

(43) International Publication Date
30 January 2014 (30.01.2014)

(51) International Patent Classification:

G06F 3/0354 (2013.01) G06F 3/044 (2006.01)
G06F 3/041 (2006.01)

(21) International Application Number:

PCT/US2013/046021

(22) International Filing Date:

14 June 2013 (14.06.2013)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

13/560,953 27 July 2012 (27.07.2012) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) Title: STYLUS DEVICE

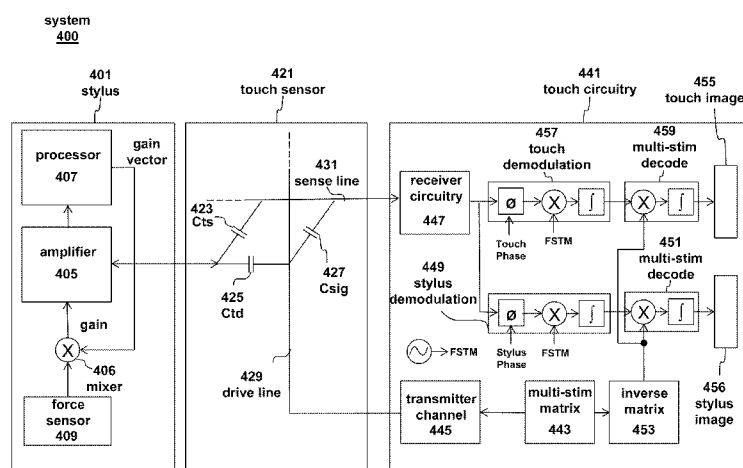


FIG. 4

(57) **Abstract:** Styluses capable of generating stylus stimulation signals and touch sensitive devices capable of receiving stylus stimulation signals are disclosed. In one example, a stylus can receive a stimulation signal from a touch sensor of a touch sensitive device and generate a stylus stimulation signal by changing an amplitude or frequency of the received stimulation signal. The stylus can transmit the stylus stimulation signal back into the touch sensor of the touch sensitive device. The touch sensor can generate a touch signal based on the device's own stimulation signals and the stylus stimulation signal. The touch sensitive device can process the touch signal to determine a location of the stylus on the touch sensor. The stylus can include a force sensor to detect an amount of force applied to a tip of the stylus. The stylus stimulation signal can be modulated based on the force detected by the force sensor.

STYLUS DEVICE

Field

[0001] This relates generally to touch sensitive devices and, more specifically, to styluses for use with touch sensitive devices.

Background

[0002] Touch sensitive devices have become popular as input devices to computing systems due to their ease and versatility of operation as well as their declining price. A touch sensitive device can include a touch sensor panel, which can be a clear panel with a touch sensitive surface, and a display device, such as a liquid crystal display (LCD), that can be positioned partially or fully behind the panel or integrated with the panel so that the touch sensitive surface can cover at least a portion of the viewable area of the display device. The touch sensitive device can allow a user to perform various functions by touching the touch sensor panel using a finger, stylus or other object at a location often dictated by a user interface (UI) being displayed by the display device. In general, the touch sensitive device can recognize a touch event and the position of the touch event on the touch sensor panel, and the computing system can then interpret the touch event in accordance with the display appearing at the time of the touch event, and thereafter can perform one or more actions based on the touch event.

[0003] As touch sensing technology continues to improve, touch sensitive devices are increasingly being used to compose and mark-up electronic documents. In particular, styluses have become popular input devices as they emulate the feel of traditional writing instruments. However, while touch sensing technology has greatly improved over the past few years, little has been done to improve the stylus itself. Most conventional styluses simply include a bulky tip made of a material capable of interacting with the touch sensitive device. As a result, conventional styluses lack the precision and control of traditional writing instruments.

Summary

[0004] Styluses capable of receiving stimulation and force signals and generating stylus stimulation signals, and touch sensitive devices capable of receiving stylus stimulation signals are disclosed. In one example, a stylus can receive a stimulation signal from a touch sensor of a touch sensitive device and generate a stylus stimulation signal by changing an amplitude or frequency of the received stimulation signal. The stylus can transmit the stylus stimulation signal back into the touch sensor of the touch sensitive device. The touch sensor can generate a touch signal based on the device's own stimulation signals and the stylus stimulation signal. The touch sensitive device can process the touch signal to determine a location of the stylus on the touch sensor. The stylus can include a force sensor to detect an amount of force applied to a tip of the stylus. The stylus stimulation signal can be modulated based on the force detected by the force sensor.

[0005] In one example, a touch sensor of a touch sensitive device can generate a touch signal based on the device's own stimulation signals and the stylus stimulation signal. The touch sensitive device can process the touch signal to determine that a stylus has been detected, a location of the stylus on the touch sensor, and an amount of pressure applied by the stylus to the touch sensitive device. The determinations can be made based on properties of the touch signal caused by the stylus stimulation signal.

[0006] Processes for generating and processing stylus stimulation signals are also disclosed.

Brief Description of the Drawings

[0007] FIG. 1 illustrates an exemplary touch sensor that can be used with a touch sensitive device according to various embodiments.

[0008] FIG. 2 illustrates a block diagram of an exemplary stylus according to various embodiments.

[0009] FIG. 3 illustrates a system block diagram showing the interaction between a touch sensitive device and an exemplary stylus according to various embodiments.

[0010] FIG. 4 illustrates a system block diagram showing the interaction between another touch sensitive device and an exemplary stylus according to various embodiments.

[0011] FIG. 5 illustrates an exemplary touch and stylus combo matrix according to various embodiments.

[0012] FIG. 6 illustrates exemplary stylus stimulus vectors according to various embodiments.

[0013] FIG. 7 illustrates an exemplary touch/stylus combo system according to various embodiments.

[0014] FIG. 8 illustrates a system block diagram showing the interaction between a touch sensitive device and another exemplary stylus according to various embodiments.

[0015] FIG. 9 illustrates an exemplary process for generating a stylus stimulation signal according to various embodiments.

[0016] FIG. 10 illustrates an exemplary process for processing a stylus stimulation signal according to various embodiments.

[0017] FIG. 11 illustrates an exemplary system for generating or processing a stylus stimulation signal according to various embodiments.

[0018] FIG. 12 illustrates an exemplary personal device that includes a touch sensor according to various embodiments.

[0019] FIG. 13 illustrates another exemplary personal device that includes a touch sensor according to various embodiments.

Detailed Description

[0020] In the following description of example embodiments, reference is made to the accompanying drawings in which it is shown by way of illustration specific embodiments that can be practiced. It is to be understood that other embodiments can be used and structural changes can be made without departing from the scope of the various embodiments.

[0021] This relates to styluses capable of receiving stimulation and force signals and generating stylus stimulation signals and touch sensitive devices capable of receiving

stylus stimulation signals. In one example, a stylus can receive a stimulation signal from a touch sensor of a touch sensitive device and generate a stylus stimulation signal by changing an amplitude or frequency of the received stimulation signal. The stylus can transmit the stylus stimulation signal back into the touch sensor of the touch sensitive device. The touch sensor can generate a touch signal based on the device's own stimulation signals and the stylus stimulation signal. The touch sensitive device can process the touch signal to determine a location of the stylus on the touch sensor. The stylus can include a force sensor to detect an amount of force applied to a tip of the stylus. The stylus stimulation signal can be modulated based on the force detected by the force sensor. A touch sensor of a touch sensitive device can generate a touch signal based on the device's own stimulation signals and the stylus stimulation signal. The touch sensitive device can process the touch signal to determine that a stylus has been detected, a location of the stylus on the touch sensor, and an amount of pressure applied by the stylus to the touch sensitive device. The determinations can be made based on properties of the touch signal caused by the stylus stimulation signal. Processes for generating and processing stylus stimulation signals are also disclosed.

[0022] FIG. 1 illustrates touch sensor 100 that can be used to detect touch events on a touch sensitive device, such as a mobile phone, tablet, touchpad, portable computer, portable media player, or the like. Touch sensor 100 can include an array of touch regions or nodes 105 that can be formed at the crossing points between rows of drive lines 101 (D0-D3) and columns of sense lines 103 (S0-S4). Each touch region 105 can have an associated mutual capacitance C_{sig} 111 formed between the crossing drive lines 101 and sense lines 103 when the drive lines are stimulated. The drive lines 101 can be stimulated by stimulation signals 107 provided by drive circuitry (not shown) and can include an alternating current (AC) waveform. The sense lines 103 can transmit touch signals 109 indicative of a touch at the touch sensor 100 to sense circuitry (not shown), which can include a sense amplifier for each sense line, or a fewer number of sense amplifiers that can be multiplexed to connect to a larger number of sense lines.

[0023] To sense a touch at the touch sensor 100, drive lines 101 can be stimulated by the stimulation signals 107 to capacitively couple with the crossing sense lines 103, thereby forming a capacitive path for coupling charge from the drive lines 101 to the sense lines 103. The crossing sense lines 103 can output touch signals 109, representing

the coupled charge or current. When an object, such as a stylus, finger, etc., touches the touch sensor 100, the object can cause the capacitance C_{sig} 111 to reduce by an amount ΔC_{sig} at the touch location. This capacitance change ΔC_{sig} can be caused by charge or current from the stimulated drive line 101 being shunted through the touching object to ground rather than being coupled to the crossing sense line 103 at the touch location. The touch signals 109 representative of the capacitance change ΔC_{sig} can be transmitted by the sense lines 103 to the sense circuitry for processing. The touch signals 109 can indicate the touch region where the touch occurred and the amount of touch that occurred at that touch region location.

[0024] While the embodiment shown in FIG. 1 includes four drive lines 101 and five sense lines 103, it should be appreciated that touch sensor 100 can include any number of drive lines 101 and any number of sense lines 103 to form the desired number and pattern of touch regions 105. Additionally, while the drive lines 101 and sense lines 103 are shown in FIG. 1 in a crossing configuration, it should be appreciated that other configurations are also possible to form the desired touch region pattern. While FIG. 1 illustrates mutual capacitance touch sensing, other touch sensing technologies may also be used in conjunction with embodiments of the disclosure, such as self-capacitance touch sensing, resistive touch sensing, projection scan touch sensing, and the like. Furthermore, while various embodiments describe a sensed touch, it should be appreciated that the touch sensor 100 can also sense a hovering object and generate hover signals therefrom.

[0025] FIG. 2 illustrates a block diagram of an exemplary stylus 200 that can be used with a touch sensitive device, such as a mobile phone, touchpad, portable computer, or the like. Stylus 200 can generally include tip 201, ring 203, body 207, and stylus stimulation signal circuitry 205 located within body 207. As will be described in greater detail below, stylus stimulation signal circuitry 205 can be used to generate a stimulation signal that can be transmitted to a touch sensitive device through tip 201. Tip 201 can include a material capable of transmitting the stylus stimulation signal from stylus stimulation signal circuitry 205 to the touch sensitive device, such as a flexible conductor, a metal, a conductor wrapped by a non-conductor, a non-conductor coated with a metal, a transparent conducting material (e.g., indium tin oxide (ITO)) or a transparent non-conductive material (e.g., glass) coated with a transparent (e.g., ITO) (if the tip is also

used for projection purposes) or opaque material, or the like. In some examples, tip 201 can have a diameter of 1mm or less. Tip 201 can be coupled to body 207 by ring 203. Ring 203 can include a conductive material, such as a flexible conductor, a metal, a conductor wrapped by a non-conductor, a non-conductor coated with a metal, a transparent conducting material (e.g., ITO) or a transparent non-conductive material (e.g., glass) coated with a transparent (e.g., ITO if the tip is used for projection purposes) or opaque material, or the like. Ring 203 can serve other purposes, such as providing an alternative means for transmitting the stylus stimulation signal from the stylus to the touch sensitive device by serving as an antenna for a wireless module (e.g., RFID, Bluetooth, WI-FI, or the like). Similarly, tip 201 can also be used to sense the touch signal from the touch sensitive device. Both tip 201 and ring 203 can be segmented and each segment can be independently controlled according to the description above.

[0026] In some examples, stylus 200 can be a modular stylus, such as that described in U.S. Patent Application No. 13/560,960, entitled “Modular Stylus Device,” filed on March 5, 2012.

[0027] FIG. 3 illustrates a functional block diagram of an exemplary system 300 showing the interaction between stylus 301, touch sensor 321, and touch circuitry 341. In this embodiment, a stimulation signal from touch sensor 321 can be detected at a location where the tip of stylus 301 contacts or is near touch sensor 321 (e.g., where the tip contacts or hovers above a screen of a touch sensitive device). A modified stimulation signal can then be transmitted back into touch sensor 321 at the same frequency in phase or at an arbitrary phase (including quadrature) at the same location. The modified stimulation signal can be transmitted back into touch sensor 321 through the tip and/or ring of stylus 301. It should be appreciated that FIG. 3 is a functional block diagram and that the actual components used to implement the various portions of system 300 can vary and one of ordinary skill, given the functional diagram, can select known circuit elements to implement the system.

[0028] Stylus 301 is one example of stylus 200 that can be used as an input device to a touch sensitive device having a touch sensor similar or identical to touch sensor 100. Stylus 301 can be configured to generate a stylus stimulation signal having a greater magnitude than that generated by the touch sensitive device. Thus, when stylus 301 is used with a touch sensitive device, stylus 301 can cause the touch sensitive device to

measure a “negative” touch. In other words, the charge detected at the stylus’ touch location can be greater than the amount of charge detected when no touch is present. This is different than non-stylus touch events, which typically cause the charge detected at the touch location to decrease.

[0029] Stylus 301 can include amplifier 305 coupled to receive a stimulation signal (e.g., a stimulation signal similar or identical to stimulation signal 107) generated by an associated touch sensitive device and transmit a stylus stimulation signal to the associated touch sensitive device. The associated touch sensitive device can include a touch sensitive device in contact with, or in close proximity to, the tip of stylus 301. Stylus 301 can receive the stimulation signal through the touch sensor (e.g., touch sensor 321) of the touch sensitive device. Amplifier 305 can be configured to receive and amplify the stimulation signal by an amount based at least in part on a force detected by force sensor 309 and a gain vector generated by processor 307. In some examples, amplifier 305 can be configured to amplify the received stimulation signal by an amount representing an increase of capacitance by 0.1pF or more, depending on the particular configuration. However, it should be appreciated that other amplifications can be used depending on the system design.

[0030] Stylus 301 can further include force sensor 309 to detect an amount of force applied to the tip of stylus 301. Force sensor 309 can include any type of force sensor, such as a capacitive pressure sensor, semiconductor strain gauge, or the like. The amount of force detected by force sensor 309 can be used by amplifier 305 to determine the amount of amplification to be applied to the stimulation signal received from the associated touch sensitive device. In this way, the magnitude of the amplified stimulation signal generated by amplifier 305 can be adjusted based on how hard the stylus tip is applied to the surface of the associated touch sensitive device. This allows stylus 301 to convey information associated with the location of its tip on the surface of the touch sensitive device as well as the amount of force being applied to the surface of the touch sensitive device. In response, the touch sensitive device can interpret the location and force information as two different inputs. For example, in a drawing application, a brush stroke can be displayed on the screen of the touch sensitive device corresponding to a location of the tip of stylus 301 and with a width corresponding to the amount of force being applied to the touch sensitive device by the tip of stylus 301.

[0031] Stylus 301 can further include processor 307 coupled to receive an amplified stimulation signal from amplifier 305. Processor 307 can be configured to generate a signal representative of a gain vector that can be used to modulate the amplified output of amplifier 305. The processor can monitor the stimulation signal received from the touch sensor 321 in order to synchronize the gain vector with the received stimulation sequence. The gain vector signal can be transmitted to mixer 306 where it, along with the output of force sensor 309, can be used to control the amount of amplification applied to the stimulation signal from touch sensor 321. The amplified and modulated stimulation signal can be transmitted back into touch sensor 321 as the stylus stimulation signal.

[0032] It should be appreciated that amplifier 305 can be configured to amplify the received stimulation signal based on the amount of force detected by force sensor 309 and the gain vector of processor 307 in many ways. In one example, amplifier 305 can include a regenerative amplifier operable to amplify the received stimulation signal using a feedback loop between the amplifier output and the amplifier input. The received stimulation signal can be added at the amplifier input in phase. The amplified stimulation signal can be transmitted to touch sensor 321, thereby increasing the signal charge locally between drive and sense (negative pixel) as opposed to reducing it in the presence of a touch. In this example, force sensor 309 can control one or more capacitive elements coupled between the input and output of amplifier 305. Switches can also be coupled to the capacitive elements to selectively couple the capacitive elements between the input and output of amplifier 305. The one or more capacitive elements can be configured such that the capacitance of each of the one or more capacitive elements is inversely related to the amount of force applied to the tip of stylus 301. Thus, as the force against the tip of stylus 300 increases, the capacitance of the one or more capacitive elements of force sensor 309 decreases, thereby increasing the overall gain of amplifier 305. Conversely, as the force against the tip of stylus 300 decreases, the capacitance of the one or more capacitive elements of force sensor 309 increases, thereby decreasing the overall gain of amplifier 305. In this example, processor 307 can be configured to cause amplifier 305 to modulate the stimulation signal using a gain vector by selectively coupling one of the one or more capacitive elements (each having a different capacitance value) between the input and output of amplifier 305 based on the gain vector. Processor 307 can accomplish this by selectively opening and closing the switches coupled to each capacitive element. In this way, the gain caused by each of the capacitive elements can be changed by adjusting

the pressure applied to the tip of stylus 301 while processor 307 can modulate the amplified signal by selecting between each of the capacitive elements having different capacitance values.

[0033] In some examples, amplifier 305 can be configured to yield a loop gain of less than one to prevent oscillation. In other alternative examples, amplifier 305 can include a super regenerative amplifier, comprised of an amplifier with a loop gain of greater than 1 and a quench signal generator having a quench rate based on the received stimulation signal from touch sensor 321. In these examples, the quench signal generator can apply a quench signal that can cause the gain of the regenerative amplifier to drop substantially below the gain needed for the regenerative amplifier to sustain oscillation, causing the regenerative amplifier to repeatedly go into oscillation at the beginning of each scan step. In yet other examples, amplifier 305 can add the received stimulation signal at the amplifier input in a different phase (including quadrature).

[0034] System 300 can further include touch sensor 321 of a touch sensitive device. Touch sensor 321 can include a touch sensor similar or identical to touch sensor 100, described above. As shown in FIG. 3, touch sensor 321 can include a drive line 329 coupled to receive a stimulation signal similar or identical to stimulation signal 107 from touch circuitry 341 and a sense line 331 capacitively coupled to drive line 329 and coupled to transmit a touch signal similar or identical to touch signal 109 to touch circuitry 341. It should be appreciated that touch sensor 321 is shown with only one drive line and one sense line for illustrative purposes only and that touch sensor 321 can actually include any number of drive lines and any number of sense lines.

[0035] A mutual capacitance C_{sig} 327 can be formed between the crossing drive line 329 and sense line 331 when the drive line is stimulated. Similarly, a mutual capacitance C_{ts} 323 and C_{td} 325 can be formed between the tip of stylus 301 and sense line 331 and drive line 329, respectively, when the stylus stimulation signal is generated. As mentioned above, if the tip of stylus 301 is placed near or at the crossing point between drive line 329 and sense line 331, stylus 301 can receive the stimulation signal transmitted on drive line 329 via the capacitive path formed between the stylus tip and drive line 329, amplify the received stimulation signal using amplifier 305, force sensor 309, and processor 307, and transmit an amplified stimulation signal in the form of a stylus stimulation signal back into touch sensor 321 via the capacitive path formed

between the stylus tip and sense line 331. Thus, the touch signal generated by sense line 331 can include charges coupled from both drive line 329 and stylus 301. As a result, the amount of charge detected by sense line 331 can increase when the tip of stylus 301 is placed on or above the crossing point between drive line 329 and sense line 331. This increase in charge can be used by the touch sensitive device to distinguish a stylus touch event from a non-stylus touch event because, as mentioned above, non-stylus touch events typically cause capacitance C_{sig} 327 to decrease due to charge or current from the stimulated drive line 329 being shunted through the non-stylus object to ground rather than being coupled to the crossing sense line 331 at the touch location. Moreover, the touch sensitive device can determine the location of the stylus touch event because the same stimulation signal being driven on drive line 329 is being amplified and transmitted back into the touch sensor at the crossing point between drive line 329 and sense line 331.

[0036] System 300 can further include touch circuitry 341 included in or associated with the touch sensitive device. Touch circuitry 341 can include multi-stim matrix 343 stored in a computer-readable storage medium. Multi-stim matrix 343 can include a matrix containing stimulation phase information for stimulation signals that can be simultaneously applied to the drive lines of touch sensor 321, such as that described in U.S. Patent No. 12/208,329, entitled "Multiple Stimulation Phase Determination." Specifically, each row of the matrix can represent a single step among multiple steps needed to compute values for generating an image of touch, each column of the matrix can represent a drive line of touch sensor panel 321 to be stimulated, and each cell of the matrix can represent the phase of a stimulation signal to be applied to a particular drive line in a particular step. In one example, multi-stim matrix 343 can include an additional row and column to support the stylus stimulation signal from stylus 301. Specifically, the additional column can represent a drive line that is not driven, or a drive line that does not actually exist on touch sensor panel 321. The purpose of the additional column is to detect the stylus stimulation signal. Touch circuitry 341 can further include inverse multi-stim matrix 353 stored in a computer-readable storage medium. Inverse multi-stim matrix 353 can include a matrix representing an inverse of multi-stim matrix 343 for decoding a touch signal received from a sense line of touch sensor 321 to generate a touch image representing a touch detected by touch sensor 321. These matrices will be described in greater detail below with respect to FIGs. 4-7.

[0037] Referring back to FIG. 3, touch circuitry 341 can further include transmitter channel 345 coupled to transmit a stimulation signal to drive line 329 of touch sensor 321. Transmitter channel 345 can be configured to generate a stimulation signal similar or identical to stimulation signal 107 to be applied to drive line 329 based on the phase information contained in multi-stim matrix 343. In some examples, the stimulation signal can have a frequency between 80-120KHz (e.g., 90, 100, or 110KHz) and an amplitude between 3-5V (e.g., 4V). In other examples, the stimulation signal can have a frequency between 100KHz to 1MHz or higher (e.g., between 100-300KHz or 100-500KHz). Although not shown, touch circuitry 341 can include one transmitter channel for each drive line of touch sensor 321.

[0038] Touch circuitry 341 can further include receiver circuitry 347 coupled to receive a touch signal from sense line 331 of touch sensor 321. Receiver circuitry 347 can include amplifiers, filters, and/or analog to digital converters that one of ordinary skill in the art can select to appropriately process the touch signal received from sense line 331. Although not shown, touch circuitry 341 can include additional receiver circuitry for each sense line of touch sensor 321.

[0039] Touch circuitry 341 can further include in-phase (I-phase) demodulation circuitry 349 configured to demodulate the touch signal received from receiver circuitry 347. I-phase demodulation circuitry 347 can include a demodulation mixer and a demodulation integrator to extract the I-phase component of the touch signal output by sense line 331. Although not shown, touch circuitry 341 can include additional I-phase demodulation circuitry for each sense line of touch sensor 321. In some examples, transmitter channel 345, receiver circuitry 347, and I-phase demodulation circuitry 349 can include circuitry similar or identical to that described in U.S. Patent App. 11/818,345, which is incorporated by reference herein in its entirety as if put forth in full below.

[0040] Touch circuitry 341 can further include multi-stim decode circuitry 351 configured to decode the I-phase component of the touch signal received from I-phase demodulation circuitry 341. Multi-stim decode circuitry 351 can include a mixer coupled to multiply the I-phase component of the touch signal received from I-phase demodulation circuitry 341 with inverse multi-stim matrix 353. Multi-stim decode circuitry 351 can further include an integrator coupled to receive the output of the mixer and to output touch image 355 representing a touch detected by sense line 331 of touch

sensor 321. Although not shown, touch circuitry 341 can include additional multi-stim decode circuitry for each sense line of touch sensor 321.

[0041] FIG. 4 illustrates a functional block diagram of another exemplary system 400 showing the interaction between stylus 401, touch sensor 421, and touch circuitry 441. In this embodiment, similar to that shown in FIG. 3, stylus 401 can receive a stimulation signal from touch sensor 421 at a location where the tip of stylus 401 contacts or is near touch sensor 421 (e.g., where the tip contacts or hovers above a screen of a touch sensitive device). A modified stimulation signal can then be transmitted back into touch sensor 421 at the same frequency in phase or at an arbitrary phase (including quadrature) at the same location. The modified stimulation signal can be transmitted back into touch sensor 421 through the tip and/or ring of stylus 401. It should be appreciated that FIG. 4 is a functional block diagram and that the actual components used to implement the various portions of system 400 can vary and one of ordinary skill, given the functional diagram, can select known circuit elements to implement the system.

[0042] System 400 can include stylus 401, amplifier 405, processor 407, mixer 406, force sensor 409, touch sensor 421, Cts 423, Ctd 425, Csig 427, drive line 429, sense line 431, multi-stim matrix 443, transmitter channel 445, receiver circuitry 447, and inverse matrix 453 similar or identical to stylus 301, amplifier 305, processor 307, mixer 306, force sensor 309, touch sensor 321, Cts 323, Ctd 325, Csig 327, drive line 329, sense line 331, multi-stim matrix 343, transmitter channel 345, receiver circuitry 347, and inverse matrix 353, respectively. However, touch circuitry 441 can include two demodulation paths. The first demodulation path can include stylus demodulation circuitry 449 and multi-stim decode circuitry 451 for demodulating the touch signal received from receiver circuitry 447 at a first touch phase to generate stylus image 456. The second demodulation path can include touch demodulation circuitry 457 and multi-stim decode circuitry 459 for demodulating the touch signal received from receiver circuitry 447 at a second stylus phase to generate touch image 455. Including a phase shift between the touch and stylus signals further helps to distinguish the touch and stylus signals in addition to the latter having a positive phase. In some examples, the difference between the first and second phases can be 90 degrees. In other examples, the phase difference between the first and second phases can have a different value.

[0043] FIG. 5 illustrates an exemplary touch and stylus stimulus combo matrix that

can be used in systems 300 or 400. In this embodiment, a touch stimulus matrix may be extended by M columns and M rows to form the modified touch and stylus stimulus combo matrix. The first N columns may be used for touch stimulus and the M columns may be used for stylus magnitude. Each column vector can correspond to a different channel. In order for the stimulus matrix to be invertible, the matrix should be a square matrix and therefore can be extended by M rows. FIG. 6 illustrates M exemplary stylus stimulus vectors. Each stylus stimulus vector represents a copy of one of the M column vectors from the touch and stylus stimulus combo matrix shown in FIG. 5. Using the touch and stylus stimulus combo matrix, the system can support a total of N styluses.

[0044] FIG. 7 illustrates a simplified view of a touch/stylus combo system that utilizes separate channels to encode stylus magnitude. The touch and stylus stimulus combo matrix is extended by N columns and N rows, where N is the number of stylus or devices for which to encode magnitude information. In this example, the touch controller can drive the M drive lines for which touch and stylus location need to be resolved. M touch pixels can be modulated along the M touch pixels along a sense line by touch and up to N stylus devices. The N stylus devices may potentially modulate different touch pixels along a sense line. Each stylus device can have its own stylus stimulus vector, which represents a copy of one of the M column vectors from the touch and stylus stimulus combo matrix. The stylus can modulate the gain of the amplifier (e.g., amplifier 305 or 405) as a function of the stylus stimulus vector or can add its own stimulus signal directly to a given touch pixel (e.g., through the stylus ring). The stimuli from the N styluses can be synchronized in the stylus device by the respective stylus device monitoring the stimulus signal at a given touch panel location and then synchronizing its own stimulus with the received stimulus signal at that touch panel location. For example, synchronization can occur at the first scan step, representing the first row vector in the touch and stylus stimulus combo matrix. In some embodiments, all elements in the first row vector may be 1 (i.e., all M stimulus signals can be driven in positive phase), if the touch and stylus stimulus combo matrix is a hadamard matrix. The stylus device can use this first step to synchronize its own stimulus. The composite signal at the sense line can be vector demodulated with a decode matrix, which represents the inverse of the touch and stylus stimulus combo matrix. The touch and stylus locations can be stored in the touch and stylus result vector, which is comprised of M entries containing M elements indicating the location/magnitude of touch and styluses and N dedicated stylus

magnitudes.

[0045] In some examples, some or all of the functional blocks of touch circuitry 341 or 441 can be implemented by ASIC processor, ARM processor, other electrical components, or combinations thereof.

[0046] FIG. 8 illustrates a functional block diagram of another exemplary system 800 showing the interaction between stylus 801, touch sensor 821, and touch circuitry 841. It should be appreciated that FIG. 8 is a functional diagram and that the actual components used to implement the various portions of system 800 can vary and one of ordinary skill, given the functional diagram, can select known circuit elements to implement the system

[0047] Stylus 801 is one example of stylus 200 that can be used as an input device to a touch sensitive device having a touch sensor similar or identical to touch sensor 100. Stylus 801 can be configured to generate a stylus stimulation signal having a frequency that is different than a frequency of a stimulation signal generated by the touch sensitive device. In some examples, the stylus stimulation frequency can be between 40-60KHz (e.g., about 50Khz) greater than or less than the frequency of a stimulation signal from a touch sensor. Thus, when stylus 801 is used with a touch sensitive device, stylus 801 can cause the touch sensitive device to generate a touch signal containing signals having two or more different frequencies.

[0048] Stylus 801 can optionally include sense amplifier 805 coupled to receive a stimulation signal (e.g., a stimulation signal similar or identical to stimulation signal 107) generated by an associated touch sensitive device and transmit a stylus stimulation signal to the associated touch sensitive device. The associated touch sensitive device can include a touch sensitive device in contact with, or in close proximity to, the tip of stylus 801. Sense amplifier 805 can be used to amplify the received stimulation signal to a level sufficient to be used by stylus 801 to generate a stylus stimulation signal, which is described in greater detail below. However, if the strength of the received stimulation signal is sufficiently high, sense amplifier 805 can be omitted from stylus 801.

[0049] Stylus 801 can further include force sensor 809 for detecting the amount of force applied to the tip of stylus 801. Force sensor 809 can be similar or identical to force sensor 309, described above. For example, force sensor 809 can include any type of force sensor, such as a capacitive pressure sensor, semiconductor strain gauge, or the like,

operable to detect the amount of force applied to the tip of stylus 801. The amount of force detected by force sensor 809 can be used to modulate an oscillating signal generated by oscillator 813. In this way, the magnitude of the oscillating signal generated by oscillator 813 can be adjusted based on how hard the stylus tip is applied to the surface of the associated touch sensitive device. As described above, this allows stylus 801 to convey information associated with the location of its tip on the surface of the touch sensitive device as well as the amount of force being applied to the surface of the touch sensitive device.

[0050] Stylus 801 can further include comparator 811 coupled to receive the output of force sensor 809 and a threshold voltage V_{th} . Comparator 811 can be configured to compare the output of force sensor 809 to the threshold voltage V_{th} and output a force detection signal based on the comparison. For example, the force detection signal can be driven high (or low, depending on the circuit design) when the output of force sensor 809 is greater than threshold voltage V_{th} and can be drive low (or high, depending on the circuit design) when the output of force sensor 809 is less than threshold voltage V_{th} .

[0051] Stylus 801 can further include processor 803 coupled to receive the force detection signal output by comparator 811. Processor 803 can be configured to generate a power control signal based on the received force detection signal. For example, if the force detection signal is at a level indicating that the force detected by force sensor 809 is greater than a threshold amount (represented by threshold voltage V_{th}), processor 803 can drive the power control signal to a high level (or low, depending on the circuit design) to cause oscillator 813 to generate a signal. The force detection signal and the power control signal can be used to control the power state of some or all components within stylus 801 to improve battery life. For example, if the force is below the set force threshold, the device can be in an idle state and the device can remain in a low power state, thereby conserving battery power. When the force is above the force detection threshold, the device can transitions into an active mode. This way battery power can be conserved when the stylus is not actively being used.

[0052] Stylus 801 can further include oscillator 813 configured to generate an oscillating signal having frequency F_{off} . Oscillator 813 can include any type of oscillator, such as a tuned LC oscillator (e.g, a colpitts-oscillator), crystal oscillator, MEMS based oscillator, voltage controlled oscillator, RC oscillator, ring oscillator, or the like. In one

example, oscillator 813 can be configured to generate a sinusoidal signal having an amplitude between 8-12V (e.g., 9, 10, or 11V) and a frequency F_{off} between 80-120KHz (e.g., 90, 100, or 110KHz). In other examples, the stimulation signal can have a frequency between 100KHz to 1MHz or higher (e.g., between 100-300KHz or 100-500KHz). The signal generated by oscillator 813 can have the same phase as the stimulation signal received from touch sensor 821.

[0053] Stylus 801 can further include mixer 807 coupled to receive the output of force sensor 809, the signal having frequency F_{off} output by oscillator 813, and the amplified stimulation signal from sense amplifier 805. Mixer 807 can be configured to modulate the amplitude of the signal having frequency F_{off} output by oscillator 813 by an amount corresponding to the force detected by force sensor 809 to generate a modulated oscillating signal. Mixer 807 can be further configured to mix the modulated oscillating signal with the amplified signal received from sense amplifier 805 to generate a stylus stimulation signal. The resultant composite stimulation signal can have a frequency equal to the frequency of the stimulation signal received from touch sensor 821 plus or minus the offset frequency F_{off} amplitude modulated by the force signal.

[0054] Stylus 801 can further include transmission amplifier 815 coupled to receive the stylus stimulation signal output by mixer 807. Amplifier 815 can be configured to amplify the composite stimulation signal by an amount sufficient to be received by touch sensor 821.

[0055] System 800 can further include touch sensor 821 of a touch sensitive device. Touch sensor 821 can include a touch sensor similar or identical to touch sensor 100, described above. As shown in FIG. 8, touch sensor 821 can include a drive line 829 coupled to receive a stimulation signal similar or identical to stimulation signal 107 from touch circuitry 841 and a sense line 831 capacitively coupled to drive line 829 and coupled to transmit a touch signal similar or identical to touch signal 109 to touch circuitry 841. It should be appreciated that touch sensor 821 is shown with only one drive line and one sense line for illustrative purposes only and that touch sensor 821 can actually include any number of drive lines and any number of sense lines.

[0056] A mutual capacitance C_{sig} 827 can be formed between the crossing drive line 829 and sense line 831 when the drive line is stimulated. Similarly, a mutual capacitance C_{ts} 823 and C_{td} 825 can be formed between the tip of stylus 801 and sense line 831 and

drive line 829, respectively, when the stylus stimulation signal is generated. A mutual capacitance C_{rs} 833 and C_{rd} 835 can also be formed between the ring of stylus 801 and sense line 831 and drive line 829, respectively, when the composite stylus stimulation signal is generated. As mentioned above, if the tip of stylus 801 is placed at the crossing point between drive line 829 and sense line 831, stylus 801 can receive the stimulation signal transmitted on drive line 829 via the capacitive path formed between the stylus tip and drive line 829, amplify the received stimulation signal using sense amplifier 805, mix the amplified stimulation signal with a modulated oscillating signal generated by modulating a signal having frequency F_{off} by an amount corresponding to a force detected by force sensor 809, and transmit the stylus stimulation signal back into touch sensor 821 via the capacitive path formed between the stylus ring and sense line 831. Thus, the touch signal generated by sense line 831 can include charge coupled from both drive line 829 and stylus 801.

[0057] System 800 can further include touch circuitry 841 included in or associated with the touch sensitive device. Touch circuitry 841 can be similar to touch circuitry 341, described above, except that touch demodulation circuitry 849 and multi-stim decode circuitry 851 can be configured to demodulate the touch component of the signal output by receiver circuitry 847 and post the result in a touch image memory 855. Touch circuitry 841 can further include stylus demodulation circuitry 857 and multi-stim decode circuitry 859 to demodulate the stylus component of the signal output by receiver circuitry 847 and post the result to stylus image memory 861. In the illustrated example, stylus demodulation can occur at $F_{STM} \pm F_{OFF}$, since the received signal on the stylus device can be F_{STM} and modulated with F_{OFF} to generate the stylus signal. The touch demodulation can be performed at F_{STM} . Multi-stim matrix 843, transmitter channel 845, receiver circuitry 847, and inverse matrix 853 can be similar or identical to multi-stim matrix 343, transmitter channel 345, receiver circuitry 347, and inverse matrix 353 of touch circuitry 341, respectively. However, multi-stim matrix 843 and inverse matrix 853 may not include an extra row and step like that contained in multi-stim matrix 343 and inverse matrix 353. The differences between touch circuitry 341 and touch circuitry 841 will now be described in more detail.

[0058] Touch circuitry 841 can include separate demodulation and decode circuitry for handling stylus touch events and non-stylus touch events. Specifically, touch circuitry

841 can include touch demodulation circuitry 849 and multi-stim decode circuitry 851 to process non-stylus touch events and can include stylus demodulation circuitry 857 and multi-stim decode circuitry 859 to process stylus touch events.

[0059] Touch demodulation circuitry 849 can be configured to demodulate the portion of the touch signal received from receiver circuitry 847 having a frequency corresponding to the frequency of the stimulation signal generated by transmitter channel 845. Touch demodulation circuitry 849 can include a demodulation mixer and a demodulation integrator to extract the touch component of the signal output by sense line 831 having the frequency corresponding to the frequency of the stimulation signal generated by transmitter channel 845.

[0060] Multi-stim decode circuitry 851 can be configured to decode the touch component of the signal received from touch demodulation circuitry 849. Multi-stim decode circuitry 851 can include a mixer coupled to multiply the touch component of the signal received from touch demodulation circuitry 849 with inverse multi-stim matrix 853. Multi-stim decode circuitry 851 can further include an integrator coupled to receive the output of the mixer and to post the result in a touch image memory 855, representing a non-stylus touch detected by sense line 831 of touch sensor 821.

[0061] Stylus demodulation circuitry 857 can be configured to demodulate the portion of the touch signal received from receiver circuitry 847 having a frequency corresponding to the frequency of the stimulation signal generated by transmitter channel 845 plus or minus the offset frequency F_{off} . Stylus demodulation circuitry 857 can include a demodulation mixer and a demodulation integrator to extract the stylus component of the signal output by sense line 831 having the frequency corresponding to the frequency of the stimulation signal generated by transmitter channel 845 plus or minus the offset frequency F_{off} .

[0062] Multi-stim decode circuitry 859 can be configured to decode the stylus component of the signal received from stylus demodulation circuitry 857. Multi-stim decode circuitry 859 can include a mixer coupled to multiply the stylus component of the touch signal received from stylus demodulation circuitry 857 with inverse multi-stim matrix 853. Multi-stim decode circuitry 859 can further include an integrator coupled to receive the output of the mixer and to post the result in a touch image memory 861, representing a stylus touch detected by sense line 831 of touch sensor 821.

[0063] In some examples, the functional blocks of touch circuitry 841 can be implemented by ASIC processor, ARM processor, other electrical components, or combinations thereof.

[0064] While system 800 is shown and described above as using one signal having an offset frequency F_{off} , it should be appreciated that any number of these signals can be used. For example, stylus 801 can include any number of additional oscillators to generate additional signals to be modulated by an amount corresponding to the force detected by force sensor 809. These additional signals can have varying frequencies and can each be mixed with the amplified stimulation signal received from sense amplifier 805 (or non-amplified stimulation signal received from touch sensor 821 if no sense amplifier 805 is used) to generate the stylus stimulation signal. In this example, touch circuitry 841 can also include additional circuitry to process the additional signals generated by stylus 801. For example, touch circuitry can include additional I-phase demodulations circuits and multi-stim decoder circuits for each additional signal to be demodulated.

[0065] FIG. 9 illustrates an exemplary process 900 for generating and transmitting a stylus stimulation signal. At block 901, a stimulation signal can be received by a stylus from a touch sensitive device. The stimulation signal can be received by capacitively coupling a portion of the stylus to the touch sensitive device. In one example, a stimulation signal similar or identical to stimulation signal 107 can be generated by a touch sensitive device similar or identical to those shown in FIGs. 3, 4, and 8. The stimulation signal can be generated by a transmitter channel similar or identical to transmitter channels 345, 445, or 845 using a multi-stim matrix similar or identical to multi-stim matrix 343, 443, or 843. The stimulation signal can be sent through a drive line similar or identical to drive lines 329, 429, or 829 of a touch sensor similar or identical to touch sensors 321, 421, or 821. A stylus similar or identical to stylus 200, 301, 401, or 801 having a tip similar or identical to tip 201 can receive the stimulation signal via a capacitive path formed between the drive line and the tip of the stylus when the stylus tip is placed on or near the touch sensitive surface of the touch sensitive device.

[0066] At block 903, a stylus stimulation signal can be generated by changing a characteristic of the received stimulation signal. For example, one or more of a frequency or amplitude of the received stimulation signal can be changed to generate the stylus

stimulation signal.

[0067] In one example, an amplifier similar or identical to amplifier 305 or 405 including a regenerative amplifier can be used to amplify the received stimulation signal. The amplification can be based on an amount of force detected by a force sensor similar or identical to force sensor 309 or 409 and a gain vector generated by processor similar or identical to processor 307 or 407. The force sensor can detect the amount of force being applied to the tip of the stylus. In this way, the magnitude of the stylus stimulation signal can be varied by adjusting the amount of force being applied between the stylus tip and the surface of the touch sensitive device.

[0068] In another example, an oscillator and mixer similar or identical to oscillator 813 and mixer 807 can be used to change a frequency of the received stimulation signal. In this example, the oscillator can be configured to generate an oscillating signal (e.g., a sinusoidal signal) having a frequency that is different from that of the received stimulation signal. In some examples, the oscillator can be configured to turn on in response to a sufficient force being applied to the tip of the stylus as detected by a force sensor similar or identical to force sensor 809. The stylus signal generated by the oscillator can be modulated at a mixer similar or identical to mixer 807 by an output of the force sensor such that the amplitude of the amplitude modulated stylus stimulation signal corresponds to an amount of force detected by the force sensor. The amplitude modulated oscillating signal can be mixed with the received stimulation signal by a mixer similar or identical to mixer 807 to generate a stylus stimulation signal. In some examples, prior to mixing with the amplitude modulated stylus stimulation signal, the received stimulation signal can be amplified using an amplifier to increase the signal strength to a desirable amount. For example, an amplifier similar or identical to sense amplifier 805 can be used to amplify the received stimulation signal.

[0069] At block 905, the stylus stimulation signal can be transmitted to the touch sensitive device. For example, the stylus stimulation signal generated at block 903 can be transmitted to the touch sensitive device via a capacitive path formed between the stylus device and the touch sensor of the device.

[0070] In one example, an amplitude-modulated stylus stimulation signal generated by a stylus similar or identical to stylus 301 or 401 can be transmitted to a touch sensor similar or identical to touch sensor 321 or 421 of a touch sensitive device via a capacitive

path formed between the stylus device and the touch sensor of the device.

[0071] In another example, a frequency-shifted composite stylus stimulation signal generated by a stylus similar or identical to stylus 801 can be transmitted to a touch sensor similar or identical to touch sensor 821 of a touch sensitive device via a capacitive path formed between the stylus device and the touch sensor of the device. The frequency-shifted composite stylus stimulation signal can be amplified prior to transmission using a transmission amplifier similar or identical to transmission amplifier 815.

[0072] FIG. 10 illustrates an exemplary process 1000 for receiving and processing a touch signal having a stylus stimulation signal. At block 1001, a stimulation signal can be generated by a touch sensitive device. The stimulation signal can be transmitted to drive lines of a touch sensor. In one example, a stimulation signal similar or identical to stimulation signal 107 can be generated by a touch sensitive device similar or identical to those shown in FIGs. 3, 4, and 8. The stimulation signal can be generated by a transmitter channel similar or identical to transmitter channels 345, 445, or 845 using a multi-stim matrix similar or identical to multi-stim matrices 343, 443, or 843. The stimulation signal can be sent through a drive line similar or identical to drive lines 329, 429, or 829 of a touch sensor similar or identical to touch sensors 321, 421, or 821.

[0073] At block 1003, a touch signal having a stylus stimulation signal can be received by the touch sensitive device. The touch signal can represent a detected touch event on a touch sensitive surface of the touch sensitive device. In one example, a touch signal similar or identical to touch signal 109 can be received from a sense line similar or identical to sense line 331, 431, or 831 of a touch sensor similar or identical to touch sensor 321, 421, or 821. The touch signal can contain a stylus stimulation signal generated by a stylus similar or identical to stylus 301, 401, or 801. The stylus stimulation signal can be an amplitude-modulated and/or frequency-shifted version of the stimulation signal.

[0074] At block 1005, the received sense signal can be processed. For example, the received sense signal can be filtered, converted from an analog to a digital signal, amplified, or combinations thereof. The signal can further be demodulated and decoded to generate a touch image representing a touch event detected by the touch sensor. In one example, a receiver circuitry similar or identical to receiver circuitry 347, 447, or 847 can be used to filter, convert the signal from an analog to a digital signal, amplify, or

combinations thereof, the received sense signal.

[0075] In one example, the signal output by the receiver circuitry, such as receiver circuitry 347, can be sent through demodulation circuitry similar or identical to demodulation circuitry 349 to extract the I-phase component of the touch signal. The demodulated signal can be transmitted to decode circuitry similar or identical to multi-stim decode circuitry 351 to generate a touch image similar or identical to touch image 355. In another example, the signal output by the receiver circuitry, such as receiver circuitry 447, can be sent through demodulation circuitry similar or identical to touch demodulation circuitry 457 and stylus demodulation circuitry 449 to extract the touch and stylus components of the touch signal. The demodulated signals can be transmitted to decode circuitry similar or identical to multi-stim decode circuitry 451 and 459 to generate a stylus image similar or identical to stylus image 456 and a touch image similar or identical to touch image 455.

[0076] In another example, the signal output by receiver circuitry, such as receiver circuitry 847, can be sent through two or more sets of demodulation circuitry similar or identical to touch and stylus demodulation circuitry 849 and 857 to extract the touch and stylus components of the touch signal. The touch demodulation circuitry 849 can be configured to demodulate the signal output by the receiver circuitry at a frequency corresponding to the frequency of the signal transmitted at block 1001. The stylus demodulation circuitry 857 can be configured to demodulate the signal output by the receiver circuitry at the frequency corresponding to the frequency of the signal transmitted at block 1001 plus or minus an offset frequency corresponding to a frequency of an oscillating signal generated by the stylus device. If the stylus is configured to generate more than one oscillating signal, additional demodulation circuits can be used to demodulate the signal output by the receiver circuitry at frequencies corresponding to the frequency of the signal transmitted at block 1001 plus or minus offset frequencies corresponding to frequencies of the additional oscillating signals. The demodulated signal can be transmitted to decode circuitry similar or identical to multi-stim decode circuitry 851 or 859. Additional decode circuitry can be included if additional demodulation circuits are used. The multi-stim decode circuitry can be used to generate touch images similar or identical to touch and stylus images 855 and 861.

[0077] Using styluses 301, 401, and 801 or processes 900 or 1000, a stylus device

can be used to input both positional data and pressure into a touch sensitive device. These inputs can be used to improve a user experience in various applications. For example, in a drawing application, a user can use the stylus as a paintbrush, with the stylus' motion and pressure being detected by the touch sensitive device. As the user increases the pressure of the stylus against the touch sensitive device, the thickness of the brushstrokes can be increased. As the user reduces the pressure of the stylus against the touch sensitive device, the thickness of the brushstrokes can similarly decrease. In another example, when drawing with a line rather than a brush, the line thickness can change as a function of pressure. Similarly, when using the stylus as an eraser, the eraser width can vary as a function of pressure.

[0078] One or more of the functions relating to the generation or processing of a stylus stimulation signal described above can be performed by a system similar or identical to system 1100 shown in FIG. 11. System 1100 can include instructions stored in a non-transitory computer readable storage medium, such as memory 1103 or storage device 1101, and executed by processor 1105. The instructions can also be stored and/or transported within any non-transitory computer readable storage medium for use by or in connection with an instruction execution system, apparatus, or device, such as a computer-based system, processor-containing system, or other system that can fetch the instructions from the instruction execution system, apparatus, or device and execute the instructions. In the context of this document, a “non-transitory computer readable storage medium” can be any medium that can contain or store the program for use by or in connection with the instruction execution system, apparatus, or device. The non-transitory computer readable storage medium can include, but is not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus or device, a portable computer diskette (magnetic), a random access memory (RAM) (magnetic), a read-only memory (ROM) (magnetic), an erasable programmable read-only memory (EPROM) (magnetic), a portable optical disc such a CD, CD-R, CD-RW, DVD, DVD-R, or DVD-RW, or flash memory such as compact flash cards, secured digital cards, USB memory devices, memory sticks, and the like.

[0079] The instructions can also be propagated within any transport medium for use by or in connection with an instruction execution system, apparatus, or device, such as a computer-based system, processor-containing system, or other system that can fetch the

instructions from the instruction execution system, apparatus, or device and execute the instructions. In the context of this document, a “transport medium” can be any medium that can communicate, propagate or transport the program for use by or in connection with the instruction execution system, apparatus, or device. The transport medium can include, but is not limited to, an electronic, magnetic, optical, electromagnetic or infrared wired or wireless propagation medium.

[0080] The system 1100 shown in FIG. 11 can be used in either the stylus to generate a stylus stimulation signal as described above with respect to FIGs. 3, 4, 8, and 9, or the touch sensitive device to receive and process a touch signal as described above with respect to FIGs. 3, 4, 8, and 10.

[0081] It is to be understood that the system is not limited to the components and configuration of FIG. 11, but can include other or additional components in multiple configurations according to various embodiments. Additionally, the components of system 1100 can be included within a single device, or can be distributed between multiple devices.

[0082] FIG. 12 illustrates an exemplary personal device 1200, such as a tablet, that can be used with a stylus according to various embodiments.

[0083] FIG. 13 illustrates another exemplary personal device 1300, such as a mobile phone, that can be used with a stylus according to various embodiments.

[0084] Therefore, according to the above, some examples of the disclosure are directed to a stylus comprising: a stylus tip capable of receiving a stimulation signal from a touch sensitive device; and an amplification circuit coupled to receive the stimulation signal from the stylus tip, wherein the amplification circuit is capable of modulating the received stimulation signal to generate a stylus stimulation signal, and wherein the stylus tip is further capable of transmitting the stylus stimulation signal to the touch-sensitive device. Alternatively or additionally to one or more of the examples disclosed above, in some examples the stylus further comprises a force sensor circuit capable of detecting a force applied to the stylus tip, wherein the amplification circuit is further capable of modulating the received stimulation signal by an amount corresponding to the force detected by the force sensor. Additionally or alternatively to one or more of the examples disclosed above, in some examples a phase and a frequency of the stylus stimulation signal are at least substantially equal to a phase and a frequency of the stimulation signal

from the touch sensitive device. Alternatively or additionally to one or more of the examples disclosed above, in some examples the amplification circuit comprises a regenerative or super regenerative amplifier, and wherein a quench rate of the super regenerative amplifier is synchronous to at least a portion of the received stimulation signal and a gain of the super regenerative amplifier is based on the received stimulation signal. Alternatively or additionally to one or more of the examples disclosed above, in some examples the amplification circuit comprises a processor capable of modulating a amplitude of the received stimulation signal.

[0085] Some examples of the disclosure are directed to a stylus comprising: a stylus tip capable of receiving a stimulation signal from a touch sensitive device; a frequency shifting circuit capable of changing a frequency of the received stimulation signal to generate a stylus stimulation signal; and a stylus ring capable of transmitting the stylus stimulation signal to the touch-sensitive device. Alternatively or additionally to one or more of the examples disclosed above, in some examples the frequency shifting circuit comprises: an oscillator capable of generating an oscillating signal, the oscillating signal having a frequency that is different than a frequency of the stimulation signal from the touch sensitive device; a modulation circuit capable of modulating an amplitude of the oscillating signal to generate a modulated oscillating signal; a mixer coupled to receive the stimulation signal and the modulated oscillating signal, wherein the mixer is capable of generating the stylus stimulation signal by mixing the stimulation signal and the modulated oscillating signal. Alternatively or additionally to one or more of the examples disclosed above, in some examples the frequency shifting circuit comprises a force sensor circuit capable of detecting a force applied to the stylus tip, wherein the modulation circuit is further capable of modulating the oscillating signal by an amount corresponding to the force detected by the force sensor. Alternatively or additionally to one or more of the examples disclosed above, in some examples the oscillator is capable of turning on in response to the force detected by the force sensor being greater than a threshold amount. Alternatively or additionally to one or more of the examples disclosed above, in some examples the stylus further comprises a sense amplifier coupled to receive the stimulation signal from the touch sensitive device, the sense amplifier capable of amplifying the stimulation signal from the touch sensitive device to generate an amplified stimulation signal, wherein the frequency shifting circuit is coupled to receive the amplified

stimulation signal, and wherein the frequency shifting circuit is capable of changing a frequency of the amplified stimulation signal.

[0086] Some examples of the disclosure are directed to a system comprising: a capacitive touch sensor capable of generating one or more touch signals in response to one or more stimulation signals; and a touch circuit capable of generating the one or more stimulation signals, wherein: the touch circuit is coupled to transmit the one or more stimulation signals to the capacitive touch sensor and receive the one or more touch signals from the capacitive touch sensor; the touch circuit is capable of determining a location of a stylus touch event detected by the capacitive touch sensor based at least in part on a touch signal of the one or more touch signals, the touch signal being generated in response to the one or more stimulation signals and a stylus stimulation signal generated by a stylus. Alternatively or additionally to one or more of the examples disclosed above, in some examples the touch circuit comprises: a first demodulation circuit capable of demodulating the touch signal of the one or more touch signals to generate a first demodulated touch signal; and a first decoder circuit coupled to receive the first demodulated touch signal, wherein the first decoder circuit is capable of determining a location of a non-stylus touch event based at least in part on the first demodulated touch signal. Alternatively or additionally to one or more of the examples disclosed above, in some examples the system further comprises a second demodulation circuit capable of demodulating the touch signal of the one or more touch signals to generate a second demodulated touch signal; and a second decoder circuit coupled to receive the second demodulated touch signal, wherein the second decoder circuit is capable of determining a location of a stylus touch event based at least in part on the second demodulated touch signal. Alternatively or additionally to one or more of the examples disclosed above, in some examples the first demodulation circuit is capable of demodulating the touch signal of the one or more touch signals at a first frequency, and wherein the second demodulation circuit is capable of demodulating the touch signal of the one or more touch signals at a second frequency. Alternatively or additionally to one or more of the examples disclosed above, in some examples the first frequency corresponds to a frequency of one or more stimulation signals, and wherein the second frequency corresponds to a frequency of the stylus stimulation signal.

[0087] Some embodiments of the disclosure are directed to a method comprising: receiving a stimulation signal from a touch-sensitive device; generating a stylus stimulation signal based on the received stimulation signal and a pressure detected by a pressure sensor; and transmitting the generated stylus stimulation signal to the touch-sensitive device. Alternatively or additionally to one or more of the examples disclosed above, in some examples generating the stylus stimulation signal comprises modulating an amplitude of the received stimulation signal based at least in part on the pressure detected by the pressure sensor and a gain vector. Alternatively or additionally to one or more of the examples disclosed above, in some examples generating the stylus stimulation signal comprises changing a frequency of the received stimulation signal. Alternatively or additionally to one or more of the examples disclosed above, in some examples generating the stylus stimulation signal comprises mixing an oscillating signal with the received stimulation signal, wherein a frequency of the oscillating signal is different than a frequency of the received stimulation signal. Alternatively or additionally to one or more of the examples disclosed above, in some examples the method further comprises modulating an amplitude of the oscillating signal before mixing the oscillating signal with the received stimulation signal, wherein the amplitude of the oscillating signal is modulated based at least in part on the pressure detected by the pressure sensor.

[0088] Some examples of the disclosure are directed to a method comprising: receiving a stimulation signal from a touch sensitive device; generating a stylus stimulation signal based on the received stimulation signal, wherein the stylus stimulation signal is generated by changing one of an amplitude or a frequency of the received stimulation signal; and transmitting the generated stylus stimulation signal to the touch sensitive device. Alternatively or additionally to one or more of the examples disclosed above, in some examples generating the stylus stimulation signal comprises modulating the amplitude of the received stimulation signal using a regenerative amplifier. Alternatively or additionally to one or more of the examples disclosed above, in some examples generating the stylus stimulation signal comprises mixing an oscillating signal with the received stimulation signal, wherein a frequency of the oscillating signal is different than a frequency of the received stimulation signal. Alternatively or additionally to one or more of the examples disclosed above, in some examples the stimulation signal from the touch sensitive device has a frequency between 100KHz to 1MHz, and wherein the stylus stimulation signal has a frequency within 50KHz of the frequency of the touch

sensitive device. Alternatively or additionally to one or more of the examples disclosed above, in some examples the generated stylus stimulation signal is transmitted to the touch sensitive device through a ring of a stylus.

[0089] Although embodiments have been fully described with reference to the accompanying drawings, it is to be noted that various changes and modifications will become apparent to those skilled in the art. Such changes and modifications are to be understood as being included within the scope of the various embodiments as defined by the appended claims.

WHAT IS CLAIMED IS:

1. A stylus comprising:
a stylus tip capable of receiving a stimulation signal from a touch sensitive device; and
an amplification circuit coupled to receive the stimulation signal from the stylus tip, wherein the amplification circuit is capable of modulating the received stimulation signal to generate a stylus stimulation signal, and wherein the stylus tip is further capable of transmitting the stylus stimulation signal to the touch-sensitive device.
2. The stylus of claim 1, further comprising a force sensor circuit capable of detecting a force applied to the stylus tip, wherein the amplification circuit is further capable of modulating the received stimulation signal by an amount corresponding to the force detected by the force sensor.
3. The stylus of claim 1, wherein a phase and a frequency of the stylus stimulation signal are at least substantially equal to a phase and a frequency of the stimulation signal from the touch sensitive device.
4. The stylus of claim 1, wherein the amplification circuit comprises a regenerative or super regenerative amplifier, and wherein a quench rate of the super regenerative amplifier is synchronous to at least a portion of the received stimulation signal and a gain of the super regenerative amplifier is based on the received stimulation signal.
5. The stylus of claim 1, wherein the amplification circuit comprises a processor capable of modulating a amplitude of the received stimulation signal.
6. A stylus comprising:
a stylus tip capable of receiving a stimulation signal from a touch sensitive device;

a frequency shifting circuit capable of changing a frequency of the received stimulation signal to generate a stylus stimulation signal; and

a stylus ring capable of transmitting the stylus stimulation signal to the touch-sensitive device.

7. The stylus of claim 6, wherein the frequency shifting circuit comprises:

an oscillator capable of generating an oscillating signal, the oscillating signal having a frequency that is different than a frequency of the stimulation signal from the touch sensitive device;

a modulation circuit capable of modulating an amplitude of the oscillating signal to generate a modulated oscillating signal;

a mixer coupled to receive the stimulation signal and the modulated oscillating signal, wherein the mixer is capable of generating the stylus stimulation signal by mixing the stimulation signal and the modulated oscillating signal.

8. The stylus of claim 7, wherein the frequency shifting circuit comprises a force sensor circuit capable of detecting a force applied to the stylus tip, wherein the modulation circuit is further capable of modulating the oscillating signal by an amount corresponding to the force detected by the force sensor.

9. The stylus of claim 8, wherein the oscillator is capable of turning on in response to the force detected by the force sensor being greater than a threshold amount.

10. The stylus of claim 6 further comprising a sense amplifier coupled to receive the stimulation signal from the touch sensitive device, the sense amplifier capable of amplifying the stimulation signal from the touch sensitive device to generate an amplified stimulation signal, wherein the frequency shifting circuit is coupled to receive the amplified stimulation signal, and wherein the frequency shifting circuit is capable of changing a frequency of the amplified stimulation signal.

11. A system comprising:
a capacitive touch sensor capable of generating one or more touch signals in response to one or more stimulation signals; and
a touch circuit capable of generating the one or more stimulation signals, wherein:
the touch circuit is coupled to transmit the one or more stimulation signals to the capacitive touch sensor and receive the one or more touch signals from the capacitive touch sensor;
the touch circuit is capable of determining a location of a stylus touch event detected by the capacitive touch sensor based at least in part on a touch signal of the one or more touch signals, the touch signal being generated in response to the one or more stimulation signals and a stylus stimulation signal generated by a stylus.

12. The system of claim 11, wherein the touch circuit comprises:
a first demodulation circuit capable of demodulating the touch signal of the one or more touch signals to generate a first demodulated touch signal; and
a first decoder circuit coupled to receive the first demodulated touch signal, wherein the first decoder circuit is capable of determining a location of a non-stylus touch event based at least in part on the first demodulated touch signal.

13. The system of claim 12 further comprising:
a second demodulation circuit capable of demodulating the touch signal of the one or more touch signals to generate a second demodulated touch signal; and
a second decoder circuit coupled to receive the second demodulated touch signal, wherein the second decoder circuit is capable of determining a location of a stylus touch event based at least in part on the second demodulated touch signal.

14. The system of claim 13, wherein the first demodulation circuit is capable of demodulating the touch signal of the one or more touch signals at a first frequency, and wherein the second demodulation circuit is capable of demodulating the touch signal of the one or more touch signals at a second frequency.

15. The system of claim 14, wherein the first frequency corresponds to a frequency of one or more stimulation signals, and wherein the second frequency corresponds to a frequency of the stylus stimulation signal.

16. A method comprising:
receiving a stimulation signal from a touch-sensitive device;
generating a stylus stimulation signal based on the received stimulation signal and a pressure detected by a pressure sensor; and
transmitting the generated stylus stimulation signal to the touch-sensitive device.

17. The method of claim 16, wherein generating the stylus stimulation signal comprising modulating an amplitude of the received stimulation signal based at least in part on the pressure detected by the pressure sensor and a gain vector.

18. The method of claim 16, wherein generating the stylus stimulation signal comprising changing a frequency of the received stimulation signal.

19. The method of claim 16, wherein generating the stylus stimulation signal comprising mixing an oscillating signal with the received stimulation signal, wherein a frequency of the oscillating signal is different than a frequency of the received stimulation signal.

20. The method of claim 19 further comprising modulating an amplitude of the oscillating signal before mixing the oscillating signal with the received stimulation signal, wherein the amplitude of the oscillating signal is modulated based at least in part on the pressure detected by the pressure sensor.

21. A method comprising:
receiving a stimulation signal from a touch sensitive device;

generating a stylus stimulation signal based on the received stimulation signal, wherein the stylus stimulation signal is generated by changing one of an amplitude or a frequency of the received stimulation signal; and

transmitting the generated stylus stimulation signal to the touch sensitive device.

22. The method of claim 21, wherein generating the stylus stimulation signal comprises modulating the amplitude of the received stimulation signal using a regenerative amplifier.

23. The method of claim 21, wherein generating the stylus stimulation signal comprises mixing an oscillating signal with the received stimulation signal, wherein a frequency of the oscillating signal is different than a frequency of the received stimulation signal.

24. The method of claim 21, wherein the stimulation signal from the touch sensitive device has a frequency between 100KHz to 1MHz, and wherein the stylus stimulation signal has a frequency within 50KHz of the frequency of the touch sensitive device.

25. The method of claim 21, wherein the generated stylus stimulation signal is transmitted to the touch sensitive device through a ring of a stylus.

touch sensor
100

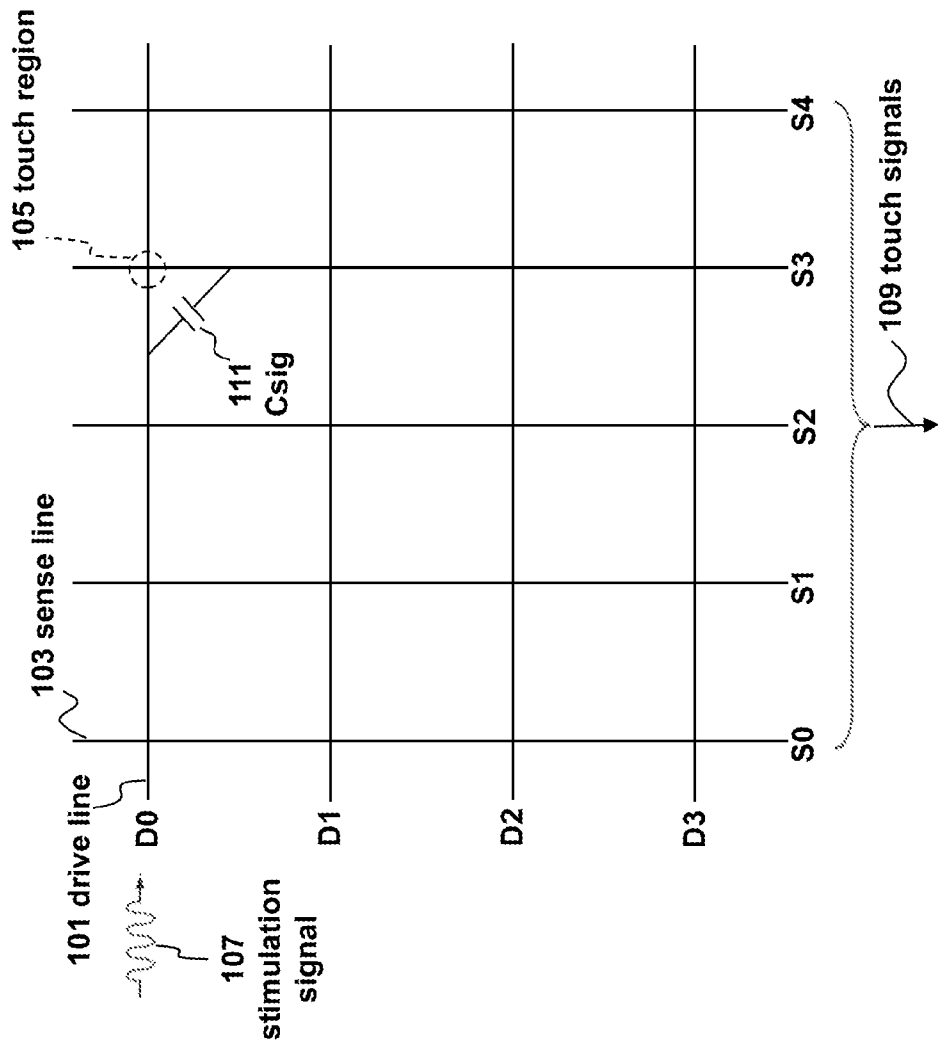


FIG. 1

stylus
200

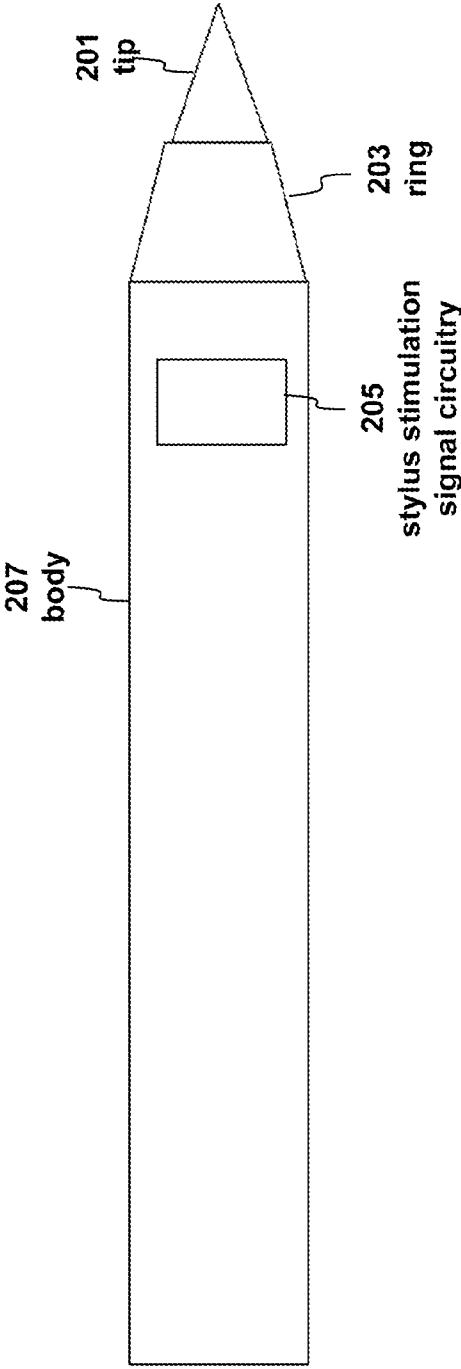


FIG. 2

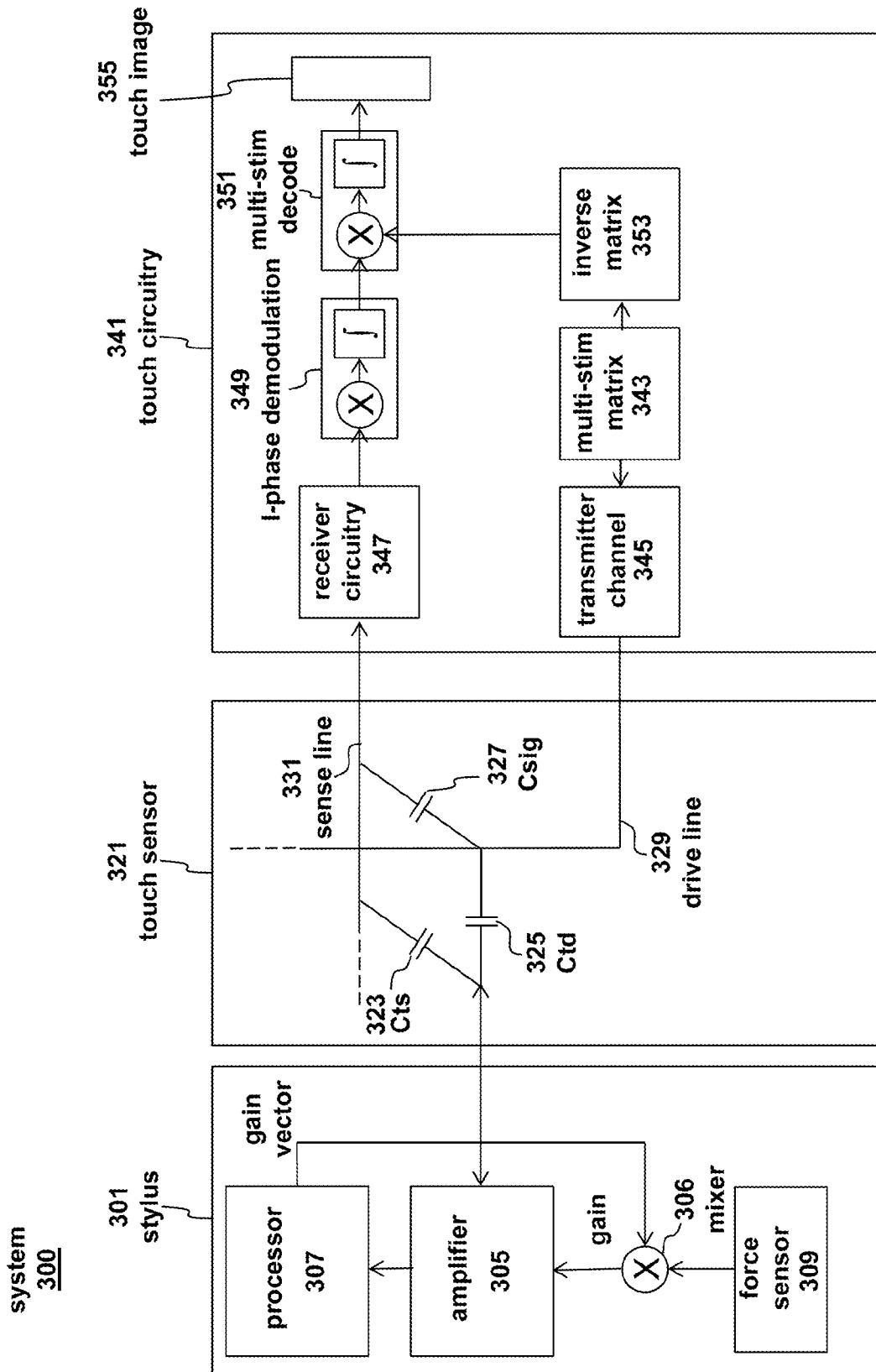


FIG. 3

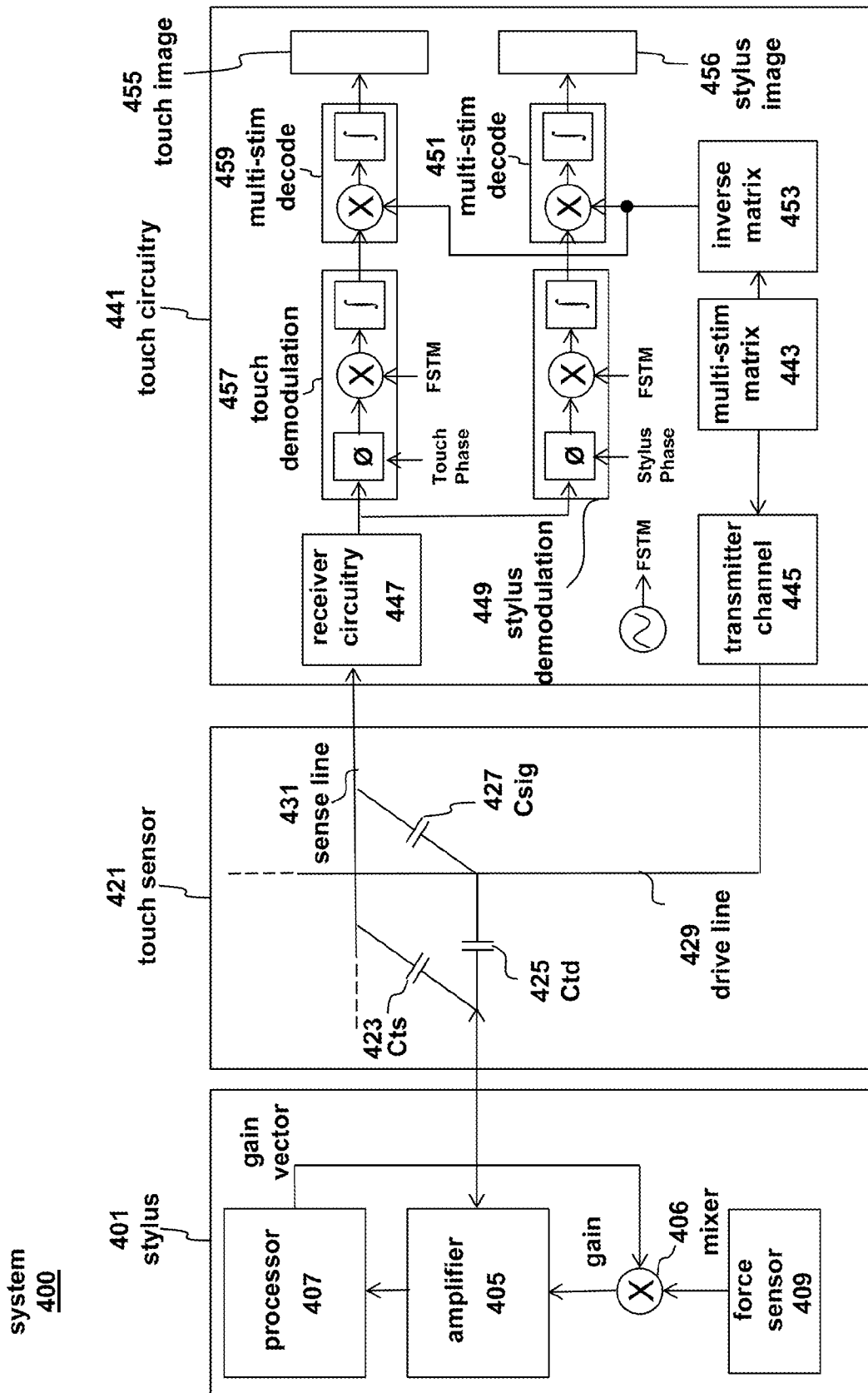


FIG. 4

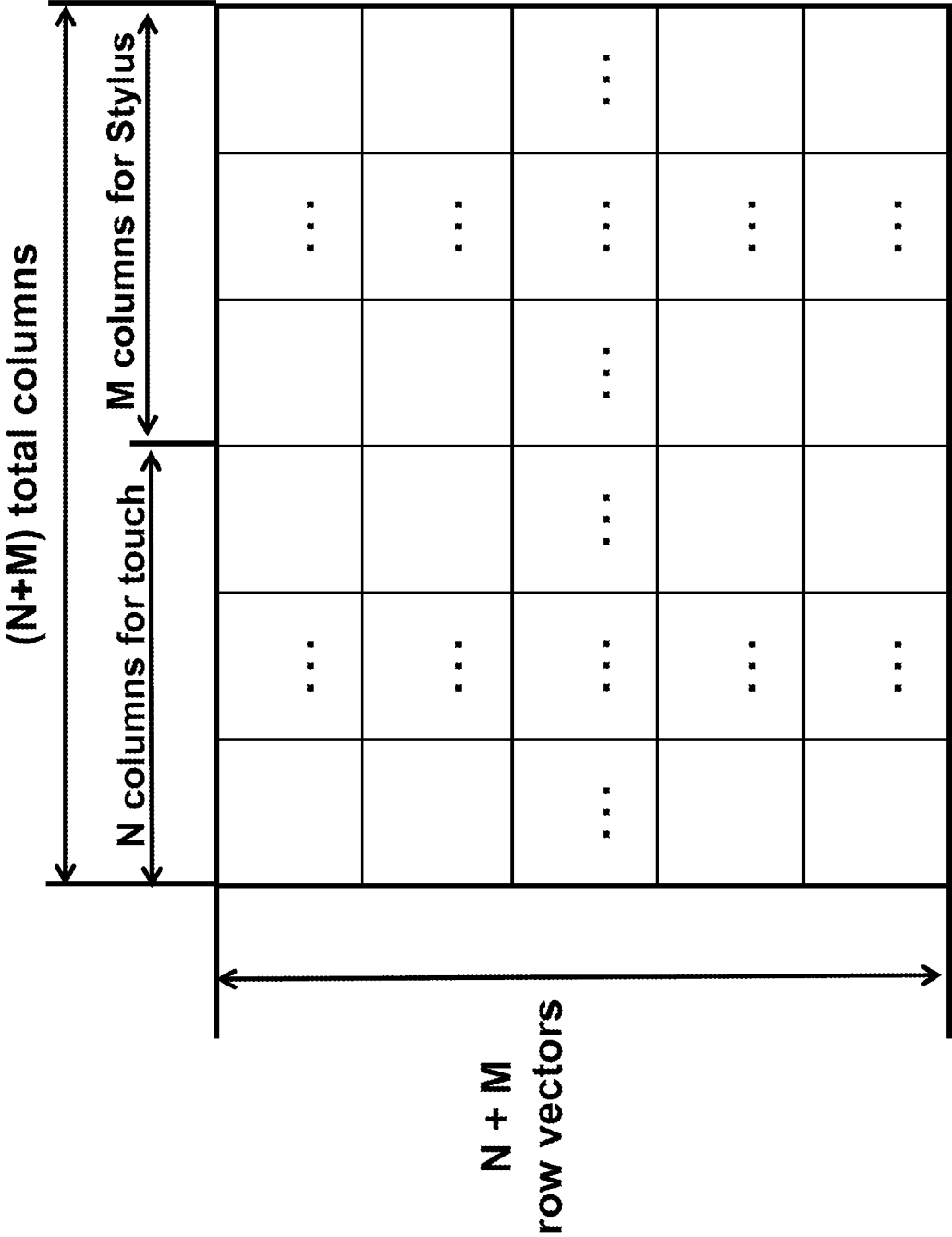


FIG. 5

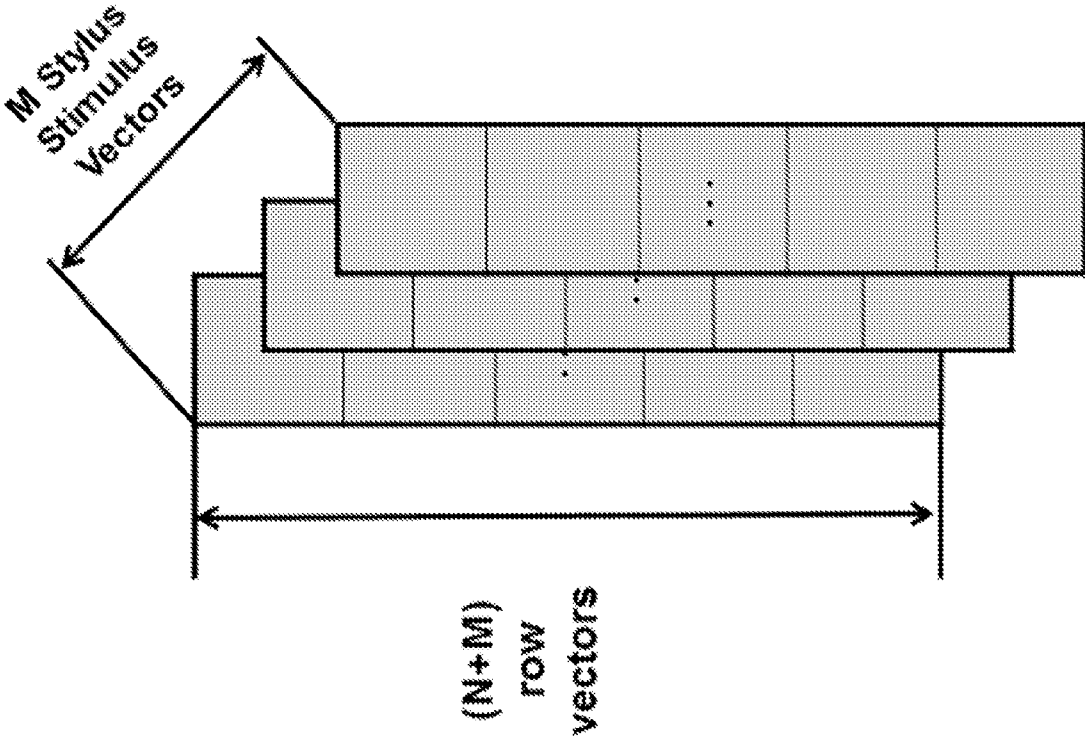


FIG. 6

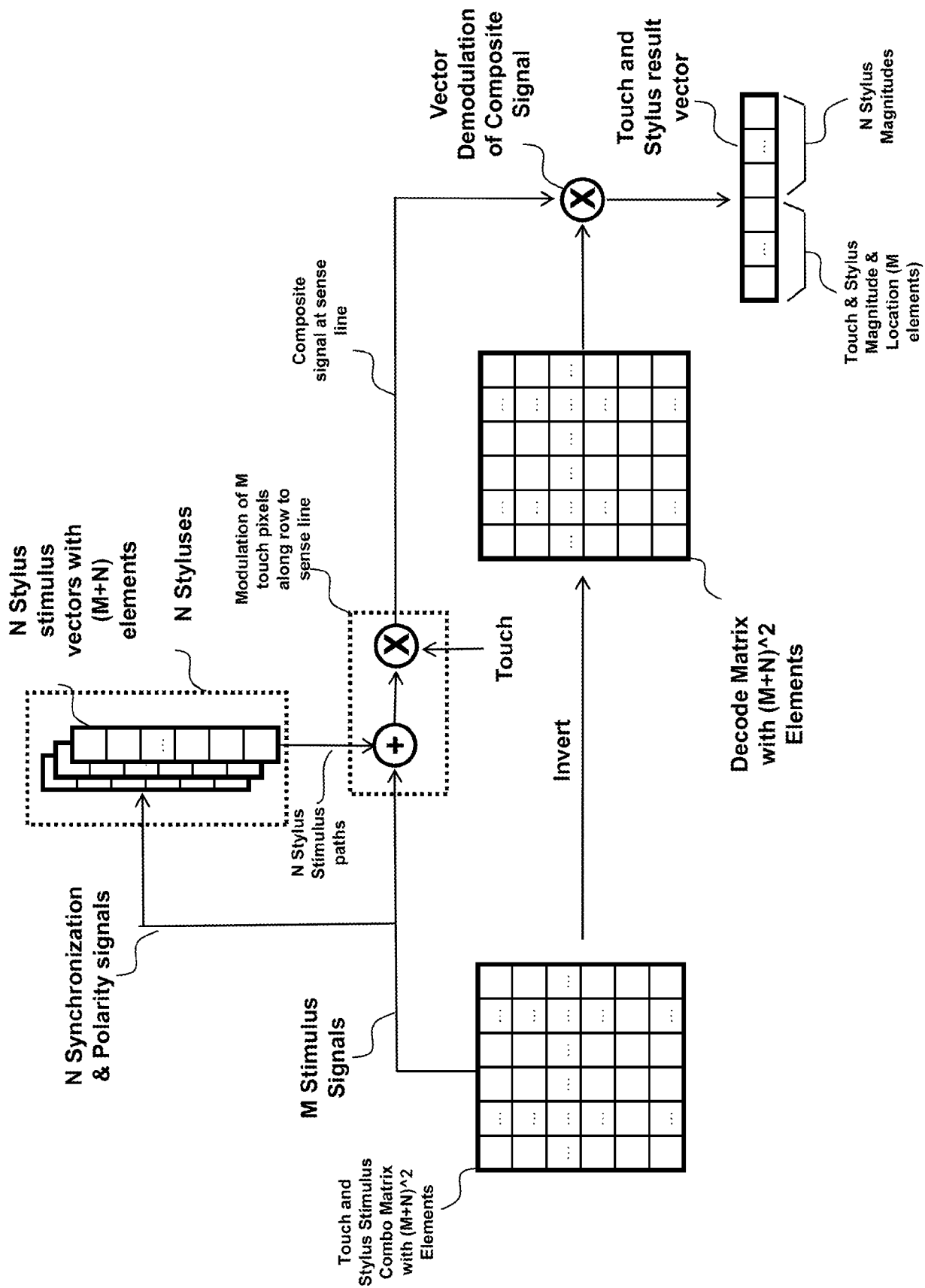


FIG. 7

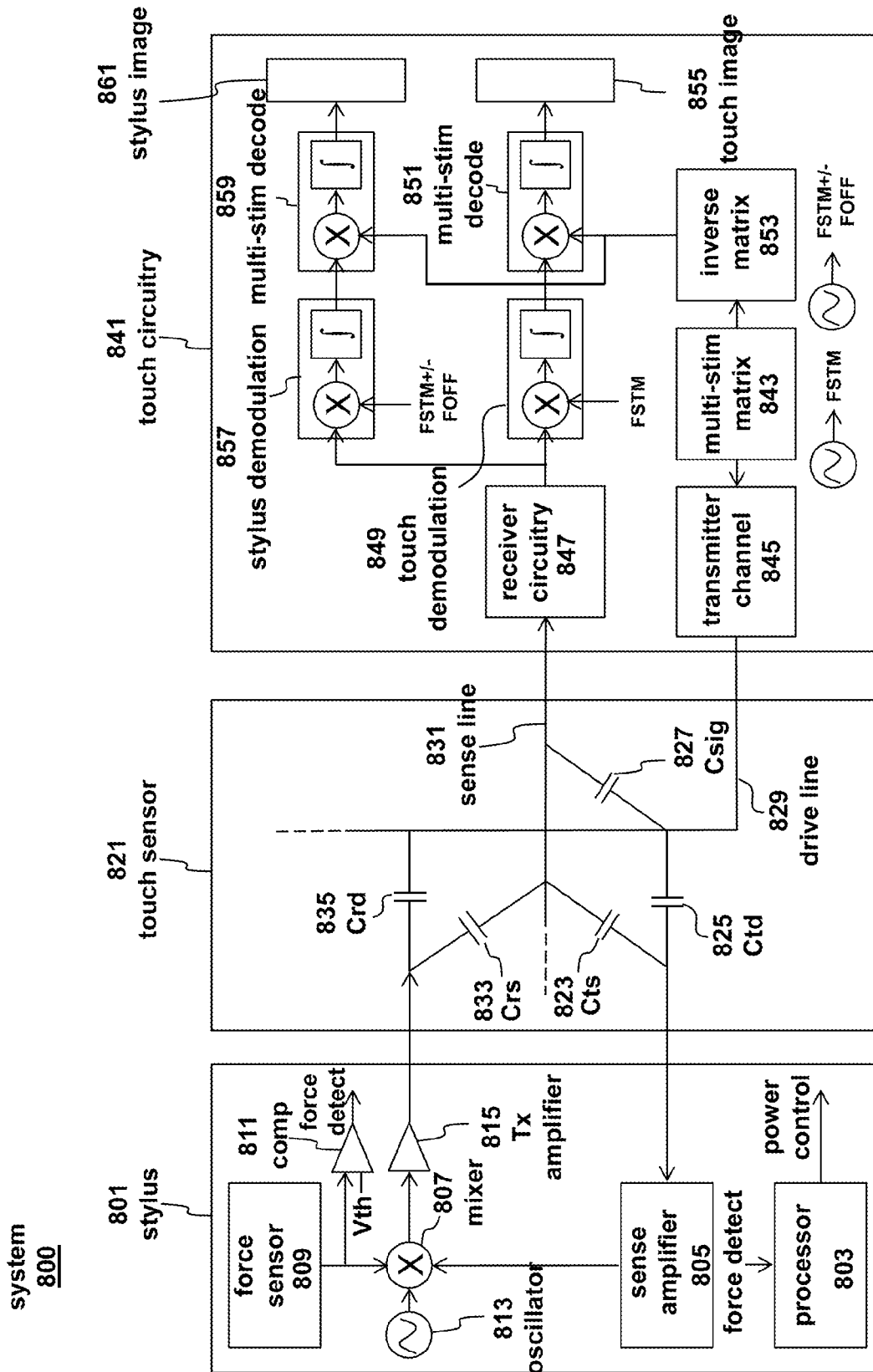


FIG. 8

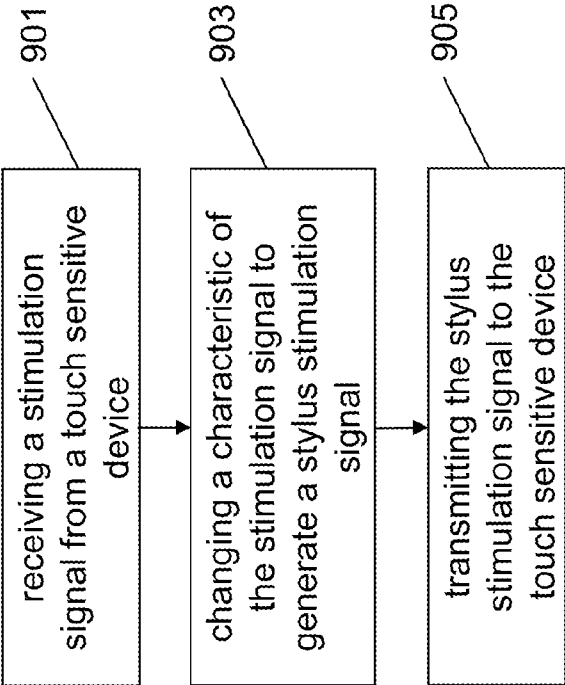


FIG. 9

process
1000

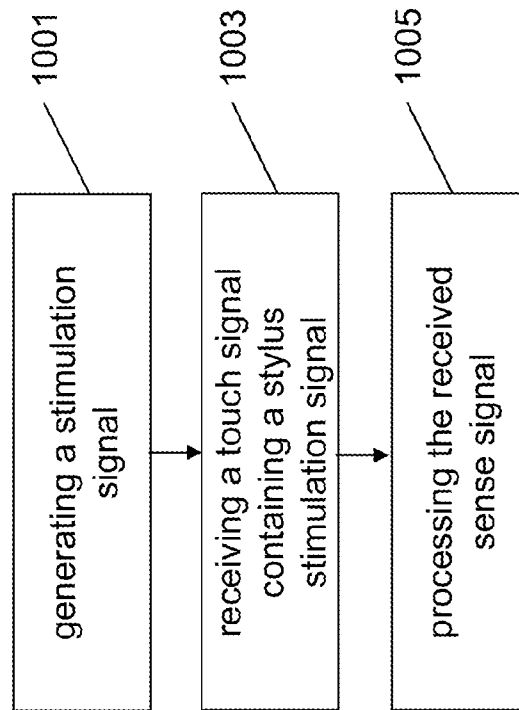


FIG. 10

system
1100

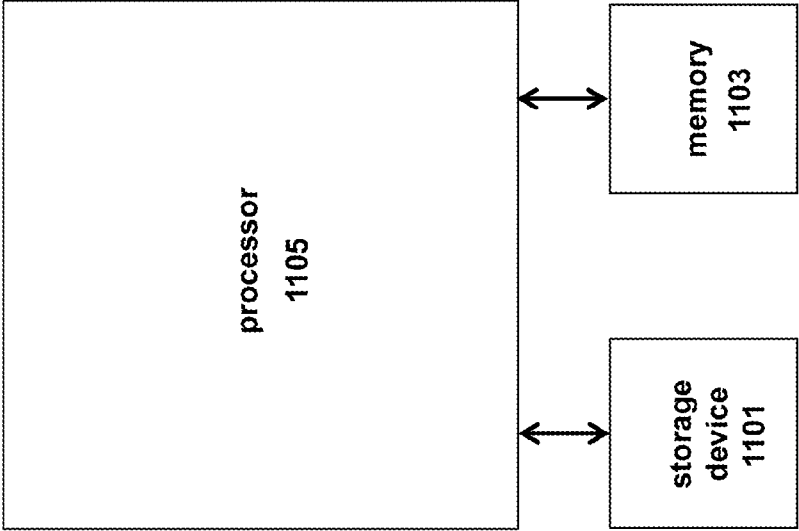


FIG. 11

personal
device
1300

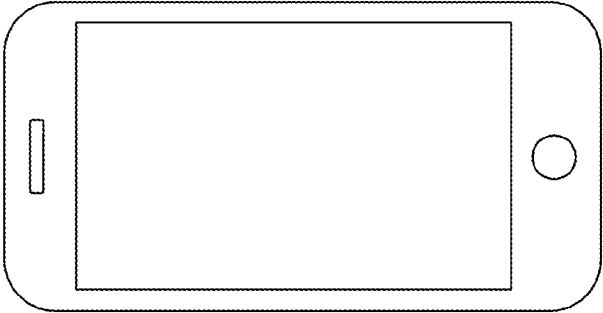


FIG. 13

personal
device
1200

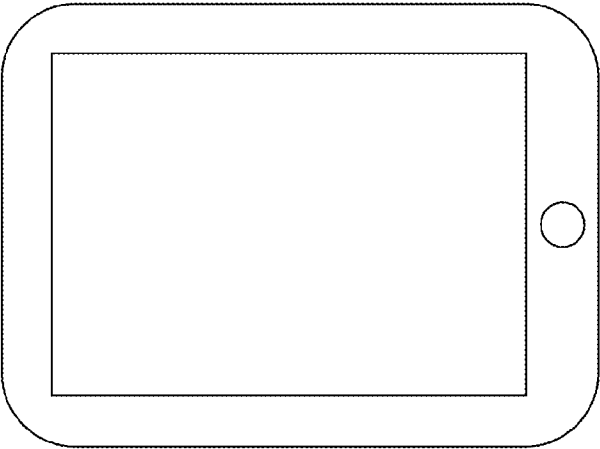


FIG. 12