mu\text{m}$  from the front surface **104** of the touchscreen **102**. Conductive islands **103** are composed of deposited ITO of a thickness that results in a resistivity of 500 ohms/square, to permit good optical transparency. In this example, each conductive island is 5 mm square and in a square array having axes called x and y. Each conductive island **103** is electrically isolated from other conductive islands **103**. Also, each conductive island **103** is separated from its neighboring conductive islands **103** by laser ablation lines **105** each 100  $\mu\text{m}$  wide, cut through the deposited ITO layer. Most of the area of the substrate **101** of the touchscreen **102** is covered by conductive islands **103**, leaving only minimal ablation lines **105** between conductive islands, as necessary for their electrical isolation one from another. For graphical clarity, FIG. 1B exaggerates the depth of the conductive islands below the front surface **104** of the touchscreen **102**, and the interval and spacing of ablation lines **105** between neighboring conductive islands.

In one embodiment disclosed in FIG. 2A, two conductive traces or pads **206**, **206a**, **207**, **207a** are capacitively coupled to a common conductive island **103** that is positioned such that it is in proximity to both traces or pads, overlapping them. The conductive island **103** serves to create a mutual capacitance between the two traces or pads **206**, **206a**, **207**, **207a**, and this mutual capacitance does not require electric field lines to project or arc out of and above the touchscreen. A user's fingertip, in proximity to the common island **103**, increases the self-capacitance of the island **103**, and by this mechanism decreases the mutual capacitance of the two traces or pads **206**, **206a**, **207**, **207a**.

The conductive islands **103** serve to mediate the capacitive interaction between a user's fingertips as they approach or contact the touchscreen front surface **104**, with conductive traces that are within the touchscreen. The configuration of these conductive traces **206**, **206a**, **207**, **207a** will be explained herein. In surface capacitive sensing applications, conductive traces or pads **206**, **206a**, **207**, **207a** individually capacitively couple to fingertips, causing the self-capacitance of the traces or pads **206**, **206a**, **207**, **207a** to increase when a fingertip is in proximity to the trace or pad. This self-capacitance is measured electronically to detect proximity of a fingertip. In projected capacitance (P-cap) sensing applications, two conductive traces or pads **206**, **206a**, **207**, **207a** capacitively couple one to the other, with the electric field lines that couple the two traces or pads **206**, **206a**, **207**, **207a** projecting or arcing out of and above the touchscreen, where they may intersect a user's fingertip if it is in proximity. The mutual capacitance of two traces or pads

**206**, **206a**, **207**, **207a** is measured electronically. A user's fingertip, by intersecting the projected electric field lines, may serve to increase or to decrease the mutual capacitance, and thus the fingertip may be detected.

Utilizing the physical mechanism discussed above by which a proximate fingertip modifies the mutual capacitance of two traces or pads produces superior touch location results. In projected capacitance sensing, the lines of electric field that couple two traces or pads arc out of the touch surface and are intercepted by a proximate fingertip. For the touchscreen depicted in FIG. 1A, the lines of electric field that couple two traces or pads **206**, **206a**, **207**, **207a** are interior to the touch surface and are not directly affected by a proximate finger. Instead, a proximate finger modifies the self-capacitance of the conductive island **103** that couples the two traces or pads **206**, **206a**, **207**, **207a**. In the present invention, the electronic measurement needed is to measure the mutual capacitance of two traces or pads **206**, **206a**, **207**, **207a**. Measurements of mutual capacitance are beneficial because they are well suited to multiplexing.

Conductive traces **206**, **206a**, **207**, **207a** may be relatively narrow conductive traces **206**, **207** such as of width 250  $\mu\text{m}$ , and/or relatively wide conductive traces **206a**, **207a** such as of width 2.5 mm. The conductive traces will be below the conductive islands **103** as shown in FIG. 2B, farther from the touched front surface **104**. In another embodiment, the conductive traces **206**, **206a**, **207**, **207a** may be positioned above the conductive islands.

Other embodiments may differ without departing from the scope of the invention. For instance, the conductive islands **103** may be at a greater or lesser depth from the front surface **104** of the touchscreen **102**, and need not all be at the same depth. The resistivity of the conductive islands **103** may be greater or less than 500 ohms/square. The conductive islands **103** may be composed of a material other than ITO, and may be placed and patterned by other means than by evaporative deposition and laser ablation. The size of the conductive islands may be other than 5 mm, and the shape may be a shape other than square. The shape of the conductive islands may be a simple shape such as a polygon or may be of a complex shape, even a non-convex shape or a shape consisting of a plurality of electrically connected parts. Moreover, the conductive islands need not all have the same shape, size, thickness, depth, resistivity, composition, or resistivity. The conductive islands may cover all, or almost all, or significantly less than all, of the surface of the substrate **101** and thereby of the respective touchscreen **102**. Conductive islands at different depths may overlap, or partially overlap, or not overlap.

In another embodiment, the conductive islands are not strictly isolated electrically from one another, but rather are of such a conductivity, and interrogation is performed at such a frequency, that the conductive communication from one to another is limited in range, or falls off strongly with increasing distance. In this way, even a uniform sheet of conductive material such as ITO, could be considered to be composed of islands, since patches of ITO are effectively substantially electrically isolated from one another.

Referring to FIGS. 2A, 2B, 3A, 3B, 4A and 4B each conductive trace **106**, **106a**, **107**, **107a**, **206**, **206a**, **207**, **207a**, **306**, **306a**, **307**, **307a**, **406**, **406a**, **407** and **407a** are each significantly capacitively coupled to each of the conductive islands **103** with which it comes into proximity. The extent of the capacitive coupling may be larger or smaller depending upon the amount of overlap in area between the conductive island **103** and the conductive trace **106**, **106a**, **107**, **107a**, **206**, **206a**, **207**, **207a**, **306**, **306a**, **307**, **307a**, **406**,

406a, 407 and 407a, the distance perpendicular to the touchscreen front surface 104, 204, 304 or 404 between them, and the dielectric constant of the material or materials between them. Thus, the mutual capacitance of a conductive trace 106, 106a, 107, 107 a, 206, 206a, 207, 207a, 306, 306a, 307, 307a, 406, 406a, 407 and 407a and conductive island 103 that are in proximity to one another may have a value in the range of a few picofarad (pF) to a few nanofarad (nF). Both larger and smaller values of the mutual capacitance have utility in the invention, as will be described.

FIG. 2C is a close up schematic illustration of a frontal view of one of the conductive islands where there are four conductive traces 206, 206a, 207, 207a substantially capacitively coupled to each conductive island 103 within a row. For clarity in FIG. 2C, only the conductive traces associated with one conductive island 103 are shown. The conductive traces 206, 206a, 207, 207a are made of ITO of relatively low resistivity, such as 50 ohms per square, to achieve good electrical conductivity. Each conductive trace runs parallel to an axis (x or y) and comes into proximity with each conductive island along one line of conductive islands arrayed parallel to that axis. Thus, there may be relatively narrow X conductive traces 206, relatively wide X conductive traces 206a, relatively narrow Y conductive traces 207 and/or relatively wide Y conductive traces 207a.

Other embodiments may differ without departing from the scope of the invention. There may be fewer or greater than four conductive traces that are substantially capacitively coupled to each conductive island. Some such variations will be detailed herein. The conductive traces 206, 206a, 207, 207a may be composed of ITO or another material, may be deposited by evaporation or other techniques, and may be patterned by laser ablation or other techniques. The depth of the layers of conductive traces 206, 206a, 207, 207a may be greater or less than the previous example figures provided. The material and thickness of the glass substrate 101 may be different. The resistivity of the conductive traces 206, 206a, 207, 207a may be greater or less than 50 ohms per square. Many patterns and routes may be used for the conductive traces. Also, conductive traces 206, 206a, 207, 207a may come into proximity to different subsets of the conductive islands depending upon the route of each conductive trace.

Electrically insulating layers 110 are interposed between conductive islands 103 and conductive traces 206, 206a, 207, 207a, and between conductive traces 206, 206a, 207, 207a and other conductive traces 206, 206a, 207, 207a at least where these cross one another. It will be appreciated that there are many known insulating materials and methods of creating them that can be applied in implementing the present invention. These materials and methods will not be reviewed here and will be understood to reside in the spaces between the respective conductive islands and conductive traces. Some of these methods make it possible for conductive traces to reside on the same ITO layer, that is, at the same depth below the front surface 204 of the touchscreen 202, and yet cross over each other without contacting each other, by way of various kinds of bridges that are known in the art.

FIGS. 3A and 3B depict another embodiment of a touchscreen 302 having a front surface 304. In the touchscreen 302, there are but two relatively narrow conductive traces 306, 307 that come into proximity to each conductive island 103. Here too for clarity, only some of the conductive traces 306, 307 and conductive islands 103 are shown. X conductive traces 306 lay at a depth of 5  $\mu$ m below the conductive islands 103. Y conductive traces 307 lay at a depth of 7  $\mu$ m

below the conductive islands. The X and Y conductive traces 306, 307 are composed of ITO having a resistivity of 50 ohms per square. The touchscreen substrate 101 is glass with a thickness of 0.5 mm, upon which the layers of ITO described above are deposited and patterned, with intervening layers of silicon dioxide as an insulator, and also a top layer of silicon dioxide as an insulator above the conductive island layer of ITO (represented by the gaps between the respective elements and surfaces).

The X and Y conductive traces 306, 307 are patterned by laser ablation, forming an intersecting network of relatively narrow conductive traces 306, 307, parallel to the respective x and y axes, as shown. The crossover points between an X and a Y conductive trace 306, 307 do not cause an electrical connection between the conductive traces 306, 307, because the lines are on different ITO layers separated by an insulator. The conductive traces 306, 307 are brought out to edge connectors in any of numerous ways that are known in the art. In this embodiment, the mutual capacitance from an X or Y conductive trace 306, 307 to a conductive island 103 is relatively small, because the small width of the conductive traces 306, 307 creates a small area of overlap between a conductive trace 306, 307 and a conductive island 103.

FIGS. 4A and 4B depict another embodiment of a touchscreen 402 for use as a surface haptic display rather than for capacitive sensing. The X and Y conductive traces 406, 407 are relatively wide, such that the overlap area of a conductive trace 406, 407 with a conductive island 103 is relatively large. In this embodiment, the mutual capacitance from an X or Y conductive trace 406, 407 to a conductive island 103 is relatively large.

Although the relatively large capacitance from an X or Y conductive trace 406, 407, to a conductive island 103 is optimal for haptic display, this does not preclude the same conductive traces 406, 407 also being used for capacitive sensing. In some situations, it may be desirable to employ fewer overall conductive traces 406, 407, and therefore, to reuse some or all of the same conductive traces 406, 407 both for haptic display and for capacitive sensing. In other situations, it may be desirable to use separate conductive traces 406, 407 for the functions of haptic display and of capacitive sensing. In general, some conductive traces 406, 407 can serve both in a capacitive sensing role and in a haptic display role, and other conductive traces 406, 407 can serve solely for capacitive sensing or for haptic display.

For clarity, the touchscreen 202 combines touchscreens 302 and 402. Consistent with this embodiment, each conductive island 103 is significantly capacitively coupled to four conductive traces 206, 206a, 207, 207a. Two of the conductive traces are used for capacitive sensing of finger position and two of the conductive traces are used for haptic display. A connection pattern in which a plurality of conductive traces 206a, 206, 207a, 207 are electrically connected as one may be of value by allowing a finer scale of electrical activation for haptics, or electrical sensing for finger position sensing, without increasing the number of channels of electronics that is needed.

FIGS. 5A and 5B depict another embodiment of a touchscreen 502. The conductive traces are spaced at 2 mm intervals, with alternate conductive traces 508 directed to opposite edges of the substrate 101 for their connection to electronics, such as a controller, microprocessor, Application Specific Integrated Circuit (ASIC), or the like, that serve to locate finger contacts by capacitive sensing or that may create haptic actuation signals, or a combination of both. By twos, conductive traces 508 are electrically con-



nected as one, by a connection that occurs near the edges. The conductive traces **508** are thus interdigitated by pairs.

FIGS. **5C** and **5D** show still more clearly that a smaller number of larger conductive islands **103** may be replaced with a larger number of smaller conductive islands **103'**, maintaining the interdigitated pattern but now at reduced scale, and with no increase in the number of conductive traces **508** that are needed to capacitively couple to the conductive islands. In FIGS. **5C** and **5D**, there are initially two conductive islands **103**, which are then subdivided each into four smaller conductive islands **103'**. By combining conductive traces **508** by twos, still only two conductive traces **508** are needed.

In other embodiments, other numbers of adjacent or non-adjacent conductive traces **508**, such as three or more, may be connected as one. The connected conductive traces **508** may be interdigitated or not. The electrical connection that connects a plurality of conductive traces **508** together as one, may be made: by connections on the substrate **101** itself as in the preferred embodiment, may be made of ITO or another conductor, or may be made by connections within an edge connector to the substrate **101**, or within a cable such as a ribbon cable or flex PCB from the edge connector to electronics, or within the electronics, for instance on a printed circuit board. The electrical connection that connects a plurality of conductive traces **508** together as one also may be made through a capacitive rather than resistive connection, as will be explained next.

Touchscreens often have one or two patterned layers of ITO and these are covered in insulating layers, and have insulating layers between them. To make electrical connection to a conductive trace **508** on a layer of ITO, some part of the ITO is left exposed and uninsulated, not covered with insulator. These exposed portions are directly connected conductively, often by a multi-conductor ribbon cable or flexible PCB, to electronics. Often a conductive metallization layer is deposited on the exposed ITO for protection and to facilitate electrical contact. In some embodiments of the present invention, more layers of ITO are called into use than the one or two layers that are typically used at present. To arrange uninsulated exposures to many layers may be undesirable.

FIGS. **6A** and **6B** depict another embodiment of a touchscreen **602** having a front surface **604**, an X conductive trace **606** is brought to electrical connection with electronics, not by a direct conductive connection to ITO on the layer that contains the conductive trace **606**, **607**, but instead by a capacitive coupling from that conductive trace **606**, **607** to a conductive trace **606**, **607** on another layer within the substrate **101** of the touchscreen **602**. The dimensions of the example capacitor forming the capacitive coupling are 4 mm by 2 mm, and the layers are separated by an insulating layer of silicon dioxide 5  $\mu$ m in thickness.

In other embodiments, the capacitive coupling may be not to another conductive layer within the substrate **101**, but rather to a conductive pad **609** on an exterior surface of the substrate. This conductive pad **609** could be conductive paint or ink or metallization, or any of the various methods of applying a conductive pad **609** that are known in the art.

Any number of the conductive traces **606**, **607** may be connected capacitively as described, not only an X conductive trace **606**, but also a Y conductive trace **607**. The dimensions of the capacitor forming the capacitive coupling may be greater or smaller than 4 mm by 2 mm, and the layers may be separated by an insulating layer of silicon dioxide greater or smaller than 5  $\mu$ m in thickness. The insulating

layer also may be a material other than silicon dioxide, for example, a material with a higher dielectric constant may be desirable.

The conductive island **103** that is substantially capacitively coupled to both of two conductive traces (for instance one X conductive trace **606** and one Y conductive trace **607**), causes a mutual capacitance of the two conductive traces. The mutual capacitance is diminished if a user's fingertip is close to the conductive island. In another embodiment, there are twenty (20) X conductive traces **606** parallel to the x axis ("X conductive traces") and twelve (12) Y conductive traces **607** parallel to the y axis ("Y conductive traces").

FIG. **7** depicts another embodiment of the touchscreen of FIG. **3A**. As illustrated in FIG. **7**, the X conductive traces **306** are energized sequentially with a square wave pulse of duration 1  $\mu$ s and amplitude 3.3 volts. The Y conductive traces **307** are monitored electrically as each receives an amount of charge from the energized X conductive trace **306**. The charge is conveyed substantially via the conductive island **103** that is common to the X conductive trace **306** and the Y conductive trace **307**, and additionally via various parasitic couplings which do not concern us. To the extent a user's fingertip is close to a conductive island **103**, the conveyance of charge from the X conductive trace **306** associated with that conductive island, to the Y conductive trace **307** associated with that conductive island, is diminished. By determining the charge conveyed from each X conductive trace **306** to each Y conductive trace **307**, the conveyance of charge at every (x, y) intersection is determined: Two hundred and forty (240) such intersections are present in this embodiment. Each of the respective conveyance values, to the extent reduced from a normal value, indicates the extent to which a user's fingertip is near that intersection.

The 1  $\mu$ s square wave pulses may be applied at a rate of five hundred thousand (500,000) per second, thus scanning the whole touchscreen twenty-five thousand (25,000) times per second. One thousand (1000) consecutive scans may be averaged to obtain a measure that is relatively immune to noise. Thus, the location of all fingers in contact or near the screen can be established twenty-five (25) times per second.

Because of the use of conductive islands **103** to mediate the capacitive interaction of conductive traces **306**, **307** with each other and with a user's finger identification of a touch location is greatly improved. Much of the electronic methods for driving and reading conductive traces **306**, **307** especially with low power consumption, patterns for the conductive traces **306**, **307**, and algorithms for best interpreting the measurements especially in the presence of noise that have been invented for P-cap touch sensing can be applied to the present invention, either directly or with minor modification. However, the prior art P-cap sensing uses electrodes near the rear surface. The present disclosure's use of electrodes near the front surface is important to allow haptic actuation with reasonable actuation voltages.

Other embodiments may differ from the embodiment described herein. Other numbers of conductive traces **306**, **307** besides twelve (12) and twenty (20) may be used, as well as other patterns besides the x-y grid. Other pulse shapes, durations, and repetition rates may be used. Other numbers of consecutive scans may be averaged for noise reduction, and other methods of noise reduction that are known in the art may be used. Other rates of scan of the entire touchscreen may be achieved, either more or fewer completed scans per second than 25. Partial scans may be used, or adaptive changes in the rate of scans, in ways known in the art.

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Other quantities besides the charge transferred may be used to determine finger positions, that reflect the mutual capacitance between two conductive traces coupled to a conductive island. Methods are known in the art to minimize power consumed, avoid noise, best identify fingers, and to accomplish many other desirable goals in P-cap, and these methods may be adapted to the present invention. However, as noted above, near front surface placement of electrodes is advantageous.

A user's fingertip can be electrostatically attracted toward the front surface **104** of the touchscreen **102** by a difference of potential between the fingertip and a conductive island **103** within the substrate **101**, as we above described. It may be desirable to have, beneath the area of one fingertip on the substrate **101**, two or more conductive islands **103**, with some of the conductive islands **103** charged to a positive potential relative to that of the fingertip, and others negative. If the area of a fingertip (typically 1 square cm) is large compared to the area of a conductive island **103**, then there may be many conductive islands within the area of a fingertip. The present invention allows us to charge some of the conductive islands positive and some negative.

In one embodiment, there are four conductive traces **206**, **206a**, **207**, **207a** in proximity to each conductive island **103**, as shown in FIG. 2A. By way of example, let us suppose that in a typical situation there are four conductive islands **103** on the substrate **101** under a fingertip that is in contact with the front surface **204** of the touchscreen **202**, although there could be more or fewer depending on the size and exact location of the fingertip, and the size of the conductive islands **103**. FIG. 8A illustrates this example, showing however only the conductive traces **806**, **807** used for haptic display actuation. Then, in order to charge some of the conductive islands **103** under the fingertip positive with respect to the fingertip, and others negative, one X conductive trace **806a'** can be changed to positive and one X conductive trace **806a''** to negative. This leaves two of the conductive islands **103** under the fingertip positive and two negative. In this embodiment there is no need to involve any Y conductive traces **807**.

Many variations are possible within the scope of the invention. For instance, above, the Y conductive traces **807** could be used in place of the X conductive traces **806**, **806a'**, **806a''** for the purpose of making each conductive island electrostatically attractive. Either the X or the Y conductive traces **806**, **806a'**, **806a''**, **807** could be eliminated. Other conductive trace patterns could be used, not just aligned with the x and y axes. The number of conductive traces **806**, **806a'**, **806a''**, **807** that are charged in order to make a conductive island **103** electrostatically attractive to a fingertip could be not one, but two, or even more if there are more conductive traces **806**, **806a'**, **806a''**, **807** that are substantially capacitively coupled to each conductive island **103**, in some conductive trace patterns.

For a touchscreen presenting a multi-haptic display, there often will be more than one fingertip in contact with the front surface **804** of the touchscreen **802**. It could be that two fingertips fall on a common conductive trace **806**, **806a'**, **806a''**, **807**, and yet it may be desired to present different haptic sensations to the two fingertips. In the above preferred embodiment, with X conductive traces **806**, **806a'**, **806a''** driven in order to charge the conductive islands **103** associated with them, it would appear not to be possible to produce different haptic sensations to different fingers both lying over the same X conductive trace **806**, **806a'**, **806a''**.

FIG. 8B shows another embodiment of the touchscreen of FIG. 8A with an alternative way of charging some of the

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conductive traces **806**, **806a'**, **806a''**, **807** to present different haptic sensations to two fingers. One method to present different haptic sensations to the two fingers, to charge the conductive islands using the Y conductive traces **807**, rather than the X conductive traces **806a**, **806a'**, **806a''** that have the unfortunate coincidence of two fingers. That is, we may choose to energize the necessary conductive islands, using either the X conductive traces **806a**, **806a'**, **806a''** or the Y conductive traces **807** to convey charges to them, depending on which set of conductive traces **806a**, **806a'**, **806a''**, **807** avoids the problem of having two fingers on it that need different haptic sensations.

Another way to avoid identically charging the conductive islands under both fingers, and which provides a further preferred embodiment, is to make use of both the X and Y conductive traces **806a**, **807**. Suppose that the unfortunate coincidence of two fingers occurs on an X conductive trace **806a**, and that one finger should be electrostatically attracted to the front surface **804** of the touchscreen **802** and the other finger not attracted. The X conductive trace **806a**, **806a'**, **806a''** may be charged positive, thus charging conductive islands **103** under both fingers, and the conductive island that is under the second finger may be reduced in attractive potential by applying a negative voltage to the Y conductive trace **807** that is in proximity to it and not in proximity to the conductive island **103** under the first finger. In this way conductive islands **103** under different fingers may be differently charged from one another, even if they lie over common conductive traces **806a**, **806a'**, **806a''**, **807**, by making use of the fact that each conductive island **103** is substantially capacitively coupled to more than one conductive trace **806a**, **806a'**, **806a''**, **807**. Thus, the attractive potential of a conductive island **103** can be controlled as a combination of the actions of several conductive traces **806a**, **806a'**, **806a''**, **807**.

FIGS. 9A and 9B show another embodiment of a touchscreen **902**. Here only conductive traces **906**, **907** for haptic actuation are shown, not any conductive traces for finger position sensing. The latter also could be added, or the conductive traces for haptic actuation could serve the purpose of finger position sensing as well, as explained earlier. Conductive traces **906**, **907** pass through the array of conductive islands **103** in a zigzag pattern. Both X and Y conductive traces **906**, **907** are shown. The conductive traces **906**, **907** are illustrated as relatively narrow, in order to better be able to see their continuity through the array of conductive islands **103** despite their frequent crossings.

In order to charge some conductive islands **103** positive and others nearby negative, alternate conductive traces **906**, **907** may be given positive and negative potential. Region A may provide a strong electrostatic attraction to a finger by charging the traces **906**, **907** that pass through region A as indicated. Each conductive island **103a** finds itself substantially capacitively coupled to X and Y traces **906**, **907**, which are both positively charged, or both negatively charged. At the same time, region B also presents a strong electrostatic attraction to a second finger, as each conductive island **103** also is doubly charged positive or doubly charged negative.

FIG. 9B shows that the electrostatic attraction of region B may be eliminated while the electrostatic attraction of region A is maintained, simply by exchanging the polarities of two of the conductive traces **906**, **907**. Now in region B, each conductive island **103** finds itself substantially capacitively coupled to X and Y traces **906**, **907** which are of opposite polarity of charge, and these cancel.

To summarize, the conductive islands **103**, each carrying a charge that is a sum of that which is conveyed to it by an

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X trace 906 and by a Y trace 907, can therefore serve to allow the Y conductive traces 907 to enhance or cancel the effect of the X conductive traces 906.

It should be understood that in all of the foregoing, the polarities specified are showing the relative phase of the voltage of a given conductive trace or conductive island. In a preferred embodiment, the voltages all alternate rapidly.

Other patterns also may be used to implement the concept of the invention, which is to allow multiple conductive traces to cancel or to enhance the electrostatic attraction of conductive islands. Having shown that multiple conductive traces can enhance or cancel, it should be understood that any intermediate level of electrostatic attraction between these two cases also may be accomplished, as a linear combination of the activation patterns described.

Conductive traces can cross in any number of ways. Actual crossings can even be avoided: a zigzag pattern can be replaced by two connected parallel straight traces, varying in width as they pass in proximity to alternate conductive islands.

It will be appreciated that a touchscreen in accordance with the present disclosure may be provided in various configurations. Any variety of suitable materials of construction, configurations, shapes and sizes for the components and methods of connecting the components may be utilized to meet the particular needs and requirements of an end user. It will be apparent to those skilled in the art that various modifications can be made in the design and construction of such touchscreens without departing from the scope or spirit of the claimed subject matter, and that the claims are not limited to the preferred embodiments illustrated herein.

What is claimed is:

1. A touchscreen comprising:

a front surface having a plurality of conductive islands positioned at a depth in close proximity to the front surface, and wherein the conductive islands are conductively isolated; a plurality of conductive traces, each conductive island being substantially capacitively coupled to at least one of the conductive traces; wherein a location of a fingertip in contact with the touchscreen is determined by measuring a decrease in a mutual capacitance of at least two of the plurality of conductive traces each of which are substantially capacitively coupled to one of the plurality of conductive islands, wherein the presence of the fingertip in proximity to the one of the plurality of conductive islands increases a self-capacitance of the one of the plurality of conductive islands and correspondingly decreases the mutual capacitance;

wherein an attractive electrostatic force is generated on a fingertip contiguous with the front surface that increases a perceived friction force on the fingertip against movement of the fingertip parallel to the front surface when at least one of the conductive islands that is close to the fingertip is charged via a capacitive coupling of the at least one conductive island to at least one conductive trace that is in proximity to the at least one conductive island.

2. The touchscreen of claim 1, wherein when each conductive island is substantially capacitively coupled to at least one of the conductive traces, each conductive island is substantially capacitively coupled to another of the plurality of conductive traces, wherein one of the traces substantially capacitively coupled to each conductive island is configured to transmit a signal to the conductive island and an other of

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the traces substantially capacitively coupled to each conductive island is configured to receive a signal from the conductive island.

3. The touchscreen of claim 2, wherein a plurality of the conductive traces are electrically connected to additional electronics.

4. The touchscreen of claim 2, wherein each of the plurality of conductive traces is positioned above the conductive islands.

5. The touchscreen of claim 2, wherein at least a subset of the plurality of conductive traces are each positioned below the conductive islands.

6. The touchscreen of claim 2, wherein a capacitive coupling connects a plurality of the conductive traces to additional electronics.

7. The touchscreen of claim 2, wherein a magnitude of the friction force is relative to a duty cycle of a signal.

8. The touchscreen of claim 2, wherein a touch location is determined by transmitting a signal from at least one conductive trace, and receiving a signal from at least one conductive trace.

9. The touchscreen of claim 2, wherein the mutual capacitance of at least one transmitting conductive trace and at least one receiving conductive trace, is enhanced by at least one conductive island.

10. The touchscreen of claim 8, wherein the strength of the received signal is enhanced by the at least one conductive island.

11. The touchscreen of claim 1, wherein each of the plurality of conductive islands are not conductively coupled to any electronics.

12. The touchscreen of claim 1, wherein the plurality of conductive islands are arranged in a pattern such that each of the plurality of conductive islands are adjacent to other of the plurality of conductive islands in both a first direction and in a second direction, wherein the first direction is substantially perpendicular to the second direction.

13. A method of determining a touch location in a touchscreen, the method including the steps of forming a plurality of conductive islands at a first depth in close proximity to a front surface; conductively isolating the conductive islands; forming a plurality of conductive traces at a second depth, each conductive island being substantially capacitively coupled to at least two of the conductive traces; measuring a mutual capacitance of a plurality of the conductive traces to determine a location of a fingertip in contact with the touchscreen, wherein a distance between the first depth and the second depth is constant; generating an attractive electrostatic force on a fingertip contiguous with the front surface; and charging at least one of the conductive islands that is close to the fingertip via a capacitive coupling to at least one conductive trace that is in proximity to the at least one conductive island and wherein the attractive electrostatic force on the fingertip contiguous with the front surface increases a perceived friction force on the fingertip against movement of the fingertip parallel to the front surface.

14. The method of claim 13, further comprising the steps of capacitively coupling the at least one conductive island to a second conductive trace that is in proximity to the at least one conductive island and reducing the charge on the at least one conductive island so that the attractive electrostatic force on the fingertip is diminished.

15. The method of claim 13, wherein the conductive traces pass through an array of the conductive islands in a zigzag pattern.

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16. A touchscreen comprising:  
 a front surface having a plurality of conductive islands  
 positioned at a depth in close proximity to the front  
 surface, and wherein the conductive islands are con-  
 ductively isolated; a plurality of conductive traces, each  
 conductive island being substantially capacitively  
 coupled to at least one of the plurality of conductive  
 traces, wherein each of the plurality of conductive  
 traces is substantially capacitively coupled to at least  
 two of the plurality of conductive islands; wherein a  
 location of a fingertip in contact with the touchscreen is  
 determined by measuring a decrease in a mutual  
 capacitance of at least two of the plurality of conduc-  
 tive traces each of which are substantially capacitively  
 coupled to one of the plurality of conductive islands;  
 wherein an attractive electrostatic force is generated on  
 a fingertip contiguous with the front surface that  
 increases a perceived friction force on the fingertip  
 against movement of the fingertip parallel to the front  
 surface when at least one of the conductive islands that  
 is close to the fingertip is charged via a capacitive  
 coupling of the at least one conductive island to the at

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least one conductive trace that is in proximity to the at  
 least one conductive island.

17. A method of confirming a touch location in a touch-  
 screen, the method including the steps of forming a plurality  
 of conductive islands at a depth in close proximity to a front  
 surface; conductively isolating the conductive islands; form-  
 ing a plurality of conductive traces, each conductive island  
 being substantially capacitively coupled to at least one of the  
 plurality of conductive traces, wherein each of the plurality  
 of conductive traces is substantially capacitively coupled to  
 at least two of the plurality of conductive islands; and  
 measuring a mutual capacitance of a plurality of the con-  
 ductive traces to determine a location of a fingertip in  
 contact with the touchscreen; and generating an attractive  
 electrostatic force on a fingertip contiguous with the front  
 surface that increases a perceived friction force on the  
 fingertip against movement of the fingertip parallel to the  
 front surface by charging at least one of the conductive  
 islands that is close to the fingertip via a capacitive coupling  
 of the at least one conductive island to the at least one  
 conductive trace that is in proximity to the at least one  
 conductive island.

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