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[Continued on next page]

(54) Title: ACTIVE INTEGRATOR FOR A CAPACITIVE SENSE ARRAY

FIGURE 4

(57) Abstract: An active integrator for sensing capacitance of a touch sense array is disclosed. The active integrator is configured to receive from the touch sense array a response signal having a positive portion and a negative portion. The response signal is representative of a presence or an absence of a conductive object on the touch sense array. The active integrator is configured to continuously integrate the response signal.

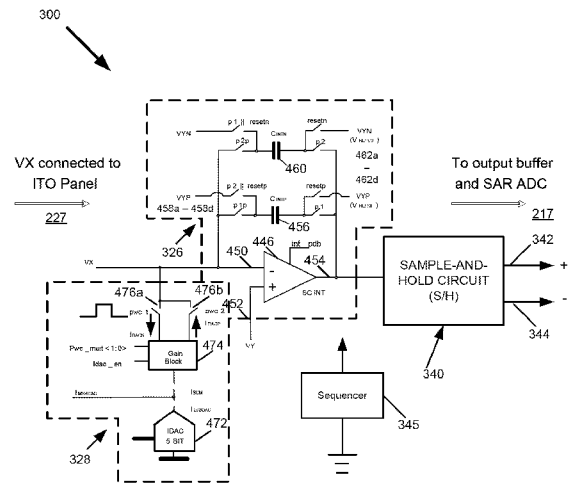

FIGURE 4

WO 2012/138397 A1

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ACTIVE INTEGRATOR FOR A CAPACITIVE SENSE ARRAY

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/472,161 filed April 5, 2011, the disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present invention relates generally to capacitive touch sense arrays, and more particularly, to an active integrator receiving circuit for a touch sense array.

BACKGROUND

[0003] Computing devices, such as notebook computers, personal data assistants (PDAs), kiosks, and mobile handsets, have user interface devices, which are also known as human interface devices (HID). One user interface device that has become more common is a touch-sensor pad (also commonly referred to as a touchpad). A basic notebook computer touch-sensor pad emulates the function of a personal computer (PC) mouse. A touch-sensor pad is typically embedded into a PC notebook for built-in portability. A touch-sensor pad replicates mouse X/Y movement by using two defined axes which contain a collection of sensor elements that detect the position of one or more conductive objects, such as a finger. Mouse right/left button clicks can be replicated by two mechanical buttons, located in the vicinity of the touchpad, or by tapping commands on the touch-sensor pad itself. The touch-sensor pad provides a user interface device for performing such functions as positioning a pointer, or selecting an item on a display. These touch-sensor pads may include multi-dimensional sensor arrays for detecting movement in multiple axes. The sensor array may include a one-

dimensional sensor array, detecting movement in one axis. The sensor array may also be two dimensional, detecting movements in two axes.

[0004] Another user interface device that has become more common is a touch screen. Touch screens, also known as touchscreens, touch windows, touch panels, or touchscreen panels, are transparent display overlays which are typically either pressure-sensitive (resistive or piezoelectric), electrically-sensitive (capacitive), acoustically-sensitive (surface acoustic wave (SAW)) or photo-sensitive (infra-red). The effect of such overlays allows a display to be used as an input device, removing the keyboard and/or the mouse as the primary input device for interacting with the display's content. Such displays can be attached to computers or, as terminals, to networks. Touch screens have become familiar in retail settings, on point-of-sale systems, on ATMs, on mobile handsets, on kiosks, on game consoles, and on PDAs where a stylus is sometimes used to manipulate the graphical user interface (GUI) and to enter data. A user can touch a touch screen or a touch-sensor pad to manipulate data. For example, a user can apply a single touch, by using a finger to touch the surface of a touch screen, to select an item from a menu.

[0005] A certain class of touch sense arrays includes a first set of linear electrodes separated and a second set of electrodes arranged at right angles and separated by a dielectric layer. The resulting intersections form a two-dimensional array of capacitors, referred to as sense elements. Touch sense arrays can be scanned in several ways, one of which (mutual-capacitance sensing) permits individual capacitive elements to be measured. Another method (self-capacitance sensing) can measure an entire sensor strip, or even an entire sensor array, with less information about a specific location, but performed with a single read operation.

[0006] The two-dimensional array of capacitors, when placed in close proximity, provides a means for sensing touch. A conductive object, such as a finger or a stylus, coming in close proximity to the touch sense array causes changes in the total capacitances of the sense

elements in proximity to the conductive object. These changes in capacitance can be measured to produce a "two-dimensional map" that indicates where the touch on the array has occurred.

[0007] One way to measure such capacitance changes is to form a circuit comprising a signal driver (e.g., an AC current or a voltage source ("transmit (TX) signal)) which is applied to each horizontally aligned conductor in a multiplexed fashion. The charge accumulated on each of the capacitive intersections are sensed and similarly scanned at each of the vertically aligned electrodes in synchronization with the applied current/voltage source. This charge is then measured, typically with a form of charge-to-voltage converter (i.e., receive or "RX signal"), which is sampled-and-held for an A/D converter to convert to digital form for input to a processor. The processor, in turn, renders the capacitive map and determines the location of a touch.

[0008] Conventional capacitive sensing receiving circuits suffer from a number of deficiencies. Changes in capacitance, as a result of a touch by a conductive object, are generally small. As a result, much of the voltage appearing at the ADC is representative of the baseline capacitance of the sense elements of the array, which results in a large DC component. Capacitance changes due to touch may account for only 1% of the baseline capacitance. Further, the source circuits are often noisy, further complicating accurate capacitance change measurements and resulting in a low signal-to-noise (SNR) ratio.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Embodiments of the present invention will be more readily understood from the detailed description of exemplary embodiments presented below considered in conjunction with the attached drawings in which like reference numerals refer to similar elements and in which:

[0010] **Figure 1** illustrates a block diagram of one embodiment of an electronic system including a processing device that may be configured to measure capacitances from a flexible touch-sensing surface and calculate or detect the amount of force applied to the flexible touch-sensing surface.

[0011] **Figure 2** is a block diagram illustrating one embodiment of a capacitive touch sensor array and a capacitance sensor that converts measured capacitances to coordinates.

[0012] **Figure 3** depicts an electrical block diagram of one embodiment of an active integration circuit configured to receive an RX signal from receive electrodes to measure a capacitance of the touch sense array of **Figure 2**.

[0013] **Figure 4** is a block diagram of the components of an active integrator, a baseline compensation circuit, and a sample-and-hold (S/H) circuit employed in the active integration circuit of **Figure 3**, according to an embodiment.

[0014] **Figure 5** is a schematic diagram of the components of one embodiment of the S/H circuit employed in the active integration circuit of **Figure 3 and 4**.

[0015] **Figures 6A and 6B** are diagrams illustrating one embodiment of the relative timing of the operation and presence of the various switches and signals associated with the active integrator of **Figure 4** and the S/H circuit of **Figure 5,** respectively.

[0016] **Figure 7** is a graph of one embodiment of the spectral response of the response channel of the capacitance sensor of the touch sense array of **Figure 1** employing the components of **Figures 4 and 5**.

[0017] Figure 8 is a flow diagram of one embodiment of a method for operating the active integrator and the S/H circuit of the active integration circuit for measuring a capacitance of the touch sense array

[0018] Figure 9 is a flow diagram illustrating the step of continuously integrating the response signal of **Figure 9** in greater detail.

[0019] Figure 10 is another embodiment of **Figure 2** showing the capacitance sensor of **Figure 2** configured to provide a calibration unit configured to provide a self-calibration of the capacitance sensor.

DETAILED DESCRIPTION

[0020] Embodiments of the invention provide an active integrator configured to measure a capacitance of a touch sense array or part of an array (e.g., a single strip). The active integrator is configured to receive from the touch sense array a response signal representative of a presence or an absence of a conductive object on the touch sense array. The response signal is generally assumed to be supplied from a touch sense array, which is driven by an AC current/voltage source. As a result, the response signal includes a positive portion and a negative portion. The embodiments described herein employ the active integrator and supporting circuitry to continuously integrate the response signal. This continuous integration property is primarily a result of the switch-capacitance nature of the active integrator. One possible advantage of employing a switched-capacitive active integrator may be an improved SNR over conventional designs. In one embodiment, when the frequency of switching matches the fundamental frequency and phase of the response signal, an output signal has a narrow pass-band centered about a fundamental frequency of the response signal, resulting in a substantially improved SNR. This method is also referred to as full-wave demodulation.

[0021] In one embodiment, the active integrator includes an operational amplifier (opamp) coupled to a pair of feedback capacitors. One feedback capacitor is configured to store a charge responsive to the positive portion of the response signal, and a second feedback capacitor is configured to store a charge responsive to the negative portion of the response signal. The first feedback capacitor and the second feedback capacitor may be configured to be variable to permit sensitivity calibration of the touch sense receivers. In one embodiment, the active integrator is coupled to a sample-and-hold (S/H) circuit configured to full-wave demodulate the output signal of the active integrator by means of a one or more switches. A first capacitor is configured to hold a positive signal on the output terminal of the active integrator when the positive portion of the response signal is present, and a second capacitor

is configured to hold a negative signal on the output terminal of the active integrator when the negative portion of the response signal is present.

[0022] Figure 1 illustrates a block diagram of one embodiment of an electronic system 100 including a processing device 110 that may be configured to measure capacitances from a flexible touch-sensing surface and calculate or detect the amount of force applied to the flexible touch-sensing surface. The electronic system 100 includes a touch-sensing surface 116 (e.g., a touch screen, or a touch pad) coupled to the processing device 110 and a host 150. In one embodiment, the touch-sensing surface 116 is a two-dimensional user interface that uses a sensor array 121 to detect touches on the surface 116.

[0023] In one embodiment, the sensor array 121 includes sensor elements 121(1)–121(N) (where N is a positive integer) that are disposed as a two-dimensional matrix (also referred to as an XY matrix). The sensor array 121 is coupled to pins 113(1)–113(N) of the processing device 110 via one or more analog buses 115 transporting multiple signals. In this embodiment, each sensor element 121(1)-121(N) is represented as a capacitor. The self capacitance of each sensor in the sensor array 121 is measured by a capacitance sensor 101 in the processing device 110.

[0024] In one embodiment, the capacitance sensor 101 may include a relaxation oscillator or other means to convert a capacitance into a measured value. The capacitance sensor 101 may also include a counter or timer to measure the oscillator output. The capacitance sensor 101 may further include software components to convert the count value (e.g., capacitance value) into a sensor element detection decision (also referred to as switch detection decision) or relative magnitude. In another embodiment, the capacitance sensor 101 includes an active integration circuit 300 to be described below.

[0025] It should be noted that there are various known methods for measuring capacitance, such as current versus voltage phase shift measurement, resistor-capacitor charge timing,

capacitive bridge divider, charge transfer, successive approximation, sigma-delta modulators, charge-accumulation circuits, field effect, mutual capacitance, frequency shift, or other capacitance measurement algorithms. It should be noted however, instead of evaluating the raw counts relative to a threshold, the capacitance sensor 101 may be evaluating other measurements to determine the user interaction. For example, in the capacitance sensor 101 having a sigma-delta modulator, the capacitance sensor 101 is evaluating the ratio of pulse widths of the output, instead of the raw counts being over or under a certain threshold.

[0026] In one embodiment, the processing device 110 further includes processing logic 102. Operations of the processing logic 102 may be implemented in firmware; alternatively, it may be implemented in hardware or software. The processing logic 102 may receive signals from the capacitance sensor 101, and determine the state of the sensor array 121, such as whether an object (e.g., a finger) is detected on or in proximity to the sensor array 121 (e.g., determining the presence of the object), where the object is detected on the sensor array (e.g., determining the location of the object), tracking the motion of the object, or other information related to an object detected at the touch sensor.

[0027] In another embodiment, instead of performing the operations of the processing logic 102 in the processing device 110, the processing device 110 may send the raw data or partially-processed data to the host 150. The host 150, as illustrated in **Figure 1**, may include decision logic 151 that performs some or all of the operations of the processing logic 102. Operations of the decision logic 151 may be implemented in firmware, hardware, software, or a combination thereof. The host 150 may include a high-level Application Programming Interface (API) in applications 152 that perform routines on the received data, such as compensating for sensitivity differences, other compensation algorithms, baseline update routines, start-up and/or initialization routines, interpolation operations, or scaling operations. The operations described with respect to the processing logic 102 may be implemented in the

decision logic 151, the applications 152, or in other hardware, software, and/or firmware external to the processing device 110. In some other embodiments, the processing device 110 is the host 150.

[0028] In another embodiment, the processing device 110 may also include a non-sensing actions block 103. This block 103 may be used to process and/or receive/transmit data to and from the host 150. For example, additional components may be implemented to operate with the processing device 110 along with the sensor array 121 (e.g., keyboard, keypad, mouse, trackball, LEDs, displays, or other peripheral devices).

[0029] In one embodiment, the electronic system 100 is implemented in a device that includes the touch-sensing surface 116 as the user interface, such as handheld electronics, portable telephones, cellular telephones, notebook computers, personal computers, personal data assistants (PDAs), kiosks, keyboards, televisions, remote controls, monitors, handheld multi-media devices, handheld video players, gaming devices, control panels of a household or industrial appliances, or other computer peripheral or input devices. Alternatively, the electronic system 100 may be used in other types of devices. It should be noted that the components of electronic system 1000 may include all the components described above. Alternatively, electronic system 100 may include only some of the components described above, or include additional components not listed herein.

[0030] **Figure 2** is a block diagram illustrating one embodiment of a capacitive touch sensor array 121 and a capacitance sensor 101 that converts measured capacitances to coordinates. The coordinates are calculated based on measured capacitances. In one embodiment, sensor array 121 and capacitance sensor 101 are implemented in a system such as electronic system 100. Sensor array 121 includes a matrix 225 of N×M electrodes (N receive electrodes and M transmit electrodes), which further includes transmit (TX) electrode

222 and receive (RX) electrode 223. Each of the electrodes in matrix 225 is connected with capacitance sensing circuit 201 through demultiplexer 212 and multiplexer 213.

[0031] Capacitance sensor 101 includes multiplexer control 211, demultiplexer 212 and multiplexer 213, clock generator 214, signal generator 215, demodulation circuit 216, and analog to digital converter (ADC) 217. ADC 217 is further coupled with touch coordinate converter 218. Touch coordinate converter 218 outputs a signal to the processing logic 102.

[0032] In one embodiment, processing logic 102 may be a processing core 102. The processing core may reside on a common carrier substrate such as, for example, an integrated circuit ("IC") die substrate, a multi-chip module substrate, or the like. Alternatively, the components of processing core 102 may be one or more separate integrated circuits and/or discrete components. In one exemplary embodiment, processing core 102 is configured to provide intelligent control for the Programmable System on a Chip ("PSoC®") processing device, manufactured by Cypress Semiconductor Corporation, San Jose, California. Alternatively, processing core 102 may be one or more other processing devices known by those of ordinary skill in the art, such as a microprocessor or central processing unit, a controller, special-purpose processor, digital signal processor ("DSP"), an application specific integrated circuit ("ASIC"), a field programmable gate array ("FPGA"), or the like. In one embodiment, the processing core 102 and the other components of the processing device 110 are integrated into the same integrated circuit.

[0033] It should also be noted that the embodiments described herein are not limited to having a configuration of a processing core 102 coupled to a host 150, but may include a system that measures the capacitance on the touch sense array 121 and sends the raw data to a host computer where it is analyzed by an application. In effect, the processing that is done by processing core 102 may also be done in the host. The host may be a microprocessor, for

example, as well as other types of processing devices as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure.

[0034] The components of the electronic system 100 excluding the touch sense array 121 may be integrated into the IC of the processing core 102, or alternatively, in a separate IC. Alternatively, descriptions of the electronic system 100 may be generated and compiled for incorporation into other integrated circuits. For example, behavioral level code describing the electronic system 100, or portions thereof, may be generated using a hardware descriptive language, such as VHDL or Verilog, and stored to a machine-accessible medium (e.g., CD-ROM, hard disk, floppy disk, etc.). Furthermore, the behavioral level code can be compiled into register transfer level ("RTL") code, a netlist, or even a circuit layout and stored to a machine-accessible medium. The behavioral level code, the RTL code, the netlist, and the circuit layout all represent various levels of abstraction to describe the electronic system 100.

[0035] It should be noted that the components of the electronic system 100 may include all the components described above. Alternatively, the electronic system 100 may include only some of the components described above.

[0036] In one embodiment, the electronic system 100 is used in a notebook computer. Alternatively, the electronic device may be used in other applications, such as a mobile handset, a personal data assistant ("PDA"), a keyboard, a television, a remote control, a monitor, a handheld multi-media device, a handheld video player, a handheld gaming device, or a control panel.

[0037] The transmit and receive electrodes in the electrode matrix 225 may be arranged so that each of the transmit electrodes overlap and cross each of the receive electrodes such as to form an array of intersections, while maintaining galvanic isolation from each other. Thus, each transmit electrode may be capacitively coupled with each of the receive electrodes. For

example, transmit electrode 222 is capacitively coupled with receive electrode 223 at the point where transmit electrode 222 and receive electrode 223 overlap.

[0038] Clock generator 214 supplies a clock signal to signal generator 215, which produces a TX signal 224 to be supplied to the transmit electrodes of touch sense array 121. In one embodiment, the signal generator 215 includes a set of switches that operate according to the clock signal from clock generator 214. The switches may generate a TX signal 224 by periodically connecting the output of signal generator 215 to a first voltage and then to a second voltage, wherein said first and second voltages are different. In another embodiment, the active integration circuit 300 is coupled to the signal generator 215 to be described below. A person of ordinary skill in the art would appreciate that the signal generator 215 may supply a TX signal 224 that may be any periodic signal having a positive portion and a negative portion, including, for example, a sine wave, a square wave, a triangle wave, etc.

[0039] The output of signal generator 215 is connected with demultiplexer 212, which allows the TX signal 224 to be applied to any of the M transmit electrodes of touch sense array 121. In one embodiment, multiplexer control 211 controls demultiplexer 212 so that the TX signal 224 is applied to each transmit electrode 222 in a controlled sequence. Demultiplexer 212 may also be used to ground, float, or connect an alternate signal to the other transmit electrodes to which the TX signal 224 is not currently being applied.

[0040] Because of the capacitive coupling between the transmit and receive electrodes, the TX signal 224 applied to each transmit electrode induces a current within each of the receive electrodes. For instance, when the TX signal 224 is applied to transmit electrode 222 through demultiplexer 212, the TX signal 224 induces an RX signal 227 on the receive electrodes in matrix 225. The RX signal 227 on each of the receive electrodes can then be measured in sequence by using multiplexer 213 to connect each of the N receive electrodes to demodulation circuit 216 in sequence.

[0041] The mutual capacitance associated with each intersection between a TX electrode and an RX electrode can be sensed by selecting every available combination of TX electrode and an RX electrode using demultiplexer 212 and multiplexer 213. To improve performance, multiplexer 213 may also be segmented to allow more than one of the receive electrodes in matrix 225 to be routed to additional demodulation circuits 216. In an optimized configuration, wherein there is a 1-to-1 correspondence of instances of demodulation circuit 216 with receive electrodes, multiplexer 213 may not be present in the system.

[0042] When an object, such as a finger, approaches the electrode matrix 225, the object causes a decrease in the mutual capacitance between only some of the electrodes. For example, if a finger is placed near the intersection of transmit electrode 222 and receive electrode 223, the presence of the finger will decrease the mutual capacitance between electrodes 222 and 223. Thus, the location of the finger on the touchpad can be determined by identifying the one or more receive electrodes having a decreased mutual capacitance in addition to identifying the transmit electrode to which the TX signal 224 was applied at the time the decreased mutual capacitance was measured on the one or more receive electrodes.

[0043] By determining the mutual capacitances associated with each intersection of electrodes in the matrix 225, the locations of one or more touch contacts may be determined. The determination may be sequential, in parallel, or may occur more frequently at commonly used electrodes.

[0044] In alternative embodiments, other methods for detecting the presence of a finger or conductive object may be used where the finger or conductive object causes an increase in capacitance at one or more electrodes, which may be arranged in a grid or other pattern. For example, a finger placed near an electrode of a capacitive sensor may introduce an additional capacitance to ground that increases the total capacitance between the electrode and ground.

The location of the finger can be determined from the locations of one or more electrodes at which an increased capacitance is detected.

[0045] The induced current signal 227 is rectified by demodulation circuit 216. The rectified current output by demodulation circuit 216 can then be filtered and converted to a digital code by ADC 217. In an embodiment, the demodulation circuit may include an active integration circuit 300 to be described below.

[0046] The digital code is converted to touch coordinates indicating a position of an input on touch sensor array 121 by touch coordinate converter 218. The touch coordinates are transmitted as an input signal to the processing logic 102. In one embodiment, the input signal is received at an input to the processing logic 102. In one embodiment, the input may be configured to receive capacitance measurements indicating a plurality of row coordinates and a plurality of column coordinates. Alternatively, the input may be configured to receive row coordinates and column coordinates.

[0047] In one embodiment, a system for tracking locations of contacts on a touch-sensing surface may determine a force magnitude for each of the contacts based on the capacitance measurements from the capacitive sensor array. In one embodiment, a capacitive touch-sensing system that is also capable of determining a magnitude of force applied to each of a plurality of contacts at a touch-sensing surface may be constructed from flexible materials, such as PMMA, and may have no shield between the capacitive sensor array and an LCD display panel. In such an embodiment, changes in capacitances of sensor elements may be caused by the displacement of the sensor elements closer to a VCOM plane of the LCD display panel.

[0048] **Figure 3** depicts an electrical block diagram of one embodiment of the active integration circuit 300 configured to receive the RX signal 227 from the receive electrodes to measure a capacitance of the touch sense array 121 or part of an array (e.g., a single strip) of

Figure 2. The active integration circuit 300 includes a calibration unit 321, an active integrator 326, a sample-and-hold (S/H) circuit 340, and a sequencer circuit 345. The multiplexer 213 of **Figure 2** is coupled to a first input 324 of an active integrator 326. A baseline compensation circuit 328 is coupled via one or more switches 330 to the first input 324 of an active integrator 326. A virtual-ground VY is coupled to a second input 338 of the active integrator 326. An output 339 of the active integrator 326 is coupled to a sample-and-hold (S/H) circuit 340. The S/H circuit 340 is differentially coupled to the ADC 217, via first and second outputs 342, 344. A central control circuit, referred to hereinafter as the sequencer circuit 345, has full control over all switches and activities in general in an entire touch-screen subsystem (TSS), including the active integration circuit 300 (as indicated by reference "A") to be described below in connection with **Figures 3, 6A, 6B and 8**. The calibration unit 321 provides a self-calibration of the capacitance sensor 101 and is coupled to both the RX signal 227 and multiplexor 213 via one or more switches 331 and to the TX signal 227 and the demultiplexor 212 via one or more switches (not shown) to be described below in connection with **Figure 10**.

[0049] Figure 4 is a block diagram of the components of the active integrator 326, the baseline compensation circuit 328, and the S/H circuit 340 employed in the active integration circuit 300 of **Figure 3**. In an embodiment, the active integrator 326 may be a switched capacitor integrator including an operational amplifier 446 having a negative input terminal 450, a positive input terminal 452, and an output terminal 454. A first integrating capacitor 456, also labeled C_{INTP}, is coupled between the output terminal 454 and the negative input terminal 450 via a switches 458a-458d. A second integrating capacitor 460, also labeled C_{INTN}, is coupled between the output terminal 454 and the negative input terminal 450 via a plurality of switches 462a-462d.

[0050] **Figure 5** is a schematic diagram of the components of one embodiment of the S/H circuit 340 employed in the active integration circuit 300 of **Figure 3 and 4**. In one embodiment, the S/H circuit 340 comprises a first S/H capacitor 466a, also labeled C_{SHP}, coupled or decoupled between an input terminal of an S/H buffer 467a and the output terminal 454 of the operational amplifier 446 via a switch 468a, also labeled "shp". The S/H circuit 340 also comprises a second S/H capacitor 466b, also labeled C_{SHN}, coupled or decoupled between an input terminal of an S/H buffer 467b and the output terminal 454 of the operational amplifier 46 via a switch 468b, also labeled "shn". Output terminals of the S/H buffer 467a, 467b and the S/H buffers themselves are couple or decoupled to a positive input 342 and negative input 344 of a differential ADC 217 via switches 469a-469d labeled "adc_sample." A plurality of switches 470a-470d, labeled "shpp", "shnn", "!shp && !adc_sample", and "!shn && !adc_sample" configure the S/H buffers for purposes to be described below. Inputs 471a, 471b labeled "bufp_pdb" and "bufn_pdb" to the S/H buffers 467a,467b, respectively are employed to power up or power down each of the S/H buffers 467a, 467b for purposes to be described below

[0051] Referring to **Figures 3-5**, the sequencer 345 has full control over all switches and activities in general in an entire touch-screen subsystem (TSS). This includes activating TX signals applied to the touch sense array 121 (e.g., going high or going low), switches in the active integrator 326 (e.g., p1, p2, p1p, p2p), baseline control switches pwc1/pwc2, IDAC values, the S/H circuit 340, and so forth. Using the sequencer 345, all activities in the RX and TX circuits occur in a fully synchronous fashion to be described below in connection with Figure 7. The sequencer circuit 345 is implemented as part of the PSoC® processing device comprised of custom universal digital blocks (UDB) configured to provide timing for all switches in the active integrator 326 according to the timing diagrams of Figures 6A and 6B. As used herein, UDBs are a collection of uncommitted logic (PLD) and structural logic

(Datapath) optimized to create all common embedded peripherals and customized functionality that are application or design specific. UDBs may be employed to implement a variety of general and specific digital logic devices including, but not limited to, field programmable gate arrays (FPGA), programmable array logic (PAL), complex programmable logic devices (CPLD) etc.

[0052] In the depicted embodiment of **Figure 4**, the baseline compensation circuit 328 includes a current-output digital-to-analog converter (IDAC) 472 coupled between ground and a gain block 474. The gain block 474 is coupled to the input negative input terminal 450 of the operational amplifier 446 by a pair of switches 476a-476b, also labeled pwc1 and pwc2, respectively. The switch 476a (pwc1) is configured to apply a negative current I_{DACN} to the negative input terminal 450 of the operational amplifier 446 to cancel a positive baseline charge originating from the response signal present on an output of the touch sense array 121 via operation of pwc1. Likewise, the switch 476b (pwc2) is configured to apply a positive current I_{DACP} to the negative input terminal 450 of the operational amplifier 446 to cancel a negative baseline charge originating from the response signal present on an output of the touch sense array 121 via operation of pwc2.

[0053] In one embodiment, the baseline compensation circuit 328 serves to minimize the baseline offset of the response signal appearing at the differential inputs of the ADC 217 so as to maximize the number of output bits that are representative of a change in capacitance due to the approach of the touch sense array 121 of a conductive object. As a result, the dynamic range of the capacitance sensor 101 may be improved.

[0054] Tolerances associated with the design and manufacturing of the sensor panel can make the baseline capacitance of some sensor elements vary significantly, even within a single touch sense array 121. This can further reduce the dynamic range of the ADC 217, because a fixed charge from any sense line is simply a baseline charge carrying no

information about a touch event. Thus, instead of using a single, fixed value in the baseline compensation circuit (i.e., the IDAC 472), the value can be programmed in real-time to compensate for the actual baseline charge for the sense line currently sensed. The best setting can be determined in a "self-tuning" routine either at manufacturing time for the entire touch subsystem, or during power-up in the final end product.

[0055] Figures 6A and 6B are diagrams illustrating one embodiment of the relative timing of the operation and presence of the various switches and signals associated with the active integrator 326 of **Figure 4** and the S/H circuit 340 of **Figure 5,** respectively. The switches 458a-458d, 462a-462d coupled to the active integrator 326 and the switches 468a,468b, 469a-469d, and 470a-470d coupled to the S/H circuit 340 are timed to continuously integrate a positive portion and a negative portion of a response signal continuously with substantially no "dead times." As soon as a negative portion of the response signal has been integrated, there is virtually no delay in switching over to the capacitor C_{INTP} before a positive portion of the response signal may be integrate on the capacitor C_{INTP}. Moreover, as soon as a positive or negative signal has been integrated, the integrated signal may be impressed on C_{SHP} and then C_{SHN} via the switches 468a, 468b, 469a-469d, and 470a-470d coupled to the S/H circuit 340, respectively. The "differential" outputs of the S/H circuit 340 thus are configured to full-wave rectify an incoming integrated response signal, such that the same polarity of incoming signal is always presented to the differential inputs 342, 344 of the ADC 217.

[0056] Figure 7 is a graph of one embodiment of the spectral response of the response channel of the capacitance sensor 101 of the touch sense array 121 of **Figure 1** employing the components of **Figures 4 and 5**. Since the active integrator 326 may substantially simultaneously drive the S/H circuit 340 while integrating, and one of the capacitors 456, 460 may be held or reset while the other is integrating continuously with substantially no dead time, the resulting channel has a narrow band frequency response 880 compared to a channel

that integrates using a single capacitor and non-time/polarity coordinated S/H circuit 340, its response 882 shown also in **Figure 7**. The narrow band frequency response has a peak 884 that corresponds to the fundamental frequency of the input signal (i.e., TX signal 224). As a result, the SNR is significantly improved compared to conventional designs.

[0057] Figure 8 is a flow diagram 800 of one embodiment of a method for operating the active integrator 326 and the S/H circuit 340 of the active integration circuit 300 for measuring a capacitance of the touch sense array 121. At block 802, the active integrator 300 receives from the touch sense array 121 a response signal having a positive portion and a negative portion (e.g., a periodic response signal having a negative portion followed by a positive portion, such as a sine wave, a square wave, a triangle wave, etc.). The response signal is representative of a presence or an absence of a conductive object on the touch sense array 121. At block 804, the active integrator 300 continuously integrates the response signal (in a full-wave rectification fashion, see **Figure 8** below). Blocks 802 and 804 are repeated *ad infinitum* for each cycle of the response signal for as long as the response signal is present.

[0058] Figure 9 is a flow diagram illustrating block 804 of continuously integrating the response signal of **Figure 8** in greater detail. Referring now to **Figures 4, 5 and 9**, at block 902, a charge responsive to the negative portion of the response signal is accumulated on the first integrating capacitor 456, C_{INTP}. More particularly, when a TX signal 227 is activated to go from high-to-low, corresponding switches 458a, 458b (p1/p1p) in the active integrator 326 are closed, while switches 462a, 462b (p2/p2p) are opened. Incoming charge may then be integrated on the capacitor 456 (C_{INTP}), such that the voltage across the capacitor 456 produces an increasing voltage at the output of the integrator (i.e., node 454). The input side of the integration capacitor 450 is held constant at Vx, which is the same as Vy (i.e., node 452), which does not change in operation.

[0059] At block 904, a charge responsive to the positive portion of the response signal is accumulated on the second integrating capacitor 460, C_{INTN}. More particularly, after all signals have settled down, the TX signal 227 is directed by the sequencer 345 to apply a low-to-high transition while simultaneously switches 458a, 458b (p1/p1p) are opened and switches 462a, 462b (p2/p2p) are closed. This connects the capacitor 460 (C_{INTN}) to the active integrator 326 while the capacitor 456 (C_{INTP}) is left floating, thereby temporarily holding its charge (the charge on the capacitor 456 cannot leak off). Again, after the incoming charge has been integrated, at block 906, the cycle starts over, switching the capacitor 456 (C_{INTP}) back into the active integrator 326 to collect a next charge packet, and so forth. Thus, positive charge packets are accumulated on capacitor 456 (C_{INTP}), while negative packets are accumulated on capacitor 460 (C_{INTN}).

[0060] While the positive and negative charges are producing corresponding positive and negative voltages across capacitor 456 (C_{INTP}) and capacitor 460 (C_{INTN}), relative to node 450 (Vy), at blocks 908, 910, respectively, output sampling capacitors 466 (C_{SHP}) and 469 (C_{SHN}) have been connected/removed to/from the integrator output 454 via corresponding non-overlapping closure/opening of the pair of switches 468a-468b (shp) and the pair of switches 470a-470b (shn), respectively. As a result, the output sampling capacitors 466 (C_{SHP}) and 469 (C_{SHN}) carry the same voltages across them as the corresponding integration capacitors, 456, 460, respectively.

[0061] After a predetermined number of cycles, N, at block 912, the downstream ADC 217 of **Figure 2** is directed by the sequencer 345 to measure the differential voltage across the capacitors 466 (C_{SHP}) and 469 (C_{SHN}) (referred to as a "sub-integration"), at which point, in block 914, the capacitors 456, 460, 466, and 469 are reset, and the whole process starts over. This differential voltage represents the difference in the positive and negative charge across the capacitors 456 (C_{INTP}) and 460 (C_{INTN}), respectively. As a result, both half-cycles of any

TX pulse are added together, which amounts to a full-wave rectification. Although both half cycles are integrated in discrete steps, with very short interruptions between them to accommodate switch-over of the integration capacitors, this operation is referred to as substantially "continuous" integration.

[0062] More particularly, the S/H circuit 340 operated in three stages to present a differential voltage to the ADC 217. The three stages include sampling from the integrator circuit 326, holding the sampled charge on the S/H circuit 340, and driving the ADC 217. The following steps describe the signals involved.

[0063] Each of the S/H buffers 467a, 467b samples the integrator output 454 on the last Tx clock period. The positive S/H buffer 467a samples the positive integration capacitor 456 (C_{INTP}) (nominally when the Tx has it's last high edge) and the negative S/H buffer 467a samples the negative integration capacitor integration capacitor 460 (C_{INTP}) (when the Tx has it's last low edge). The first signal to transition are the buffer power up signals 471a, 471b (bufp_pdb and bufn_pdb). The S/H buffers 467a, 467b are dynamically powered so they only burn current when required during the sample phase (shp) and during the drive ADC phase (adc_sample). In the sample mode, switch 470a (shpp) is operated to put the S/H buffer 467a into a unity gain mode and to set up V_Y on the right hand side of the sampling capacitors 466a (C_{SHP}) and 466b (C_{SHN}). Switch 468a (shp) is operated to sample the positive input (from the active integrator 326) on the sample/hold capacitor 466a (C_{SHP}). When both of these signals return to zero, the S/H buffers 467a, 467b are powered down via inputs 471a, 471b (bufp_pdb and bufn_pdb), one node of the sample/hold capacitor 468a (C_{SHP}) is tied to V_Y via switch 470b (!shp && !adc_sample) and the second node is floating. This allows a 'hold' of the sampled positive integrator voltage on C_{SHP}. A similar operation samples and holds the negative integrator voltage on sample/hold capacitor 466b (C_{SHN}). Just before adc_sample transitions, the S/H buffers 467a, 467b are again powered up (bufp_pdb and

bufn_pdb), both C_{SHP} and C_{SHN} are put in feedback around their respective buffers and the SAR capacitors C_{ADCP} and C_{ADCN} within the ADC 217 are charged to the values stored on C_{SHP} and C_{SHN}.

[0064] This time-overlapping continuous integration at the input and output of the active integrator 326 results in faster panel scan time, which can also reduce operational current. A reduction in operational current may reduce battery consumption, which is particularly important in batter-operated systems having touch sense arrays.

[0065] In another embodiment of the active integration circuit 300, the single input, dual output S/H circuit 340 may be eliminated and the ADC 217 may be replaced with a sufficiently fast single input ADC. With a sufficiently fast AC, the ADC may rapidly sample the positive going and negative going signals emanating from the integrator circuit 326 on the output 454 directly and then the processing core 102 may subtract the two signals digitally.

[0066] **Figure 10** is another embodiment of **Figure 2** showing the capacitance sensor 101 configured to provide a calibration unit 321 configured to provide a self-calibration of the capacitance sensor 101 and coupled between the input TX signal 227 and the touch sense array 121 via a selection circuit 1092 and the demultiplexer 212. The calibration unit 321 comprises a first capacitor 1094, also labeled CFM, a second capacitor 1096, also labeled CM, and a switch 1098 in series with the second capacitor 1096. The calibration unit 321 is configured to facilitate calibration of the capacitance sensor 101 by using the capacitors 1094, 1096 to simulate an absence and a presence of a conductive object. The calibration unit 321 can be used to calibrate for mutual capacitance sensing, as well as self capacitance sensing. For example, a touch event can be simulated by the switch 1098 being opened, and a no-touch event can be simulated by the switch 1098 being closed, respectively (i.e., since the value of the mutual capacitance is actually reduced during touch). Using these on-chip capacitors, a touch-like signal can be produced which permits a measurement (and

subsequent correction) of each channel's front-to-end gain. After calibration is complete, all channels exhibit the same overall gain to a real touch signal, which significantly improves the calculation accuracy of the finger-touch location. A method for gain calibration may include programming of the actual capacitance value of each of the integration capacitors (or a digital value 1004).

[0067] In self calibration mode, each channel 1000a-1000n of the touch sense array 121 may be further calibrated by scanning through the channels 1000a-1000n one at a time via the demultiplexor 212, multiplexor 213, the active integrator 326, the sample-and-hold circuit 340, and the ADC 217, which in turn is digitally interfaced to the processing core 102. In an embodiment, a selected one of the channels 1000a-1000n is continuously integrate by the active integrator 326, the sample-and-hold circuit 340, and the ADC 217 according to the method illustrated in **Figure 8**. A selection circuit 802 and two or more gain correction values 804 are simulated in software within the processing core 102 for digitally calibrating channel variance due to component variations within and between the same or different touch sense arrays 121 during factory or in-service operation of the capacitance sensor 101. Some or all of the components 1002, 1004 may be implemented using other techniques as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure.

[0068] Returning again to **Figure 10**, resulting calibration values 1004 are stored in memory and may be applied as a "digital gain correction" factor to each output of the channels 1000a-1000n. Digital gain correction permits touch location accuracies to less than about approximately 0.2 mm.

[0069] Returning to **Figure 4**, in an embodiment, the first integrating capacitor 456 and the second integrating capacitor 460 may be variable/programmable capacitors to permit a second degree of gain correction for eliminating channel gain variances.

[0070] Embodiments of the present invention, described herein, include various operations. These operations may be performed by hardware components, software, firmware, or a combination thereof. As used herein, the term "coupled to" may mean coupled directly or indirectly through one or more intervening components. Any of the signals provided over various buses described herein may be time multiplexed with other signals and provided over one or more common buses. Additionally, the interconnection between circuit components or blocks may be shown as buses or as single signal lines. Each of the buses may alternatively be one or more single signal lines and each of the single signal lines may alternatively be buses.

[0071] Certain embodiments may be implemented as a computer program product that may include instructions stored on a computer-readable medium. These instructions may be used to program a general-purpose or special-purpose processor to perform the described operations. A computer-readable medium includes any mechanism for storing or transmitting information in a form (e.g., software, processing application) readable by a machine (e.g., a computer). The computer-readable storage medium may include, but is not limited to, magnetic storage medium (e.g., floppy diskette); optical storage medium (e.g., CD-ROM); magneto-optical storage medium; read-only memory (ROM); random-access memory (RAM); erasable programmable memory (e.g., EPROM and EEPROM); flash memory, or another type of medium suitable for storing electronic instructions. The computer-readable transmission medium includes, but is not limited to, electrical, optical, acoustical, or other form of propagated signal (e.g., carrier waves, infrared signals, digital signals, or the like), or another type of medium suitable for transmitting electronic instructions.

[0072] Additionally, some embodiments may be practiced in distributed computing environments where the computer-readable medium is stored on and/or executed by more than one computer system. In addition, the information transferred between computer

systems may either be pulled or pushed across the transmission medium connecting the computer systems.

[0073] Although the operations of the method(s) herein are shown and described in a particular order, the order of the operations of each method may be altered so that certain operations may be performed in an inverse order or so that certain operation may be performed, at least in part, concurrently with other operations. In another embodiment, instructions or sub-operations of distinct operations may be in an intermittent and/or alternating manner.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

CLAIMS

What is claimed is:

1. A circuit, comprising

an active integrator configured to measure a capacitance of a touch sense array, wherein the active integrator is configured to receive from the touch sense array a response signal having a positive portion and a negative portion, wherein the response signal is representative of a presence or an absence of a conductive object on the touch sense array, and wherein the active integrator is configured to continuously integrate the response signal.

2. The circuit of claim 1, wherein the active integrator comprises a switched capacitor integrator.

3. The circuit of claim 1, wherein the active integrator is configured to have a pass-band centered about a fundamental frequency of the response signal.

4. The circuit of claim 1, further comprising:

a first feedback capacitor coupled to an output terminal of the active integrator and a first input terminal of the active integrator, wherein the first feedback capacitor is configured to store a charge responsive to the positive portion; and

a second feedback coupled to the output terminal of the active integrator and the first input terminal of the active integrator, wherein the second feedback capacitor is configured to store a charge responsive to the negative portion.

5. The circuit of claim 4, further comprising:

a first switch configured to connect or disconnect the first feedback capacitor between the output terminal and the first input terminal; and

a second switch connect to connect or disconnect the second feedback capacitor between the output terminal and the first input terminal.

6. The circuit of claim 5,

wherein the first switch is closed responsive to the positive portion and open responsive to the negative portion, and

wherein the second switch is closed responsive to the negative portion and open responsive to the positive portion.

7. The circuit of claim 1, further comprising a baseline compensation circuit coupled to a second input terminal of the active integrator and configured to minimize a direct current (DC) component of the response signal.

8. The circuit of claim 7, wherein the baseline compensation circuit comprises:

a digital-to-analog (D/A) converter;

a gain circuit coupled to the D/A converter; and

a first switch and a second switch, each coupled to the gain circuit and the second input terminal of the active integrator,

wherein the first switch is configured to apply a negative signal to the second input terminal of the active integrator when the positive portion is present, and wherein the second switch is configured to apply a positive signal to the second input terminal of the active integrator when the negative portion is present.

9. The circuit of claim 1, further comprising a sample-and-hold circuit coupled to an output terminal of the active integrator, wherein the output signal of the active integrator is impressed upon the sample-and-hold circuit.

10. The circuit of claim 9, wherein the sample-and-hold circuit comprising:

a first capacitor and a first switch connected in series and coupled between the output terminal of the active integrator and a first input terminal of an analog-to-digital converter (ADC); and

a second capacitor and a second switch connected in series and coupled between the output terminal of the active integrator and a second input terminal of the ADC,

wherein the first switch is configured to cause the first capacitor to hold a positive signal on the output terminal of the active integrator when the positive portion is present, and wherein the second switch is configured to cause the second capacitor to hold a negative signal on the output terminal of the active integrator when the negative portion is present.

11. The circuit of claim 1, further comprising a self-calibration circuit coupled between an input signal source and the touch sense array.

12. The circuit of claim 11, wherein the self-calibration circuit comprises:

a first capacitor coupled between the input signal source and the touch sense array;

a second capacitor coupled between the input signal source and the touch sense array; and

a switch in series with the second capacitor,

wherein the switch is configured to insert or remove the first capacitor to simulate a presence or an absence of a touch object.

13. The circuit of claim 1, further comprising a mode select circuit coupled to the active integrator and configured to permit the active integrator to integrate in a self-capacitance sensing mode and a mutual-capacitance sensing mode.

14. A method, comprising:

receiving a response signal at an active integrator from a touch sense array, the response signal having a positive portion and a negative portion; and

continuously integrating the response signal using the active integrator to measure a change in capacitance, wherein the change in capacitance is representative of an absence or a presence of the conductive object.

15. The method of claim 14, wherein continuously integrating the response signal further comprises:

(a) accumulating a charge responsive to the negative portion using a first capacitor coupled between an input terminal and an output terminal of the active integrator;

(b) accumulating a charge responsive to the positive portion using a second capacitor coupled between the input terminal and the output terminal of the active integrator; and

(c) repeating steps (a) and (b) for a predetermined number of cycles.

16. The method of claim 15, wherein said steps (a) and (b) further comprise:

sample-and-holding the charge responsive to the negative portion on a third capacitor coupled between the output terminal of the integration circuit and a first input terminal of an analog-to-digital converter (ADC); and

sample-and-holding the charge responsive to the positive portion to on fourth coupled between the output terminal of the integration circuit and a second input terminal of the ADC.

17. The method of claim 16, wherein said steps (a) and (b) further comprise:

(d) measuring a differential voltage across a combination of the third capacitor and the fourth capacitor;

(e) discharging charge across each of the first, second, third, and fourth capacitors; and

(f) repeating steps (a)-(e).

17. The method of claim 14, further comprising:

applying a baseline compensation to a first input terminal of the integration circuit, wherein said applying comprises:

applying a negative signal to the a first input terminal when the positive portion is present; and

applying a positive signal to the a first input terminal when the negative portion is present.

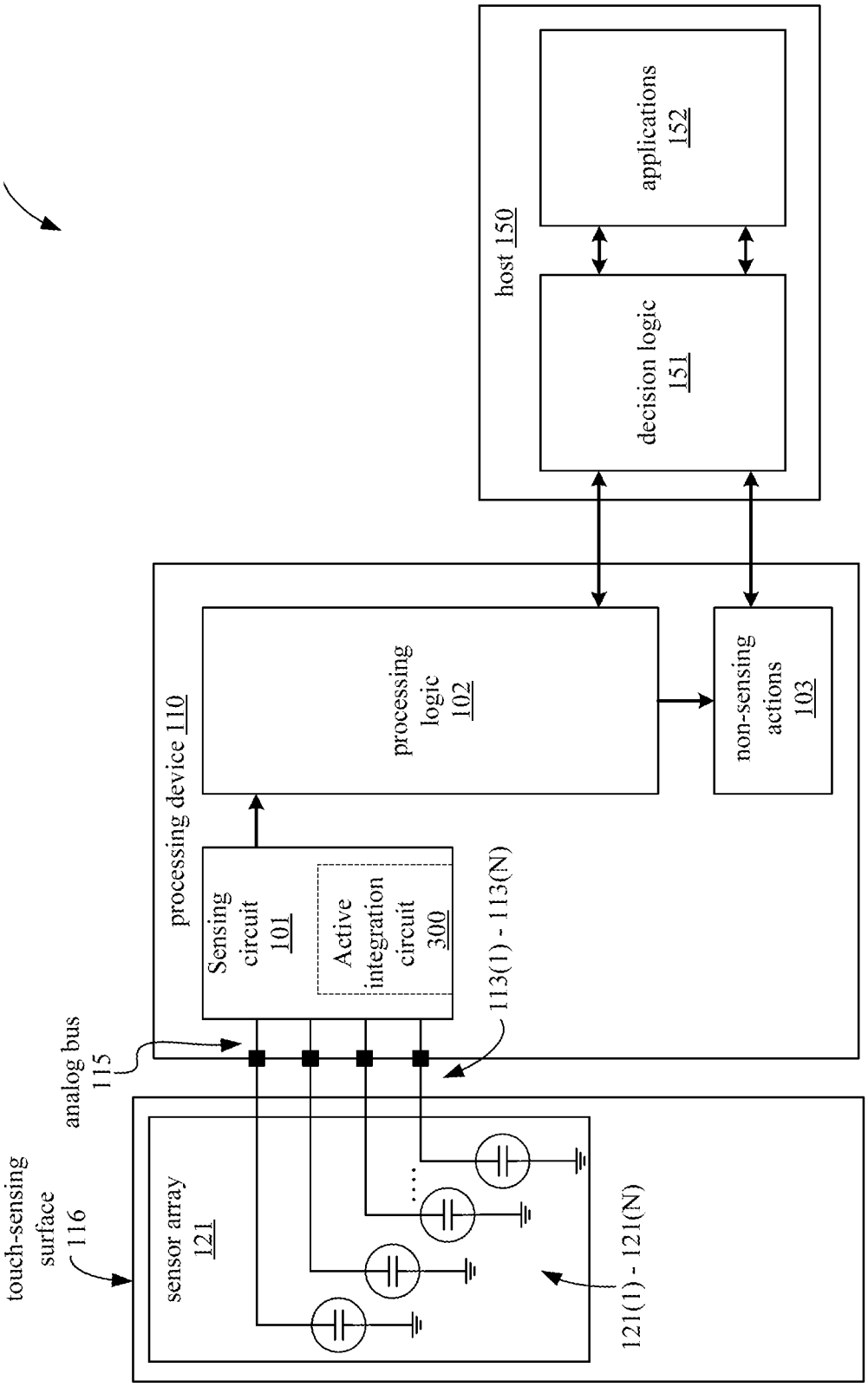
19. An apparatus, comprising:

a processing device configured to detect a presence of a conductive object on a touch sense array, wherein the processing device comprises a capacitive sensing circuit, comprising an active integrator configured to measure a capacitance of the touch sense array, wherein the active integrator is configured to receive from the touch sense array a response signal having a positive portion and a negative portion, wherein the response signal is representative of a presence or an absence of the conductive object on the touch sense array, and wherein the active integrator is configured to continuously integrate the response signal.

20. The apparatus of claim 19, further comprising:

a first feedback capacitor coupled to an output terminal of the active integrator and a first input terminal of the active integrator, wherein the first feedback capacitor is configured to store a charge responsive to the positive portion; and

a second feedback coupled to the output terminal of the active integrator and the first input terminal of the active integrator, wherein the second feedback capacitor is configured to store a charge responsive to the negative portion.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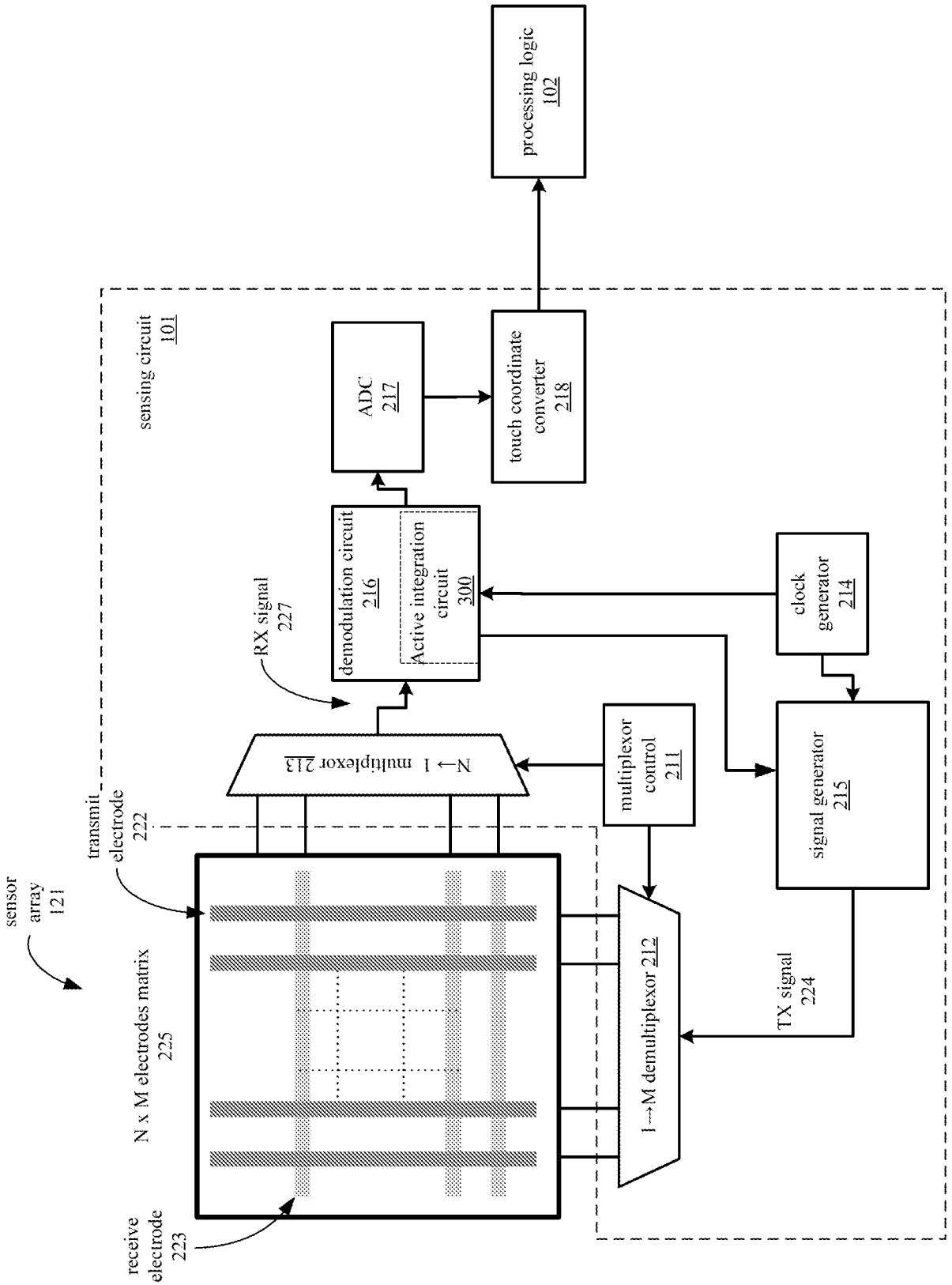
100
host 150
applications
152
decision logic
151
processing device 110
processing
logic
102
non-sensing
actions
103
Sensing
circuit
101
Active
integration
circuit
300
113(1) - 113(N)
analog bus
115
touch-sensing
surface
116
sensor array
121
121(1) - 121(N)

FIGURE 1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sensing circuit 101
ADC 217
touch coordinate converter 218
demodulation circuit 216
Active integration circuit 300
RX signal 227
clock generator 214
N→1 multiplexor 213
multiplexor control 211
signal generator 215
transmit electrode 222
sensor array 121
N x M electrodes matrix 225
1→M demultiplexor 212
TX signal 224
receive electrode 223

FIGURE 2

FIGURE 3

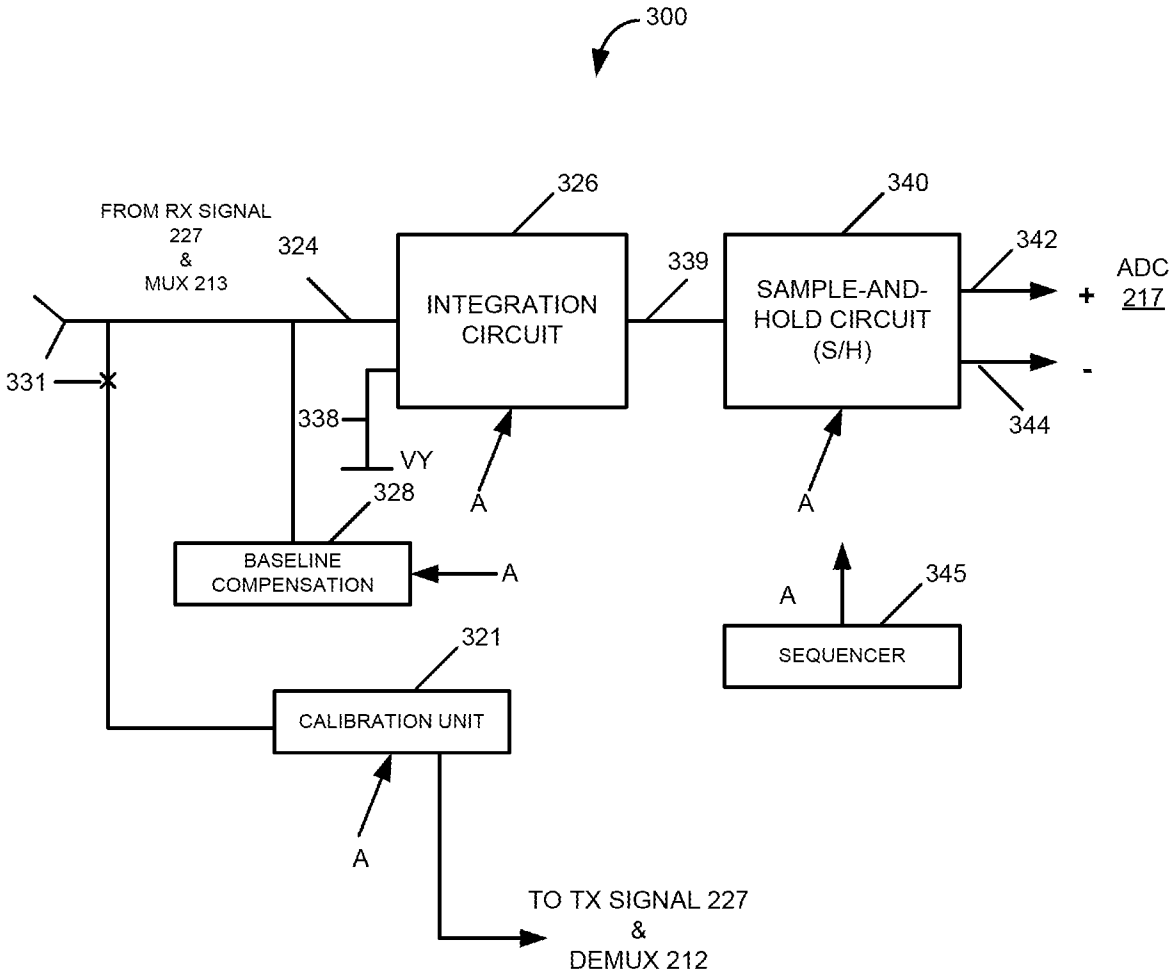

300
FROM RX SIGNAL 227 & MUX 213
324
326
INTEGRATION CIRCUIT
339
340
SAMPLE-AND-HOLD CIRCUIT (S/H)
342
ADC 217
+
-
344
331
338
VY
328
A
A
BASELINE COMPENSATION
A
A
345
SEQUENCER
321
CALIBRATION UNIT
A
TO TX SIGNAL 227 & DEMUX 212

FIGURE 4

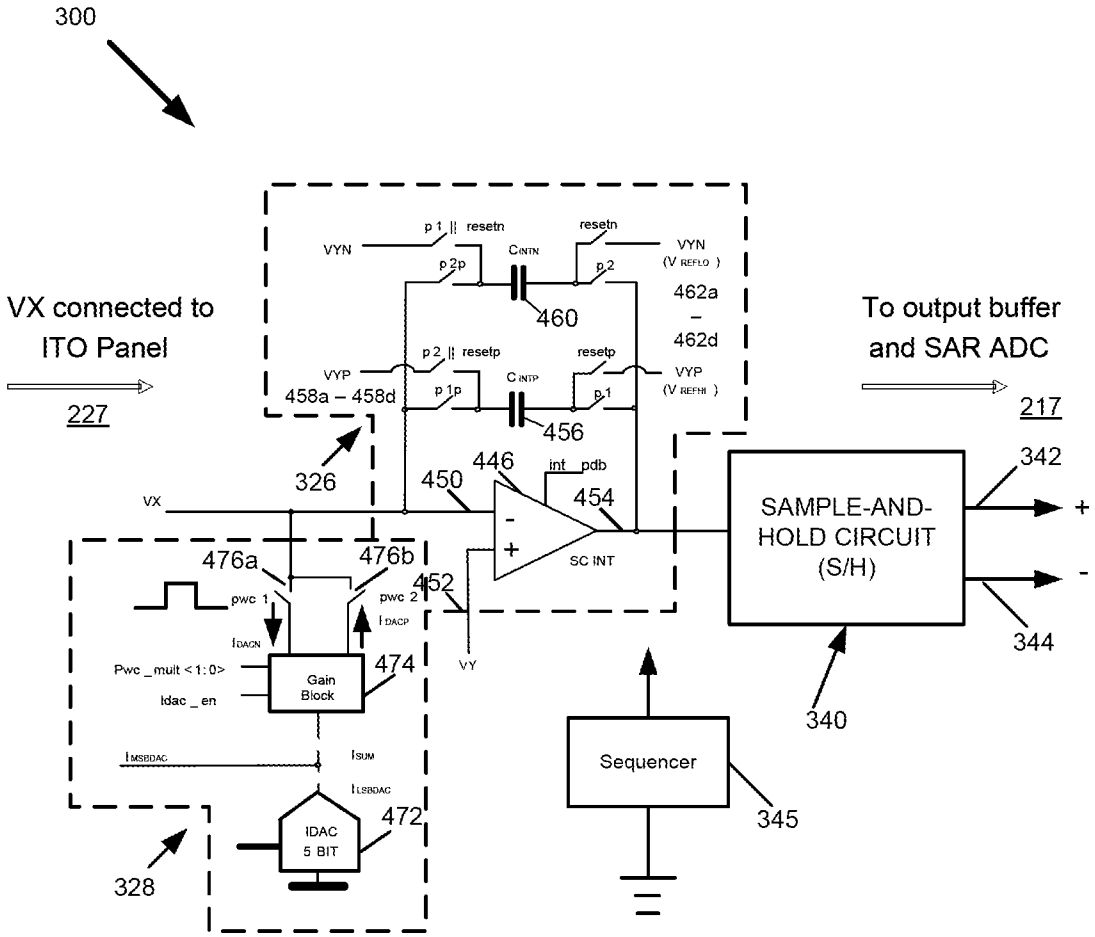
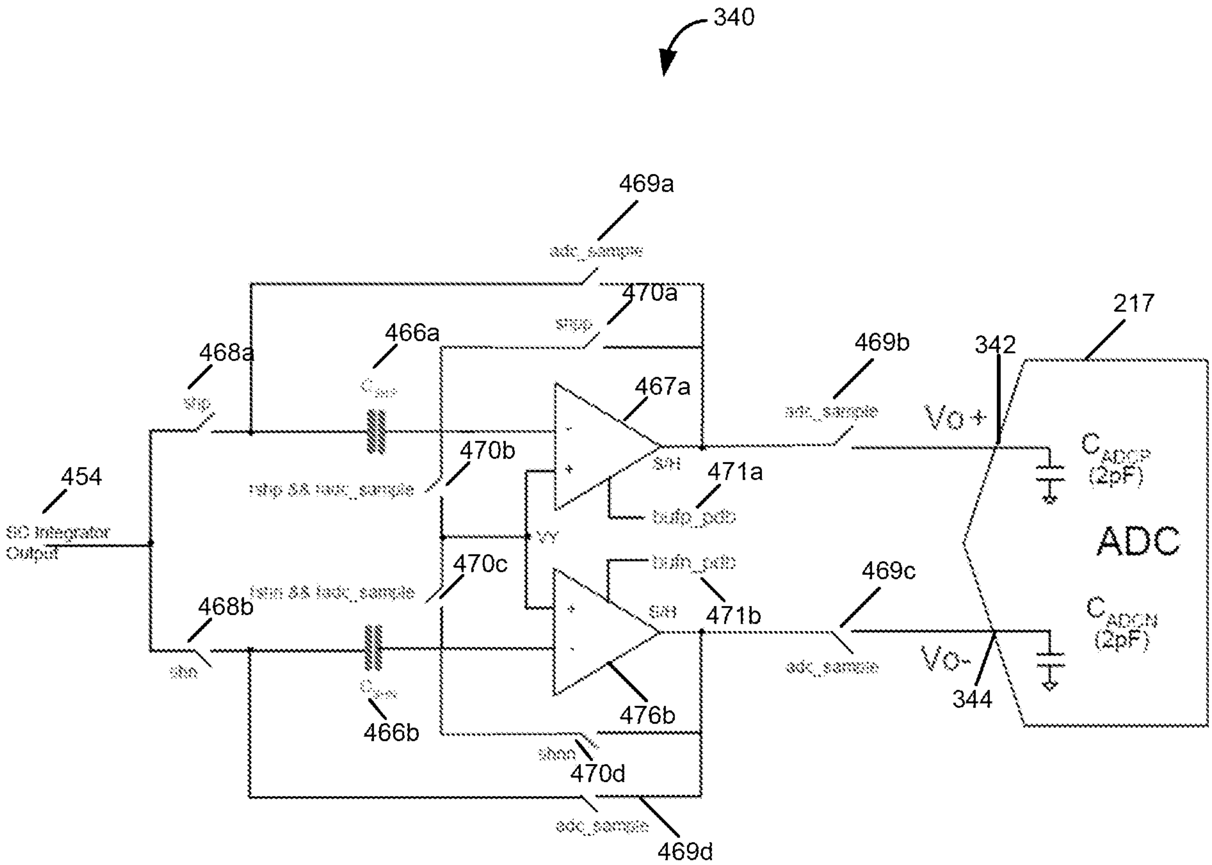


FIGURE 4

FIGURE 5


340
469a
adc_sample
470a
466a
468a
467a
469b
342
217
454
470b
471a
Vo+
ADC
VY
470c
469c
468b
471b
Vo-
adc_sample
344
466b
476b
470d
adc_sample
469d
(2pF)
(2pF)

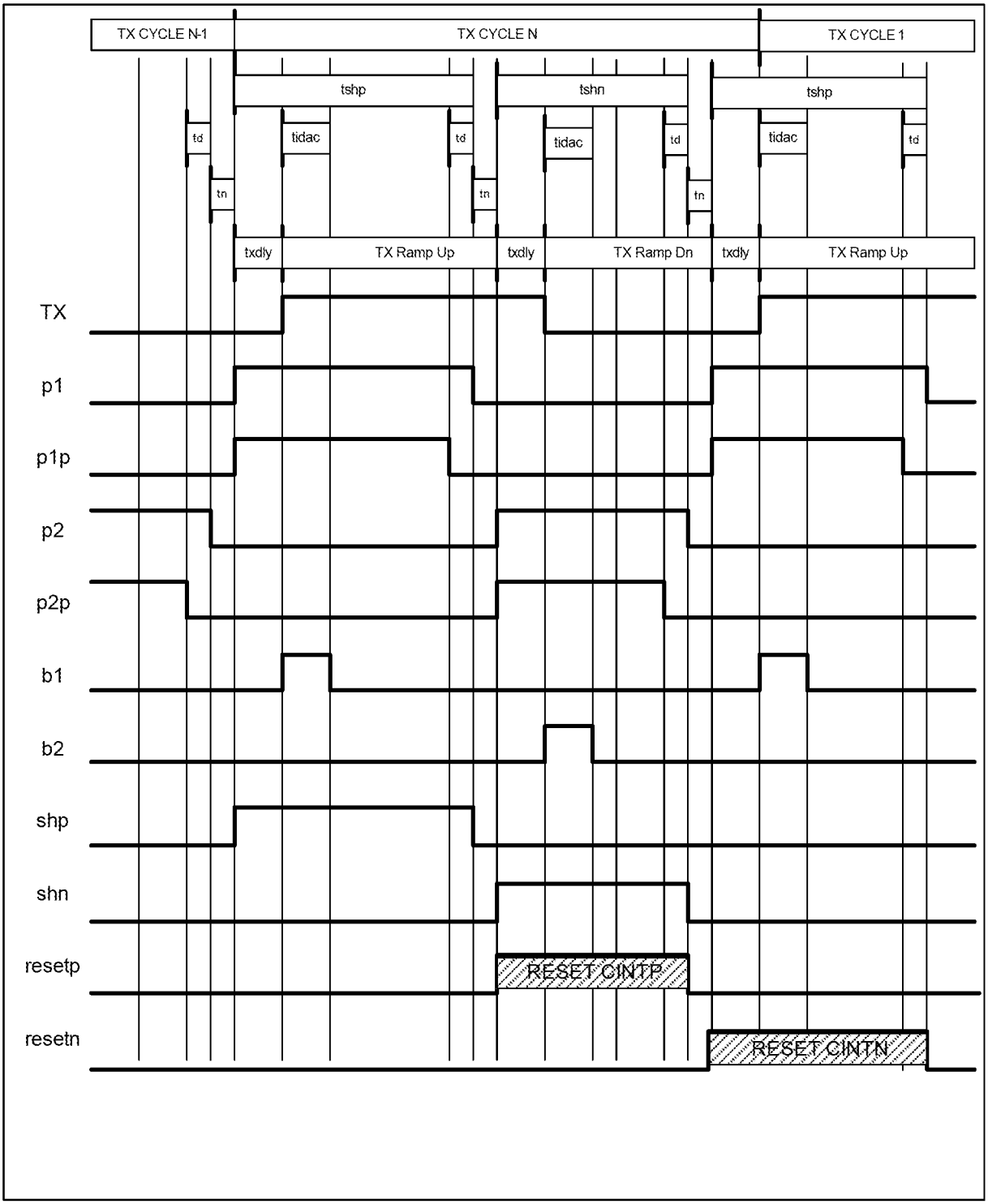

TX CYCLE N-1
TX CYCLE N
TX CYCLE 1
tshp
tshn
tshp
td
tidac
td
tidac
td
tidac
td
tn
tn
tn
txdly
TX Ramp Up
txdly
TX Ramp Dn
txdly
TX Ramp Up
TX
p1
p1p
p2
p2p
b1
b2
shp
shn
resetp
RESET CINTP
resetn
RESET CINTN

FIGURE 6A

FIGURE 6B

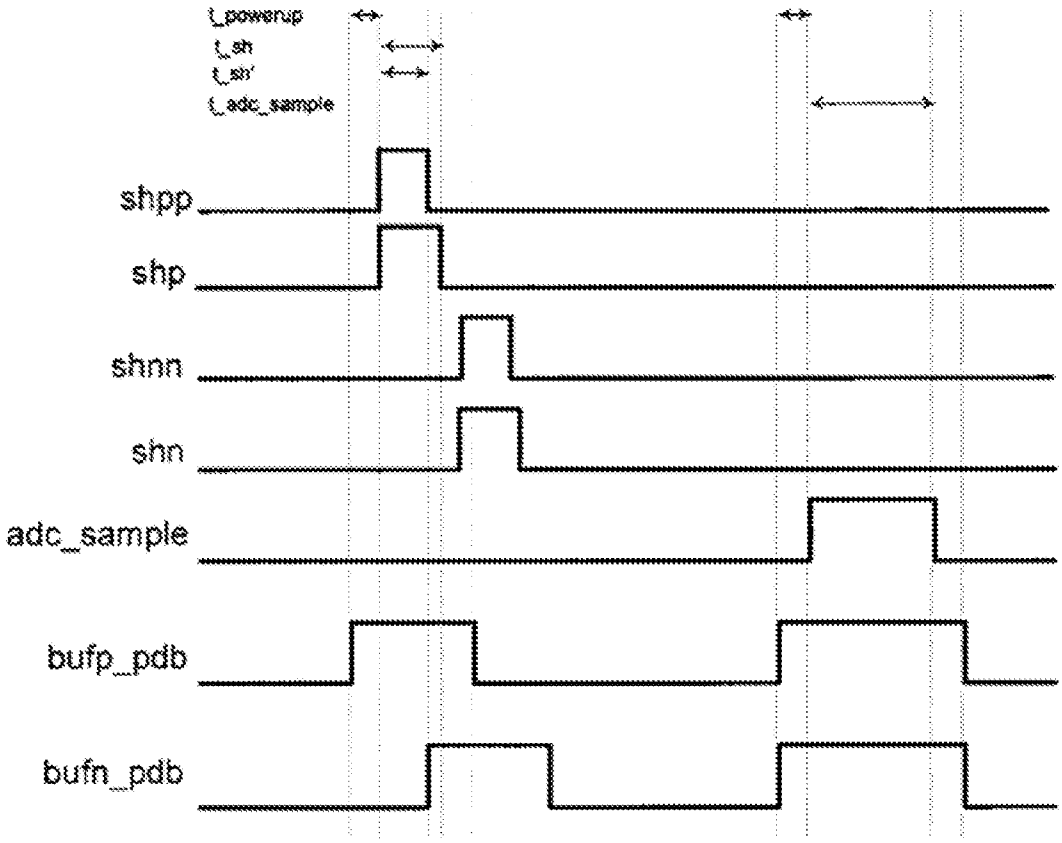
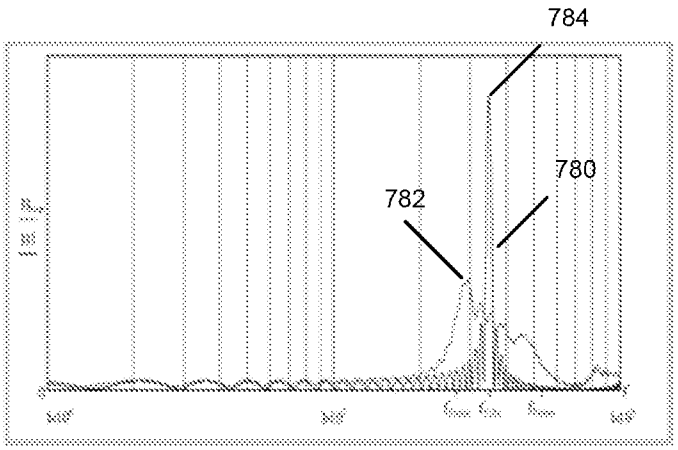

t_powerup
t_sh
t_sh'
t_adc_sample
shpp
shp
shnn
shn
adc_sample
bufp_pdb
bufn_pdb

FIGURE 7



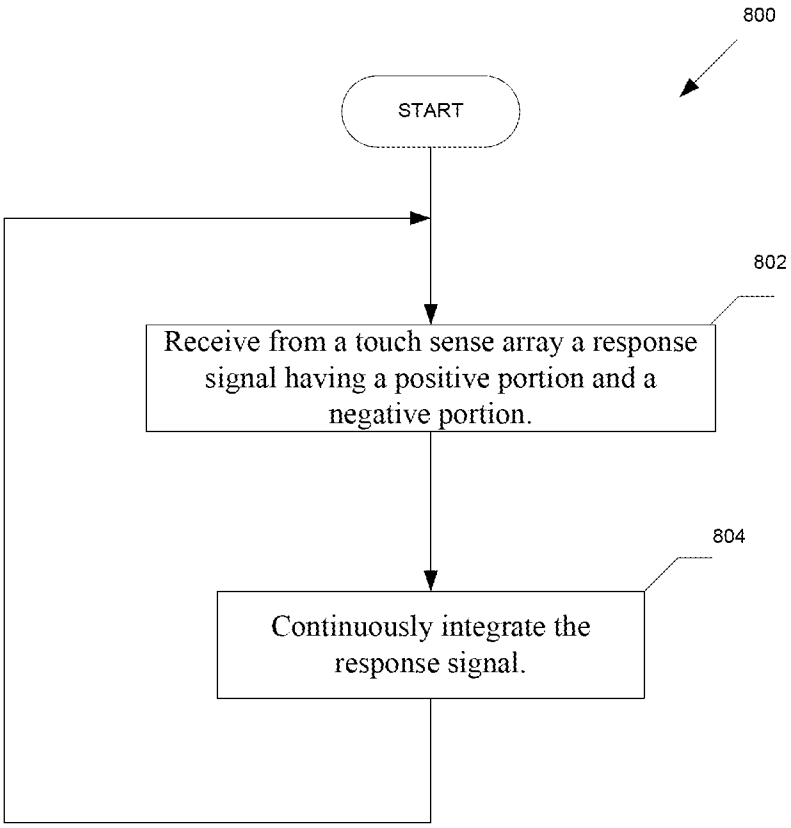

800
START
802
Receive from a touch sense array a response signal having a positive portion and a negative portion.
804
Continuously integrate the response signal.

FIG. 8

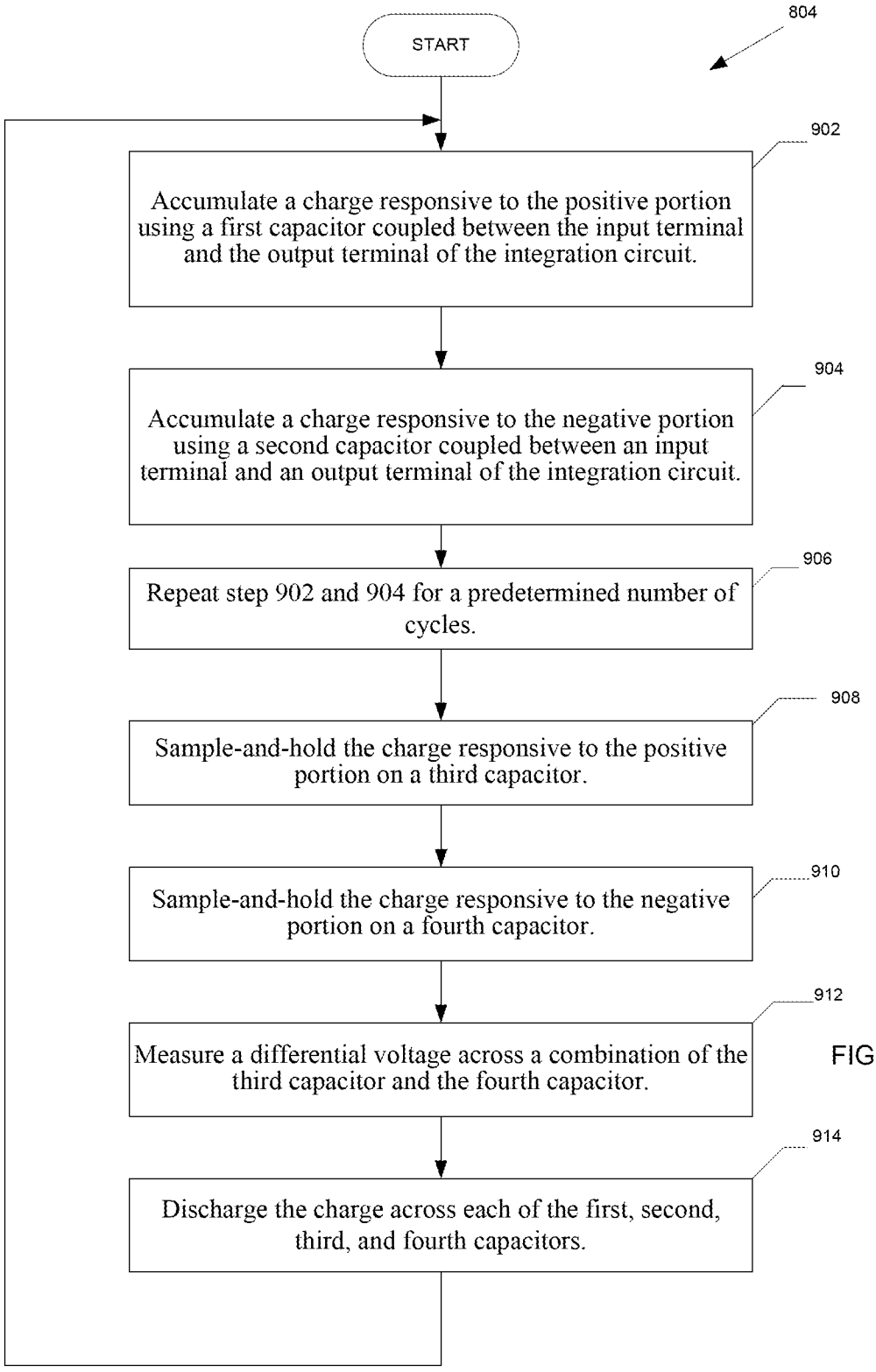

804
START
902
Accumulate a charge responsive to the positive portion using a first capacitor coupled between the input terminal and the output terminal of the integration circuit.
904
Accumulate a charge responsive to the negative portion using a second capacitor coupled between an input terminal and an output terminal of the integration circuit.
906
Repeat step 902 and 904 for a predetermined number of cycles.
908
Sample-and-hold the charge responsive to the positive portion on a third capacitor.
910
Sample-and-hold the charge responsive to the negative portion on a fourth capacitor.
912
Measure a differential voltage across a combination of the third capacitor and the fourth capacitor.
914
Discharge the charge across each of the first, second, third, and fourth capacitors.

FIGURE 9

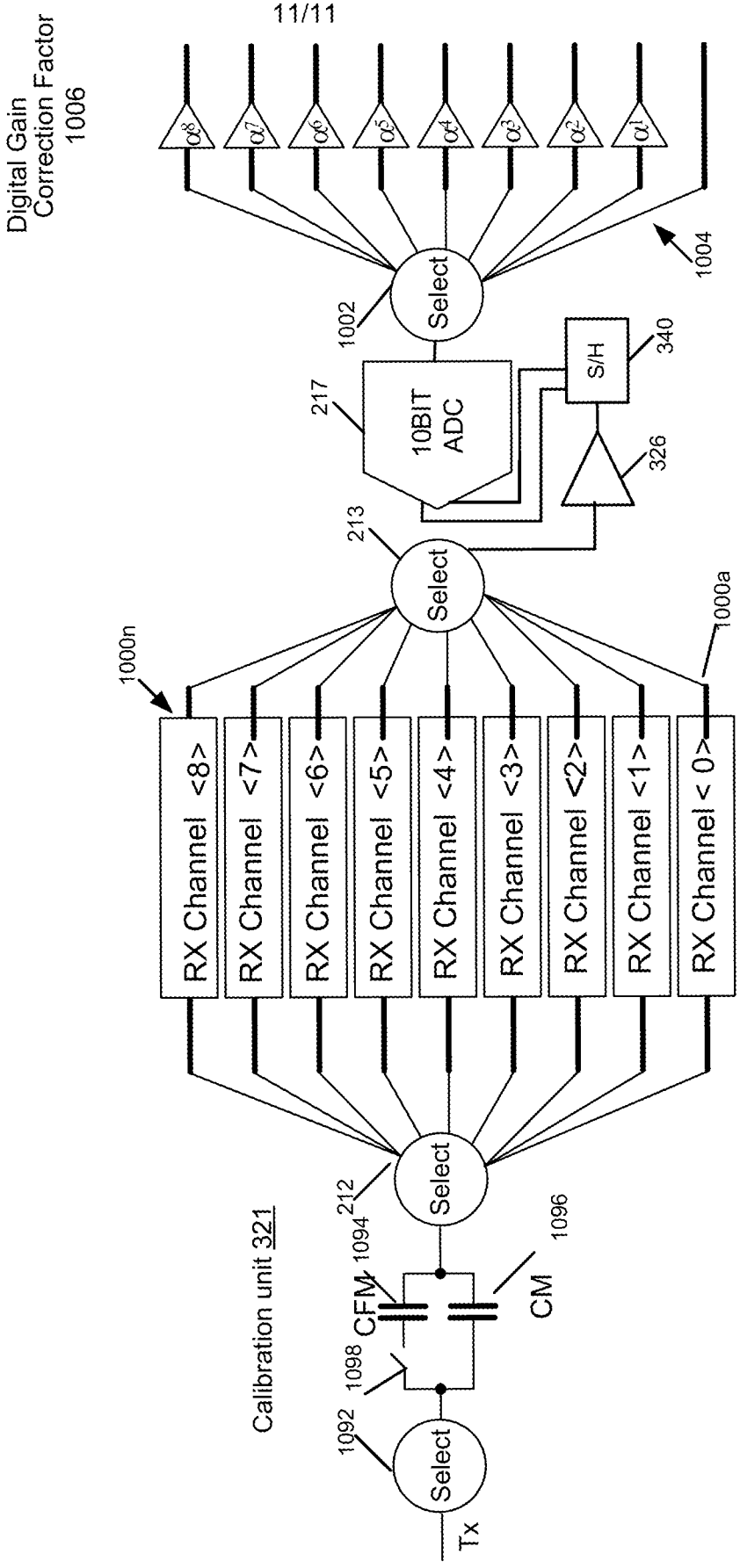

Digital Gain Correction Factor 1006
α8
α7
α6
α5
α4
α3
α2
α1
1004
Select
1002
217
10BIT ADC
S/H
340
326
213
Select
1000n
1000a
RX Channel <8>
RX Channel <7>
RX Channel <6>
RX Channel <5>
RX Channel <4>
RX Channel <3>
RX Channel <2>
RX Channel <1>
RX Channel < 0>
Select
212
Calibration unit 321
1094
CFM
1096
CM
1098
1092
Select
Tx

FIGURE 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 11/67153

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G06F 3/045 (2012.01)
USPC - 345/174
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)
345/174

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
178/18.06 | 324/686 | 156/253 | 156/60

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST(USPT, PGPB, EPAB, JPAB); Google Scholar; Self-calibration, sample-and-hold, analog-to-digital, touch sense array, feedback, converter, open, close, switch, presence, absence, conductive object, measuring, integrating, pass-band,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2011/0025629 A1 (Grivna et al.) 03 February 2011 (03.02.2011) entire document (especially para [0016]-[0117],[0023],[0026],[0029],[0033]-[0037],[0045]-[0046])	1-6 , 13-15, 17b, 19-20 --- 7-12, 16-17a
Y	US 2008/0048997 A1 (Gilliespie et al.) 28 February 2008 (28.02.2008) entire document (especially para [0070],[0109][0114],[0123],[0127]-[0131],[0141]-[0144],[0147],[0165]-[0067], [0177])	7-12, 16-17a
Y	US 2009/0160461 A1 (Zangl et al.) 25 June 2009 (25.06.2009) para [0076]-[0079]	1-17a, 17b, 19-20
Y	US 2009/0008161 A1 (Jones et al.) 08 January 2009 (08.01.2009) para [0052]-[0056], [0071],[0076]-[0077])	1-17a, 17b, 19-20
A	US 2011/0007021 A1 (Bernstein et al.) 13 January 2011 (13.01.2011) entire document	1-17a, 17b, 19-20

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
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Date of the actual completion of the international search	Date of mailing of the international search report
05 April 2012 (05.04.2012)	24 APR 2012
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

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