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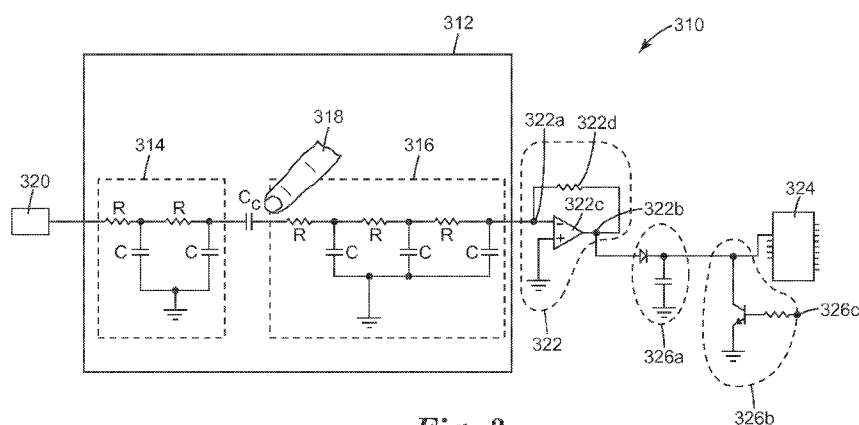
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(54) Title: HIGH SPEED MULTI-TOUCH TOUCH DEVICE AND CONTROLLER THEREFOR

**Fig. 3a**

(57) Abstract: A touch-sensitive device includes a touch panel, a drive unit, a sense unit, and a measurement unit. A touch applied to a node of the panel changes a capacitive coupling between two electrodes (a drive electrode and a sense electrode) of the touch panel. The drive unit delivers a drive signal, which may comprise one or more drive pulses, to the drive electrode. The sense unit couples to the sense electrode, and generates a response signal that includes a differentiated representation of the drive signal. The amplitude of the response signal is responsive to the capacitive coupling between the electrodes, and is measured to provide an indication of a touch at the node.

HIGH SPEED MULTI-TOUCH TOUCH DEVICE AND CONTROLLER THEREFOR

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CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional patent application

No. 61/182366, filed May 29, 2009, and U.S. Provisional patent application

10 No. 61/231471, filed August 5, 2009, the disclosure of which is incorporated by reference
herein in its entirety.

FIELD OF THE INVENTION

This invention relates generally to touch-sensitive devices, particularly those that
15 rely on a capacitive coupling between a user's finger or other touch implement and the
touch device, with particular application to such devices that are capable of detecting
multiple touches applied to different portions of the touch device at the same time.

BACKGROUND

20 Touch sensitive devices allow a user to conveniently interface with electronic
systems and displays by reducing or eliminating the need for mechanical buttons, keypads,
keyboards, and pointing devices. For example, a user can carry out a complicated
sequence of instructions by simply touching an on-display touch screen at a location
identified by an icon.

25 There are several types of technologies for implementing a touch sensitive device
including, for example, resistive, infrared, capacitive, surface acoustic wave,
electromagnetic, near field imaging, etc. Capacitive touch sensing devices have been
found to work well in a number of applications. In many touch sensitive devices, the input
is sensed when a conductive object in the sensor is capacitively coupled to a conductive
30 touch implement such as a user's finger. Generally, whenever two electrically conductive
members come into proximity with one another without actually touching, a capacitance is
formed therebetween. In the case of a capacitive touch sensitive device, as an object such
as a finger approaches the touch sensing surface, a tiny capacitance forms between the

object and the sensing points in close proximity to the object. By detecting changes in capacitance at each of the sensing points and noting the position of the sensing points, the sensing circuit can recognize multiple objects and determine the characteristics of the object as it is moved across the touch surface.

5 There are two known techniques used to capacitively measure touch. The first is to measure capacitance-to-ground, whereby a signal is applied to an electrode. A touch in proximity to the electrode causes signal current to flow from the electrode, through an object such as a finger, to electrical ground.

10 The second technique used to capacitively measure touch is through mutual capacitance. Mutual capacitance touch screens apply a signal to a driven electrode, which is capacitively coupled to a receiver electrode by an electric field. Signal coupling between the two electrodes is reduced by an object in proximity, which reduces the capacitive coupling.

15 Within the context of the second technique, various additional techniques have been used to measure the mutual capacitance between electrodes. In one such technique, a capacitor coupled to a receiver electrode is used to accumulate multiple charges associated with multiple pulses of a drive signal. Each pulse of the drive signal thus contributes only a small portion of the total charge built up on this “integrating capacitor”. Reference is made to U.S. Patent 6,452,514 (Philipp). This technique has good noise immunity, but its
20 speed may be limited depending upon the number of pulses needed to charge the integrating capacitor.

BRIEF SUMMARY

25 The present application discloses, *inter alia*, touch-sensitive devices capable of detecting multiple touches applied to different portions of the touch device at the same time or at overlapping times. Moreover, the touch devices need not employ an integrating capacitor in order to measure the capacitive coupling between the drive electrodes and the receive electrodes. Rather, in at least some embodiments, a single pulse from a drive signal may be all that is necessary to measure the capacitive coupling between a particular
30 drive electrode and a particular receive electrode, or even between a particular drive electrode and a large plurality of (e.g. all of the) receive electrodes. To accomplish this, assuming a suitable pulse shape is used for the drive signal, differentiation circuits are

preferably coupled to the receive electrodes so that a differentiated representation of the drive signal, referred to as a response signal, is generated for each receive electrode. In an exemplary embodiment, each differentiation circuit may comprise an operational amplifier (op amp) with a feedback resistor connected between an inverting input of the op amp and the output of the op amp, with the inverting input also being connected to a given receive electrode. Other known differentiation circuit designs can also be used, so long as the circuit provides an output that includes in some form at least an approximation of the derivative with respect to time of the drive signal.

A characteristic amplitude, such as a peak amplitude or average amplitude, of the response signal is indicative of the capacitive coupling between the drive electrode and the receive electrode being sampled. A touch at the node corresponding to the particular drive and receive electrodes has the effect of reducing capacitive coupling and reducing the characteristic amplitude. Such a reduction in amplitude can be measured even with only a single pulse of the drive signal. Multiple touches at different portions of the touch device that are simultaneous or that otherwise overlap in time can be detected in this manner. If noise reduction is desired, a selected number of multiple pulses from a drive signal may be employed for each drive/receive electrode pair (i.e., node), and the amplitude measurements measured or otherwise processed to provide a lower noise measurement.

The application also discloses touch-sensitive apparatuses that include a touch panel, a drive unit, a sense unit, and a measurement unit. The panel may include a touch surface and a plurality of electrodes defining an electrode matrix, the plurality of electrodes including a plurality of drive electrodes and a plurality of receive electrodes. Each drive electrode is capacitively coupled to each receive electrode at a respective node of the matrix. The panel is configured such that a touch on the touch surface proximate a given one of the nodes changes a coupling capacitance between the drive electrode and the receive electrode associated with the given node. The drive unit, in turn, is configured to generate a drive signal and to deliver the drive signal to the drive electrodes one at a time, e.g. through a multiplexer. The drive signal may be or include only one individual drive pulse, or it may include a plurality or train of such drive pulses. The sense unit may be configured to generate, for each drive signal delivered to each drive electrode, response signals for the plurality of receive electrodes that are capacitively coupled to such drive electrode, each of the response signals including a differentiated representation of the

drive signal. An amplitude of each of these response signals is responsive to the coupling capacitance at the associated node. Finally, the measurement unit is preferably configured to measure the amplitude of each of the response signals for each of the nodes, and to determine therefrom the positions of multiple temporally overlapping touches, if present,
5 on the touch surface.

The shape of the drive pulse(s) used in the drive signal may be tailored or selected so as to provide a desired waveform shape for the response signals. For example, if a rectangle shape is used for the drive pulse, the response signal generated by the sense unit typically comprises a pair of opposite polarity impulse pulses, the peak amplitude of
10 which can be isolated with a peak detector and optional sample/hold buffer. Alternatively, if a ramp-shaped drive pulse is selected, the response signal typically comprises a pulse shape that is nominally rectangular, i.e., it includes a relatively constant amplitude plateau disposed between two relatively steep high-to-low transitions, examples of which are described below. Such a rectangular-shaped response signal allows for the possible
15 elimination of certain circuit elements, and overall simplification of the touch device, as described further below.

The application also discloses touch-sensitive apparatuses that include a touch panel, a drive unit, and a sense unit. The panel includes a touch surface and a plurality of electrodes defining an electrode matrix, the electrode matrix being configured such that a
20 touch on the touch surface proximate a given node of the matrix changes a coupling capacitance between two of the electrodes. The drive unit is coupled to the electrode matrix and configured to generate a drive signal that includes one or more ramped pulses. The sense unit is also coupled to the electrode matrix, and is configured to generate, in response to the drive signal, at least one response signal that includes one or more
25 rectangle pulses, an amplitude of the at least one response signal being responsive to a touch on the touch surface.

Related methods, systems, and articles are also discussed.

These and other aspects of the present application will be apparent from the detailed description below. In no event, however, should the above summaries be
30 construed as limitations on the claimed subject matter, which subject matter is defined solely by the attached claims, as may be amended during prosecution.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic view of a touch device;

FIG. 2 is a schematic side view of a portion of a touch panel used in a touch device;

5 FIG. 3a is a schematic view of a touch device in which relevant drive and detection circuitry is shown in the context of one drive electrode and one receive electrode capacitively coupled thereto;

10 FIG. 3b is a schematic view of a touch sensitive device similar to that of FIG. 3a, but including additional circuitry to account for differences of signal strength on receiver electrodes;

FIG. 3c is a schematic view of a touch sensitive device similar to that of FIG. 3a, but including additional circuitry to account for noise from, for example, a display;

15 FIG. 4a is a graph of a drive signal and a corresponding (modeled) response signal for the touch device of FIG. 3a, wherein the drive signal includes rectangle pulses and the response signal includes impulse pulses;

FIG. 4b is a graph showing modeled waveforms for three driven electrodes, and associated response waveforms on three receive electrodes;

20 FIG. 5a is a graph similar to that of FIG. 4a but for a different drive signal, the drive signal including ramped pulses and the response signal including rectangle-like pulses;

FIG. 5b is a graph showing modeled waveforms for three driven electrodes, and associated response waveforms on three receive electrodes, similar to Fig. 4b;

25 FIG. 6a is a graph of still another drive signal and a schematic depiction of an expected response signal for the touch device of FIG. 3a, the drive signal including ramped pulses and the response signal including rectangle pulses;

FIG. 6b is a graph showing modeled waveforms for three driven electrodes, and associated response waveforms on three receive electrodes, similar to Fig. 4b and 5b;

30 FIG. 7 is a graph of a drive signal and corresponding (modeled) response signal for the touch device of FIG. 3c, wherein the drive signal includes rectangle pulses and the response signal includes impulse pulses; and,

FIG. 8 is a schematic view of a touch device that includes a touch panel having a 4x8 matrix of capacitively coupled electrodes, and various circuit components that can be used to detect multiple simultaneous touches on the touch panel.

In the figures, like reference numerals designate like elements.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

In FIG. 1, an exemplary touch device **110** is shown. The device **110** includes a touch panel **112** connected to electronic circuitry, which for simplicity is grouped together into a single schematic box labeled **114** and referred to collectively as a controller.

The touch panel **112** is shown as having a 5x5 matrix of column electrodes **116a-e** and row electrodes **118a-e**, but other numbers of electrodes and other matrix sizes can also be used. The panel **112** is typically substantially transparent so that the user is able to view an object, such as the pixilated display of a computer, hand-held device, mobile phone, or other peripheral device, through the panel **112**. The boundary **120** represents the viewing area of the panel **112** and also preferably the viewing area of such a display, if used. The electrodes **116a-e**, **118a-e** are spatially distributed, from a plan view perspective, over the viewing area **120**. For ease of illustration the electrodes are shown to be wide and obtrusive, but in practice they may be relatively narrow and inconspicuous to the user. Further, they may be designed to have variable widths, e.g., an increased width in the form of a diamond- or other-shaped pad in the vicinity of the nodes of the matrix in order to increase the inter-electrode fringe field and thereby increase the effect of a touch on the electrode-to-electrode capacitive coupling. In exemplary embodiments the electrodes may be composed of indium tin oxide (ITO) or other suitable electrically conductive materials. From a depth perspective, the column electrodes may lie in a different plane than the row electrodes (from the perspective of FIG. 1, the column electrodes **116a-e** lie underneath the row electrodes **118a-e**) such that no significant ohmic contact is made between column and row electrodes, and so that the only significant electrical coupling between a given column electrode and a given row electrode is capacitive coupling. The matrix of electrodes typically lies beneath a cover glass, plastic film, or the like, so that the electrodes are protected from direct physical contact with a user's finger or other touch-related implement. An exposed surface of such a cover glass, film, or the like may be referred to as a touch surface. Additionally, in display-type applications, a back shield may be placed between the display and the touch panel **112**. Such a back shield typically consists of a conductive ITO coating on a glass or film, and can be grounded or driven with a waveform that reduces signal coupling into touch panel **112** from external electrical interference sources. Other approaches to back shielding are

known in the art. In general, a back shield reduces noise sensed by touch panel **112**, which in some embodiments may provide improved touch sensitivity (e.g., ability to sense a lighter touch) and faster response time. Back shields are sometimes used in conjunction with other noise reduction approaches, including spacing apart touch panel **112** and a display, as noise strength from LCD displays, for example, rapidly decreases over distance. In addition to these techniques, other approaches to dealing with noise problems are discussed in reference to various embodiments, below.

The capacitive coupling between a given row and column electrode is primarily a function of the geometry of the electrodes in the region where the electrodes are closest together. Such regions correspond to the “nodes” of the electrode matrix, some of which are labeled in FIG. 1. For example, capacitive coupling between column electrode **116a** and row electrode **118d** occurs primarily at node **122**, and capacitive coupling between column electrode **116b** and row electrode **118e** occurs primarily at node **124**. The 5x5 matrix of FIG. 1 has 25 such nodes, any one of which can be addressed by controller **114** via appropriate selection of one of the control lines **126**, which individually couple the respective column electrodes **116a-e** to the controller, and appropriate selection of one of the control lines **128**, which individually couple the respective row electrodes **118a-e** to the controller.

When a finger **130** of a user or other touch implement comes into contact or near-contact with the touch surface of the device **110**, as shown at touch location **131**, the finger capacitively couples to the electrode matrix. The finger draws charge from the matrix, particularly from those electrodes lying closest to the touch location, and in doing so it changes the coupling capacitance between the electrodes corresponding to the nearest node(s). For example, the touch at touch location **131** lies nearest the node corresponding to electrodes **116c/118b**. As described further below, this change in coupling capacitance can be detected by controller **114** and interpreted as a touch at or near the **116a/118b** node. Preferably, the controller is configured to rapidly detect the change in capacitance, if any, of all of the nodes of the matrix, and is capable of analyzing the magnitudes of capacitance changes for neighboring nodes so as to accurately determine a touch location lying between nodes by interpolation. Furthermore, the controller **114** advantageously is designed to detect multiple distinct touches applied to different portions of the touch device at the same time, or at overlapping times. Thus, for example, if another finger **132**

touches the touch surface of the device **110** at touch location **133** simultaneously with the touch of finger **130**, or if the respective touches at least temporally overlap, the controller is preferably capable of detecting the positions **131**, **133** of both such touches and providing such locations on a touch output **114a**. The number of distinct simultaneous or
5 temporally overlapping touches capable of being detected by controller **114** is preferably not limited to 2, e.g., it may be 3, 4, or more, depending on the size of the electrode matrix.

As discussed further below, the controller **114** preferably employs a variety of circuit modules and components that enable it to rapidly determine the coupling
10 capacitance at some or all of the nodes of the electrode matrix. For example, the controller preferably includes at least one signal generator or drive unit. The drive unit delivers a drive signal to one set of electrodes, referred to as drive electrodes. In the embodiment of FIG. 1, the column electrodes **116a-e** may be used as drive electrodes, or the row electrodes **118a-e** may be so used. The drive signal is preferably delivered to one
15 drive electrode at a time, e.g., in a scanned sequence from a first to a last drive electrode. As each such electrode is driven, the controller monitors the other set of electrodes, referred to as receive electrodes. The controller **114** may include one or more sense units coupled to all of the receive electrodes. For each drive signal that is delivered to each
20 drive electrode, the sense unit(s) generate response signals for the plurality of receive electrodes. Preferably, the sense unit(s) are designed such that each response signal comprises a differentiated representation of the drive signal. For example, if the drive signal is represented by a function $f(t)$, which may represent voltage as a function of time, then the response signal may be or comprise, at least approximately, a function $g(t)$, where $g(t) = d f(t)/dt$. In other words, $g(t)$ is the derivative with respect to time of the drive signal
25 $f(t)$. Depending on the design details of the circuitry used in the controller **114**, the response signal may include: (1) $g(t)$ alone; or (2) $g(t)$ with a constant offset ($g(t) + a$); or (3) $g(t)$ with a multiplicative scaling factor ($b * g(t)$), the scaling factor capable of being positive or negative, and capable of having a magnitude greater than 1, or less than 1 but greater than 0; or (4) combinations thereof, for example. In any case, an amplitude of the
30 response signal is advantageously related to the coupling capacitance between the drive electrode being driven and the particular receive electrode being monitored. Of course, the amplitude of $g(t)$ is also proportional to the amplitude of the original function $f(t)$.

Note that the amplitude of $g(t)$ can be determined for a given node using only a single pulse of a drive signal, if desired.

The controller may also include circuitry to identify and isolate the amplitude of the response signal. Exemplary circuit devices for this purpose may include one or more
5 peak detectors, sample/hold buffer, and/or low-pass filter, the selection of which may depend on the nature of the drive signal and the corresponding response signal. The controller may also include one or more analog-to-digital converters (ADCs) to convert an analog amplitude to a digital format. One or more multiplexers may also be used to avoid unnecessary duplication of circuit elements. Of course, the controller also preferably
10 includes one or more memory devices in which to store the measured amplitudes and associated parameters, and a microprocessor to perform the necessary calculations and control functions.

By measuring an amplitude of the response signal for each of the nodes in the electrode matrix, the controller can generate a matrix of measured values related to the
15 coupling capacitances for each of the nodes of the electrode matrix. These measured values can be compared to a similar matrix of previously obtained reference values in order to determine which nodes, if any, have experienced a change in coupling capacitance due to the presence of a touch.

Turning now to FIG. 2, we see there a schematic side view of a portion of a touch
20 panel **210** for use in a touch device. The panel **210** includes a front layer **212**, first electrode layer **214** comprising a first set of electrodes, insulating layer **216**, second electrode layer **218** comprising a second set of electrodes **218a-e** preferably orthogonal to the first set of electrodes, and a rear layer **220**. The exposed surface **212a** of layer **212**, or the exposed surface **220a** of layer **220**, may be or comprise the touch surface of the touch
25 panel **210**.

FIG. 3a depicts a touch device **310** in which relevant controller circuitry, such as drive and detection circuitry, is shown in the context of a touch panel **312** having one drive electrode **314** and one receive electrode **316** capacitively coupled thereto via coupling capacitance C_c . The reader will understand that this is a generalization of a touch panel in
30 which drive electrode **314** may be one of a plurality of drive electrodes, and receive electrode **316** likewise may be one of a plurality of receive electrodes, arranged in a matrix on the touch panel.

Indeed, in one specific embodiment of interest capable of use with at least some of the touch measurement techniques described herein, the touch panel may comprise a 40 x 64 (40 rows, 64 columns) matrix device having a 19 inch diagonal rectangular viewing area with a 16:10 aspect ratio. In this case, the electrodes may have a uniform spacing of about 0.25 inches. Due to the size of this embodiment, the electrodes may have significant stray impedances associated therewith, e.g., a resistance of 40K ohms for the row electrodes and 64K ohms for the column electrodes. For good human factors touch response, the response time to measure the coupling capacitance at all 2,560 nodes of the matrix ($40 * 64 = 2560$) may, if desired, be made to be relatively fast, e.g., less than 20 or even less than 10 milliseconds. If the row electrodes are used as the drive electrodes and the column electrodes used as the receive electrodes, and if all of the column electrodes are sampled simultaneously, then the 40 rows of electrodes have, for example, 20 msec (or 10 msec) to be scanned sequentially, for a time budget of 0.5 msec (or 0.25 msec) per row electrode (drive electrode).

The drive electrode **314** and receive electrode **316** of FIG. 3a, which are depicted by their electrical characteristics (in the form of lumped circuit element models) rather than by their physical characteristics, are representative of electrodes that may be found in a touch device having a matrix smaller than 40 x 64, but this is not to be considered limiting. In this representative embodiment of FIG. 3a, the series resistances R shown in the lumped circuit models may each have values of 10K ohms, and the stray capacitances C shown in the lumped circuit models may each have values of 20 picofarads (pf), but of course these values are not to be taken as limiting in any way. In this representative embodiment the coupling capacitance C_c is nominally 2 pf, and the presence of a touch by a user's finger **318** at the node between electrodes **314**, **316** causes the coupling capacitance C_c to drop by about 25%, to a value of about 1.5 pf. Again, these values are not to be taken as limiting.

In accordance with the controller described earlier, the touch device **310** uses specific circuitry to interrogate the panel **312** so as to determine the coupling capacitance C_c at each of the nodes of the panel **312**. In this regard, the reader will understand that the controller may determine the coupling capacitance by determining the value of a parameter that is indicative of, or responsive to, the coupling capacitance, e.g., an amplitude of a response signal as mentioned above and described further below. To

accomplish this task, the device **310** preferably includes: a low impedance drive unit **320** coupled to the drive electrode **314**; a sense unit **322** coupled to the receive electrode **316**, which, in combination with the coupling capacitance, performs a differentiation on the drive signal supplied by the drive unit; and an analog-to-digital converter (ADC) unit **324**

5 that converts an amplitude of the response signal generated by the sense unit **322** into a digital format. Depending on the nature of the drive signal supplied by the drive unit **320** (and hence also on the nature of the response signal generated by the sense unit **322**), the device **310** may also include a peak detection circuit **326a** which in this embodiment also serves as a sample/hold buffer, and an associated reset circuit **326b** operable to reset the
10 peak detector. In most practical applications the device **310** will also include a multiplexer between the signal generator **320** and the touch panel **312**, so as to have the capability of addressing any one of a plurality of drive electrodes at a given time, as well as a multiplexer between the sense unit **322** (or between the optional circuit **326b**) and the ADC unit **324**, to allow a single ADC unit to rapidly sample the amplitudes associated
15 with multiple receive electrodes, thus avoiding the expense of requiring one ADC unit for each receive electrode.

The drive unit **320** preferably is or includes a voltage source with an internal impedance that is preferably low enough to maintain good signal integrity, reduce injected noise, and/or maintain fast signal rise and fall times. The drive unit **320** provides a time-
20 varying drive signal at an output thereof to the drive electrode **314**. The drive signal may consist essentially of a single, isolated pulse, or it may comprise a plurality of such pulses or a train of pulses that form a continuous AC waveform, or waveform packet, such as a sinusoidal wave, a square wave, a triangle wave, and so forth. In this regard, the term “pulse” is used in a broad sense to refer to a distinctive signal variation and is not limited
25 to a rectangular shape of short duration and high amplitude. If rapid detection of touch(es) on the touch panel is desired, the drive signal preferably includes only the smallest number of pulses necessary to obtain a reliable measurement of the coupling capacitance at a given node. This becomes particularly important for touch panels that have large electrode matrices, i.e., a large number of nodes to sense. The peak or maximum amplitude of the
30 drive pulse(s) is preferably relatively high, e.g., from 3 to 20 volts, to provide good signal-to-noise ratios. Though shown in FIG. 3a as driving electrode **314** from only one end, in some embodiments drive unit **320** may be configured to drive electrode **314** from both of

its ends. This may be useful, for example, when electrode **314** has high resistance (thus increased drive signal attenuation and susceptibility to noise contamination), as may exist on large ITO-based matrix-type touch sensors.

The reader should keep in mind that there may be a distinction between the drive
5 signal provided at the output of drive unit **320**, and the drive signal being delivered to a particular drive electrode **314**. The distinction becomes important when, for example, a multiplexer or other switching device is placed between the drive unit **320** and the touch panel **312** in order to selectively couple the drive unit to a plurality of drive electrodes, e.g., one at a time. In such a case, the drive unit **320** may have at its output a continuous
10 AC waveform, such as square wave, triangle wave, or the like, yet by virtue of the switching action of the multiplexer, only one pulse of such a waveform, or only a few pulses, may be delivered to any given drive electrode at a time. For example, one pulse of a continuous AC waveform may be delivered to a first drive electrode, the next pulse of the AC waveform may be delivered to the next drive electrode, and so on until all drive
15 electrodes have been driven, whereupon the next pulse of the AC waveform is delivered again to the first drive electrode and so forth in a repeating cycle.

As will be explained further below in connection with FIGS. 4-6, the shape of the pulses used in the drive signal may have an impact on the choice of
detection/measurement electronics to be used in the device. Examples of useable pulse
20 shapes include rectangle pulses, ramped pulses (whether symmetric or asymmetric), and sine wave (e.g., bell-shaped) pulses.

The drive unit **320** may if desired be programmable to provide different pulses at different times. For example, if the drive unit is coupled to a plurality of drive electrodes through a multiplexer, the drive unit may be programmed to provide different signal levels
25 for different drive electrodes to compensate for electrode-to-electrode variations in line resistance and stray capacitance. For example, a drive electrode disposed at a position that requires a long conduction length through the receive electrode(s) is beneficially driven with a higher amplitude drive signal than a drive electrode disposed at a position that requires a shorter conduction length, so as to compensate for losses associated with the
30 receive electrodes. (For example, referring to the electrode matrix of FIG. 1, if row electrodes **118a-e** are the drive electrodes, then a drive signal on electrode **118a** is coupled through longer lengths of the receive electrodes **116a-e** than a drive signal on electrode

118e due to the placement of the control lines **126** proximate electrode **118e**.) Providing different drive signal levels for different drive electrodes in this way is particularly advantageous for large electrode matrices, because rather than programming a large number of detection circuits (corresponding to the number of receive electrodes) for losses in the touch screen, only one drive signal is adjusted by a selected amount, with drive signals delivered to different drive electrodes being adjusted by differing amounts as appropriate.

The drive signal provided to the drive electrode **314** is capacitively coupled to receive electrode **316** via the coupling capacitance C_c , the receive electrode in turn being connected to sense unit **322**. The sense unit **322** thus receives at an input thereof **322a** the drive signal (as transmitted by the electrodes **314**, **316** and coupling capacitance C_c), and generates therefrom a response signal at an output **322b**. Preferably, the sense unit is designed so that the response signal includes a differentiated representation of the drive signal, an amplitude of which is responsive to the coupling capacitance C_c . That is, the response signal generated by the sense unit preferably includes in some form at least an approximation of the derivative with respect to time of the drive signal. For example, the response signal may include the time derivative of the drive signal, or a version of such signal that is inverted, amplified (including amplification less than 1), offset in voltage or amplitude, and/or offset in time, for example. To repeat from the earlier discussion, if the drive signal delivered to the drive electrode is represented by a function $f(t)$, then the response signal may be or comprise, at least approximately, a function $g(t)$, where $g(t) = df(t)/dt$.

An exemplary circuit to perform such function is shown in FIG. 3a. The input to such circuit, shown at **322a**, is the inverting input (-) of an operational amplifier **322c**. The other input of the op amp, a non-inverting input (+), is set to a common reference level that can be optimized for maximum signal range. In FIG. 3, this reference level is shown as ground potential for simplicity, but non-zero offset voltages can also be used. A feedback resistor **322d** is connected between the output of the op amp at **322b** and the inverting input. When connected in this way, the inverting input of the op amp **322c**, i.e., the input **322a**, is maintained as a virtual ground summing point, and no signal is observed at that point. This also means that the receive electrode **316** is maintained at a constant voltage substantially equal to the voltage at which the non-inverting input of the op amp is

held. The feedback resistor **322d** can be selected to maximize signal level while keeping signal distortion low, and can be otherwise set or adjusted as described herein.

The op amp **322c** connected in this fashion, in combination with the coupling capacitance C_c , has the effect of producing a differentiated representation of the drive signal that is delivered to drive electrode **314**. In particular, the current I flowing through the feedback resistor **322d** at any given time is given by:

$$I \approx C_c * dV/dt,$$

where C_c is the coupling capacitance, V represents the time-varying drive signal delivered to the drive electrode, and dV/dt is the derivative with respect to time of V . Although this equation is nominally correct, the reader will understand that it does not take into account various second order effects caused by, for example, parasitic resistance and capacitance of the electrodes being used, op amp characteristics and limitations, and the like, which can affect both the magnitude and the dynamic response of the current I . Nevertheless, the current I , flowing through the feedback resistor, produces a voltage signal at the output **322b** which corresponds to the response signal discussed above. Due to the direction of current flow through the feedback resistor, this response signal is inverted insofar as a positive dV/dt (V increases with time) produces a negative voltage at output **322b**, and a negative dV/dt (V decreases with time) produces a positive voltage at output **322b**, with specific examples given below in connection with FIGS. 4-6. This can be expressed as:

$$V_{RS} \approx -R_f * C_c * dV/dt,$$

where V_{RS} represents the response signal voltage at the output **322b** at any given time, and R_f is the resistance of feedback resistor **322d**. Note that the amplitude (voltage) of the response signal is nominally proportional to the coupling capacitance C_c . Thus, since a touch at the node of the electrodes **314**, **318** reduces the coupling capacitance C_c , a measure of the peak amplitude or other characteristic amplitude of the response signal provided by sense unit **322** can be analyzed to determine the presence of a touch at that node.

In embodiments in which receive electrode **316** is one of a plurality of receive electrodes, it may be desirable to include a dedicated sense unit **322** for each receive electrode. Further, it may be advantageous to provide different amounts of amplification (e.g., different feedback resistor values for the different op amps) for the different sense units to compensate for signal losses in the touch screen that are different for different

drive electrodes. For example, a receive electrode disposed at a position that requires a long conduction length through the drive electrode(s) is beneficially provided with a greater amplification than a receive electrode disposed at a position that requires a shorter conduction length, so as to compensate for losses associated with the drive electrodes.

- 5 (For example, referring to the electrode matrix of FIG. 1, if row electrodes **116a-e** are the receive electrodes, then a signal received from electrode **116a** is coupled through longer lengths of the drive electrodes **118a-e** than a signal received from electrode **116e** due to the placement of the control lines **128** proximate electrode **116e**.) Providing different amounts of amplification for different receive electrodes in this way is particularly
- 10 advantageous for large electrode matrices, because it can reduce the need to program a large number of detection circuits (corresponding to the number of receive electrodes) for losses in the touch screen.

- As mentioned above, device **310** may also include peak detection circuit **326a** which in this embodiment also serves as a sample/hold buffer, and an associated reset
- 15 circuit **326b** operable to reset the peak detector. These circuit elements can be used in cases where the peak amplitude of the response signal generated by the sense unit **322** is to be used as a measure of the coupling capacitance C_c . Such cases can include embodiments in which the response signal provided by the sense unit **322** is highly transient, e.g., in cases where one or more rectangle pulses are used for the drive signal
- 20 (see e.g. FIG. 4a below). In such cases, the peak detector **326a** operates to maintain the peak amplitude of the response signal for a relatively long time to allow reliable sampling and conversion to a digital value by the ADC **324**. In embodiments having a plurality of receive electrodes, a single ADC may be cyclically coupled to the detection circuitry of each receive electrode, requiring each detection circuit to maintain the measurement
- 25 voltage for an extended period of time. After the measurement is made by the ADC **324**, the peak detector can be reset by operation of reset circuit **326b** so that a new peak value can be measured in a subsequent cycle.

- The basic operation of the diode/capacitor combination depicted for peak detector **326a**, including its ability to maintain the peak voltage for an extended period without
- 30 discharging the capacitor through the sense unit **322**, will be apparent to the person of ordinary skill in the art, with no further explanation being necessary. Likewise, the basic operation of the reset circuit **326b**, responding to a suitable reset control signal provided at

contact **326c**, will be apparent to the person of ordinary skill in the art. Note that other known electronic devices capable of carrying out one or more functions of the described sense unit, peak detector, sample/hold buffer, and/or reset circuit, whether in hardware, software, or combinations thereof, are fully contemplated herein.

5 As mentioned previously, the ADC **324** is preferably provided to convert the amplitude value associated with the response signal to a digital format for use with digital components such as a microprocessor for further processing. The ADC may be of any suitable design, e.g., it may comprise a high speed successive approximation register (SAR) and/or a sigma-delta type converter.

10 With regard to further processing of the measured amplitude value of a given node, the measured amplitude value can be stored in a memory register. If desired, multiple such values associated with the given node may be stored and averaged, e.g. for noise reduction purposes. Furthermore, the measured amplitude value is preferably compared to a reference value in order to determine if a reduction of the coupling capacitance has
15 occurred, i.e., if some amount of touch is present at the given node. Such comparison may involve subtraction of the measured value from the reference value, for example. In embodiments involving a large touch matrix containing many nodes, the measured values for all of the nodes can be stored in memory, and individually compared to respective reference values in order to determine if some amount of touch is present at each node.
20 By analyzing the comparison data, the positions of multiple temporally overlapping touches, if present on the touch surface, can be determined. The number of temporally overlapping touches capable of being detected may be limited only by the dimensions of the electrode grid in the touch panel and the speed of the drive/detection circuitry. In exemplary embodiments, interpolation is performed for differences detected for
25 neighboring nodes so as to accurately determine a touch location lying between nodes.

 FIG. 3b depicts touch device **348** which is similar to touch device **310** shown in FIG. 3a, except that it includes voltage source **349** as an input to the differentiating amplifier that is part of sense unit **322**. This voltage input may be configured as needed to bring circuit output into a sensing range for the ADC. For example, some ADCs have
30 sensing ranges from 0.5V to +3V. The peak of the sense unit **322** output signal should be within this range to digitize the voltage accurately. Voltage source **349** (or gain, in the context of sense unit **322**) can be fixed at one voltage for all receiver electrodes, or it can

be adjusted for particular receive electrodes. In some embodiments, differing voltages are provided to sense units in groups of 4-10 receive electrodes using a resistor ladder network. In some embodiments, gain is set to compensate for signal drop off due to resistance on the driven electrodes.

5 FIG. 3c depicts touch device **350** which is similar to touch device **310** shown in FIG. 3a, but containing additional circuitry that in some embodiments may better accommodate noise from displays such as LCD displays. LCD addressing frequencies are generally near or overlapping the frequencies used by controller **114** to interface with touch panel **112**. This results in noise on the receiver electrodes which may show up as a
10 common mode signal. A differential amplifier may be used to eliminate this common mode signal. The circuit shown in FIG. 3c adds a differential amplifier **352** and additional peak detection circuit **351** (configured to detect peaks of negative voltage), and an additional reset circuit **353**.

Turning now to FIG. 4a, we see there a voltage vs. time graph of a particular drive
15 signal **410** and a corresponding voltage vs. time graph of a (modeled) response signal **412** generated by a sense unit of the type depicted in FIG. 3a. For purposes of the model, the electronic characteristics of the drive electrode, receive electrode, and coupling capacitance (including the effect of a touch thereon, i.e., decreasing the capacitance from 2.0 pf to 1.5 pf) were assumed to be as described above in connection with the
20 representative embodiment of FIG. 3a. Furthermore, the feedback resistor **322d** for the op amp **322c** was assumed to be on the order of 2M ohms.

The drive signal **410** is seen to be a square wave, containing a series of rectangle pulses **411a**, **411c**, **411e**, ... **411k**. This entire signal was assumed to be delivered to a particular drive electrode, although in many embodiments a smaller number of pulses, e.g.
25 only one or two, may be delivered to a given drive electrode at a given time, after which one or more pulses may be delivered to a different drive electrode, and so on. The response signal **412** generated by the sense unit is seen to comprise a plurality of impulse pulses **413a-l**, two for each rectangle pulse **411a**, as one would expect for a differentiated square wave. Thus, for example, the drive pulse **411a** yields a negative-going impulse
30 pulse **413a** associated with the positive-going transition (left side) of the rectangle pulse, and a positive-going impulse pulse **413b** associated with the negative-going transition (right side) of the rectangle pulse. The impulse pulses are rounded as a result of the op

amp signal bandwidth and the RC filter effects of the touch screen. Despite these deviations from an ideal derivative with respect to time of signal **410**, the response signal **412** can be considered to comprise a differentiated representation of the drive signal.

As shown, the drive pulses **411a**, **411c**, **411e**, ... **411k**, all have the same amplitude, although pulses of differing amplitude can also be delivered as explained above. However, despite the common amplitude of the drive pulses, the impulse pulses **413a-g** occurring in the time period **412a** are seen to have a first peak amplitude, and impulse pulses **413h-l** occurring in the time period **412b** are seen to have a second peak amplitude less than the first peak amplitude. This is because the model introduced a change in coupling capacitance C_c at a point in time after impulse pulse **413g** and before impulse pulse **413h**, the change corresponding to a transition from a non-touch condition ($C_c = 2$ pf) to a touch condition ($C_c = 1.5$ pf). The reduced peak amplitude of the impulse pulses during time period **412b** can be readily measured and associated with a touch event at the applicable node.

The transient nature of the impulse pulses **413a-l** make them particularly suited for use with a peak detector and sample/hold buffer as described in connection with FIG. 3, so that an accurate measurement of the peak amplitude can be obtained and sampled by the ADC.

FIG. 4b depicts graphs showing representative waveforms from an embodiment that includes sequential driving of driven electrodes. Waveforms **430**, **431**, and **432** are representative of pulsed signals during a period of time, t , on three separate (possibly adjacent one another) driven electrodes (a first, second, and third row on a matrix-type sensor, for example). Waveforms **433**, **434**, and **435** are representative of differentiated output resulting from the pulsed signals on three separate receive electrodes (columns on a matrix-type sensor, for example) during the same time period. Note that each receive electrode (column) has a similar response profile. The driven electrodes corresponding to waveforms **432**, **431**, and **431** are driven sequentially. After each an electrode is driven (represented by any individual ones of waveforms **430**, **431**, or **432**), a voltage representative of peak amplitude will be available in the peak detect circuit associated with each receive electrode (column) as described above in connection with FIG. 3. Thus, after each driven electrode is driven (row), the resultant voltage on the peak detect circuit for all receive electrodes (columns) is sampled, then the associated peak detect circuit reset, then

the next sequential driven electrode is driven (and so on). In this way, each node in the matrix-type capacitive touch sensor can be individually addressed and sampled.

FIG. 5a depicts a pair of graphs similar to those of FIG. 4a, and for the same electronic configuration of drive electrode, receive electrode, coupling capacitance, and sense unit, but for a different drive signal shape. The drive signal **510** of FIG. 5a includes ramped pulses **511a**, **511c**, **511e**, ... **511i**, so that the resultant response signal **512** includes rectangle pulses **513a-j**. The rectangle pulses predicted by the model exhibited near-vertical hi/lo transitions with slightly rounded corners, which have been redrawn as vertical lines and sharp corners for simplicity. The rise and fall times of the rectangle pulses are limited by the RC transmission line in the drive and receive electrodes being used. The drive pulses **511a**, etc. are characterized by a symmetrical ramp shape, with the first half of each pulse having a positive-going slope and the second half having a negative-going slope of the same magnitude. This symmetry is also then carried over to the response signal **512**, where negative-going pulses **513a**, **513c**, and so forth are substantially balanced by positive-going pulses **513b**, **513d**, and so on. Similar to the description of FIG. 4a, the model introduces a change in coupling capacitance C_c at a point in time after rectangle pulse **513e** and before rectangle pulse **513f**, i.e., in the transition from time period **512a** to time period **512b**, the change corresponding to a transition from a non-touch condition ($C_c = 2$ pf) to a touch condition ($C_c = 1.5$ pf). The reduced amplitude of the response signal pulses occurring during time period **512b** can be readily measured and associated with a touch event at the applicable node. A feature of FIG. 5a worth noting is the relatively steady-state characteristic (over the time scale of given pulse) of the response signal **512** at each plateau of each pulse **513a-j**, where the “plateau” of a negative-going pulse **513a**, **513c**, and so on is understood to be the “bottom” of the pulse shape rather than the “top” as with pulses **513b**, **d**, and so forth. This steady-state characteristic is a consequence of the drive pulses having a constant slope over a substantial portion of the drive pulses, i.e., a ramped shape. In some embodiments, the touch device designer may wish to take advantage of this steady-state characteristic so as to eliminate unnecessary circuit items and reduce cost. In particular, since the response signal itself maintains a substantially constant amplitude (the plateau of a pulse) over the time scale of the pulse, and since this constant amplitude is indicative of or responsive to the coupling capacitance C_c , the peak detector, sample/hold buffer, and

reset circuit described in connection with FIG. 3a may no longer be necessary and may be eliminated from the system, provided the time scale of the steady-state characteristic is long enough for the ADC to sample and measure the amplitude. If desired, for noise-reduction, the response signal generated by the sense unit in such cases can be sent
5 through a low-pass filter whose cutoff frequency is selected to substantially maintain the same overall fidelity or shape as the unfiltered pulses while filtering out higher frequency noise. The output of such a filter, i.e., the filtered response signal, may then be supplied to the ADC. Of course, in some cases it may be desirable to keep the peak detector, sample/hold buffer, and reset circuit, whether or not the low-pass filter is utilized, for
10 ramp-type drive pulses.

If desired, a rectifying circuit can be used in touch device embodiments that produce positive- and negative-going pulses in the response signal, see e.g. signal **412** of FIG. 4a and signal **512** of FIG. 5a. The rectification of these signals may have corresponding benefits for other circuit functions, such as peak detection and analog-to-
15 digital conversion. In the case of signal **512** of FIG. 5a, a rectified version of that signal advantageously maintains a steady-state voltage level substantially continuously (ignoring transient effects due to op amp limitations and RC transmission line effects) as a result of the symmetry of the respective signals.

FIG. 5b depicts pairs of graphs showing representative waveforms from
20 embodiments that include sequential driving of driven electrodes, similar to FIG. 4b, except using a different type of driven waveform. Waveforms **760**, **761**, and **762** are representative driven triangle pulse signals during a time period, t , on three separate (possibly adjacent one another) driven electrodes (a first, second, and third row on a matrix-type sensor, for example). Waveforms **763**, **764**, and **765** are respective resultant
25 waveforms as would be seen on receive electrodes (for example, columns) during the same time period.

Turning now to FIG. 6a, the pair of graphs there are similar to those of FIGS. 5a and 4a, and assume the same electronic configuration of drive electrode, receive electrode, coupling capacitance, and sense unit, but a yet another drive signal shape is used. The
30 drive signal **610** of FIG. 6b includes ramped pulses **611a-e**, which yield the resultant response signal **612** having substantially rectangle pulses **613a-e**. Unlike the symmetrical ramp shapes of FIG. 5a, ramped pulses **611a-e** are asymmetrical so as to maximize the

fraction of the pulse time used by the ramp. This ramp maximization, however, results in a rapid low-to-high transition on one side of each drive pulse, which produces a negative-going impulse pulse bounding each rectangle pulse of the response signal **612**. In spite of the resulting deviations from perfect rectangularity, the pulses **613a-e** are nevertheless

5 substantially rectangular, insofar as they maintain a relatively constant amplitude plateau between two relatively steep high-to-low transitions. As such, and in a fashion analogous to signal **512** of FIG. 5a, the pulses of signal **612** include a steady-state characteristic as a consequence of the drive pulses having a constant slope over a substantial portion of the drive pulses, i.e., a ramped shape. The touch device designer may thus again wish to take

10 advantage of this steady-state characteristic by eliminating the peak detector, sample/hold buffer, and reset circuit, provided the time scale of the steady-state characteristic is long enough for the ADC to sample and measure the amplitude. A low-pass filter may also be added to the circuit design as described above.

FIG. 6b depicts a pair of graphs showing representative waveforms from

15 embodiments that include sequential driving of driven electrodes, similar to FIG. 4b and FIG. 5b, except using a different type of driven waveform. Waveforms **750**, **751**, and **752** are representative driven ramped pulse signals during a time period, t , on three separate (possibly adjacent one another) driven electrodes (a first, second, and third row on a matrix-type sensor, for example). Waveforms **753**, **754**, and **755** (FIG. 7b) and **763**, **764**,

20 and **765** (FIG. 7c) are respective resultant waveforms as would be seen on receive electrodes (for example, columns) during the same time period.

Turning now to FIG. 7, we see there a voltage vs. time graph of a pulsed drive signal **807** and a corresponding voltage vs. time graph of a (modeled) first response signal **801** and second response signal **802** as would be output generated by sense unit **322** and

25 differential amplifier **352**, respectively, of the circuit depicted in FIG. 3c. For purposes of the model, the electronic characteristics of the drive electrode, receive electrode, and coupling capacitance (including the effect of a touch thereon, i.e., decreasing the capacitance from 2.0 pf to 1.5 pf) were assumed to be as described above in connection with the representative embodiment of FIG. 3a.

30 First response signal **801** is the modeled output from sense unit **322**. It includes a sinusoidal form indicative of a common mode signal similar to that which might be received as noise from an LCD panel. Response signal **802** is the respective modeled

output from differential amplifier **352** (shown for the purposes of illustration as a short-dashed line; the actual output would be a solid line). The output from differential amplifier **352** is in effect the sum of the pulses (shown not to scale for illustrative purposes). The individual pulses on FIG. 7 (**803a...d, 804e, f, g**) have the same profile as pulses **413a...k** in FIG. 4a, but they appear differently in FIG. 7 due to scaling. The first negative pulse (**803a**) is peak detected and summed on the inverting input of the amplifier giving the first step on response signal **802** (step **805a**). The positive pulse (**804e**) is then peak detected and summed on the non-inverting input on the amplifier, giving the sum of both the positive and negative peaks at the output (step **805b**). Neither succeeding pulses nor the common mode signal substantially effect the voltage level of response signal **802** after step **805b**. A touch may be sensed by measuring a first voltage sample represented by waveform **802** after a series of pulses (that is, after the voltage has reached a plateau defined by step **805b**), resetting peak detectors using reset circuits **353** and **326b** (FIG. 3c), and then measuring a second voltage sample using the same or a similar process, and so forth. In certain embodiments, changes to these sample voltages, relative to some threshold, are indicative of a touch.

FIG. 8 is a schematic view of a touch device **710** that includes a touch panel **712** having a 4x8 matrix of capacitively coupled electrodes, and various circuit components that can be used to detect multiple simultaneous touches on the touch panel. The electrode matrix includes a top electrode array comprising parallel drive electrodes **a, b, c, and d**. Also included is a lower array comprising parallel receive electrodes **E1, E2, E3, E4, E5, E6, E7, and E8**. The top electrode array and the lower electrode array are arranged to be orthogonal to one another. The capacitive coupling between each pair of orthogonal electrodes, referred to above for a given node as the coupling capacitance C_c , is labeled for the various nodes of the matrix as **C1a, C2a, C3a, C4a, C1b, C2b, and C3b**, etc., through **C8d** as shown, the values of which may all be approximately equal in an untouched state but which decrease when a touch is applied as described previously. Also depicted in the figure is the capacitance between the various receive electrodes and ground (**C1-C8**) and between the various drive electrodes and ground (**a' through d'**).

The 32 nodes of this matrix, i.e., the mutual capacitances or coupling capacitances associated therewith, are monitored by circuitry as described with respect to FIG. 3a: drive unit **714**; multiplexer **716**; sense units **S1-S8**; optional peak detectors **P1-P8**, which

may also function as sample/hold buffers; multiplexer **718**; as well as ADC **720**; and controller **722**, all connected as shown with suitable conductive traces or wires (except that connections between controller **722** and each of the peak detectors **P1-P7** are omitted from the drawing for ease of illustration).

5 In operation, controller **722** causes drive unit **714** to generate a drive signal comprising one or more drive pulses, which are delivered to drive electrode **a** by operation of multiplexer **716**. The drive signal couples to each of receive electrodes **E1-E8** via their respective mutual capacitances with drive electrode **a**. The coupled signal causes the sense units **S1-S8** to simultaneously, or substantially simultaneously, generate response
10 signals for each of the receive electrodes. Thus, at this point in time in the operation of device **710**, the drive signal being delivered to drive electrode **a** (which may include, for example, a maximum of 5, 4, 3, or 2 drive pulses, or may have only one drive pulse) is causing sense unit **S1** to generate a response signal whose amplitude is indicative of coupling capacitance **C1a** for the node **E1/a**, and sense unit **S2** to generate a response
15 signal whose amplitude is indicative of coupling capacitance **C2a** for the node **E2/a**, etc., and so on for the other sense units **S3-S8** corresponding to nodes **E3/a** through **E8/a**, all at the same time. If the response signals are of a highly transient nature, e.g. as with signal **412** of FIG. 4a, then peak detectors **P1-P8** may be provided to detect the peak amplitudes of the respective response signals provided by sense units **S1-S8**, and optionally to sample
20 and hold those amplitudes at the outputs thereof which are provided to the multiplexer **718**. Alternatively, if the response signals have a significant steady-state characteristic, e.g. if they are in the form of one or more rectangle pulses as with signals **512** and **612** described above, then the peak detectors may be replaced with low-pass filters, or the peak detectors may simply be omitted so that the outputs of the sense units feed directly into the
25 multiplexer **718**. In either case, while the characteristic amplitude signals (e.g. peak amplitude or average amplitude of the response signals) are being delivered to the multiplexer **718**, the controller **722** rapidly cycles the multiplexer **718** so that the ADC **720** first couples to peak detector **P1** (if present, or to a low-pass filter, or to **S1**, for example) to measure the characteristic amplitude associated with node **E1/a**, then couples to peak
30 detector **P2** to measure the characteristic amplitude associated with node **E2/a**, and so forth, lastly coupling to peak detector **P8** to measure the characteristic amplitude associated with node **E8/a**. As these characteristic amplitudes are measured, the values

are stored in the controller **722**. If the peak detectors include sample/hold buffers, the controller resets them after the measurements are made.

In the next phase of operation, the controller **722** cycles the multiplexer **714** to couple the drive unit **714** to drive electrode **b**, and causes the drive unit to generate another
5 drive signal that again comprises one or more drive pulses, now delivered to electrode **b**. The drive signal delivered to electrode **b** may be the same or different from that delivered previously to electrode **a**. For example, for reasons relating to touch panel losses explained above, the drive signal delivered to electrode **b** may have a smaller amplitude than that delivered to electrode **a**, due to electrode **b**'s closer proximity to the ends of
10 sense electrodes **E1-E8** from which the response signals are derived (and thus lower losses). In any case, the drive signal delivered to electrode **b** causes sense unit **S1** to generate a response signal whose amplitude is indicative of coupling capacitance **C1b** for the node **E1/b**, and sense unit **S2** to generate a response signal whose amplitude is indicative of coupling capacitance **C2b** for the node **E2/b**, etc., and so on for the other
15 sense units **S3-S8** corresponding to nodes **E3/b** through **E8/b**, all at the same time. The presence or absence of peak detectors **P1-P8**, or of sample/hold buffers, or of low-pass filters discussed above in connection with the first phase of operation is equally applicable here. In any case, while the characteristic amplitude signals (e.g. peak amplitude or average amplitude of the response signals) are being delivered to the multiplexer **718**, the
20 controller **722** rapidly cycles the multiplexer **718** so that the ADC **720** first couples to peak detector **P1** (if present, or to a low-pass filter, or to **S1**, for example) to measure the characteristic amplitude associated with node **E1/b**, then couples to peak detector **P2** to measure the characteristic amplitude associated with node **E2/b**, and so forth, lastly coupling to peak detector **P8** to measure the characteristic amplitude associated with node
25 **E8/b**. As these characteristic amplitudes are measured, the values are stored in the controller **722**. If the peak detectors include sample/hold buffers, the controller resets them after the measurements are made.

Two more phases of operation then follow in similar fashion, wherein a drive signal is delivered to electrode **c** and the characteristic amplitudes associated with nodes
30 **E1/c** through **E8/c**, are measured and stored, and then a drive signal is delivered to electrode **d** and the characteristic amplitudes associated with nodes **E1/d** through **E8/d**, are measured and stored.

At this point, characteristic amplitudes of all of the nodes of the touch matrix have been measured and stored within a very short timeframe, e.g., in some cases less than 20 msec or less than 10 msec, for example. The controller 722 may then compare these amplitudes with reference amplitudes for each of the nodes to obtain comparison values (e.g., difference values) for each node. If the reference amplitudes are representative of a non-touch condition, then a difference value of zero for a given node is indicative of “no touch” occurring at such node. On the other hand, a significant difference value is representative of a touch (which may include a partial touch) at the node. The controller 722 may employ interpolation techniques in the event that neighboring nodes exhibit significant difference values, as mentioned above.

Unless otherwise indicated, all numbers expressing quantities, measurement of properties, and so forth used in the specification and claims are to be understood as being modified by the term “about”. Accordingly, unless indicated to the contrary, the numerical parameters set forth in the specification and claims are approximations that can vary depending on the desired properties sought to be obtained by those skilled in the art utilizing the teachings of the present application. Not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the invention are approximations, to the extent any numerical values are set forth in specific examples described herein, they are reported as precisely as reasonably possible. Any numerical value, however, may well contain errors associated with testing or measurement limitations.

Various modifications and alterations of this invention will be apparent to those skilled in the art without departing from the spirit and scope of this invention, and it should be understood that this invention is not limited to the illustrative embodiments set forth herein. For example, the reader should assume that features of one disclosed embodiment can also be applied to all other disclosed embodiments unless otherwise indicated. It should also be understood that all U.S. patents, patent application publications, and other patent and non-patent documents referred to herein are incorporated by reference, to the extent they do not contradict the foregoing disclosure.

CLAIMS

1. A touch-sensitive apparatus, comprising:

5 a panel comprising a touch surface and a plurality of electrodes defining an electrode matrix, the plurality of electrodes comprising a plurality of drive electrodes and a plurality of receive electrodes, each drive electrode being capacitively coupled to each receive electrode at a respective node of the matrix, the panel being configured such that a touch on the touch surface
10 proximate a given one of the nodes changes a coupling capacitance between the drive electrode and the receive electrode associated with the given node;
a drive unit configured to generate a drive signal and to deliver the drive signal to the drive electrodes one at a time;
a sense unit configured to generate, for each drive signal delivered to each drive
15 electrode, response signals for the plurality of receive electrodes, each of the response signals comprising a differentiated representation of the drive signal, an amplitude of each of the response signals being responsive to the coupling capacitance at the associated node; and
a measurement unit configured to measure the amplitude of each of the response
20 signals for each of the nodes, and to determine therefrom the positions of multiple temporally overlapping touches, if present, on the touch surface.

2. The apparatus of claim 1, wherein the drive unit includes a drive signal generator and a multiplexer, the drive signal generator being selectively couplable to a given one of the
25 drive electrodes through the multiplexer.

3. The apparatus of claim 1, wherein the sense unit includes, for each of the receive electrodes, an operational amplifier having an inverting input coupled to the respective receive electrode.

30 4. The apparatus of claim 1, wherein the sense unit is further configured to maintain the receive electrodes at a fixed voltage.

5. The apparatus of claim 1, wherein the drive signal comprises a rectangle pulse.

6. The apparatus of claim 1, wherein the sense unit includes, for each of the receive
5 electrodes, a peak detector configured to provide a peak detector output representative of a maximum amplitude of the respective response signal.

7. The apparatus of claim 6, wherein each peak detector comprises a sample/hold buffer.

10 8. The apparatus of claim 6, wherein each peak detector comprises a diode coupled to a capacitor.

9. The apparatus of claim 8, wherein the sense unit includes, for each of the receive
15 electrodes, a reset switch coupled to the respective capacitor and configured to discharge the respective capacitor in response to a reset signal.

10. The apparatus of claim 1, wherein the measurement unit comprises an analog-to-digital converter (ADC) and a multiplexer, the ADC coupling to the sense unit through the multiplexer.

20 11. The apparatus of claim 1, wherein the drive signal comprises a plurality of sequential pulses and each response signal comprises a corresponding plurality of response pulses, and wherein the measurement unit is configured to measure for each response signal an amplitude representative of amplitudes of the plurality of response pulses.

25 12. The apparatus of claim 11, wherein the measurement unit is configured to measure for each response signal a maximum one of the amplitudes of the plurality of response pulses.

13. The apparatus of claim 1, wherein the drive signal comprises a ramped pulse.

30 14. The apparatus of claim 13, wherein each response signal comprises a rectangle pulse.

15. The apparatus of claim 14, wherein the measurement unit comprises a low pass filter to smooth a plateau of the rectangle pulse.

16. The apparatus of claim 14, wherein the measurement unit comprises an analog-to-digital converter (ADC) and is adapted to couple each response signal to the ADC without passing the response signals through any peak detector.

17. The apparatus of claim 1, wherein the drive unit is configured to deliver a first drive signal to a first drive electrode and a second drive signal to a second drive electrode, and wherein the first drive signal has a signal amplitude that differs from that of the second drive signal.

18. The apparatus of claim 1, wherein the sense unit includes a first sense unit coupled to a first receive electrode and a second sense unit coupled to a second receive electrode, and wherein the first sense unit has an amplification associated therewith that differs from an amplification associated with the second sense unit.

19. The apparatus of claim 1, wherein the measurement unit additionally includes a differential amplifier configured to reduce or eliminate common mode noise.

20. A touch-sensitive apparatus, comprising:

a panel comprising a touch surface and a plurality of electrodes defining an electrode matrix, the electrode matrix being configured such that a touch on the touch surface proximate a given node of the matrix changes a coupling

capacitance between two of the electrodes;

a drive unit coupled to the electrode matrix and configured to generate a drive signal comprising one or more ramped pulses;

a sense unit coupled to the electrode matrix and configured to generate, in response to the drive signal, at least one response signal that includes one or more rectangle pulses, an amplitude of the at least one response signal being responsive to a touch on the touch surface.

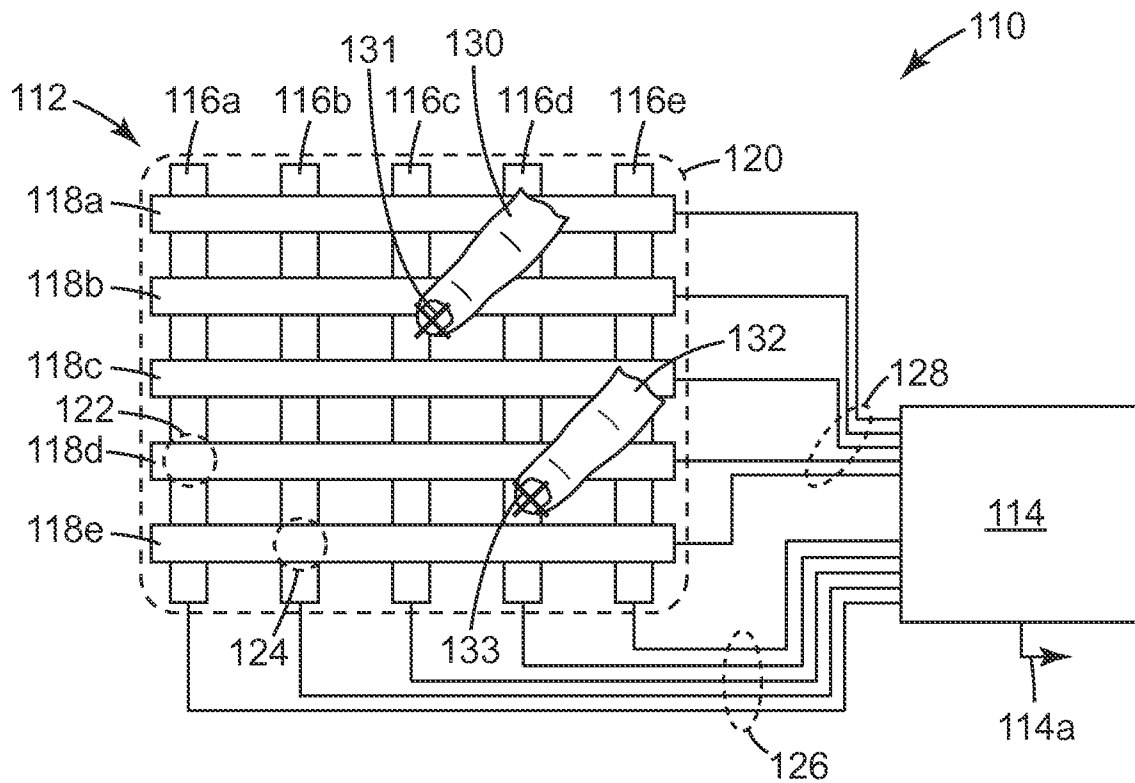


Fig. 1

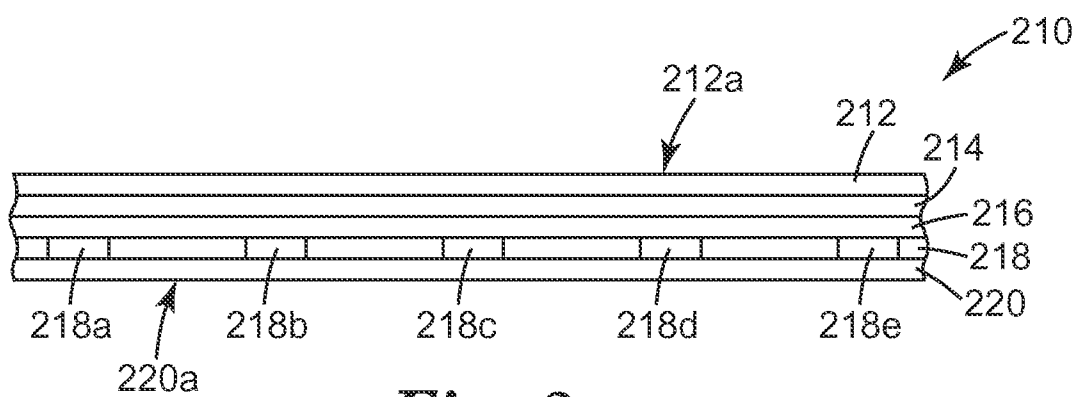


Fig. 2

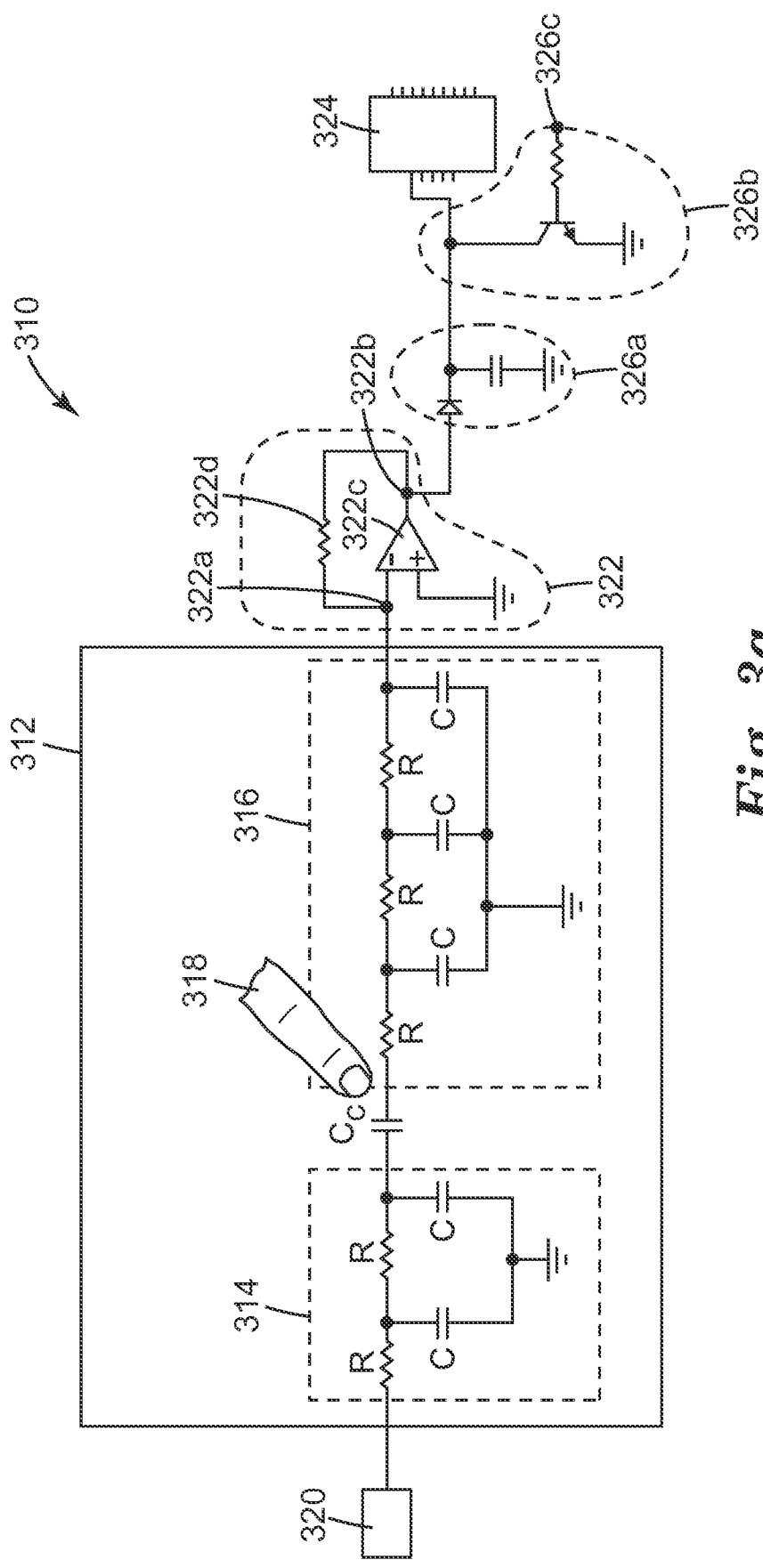


Fig. 3a

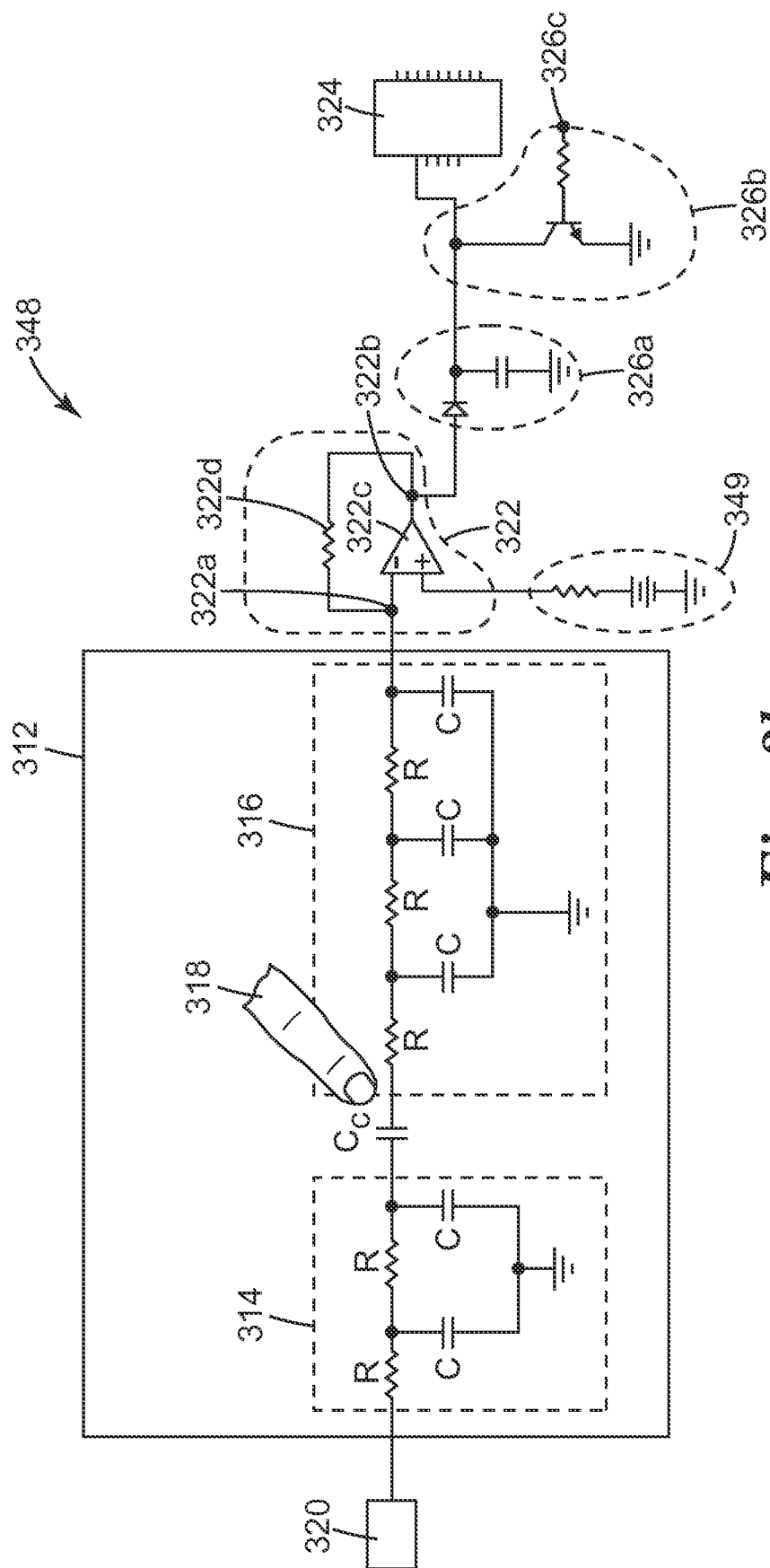


Fig. 3b

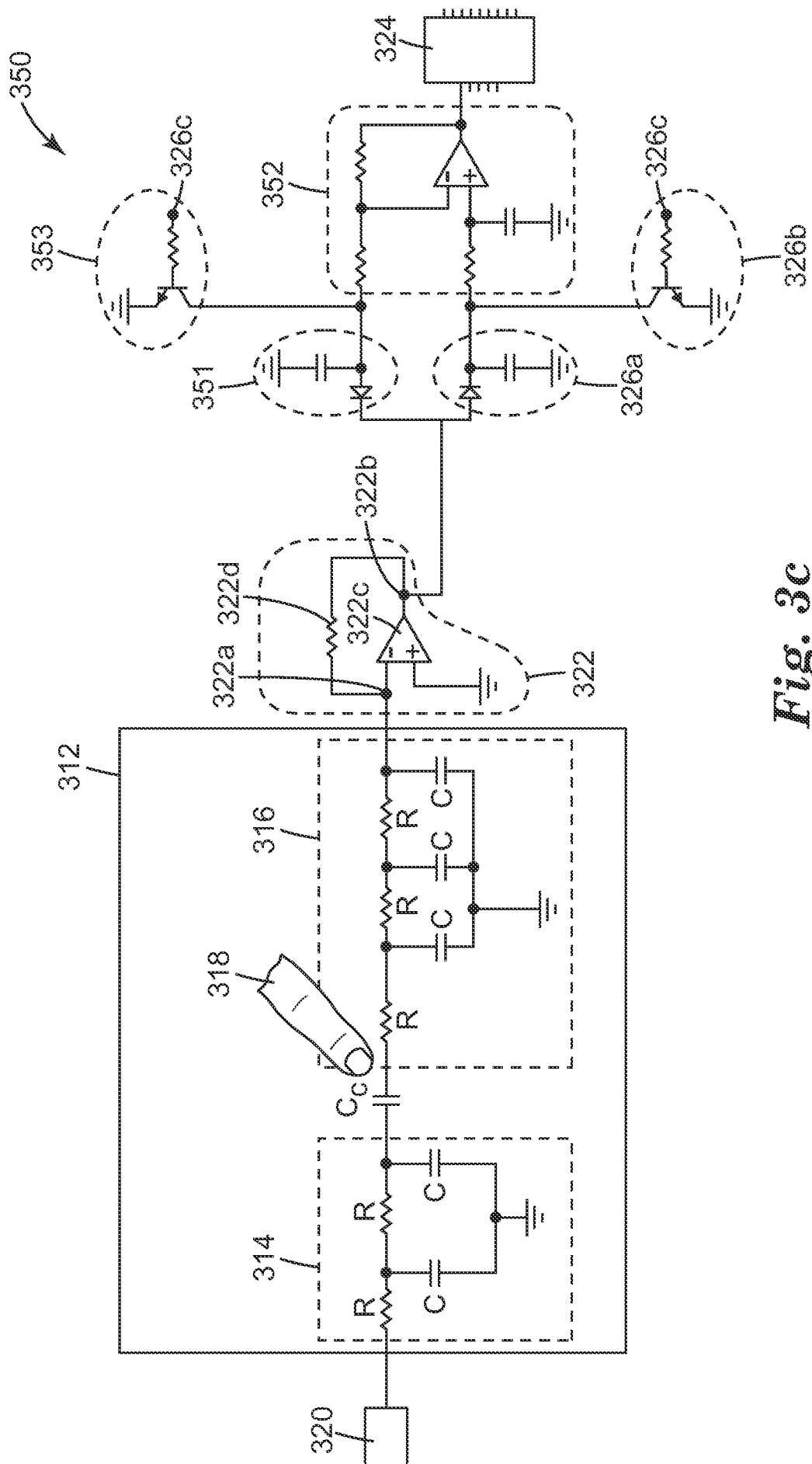
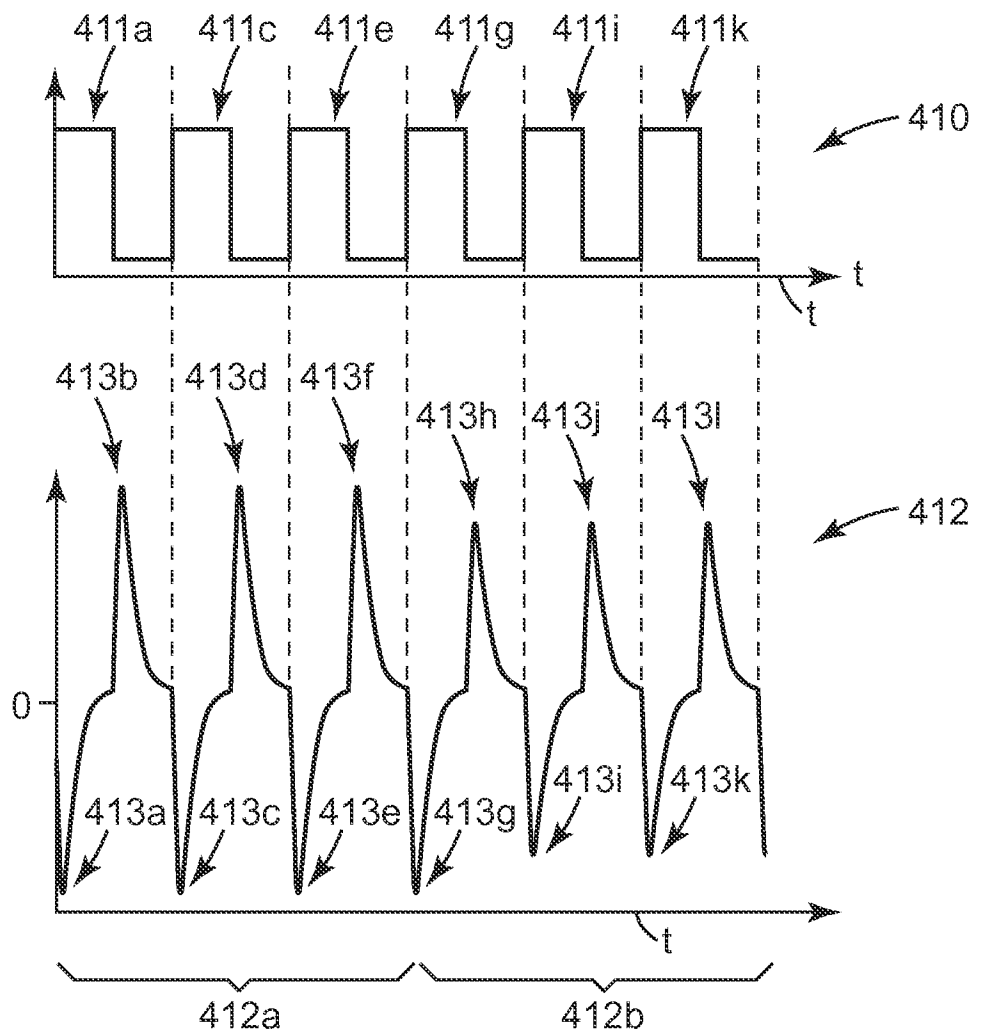


Fig. 3c

*Fig. 4a*

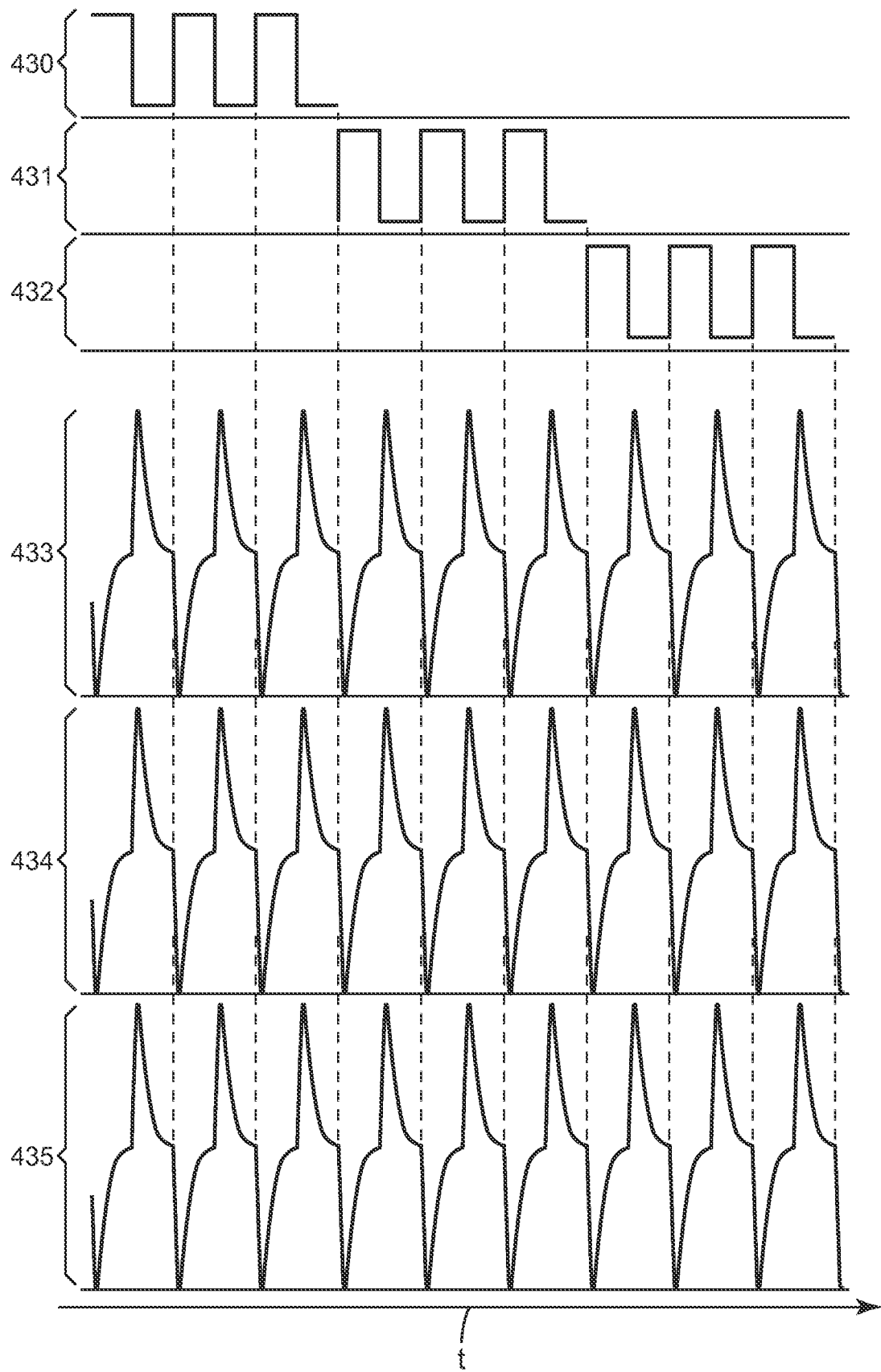


Fig. 4b

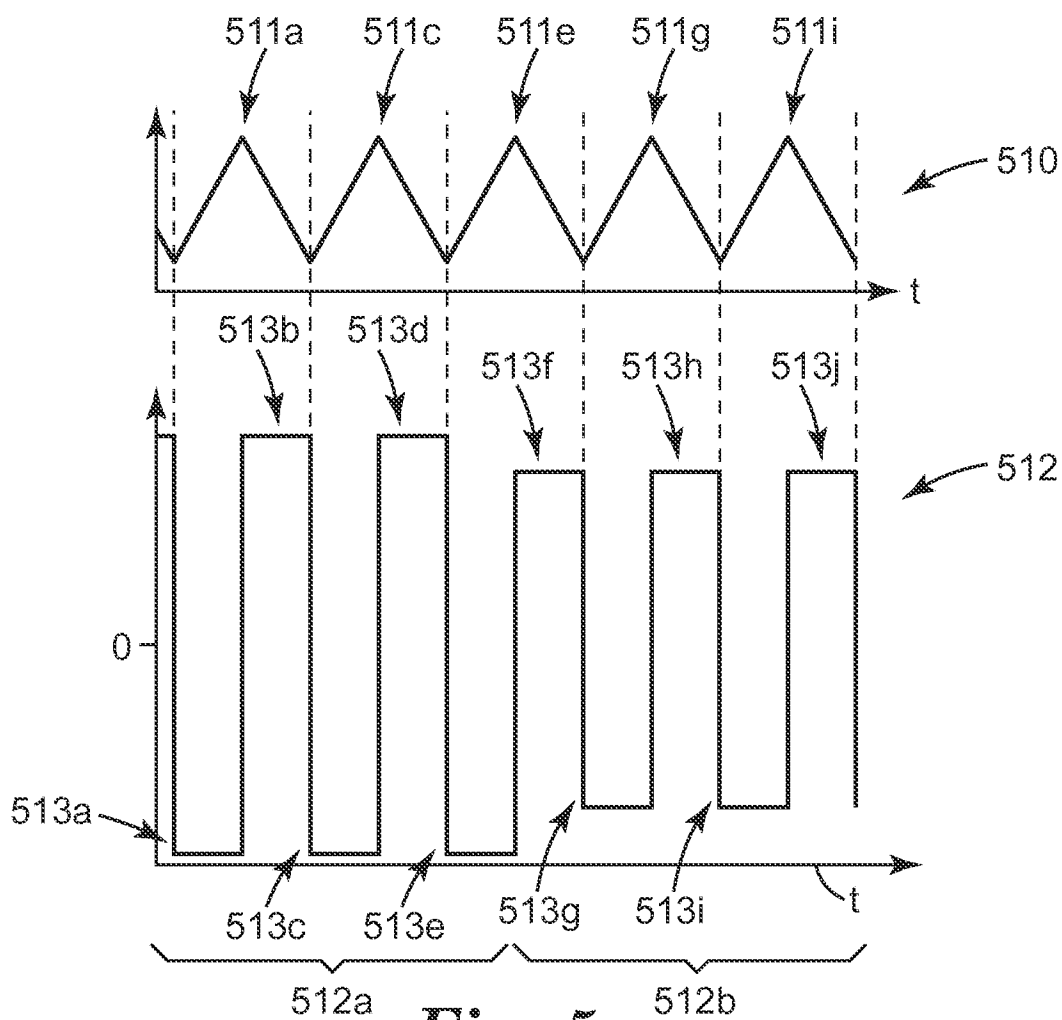


Fig. 5a

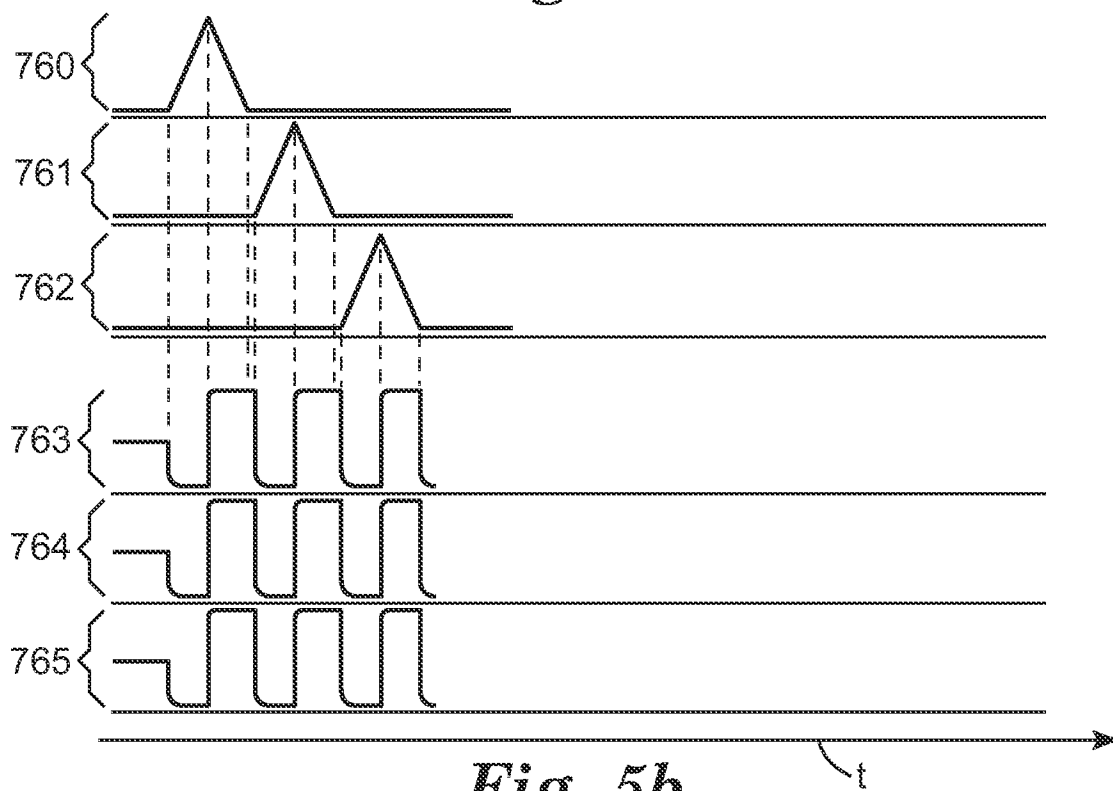
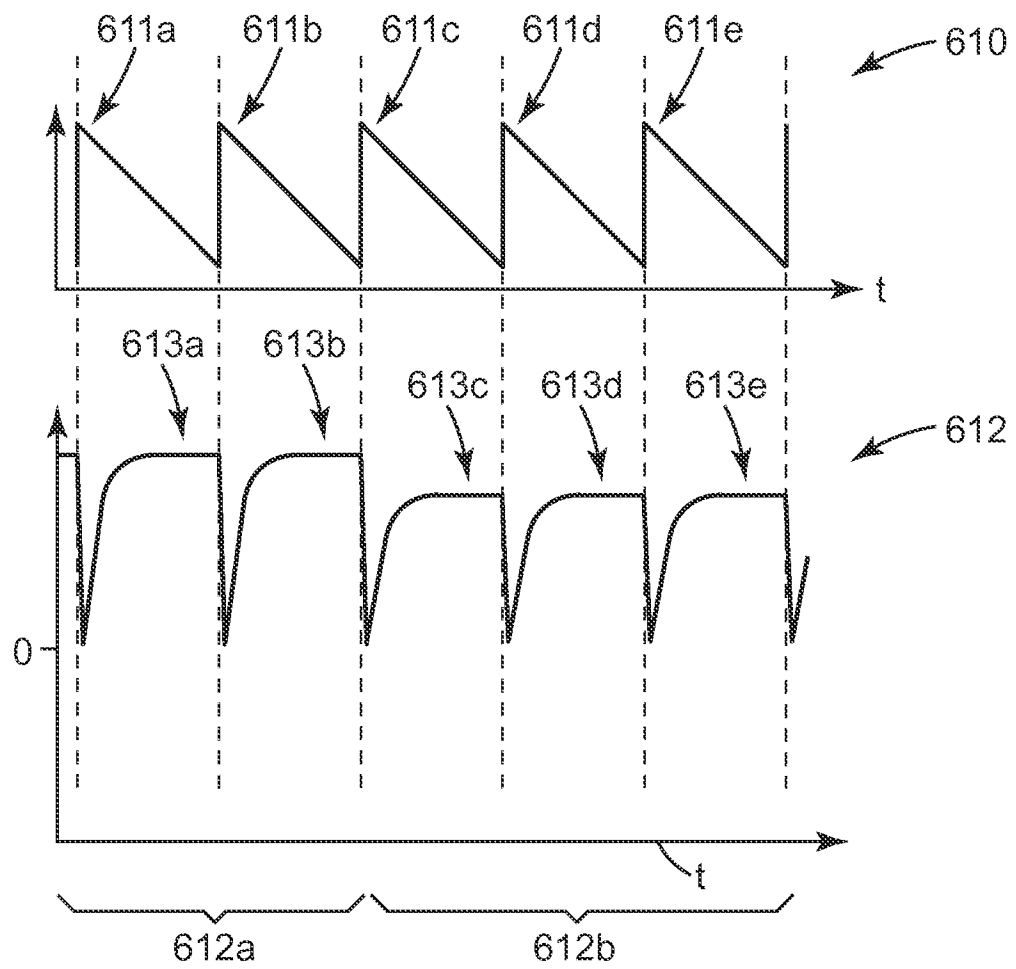
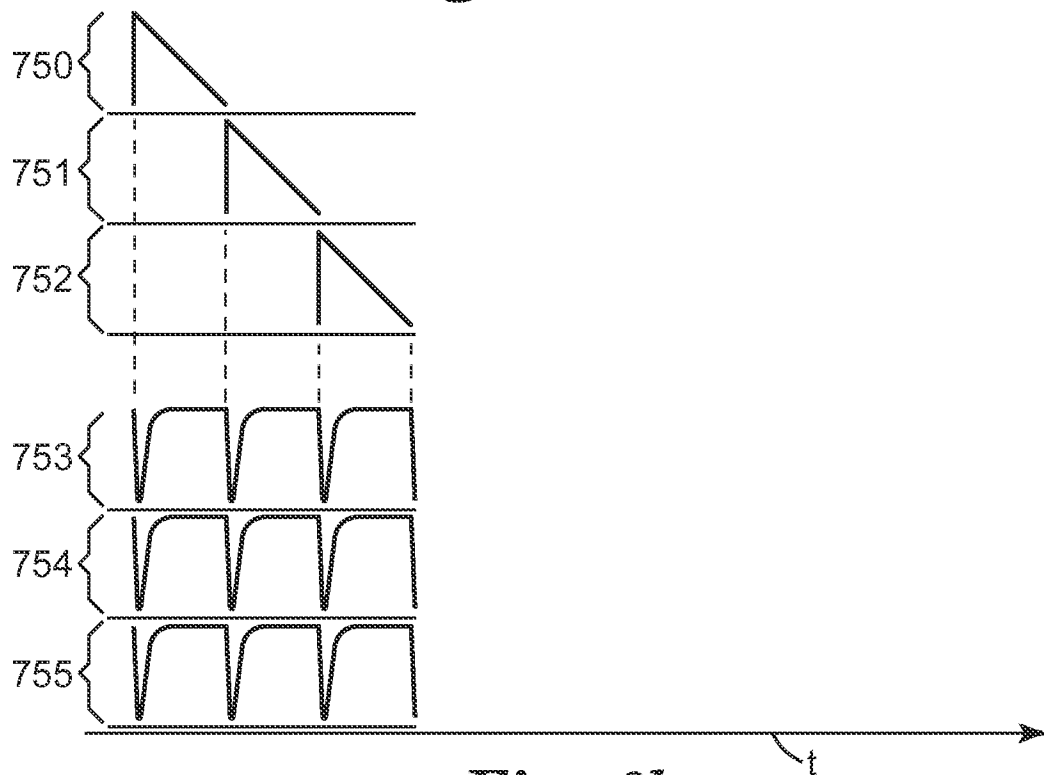


Fig. 5b

**Fig. 6a****Fig. 6b**

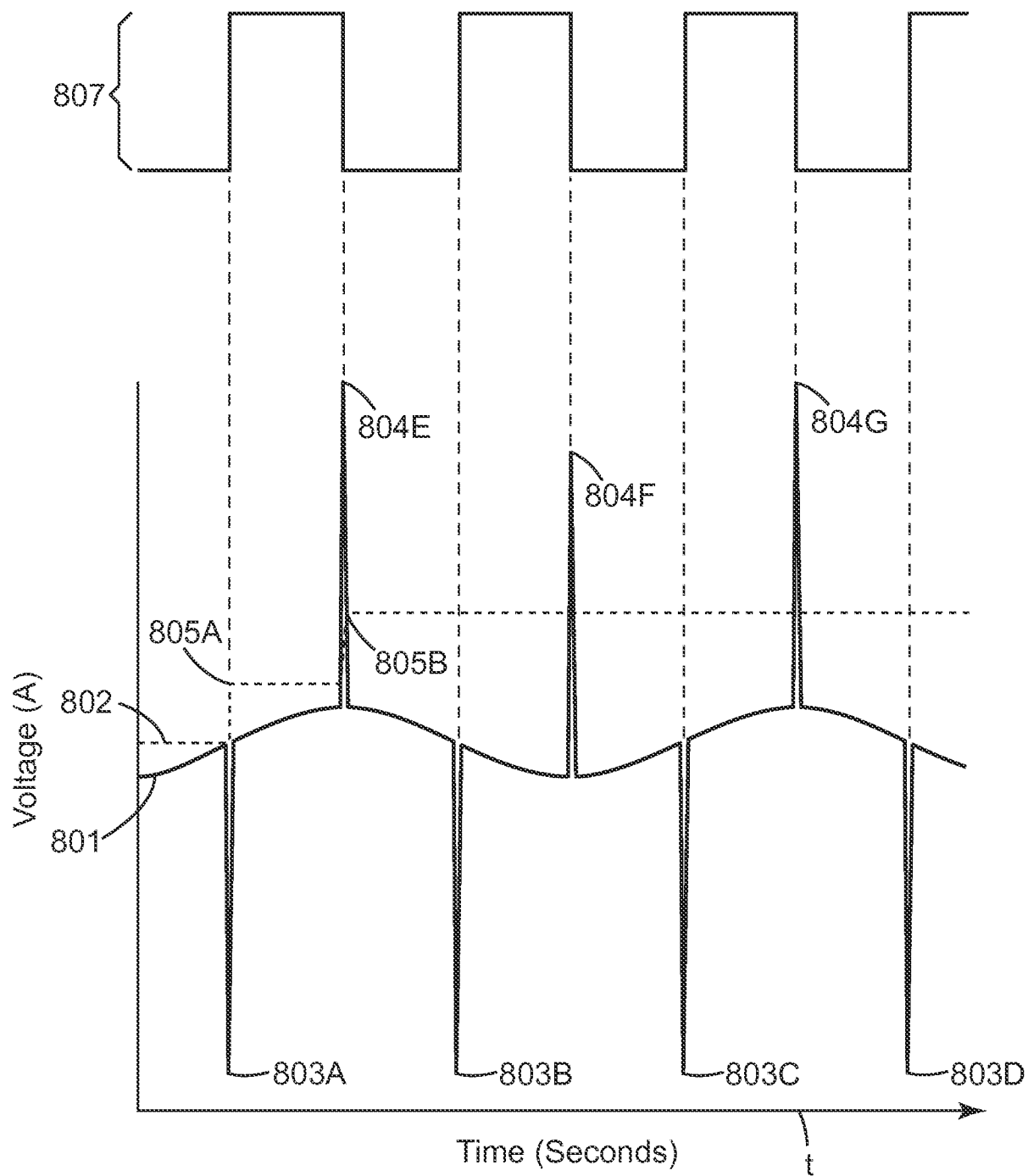
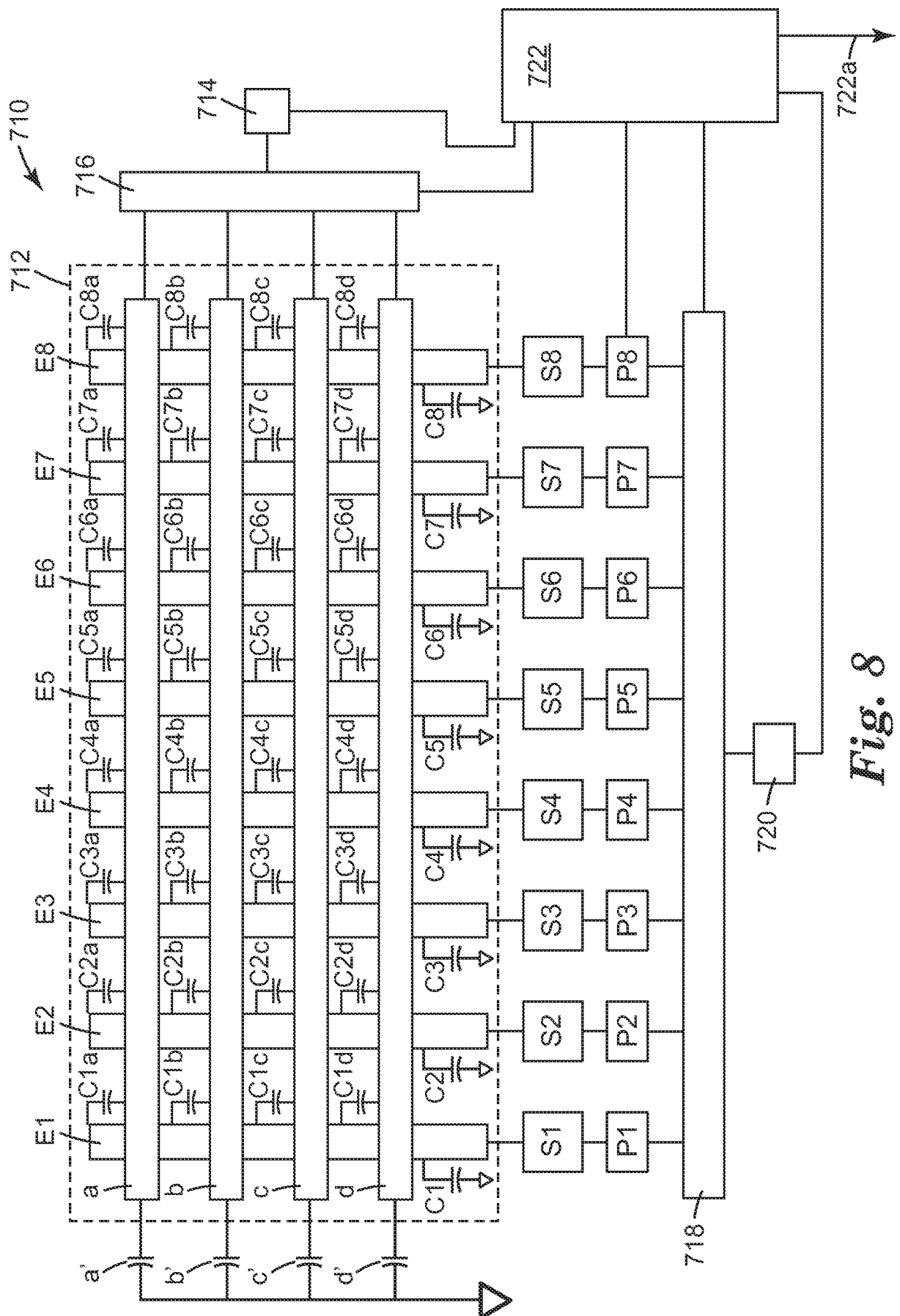


Fig. 7



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/036030

A. CLASSIFICATION OF SUBJECT MATTER

INV. G06F3/044
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 189 417 A (CALDWELL DAVID W [US] ET AL) 23 February 1993 (1993-02-23) column 2, line 49 - column 3, line 62	1-20
A	US 5 572 205 A (CALDWELL DAVID W [US] ET AL) 5 November 1996 (1996-11-05) * abstract column 4, line 55 - column 6, line 48	1-20
A	US 2009/096758 A1 (HOTELLING STEVE [US] ET AL) 16 April 2009 (2009-04-16) paragraphs [0092] - [0098]	1-20
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

9 August 2010

Date of mailing of the international search report

17/08/2010

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/036030

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 2008/162997 A1 (VU MINH-DIEU THI [US] ET AL) 3 July 2008 (2008-07-03) * abstract paragraph [0028] - paragraph [0032] -----	1-20

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