US 20120105362A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2012/0105362 A1

(43) Pub. Date: May 3, 2012

KREMIN et al.

(54) **SYNCHRONIZING A STYLUS WITH A CAPACITIVE SENSE ARRAY**

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(73) Assignee: **CYPRESS SEMICONDUCTOR CORPORATION**, SAN JOSE, CA (US)

(21) Appl. No.: **13/213,981**

(22) Filed: **Aug. 19, 2011**

Related U.S. Application Data

(60) Provisional application No. 61/407,522, filed on Oct. 28, 2010, provisional application No. 61/407,903, filed on Oct. 28, 2010, provisional application No. 61/407,905, filed on Oct. 28, 2010, provisional application No. 61/407,906, filed on Oct. 28, 2010, provisional application No. 61/407,907, filed on Oct. 28, 2010.

Publication Classification

(51) **Int. Cl.**

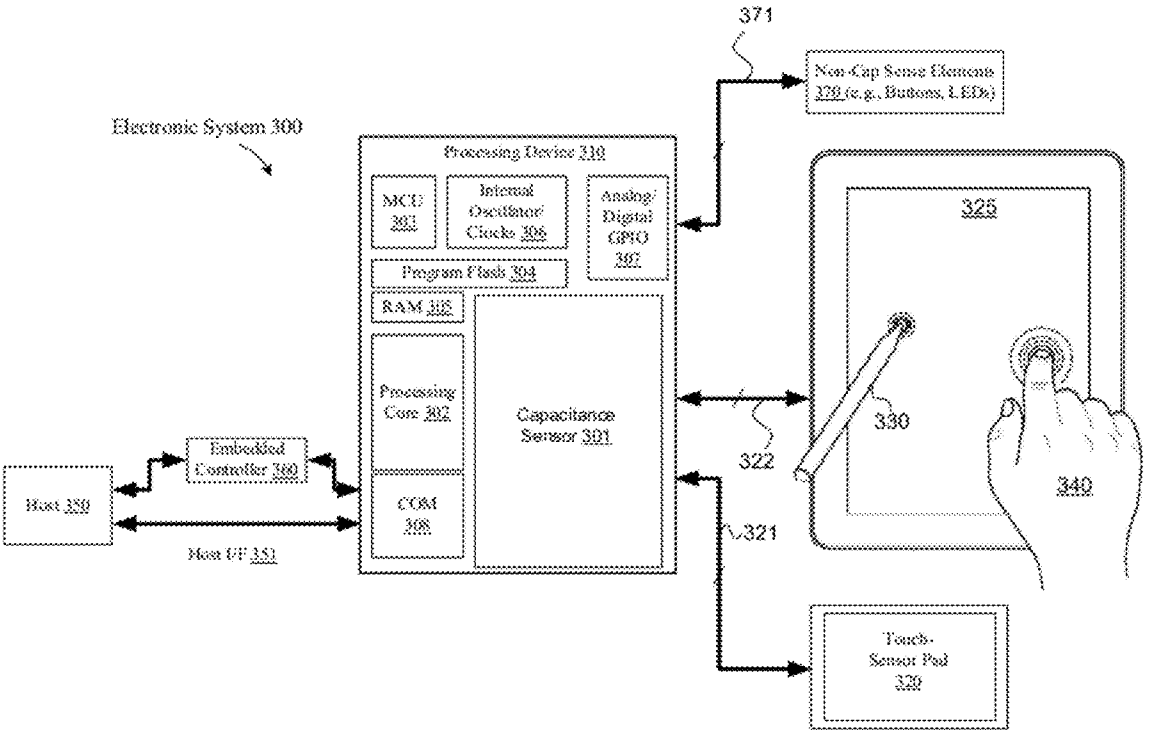
G06F 3/044 (2006.01)

G06F 3/033 (2006.01)

(52) **U.S. Cl.** **345/174**; 345/179

(57) **ABSTRACT**

A system and method for tracking a stylus on a capacitive sense array. The system comprising the capacitive sense array configured to detect a presence of the stylus, a processing device to generate a synchronization signal, and a transmitter to transmit the synchronization signal to the stylus to synchronize the stylus to the capacitive sense array. The system further comprises a magnetic antenna configured to inductively transmit the synchronization signal to the stylus, wherein the magnetic antenna is disposed around the outer edges of the capacitance sense array, according to an embodiment of the invention.



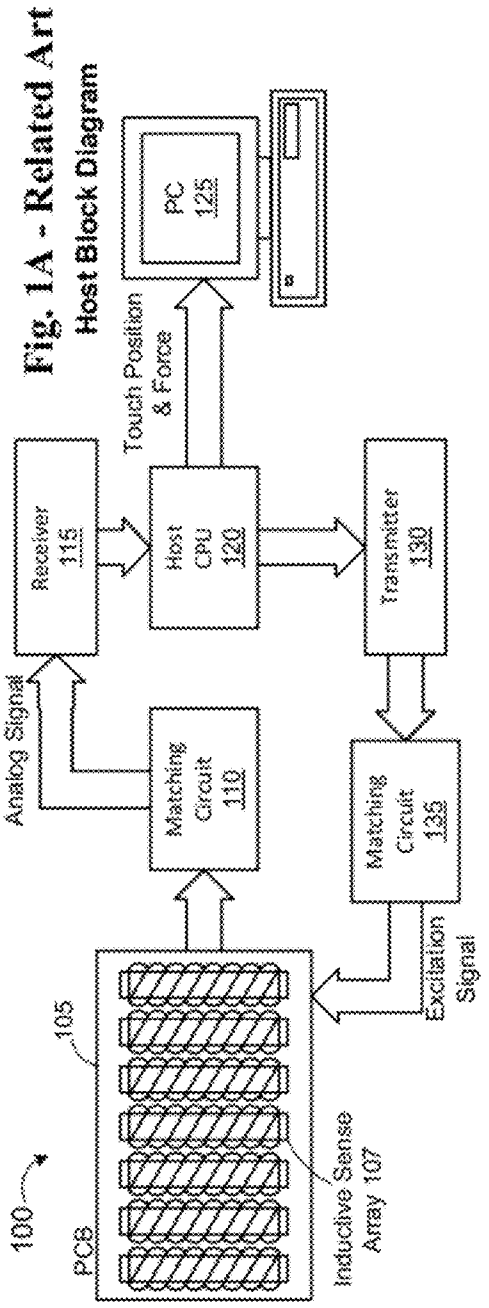


Fig. 1A - Related Art
Host Block Diagram
100
PCB
105
Inductive Sense Array 107
Excitation Signal
Analog Signal
Matching Circuit 110
Matching Circuit 135
Receiver 115
Host CPU 120
Transmitter 130
Touch Position & Force
PC 125

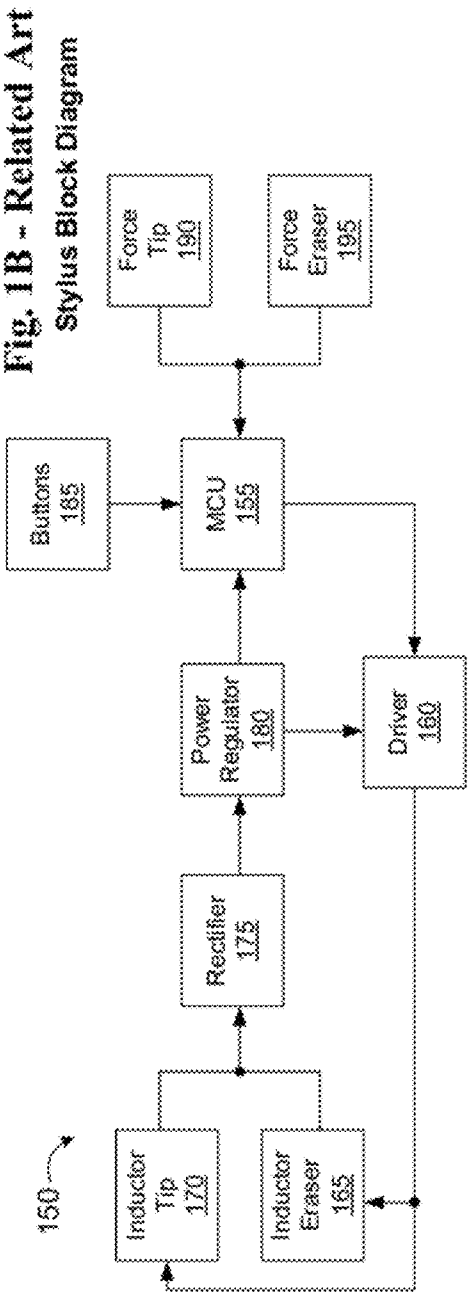


Fig. 1B - Related Art
Stylus Block Diagram
150
Inductor Tip 170
Inductor Eraser 165
Rectifier 175
Power Regulator 180
Driver 160
Buttons 185
MCU 155
Force Tip 190
Force Eraser 195

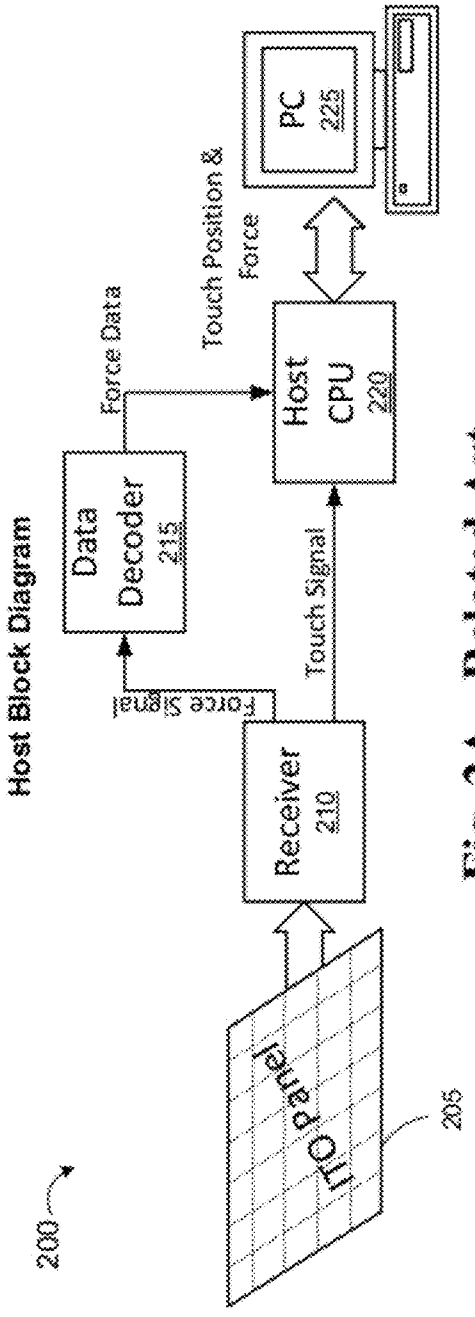


Fig. 2A - Related Art

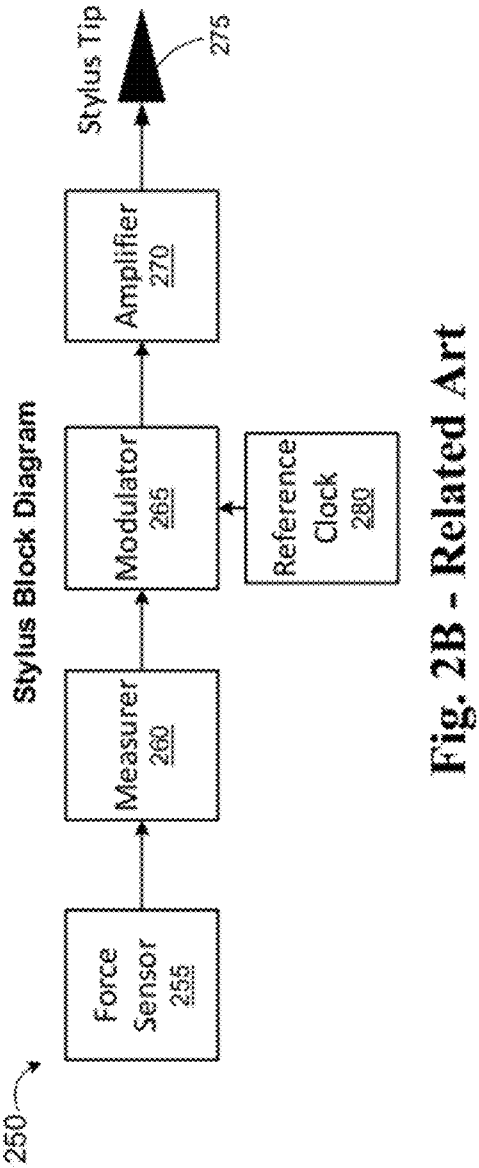


Fig. 2B - Related Art

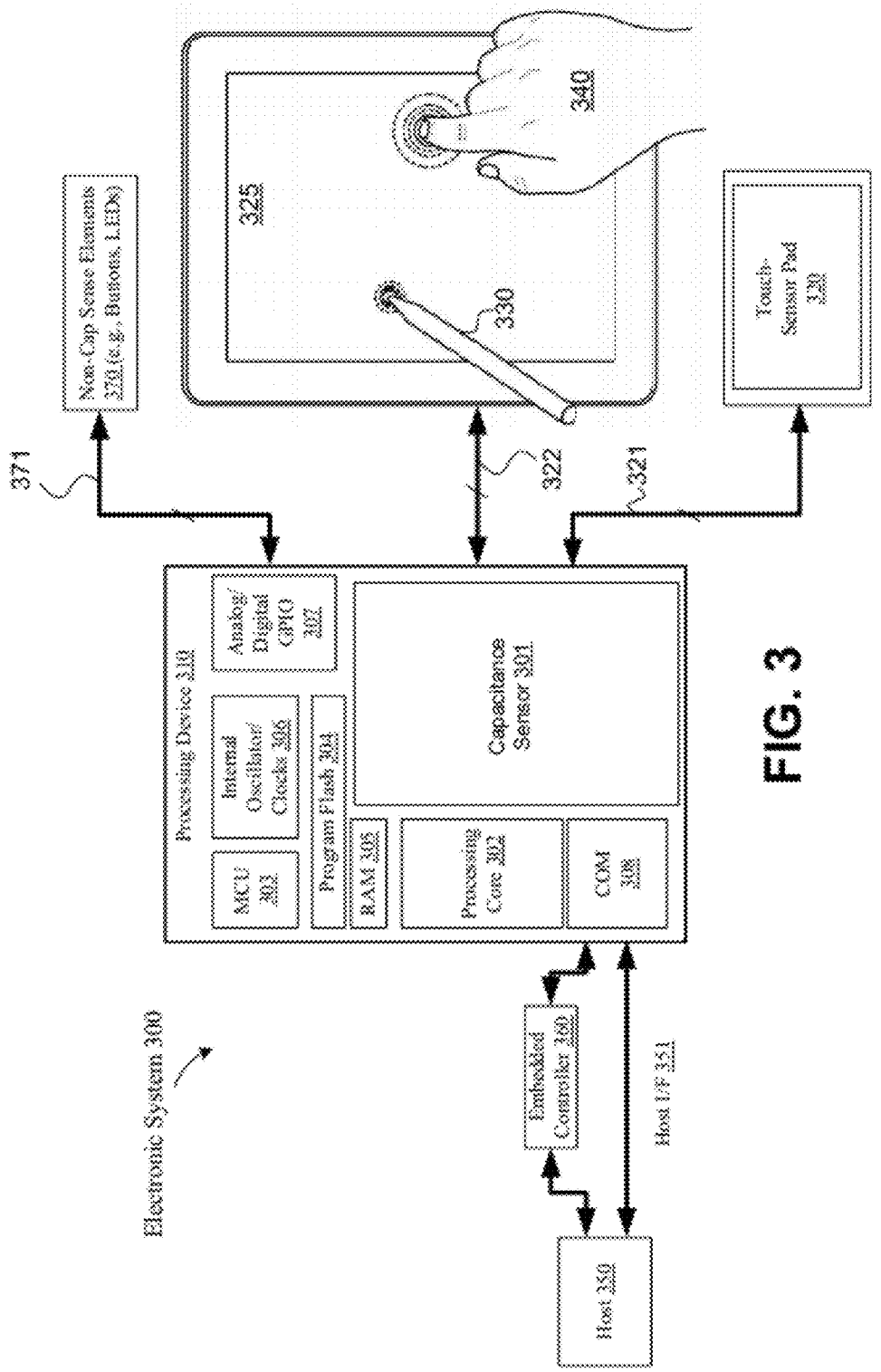

Electronic System 300
Host 350
Embedded Controller 360
Host I/F 351
Processing Device 310
MCU 303
Internal Oscillator/ Clocks 306
Analog/ Digital GPIO 307
Program Flash 304
RAM 305
Processing Core 302
COM 308
Capacitance Sensor 301
371
322
321
325
330
340
Non-Cap Sense Elements 370 (e.g., Buttons, LEDs)
Touch-Sensor Pad 320

FIG. 3

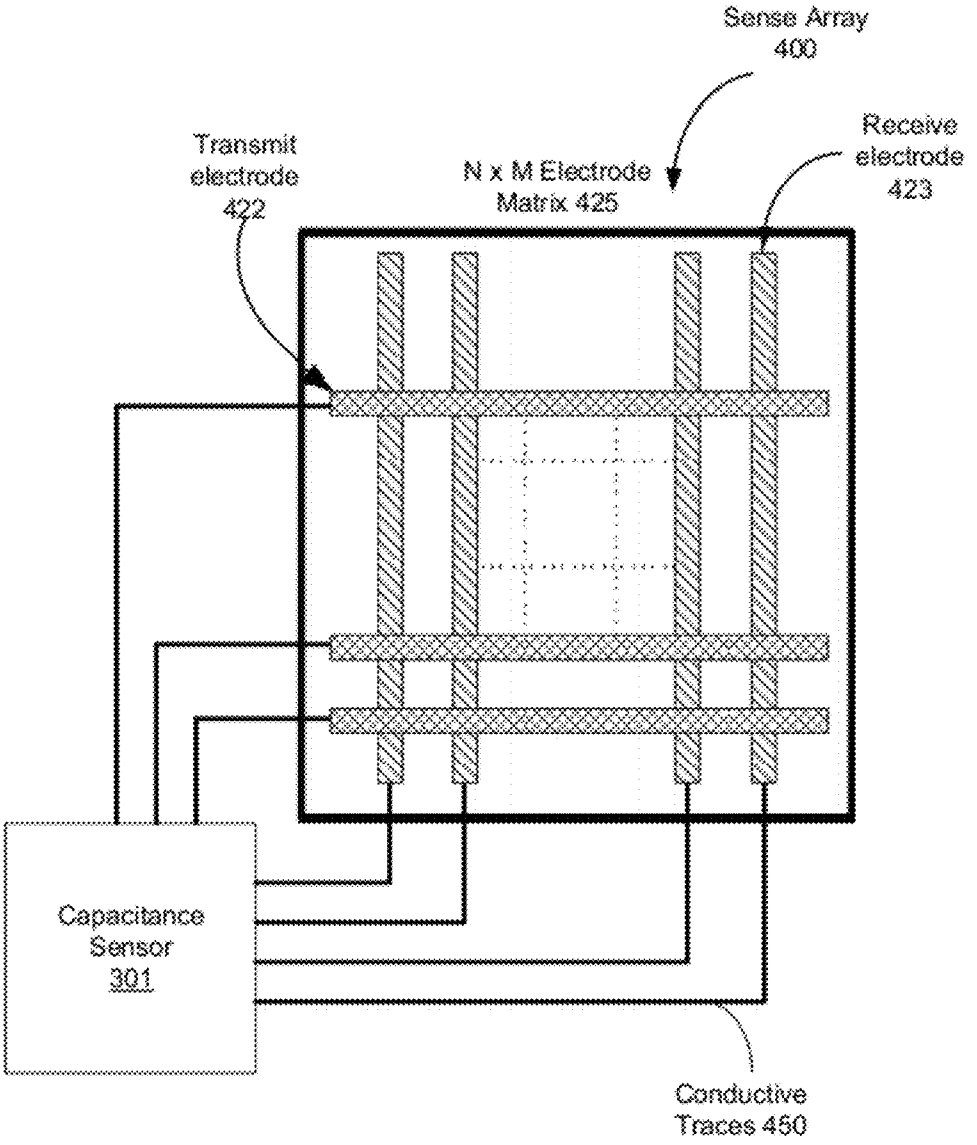

Sense Array
400
Transmit
electrode
422
N x M Electrode
Matrix 425
Receive
electrode
423
Capacitance
Sensor
301
Conductive
Traces 450

FIG. 4

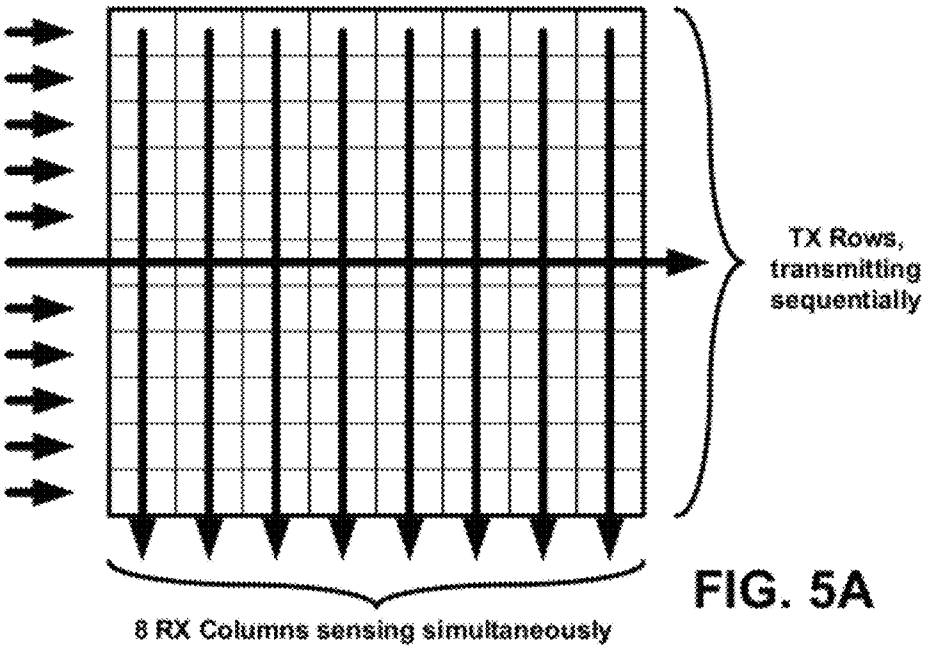

TX Rows, transmitting sequentially
8 RX Columns sensing simultaneously

FIG. 5A

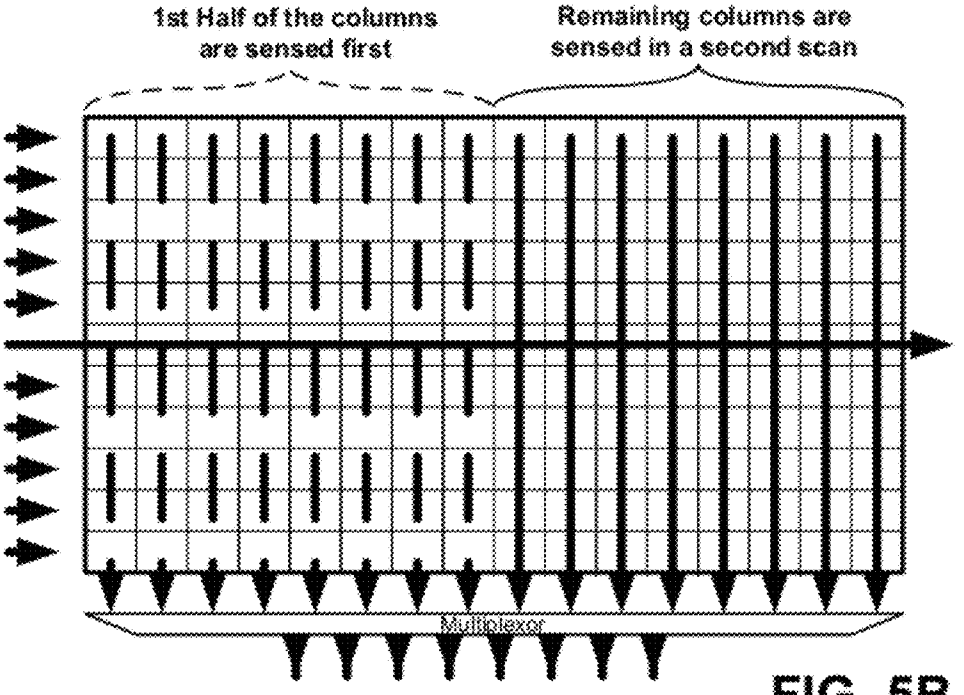

1st Half of the columns are sensed first
Remaining columns are sensed in a second scan
Multiplexor

FIG. 5B

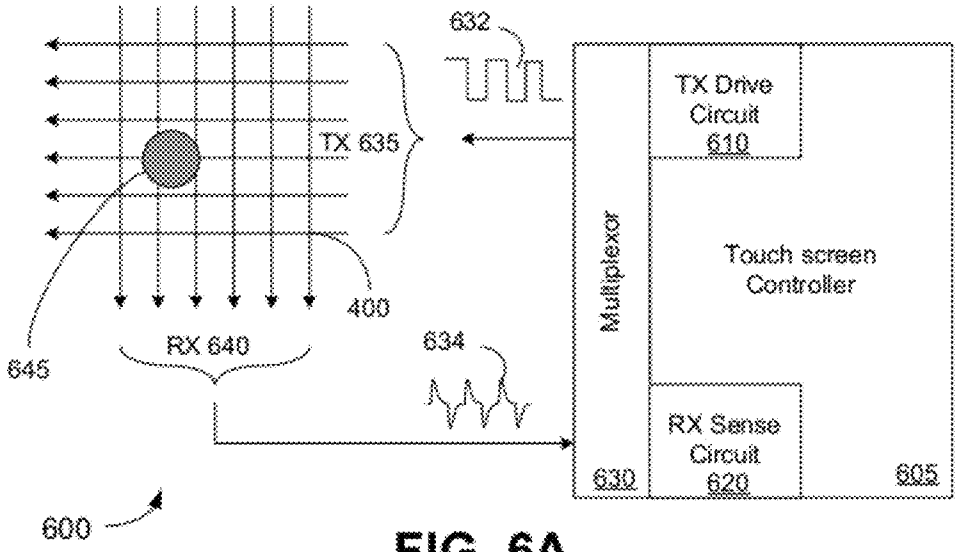

632
TX 635
TX Drive Circuit 610
Multiplexor
Touch screen Controller
400
645
RX 640
634
RX Sense Circuit 620
630
605
600

FIG. 6A

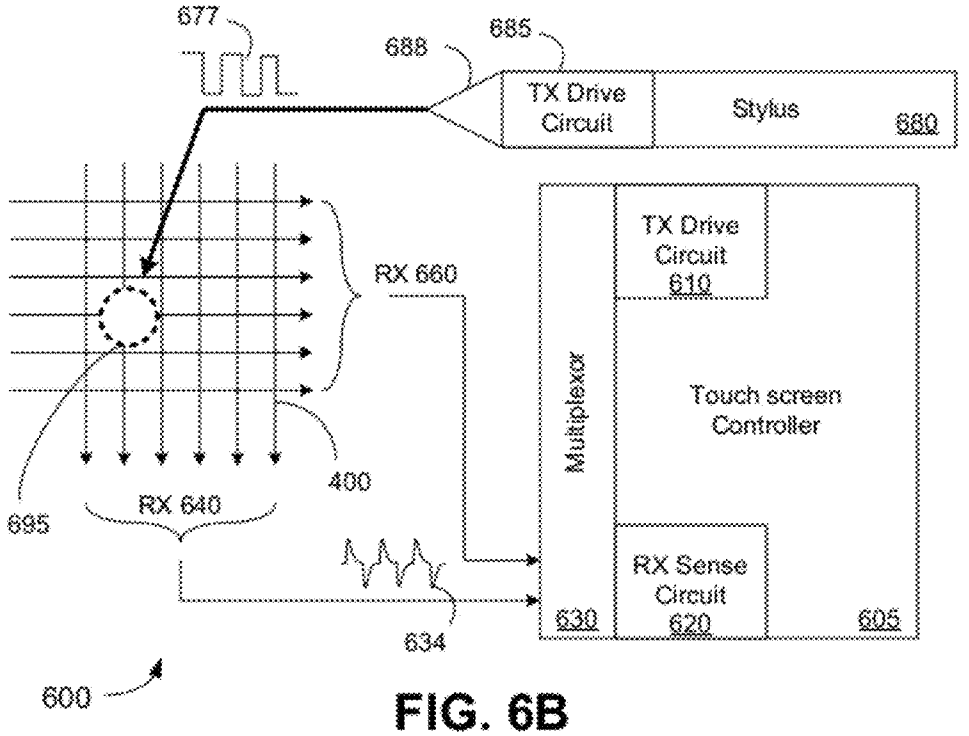

677
688
685
TX Drive Circuit
Stylus 660
RX 660
TX Drive Circuit 610
Multiplexor
Touch screen Controller
400
695
RX 640
RX Sense Circuit 620
630
605
634
600

FIG. 6B

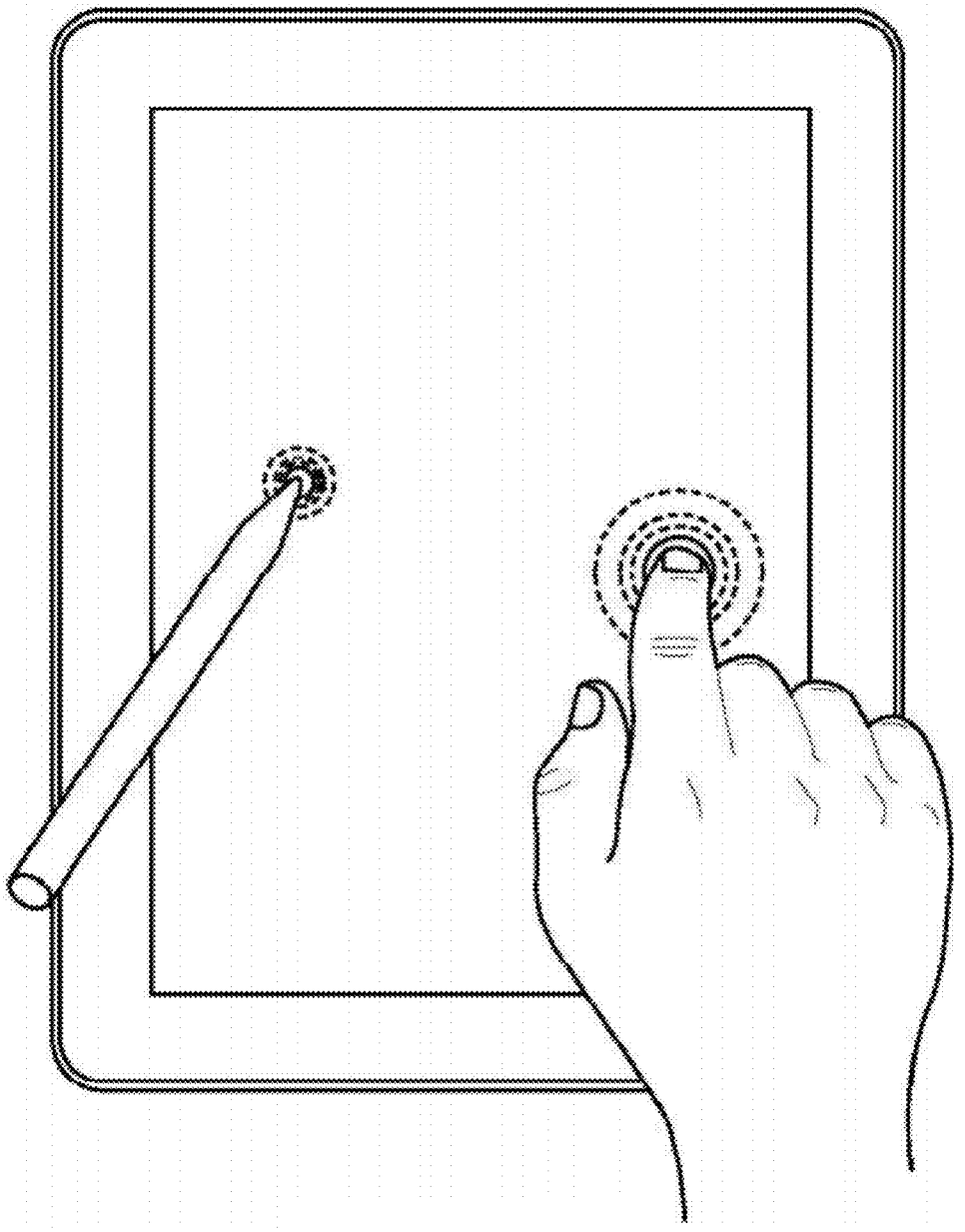


FIG. 7

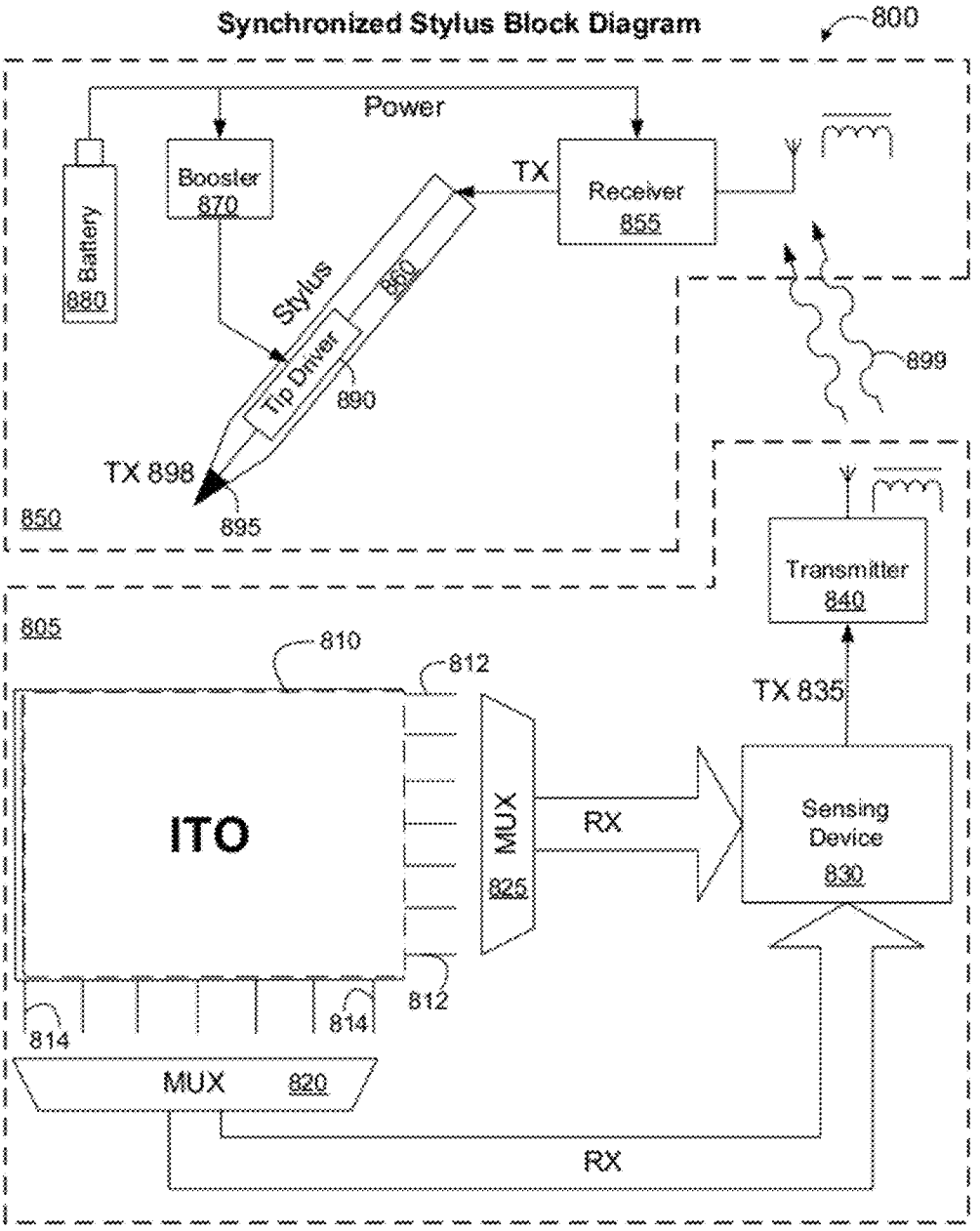

Synchronized Stylus Block Diagram
800
Power
Booster
870
Battery
880
TX
Receiver
855
Stylus
860
Tip Driver
890
899
TX 898
895
850
Transmitter
840
805
810
812
TX 835
ITO
MUX
825
RX
Sensing
Device
830
812
814
814
MUX
820
RX

Fig. 8

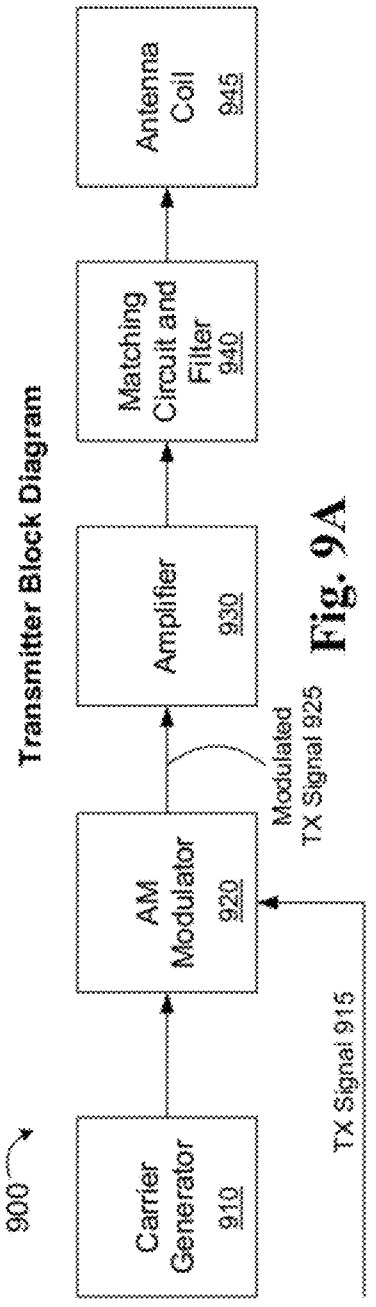

Transmitter Block Diagram
900
Carrier Generator 910
AM Modulator 920
Amplifier 930
Matching Circuit and Filter 940
Antenna Coil 945
TX Signal 915
Modulated TX Signal 925

Fig. 9A

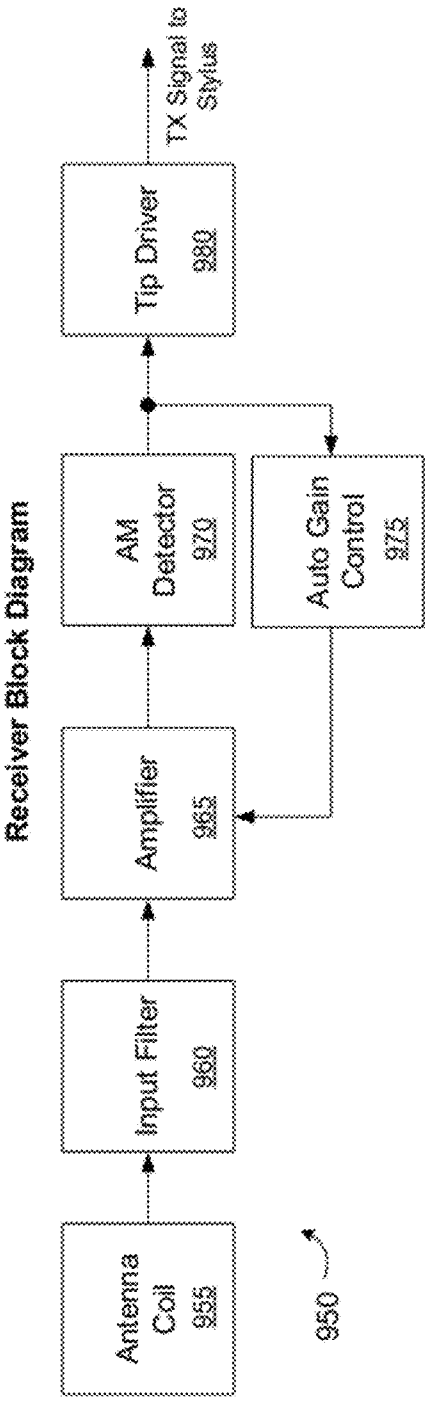

Receiver Block Diagram
950
Antenna Coil 955
Input Filter 960
Amplifier 965
AM Detector 970
Auto Gain Control 975
Tip Driver 980
TX Signal to Stylus

Fig. 9B

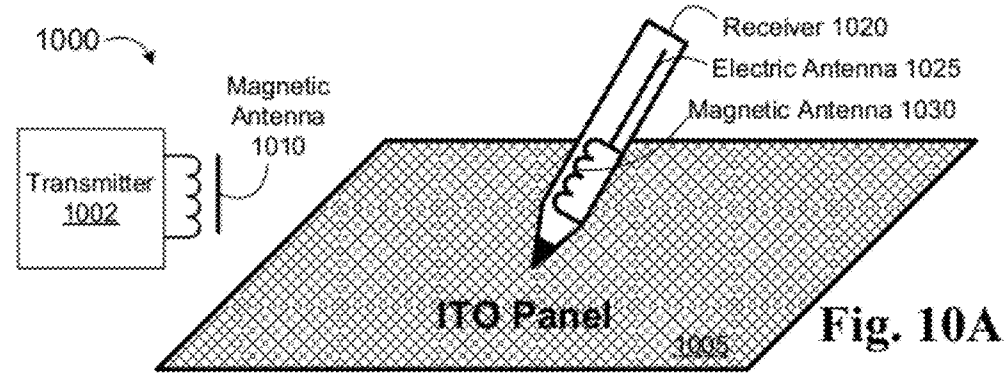


Fig. 10A

Magnetic Tranmitter Antenna

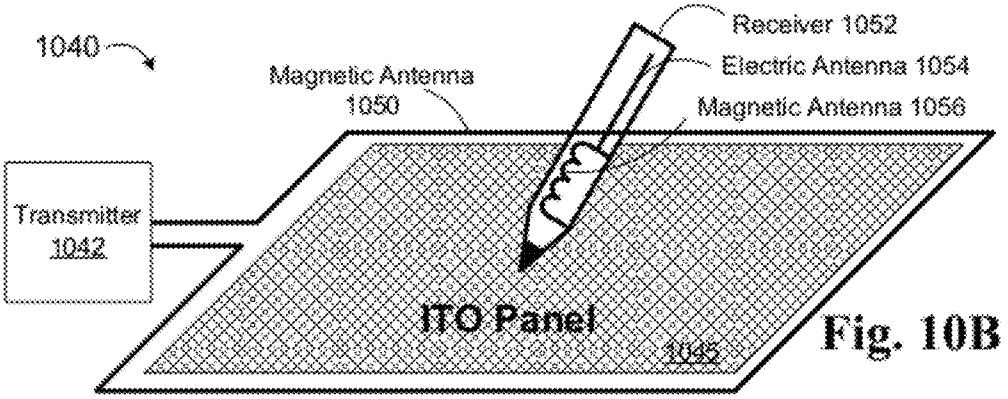


Fig. 10B

Magnetic Coil Around The Screen

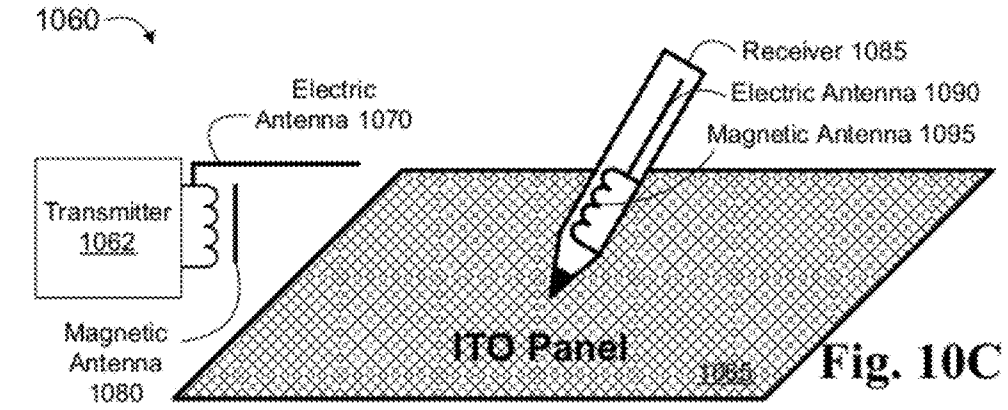


Fig. 10C

Magnetic + Electric Transmitter Antenna

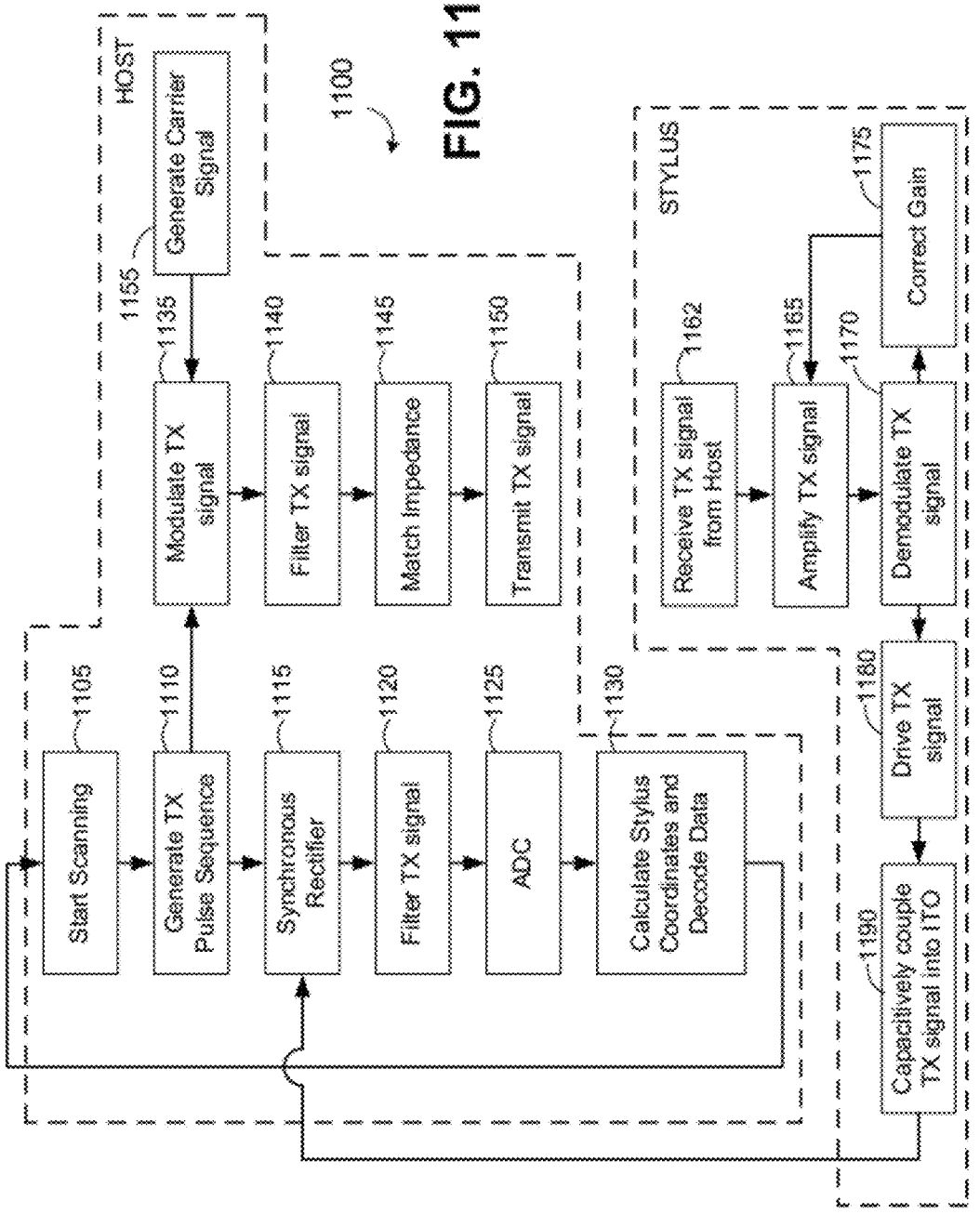

HOST
STYLUS
1100
1105
Start Scanning
1110
Generate TX Pulse Sequence
1115
Synchronous Rectifier
1120
Filter TX signal
1125
ADC
1130
Calculate Stylus Coordinates and Decode Data
1135
Modulate TX signal
1140
Filter TX signal
1145
Match Impedance
1150
Transmit TX signal
1155
Generate Carrier Signal
1160
Drive TX signal
1162
Receive TX signal from Host
1165
Amplify TX signal
1170
Demodulate TX signal
1175
Correct Gain
1190
Capacitively couple TX signal into ITO

FIG. 11

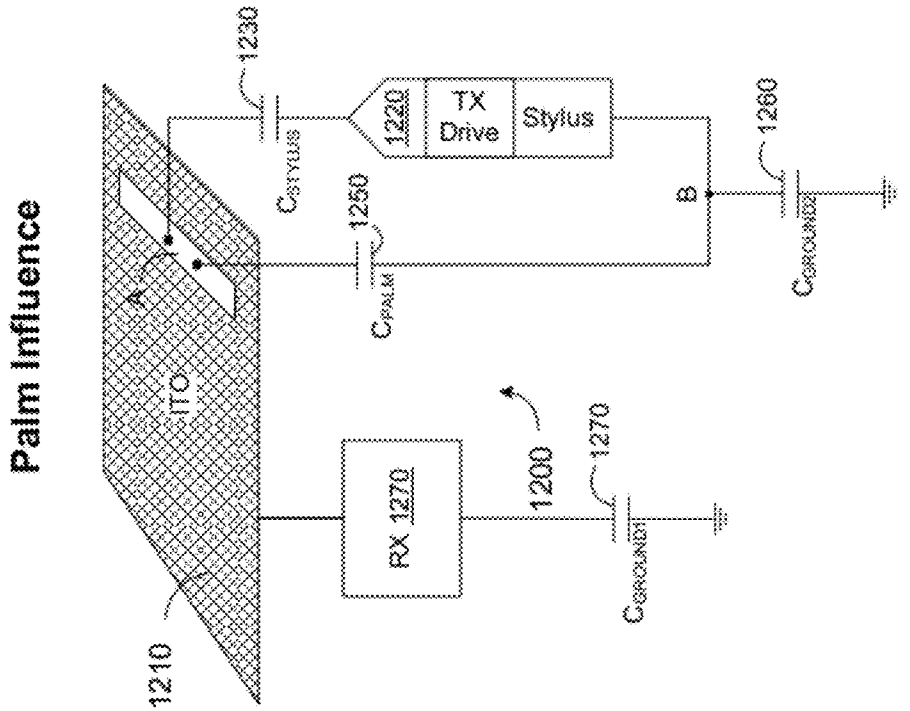


FIG. 12B

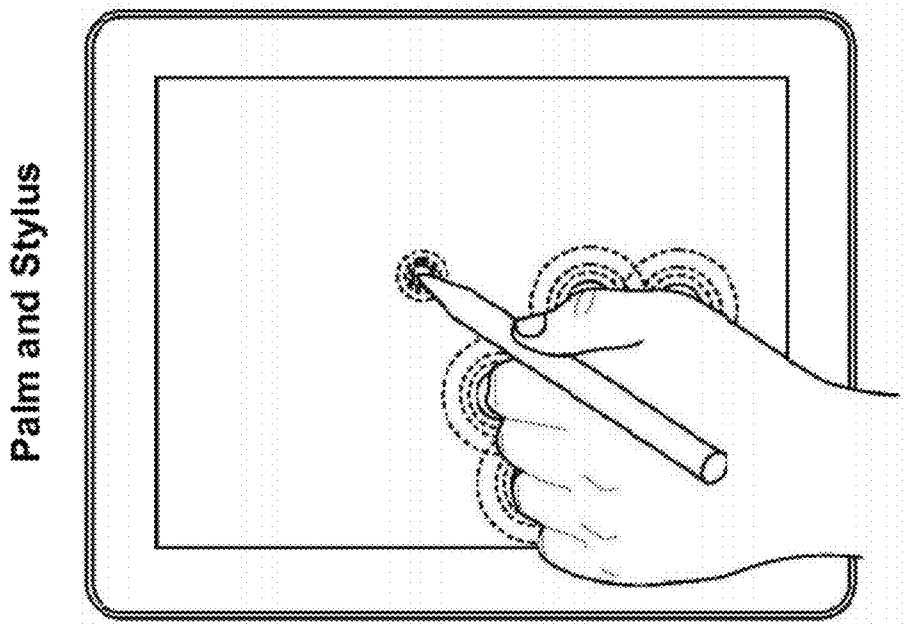


FIG. 12A

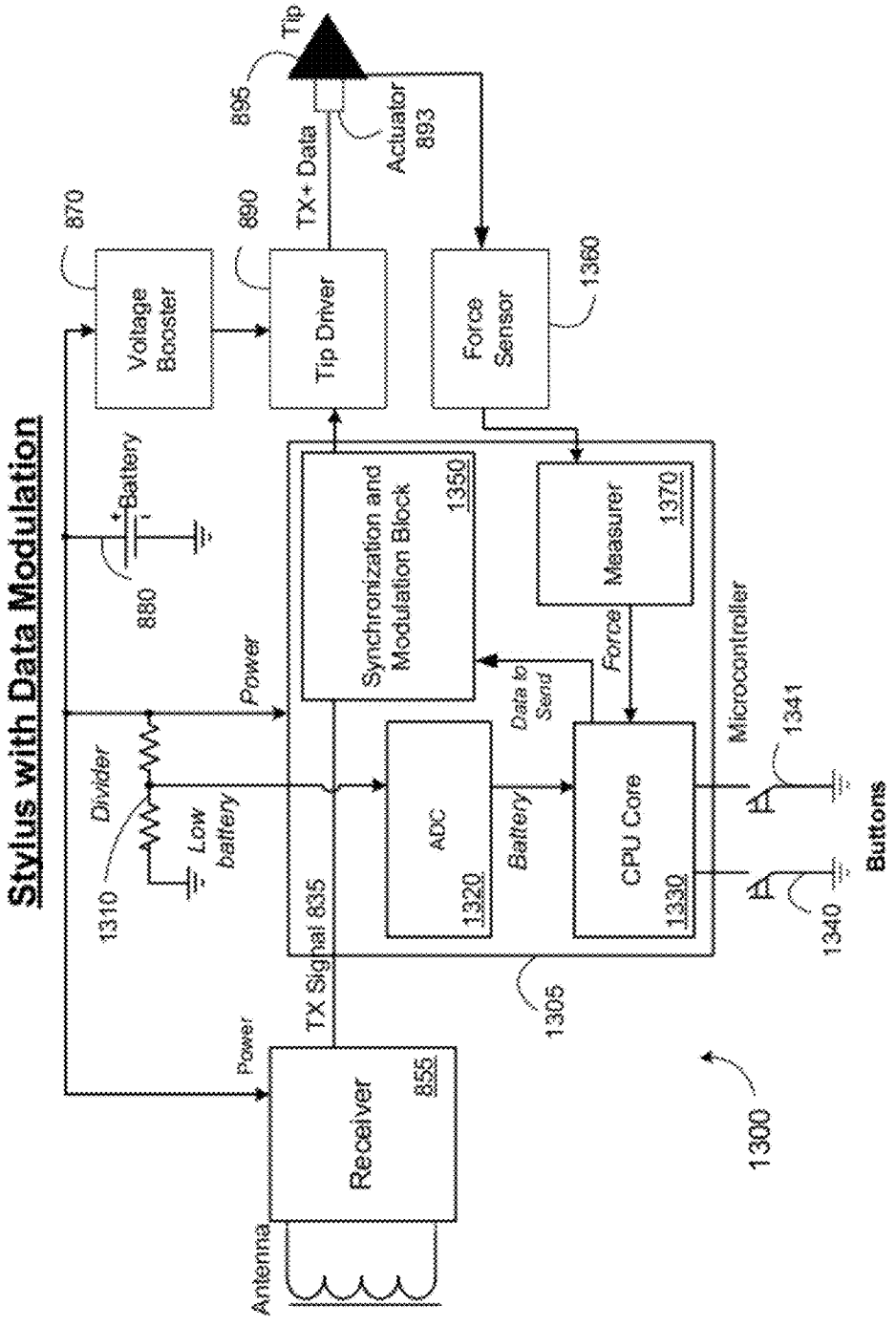

Stylus with Data Modulation
Tip
895
Actuator
893
TX+ Data
890
870
Voltage Booster
Tip Driver
Force Sensor
1360
Battery
880
Synchronization and Modulation Block
1359
Measurer
1370
Power
Data to Send
Force
Microcontroller
Divider
Low battery
1310
ADC
1320
Battery
CPU Core
1330
1341
Buttons
1340
TX Signal 835
1305
Power
Receiver
855
Antenna
1300

Fig. 13

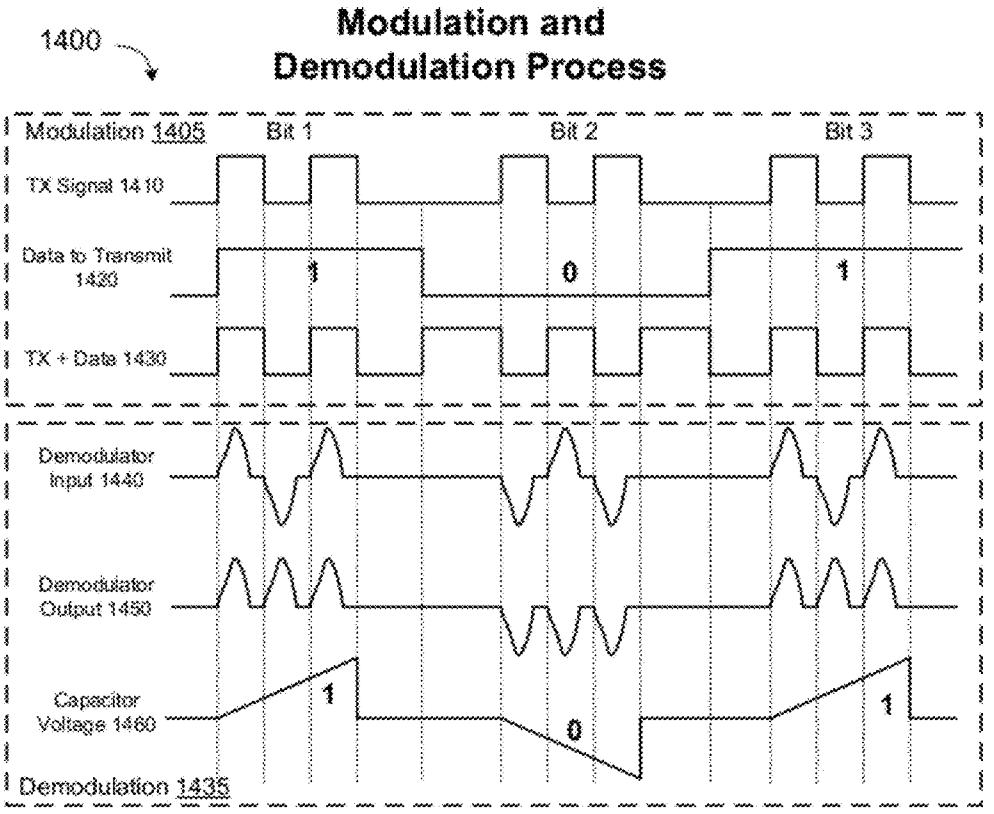

1400
Modulation and
Demodulation Process
Modulation 1405
Bit 1
Bit 2
Bit 3
TX Signal 1410
Data to Transmit
1420
1
0
1
TX + Data 1430
Demodulator
Input 1440
Demodulator
Output 1450
Capacitor
Voltage 1460
1
0
1
Demodulation 1435

Fig. 14

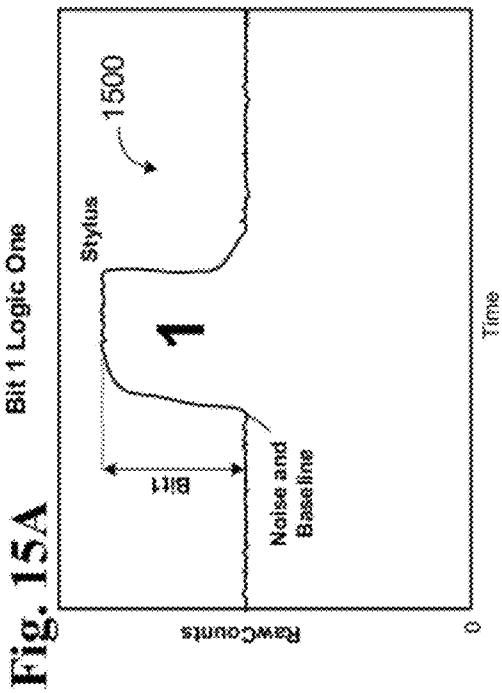


Fig. 15A

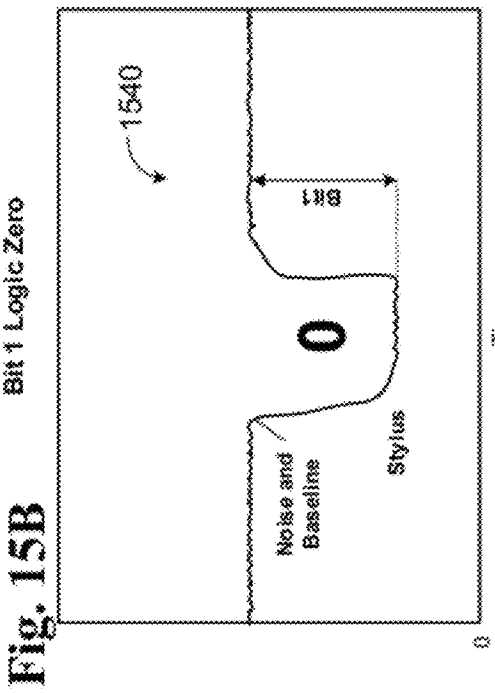


Fig. 15B

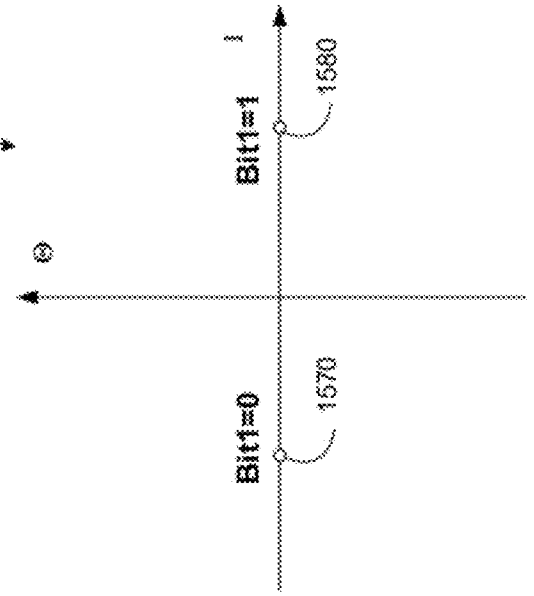


Fig. 15C

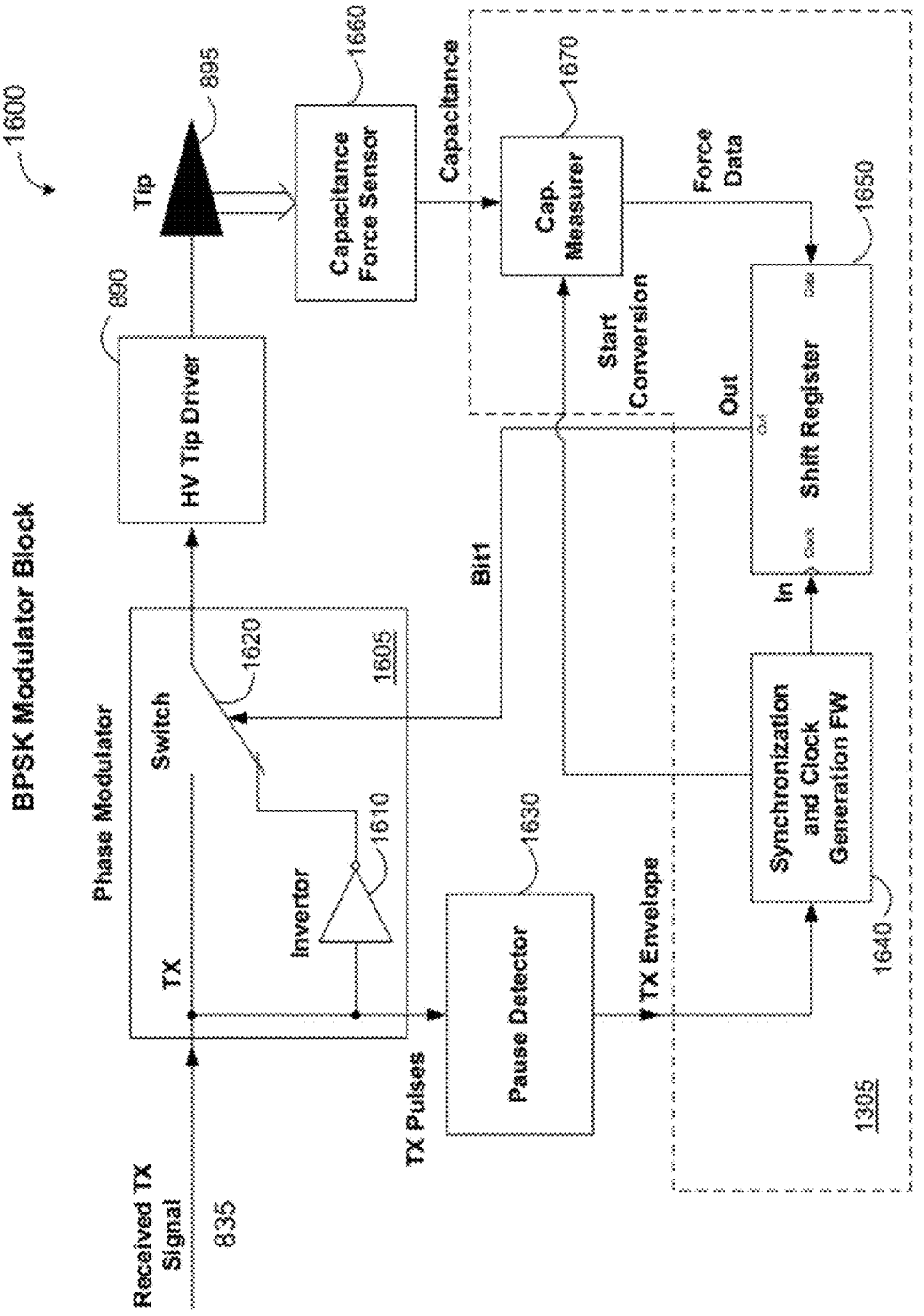

1600
BPSK Modulator Block
Tip
895
1660
Capacitance Force Sensor
Capacitance
1670
Cap. Measurer
Force Data
1650
890
HV Tip Driver
Start Conversion
Out
Shift Register
In
Bit1
1620
1605
Switch
Phase Modulator
1610
Invertor
1630
TX
Pause Detector
TX Envelope
Synchronization and Clock Generation FW
1640
TX Pulses
1305
Received TX Signal
835

Fig. 16

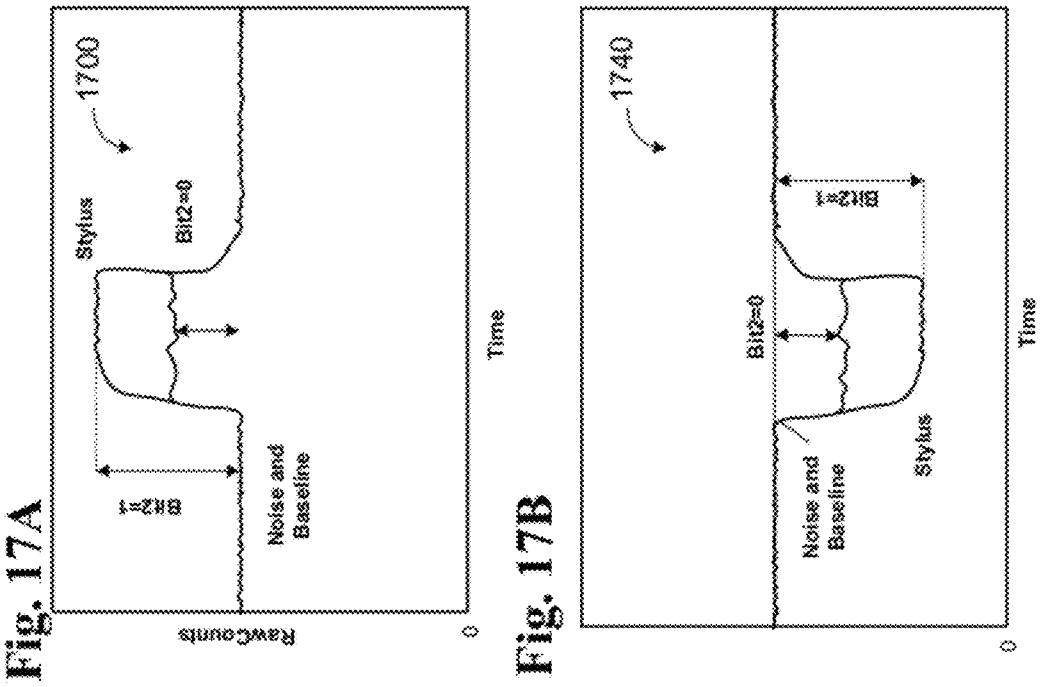


Fig. 17A

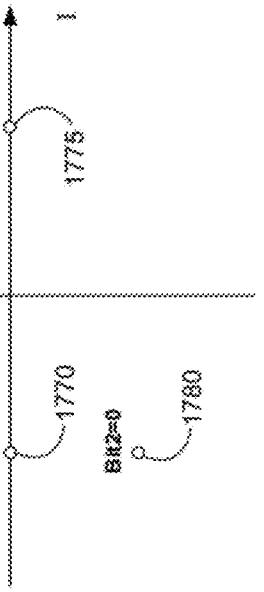


Fig. 17C

Fig. 17B

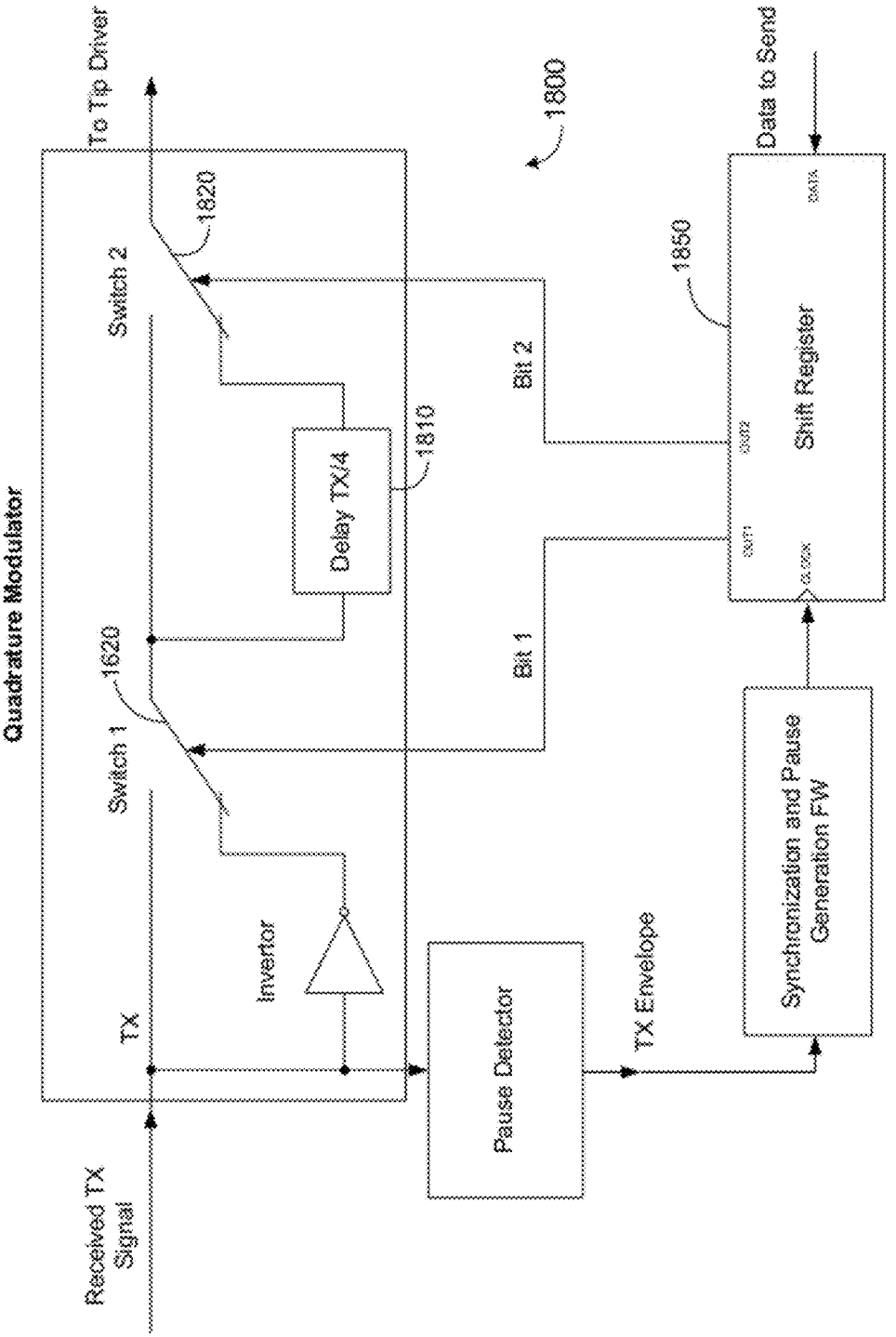

Quadrature Modulator
To Tip Driver
1800
Data to Send
1820
Switch 2
1850
Bit 2
Shift Register
Delay TX/4
1810
1620
Switch 1
Bit 1
Invertor
TX
Pause Detector
TX Envelope
Synchronization and Pause Generation FW
Received TX Signal

Fig. 18

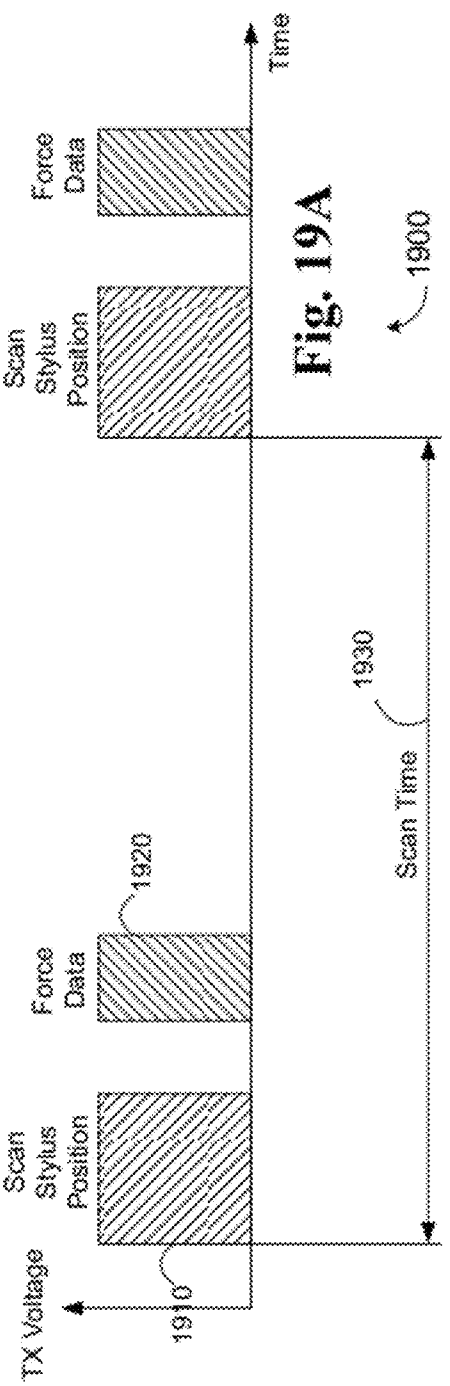


Fig. 19A

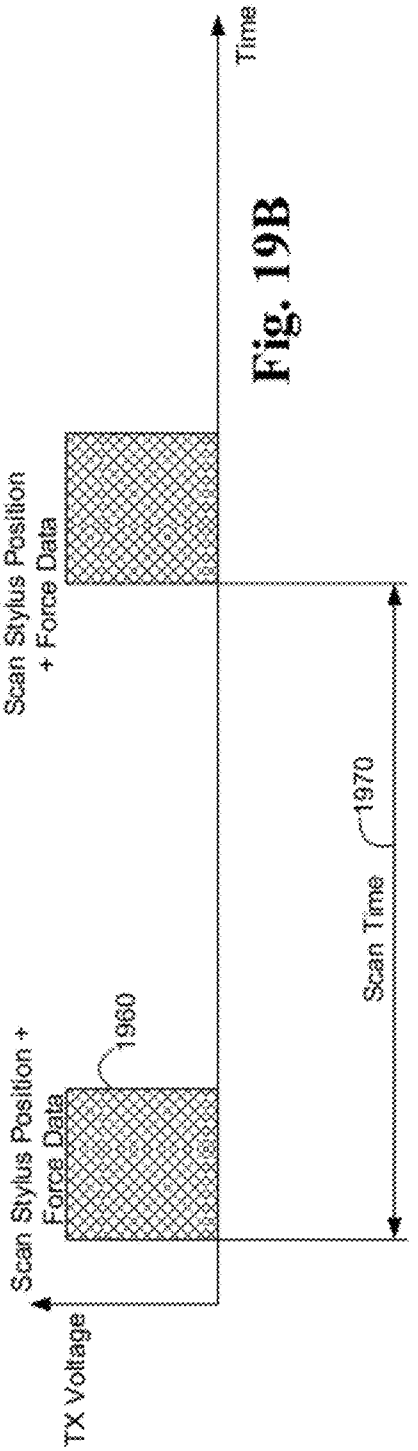
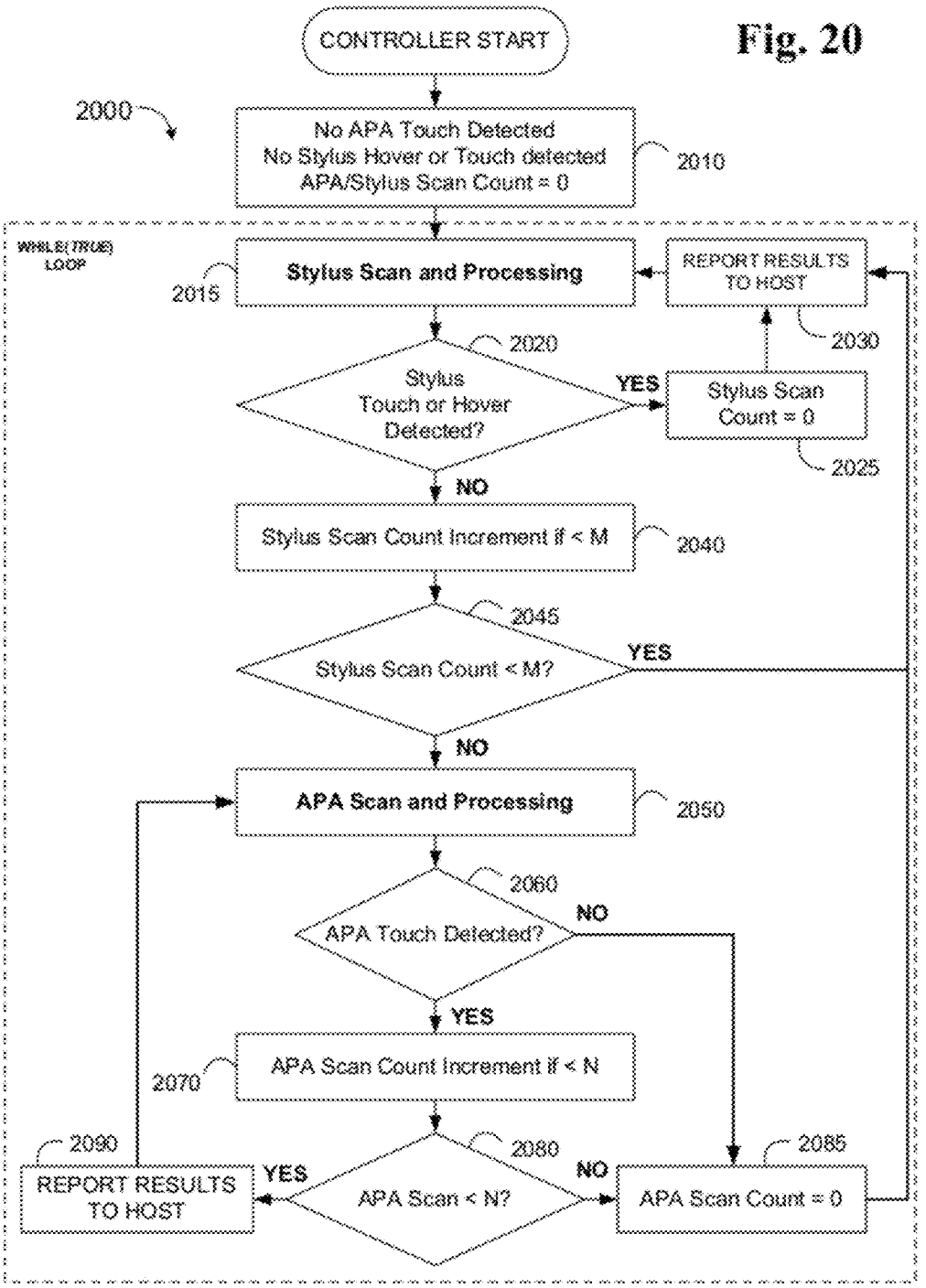


Fig. 19B

Fig. 20


CONTROLLER START
2000
No APA Touch Detected
No Stylus Hover or Touch detected
APA/Stylus Scan Count = 0
2010
WHILE(TRUE) LOOP
Stylus Scan and Processing
2015
REPORT RESULTS TO HOST
2030
2020
Stylus Touch or Hover Detected?
YES
Stylus Scan Count = 0
2025
NO
Stylus Scan Count Increment if < M
2040
2045
Stylus Scan Count < M?
YES
NO
APA Scan and Processing
2050
2060
APA Touch Detected?
NO
YES
APA Scan Count Increment if < N
2070
2090
2080
2085
REPORT RESULTS TO HOST
YES
APA Scan < N?
NO
APA Scan Count = 0

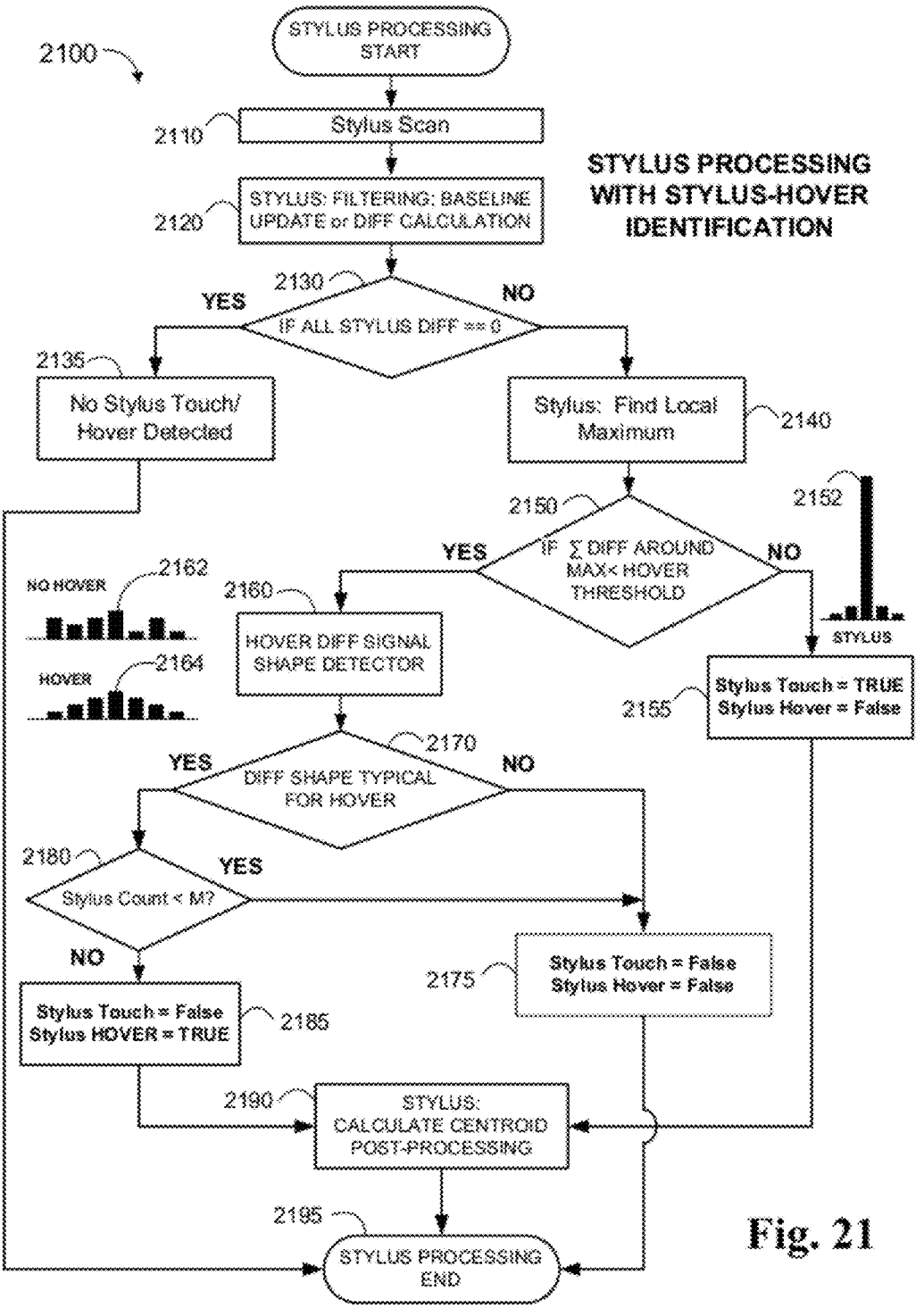

2100
STYLUS PROCESSING START
2110
Stylus Scan
2120
STYLUS: FILTERING: BASELINE UPDATE or DIFF CALCULATION
STYLUS PROCESSING WITH STYLUS-HOVER IDENTIFICATION
2130
IF ALL STYLUS DIFF == 0
YES
NO
2135
No Stylus Touch/ Hover Detected
Stylus: Find Local Maximum
2140
2150
IF ∑ DIFF AROUND MAX< HOVER THRESHOLD
YES
NO
2152
STYLUS
NO HOVER
2162
HOVER
2164
2160
HOVER DIFF SIGNAL SHAPE DETECTOR
2155
Stylus Touch = TRUE
Stylus Hover = False
2170
DIFF SHAPE TYPICAL FOR HOVER
YES
NO
2180
Stylus Count < M?
YES
NO
2175
Stylus Touch = False
Stylus Hover = False
Stylus Touch = False
Stylus HOVER = TRUE
2185
2190
STYLUS: CALCULATE CENTROID POST-PROCESSING
2195
STYLUS PROCESSING END

Fig. 21

SYNCHRONIZING A STYLUS WITH A CAPACITIVE SENSE ARRAY

RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 61/407,522, filed Oct. 28, 2010, U.S. Provisional Application No. 61/407,903, filed Oct. 28, 2010, U.S. Provisional Application No. 61/407,905, filed Oct. 28, 2010, U.S. Provisional Application No. 61/407,906, filed Oct. 28, 2010, and U.S. Provisional Application No. 61/407,907, filed Oct. 28, 2010, the contents of all are hereby incorporated by reference. This application is related to co-pending U.S. Application No. not yet assigned, Attorney docket No. CD10080, entitled "Capacitive Stylus with Palm Rejection," filed herewith, the contents of which are hereby incorporated by reference. This application is related to co-pending U.S. Application No. not yet assigned, Attorney docket No. CD10087, entitled "Capacitive Stylus for a Touch Screen," filed herewith.

TECHNICAL FIELD

[0002] This disclosure relates to the field of user interface devices and, in particular, to capacitive sensor devices.

BACKGROUND

[0003] The use of a stylus with a touch screen interface is well established. Touch screen designs have incorporated many different technologies including resistive, capacitive, inductive, and radio frequency sensing arrays. Resistive touch screens, for example, are passive devices well suited for use with a passive stylus. The original PalmPilots® devices from the mid-1990s were one of the first successful commercial devices to utilize a resistive touch screen designed for use with a stylus and helped to popularize that technology. Although resistive touch screens can sense the input from nearly any object, multi-touch is generally not supported. An example of a multi-touch application may be applying two or more fingers to the touch screen. Another example may be inputting a signature, which may include simultaneous palm and stylus input signals. Due to these and other numerous disadvantages, capacitive touch screens are increasingly replacing resistive touch screens in the consumer marketplace.

[0004] Various tethered active stylus approaches have been implemented for use with touch screens and are found in many consumer applications such as point-of-sale terminals (e.g., the signature pad used for credit card transactions in retail stores) and other public uses. However, the need for a tethered cable is a significant drawback for private applications such as personal computers ("PCs"), smart phones, and tablet PCs.

[0005] FIG. **1**A is a block diagram illustrating a conventional embodiment of a host device **100** for tracking the position of a touch object on an inductive sense array **107**. The host device **100** includes a printed circuit board ("PCB") **105**, a first matching circuit **110**, a receiver **115**, a host central processing unit ("CPU") **120**, a personal computer ("PC") **125**, a transmitter **130**, and a second matching circuit **135**. The PCB **105** is typically placed behind a touch screen (not shown) and includes an inductive sense array **107**. The inductive sense array **107** includes a series of inductive coils. Inductive sense arrays are typically heavy and expensive to manufacture.

[0006] FIG. **1**B is a block diagram illustrating a conventional embodiment of an active stylus **150** used in a system for tracking the position of a touch object on an inductive sense array **107**. The stylus **150** includes a micro-controller unit ("MCU") **155**, a driver **160**, and inductor eraser **165**, and inductor tip **170**, a rectifier **175**, a power regulator **180**, a button(s) **185**, a force tip **190**, and a force eraser **195**. The inductor eraser **165** and inductor tip **170** are configured on different stylus edges.

[0007] In operation, the inductive sense array **107** on PCB **105** generates a magnetic field to provide both stylus power generation and touch position detection. Regarding touch position, the matching circuit **110** provides impedance matching and couples the stylus **150** signal from the inductive sense array **107** to the receiver **115**. The receiver **115** and host CPU **120** receives and process the analog signal, respectively, providing touch position and force data to the PC **125**. Force data is indicative of the amount of pressure provided by the stylus tip to the touch screen. The host CPU **120** calculates the touch position based on the relative inductor signal strength of each coil of the inductive sense array **107**. More specifically, the presence of the stylus **150** changes the individual inductor currents for each coil in the inductive sense array **107** based on their relative proximity to the stylus. The maximum signal strength approximates the stylus **150** touch position on the accompanying touch screen.

[0008] The host CPU **120** sends a high frequency carrier signal to the stylus **150** via an amplifier (not shown), a transmitter **130**, an impedance matching circuit **135**, and the inductive sense array **107**. The stylus **150** receives and utilizes the high frequency carrier signal for self-powering and data transmission. In operation, the stylus **150** rectifies (rectifier **175**) and regulates (power regulator **180**) the carrier signal and feeds the resultant signal to the MCU **155** and driver **160**. The MCU **155** measures force sensors (force tip **190** and force eraser **195**) and button states (button(s) **185**) and couples the resultant data signal to the driver **160**. The driver **160** drives the inductor tip **170** and inductor eraser **165**, which inductively couples the stylus **150** to the inductive sense array **107**.

[0009] Stylus **150** sensing is implemented largely independent of the finger-sensing capability of the touch screen. As described above, stylus tracking requires generating an alternative current (AC) signal by the inductive sense array **107** and inductively coupling the AC signal to the tip of the stylus **150**. The inductive sense array **107**, located behind the touch screen, in turn receives the stylus signal and the Host CPU **120** interpolates the position of the stylus tip (inductor tip **170**) based on the relative magnitude of the received stylus signals at each of the inductive sensors of the inductive sense array **107**. While inductive sensing may be reliable, inductive stylus tracking solutions exhibit serious commercial disadvantages including high power consumption, high electromagnetic interference ("EMI"), high manufacturing costs, and heavy construction. Furthermore, retro fitting an existing touch sensor (passive touch object sensor) to include independent stylus tracking would require an additional PCB **105** layer to incorporate the inductive sense array **107**.

[0010] FIG. **2**A is a block diagram illustrating a conventional embodiment of a host device **200** for tracking the position of a touch object. The host device **200** includes an Indium-Tin-Oxide ("ITO") panel **205**, a receiver **210**, a data decoder **215**, a host CPU **220**, and a PC **225**. In FIG. **2**B, the stylus **250** includes a force sensor **255**, a measurer **260**, a

modulator **265**, an amplifier **270**, a stylus tip **275**, and a reference clock **280**. The stylus **250** is typically battery powered (not illustrated).

[0011] In operation, the stylus **250** generates, amplifies, and couples a signal from the stylus tip **275** to the ITO panel **205** via capacitive coupling. The ITO panel **205** functions as an antenna and receives the signal from the stylus **250** as described below with respect to FIG. **2**B. The selective receiver **210** demodulates the signal and couples a touch position signal to the host CPU **220** and a force data signal to the data decoder **215**. The data decoder **215** extracts the force data and couples it to the host CPU **220**. The host CPU **220** calculates the stylus touch position based on the relative maximum amplitude of the stylus signal detected on the ITO lines of ITO panel **205**. The host CPU **220** further determines the force applied to the stylus based on the force data. The host CPU **220** is controlled by the PC **225**.

[0012] FIG. **2**B is a block diagram illustrating a conventional embodiment of an active stylus used in a system for tracking the position of a touch object on an RF sense array. The measurer **260** of stylus **250** measures the force induced on the force sensor **255** and the modulator **265** modulates the resultant force data with a carrier frequency, provided by the reference clock **280**. The amplifier **270** amplifies the modulated signal and transmits the modulated carrier frequency from the stylus tip **275**. As described above, the host **200** decodes the modulated carrier signal and transmits the result to the PC **225**. While an RF sense array solution may offer cost savings and a reduced component count, they require special narrow band receivers on the host **200** and are subject to RF noise and interference. Consequently, conventional touch panel solutions may have significant disadvantages in cost, performance, applicability, and reliability.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The present invention is illustrated by way of example, and not of limitation, in the figures of the accompanying drawings in which:

[0014] FIG. **1**A is a block diagram illustrating a conventional embodiment of a host device for tracking the position of a touch object on an inductive sense array.

[0015] FIG. **1**B is a block diagram illustrating a conventional embodiment of an active stylus used in a system for tracking the position of a stylus on an inductive sense array.

[0016] FIG. **2**A is a block diagram illustrating a conventional embodiment of a host device for tracking the position of a stylus on a radio frequency sense array.

[0017] FIG. **2**B is a block diagram illustrating a conventional embodiment of an active stylus used in a system for tracking the position of a stylus on a radio frequency sense array.

[0018] FIG. **3** is a block diagram illustrating one embodiment of an electronic system having a processing device for detecting a presence of a touch object and a stylus.

[0019] FIG. **4** is a block diagram illustrating one embodiment of a capacitance sense array including an N×M electrode matrix and a capacitance sensor that converts measured capacitances to touch coordinates.

[0020] FIG. **5**A is diagram illustrating one embodiment of a method of scanning an all-points-addressable mutual capacitance sense array.

[0021] FIG. **5**B is diagram illustrating one embodiment of a method of scanning an all-points-addressable mutual capacitance sense array.

[0022] FIG. **6**A is a block diagram illustrating one embodiment of a system including a capacitive sense array and a touch screen controller that converts measured capacitances to touch coordinates.

[0023] FIG. **6**B is a block diagram illustrating one embodiment of a system including a capacitive sense array, a stylus, and a touch screen controller that converts measured capacitances to touch coordinates.

[0024] FIG. **7** illustrates the simultaneous use of a stylus and touch object on a capacitive sense array.

[0025] FIG. **8** is a block diagram illustrating one embodiment of an electronic system for synchronizing a stylus to a host device.

[0026] FIG. **9**A is a block diagram illustrating one embodiment of transmitter configured to transmit a transmit ("TX") signal from a host device to a stylus.

[0027] FIG. **9**B is a block diagram illustrating one embodiment of a stylus receiver configured to receive a TX signal from a host device.

[0028] FIG. **10**A is a block diagram illustrating one embodiment of a transmitter antenna system for wirelessly coupling a TX signal from a host device transmitter to a stylus receiver.

[0029] FIG. **10**B is a block diagram illustrating one embodiment of a transmitter antenna system for wirelessly coupling a TX signal from a host device transmitter to a stylus receiver.

[0030] FIG. **10**C is a block diagram illustrating one embodiment of a transmitter antenna system for wirelessly coupling a TX signal from a host device transmitter to a stylus receiver.

[0031] FIG. **11** is a flow chart of one embodiment of a method of synchronizing a stylus to a host device.

[0032] FIG. **12**A is a diagram illustrating the electrical effect of a stylus and palm simultaneously contacting an ITO panel.

[0033] FIG. **12**B is a block diagram illustrating the electrical equivalent circuit diagram of a palm and stylus on an ITO panel, according to an embodiment.

[0034] FIG. **13** is a block diagram illustrating one embodiment of a stylus for synchronizing and modulating additional data into a stylus TX signal.

[0035] FIG. **14** is a timing diagram illustrating a modulation and demodulation process on a data stream, according to an embodiment of the invention.

[0036] FIG. **15**A is a waveform illustrating a stylus TX signal utilizing a one-bit, binary phase shift keyed ("BPSK") modulation scheme, according to an embodiment of the invention.

[0037] FIG. **15**B is a waveform illustrating a stylus TX signal utilizing a one-bit BPSK modulation scheme, according to an embodiment of the invention.

[0038] FIG. **15**C is a graph illustrating polar coordinates and phase relationships for a one-bit BPSK modulation scheme, according to an embodiment of the invention.

[0039] FIG. **16** is a block diagram illustrating a modulator block for implementing a one-bit BPSK modulation scheme for adding force sense data to a stylus TX signal, according to an embodiment of the invention.

[0040] FIG. **17**A is a waveform illustrating a stylus TX signal utilizing a two-bit, quadrature phase shift keyed ("QPSK") modulation scheme, according to an embodiment of the invention.

[0041] FIG. **17**B is a waveform illustrating a stylus TX signal utilizing a two-bit quadrature phase shift keyed ("QPSK") modulation scheme, according to an embodiment of the invention.

[0042] FIG. **17**C is a graph illustrating polar coordinates and phase relationships for a two-bit QPSK modulation scheme, according to an embodiment of the invention.

[0043] FIG. **18** is a block diagram illustrating a modulator block for implementing a two-bit QPSK modulation scheme for adding additional data to a stylus TX signal, according to an embodiment of the invention.

[0044] FIG. **19**A is a timing diagram for a host device configured to transmit stylus position data and force data during separate intervals, according to an embodiment of the invention.

[0045] FIG. **19**B is a timing diagram for a host device configured to transmit stylus position data and force data during the same interval, according to an embodiment of the invention.

[0046] FIG. **20** is flow diagram of one embodiment of a method of tracking the position of a passive touch object and a stylus on a capacitive sense array.

[0047] FIG. **21** is flow diagram of one embodiment of a method of tracking the position of a stylus that is contacting or hovering over a capacitive sense array.

DETAILED DESCRIPTION

[0048] Apparatuses and methods of synchronizing a stylus to a capacitive sense array are described. In one embodiment, a capacitive sense array is configured to detect a presence of a stylus. A processing device provides a synchronization signal to synchronize the capacitive sense array and the stylus. In an embodiment, the system further includes a transmitter to wirelessly transmit the synchronization signal from the processing device to the stylus. In some embodiments, the transmitter may include a magnetic antenna to inductively transmit the synchronization signal to the stylus where the antenna is disposed around the outer edges of the capacitance sense array. In another embodiment, the stylus receives the synchronization signal from the transmitter, amplifies the synchronization signal to approximately 20-50V, and capacitively couples the synchronization signal from the stylus to the capacitive sense array.

[0049] In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be evident, however, to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known circuits, structures, and techniques are not shown in detail, but rather in a block diagram in order to avoid unnecessarily obscuring an understanding of this description.

[0050] Reference in the description to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The phrase "in one embodiment" located in various places in this description does not necessarily refer to the same embodiment.

[0051] FIG. **3** is a block diagram illustrating one embodiment of an electronic system **300** having a processing device **310** for detecting a presence of a touch object **340** and a stylus **330**. Electronic system **300** includes processing device **310**, touch screen **325**, touch sensor pad **320**, stylus **330**, host processor **350**, embedded controller **360**, and non-capacitance sense elements **370**. In the depicted embodiment, the electronic system **300** includes the touch screen **325** coupled to the processing device **310** via bus **322**. Touch screen **325** may include a multi-dimension capacitive sense array. The multi-dimension sense array includes multiple sense elements, organized as rows and columns. In another embodiment, the touch screen **325** operates as an all-points-addressable ("APA") mutual capacitance sense array, as described with respect to FIG. **4**. In another embodiment, the touch screen **325** operates as a coupled-charge receiver, as described with respect to FIG. **4**.

[0052] The operations and configurations of the processing device **310** and the touch screen **325** for detecting and tracking the touch object **340** and stylus **330** are described in detail below with respect to FIGS. **4**-**6**B. In short, the processing device **310** is configured to detect a presence of the stylus **330** on the touch screen **325**, as well as a presence of the touch object **340**. The processing device **310** may detect and track the stylus **330** and the touch object **340** individually on the touch screen **325**. In one embodiment, the processing device **310** can detect and track both the stylus **330** and touch object **340** concurrently on the touch screen **325**. In one embodiment, the stylus **330** is configured to operate as the timing "master," and the processing device **310** adjusts the timing of the touch screen **325** to match that of the stylus **330** when the stylus **330** is in use. As described herein, the touch screen **325** capacitively couples with the stylus **330**, as opposed to conventional inductive stylus applications. It should also be noted that the same assembly used for the touch screen **325**, which is configured to detect touch objects **340**, is also used to detect and track the stylus **330** without an additional PCB layer for inductively tracking the stylus **330** as done conventionally.

[0053] In the depicted embodiment, the processing device **310** includes analog and/or digital general purpose input/output ("GPIO") ports **307**. GPIO ports **307** may be programmable. GPIO ports **307** may be coupled to a Programmable Interconnect and Logic ("PIL"), which acts as an interconnect between GPIO ports **307** and a digital block array of the processing device **310** (not shown). The digital block array may be configured to implement a variety of digital logic circuits (e.g., DACs, digital filters, or digital control systems) using, in one embodiment, configurable user modules ("UMs"). The digital block array may be coupled to a system bus. Processing device **310** may also include memory, such as random access memory ("RAM") **305** and program flash **304**. RAM **305** may be static RAM ("SRAM"), and program flash **304** may be a non-volatile storage, which may be used to store firmware (e.g., control algorithms executable by processing core **302** to implement operations described herein). Processing device **310** may also include a memory controller unit ("MCU") **303** coupled to memory and the processing core **302**.

[0054] The processing device **310** may also include an analog block array (not shown). The analog block array is also coupled to the system bus. Analog block array also may be configured to implement a variety of analog circuits (e.g., ADCs or analog filters) using, in one embodiment, configurable UMs. The analog block array may also be coupled to the GPIO **307**.

[0055] As illustrated, capacitance sensor **301** may be integrated into processing device **310**. Capacitance sensor **301** may include analog I/O for coupling to an external compo-

nent, such as touch-sensor pad **320**, touch screen **325**, touch-sensor slider (not shown), touch-sensor buttons (not shown), and/or other devices. Capacitance sensor **301** and processing device **310** are described in more detail below.

[0056] In one embodiment, the electronic system **300** includes a touch sensor pad **320** coupled to the processing device **310** via bus **321**. Touch sensor pad **320** may include a multi-dimension capacitive sense array. The multi-dimension sense array includes multiple sense elements, organized as rows and columns. In another embodiment, the touch sensor pad **320** is an APA mutual capacitance sense array, as described with respect to FIG. **4**. In another embodiment, the touch sensor pad **320** operates as a coupled-charge receiver, as described with respect to FIG. **4**.

[0057] In an embodiment, the electronic system **300** may also include non-capacitance sense elements **370** coupled to the processing device **310** via bus **371** and GPIO port **307**. The non-capacitance sense elements **370** may include buttons, light emitting diodes ("LEDs"), and other user interface devices, such as a mouse, a keyboard, or other functional keys that do not require capacitance sensing. In one embodiment, buses **321**, **322**, and **371** are embodied in a single bus. Alternatively, these buses may be configured into any combination of one or more separate buses.

[0058] Processing device **310** may include internal oscillator/clocks **306** and communication block ("COM") **308**. In another embodiment, the processing device **310** includes a spread spectrum clock (not shown). The oscillator/clocks block **306** provides clock signals to one or more of the components of processing device **310**. Communication block **308** may be used to communicate with an external component, such as a host processor **350**, via host interface ("I/F") line **351**. Alternatively, processing block **310** may also be coupled to embedded controller **360** to communicate with the external components, such as host **350**. In one embodiment, the processing device **310** is configured to communicate with the embedded controller **360** or the host **350** to send and/or receive data.

[0059] Processing device **310** 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 device **310** may be one or more separate integrated circuits and/or discrete components. In one exemplary embodiment, processing device **310** is the Programmable System on a Chip (PSoC®) processing device, developed by Cypress Semiconductor Corporation, San Jose, Calif. Alternatively, processing device **310** 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.

[0060] It should also be noted that the embodiments described herein are not limited to having a configuration of a processing device coupled to a host, but may include a system that measures the capacitance on the sensing device 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 device **310** may also be done in the host.

[0061] Capacitance sensor **301** may be integrated into the IC of the processing device **310**, or alternatively, in a separate IC. Alternatively, descriptions of capacitance sensor **301** may be generated and compiled for incorporation into other integrated circuits. For example, behavioral level code describing capacitance sensor **301**, 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 capacitance sensor **301**.

[0062] It should be noted that the components of electronic system **300** may include all the components described above. Alternatively, electronic system **300** may include only some of the components described above.

[0063] In one embodiment, the electronic system **300** is used in a tablet computer. Alternatively, the electronic device may be used in other applications, such as a notebook computer, a mobile handset, a personal data assistant ("PDA"), a keyboard, a television, a remote control, a monitor, a handheld multi-media device, a handheld media (audio and/or video) player, a handheld gaming device, a signature input device for point of sale transactions, and eBook reader, global position system ("GPS") or a control panel. The embodiments described herein are not limited to touch screens or touch-sensor pads for notebook implementations, but can be used in other capacitive sensing implementations, for example, the sensing device may be a touch-sensor slider (not shown) or touch-sensor buttons (e.g., capacitance sensing buttons). In one embodiment, these sensing devices include one or more capacitive sensors. The operations described herein are not limited to notebook pointer operations, but can include other operations, such as lighting control (dimmer), volume control, graphic equalizer control, speed control, or other control operations requiring gradual or discrete adjustments. It should also be noted that these embodiments of capacitive sensing implementations may be used in conjunction with non-capacitive sensing elements, including but not limited to pick buttons, sliders (ex. display brightness and contrast), scroll-wheels, multi-media control (ex. volume, track advance, etc) handwriting recognition, and numeric keypad operation.

[0064] FIG. **4** is a block diagram illustrating one embodiment of a capacitive sense array **400** including an N×M electrode matrix **425** and the capacitance sensor **301** that converts measured capacitances to touch coordinates. The capacitive sense array **400** may be, for example, the touch screen **325** or the touch sensor pad of FIG. **3**. The N×M electrode matrix **425** includes N×M electrodes (N receive electrodes and M transmit electrodes), which further includes transmit ("TX") electrode **422** and receive ("RX") electrode **423**. Each of the electrodes in N×M electrode matrix **425** is connected to the capacitance sensor **301** by one of the conductive traces **450**. In one embodiment, capacitance sensor **301** operates using a charge accumulation circuit, a capacitance modulation circuit, or other capacitance sensing methods known by those skilled in the art. In an embodiment, the capacitance sensor **301** is of the Cypress TMA-3xx family of touch screen controllers. Alternatively, other capacitance sensors may be used. The mutual capacitance sense arrays, or touch screens, as described above, may include a transparent, conductive sense array disposed on, in, or under either a visual display itself (e.g. LCD monitor), or a transparent substrate in front of the display. In an embodiment, the TX and RX electrodes are

configured in rows and columns, respectively. In should be noted that the rows and columns of electrodes can be configured as TX or RX electrodes by the capacitance sensor **301** in any chosen combination. In one embodiment, the TX and RX electrodes of the sense array **400** are configured to operate as a TX and RX electrodes of a mutual capacitance sense array in a first mode to detect touch objects, and to operate as electrodes of a coupled-charge receiver in a second mode to detect a stylus on the same electrodes of the sense array. The stylus, which generates a stylus TX signal when activated, is used to couple charge to the capacitive sense array, instead of measuring a mutual capacitance at an intersection of a RX electrode and a TX electrode (a sense element) as done during mutual capacitance sensing. The capacitance sensor **301** does not use mutual capacitance or self-capacitance sensing to measure capacitances of the sense elements when performing a stylus can. Rather, the capacitance sensor **301** measures a charge that is capacitively coupled between the sense array **400** and the stylus as described herein.

[0065] The TX and RX electrodes in the N×M electrode matrix **425** are arranged orthogonally so that each of the TX electrodes intersects and overlaps each of the RX electrodes. Thus, each TX electrode is capacitively coupled with each of the RX electrodes. For example, TX electrode **422** is capacitively coupled with RX electrode **423** at the point where TX electrode **422** and RX electrode **423** overlap. The intersections of TX and RX electrodes **422** and **423** each form a capacitive sense element.

[0066] Because of the capacitive coupling between the TX and RX electrodes, the application of a TX signal at each TX electrode induces a current at each of the RX electrodes. For instance, when a TX signal is applied to TX electrode **422**, the TX signal induces an RX signal on the RX electrode **423** in N×M electrode matrix **425**. The RX signal on each of the RX electrodes can then be measured in sequence by using a multiplexor to connect each of the N RX electrodes to a demodulation circuit in sequence. The 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 RX electrode.

[0067] When a touch object, such as a finger or stylus, approaches the N×M electrode matrix **425**, the object causes a decrease in capacitance affecting only some of the electrodes. For example, if a finger is placed near the intersection of TX electrode **422** and RX electrode **423**, the presence of the finger decreases the coupling capacitance between the two electrodes **422** and **423**. In another embodiment, the presence of the finger increases the coupling capacitance between the two electrodes **422** and **423**. Thus, the location of the finger on the touchpad can be determined by identifying both the RX electrode having a decreased coupling capacitance between the RX electrode and the TX electrode to which the TX signal was applied at the time the decreased capacitance was measured on the RX electrode. Therefore, by sequentially determining the capacitances associated with each intersection of electrodes in the N×M electrode matrix **425**, the locations of one or more inputs can be determined. It should be noted that the process can calibrate the sense elements (intersections of RX and TX electrodes by determining baselines for each of the sense elements. It should also be noted that interpolation may be used to detect finger position at better resolutions than the row/column pitch as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure. In addition, various types of centroid algorithms may be used to detect the center of the touch as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure.

[0068] In other words, sensing is achieved by applying a transmit signal to each row of TX electrodes in turn for a short period of time and during that period, sensing the amount of charge coupled from that row of TX electrodes to each of the columns of RX electrodes. In one embodiment, the charge coupled from TX electrodes to RX electrodes at each intersection is measured one row at a time, (as shown in FIG. **5**A) until a map of charge measurements has been created for the entire screen. In other embodiments, each row may need to be driven twice and subsequently multiplexed if there are more columns than available sensing channels, as shown in FIG. **5**B. Other variations of scanning patterns may be used as would be appreciated by one of ordinary skill in the art. Furthermore, the conversion of the induced current waveform to touch position coordinates indicating a position of an input on a touch sensor pad would be understood by those of ordinary skill in the art.

[0069] Although the TX and RX electrodes **422**, **423**, appear as bars or elongated rectangles in FIG. **4**, alternative embodiments may use various tessellated shapes such as diamonds, rhomboids, chevrons, and other useable shapes as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure.

[0070] FIG. **6**A is a block diagram illustrating one embodiment of a system **600** including the sense array **400** and a touch screen controller **605** that converts measured capacitances to touch coordinates. In an embodiment, the touch screen controller **605** is similar to the capacitance sensor **301** described above. In another embodiment, the touch screen controller **605** is the processing device **310**. The sense array **400** includes TX lines **635** and RX lines **640**. In an embodiment, the TX lines **635** and RX lines **640** are the TX electrodes **422** and RX electrodes **423** of FIG. **4**, respectively. The touch screen controller **605** includes a TX drive circuit **610**, an RX sense circuit **620**, and a multiplexor **630**.

[0071] In an embodiment, a passive object (e.g., a finger or other conductive object) touches the sense array **400** at contact point **645**. The TX drive circuit **610** drives the TX lines **635** with TX signal **632**. The RX sense circuit **620** measures the RX signal **634** on RX lines **640**. In an embodiment, the touch screen controller **605** determines the location of contact point **645** based on the mapping techniques described above in conjunction with FIGS. **4**-**5**. The TX lines **635** and RX lines **640** are multiplexed by multiplexor **630**. The touch screen controller **605** provides the TX signal **632** on the TX lines **635** (rows) and measures the capacitance coupling on the RX lines **640** (columns). In an embodiment, the TX and RX lines **635**, **640** are orthogonal and may be used interchangeably (e.g., transmitting on columns and receiving on rows). In an embodiment, the TX drive circuit **610** transmits the TX signal **632** through a high impedance ITO panel (TX lines **635**), thus limiting the upper frequency limit and speed of the system. The total scan time may also dependent upon the number of TX lines **635** and RX lines **640** in the sense array **400**. For example, the TX drive circuit **610** provides a TX signal **632** on each TX line **635** and simultaneously reads the capacitively coupled RX signal **634** on each RX line **640**, according to one embodiment. In another embodiment, the RX lines **640** are multiplexed in two or more scans, as described in conjunction with FIG. **5**B.

[0072] FIG. **6**B is a block diagram illustrating one embodiment of a system **600** including the sense array **400**, a stylus

680, and the touch screen controller 605 that converts measured capacitances to touch coordinates. The sense array 400 includes RX lines 640 and 660. The RX lines 660 are the same as TX lines 635 in FIG. 6A, but used as a receive channel in system 600 as further described below for stylus signal sensing. In an embodiment, RX lines 640 and 660 are similar to the TX electrodes 422 and RX electrodes 423 of FIG. 4. The touch screen controller 605 includes the TX drive circuit 610, the RX sense circuit 620, and the multiplexor 630. The stylus 680 includes a TX drive circuit 685 and a stylus tip 688.

[0073] In an embodiment, the stylus TX drive circuit 685 of stylus 680 provides a TX signal 677 directly to contact point 695 on sense array 400, thus eliminating the need to dedicate the RX 660 lines (previously TX 635 in FIG. 6A) to transmitting a TX signal from the TX drive circuit 610. As such, the RX sense circuit 620 measures the RX signal 634 on both the rows (RX lines 660) and columns (RX lines 640) of sense array. This results in faster position tracking because the TX signal no longer passes through the high impedance ITO lines, thus reducing the scan time to the total RX measurement. In one embodiment, the touch screen controller 605 performs a normal scan of the sense array 400 during RX sensing of TX signal from the TX drive circuit 610 (illustrated in FIG. 6A), and a stylus scan of the sense array 400 during RX sensing of the stylus TX signal 677 (illustrated in FIG. 6B). For the stylus scan, the touch screen controller 605 measures a charge being capacitively coupled to the row and column electrodes of the sense array from the stylus. To further illustrate, a mutual capacitance scan uses both a TX and RX signal 632, 634 to track an object. As described above, this is typically done by scanning the RX lines 640 for each driven TX line 635 in a successive fashion by the touch screen controller 605. In an array of N rows (TX signal) and M columns (RX signal), a complete scan would require N×M total scans if one RX line is sensed at a time. For example, transmitting a TX signal ("TX'ing") on row 1, and receiving a receive signal ("RX'ing") on columns 1-M, followed by TX'ing on row 2 and RX'ing on columns 1-M, and so on in sequential fashion. Alternatively, more RX lines can be sensed at a time. In one embodiment, 4 or 8 RX lines are sensed at a time, but in other embodiments, all RX lines may be sense simultaneously or sequentially. With multiple RX channels to sense more than one RX line at the same time, the complete scan would be (N*M)/(#RX channels). In contrast, a stylus scan does not require a TX signal by the TX drive circuit 610 and a complete scan would only require a single RX signal measurement on each row and column, or N+M scans, thus resulting in a significantly reduced stylus scanning time for the entire sense array as compared with mutual capacitance scanning time for the entire sense array. Like above, multiple RX channels can be used to sense multiple RX lines at the same time. In this case, the complete scan would be (N+M)/(#RX channels).

[0074] It should be noted that the embodiments described herein may use the same electrodes (e.g., ITO panel lines), which served the TX function for the touch scanning may be used for the RX function for the stylus sensing. It should also be noted that both stylus and finger sensing operate at the frequencies which are not attenuated largely by the sensing device (e.g., ITO panel).

[0075] As described above, a passive stylus may be used as a touch object to interface with the various touch screens described above. In contrast to passive styluses, an active stylus described herein provides the transmit ("TX") signal that is typically provided by the touch screen controller 605 in finger sensing modes, as described above in conjunction with FIGS. 6A and 6B.

[0076] The stylus 680 capacitively couples the stylus TX signal 677 to the sense array 400, as described above in conjunction with FIGS. 4-6. In an embodiment, the stylus signal amplitude, frequency, phase, etc., may be the same or similar to that which is utilized for finger sensing by the touch screen controller 605. Alternatively, the stylus TX signal may be different than the TX signal from the TX drive circuit 610, in amplitude, frequency, and phase. In another embodiment, the stylus TX signal may have a different code for code modulation than a code used in the TX signal from the TX drive circuit 610. In an exemplary embodiment, the stylus TX signal 677 has a greater amplitude than the finger sensing TX signal 632 from the TX drive circuit 610. For example, in one exemplary embodiment, the stylus TX signal 677 ranges from approximately 20-50V, as compared with the approximately 5-10V typically provided by the touch screen controller 605. Alternatively, other voltages may be used as would be appreciated by one of ordinary skill in the art. The higher stylus TX voltage couples more charge to the MC array 400 more quickly, thus reducing the amount of time required to sense each row and column of the sense array 400. Other embodiments may incorporate higher voltages on the MC array TX line 635 to obtain similar time efficiency improvements for finger sensing.

[0077] In an embodiment, the stylus 680 applies a higher frequency on the stylus TX signal 677 than the TX signal 632 frequency from TX drive circuit 610 to achieve a reduced sensing time. Charge may be capacitively coupled from the stylus 680 to the sense array 400 during the rising and falling edges of the stylus TX signal 677. Thus, a higher TX frequency provides a greater number of rising and falling edges over a given period of time, resulting in greater charge coupling. The practical upper limit of the TX frequency in finger sensing mode (e.g., TX signal on sense array 400 for finger sensing) is dependent upon the resistor-capacitor ("RC") time constant of the panel's individual sense elements and interconnect (not shown). This is typically due to high impedance materials (e.g. ITO) used in the fabrication of the sense array 400. A high-impedance sense array 400 may result in a high time constant and resulting signal attenuation of the rows (TX lines 635) and columns (RX lines 640) of sensors, which may limit the maximum sensing frequency. When using an active stylus to transmit the stylus TX signal 677 directly to a contact point on sense array 400, the stylus TX signal 677 does not have to pass through all of the high impedance path, and therefore the maximum operating frequency for the stylus TX signal 677 can be increased, as described above in conjunction with FIGS. 6A and 6B. For example, the time constant of the RX traces (both rows and columns) may be used to determine an upper frequency limit, but this will typically be is at least double the upper frequency limit used in finger sensing. Typically the impedance is half to the impedance when performing mutual capacitance scanning, since the row's impedance is eliminated and the column's impedance remains (or vice versa). It should be noted that both finger sensing and stylus sensing use frequency selection where the operation period should be smaller than the panel's time constant; so, restrictions for the operation frequency selection are approximately the same for finger and stylus sensing.

[0078] In an embodiment, the frequency of the stylus TX signal 677 is different than the frequency of the finger sensing

TX signal **632**. By using different TX frequencies, the touch screen controller **605** can differentiate between stylus TX signals and finger sensing TX signals. Alternatively, the touch screen controller **605** can differentiate the stylus TX signals from the TX drive circuit **610** TX signals **632** using other techniques as would be appreciated by those of ordinary skill in the art with the benefit of this disclosure, such as detecting the difference in signal characteristics (e.g., phase, frequency, amplitude, and code modulation).

[0079] Various embodiments described herein are applicable to any mutual capacitance touch screen system using an untethered, or wireless active stylus configured to be capacitively coupled to the mutual capacitance array, where the active stylus receives synchronization or timing data from the touch screen controller. For example, the stylus can generate the stylus TX signals according to the synchronization or timing data received from the touch screen controller.

[0080] FIG. **8** is a block diagram illustrating one embodiment of an electronic system **800** for synchronizing a stylus **850** to a host device **805**. The host device **805** includes a capacitive sense array **810**, multiplexor ("MUX") devices **820** and **825**, sensing device **830**, and transmitter **840**. In an embodiment, the capacitance sense array **810** is an all-points addressable mutual capacitance sense array (e.g., sense array **400**). In yet another embodiment, the capacitive sense array **810** is an ITO panel. The capacitive sense array **810** ("sense array **810**" or "ITO **810**") is composed of rows **812** and columns **814** of electrodes as described in conjunction with FIG. **4**. In an embodiment, the rows **812** and column **814** are the TX lines **635** (alternatively RX lines **640**) and RX lines **640** of FIGS. **6**A and **6**B. The rows **812** and columns **814** are coupled to the MUX's **825** and **820**, respectively. MUX's **820**, **825** are coupled to the sensing device **830**. The sensing device **830** is coupled to the transmitter **840**. In an embodiment, the sensing device **830** performs a similar function as the capacitive sense circuit **301** of FIG. **3**. In another embodiment, the sensing device **830** is the touch screen controller **605** of FIGS. **6**A and **6**B.

[0081] In the depicted embodiment, the stylus block **850** comprises a receiver **855**, a battery **880**, a booster **870**, a tip driver **890**, and a stylus tip **895**. The stylus block **850** represents the components that are housed within the stylus body **860** as depicted in FIG. **8**. The battery **880** is coupled to the booster **870** and receiver **855**. The booster **870** is coupled to the tip driver **890**.

[0082] In an embodiment, the sensing device **830** generates and couples a TX signal **835** to the transmitter **840**. The transmitter **840** wirelessly couples the TX signal **835** to the receiver **855**. In one embodiment, the transmitter **840** inductively couples the TX signal **835** to the receiver **855**. In other embodiments, the transmitter may wirelessly couple the TX signal **835** in a variety of ways including radio frequency, optical, ultrasound, and other mediums that would be appreciated by one of ordinary in the art. The receiver **855** receives TX signal **899** from the transmitter **840** and couples demodulated TX signal to the stylus **850**.

[0083] In one embodiment, the TX **835** signal sent by the transmitter **840** is the same signal as the TX signal generated and applied to the ITO **810** on the TX lines **812** (or **814**) during finger position tracking. Alternatively, the TX signal **835** may be a different signal than the TX signal generated and applied to the ITO **810** and may have different signal characteristics (e.g., different frequency, phase, or code modulation). In another embodiment, the transmitter **840** sends a synchronization signal **899**, or timing data, whereby the stylus **850** generates the stylus TX signal **898** based on the synchronization signal **899** received by the receiver **855** from the transmitter **840**. In an embodiment, the synchronization signal **899** has different signal characteristics than the TX signal generated and applied to the ITO **810** during finger position tracking.

[0084] In an embodiment, the battery **880** voltage may be provided by battery cells (e.g., 1.5V AAA cells). The booster **870** boosts the battery voltage delivered to the tip driver **890**, allowing the tip driver **890** to amplify the TX signal **835** to a higher voltage (e.g., 10V-20V). A high voltage stylus TX signal **898** may enable the host device **805** to detect the stylus **850** when it is "hovering," or in close proximity to the capacitive sense array **810**, but not physically touching an overlay disposed over the capacitive sense array **810**. A high voltage stylus TX signal **898** may also provide for faster and more robust detection by the sensing device **830**. Hover touch recognition is described in conjunction with FIG. **21**.

[0085] The stylus **850** capacitively couples the amplified stylus TX signal **898** from the stylus tip **895** to the capacitive sense array **810**. The rows **812** and columns **814** of electrodes (configured as RX electrodes in stylus position tracking mode) sense the stylus TX signals **898** and send the received stylus TX signals **898** to the sensing device **830** via MUX's **820** and **825**. In an embodiment, the stylus TX signals **898** are referred to as RX signals once they are sensed by the rows **812** and/or columns of electrodes on the ITO **810**. As shown, the sensing device **830** receives the stylus TX signal **898** by RX'ing on both the rows **812** and columns **814** of electrodes of capacitive sense array **810**, as described above in conjunction with FIG. **6**B (i.e., RX lines **640** and **660**). In an embodiment, the sensing device **830** performs a stylus scan of the rows **812** and columns **814** of capacitance sense array **810** when sensing the stylus TX signal **898**. The sensing device **830** determines the location of the stylus **850** based on the relative strength of the TX signal **898** on each of the rows **812** and columns **814** elements of the capacitance sense array **810**, as previously described in conjunction with FIGS. **4-6**.

[0086] The synchronized operation of the host **805** and stylus **850** enables the sensing device **830** to substantially simultaneously track a passive touch object (e.g., finger) and stylus **850** on the sense array **810**. Synchronization ensures that the stylus **850** transmits a stylus TX signal **898** during a period when the sensing device **830** is not TX'ing for passive touch object sensing.

[0087] FIG. **9**A is a block diagram illustrating one embodiment of transmitter **900** configured to transmit a TX signal **915** from a host device **805** to a stylus **850**. The transmitter **900** comprises a carrier generator **910**, an amplitude modulation ("AM") modulator **920**, an amplifier **930**, a matching circuit and filter **940**, and antenna coil **945**.

[0088] In an embodiment, the carrier generator **910** is a local oscillator that generates a predetermined carrier frequency. The carrier generator may utilize a ring oscillator, a relaxation oscillator, a crystal oscillator, etc., or other oscillators that would be known by one of ordinary skill in the art. The carrier frequency may be significantly higher than the TX signal **915**. In one embodiment, the carrier generator **910** generates a carrier frequency of 13.56 MHz (radio-frequency identification (RFID) standard), whereas the TX signal **915** frequency may be approximately 100 kHz to 500 kHz. In an embodiment, the TX signal **915** may be generated by frequency dividing the carrier signal or by a separate oscillator

circuit. In another embodiment, a circuit within the processing device **310** of FIG. **3** generates the TX signal **915**.

[0089] According to one embodiment, the AM modulator **920** receives the carrier frequency from the carrier generator **910** and modulates its amplitude with the TX signal **915**. In one embodiment, the synchronization signal **899** is modulated with the carrier frequency from the carrier generator **910**. Although amplitude shift-keying ("ASK") is described herein, other types of modulation schemes may be used (e.g., frequency shift keying ("FSK"), phase-shift keying ("PSK"), binary phase shift keying ("BPSK")) and would be known by one of ordinary skill in the art. The amplifier **930** amplifies the modulated TX signal **925** and sends the amplified TX signal to the matching circuit and filter **940**. In an embodiment, the amplifier **930** amplifies the modulated TX signal **925** to a sufficiently high amplitude to accommodate the high attenuation typically associated with wireless transmission, as would be appreciated by one of ordinary skill in the art. The matching circuit and filter **940** provides impedance matching between the amplifier **930** and the antenna coil **945**, filtering out any unwanted frequencies on the modulated TX signal **925**. For example, a high pass or band pass filter may be used to remove unnecessary noise or harmonics in the modulated TX signal **925**.

[0090] The antenna coil **945** wirelessly broadcasts the filtered and modulated TX signal **925**. In an embodiment, the antenna coil **945** may broadcast the modulated TX signal **925** in a variety of formats including, but not limited to, radio frequency ("RF"), inductance, optics, electrostatic coupling, and ultrasound. In one embodiment, the transmitter **900** modulates the TX signal **915** with an RF carrier wave (e.g., 433 MHz, 900 MHz, or 2.4 GHz). In another embodiment, the transmitter **900** utilizes an inductive link to inductively couple the lower frequency RFID modulated carrier wave (modulated TX signal **925**) to the inductive receiver **950**. Inductively coupling an RFID carrier frequency generally consumes less power than an RF carrier wave and may provide longer battery life in the stylus. In some embodiments, using an RFID carrier frequency may provide significant advantages. For example, there are no broadcast licensing requirements associated with broadcasting RFID frequencies worldwide. Furthermore, at RFID frequencies, the metal stylus case and stylus tip may function as additional electric field antennas, providing for a more robust receiver block. In one embodiment, the RFID carrier frequency is frequency divided to generate the TX signal **915**, thus providing good noise suppression at the receiver block.

[0091] FIG. **9**B is a block diagram illustrating one embodiment of a stylus receiver **950** configured to receive the modulated TX signal **925** from a host device **805**. The receiver **950** comprises an antenna coil **955**, an input filter **960**, an amplifier **965**, an AM detector **970**, an auto gain control block **975**, and a tip driver **980**. In an embodiment, the transmitter **900** and stylus receiver **950** are similar to the transmitter **840** and receiver **855** of FIG. **8**, respectively. Alternatively, other circuit configurations for transmitters and receivers may be used as would be appreciated by one of ordinary skill in the art having benefit of this disclosure.

[0092] The antenna coil **955** receives the AM modulated TX signal **925** wirelessly coupled from the transmitter **900**. The modulated TX signal **925** is typically attenuated by losses inherently associated with wireless transmission. The input filter **960** may be used to filter out noise, unnecessary harmonics, and other unwanted signals from the modulated TX signal **925**. The amplifier **965** amplifies the modulated TX signal **925** to logic levels that are detectable by the AM detector **970**. The AM detector **970** demodulates the modulated TX signal **925** (e.g., removes the carrier frequency (e.g., 13.56 MHz)), thus leaving the TX signal **915** remaining. The auto gain control block **975** provides an automatic gain control loop to maintain a constant TX signal amplitude over a wide-input-signal voltage range. The tip driver **980** further amplifies the TX signal **915** to a high voltage output (10V-20V) for capacitively coupling the TX signal to the capacitive sense array **810**, as described above in conjunction with FIG. **8**.

[0093] In an alternative embodiment, a stylus is configured to operate as the timing "master," and has a transmitter similar to transmitter **900** to send synchronization information to the host, which would include a receiver similar to receiver **950**. In another embodiment, the stylus and/or the host may each include transceivers that allow for bi-directional communication. It should be noted that the communication between the host and the stylus for synchronization is done on a communication channel or communication link. The communication channel or link may be considered a backchannel that is used to communication data between the host and stylus. The communication data may include synchronization information as described herein, as well as additional data, such as force data, button data, or the like. The communication channel or link may be a RF link, Bluetooth link, an optical link, an infrared (IR) link, or other communication channels/links as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure.

[0094] When the stylus **850** operates as the timing "master," the stylus **850** sends the carrier modulated TX signal **925** to the host. A carrier generator, frequency divider, and modulator on stylus **850** provide a modulated TX signal to the host, where the host is synchronized to operate at the same phase and frequency as the stylus TX signal. The modification required for system **800** to synchronize the host to a master stylus TX signal would be appreciated by one having ordinary skill in the art with the benefit of this disclosure.

[0095] FIG. **10**A is a block diagram illustrating one embodiment of a transmitter antenna system **1000** for wirelessly coupling a TX signal from a host device transmitter **1002** to a stylus receiver **1020**. The system **1000** includes an ITO capacitance sense array ("ITO panel") **1005**, a host transmitter **1002**, and a stylus receiver **1020**. The host transmitter includes a magnetic antenna **1010**. The stylus receiver **1020** includes a stylus electric antenna **1025** and a stylus magnetic antenna **1030**. The host magnetic antenna **1010** inductively couples a TX signal (not shown) to the stylus receiver **1020**. The TX signal is received by the electric antenna **1025** and magnetic antenna **1030**. The host magnetic antenna **1010** is a very compact antenna that can be easily integrated into existing designs and does not require any alteration to the ITO panel **1005** for implementation. The antenna system **1000** may be well-suited for stylus-ITO panel systems having a maximum range of approximately 10 cm (4 inches).

[0096] FIG. **10**B is a block diagram illustrating one embodiment of a transmitter antenna system **1040** for wirelessly coupling a TX signal from a host device transmitter **1042** to a stylus receiver **1052**. The system **1040** includes an ITO panel **1045**, a host transmitter **1042**, and a stylus receiver **1052**. The host transmitter **1042** includes a host magnetic antenna **1050**. The stylus receiver **1052** includes a stylus electric antenna **1054** and a stylus magnetic antenna **1056**. In

an embodiment, the host magnetic antenna **1050** is configured around the outer edge of ITO panel **1045**. The host magnetic antenna **1050** inductively couples a TX signal (not shown) to the stylus receiver **1052**. The TX signal is received by the electric antenna **1054** and magnetic antenna **1056**. The host magnetic antenna **1050** may have a maximum transmission range of approximately 20 cm (8 inches), which may be well-suited for 15 inch ITO panels. In an embodiment, the host magnetic antenna **1050** may require increasing the screen border (ITO panel housing) to accommodate both the ITO panel **1045** and the host magnetic antenna **1050**.

[0097] FIG. **10**C is a block diagram illustrating one embodiment of a transmitter antenna system **1060** for wirelessly coupling a TX signal from a host device transmitter **1062** to a stylus receiver **1085**. The system **1000** includes an ITO panel **1065**, a host transmitter **1062**, and a stylus receiver **1085**. The host transmitter **1062** includes a host magnetic antenna **1080** and a host electric antenna **1070**. The stylus receiver **1085** includes a stylus electric antenna **1090** and a stylus magnetic antenna **1095**. The host magnetic antenna **1080** and host electric antenna **1070** couple a TX signal (not shown) to the stylus receiver **1085**. The TX signal is received by the electric antenna **1090** and magnetic antenna **1095**. The host electric antenna **1070** may be a 10 cm long wire configured in close proximity to the screen border (ITO panel housing) with a maximum transmission range of approximately 20 cm. In an embodiment, the host electric antenna **1070** is implemented on a printed circuit board ("PCB") which may not require any alternations to the ITO panel housing. The antennas have been depicted as coil and loop antennas, however, various types of antennas may be used, such as slot antennas, patched antennas, dipoles, folded dipoles, mono pole, as well as other types of antennas as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure. The transmission of data using these antennas may be done using any modulation technique as described herein.

[0098] FIG. **11** is a flow chart of one embodiment of a method **1100** of synchronizing a stylus to a host device. The method **1100** begins with the host device starting the scanning process (block **1105**). The sensing device generates a TX pulse sequence (block **1110**). In an embodiment, the TX pulse sequence is a pulse train of TX signals. At block **1155**, the carrier generator generates a carrier signal (e.g., 13.56 MHz RFID carrier frequency). The AM modulator modulates the carrier signal (block **1135**) with the TX pulse sequence generated at block **1110**. In other embodiments, the host device may implement other modulation schemes, as described in conjunction with FIG. **9**A. A band pass filter filters the modulated TX signal (block **1140**). It should be noted that other types of filters may be used including low pass, high pass, notch filters, and others as would be appreciated by those of ordinary skill in the art. At block **1145**, a matching network matches the impedance of the filter and antenna, and the transmit block wirelessly transmits the modulated TX signal to the stylus (block **1150**).

[0099] The receiver block of the stylus wirelessly receives the modulated TX signal from the host device (block **1162**). The amplifier block amplifies the modulated TX signal (block **1165**), and the AM demodulator removes the carrier frequency from the TX signal (block **1170**). The gain correction block dynamically adjusts the gain of the amplifier to maintain a predetermined TX signal magnitude at the input of the demodulator (block **1175**). At block **1180**, the TX driver drives (amplifies) the TX signal. In one embodiment, the TX driver amplifies the TX signal to approximately 20-50V to improve the capacitive coupling between the stylus and sense array and enable hover detection capabilities by the host device (block **1180**). The stylus tip capacitively couples the amplified TX signal (stylus TX signal) to the ITO panel (block **1190**).

[0100] At block **1115**, the synchronous rectifier receives the stylus TX signal. A filtering block may be configured to operate as a low-pass filter (LPF) and integrate the rectified stylus TX signal to remove unwanted noise, harmonics, etc., (block **1120**). An analog-to-digital ("ADC") converter converts the analog stylus TX signal to a digital representation for further digital processing on the host CPU or other processing device (block **1125**). At block **1130**, the host CPU calculates the stylus coordinates, processes any additional data, and the scanning process repeats (block **1105**). In an embodiment, the additional data may include force data, button data, or other additional functionality encoded by stylus onto the stylus TX signal, as further described with reference to FIGS. **13-18**.

[0101] FIG. **12**A is a diagram illustrating the electrical effect of the stylus **850** and palm simultaneously contacting an ITO panel **810**. In an embodiment, system **800** performs a palm rejection feature that enables the sensing device **830** to accurately track the position of a stylus **680** with a hand or palm simultaneously present on the ITO panel **810**. This condition may occur, for example, when a user inputs their signature with the stylus while supporting their hand or palm on the ITO panel **810**.

[0102] FIG. **12**B is a block diagram **1200** illustrating the electrical equivalent circuit diagram of a palm and stylus on an ITO panel **1210**, according to an embodiment. The block diagram includes an ITO panel **1210**, capacitive sense element A, a stylus **1220**, a stylus-to-panel capacitance ("C_stylus") **1230**, palm-to-panel capacitance ("C_palm") **1250**, an RX circuit **1270**, receive circuit to ground capacitance C_ground**1 1270** and the capacitance from point B to electrical ground ("C_ground**2 1260**"). The C_ground**1 1270** capacitance is own device capacitance. The C_ground**2 1260** capacitance is own stylus capacitance. The stylus **1220** and palm (not shown) contact the ITO panel **1210** at capacitive sense element A. C_Stylus **1230** is the capacitance of the stylus **1220** when the stylus **1220** is capacitively coupling a stylus TX signal to the ITO panel **1210**. The palm capacitance **1250** is the capacitance of a hand or palm contacting the surface of the ITO (illustrated in FIG. **12**A). The casing or enclosure of the stylus is the local ground for the stylus **1220**. C_ground**2 1260** is the capacitance of the human body from the node ("B") where the palm contacts the casing of stylus **1220**. In an embodiment, the palm may couple a parasitic TX charge on the ITO panel **1210** which can significantly affect the TX stylus signal measured by the RX circuit **1270**. The magnitude of C_palm **1250** is approximately zero when hovering over the ITO panel **1210**. When touching the ITO panel **1210**, the capacitive influence of the palm depends on the magnitude of C_palm **1250** and C_stylus **1230**. The human body is connected to ground return path via some finite capacitance C_ground**2 1260**. It means that palm is not really grounded and always has some TX potential too. This potential may cause small signal changes when hand is on the panel due capacitive coupling with panel. The stylus tip TX signal is much stronger then palm TX signal. It allows us separate stylus and palm touches by signal level thresholds without problems.

[0103] Palm rejection is achieved due to the inherent properties of synchronizing the host and stylus so that finger position tracking and stylus position tracking may be performed simultaneously without interfering with one another. For example, during stylus tracking, the stylus may capacitively couple the stylus TX signal to the ITO **1210** proximal to the location of the stylus. Thus, a palm (i.e., a passive touch object) would not interfere with stylus position tracking in a noticeable way because the palm would not be stimulated by the TX signal originating from the TX drive circuit of the touch screen controller (e.g., TX drive circuit **610** of touch screen controller **605**, or sensing device **830** of host **805**). It should be noted that the palm has much smaller stylus TX signal propagation as compared to the stylus tip. The palm influence on TX signal is close to own system noise floor and can be easily removed.

[0104] FIG. **13** is a block diagram illustrating one embodiment of a stylus **1300** for synchronizing and modulating additional data into a stylus transmit signal **898**. The stylus **1300** includes a receiver **855**, microcontroller block **1305**, voltage booster **870**, battery **880**, tip driver **890**, actuator **893**, stylus tip **895**, voltage divider **1310**, and force sensor **1360**. In one embodiment, the microcontroller block **1305** includes ADC **1320**, CPU core **1330**, buttons **1340** and **1341**, synchronization and modulation block ("synch mod block") **1350**, and measurer **1370**.

[0105] In an embodiment, the synch mod block **1350** is configured to modulate additional data into the TX signal **835**. Some types of additional data that may be modulated into the stylus TX signal **835** include battery data, acceleration data, button data, force data, and other data as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure.

[0106] In one embodiment, if no modulation of additional data is required on the stylus TX signal **898**, the stylus **1300** operates similar to the stylus block **850** of FIG. **8**. In particular, the receiver **855** wirelessly receives the TX signal **835**, the synch mod block **1350** receives the TX signal **835** from the receiver **855**, the tip driver **890** drives or amplifies the TX signal **835**, and the stylus tip **895** capacitively couples the amplified stylus TX signal **898** to the sense array **810**. In an embodiment, the synch mod block **1350** may be bypassed if no modulation of additional data in the stylus TX signal **898** is required.

[0107] In an embodiment, the stylus **1300** modulates battery data (e.g., battery charge status) into the stylus TX signal **835**. In one embodiment, the battery data may be obtained by using a voltage divider and ADC. In particular, the voltage divider **1310**, which may be a resistor divider network as shown in FIG. **13**, measures an analog voltage potential (e.g., at the resistor divider midpoint) of the battery **880**, and the ADC **1320** converts the measured analog voltage potential to a digital value and sends it to the CPU core **1330**. The CPU core **1330** processes the digital value and sends it to the synch mod block **1350**. The synch mod block **1350** modulates the battery data into the stylus TX signal **835**. The tip driver **890**, in conjunction with the voltage booster **870**, amplifies the modulated stylus TX signal **835**. The stylus tip **895** capacitively couples the modulated stylus TX signal **898** to the sense array **810**. In other embodiments, the synch mod block **1350** may modulate other types of additional data into the stylus TX signal **835** in addition to the battery data, such as button data described below.

[0108] In one embodiment, the stylus **1300** includes buttons **1340** and **1341**. Buttons may provide additional functionality to the stylus including, but not limited to, "left click" and "right click" functions, similar to that of a computer mouse. Buttons **1340** and **1341** of stylus **1300** are coupled to the CPU core **1330**. The buttons **1340**, **1341**, may be mechanical, electrical, capacitive, or other types that would be known by one of ordinary skill in the art. The CPU core **1330** processes the button input data and sends it to the synch mod block **1350**. The synch mod block **1350** modulates the button data into the stylus TX signal **835**. The tip driver **890**, in conjunction with the voltage booster **870**, amplifies the modulated stylus TX signal **835** and the stylus tip **895** capacitively couples the modulated stylus TX signal **898** to the sense array **810**. In an embodiment, the synch mod block **1350** may modulate one or more other types of additional data into the stylus TX signal **835** in addition to the button data and/or battery data, such as the force data described below.

[0109] In an embodiment, force sensing is implemented in the stylus **1300**. Force sensing provides additional data relating to the stylus tip **895** contact pressure on the sense array **810**. The force sensor **1360** detects the force applied to the actuator **893**. The measurer **1370** determines the amount of force (e.g., magnitude of force signal) applied to the tip **895**. The CPU core **1330** processes the force signal and sends it to the synch mod block **1350**. The synch mod block **1350** modulates the force data into the stylus TX signal **835**. The tip driver **890**, in conjunction with the voltage booster **870**, amplifies the modulated stylus TX signal **835** and the stylus tip **895** capacitively couples the modulated stylus TX signal **898** to the sense array **810**. Force sense may be detected by either a passive sensor (e.g., force sensing resistor) or active sensor (e.g., capacitive linear position sensor or a moving element in relation to a coil) within the stylus **1300**. Alternatively, other methods may be used to quantitatively determine and digitize a force applied to the stylus tip **895**, as would be appreciated by one of ordinary skill in the art. In an embodiment, the synch mod block **1350** may modulate one or more other types of additional data into the stylus TX signal **835** in addition to the force data. For example, in another embodiment, the orientation or acceleration of the stylus may be detected (e.g., by an accelerometer) and encoded in the stylus TX signal **835**.

[0110] In an embodiment, the synch and mod block **1350** may modulate the additional data by way of frequency modulation ("FM"), frequency-shift keying ("FSK"), amplitude modulation ("AM"), amplitude-shift keying ("ASK"), on-off keying ("OOK"), pulse position modulation, phase modulation ("PM"), Manchester encoding, direct sequence spread spectrum ("DSSS"), or other modulation schemes that would be appreciated by one of ordinary skill in the art. PM modulation may further include binary phase shift keying ("BPSK") or quadrature phase shift keying ("QPSK") encoding schemes which are further discussed below with respect to FIGS. **15-18**.

[0111] Other embodiments may be configured to alternatively transfer additional data from the stylus **1300** to the sensing device (not shown) without modulating the stylus TX signal **835**. For example, using time division multiplexing ("TDM"), the stylus **1300** transmits the stylus TX signal **898** in one time slot, and transmits the additional data (e.g., force data, acceleration data) in another time slot, as described with respect to FIG. **19**. Similarly, code division multiplying (CDM) may be used to transmit the stylus TX signal and the

additional data. The stylus **1300** may transmit the stylus TX signal **898** using one code, and may transmit the additional data using another code. In an embodiment, the stylus TX signal **898** and additional data may utilize the same frequency or different frequencies. In other embodiments, optical, ultrasonic, inductive, or RF signal transmissions may be utilized to transfer the additional data from the stylus **1300** to the sensing device **830**. For example, additional data may be wirelessly coupled from the stylus **1300** to the sensing device **830**. It should be noted that additional hardware, such as antennas and/or amplifiers, may be required to transmit the additional data to the sensing device **830**. Such embodiments would be known by those of ordinary skill in the art with the benefit of this disclosure.

[0112] FIG. **14** is a timing diagram **1400** illustrating a modulation and demodulation process on a data stream, according to an embodiment of the invention. Timing diagram **1400** includes a modulation process **1405** and demodulation process **1435**. The modulation process **1405** includes TX data signal **1410**, data-to-transmit signal **1420**, and TX+Data signal **1430**. The demodulation process **1435** includes demodulator input signal **1440**, demodulator output signal **1450**, and capacitor voltage **1460**.

[0113] In an embodiment, the TX data signal **1410** and data-to-transmit signal **1420** are a stylus TX signal and additional data (e.g., force sense, button, battery data), as described above in conjunction with FIG. **13**. The TX+Data signal **1430** is a modulated TX signal containing information from both the TX signal and the data to transmit (e.g., force data, button data, etc.). In an embodiment, the TX and Data signal **1430** pulses are inverted or non-inverted depending on the data-to-transmit signal bits **1420**. In one embodiment, the TX+Data signal **1430** is capacitively coupled from the stylus tip **895** to the ITO array **810**. Alternatively, the TX+Data signal **1430** is wirelessly coupled from the stylus to the sensing device **830**.

[0114] In an embodiment, the TX+data signal **1430** arrives at a demodulator block in the form of current spikes, as illustrated by demodulator input **1440**. The synchronous detector output signal (demodulator output **1450**) consists of positive or negative rectifier spikes correlating to the modulated additional data. The receiver demodulator integration capacitor (not shown on the circuit diagrams) voltages **1460** represent the decoded data bits that correspond to the data-to-transmit **1420** signal, which is further processed by the sensing device **830**.

[0115] FIG. **15**A is a waveform **1500** illustrating a stylus TX signal utilizing a one-bit, binary phase shift keyed ("BPSK") modulation scheme, according to an embodiment of the invention. BPSK utilizes one bit with two logic states (binary signal) which are represented as positive and negative pulses that are 180 degrees out of phase with each other. Waveform **1500** illustrates a logic pulse representing a logic level "1." FIG. **15**B is a waveform **1540** illustrating a stylus TX signal utilizing a one-bit BPSK modulation scheme, according to an embodiment of the invention. Waveform **1540** illustrates a logic pulse representing a logic level "0." FIG. **15**C is a graph **1560** illustrating polar coordinates and phase relationships for a one-bit BPSK modulation scheme, according to an embodiment of the invention. In an embodiment, a single bit ("Bit **1**") may be represented as a positive or negative signal. Bit **1 1580** is a logic level "1" with a zero degree phase shift. Bit **1 1570** is a logic level "0" with a 180 degree phase shift. In an embodiment, BPSK may be used to modulate additional data into the stylus TX signal **898** as described above with reference to FIG. **8**. For example, button data may be encoded by BPSK. A pressed and non-pressed button is represented in polar coordinates by Bit **1 1570** and Bit **1 1580**, respectively. It should be noted that changing the phase of the TX signal to incorporate additional data will not necessarily change the timing, absolute magnitude, or frequency of the TX signal. In other words, the timing and synchronization information contained in the stylus TX signal **898** may remain unchanged despite a change in signal phase. As described above, BPSK modulation is one of several preferred modulation schemes for adding additional data to a stylus TX signal. BPSK may allow for reliable detection at a low signal-to-noise ratio and may reduce data transmission overhead for a stylus. Other modulation schemes may be used as would be known by one of ordinary skill in the art with the benefit of this disclosure.

[0116] FIG. **16** is a block diagram illustrating a modulator block **1600** for implementing a one-bit BPSK modulation scheme for adding force sense data to a stylus TX signal **835**, according to an embodiment of the invention. The modulator block **1600** includes switching block **1605**, pause detector **1630**, synchronization and clock generation firmware ("synchro clock gen") **1640**, shift register **1650**, capacitance force sensor **1660**, capacitance measurer**1670**, high voltage tip driver **890**, and stylus tip **895**. The switching block **1605** includes an inverter **1610** and switch **1620**. In an embodiment, the modulator block is part of the synch mod block **1350** of FIG. **13**. In another embodiment, the capacitance measurer **1670**, the shift register, and synchro clock gen **1640** are implemented in the processing device **310**. Alternatively, the processing device **310** may include more or less components to modulate data in the stylus TX signal **835**.

[0117] In operation, the switching block **1605** is configured to controllably toggle switch **1620** to generate an inverted or non-inverted TX signal **835**. The inverted stylus TX signal **835** is generated by the inverter **1610**. In an embodiment, the inverted and non-inverted signals of switching block **1610** are the zero and 180 degree phase shifted BPSK signals illustrated in FIGS. **15**A-C.

[0118] The modulator block **1600** incorporates force sensing into the TX signal **835**. Force sensing is detected, in part, by an actuator (not shown) and the capacitance force sensor **1660**, and is further described above in conjunction with FIG. **13**. It should be noted that other types of additional data may be modulated into the stylus TX signal **835**, as would be appreciated by one of ordinary skill in the art with the benefit of this disclosure.

[0119] In an embodiment, switch **1620** timing is controlled by the pause detector **1630**, synch clock gen **1640** and shift register **1650**. The modulator block **1600** is configured to toggle the switch **1620** between stylus TX signal **835** pulses. It should be noted that toggling the switch **1620** during stylus TX pulses may cause distortion and adversely affect the synchronization of the stylus **850** and ITO array **810**. The pause detector **1630** detects the period between stylus TX pulses. The synch clock gen **1640** provides a synchronization and clock generation algorithm to generate synchronized clock pulses to the shift register **1650**. The shift register **1650** controllably toggles the switch **1620** in response to the input force data from capacitance measurer**1670**, resulting in a modulated stylus TX signal. Thus, the resulting stylus TX signal **898** at stylus tip **895** retains its timing information for host-

stylus synchronization with additional force data via the phase modulation techniques described herein.

[0120] In one embodiment, when no modulation of additional data is required on the stylus TX signal, the switching block **1605** sends the stylus TX signal to the tip driver **890** with no phase modulation. In an embodiment, the switching block **1605** may be bypassed if no modulation of additional data in the stylus TX signal **898** is required.

[0121] FIG. **17**A is a waveform **1700** illustrating a stylus TX signal utilizing a two-bit, quadrature phase shift keyed ("QPSK") modulation scheme, according to an embodiment of the invention. In QPSK, two bits (Bit**1** and Bit**2**) are transmitted at the same time and may be modulated by phase or delay, as described below with reference to FIG. **17**C. Waveform **1700** illustrates two logic states for two logic pulses where Bit**1**=1 and Bit**2**=1 or 0. The Bit**2** logic states differ by signal magnitude due to a TX/4 delay, as further described below. It should be noted FIG. **17**A shows that the bit states are different from commonly used quadrature detectors diagrams, since there is no quadrature channel here. In this embodiment, the stylus signal phase is predefined as compared to the receiver's synchronous demodulator reference signal phase due to the synchronization between the stylus and host controller.

[0122] FIG. **17**B is a waveform **1740** illustrating a stylus TX signal utilizing a two-bit quadrature phase shift keyed ("QPSK") modulation scheme, according to an embodiment of the invention. Waveform **1740** illustrates two logic states for two logic pulses where Bit**1**=0 and Bit**2**=1 or 0. FIG. **17**C is a graph **1760** illustrating polar coordinates and phase relationships for a two-bit QPSK modulation scheme, according to an embodiment of the invention. As described above with respect to FIG. **15**C, Bit **1 1775** is a logic level "1" with a zero degree phase shift and Bit **1 1770** is a logic level "0" with a 180 degree phase shift. In an embodiment, Bit **2** may have a TX/4 time delay that results in reduced amplitude at the demodulator output (not shown). The reduced amplitude is approximately one-half the magnitude of a non-delayed signal, as shown in FIGS. **17**A and **17**B.

[0123] FIG. **18** is a block diagram illustrating a modulator block **1800** for implementing a two-bit QPSK modulation scheme for adding additional data to a stylus TX signal **835**, according to an embodiment of the invention. Modulator block **1800** is similar to modulator block **1600** of FIG. **16**, with the addition of a delay block **1810** and a second switch **1820** controllably toggled by 2-bit shift register **1850**. The two bits may be transmitted at the same time. One bit may be coded in the same way by switch **1 1620**. Fully inverted or non inverted signal means logic zero or one. The second bit may be coded by changing the absolute value of the capacitor voltage **1460**. The receiver may use synchronous rectifier topology. If received TX signal is shifted by +/−90 degrees, then resulting received amplitude is two times lower. The switch **2 1820** adds or removes 90 degrees (or TX/4) delay.

[0124] FIG. **19**A is a timing diagram **1900** for a host device configured to transmit stylus position data and force data during separate intervals, according to an embodiment of the invention. The timing diagram **1900** includes stylus position scan interval **1910** and force data interval **1920**. The scan time **1930** is the time interval from the start of one stylus position scan to the start of the next stylus position scan. In an embodiment, other types of additional data may be included (e.g., button data, battery data, acceleration data, etc.) as would be appreciated by one of ordinary skill in the art.

[0125] In an embodiment, the host utilizes the interval between the end of one stylus position scan to the beginning of the next stylus position scan to synchronize the host and stylus to provide robust data transfer and error-free stylus position tracking. By transmitting force data separately in time (e.g., time division multiplexing the stylus TX signal and force data), less time is available in the scan time **1930** for the host device to perform the synchronization and tracking operations. In an embodiment, an increased scan time (i.e., reduced system operating frequency) may be needed. It should be noted that high bit rates may be achieved with this method. In an embodiment, 16 bits are transferred per scan time interval. Alternatively, less or more than 16 bits may be transferred per scan time interval.

[0126] FIG. **19**B is a timing diagram **1950** for a host device configured to transmit stylus position data and force data during the same interval, according to an embodiment of the invention. The timing diagram **1950** includes a stylus position scan and force data interval **1960** and scan time interval **1970**. In an embodiment, the stylus modulates one additional data bit (e.g., force data, battery data, button data, etc.) for each position scan without an increase in total scan time **1970**. It should be noted that this scanning method may support lower maximum bit rates than the scanning method of FIG. **19**A.

[0127] FIG. **20** is flow diagram of one embodiment of a method **2000** of tracking the position of a passive touch object and a stylus on a sense array. The method **2000** is performed by processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a general purpose computing system or a dedicated machine), firmware (embedded software), or any combination thereof. In one embodiment, the touch screen controller **605** of FIG. **6** performs some of operations of method **2000**. In another embodiment, the sensing device **830** of FIG. **8** performs the method **2000**. In yet another embodiment, the capacitance sense circuit **310** of FIG. **3** performs the method **2000**. Alternatively, other components of the electronic system **300** (FIG. **3**) can perform some or all of the operations of method **2000**.

[0128] Referring to FIG. **20**, tracking begins where no APA touch (e.g., by a passive touch object) or stylus touch (including touch and hover detection) are present on a sense array (block **2010**). The goal of this method is providing the adaptive active stylus and passive touch objects scanning technique. When no stylus and no touch the short burst of stylus scan cycles are executed per one APA scan (takes typically much longer time than stylus scan). This burst is used for reliable hover detection under noisy environments. If APA touch is detected, the burst of the APA scan cycles is executed to provide adequate touch response. No stylus is scanned within burst of the APA cycles when touch is detected. Once stylus is detected, it is scanned in the highest rate to get best stylus report rate, taking into account applications which use stylus are pretty sensitive to the report rate and stylus scanning has higher priority than APA scanning. There is no APA scanning while stylus touch or hover is sensed. Hover detection is further described in conjunction with FIG. **21**. The processing logic initializes and sets the APA scan count and the stylus scan count to zero. The scan count determines the amount of time the processing logic remains in a particular scan setting. For example, the processing logic scans for the stylus while the scan count is less than a predetermined value. In an embodiment, the predetermined maximum scan count values for an APA touch and stylus touch are denoted as variables "N" and "M," respectively.

[0129] The stylus scan and processing begins (block **2015**). In an embodiment, the active stylus has a higher priority than an APA scan for a passive touch object. If at block **2020**, the processing logic detects a stylus touch or stylus hover signal, the sensing device sets the stylus scan count to zero (block **2025**), the processing logic reports the results to a host processor, (block **2030**), and the stylus scan and processing restarts (block **2015**). In an embodiment, the host processor may be host **350** of FIG. **3**. If at block **2020**, a stylus touch or hover is not detected, the processing logic increments the stylus scan count if the current stylus scan count value is less than the predetermined maximum value (i.e., "M"), block **2040**. If the stylus scan count is less than M (block **2045**), the processing logic reports the results to a host processor, (block **2030**) and stylus scan and processing restarts (block **2015**). If the stylus scan count is equal to or greater than M, then APA scan and processing begins (block **2050**).

[0130] If at block **2060**, an APA touch is not detected (e.g., a touch by a passive touch object such as a finger), the touch screen controller **605** sets the APA scan count value to zero (block **2085**), the processing logic reports the results to a host processor, (block **2090**) and stylus scan and processing restarts (block **2015**). If at block **2060**, an APA touch is detected, the processing logic increments the APA scan count if the current APA scan count is less than the predetermined maximum value (i.e., "N") (block **2070**). If the APA scan count is less than N (block **2080**), the processing logic reports the results to a host processor (block **2030**), and APA scan and processing restarts (block **2050**). If the APA scan count is equal to or greater than N, then the processing logic sets the APA scan count to zero (block **2085**), the processing logic reports the results to a host processor, (block **2030**) and stylus scan and processing restarts (block **2015**).

[0131] In summary, the stylus scan has a higher priority than the APA scan, according to an embodiment of the invention. The stylus scan may continue in iterative scan periods until either a stylus is detected (in which case the stylus scan count is reset to zero and stylus position tracking period restarts) or until the stylus scan period ends (when the stylus scan count reaches a threshold value). The APA scan may begin once the stylus scan period ends. The APA scan may continue tracking the touch object until the APA scan period ends (scan count reaches a threshold value) or until no APA touch object is detected, whichever occurs first. Alternatively, other methods of prioritizing and substantially simultaneously tracking the position of a stylus and a passive touch object on a sense array would be known by those of ordinary skill in the art with the benefit of this disclosure.

[0132] FIG. **21** is flow diagram of one embodiment of a method **2100** of tracking the position of a stylus that is contacting or hovering over a sense array. The method **2100** is performed by processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a general purpose computing system or a dedicated machine), firmware (embedded software), or any combination thereof. In one embodiment, the touch screen controller **605** of FIG. **6** performs some of operations of method **2100**. In another embodiment, the sensing device **830** of FIG. **8** performs the method **2100**. In yet another embodiment, the capacitance sense circuit **310** of FIG. **3** performs the method **2100**. Alternatively, other components of the electronic system **300** (FIG. **3**) can perform some or all of the operations of method **2100**.

[0133] In an embodiment, the stylus scan method **2100** describes a stylus hover detection scheme and may be substituted for the stylus scan and processing method of FIG. **20**. A stylus TX hover signal occurs when a stylus tip is in close proximity to, but not touching the overlay, a sense array and the stylus capacitively couples the stylus TX signal to the sense array.

[0134] Referring to FIG. **21**, the stylus scan phase begins (block **2110**). The processing logic performs filtering, baseline updates, or difference calculations (block **2120**). Filtering may be an infinite impulse response (IIR), a finite impulse response (FIR), or a median applied to the raw data, depending on the noise environment and allowable processing overhead. Difference calculations may be used as a method of extracting usable signals from background noise. A baseline is maintained for each sense element over time, tracking its response to temperature, noise etc. This baseline is subtracted from each raw data sample to obtain "difference counts". In other words DIFF_COUNTS=RAW_COUNTS−BASELINE. The difference calculation may be used for distinguishing the stylus signal from the receiver baseline signal at the absence signal from stylus. The baseline is calculated as low pass filtered receiver signal when no stylus is detected. To improve the signal-to-noise ratio under noisy conditions the receiver signal could be filtered optionally. The filters are low-pass filters, common-mode noise filters, or the like. At block **2130**, if the difference calculation for the entire sensors array is zero, then the processing logic does not detect a stylus touch or stylus hover condition (block **2135**) and the stylus process ends (block **2195**). This means that all measured difference counts were zero, i.e., there was no stylus touch detected.

[0135] At block **2130**, if the difference calculation for the entire APA is greater than zero, the processing logic determines the local maximum stylus TX signal (block **2140**). In an embodiment, the local maximum stylus TX signal is the row or column of electrodes that have the highest amplitude stylus TX signal. In an embodiment, the row and column electrodes are RX lines **640** and **660** of FIG. **6**. At block **2150**, if the sum of the difference calculation around the local maximum is less than a hover threshold value, then processing logic detects a stylus touch (block **2155**). For example, a typical stylus touch signal may look like signal **2152**. At block **2190**, the processing logic calculates the centroid in post processing and stylus processing ends (block **2195**).

[0136] At block **2150**, if the sum of the difference calculation around the local maximum is equal to or greater than the hover threshold value, then the hover differential signal shape detector ("shape detector") detects the shape (i.e., the signal gradient) of the stylus TX signal on the sense array (process block **2160**). The shape detector determines if the relative magnitudes of the stylus TX signal on the RX lines **640**, **660** adjacent to the electrode with the local maximum are indicative of a hovering stylus TX signal. The magnitude of the coupled stylus TX signal depends on the relative proximity of the stylus tip **895** and the electrodes on the sense array **810**. In an embodiment, a hovering stylus TX signal may look like signal **2164**. Alternatively, a signal attributable to noise or other non-stylus TX signal may look randomly shaped, similar to signal **2162**.

[0137] The shape detector determines if the detected signal is a legitimate hovering stylus TX signal from a hovering stylus (block **2170**). If the shape detector determines that the detected is a legitimate hovering stylus TX signal, the processing logic determines the current stylus count. At block **2180**, if the stylus count is less than a predetermined count

value, the processing logic determines that there is no stylus touch or stylus hover signal on the sense array (block **2175**) and stylus processing ends (block **2195**). At block **2180**, if the stylus count is equal to or greater than the predetermined count value, the processing logic determines that the signal is a stylus hover TX signal (block **2185**). At block **2190**, the processing logic calculates the centroid in post processing and stylus processing ends, block **2195**.

[0138] If the shape detector determines that the detected signal is not a legitimate stylus hover TX signal (e.g., signal **2162**), the processing logic determines that no stylus touch occurred (block **2175**) and stylus processing ends (block **2195**).

[0139] 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.

[0140] 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.

[0141] 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.

[0142] 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.

[0143] 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.

What is claimed is:

1. A method comprising:

generating, by a stylus, a transmit signal to be capacitively coupled to a capacitive sense array;

modulating stylus data into the transmit signal; and

transmitting the modulated signal to the capacitive sense array via a capacitive coupling between the stylus and the capacitance sense array.

2. The method of claim **1**, wherein the stylus data comprises force sense data.

3. The method of claim **1**, wherein the stylus data comprises at least one of force sense data, battery data, acceleration data, or button status data.

4. The method of claim **1**, wherein said modulating comprises modulating the data using at least one of frequency modulation (FM), frequency-shift keying (FSK), amplitude modulation (AM), amplitude-shift keying (ASK), on-off keying (OOK), pulse position modulation, phase modulation (PM), Manchester encoding, or direct sequence spread spectrum (DSSS).

5. The method of claim **1**, further comprising measuring a force with which a tip of the stylus is pressed, and wherein the stylus data comprises the measured force.

6. A stylus, comprising:

a stylus tip configured to capacitively couple to a capacitive sense array;

a tip driver configured to drive a transmit signal to the capacitive sense array via the stylus tip; and

a processing device configured to modulate data into the transmit signal and ton control the tip drive to transmit the modulated signal to the capacitive sense array via the stylus tip.

7. The stylus of claim **6**, wherein the processing device comprises:

a synchronization and modulation block configured to receive the transmit signal and to modulate the data into the transmit signal to generate the modulated signal; and

a processing core configured to provide the data to the synchronization and modulation block.

8. The stylus of claim **7**, wherein the processing device further comprises an analog-to-digital converter (ADC) to receive a voltage representative of a battery status of the stylus and to convert the voltage into a digital value, wherein the processing core is configured to include the digital value in the data sent to the synchronization and modulation block to be modulated into the transmit signal.

9. The stylus of claim **7**, further comprising a button, wherein the processing core is configured to receive button input data from the button and to include the button input data in the data sent to the synchronization and modulation block to be modulated into the transmit signal.

10. The stylus of claim **7**, wherein the processing device further comprises a measurer configured to determine an amount of force applied to the stylus tip and send a digital value representative of the amount of force, and wherein the processing core is configured to include the digital value in the data sent to the synchronization and modulation block to be modulated into the transmit signal.

11. The stylus of claim **10**, further comprising a force sensor, coupled to the processing device, configured to detect the amount of force applied to the stylus tip.

12. The stylus of claim **11**, wherein the force sensor is an active sensor.

13. The stylus of claim **10**, further comprising a motion sensor, coupled to the processing device, configured to detect motion of the stylus.

14. The stylus of claim **7**, wherein the synchronization and modulation block is configured to modulate the data using at least one of frequency modulation (FM), frequency-shift keying (FSK), amplitude modulation (AM), amplitude-shift keying (ASK), on-off keying (OOK), pulse position modulation, phase modulation (PM), Manchester encoding, or direct sequence spread spectrum (DSSS).

15. The stylus of claim **14**, wherein the PM modulation uses at least one of a binary phase shift keying (BPSK) encoding scheme or a quadrature phase shift keying (QPSK) encoding scheme.

16. A stylus comprising:

a stylus tip configured to capacitively couple to a capacitive sense array;

a tip driver configured to transmit signals to the capacitive sense array via the stylus tip; and

a processing device configured to transmit a stylus touch signal to a host via the capacitive sense array and a stylus data to the host using a same channel as the stylus touch signal.

17. The stylus of claim **16**, wherein the processing device is configured to modulate the stylus data into the stylus touch signal.

18. The stylus of claim **16**, wherein the processing device is configured to multiplex the stylus data and the stylus touch signal.

19. The stylus of claim **18**, wherein the processing device is configured to use at least one of time divisional multiplexing (TDM) to transmit the stylus touch signal in one time slot and transmit the stylus data in another time slot or code divisional multiplexing (CDM) to transmit the stylus touch signal using one code and transmit the stylus data using another code.

20. The stylus of claim **16**, wherein the processing device is configured to transmit the stylus touch signal using a first frequency and transmit the stylus data using another frequency.

21. The stylus of claim **16**, further comprising:

a switching block configured to generate an inverted and non-inverted transmit signal based on the stylus touch signal, wherein the switching block comprises a switch that toggles an output signal between the inverted and non-inverted transmit signal; and

a pause detector configured to detect periods between pulses of the stylus touch signal, wherein the processing device comprises:

a shift register configured to receive input force data from a force sensor, wherein the stylus data comprises the input force data; and

a synchronization and clock generation block to generate synchronized clock pulses for the shift register, and wherein the shift register controls the switch of the switching block in response to the input force data, wherein the output signal of the switching block is a modulated signal comprising the stylus data and the stylus touch signal.

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