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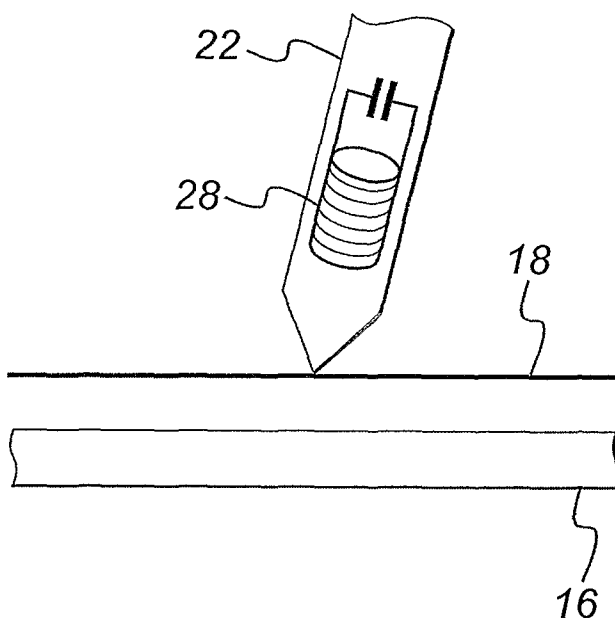
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(54) Title: NAVIGATION ARRANGEMENT FOR AN ELECTRONIC DEVICE



(57) Abstract: A navigation arrangement for an electronic device that includes a screen, comprises: (i) a substantially transparent two dimensional capacitive position sensor that can be located over a screen of the device, and which can detect the position of an object with respect to the screen, and (ii) a two dimensional inductive position sensor for detecting the position of an intermediate coupler for example in the form of a pen or stylus with respect to the screen. The inductive position sensor comprises a transmit aerial for transmitting a signal, and a receive aerial for receiving the signal via the intermediate coupler so that the position of the intermediate coupler can be determined- The wiring of the inductive position sensor may be formed from a transparent conductor, or it may be arranged around the edge of the screen or behind the screen to enable the user to view the screen. Further forms of inductive position sensor, with or without capacitive position sensors, can enable a user to view a screen, for example by placing the inductive sensor tracks around the screen, or by connecting transparent conductors in parallel using low resistance busbars at the edge of the screen. Inductive position sensors may also be arranged to determine the position of the intermediate coupler in three directions, optionally in combination with other forms of sensor, and also to determine its orientation.

NAVIGATION ARRANGEMENT FOR AN ELECTRONIC DEVICE

5 This invention relates to electronic equipment,
and especially to arrangements for enabling a user to
navigate about a screen of the device or otherwise to
input information into the device and to output
information from it.

10 Many forms of electronic device are designed to
enable a user to navigate over a screen on the device,
for example to "click" on various icons on the screen
in order to actuate the device or to select various
options. For this purpose, such devices have often
15 been provided with a touch screen, for example in the
form of a capacitive position detector that can detect
the position of an object such as a user's digit on
the screen. Typically the capacitive position sensor
will be in the form of a two dimensional detector
20 comprising one or more transparent supports on which
are located a plurality of transparent conductive
tracks or regions and arranged so that different
combinations of tracks or regions exhibit mutual
capacitive coupling that is affected by the proximity
25 of the object, e.g. the user's digit, whose position
is to be detected. The conductive tracks may be
formed from any transparent conductor, and usually are
formed from a material such as indium tin oxide. Some
of the tracks may, for example, be formed on a
transparent, e.g. glass, substrate which is overlaid
30 with another transparent insulator having further
tracks or regions that are capacitively coupled
thereto. Finally a transparent protective layer may
be located on top of the capacitive position detector.
Such capacitive detectors are described, for example,

in US patents Nos. 5,730,165, 6,288,707 and 7,030,860, the disclosures of which are incorporated herein by reference.

However, such capacitive position detectors have the disadvantage that they cannot resolve position to a fine degree, and are typically intended to be actuated by a finger, thereby providing a relatively coarse "button" functionality for actuating the device.

According to the present invention, there is provided a navigation arrangement for an electronic device that includes a screen, the arrangement comprising:

- (i) a two dimensional capacitive position sensor that can be located over a screen of the device, and which can detect the position of an object with respect to the screen, the capacitive position sensor having a substantially transparent region located over the screen to enable a user to view the screen, and
- (ii) a two dimensional inductive position sensor for detecting the position of an intermediate coupler with respect to the screen, the inductive position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and is sent from the transmit aerial to the receive aerial via the intermediate coupler is induced, the received signal varying in dependence on the position of the intermediate coupler, the inductive position sensor also having a substantially transparent region located over the screen to enable a user to view the screen.

The navigation arrangement according to the invention has the advantage that it can provide a relatively coarse "button" functionality that enables a user to point to icons on the screen, for example for inputting numbers, and also a "fine" detecting functionality that enables a user to write on the screen by means of the intermediate coupler which, in such a case, will be in the form of an implement such as a stylus or pen, thereby providing a so-called "touch and pen" functionality. The navigation arrangement may be employed with a number of devices, and is especially suitable for use with portable devices such as laptop computers, ultramobile PCs (UMPC), personal digital assistants, slates (laptop computers having no keyboard), cellular telephones and the like, although it is also applicable to larger devices such as interactive whiteboards. The arrangement according to the invention has the advantage that it is possible to design the arrangement so that it has a relatively low power consumption which is particularly important with battery powered portable devices such as those mentioned above.

In its broadest aspect, the transmit and/or receive aerial may be located on a side of the screen that, in use, faces away from the user. This form of device enables the transmit and receive aerials not to obstruct the view of the screen by the user.

In other forms of arrangement, it may be necessary or desirable for the two dimensional inductive position sensor to be located on the same side of the screen as the user, with the possibility that the aerial(s) will prevent the user having a clear view of the screen. One such arrangement may be

required if it is in the form of an overlay that is intended to be positioned over the screen during manufacture of the device or positioned over the device by the user before use.

5 One form of inductive sensor that may be employed in the arrangement according to the present invention is a simultaneous transmit-receive device described in British patent application No. 2,374,424, the disclosure of which is incorporated herein by
10 reference. In this form of arrangement a signal generator generates an excitation signal in the transmit aerial, and a sensed signal is induced in the receive aerial. The excitation signal comprises a periodic carrier signal that is modulated by a
15 periodic modulation signal at a lower frequency, and the signal that is induced in the receive aerial is indicative of the position of the intermediate coupler (often referred to as the target) with respect to the transmit or receive aerial. The transmit aerial may
20 be formed by a pair of loops, one being in the general form of a sine while the other is in the general form of a cosine and positioned with respect to each other in spatial quadrature, although other forms of coils are possible. The intermediate coupler may have any
25 of a number of forms. For example, it may be in the form of a passive resonant coupler based on an LC circuit that may be formed in a simple manner by connecting the ends of a coil by means of a capacitor, so that it will resonate at a particular frequency,
30 and the signal received by the receive aerial from the intermediate coupler will have a phase that differs from that of the signal transmitted by the transmit aerial, the phase difference indicating the position of the coupler. Alternatively, the intermediate

coupler may comprise an element formed from a material that will perturb the magnetic field generated by the transmit aerial, for example it may be formed from a material having a high relative magnetic permeability such as a ferromagnetic material, although low-cost couplers can be made simply from a conductive material in which case the sensor responds to eddy currents that flow in the material. Although as described in GB-A-2,374,424, the sine and cosine windings each have only a single loop, this is a simplification, and in practice each sine and cosine loop will have a number of windings connected in series, either nested one inside the other so that different lobes of the sine and cosine loops take on the form of a spiral, or each sine and cosine loop may have a number of windings that are slightly offset with respect to one another. The use of a large number of windings to form each lobe of the sine and cosine loops is often necessary or desirable in order to increase the magnetic field generated by the windings, and so increase the magnetic field gradients across the aerial.

Another form of inductive sensor is described in US patent No. 5,815,091 to Scientific Generics, the disclosure of which is incorporated herein by reference, in which the transmit aerial is in the form of a single loop, and the receive aerial comprises a pair of loops, one in the general form of a sine and the other in the general form of a cosine. Such a sensor, employing only a single transmit loop, may have the advantage that only a single transmit pulse lasting only a single number of clock cycles, is used to energise a resonant coupler, whereas if a pair of transmit coils is used, two transmit pulses lasting twice the number of clock cycles may be needed.

Similarly with the form of inductive position sensor described above, the loops of the transmit and receive aerials may be formed from a number of windings in order to increase magnetic coupling between the aerials.

In such forms of inductive position sensor, the use of very fine metallic tracks or transparent conductive tracks connected in series will have the disadvantage that the overall resistance will be very high and will dominate the reactance of the circuit, thereby limiting the current and reducing the magnetic field. This problem may be overcome by connecting a number of windings forming parts of the lobes of the sine or the cosine windings in parallel, or in the case of transparent conductors, by forming very wide tracks in order to reduce their resistance. The different parts of the lobes may be connected together using relatively low resistance tracks or busbars, for example formed from relatively thick copper or other metal strips. These low resistance tracks may be placed in the region of the periphery of the screen so that they will not obscure the view of the screen by the user.

Alternatively, it is possible for the sine and/or cosine loops or other loops of the various aerials to be located around the periphery of the screen so that the view of the screen is unobstructed. For example, in the case of a sine coil, instead of forming a coil having a pair of lobes from tracks that cross one another in the central region, a pair of lobes may be formed at opposite edge regions of the screen and the lobes may be connected by a pair of tracks extending along a connecting edge region of the screen. Similarly, a cosine coil may be formed from a pair of

lobes extending along opposite edge regions of the screen that are connected to a central lobe formed from tracks that extend along opposite connecting regions of the screen. In this way, the sine and cosine loops of the aerials extend over the entire screen without any conductive tracks obscuring the screen.

Indeed, it is possible for the lobes of the sine and cosine coils to be formed separately from one another, each lobe being located in the region of one edge of the screen, and the lobes to be subjected to separate transmit signals or to generate separate receive signals.

Yet another form of inductive sensor that may be employed in the arrangement according to the invention is a pulse-echo type of system disclosed in US patent No. 4,878,553 to Wacom Co. Ltd, the disclosure of which is incorporated herein by reference. In this arrangement, the position of a resonant circuit is detected from waves sent by a generating circuit and transmit coils to a receive aerial. The transmit and receive aerials are in the form of an array of loops, that are located at defined positions along the screen, and the coordinate values of the position of the resonant circuit is determined from the amplitude of the signal received in different coils of the receive aerial.

In all these forms of position sensor, the wires or tracks of the transmit and/or receive aerial are distributed substantially evenly over the entirety of the sensor with the result that they may obscure the view of the screen by the user.

A number of designs may be employed in order to enable the user to view the screen if the inductive

position detector is intended to be located on the same side of the screen as the user. In one design, the tracks or wires forming the aerial (whether a transmit or receive aerial) may be made sufficiently fine that they are not noticed by the user when looking at the screen. The particular degree of fineness will depend on a number of factors such as the proximity of the user's eyes to the screen, but typically a wire or track of 50 to 60 AWG e.g. about 55 AWG would be suitable. Alternatively, the tracks forming the transmit and/or receive aerials may be formed from a transparent conductor, for example from indium tin oxide (ITO) deposited on a transparent substrate. It will be appreciated that the transmit and receive aerials of the inductive position detector will need to carry a higher current than the tracks forming the capacitive sensor since the transmit aerial will need to generate a sufficiently large magnetic field. Because of this, the use of nested windings is not appropriate because the resistance of the windings would then be so great that the current would be limited to too small a value.

Thus, according to another aspect, the invention provides a navigation arrangement for an electronic device that includes a screen, the arrangement comprising a two-dimensional inductive position sensor for detecting the position of an intermediate coupler with respect to the screen, the inductive position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and sent from the transmit aerial to the receive aerial via the intermediate coupler is induced, the received signal varying in dependence on

the position of the intermediate coupler, the transmit aerial and/or the receive aerial being arranged to be located over the surface of the screen and being formed from a plurality of substantially transparent electrically conductive tracks that enable a user to view the screen, wherein at least some of the electrically conductive tracks in the transmit aerial and/or the receive aerial are connected in parallel with one another by means of one or more conductors of relatively low resistance that are arranged in the region of the edge of the screen so that the view of the screen by the user is not obstructed.

By connecting the various tracks in a group of tracks in parallel, and by using busbars or relatively low resistance conductors to connect the tracks that extend over the screen and which will necessarily be of high resistance, the overall resistance of the coils can be made acceptably low.

According to yet another aspect, the invention provides a navigation arrangement for an electronic device that includes a screen, the arrangement comprising a two-dimensional inductive position sensor for detecting the position of an intermediate coupler with respect to the screen, the inductive position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and sent from the transmit aerial to the receive aerial via the intermediate coupler is induced, the received signal varying in dependence on the position of the intermediate coupler, wherein the transmit aerial and/or the receive aerial are formed from a plurality of electrically conductive tracks that are located around the periphery of the screen so

that the view of the screen by the user is unobstructed.

In this aspect of the invention, because the tracks forming the transmit and receive coils are not in the line of sight of the user to the screen, they may be formed from relatively thick, and hence low resistance, conductors while enabling the user to view the screen.

These arrangements may be formed as part of an electronic device, for example a laptop computer or PDA, or they may include means for attaching the arrangement to the device so that it can be provided as an overlay for the device.

In addition to sensing the position of the intermediate coupler in two dimensions over the screen, a device according to the present invention may also be operative to determine the distance of the intermediate coupler away from the two-dimensional inductive position sensor. It is possible to determine the position in a direction normal to the plane of the two-dimensional inductive position sensor, for example by detecting the signal amplitude and knowing how the amplitude falls away with increasing distance.

Thus, according to yet another aspect, the invention provides a device for detecting the position of an object in three dimensions, which comprises:

- (i) a planar two-dimensional inductive position sensor for detecting the position of an intermediate coupler located in the object in two directions in the plane of the position sensor, the inductive position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that

originates from the signal transmitted by the transmit aerial and is sent from the transmit aerial to the receive aerial via the intermediate coupler is induced, the received signal varying in dependence on the position of the intermediate coupler in the two directions; and

(ii) a detector for detecting the position of the object in a direction normal to the two-dimensional position sensor by sensing the amplitude of the received signal.

However, such amplitude measurements may suffer from the disadvantage that they are susceptible to changes in the magnetic field due to variations in the input power supply or transmit levels or to interference from other equipment. The device therefore may advantageously include a further sensor, preferably an inductive position sensor, that is arranged to detect the position of the intermediate coupler along the separation axis from the two-dimensional inductive position sensor. This may be in the form of a further inductive position sensor located in a plane oriented at an angle to the plane of the screen (and preferably substantially perpendicular thereto), the further inductive sensor being capable of detecting the position of the intermediate coupler at least in a direction toward and away from the screen so that the two-dimensional inductive sensor and the further inductive sensor together can determine the position of the intermediate coupler in three coordinate directions.

Thus, according to another aspect, the invention provides a device for detecting the position of an object in three dimensions, which comprises:

(i) a planar two-dimensional inductive position

sensor for detecting the position of an intermediate coupler located in the object in two directions in the plane of the position sensor, the inductive position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and is sent from the transmit aerial to the receive aerial via the intermediate coupler is induced, the received signal varying in dependence on the position of the intermediate coupler in the two directions; and

(ii) a further inductive position sensor for detecting the position of the intermediate coupler in a third direction that is normal to the plane of the two-dimensional inductive position sensor.

The further inductive position sensor may be in the form of one or more discrete inductive position sensors provided in the region of the screen that are capable of determining the distance of the intermediate coupler in a direction normal to the plane of the screen, for example as described in international patent application No. WO 2005/055426, the disclosure of which is incorporated herein by reference. Alternatively, if the device is formed in two parts that are joined together by a hinge, for example in the manner of a clamshell, the further inductive position sensor may be provided in the part of the device other than that part carrying the screen. Such devices may include laptop computers in which the further inductive sensor is located for example beneath the keyboard, or it may be another clamshell type device such as a flip-top cellular telephone.

Preferably the two-dimensional inductive sensor and the further inductive sensor are arranged substantially perpendicularly to one another when the device is "open" so that determination of the position in a direction in the plane of one inductive sensor is not associated with changes in position in the other inductive position sensor. It is not essential that the two-dimensional inductive position sensor and the further inductive position sensor be positioned perpendicularly to one another when they are located in different parts of a hinged device: if the two-dimensional inductive position sensor and the further inductive position sensor are not perpendicular to one another, the apparent position of the intermediate coupler on the two-dimensional position sensor will change as the intermediate coupler is moved toward or away from it in the plane of the further inductive position sensor, and the device will need to include some means to compensate for this change in apparent position. It is, of course, possible for the further inductive position sensor to determine the position of the intermediate coupler in two directions, but in this case one measurement (the measurement in a direction parallel to the hinge of the device) would be redundant. Such a measurement could be used as a cross-check or to verify that the lid has been properly opened. In any case, it is desirable to employ some means to ensure that the lid and the remainder of the body of the device are oriented correctly, for example by limiting movement of the hinge or by providing a detent. Alternatively, the angle between the lid and the body may be detected by a further sensor which can be used to calculate the true 3D position of the intermediate coupler,

compensating for the angular separation of the two sensors with respect to one another.

It is possible to detect not only the position of a single intermediate coupler, but also the orientation of an element that includes a plurality of intermediate couplers, preferably couplers that can be distinguished from one another for example by having different resonant frequencies, by determining differences in distance of different intermediate couplers located in the element from one or more of the inductive position sensors. Such an element, if elongate, could comprise a pen or pointer, an optical device, a gun for example for use in an arcade type game, or otherwise may include any other virtual reality device e.g. a flight simulator, in which it is necessary to know the degree of pitch, roll and yaw in addition to the coordinate position of the elements. An elongate element could, for example, have an intermediate coupler located in the region of each end thereof.

The object in which the intermediate coupler is located will often be formed as a pen-like device, but other shapes of pointer are possible. For example the device may provide a game such as a shooting game in which the object is shaped as a rifle, or a golf game in which it is shaped as a golf club. Corporate branding could be provided on the object, and different objects may have different functionalities. For example, a drawing tablet may have one type of object (pointer) to mimic the effect of a spray-can, while another pointer may mimic a crayon or a fine brush. The different pointers can look different from one another and can be sensed by the inductive position sensor by means of different properties of

the intermediate couplers e.g. different resonant frequencies. In addition, the invention is not limited to equipment that includes passive intermediate couplers, but may include active devices, for example hand-held devices that can communicate with the equipment by means of electromagnetic radiation, e.g. laser guns, or by acoustic or other means. Thus, according to yet a further aspect, the invention provides an arrangement for detecting the position of a movable object in three dimensions, which comprises:

- (i) a static device that includes a planar two-dimensional inductive position sensor for detecting the position of an intermediate coupler located in the object in two directions in the plane of the position sensor, the inductive position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and is sent from the transmit aerial to the receive aerial via the intermediate coupler is induced, the received signal varying in dependence on the position of the intermediate coupler in the two directions; and
- (ii) the movable object; wherein the object also includes means for communicating with the static device so that the static device can determine the position of the movable object with respect to the inductive position sensor.

Various forms of arrangement according to the present invention will now be described by way of example with reference to the accompanying drawings in which:

Figures 1A and 1B show the principle of a capacitive position sensor for a touch screen;

Figure 2 is a block diagram showing the basic elements of a position sensor employed in the arrangement according to GB 2,374,424 which may be employed in the present invention;

Figures 3A to 3C are schematic views of transmit and receive windings that may be used in the transmit and receive aerials of an inductive position sensor employed in the arrangement according to the invention;

Figure 4 is a more detailed block diagram explaining the operation of the position sensor shown in figure 2;

Figure 5 is a schematic plan view of the tracks of a two dimensional inductive position sensor employed in the arrangement according to the invention;

Figure 6 is a schematic perspective view of one form of arrangement according to the present invention that employs a capacitive position sensor overlay and an inductive position sensor underlay;

Figure 7 is a schematic perspective view of an arrangement according to the present invention in the form of an overlay for an electronic device;

Figure 8 is a schematic sectional view of part of the arrangement showing an intermediate coupler in the form of a stylus or pen;

Figure 9 is a more accurate schematic plan view of a sine coil for detecting position in the x or horizontal direction in the inductive position sensor employed in the present invention;

Figures 10A and 10B are schematic views of staggered windings of sine and cosine coils in the x

or horizontal direction and the y or vertical direction respectively employed in an inductive position sensor according to the invention;

Figure 10C is a plan view of the windings shown in figures 10A and 10B together with windings forming the receive aerial of a two-dimensional inductive position sensor;

Figures 11A and 11B are simplified schematic views of a sine and cosine winding (for the x or horizontal direction) that may be employed in an inductive position sensor employed in the arrangement according to the present invention;

Figure 12 is a graphical representation of a typical output of the sensor shown in figure 11 with respect to position;

Figure 13 is a simplified schematic plan view of an alternative two-dimensional inductive position sensor employed in the arrangement according to the invention;

Figure 14 is a graphical representation of a typical output of the sensor shown in figure 13 with respect to position;

Figures 15A and 15B are schematic views of a further arrangement according to the invention that may be employed as an overlay for an electronic device;

Figures 16 and 17 are schematic plan views of transparent sine and cosine windings for an inductive position sensor that may be placed over the screen of an electronic device;

Figure 18 is a further design of a transparent cosine winding;

Figure 19 is a schematic perspective view of an electronic device that can detect the position of an

article in three directions;

Figure 20 is a schematic view of a pointer employing two resonant couplers for determining both orientation and position thereof; and

5 Figure 21 is a schematic view of yet a further form of transmit and receive coils that may be employed in the arrangement according to the invention.

Referring to the accompanying drawings, figure 1A
10 shows schematically a small part of an overlay for a screen of an electronic device that provides a capacitive position sensor and enables the screen to be used as a touch screen. The overlay comprises a transparent insulating layer 1 which may be formed for
15 example from glass, and which has further transparent layers 2 and 4 on the upper and lower surface thereof. Part of the layers 2 and 4 are formed from a transparent conductive material, for example from indium tin oxide (ITO) and may be present in the form
20 of tracks 6 and 8 on the top layer and 10 on the lower layer. These tracks may for example be formed as an array of horizontal (x direction) and vertical (y direction) tracks that cross over one another at regular intervals along the x and y directions of the
25 screen, or they may be formed as other patterns. For example, as shown in figure 1, in the region where the tracks cross one another, they may contain apertures 12. In addition, a number of additional transparent layers (not shown) may be present in order to provide
30 a support or to provide protection against handling or wear. The tracks on one of the layers 2 or 4 may be driven by an appropriate signal or held at a given voltage while the tracks on the other layer may be held at a different voltage. As shown in figure 1A,

when no object is present in the vicinity of the tracks, all the electric field lines from one of the tracks 10 extend to the other tracks 6 and 8. However, as shown in figure 1B, when an object 14 such as a user's finger or a stylus approaches the tracks, some of the electric field lines are coupled to the object leaving fewer field lines extending between the tracks, thereby altering the mutual capacitive coupling between the tracks, thereby enabling the position of the object to be determined.

In addition to a capacitive position detector, the arrangement includes an inductive position detector. The principle of operation of the inductive position sensor is shown in figures 2 to 4.

In order to detect the position of an intermediate coupler in one direction, a control unit includes a quadrature signal generator 31 which generates an in-phase signal $I(t)$ and a quadrature signal $Q(t)$ at respective different outputs. The in-phase signal $I(t)$ is generated by amplitude modulating an oscillating carrier signal having a carrier frequency f_0 , which in this embodiment is 2MHz, using a first modulation signal which oscillates at a modulation frequency f_1 , which in this embodiment is 3.9kHz. The in-phase signal $I(t)$ is therefore of the form:

$$I(t) = A \sin 2\pi f_1 t \cos 2\pi f_0 t \quad (1)$$

Similarly, the quadrature signal $Q(t)$ is generated by amplitude modulating the oscillating carrier signal having carrier frequency f_0 using a second modulation signal which oscillates at the modulation frequency f_1 ,

with the second modulation signal being $\pi/2$ radians (90°) out of phase with the first modulation signal. The quadrature signal $Q(t)$ is therefore of the form:

$$Q(t) = A \cos 2\pi f_1 t \cos 2\pi f_0 t \quad (2)$$

The in-phase signal $I(t)$ is applied to a sine coil 37 and the quadrature signal $Q(t)$ is applied to the cosine coil 39.

The sine coil 37 is formed in a pattern which causes current flowing through the sine coil 37 to produce a first magnetic field B_1 whose field strength component resolved perpendicular to the PCB forming the sensor pad 20 varies sinusoidally along the measurement direction in accordance with the function:

$$B_1 = B \sin\left(\frac{2\pi x}{L}\right) \quad (3)$$

where L is the period of the sine coil in the x direction.

Similarly, the cosine coil 39 is formed in a pattern which causes current flowing through the cosine coil 39 to produce a second magnetic field B_2 whose field strength component resolved perpendicular to the sensor pad 20 also varies sinusoidally along the measurement direction, but with a phase difference of $\pi/2$ radians (90°) from the phase of the first magnetic field B_1 , giving:

$$B_2 = B \cos\left(\frac{2\pi x}{L}\right) \quad (4)$$

In this way, the total magnetic field B_T generated at any position along the measurement direction will be formed by a first component from the first magnetic field B_1 and a second component from the second magnetic field B_2 , with the magnitudes of the first and second components resolved perpendicular to the sensor pad 20 varying along the measurement direction.

By applying the in-phase signal $I(t)$ and the quadrature signal $Q(t)$ to the sine coil 37 and the cosine coil 39 respectively, the generated total magnetic field component B_T resolved perpendicular to the sensor pad 20 oscillates at the carrier frequency f_0 in accordance with an amplitude envelope function which varies at the modulation frequency f_1 , with the phase of the amplitude envelope function varying along the measurement direction. Thus:

$$B_T \propto \cos 2\pi f_0 t \cdot \cos \left(2\pi f_1 t - \frac{2\pi x}{L} \right) \quad (5)$$

In effect, the phase of the amplitude envelope function rotates along the measurement direction.

A sensor element 40 whose position along the measurement direction is to be sensed may include a passive resonant circuit having a resonant frequency substantially equal to the carrier frequency f_0 . The total magnetic field component B_T therefore induces an electric signal in the resonant circuit which oscillates at the carrier frequency f_0 and has an amplitude which is modulated at the modulation frequency f_1 with a phase which is dependent upon the position of the sensor element 40 along the measurement direction. The electric signal induced in

the resonant circuit in turn generates a magnetic field which induces a sensed electric signal $S(t)$ in the sense coil 41, with the sensed electric signal $S(t)$ oscillating at the carrier frequency f_0 . The amplitude of the sensed signal $S(t)$ is also modulated at the modulation frequency f_1 with a phase which is dependent upon the position of the sensor element 40 along the measurement direction. The sensed signal $S(t)$ is input to a phase detector 43 which demodulates the sensed signal $S(t)$, to remove the component at the carrier frequency f_0 , and detects the phase of the remaining amplitude envelope function relative to the excitation waveform. The phase detector 43 then outputs a phase signal $P(t)$ representative of the detected phase to a position calculator 45, which converts the detected phase into a corresponding position value and outputs a drive signal to the display 45, for example provided by the screen 4 of the device, to display the corresponding position value.

By using a carrier frequency f_0 which is greater than the modulation frequency f_1 , the inductive coupling is performed at frequencies away from low-frequency noise sources such as the electric mains at 50/60 Hz, while the signal processing can still be performed at a relatively low frequency which is better suited to digital processing. Further, increasing the carrier frequency f_0 facilitates making the sensor element 40 small, which is a significant advantage in many applications. Increasing the carrier frequency f_0 also produces higher signal strengths.

As shown in Figure 3A, the sine coil 37 is formed by a conductive track which generally extends around

the periphery of the PCB forming the inductive position detector apart from a cross-over point halfway along the PCB in the measurement direction, at which the conductive track on each widthwise edge of the PCB crosses to the corresponding opposing widthwise edge of the PCB. In this way, effectively a first current loop 21a and a second current loop 21b are formed. When a signal is applied to the sine coil 37, current flows around the first current loop 21a and the second current loop 21b in opposite directions, and therefore the current flowing around the first current loop 21a generates a magnetic field which has an opposite polarity to the magnetic field generated by current flowing around the second current loop 21b. This results in the sinusoidal variation of the field strength of the component of the first magnetic field B_1 resolved perpendicular to the PCB given by equation 3 above.

In particular, the lay-out of the sine coil 37 is such that the field strength of the component of the first magnetic field B_1 resolved perpendicular to the PCB which is generated by current flowing through the sine coil 37 varies along the measurement direction from approximately zero at the point where x equals 0, to a maximum value at x equals $L/4$ (the position A as shown in Figure 3A), then back to zero at x equals $L/2$ (the position C as shown in Figure 3A), then to a maximum value (having opposite polarity to the maximum value at position A) at x equals $3L/4$, and then back to zero at x equals L . Thus the sine coil 37 generates a magnetic field component perpendicular to the PCB which varies according to one period of the sine function.

As shown in Figure 3B, the cosine coil 39 is

formed by a conductive track which generally extends around the periphery of the PCB apart from two cross-over points, located one-quarter and three-quarters of the way along the PCB in the measurement direction respectively. In this way, three loops 39a, 39b and 39c are formed of which the outer loops 39a and 39c are half the size of the inner loop 39b. When a signal is applied to the cosine coil 39, current flows in one direction around the outer loops 39a and 39c and in the opposite direction around the inner loop 39b. The magnetic field generated by the current flowing around the inner loop 39b has an opposite polarity to the magnetic field generated by the current flowing around the outer loops 39a and 39c. This results in the sinusoidal variation of the field strength of the component of the second magnetic field B_2 resolved perpendicular to the PCB given by equation 4 above.

In particular, the lay-out of the cosine coil 39 is such that the field strength of the component of the second magnetic field B_2 resolved perpendicular to the PCB which is generated by current flowing through the cosine coil 39 varies along the measurement direction from a maximum value at x equals 0, to zero at x equals $L/4$ (the position A as shown in Figure 6B), then back to a maximum value (having opposite polarity to the maximum value at x equals 0) at x equals $L/2$ (the position C as shown in Figure 6B), and then back to zero at x equals $3L/4$, and then back to a maximum value (having the same polarity as the maximum value at x equals 0) at x equals L . Thus, the cosine coil 7 generates a magnetic field component perpendicular to the PCB 5 which varies according to one period of the cosine function as given by equation

4 above.

As shown in Figure 3C, the sense coil 41 is formed by a conductive track which generally extends around the periphery of the PCB forming a single loop.

5 The layout of the sine coil 37 is such that the electric current induced in the sense coil 41 by current flowing around the first current loop 37a is substantially cancelled out by the electric current induced in the sense coil 41 by current flowing around
10 the second current loop 37b. Similarly, for the cosine coil 39 the current induced in the sense coil 41 by the outer loops 39a, 39c is cancelled out by the current induced in the sense coil 11 by the inner loop 39b.

15 As shown in Figure 4, the processing circuitry used to generate the in-phase signal $I(t)$ and the quadrature signal $Q(t)$ consists of a microprocessor 31, digital components 61, analogue driving circuitry 81 and analogue signal processing components 91.

20 The microprocessor 31 includes a first square wave oscillator 33 which generates a square wave signal at twice the carrier frequency f_0 (i.e. at 4 MHz). This square wave signal is output from the microprocessor 31 to a quadrature divider unit 63
25 which divides the square wave signal by two and forms an in-phase digital carrier signal $+I$ at the carrier frequency, an anti-phase digital carrier signal $-I$ at the carrier frequency and a quadrature digital carrier signal $+Q$, also at the carrier frequency. As
30 described hereafter, the quadrature digital carrier signal $+Q$ is modulated to form the drive signals applied to the sine coil 37 and the cosine coil 39, while the in-phase and anti-phase digital carrier

signals $\pm I$ are used to perform synchronous detection in order to demodulate the sensed signal $S(t)$.

The microprocessor 31 also includes a second square wave oscillator 35 which outputs a modulation synchronisation signal MOD_SYNC at the modulation frequency f_1 to provide a reference timing. The modulation synchronisation signal MOD_SYNC is input to a Pulse Width Modulation (PWM) type pattern generator 47 which generates digital data streams at 2MHz representative of the modulation signals at the modulation frequency f_1 , i.e. 3.9 kHz. In particular, the PWM type pattern generator 47 generates two modulation signals which are in phase quadrature with one another, namely a cosine signal COS and either a plus sine or a minus sine signal $\pm \text{SIN}$ in dependence upon whether the in-phase signal $I(t)$ or the anti-phase signal $\bar{I}(t)$ is to be generated.

The cosine signal COS is output by the microprocessor 31 and applied to a first digital mixer 65, in this embodiment a NOR gate, which mixes the cosine signal with the quadrature digital carrier signal, $+Q$, to generate a digital representation of the quadrature signal $Q(t)$. The sine signal $\pm \text{SIN}$ is output by the microprocessor and applied to a second digital mixer 67, in this embodiment a NOR gate, together with the quadrature digital carrier signal $+Q$ to generate a digital representation of either the in-phase signal $I(t)$ or the anti-phase signal $\bar{I}(t)$. The digital signals output from the first and second digital mixers 65, 67 are input to first and second coil driver circuits 83, 85 respectively and the amplified signals output by the coil drivers 83, 85

are then applied to the cosine coil 39 and sine coil 37 respectively.

The digital generation of the drive signals applied to the sine coil 37 and the cosine coil 39 introduces high frequency harmonic noise. However, the coil drivers 65, 67 remove some of this high frequency harmonic noise, as does the frequency response characteristics of the cosine and sine coils 37, 39. Furthermore, the resonant circuit within the sensor element 1 will not respond to signals which are greatly above the resonant frequency and therefore the resonant circuit will also filter out a portion of the unwanted high frequency harmonic noise.

As discussed above, the signals applied to the sine coil 37 and the cosine coil 39 induce an electric signal in the resonant circuit of the sensor element 40 which in turn induces the sensed signal $S(t)$ in the sense coil 41. The sensed signal $S(t)$ is passed through the analogue signal processing components 91. In particular, the sensed signal $S(t)$ is initially passed through a high pass filter amplifier 93 which both amplifies the received signal, and removes low frequency noise (e.g. from a 50 Hertz mains electricity supply device) and any DC offset. The amplified signal output from the high pass filter 93 is then input to a crossover analogue switch 95 which performs synchronous detection at the carrier frequency of 2 MHz, using the in-phase and anti-phase square wave carrier signals $\pm I$ generated by the quadrature divider 21. The in-phase and anti-phase digital carrier signals which are 90 degrees out of phase to the quadrature digital carrier signal $+Q$ used to generate the drive signals applied to the sine coil

37 and the cosine coil 39, which are used for the synchronous detection, because, as discussed above, the resonant circuit of the sensor element 1 introduces a substantially 90 degrees phase shift to the carrier signal.

The signal output from the crossover analogue switch 95 substantially corresponds to a fully rectified version of the signal input to the crossover analogue switch 95 (i.e. with the negative voltage troughs in the signal folded over the zero voltage line to form voltage peaks lying between the original voltage peaks). This rectified signal is then passed through a low pass filter amplifier 97 which essentially produces a time-averaged or smoothed signal having a DC component and a component at the modulation frequency f_1 . The DC component appears as a result of the rectification performed by the synchronous detection process.

The signal output from the low pass filter amplifier 97 is then input to a band-pass filter amplifier 99, centred at the modulation frequency f_1 , which removes the DC component. The signal output from the bandpass filter amplifier 99 is input to a comparator 101 which converts the input signal to a square wave signal whose timing is compared with the timing of the modulation synchronisation signal MOD_SYNC to determine the position of the sensor element 40.

In this way, it is possible to detect the position of a sensor element formed from a resonant circuit in one direction. If a pair of sine and cosine coils are used so that one sine and cosine coil extend in one direction, and another sine and cosine coil extend in an orthogonal direction, it is possible

to determine the position of the resonant circuit in the two orthogonal directions. Figure 5 shows an example of a transmit aerial that may be used in the arrangement according to the invention. The aerial comprises one sine coil 37x that extends over the horizontal dimension of the sensor pad 20 and a cosine coil 39x that also extends over the horizontal dimension of the pad and is superposed on the sine coil. In addition, a sine coil 37y and a cosine coil 39y are also present in order to monitor the vertical position of the sensor element. A single sense coil 41 that extends around the periphery of the sine and cosine coils may be present, or alternatively, separate sense coils 41 may be employed for measurement in each of the horizontal and vertical directions.

Also, although the arrangement has been described with reference to the use of a sine and cosine transmit coil and detection of the phase of the received signal in the receive coil by means of the phase detector 43, other forms of arrangement may be used. For example, a single transmit coil may be employed together with a receive aerial having balanced sine and cosine receive coils. In such a system, the phase difference in the receive coils may be detected, or the relative amplitude of the received signal in the two receive coils may be determined. Other forms of coil may alternatively be employed.

As explained with respect to figures 2 to 5, the sensor element 40 which may form the intermediate coupler, may comprise a passive resonant circuit, for example a simple LC circuit formed by a conductor loop whose ends are connected by a capacitor. However this is not essential. A non-resonant intermediate coupler

formed from a conductive material, for example a metal, may instead be used in which the magnetic field formed by the transmit aerial generates eddy currents in the intermediate coupler which are detected by the sense coil. Alternatively, the intermediate coupler may be formed from a permanent magnet, and the inductive position sensor may include a layer of material having a high magnetic permeability for example mu-metal. When the magnet of the intermediate coupler is not present, eddy currents flow in the mu-metal, but when the magnet is close to the mu-metal layer, the layer becomes locally saturated and so its permeability drops. The localised change in permeability will modify the eddy current pattern which can be detected by the inductive position detector. Such a form of detector is described in WO 2007/003913, the disclosure of which is incorporated herein by reference.

It is preferred for the intermediate coupler, whether in the form of a resonant circuit, a magnet or other device, to be passive, especially if it is small for example in the form of a stylus, so that it will not need any batteries to power it. However, in some applications it may be desirable to employ active intermediate couplers. For example an intermediate coupler may transmit an electromagnetic pulse, a laser beam or sound, and for this to be detected by one or more detectors arranged around the screen and triangulated.

While the capacitive position sensor will not be able to detect the position of an object unless it is in very close proximity thereto, and usually touching it, the inductive position sensor has the advantage that it can detect the position of the intermediate

coupler in the plane of the screen even if the coupler is located at a significant distance from the screen in a direction normal to the screen. It is thus possible to place the inductive position sensor behind the screen so that it will not obscure the view of the screen by the user. Figure 6 is a schematic perspective view of a screen 16 of an electronic device on which a transparent capacitive position sensor 18 has been placed as an overlay, and under which an inductive position sensor 20 has been positioned as an underlay. A pen or stylus 22, shown in greater detail in figure 8 may be moved over the screen and its position determined by means of the inductive position sensor 20.

An alternative arrangement according to the invention is shown in figure 7 in which an electronic device 24 which has a screen 16 is provided with an overlay 26 that can be placed on the front of the device in the region of the screen. The overlay has both a capacitive position sensor and an inductive position sensor located in front of the screen. Figure 8 is a section through part of the electronic device in the region of the screen showing an intermediate coupler in the form of a passive resonant circuit 28 formed from an inductor winding whose ends are connected by a capacitor, and contained in a stylus or pen.

However, although the capacitive position sensor may be formed as a transparent sheet that can be located in front of the screen, it is more difficult to form the inductive position sensor in such a way that the screen can be observed. The sine and cosine coils shown in figures 3A and 3B are, in fact, a simplification, and in practice, in order to maintain

a smoothly varying field, particularly when the intermediate coupler is close to the transmit and receive coils, it is usual to increase the number of turns in each winding as shown in figures 9 and 10. Figure 9 shows a sine coil in which each lobe is formed from a number of turns, in this case four, and where the track leaves the central part of the lobe to join the other lobe, it is necessary for the track to cross over the outer turns. In the case of tracks laid on a pcb, this may be achieved by means of vias through the pch. A similar form of coil may be formed for the cosine coil. In order to form a two-dimensional position sensor, it is necessary to employ two pairs of sine and cosine coils, one pair being rotated with respect to the other pair so that one pair can detect position in the x direction and the other pair can detect position in the y direction, with the result that the sensor will have a large number of tracks extending over the sensing area.

Another form of sine and cosine coils are shown in figures 10A to 10C. In this arrangement, instead of nesting different turns within each other as shown in figure 9, a number of turns are formed in each coil that are offset to each other or staggered. Thus figure 10A shows a sine coil 37x and a cosine coil 39x each formed with five turns in each lobe, and extending in the x direction, while figure 10B shows a sine coil 37y and a cosine coil 39y formed with five turns in each lobe extending in the y direction. Figure 10C shows the tracks of an inductive position sensor formed by superposing the two sine and cosine coils shown in figure 10A and 10B to form transmit aerials, together with a receive aerial formed from a number of sense coils extending around the periphery

of the sensor. As can be seen, substantially the entire area of the inductive position sensor is covered by tracks that will obscure the view of the screen by the user.

5 Although there are, as shown, disadvantages of placing the inductive sensor above the screen, there are advantages as well. For example, it is often easier to integrate such a user interface into a device above the screen. Often the screens are
10 assembled first into the electronic device such as a telephone or laptop, and then sensing overlays are added as a secondary operation. Capacitive sensors (for users' finger-controlled input) must be placed above the screen since they do not have the range in a
15 direction normal to the screen to enable them to be located beneath the screen. Therefore the inductive sensor can be added at the same time as the capacitive sensor, thus minimising assembly costs. In addition, it is possible for the inductive sensor to be
20 manufactured onto the same overlay as the capacitive sensor, so that the incremental cost of adding an inductive sensor is reduced still further, and the component count is reduced.

One way of arranging the coils in order to enable
25 the screen to be viewed is to change the shape of the sine and cosine coil as shown in figure 11A and 11B. In figure 11A, a sine coil extending in the x direction is shown in which the two lobes 37a and 37b are located along opposite (y) edge regions of the
30 screen 16, and are connected by tracks 37c that extend along one of the edges in the x direction, so that none of the screen is obscured by the tracks. Similarly, in figure 11B, a cosine coil extending along the x direction is formed with a pair of lobes

39a and 39c located on opposite (y) edge regions of the screen 16 while the central lobe 39b is formed from a pair of tracks extending along the top and bottom edge region of the screen. In a similar manner, a sine and cosine coil for detecting position in the y direction may be formed simply by rotating the sine and cosine coils shown in figure 11A and 11B through 90°. Of course, each lobe may be formed from a number of turns. The receive aerial may be formed from one or more sense coils 41 that extend around the periphery of the screen 16. Figure 12 shows the sensor output from such a detector from which it can be seen that it is able to detect position in a generally linear and monotonic manner.

Indeed, it is not necessary for the coils to be formed as single items, or to be formed as sine and cosine winding patterns. For example the two windings may be moved entirely to opposite sides of the sensing region as shown in figure 13. In this form of position detector, the transmit coil in the x direction is formed in two parts x1 and x2 on opposite edge regions of the screen, while the transmit coil in the y direction is also formed in two parts y1 and y2 at the top and bottom edge regions of the screen. A single receive coil RX is formed in a single loop extending around the screen, with the result that no tracks obscure the screen. If the transmit and receive coils are reversed, i.e. so that there is a single transmit coil extending around the screen and four receive coils are provided at the edge regions of the screen, the inductive position sensor will operate in a manner similar to that described in US patent No. 5,815,091. The output of the type of sensor shown in figure 13 is shown in figure 14 from which it can be

seen that it will operate in a reasonably linear and monotonic manner. The slight loss of linearity is a reasonable compromise for the simpler and lower cost coil design that can be compensated for by the sensor's hardware and software.

Other forms of transmit and receive aerials are also possible, for example as shown in figure 21. In this case, as shown in figure 21A and B, similar x-axis and y-axis sine coils are used as in figure 11A, but instead of different cosine coils for each axis, a common coil is used for both axes as shown in figure 21C. This coil has a single lobe 128 extending around the periphery of the sensing region similar to the receive coil shown in figure 3C and replaces the cosine coil shown in figure 3B since the pen does not need to operate in the region of the outer lobes 39a and 39c of figure 3B since they are deliberately placed outside the sensing zone.

The receive coil needs to be subtly changed in order to allow it to be balanced with respect to the new cosine coil. For example as shown in figure 21D, the receive coil may have a plurality of turns with the outermost turn 130 wound in the opposite sense to the inner turns 132 and 134. The cosine coil may be placed closer to the outer receive turn 130 than to the inner turns 132 and 134 so that the inner turns balance the outer turn with respect to the cosine coil. However, because the signal from the intermediate coupler in the pen originates from the centre of the winding, the inner turns of the receive coil are more sensitive to the pen than the outer turn. This means that while the receive coil is balanced with respect to the cosine coil, it still receives a significant signal from the intermediate

coupler. Figure 21E shows the combined sense and receive aerials together with the screen 16.

Figure 15A shows a further form of arrangement according to the invention that may be used to prevent the inductive sensor coils obscuring the sensing region above the screen. In this form of arrangement the coils for detecting the position of the intermediate coupler in the x and the y directions are located around each edge of the screen and arranged in planes that are perpendicular to the plane of the sensing region. As with the arrangement shown in figure 13, the coils in the x and y direction are divided into two separate parts x1, x2, y1 and y2 , and a single receive coil, RX is located around the periphery of the sensing region. Also, as with the arrangement shown in figure 13, the transmit and receive coils may be reversed so that a single transmit coil extends around the sensing area and the receive coils extend around the edge of the sensing area in the manner of U.S. patent No. 5,815,091.

The advantage of such an arrangement is that it requires minimal additional lateral space at the edges of the screen. It does require a deeper housing for the electronic device than the flat overlay, but the screens themselves can be reasonably thick and the depth of the sensor does not need to be any greater than the available depth.

The arrangement may be manufactured as part of the electronic device with the coil windings arranged around the screen or as a rigid three dimensional device that can be positioned over the electronic device. Alternatively, the arrangement may be formed as a flexible overlay in a generally cruciform shape as shown in figure 15B having four tabs that are

flexible or hinged and which may be folded down either against the sides of the screen or against a moulding into which the screen fits.

Figure 16 shows one form of winding that may be used for a sine coil in an arrangement where the sine and cosine coils of the transmit or receive aerials are placed between the screen and the user and which must therefore be generally transparent. The required transparency may be achieved in two ways, either by forming the windings from very thin conductive wires in the manner of some automobile windscreens that incorporate electric resistance heaters so that the individual wires are too small to interfere with the user's view of the screen, or by forming the windings from a transparent conductor such as indium tin oxide (ITO). In both cases, however, if the windings are formed as shown in figures 9 or 10, where the conductive tracks extend across the screen or sensing area until they reach an edge region where they are connected to tracks of the same type extending at 90° before extending back across the screen in the opposite direction to form a number of loops so that all the tracks forming one sine or cosine winding are connected in series, the overall resistance of each winding will be so high that its resistance will dominate its reactance at the relevant frequency, and so will limit the current flowing in the winding and thereby reduce the magnetic field.

In the form of coil shown in figure 16, the tracks forming the windings of the sine coil are formed in two parts. The tracks 110 that extend across the sensing area and correspond to the parts of the tracks extending vertically in figure 9 are formed either from thin wires or from ITO and are connected

in parallel to relatively thick, low resistance, wires or busbars 110 and 114 that extend horizontally along the edge of the sensing region. The direction of current flow is indicated by the arrows, so that where the arrow enters the winding where the higher potential (e.g. 5V) is applied and leaves the winding at the lower potential end (e.g. ground). The busbars are typically made using copper or silver-printed connections since they are located in regions along the edge of the sensing area where there is no requirement for optical transparency. A corresponding cosine coil is shown in figure 17. In order to form the sine and cosine coil in the y direction, the windings shown in figures 16 and 17 can simply be rotated by 90°. The effect of this design is to place all the high resistance paths in parallel rather than in series as is the case for the standard design shown in figures 9 and 10 and so the overall resistance of the coil is significantly reduced.

In the extreme case, the different groups of vertical tracks 110 can overlap to become a solid bar, but this does not allow them magnetic field to be manipulated as is often required for an inductive sensor. More importantly, the use of discrete lines of ITO is precisely the type of pattern required by many forms of capacitive sensor, so that by altering the end connections it is possible to combine the inductive and capacitive sensors onto the same optically transparent member. Altering the end connections to switch functionality between the inductive and capacitive sensor is something that can be achieved using standard electronic switches under the action of a microcontroller. Such an arrangement has the advantage that it reduces the component count,

and makes the integration of a capacitive and inductive input device more straightforward. Indeed, similar grid-like patterns may also be required for resistive user interfaces, so that the same design, again with different end connections, can be employed to accommodate a resistive, capacitive and/or inductive interface, or any combination thereof.

If the conductance of the tracks 110 is high, then as the transmitted frequency is increased, more current will tend to flow in those tracks that are near to other tracks in which the current flows in the opposite direction than in tracks that are near to other tracks in which the current flows in the same direction due to the mutual inductance between neighbouring wires. Thus, if two wires run parallel to each other, if one is carrying current, it will induce currents in the other such that the current runs in the opposite direction. In effect, if two parallel wires carry current in the same direction, the mutual inductance adds impedance to both wires, thereby reducing the currents, but if the parallel wires carry current in opposite directions the mutual inductance reduces the impedance of both wires thereby increasing the currents. This effect is more pronounced at higher frequencies and depends on the ratio of the DC resistance to the AC reactance. In addition, capacitive coupling between the wires will smooth out some of this variation.

If discrete tracks are not required to allow combinations of inductive, capacitive and/or resistive sensors, then the use of wide tracks as shown in figure 18 can be advantageous for inductive sensors. As mentioned above, the magnetic fields generated by the currents will act to steer those currents to flow

only in particular parts of the tracks. In fact, for the sine coil winding shown in figure 16, the perpendicular component of the magnetic field generated by just four broad tracks is virtually sinusoidal as a function of position along the measurement axis. This substantially reduces the winding design and significantly reduces the cost of any pcb or other support since it also minimises the numbers of crossovers and vias required, and the tracks do not need to be placed with any great accuracy. In principle, a single-layer pcb using cheap substrates such as CEM rather than the more expensive FR4 can be used with a few jumpers or links to bridge where the tracks cross one another.

Normally, the receive aerial or coil will just be a rectangular design extending around the periphery of the sense region (or the transmit aerial in the case described in U.S. patent No. 5,815,091 where sine and cosine receive coils are used). In order to improve signal quality in a large area application, it may be necessary to divide such a coil into a number of smaller windings, either in overlapping strips or overlapping zones, in which case all the separate windings may be multiplexed together so that each can be interrogated individually. In this way, one winding will normally be closer to the intermediate coupler than the others, so that the signal associated with this winding will be improved and the signal-to-noise ratio of the system will improve.

Figure 19 shows an example of an electronic device that is in the form of a laptop computer having a body 118 and a lid 120 that is connected to the body by means of a hinge and which may be opened and closed simply by swinging the lid up and down. The main body

of the computer may include a keyboard 119 in conventional manner and the lid 120 is provided with a screen 16. In addition, a pair of inductive position sensors 122 and 124 are provided, one sensor 122 located in the plane of the body of the laptop and the other position sensor 124 provided in the plane of the lid. At least one of the inductive position sensors will be a two-dimensional position sensor, while the other position sensor may be either a one dimensional position sensor arranged so that it can detect position of an intermediate coupler in the y direction (i.e. in a direction toward or away from the hinge connecting the body and the lid). In this way, if an object 22 such as a pen that contains an intermediate coupler is included, and the lid of the device is opened so that the plane of the lid is perpendicular to the plane of the body, the two inductive position sensors can determine the position of the object 22 (or more accurately, the position of the intermediate coupler in the object) in three dimensions.

It is possible to employ two-dimensional inductive position sensors in both the body of the device and the lid, which will give four positional readings, one of which will be redundant. Thus, one of the aeriels may be discarded or it can be used as a cross-check, or alternatively it can be used to verify that the lid has been correctly opened and aligned. It is advantageous to employ some means, normally mechanical, to ensure that the sensors in the lid and the body are oriented perpendicularly to each other, for example by providing a detent or by limiting movement of the hinge. Alternatively, the angle between the moving lid and the body can be measured by another sensor and the tilt of the lid can be

compensated for.

Alternatively, one or more inductive position sensors of the type that can detect the position of the intermediate coupler normal to the plane of the sensor, for example as described in international application No. WO 2005/055426, the disclosure of which is incorporated herein by reference, may be incorporated in the two-dimensional sensor. In this way, it is possible to dispense with one of the sensors 122 and 124, and to include all the sensors in a single pad and still obtain a three dimensional position of the intermediate coupler.

Such a device may include a capacitive position sensor, or the capacitive position sensor may be absent.

It is possible to extend such a device to one that can obtain information about the position of the intermediate coupler or object in which it is located in six dimensions, that is to say to measure its position in three Cartesian coordinates, and also to measure its orientation in three coordinates (pitch, roll and yaw). This may, for example, be achieved by incorporating two intermediate couplers at opposite end regions of a linear object as shown in figure 20. In this arrangement a pair of intermediate couplers 28 located at opposite ends of a pointer or other linear object and separated by a know distance are tuned to different frequencies so that six positional measurements of the intermediate couplers can be converted into a position in three directions and three orientation measurements.

Alternatively, three intermediate couplers may be located in an object and tuned to different frequencies. If each coupler is measured in two

dimensions, six measurements are obtained which can be converted into the required position and orientation measurements.

5 This arrangement may be employed where the linear object takes the form of a pen that is grasped in the user's hand and is used for writing or pointing. One problem with forming a pen with an intermediate coupler for an inductive sensor is that as the pen tilts, the coil within it moves across the sensing
10 region with the result that the position at which the coil reports it to be is not necessarily the same as the position at which the tip of the pen is located. To compensate for this it may be necessary to incorporate two intermediate couplers in the pen, one
15 displaced along the length of the pen with respect to the other so that the degree of tilt of the pen can be determined by the difference in apparent position between the two intermediate couplers. This tilt determination can be used to compensate for any
20 positional inaccuracies in reporting the tip position due to the tilt. Tilt can cause other positional problems, in that a clockwise rotation of the pen means that the pen actually appears to have moved to the left. This is explained by considering that for a
25 pen in the centre of the sensing zone, if it is vertical then it may receive no signal from the sine coil, while if it tilts clockwise then it may pick up flux emanating from the left-hand sine lobe. Hence a pen rotated in the clockwise direction may appear to
30 have moved to the left, but if the tilt is about the tip of the pen a clockwise tilt actually moves the coil to the right. Therefore, if the intermediate coupler is low in the pen the effect of tilt is to move the apparent position of the pen to the left, but

if the intermediate coupler is high in the pen the lateral movement dominates and the apparent position of the pen moves to the right. Between these two extremes is an optimal position where the effect of tilting of the pen is minimised.

Such forms of arrangement may also be employed in other equipment where the position and orientation of the object is required to be known, for example in games where the linear object may represent a gun or telescope or golf club, or in sensing equipment for determining posture, for example for practising golf swings, or orthopaedics.

The arrangement and device according to the present invention may be combined with other sensing technologies, not only capacitive but also resistive, optical, acoustic, surface wave, ultrasonic, magnetic and the like. One drawback of inductive pens is that the pen is bespoke and requires an inductive coupler, whereas technologies such as capacitive sensing can be activated by a finger and resistive techniques can be activated by any pointed implement. The advantage of an inductive sensor is that it can allow both menu-driven inputs or character input.

Claims:

1. A navigation arrangement for an electronic device that includes a screen, the arrangement comprising:

5 (i) a two-dimensional capacitive position sensor that can be located over a screen of the device, and which can detect the position of an object with respect to the screen, the capacitive position sensor having a substantially transparent region
10 located over the screen to enable a user to view the screen, and

(ii) a two-dimensional inductive position sensor for detecting the position of an intermediate coupler with respect to the screen, the inductive
15 position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and sent from the transmit aerial to the receive
20 aerial via the intermediate coupler is induced, the received signal varying in dependence on the position of the intermediate coupler, the inductive position sensor also having a substantially transparent region located over the
25 screen to enable a user to view the screen.

2. An arrangement as claimed in claim 1, wherein the capacitive position sensor comprises a one or more transparent supports on which are located a plurality
30 of transparent conductive tracks or regions.

3. An arrangement as claimed in claim 2, wherein the capacitive position sensor is arranged so that different combinations of tracks exhibit mutual
35 capacitive coupling that is affected by the proximity

of the object whose position is to be detected.

4. An arrangement as claimed in claim 2 or claim 3,
wherein the conductive tracks or regions are formed
from indium tin oxide.

5. An arrangement as claimed in any one of claims 1
to 4, wherein at least one of the transmit aerial and
the receive aerial of the inductive position sensor is
located on a side of the screen that in use faces away
from the user.

6. An arrangement as claimed in claim 5, wherein the
capacitive position sensor is arranged in use to be
positioned between the screen and the user.

7. An arrangement as claimed in any one of claims 1
to 5, wherein at least one of the transmit aerial and
the receive aerial is arranged to be located in use
over the surface of the screen and is formed from a
plurality of substantially transparent electrically
conductive tracks.

8. An arrangement as claimed in claim 7, wherein any
aerial that is arranged to be located in use over the
surface of the screen comprises tracks that are
sufficiently fine that they are not noticed by a user.

9. An arrangement as claimed in claim 7, wherein any
aerial that is arranged to be located in use over the
surface of the screen comprises tracks that are formed
from a transparent conductor.

10. An arrangement as claimed in claim 8, wherein the
transparent conductor comprises indium tin oxide.

11. An arrangement as claimed in claim 7, wherein the electrically conductive tracks are connected in parallel with one another by means of one or more conductors of relatively low resistance that are arranged at the edge of the screen.

12. A navigation arrangement for an electronic device that includes a screen, the arrangement comprising a two-dimensional inductive position sensor for detecting the position of an intermediate coupler with respect to the screen, the inductive position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and sent from the transmit aerial to the receive aerial via the intermediate coupler is induced, the received signal varying in dependence on the position of the intermediate coupler, the transmit aerial and/or the receive aerial being arranged to be located over the surface of the screen and being formed from a plurality of substantially transparent electrically conductive tracks that enable a user to view the screen, wherein at least some of the electrically conductive tracks in the transmit aerial and/or the receive aerial are connected in parallel with one another by means of one or more conductors of relatively low resistance that are arranged in the region of the edge of the screen so that the view of the screen by the user is not obstructed.

13. An arrangement as claimed in any one of claims 1 to 6, wherein at least one of the transmit and/or receive aerial is arranged to be located around the periphery of the screen so that the view of the screen

by the user is unobstructed.

14. A navigation arrangement for an electronic device that includes a screen, the arrangement comprising a two-dimensional inductive position sensor for detecting the position of an intermediate coupler with respect to the screen, the inductive position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and sent from the transmit aerial to the receive aerial via the intermediate coupler is induced, the received signal varying in dependence on the position of the intermediate coupler, wherein the transmit aerial and/or the receive aerial are formed from a plurality of electrically conductive tracks that are located around the periphery of the screen so that the view of the screen by the user is unobstructed.

15. An arrangement as claimed in any one of claims 1 to 6 or 14, wherein at least one of the transmit and/or receive aerial is formed in a plurality of separate parts, the parts arranged to be located at the periphery of the screen so that the view of screen by the user is unobstructed.

16. An arrangement as claimed in any one of claims 1 to 15, which includes a plurality of transmit aerials and/or receive aerials so that the arrangement can detect movement of the intermediate coupler in two orthogonal directions in the plane of the screen,

17. An arrangement as claimed in claim 16, wherein each transmit aerial comprises a pair of loops formed

from conductive tracks, one coil having a generally sinusoidal shape and the other coil having a generally cosinusoidal shape and arranged spatially in quadrature with one another.

5

18. An arrangement as claimed in claim 16, wherein the or each receive aerial comprises a loop formed from a conductive track which extends around the periphery of the transmit aerial.

10

19. An arrangement as claimed in claim 14, wherein each receive aerial comprises a pair of coils formed from conductive tracks, one coil having a generally sinusoidal shape and the other having a generally cosinusoidal shape and arranged spatially in quadrature with one another.

15

20. An arrangement as claimed in claim 19, wherein the or each transmit aerial comprises a coil formed from a conductive track which extends around the periphery of the receive aerial.

20

21. An arrangement as claimed in claim 16, wherein each transmit aerial and/or each receive aerial is in the form of an array of coils that are located at defined positions along the screen, and the coordinate values of the position of the intermediate coupler can be determined from the amplitude of the signal received in different loops of the receive aerial.

25

30

22. An electronic device that includes a screen and an arrangement as claimed in any one of claims 1 to 21.

35

23. An arrangement as claimed in any one of claims 1

to 21 which includes means for attaching it to an electronic device that includes a screen.

24. An electronic device as claimed in claim 22,
5 which includes a further inductive sensor that is located in a plane oriented at an angle to the plane of the screen, the further inductive sensor being capable of detecting the position of an intermediate coupler at least in a direction toward and away from
10 the screen so that the two-dimensional inductive sensor and the further inductive sensor together can determine the position of the intermediate coupler in three coordinate directions.

25. A device as claimed in claim 24, wherein the further inductive sensor is capable of detecting the position of an intermediate coupler in two dimensions.

26. An arrangement as claimed in any one of claims 1
20 to 23, which includes the intermediate coupler.

27. An arrangement as claimed in claim 26, wherein the intermediate coupler forms part of a manually operable element that includes at least two such
25 identical or non-identical intermediate couplers, and the arrangement is operable to determine the orientation of the manually operable element with respect to the device by determining the position of each intermediate coupler from the device.

28. A device as claimed in claim 24 or claim 25 that
30 comprises a pair of articulated parts that can be moved from a closed position to an open position in which the two dimensional inductive sensor and the
35 further inductive sensor are arranged in planes

oriented at an angle to one another.

29. A device as claimed in claim 28, which includes means for ensuring correct orientation of the two dimensional inductive sensor and the further inductive sensor.

30. A device as claimed in claim 24, 25 or 27, wherein the plane of the two dimensional inductive sensor and the further inductive sensor are oriented substantially perpendicularly with respect to one another.

31. An arrangement as claimed in claim 26, wherein the intermediate coupler comprises a passive resonant circuit or a non-resonant element.

32. A device for detecting the position of an object in three dimensions, which comprises:

- (i) a planar two-dimensional inductive position sensor for detecting the position of an intermediate coupler located in the object in two directions in the plane of the position sensor, the inductive position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and is sent from the transmit aerial to the receive aerial via the intermediate coupler is induced, the received signal varying in dependence on the position of the intermediate coupler in the two directions; and
- (ii) a detector for detecting the position of the object in a direction normal to the two-dimensional position sensor by sensing the

amplitude of the received signal.

33. A device for detecting the position of an object in three dimensions, which comprises:

- 5 (i) a planar two-dimensional inductive position sensor for detecting the position of an intermediate coupler located in the object in two directions in the plane of the position sensor, the inductive position sensor comprising a
10 transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and is sent from the transmit aerial to the receive aerial via the intermediate
15 coupler is induced, the received signal varying in dependence on the position of the intermediate coupler in the two directions; and
(ii) a further inductive position sensor for detecting the position of the intermediate coupler in a
20 third direction that is normal to the plane of the two-dimensional inductive position sensor.

34. An arrangement for detecting the position of a movable object in three dimensions, which comprises:

- 25 (i) a static device that includes a planar two-dimensional inductive position sensor for detecting the position of an intermediate coupler located in the object in two directions in the plane of the position sensor, the inductive
30 position sensor comprising a transmit aerial for transmitting a signal, and a receive aerial in which a received signal that originates from the signal transmitted by the transmit aerial and is sent from the transmit aerial to the receive
35 aerial via the intermediate coupler is induced,

the received signal varying in dependence on the position of the intermediate coupler in the two directions; and

(ii) the movable object; wherein the object also includes means for communicating with the static device so that the static device can determine the position of the movable object with respect to the inductive position sensor.

35. An arrangement as claimed in claim 34, wherein the means for communicating comprises a device for sending a beam of electromagnetic radiation or an acoustic signal.

36. An arrangement as claimed in claim 34 or claim 35, wherein the static device is operative to determine the position of the object by triangulation.

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FIG. 1A

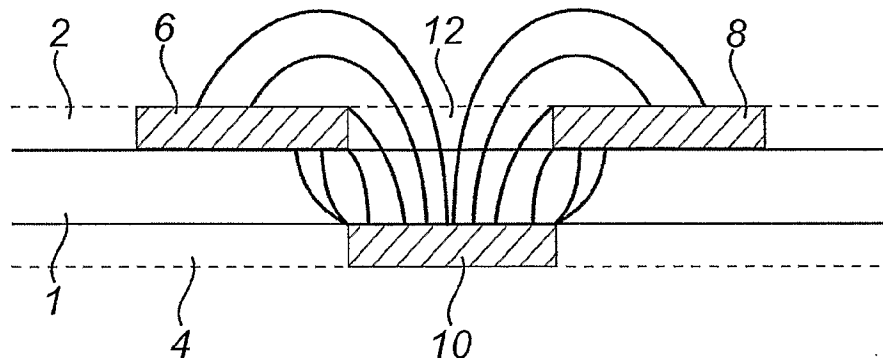
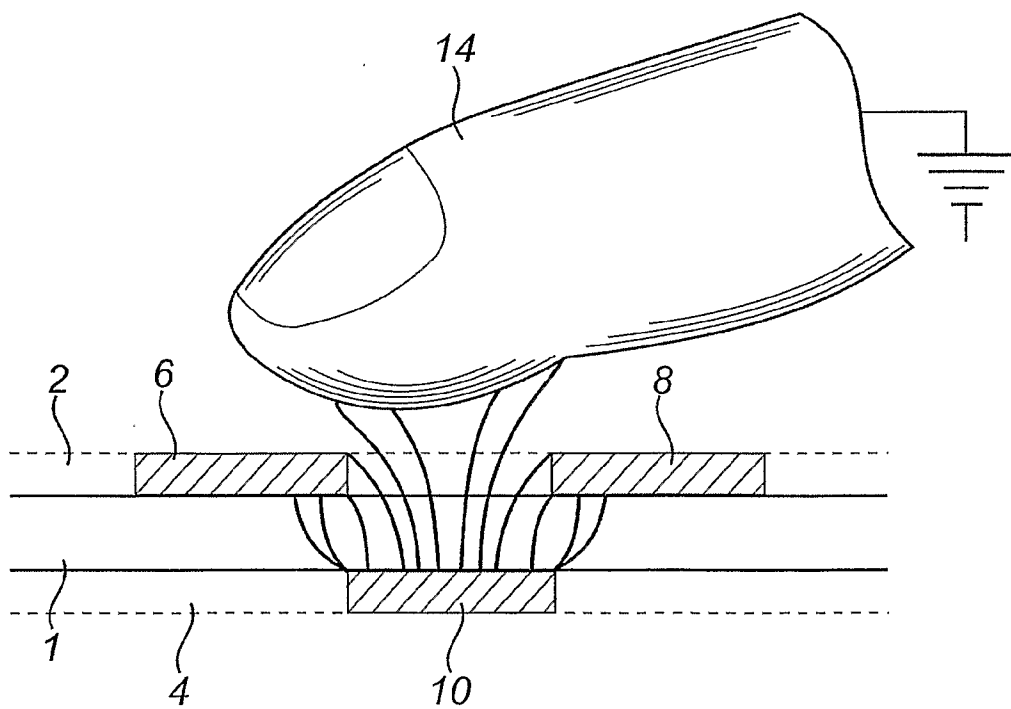
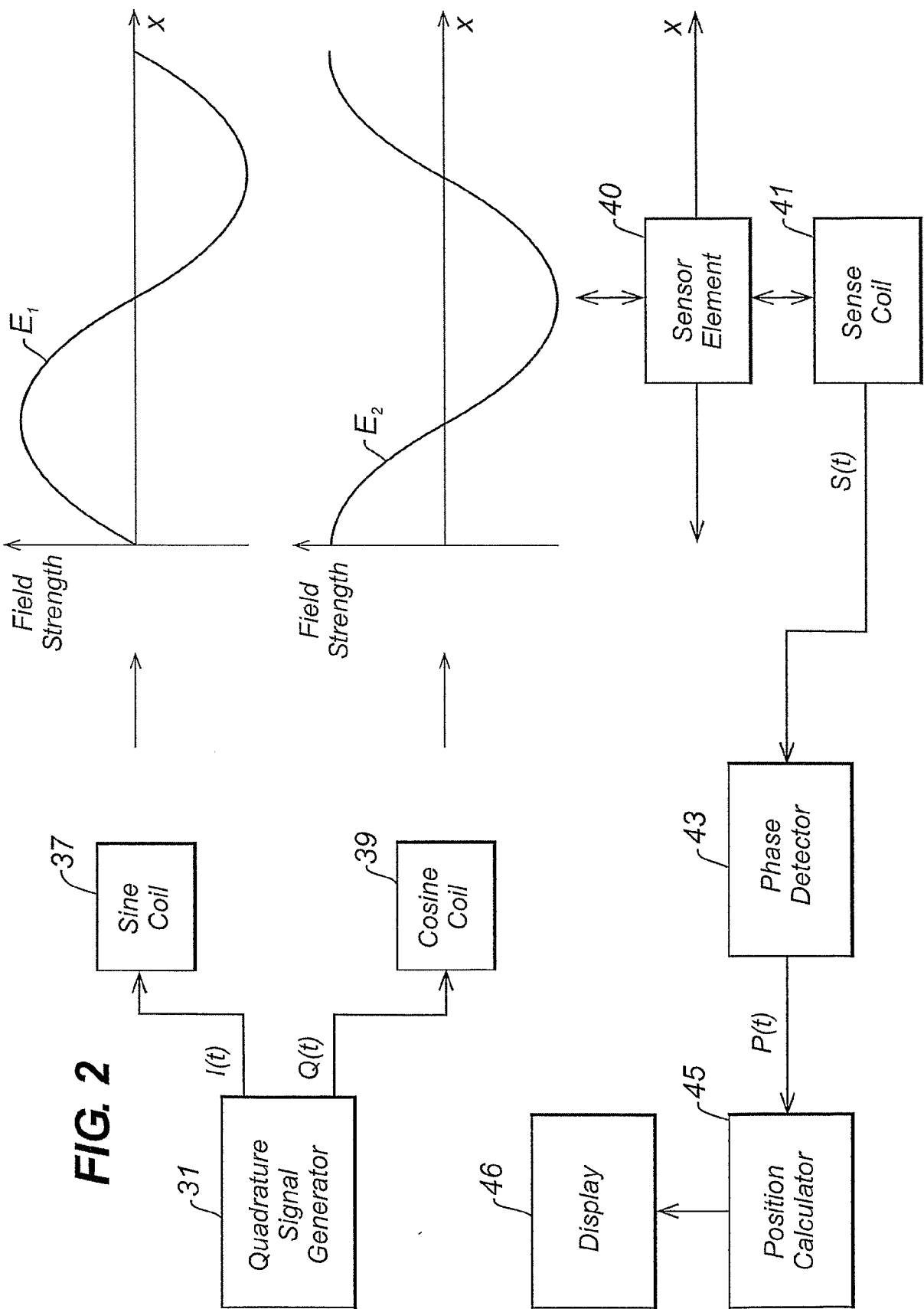


FIG. 1B





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FIG. 3A

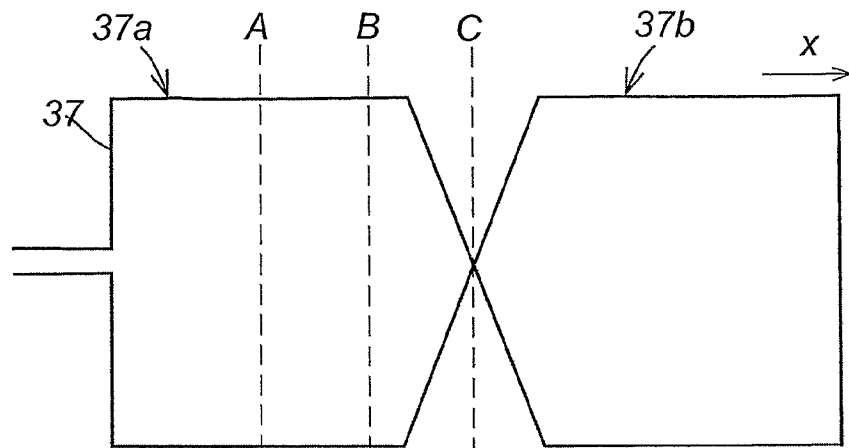


FIG. 3B

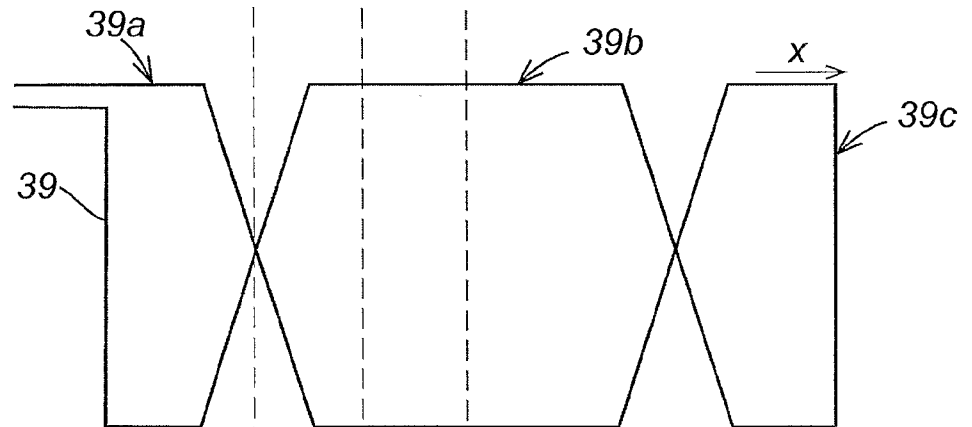
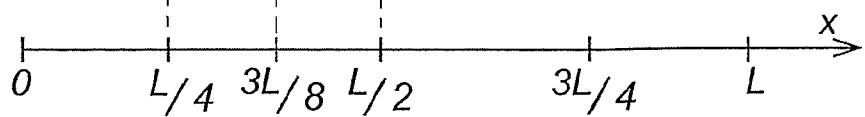
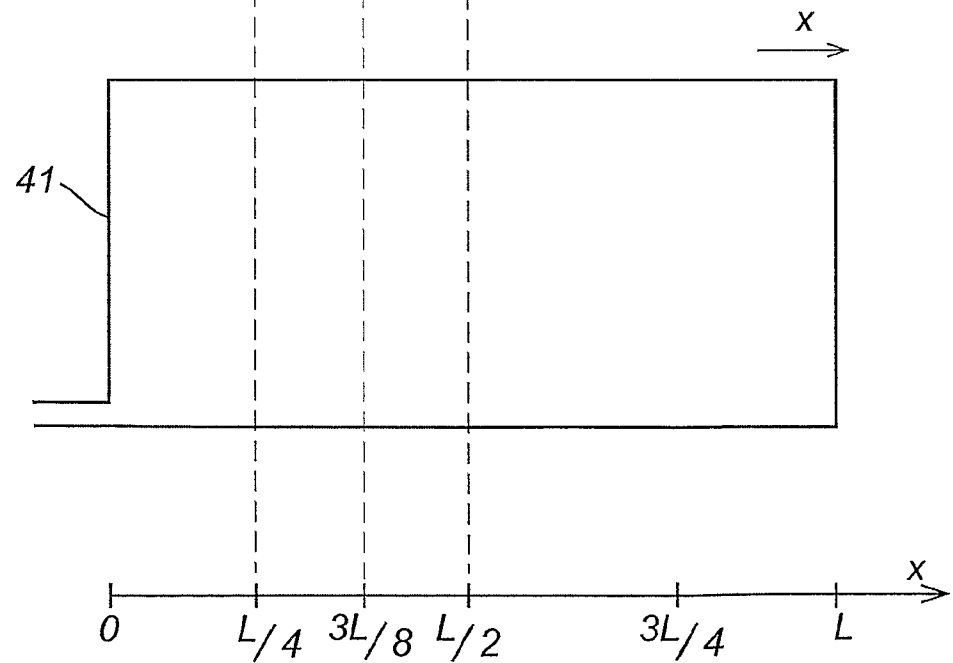
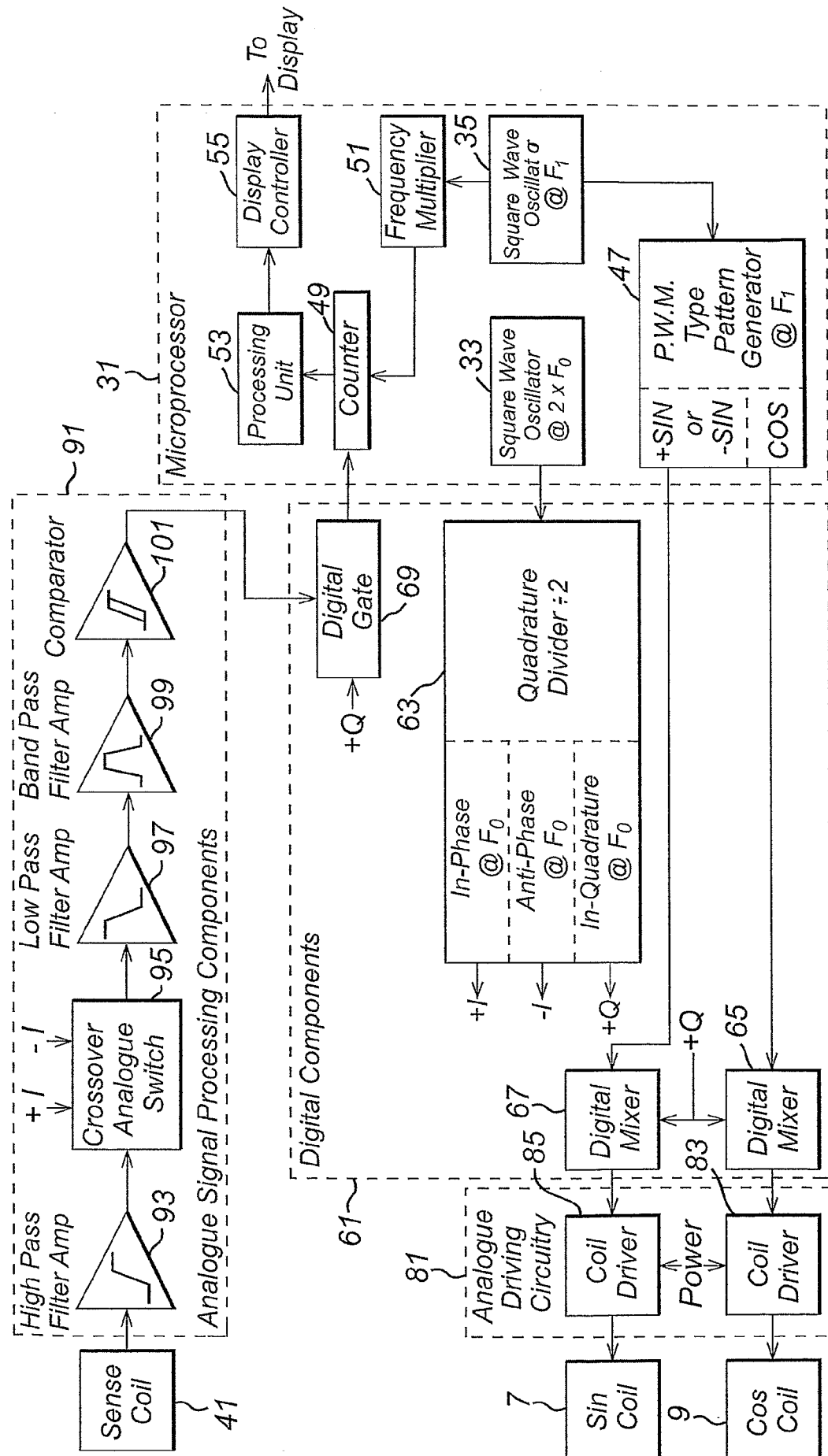


FIG. 3C



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FIG. 4



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FIG. 5

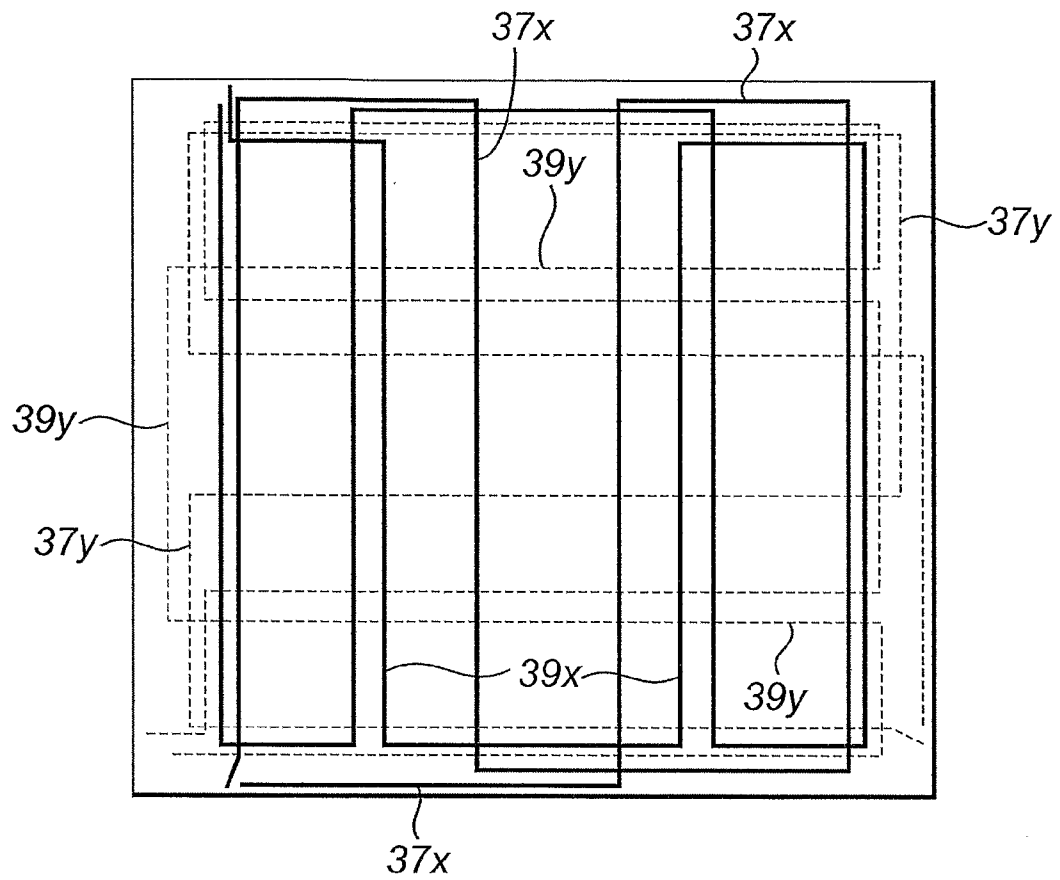
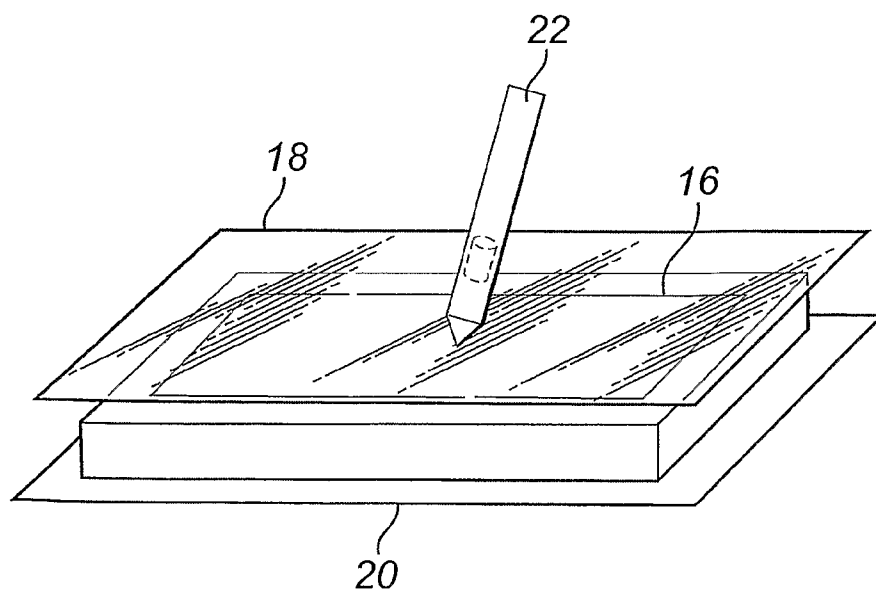


FIG. 6



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FIG. 7

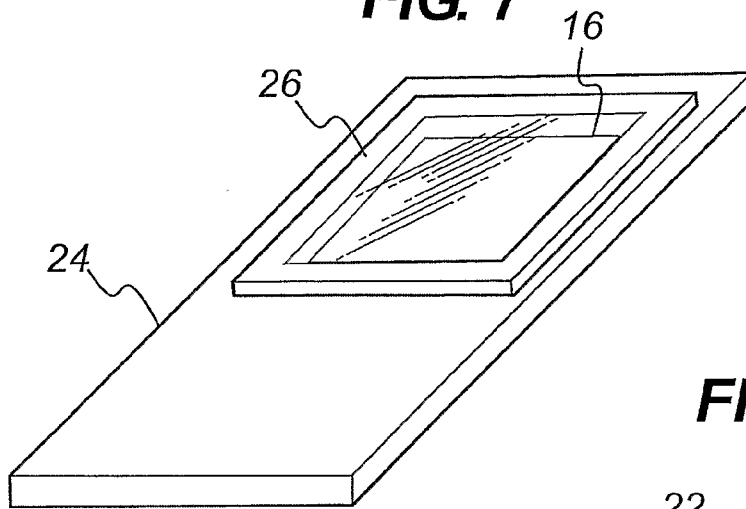


FIG. 8

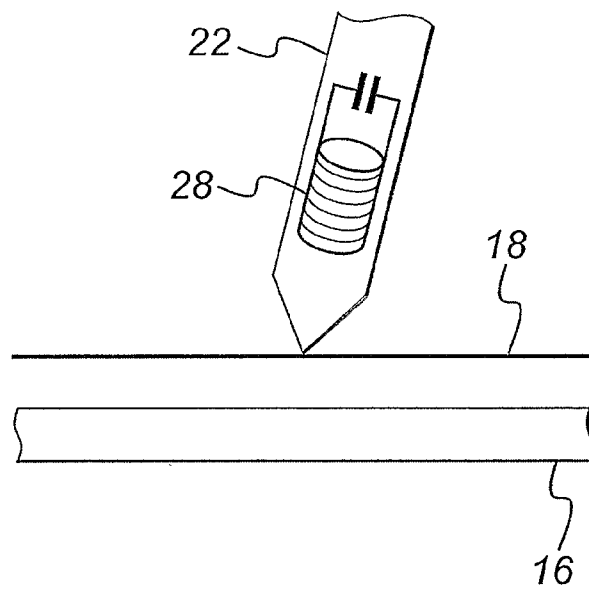
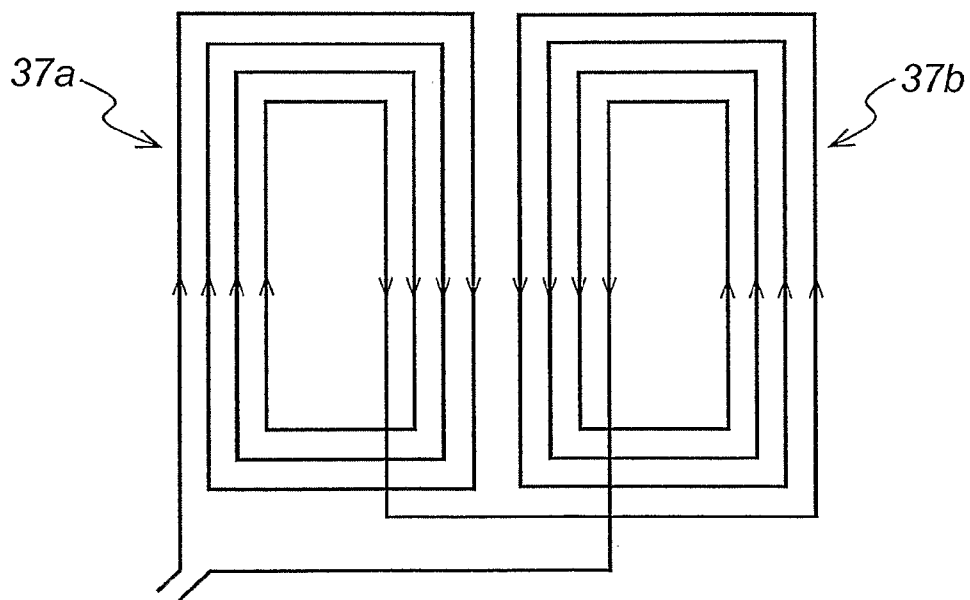
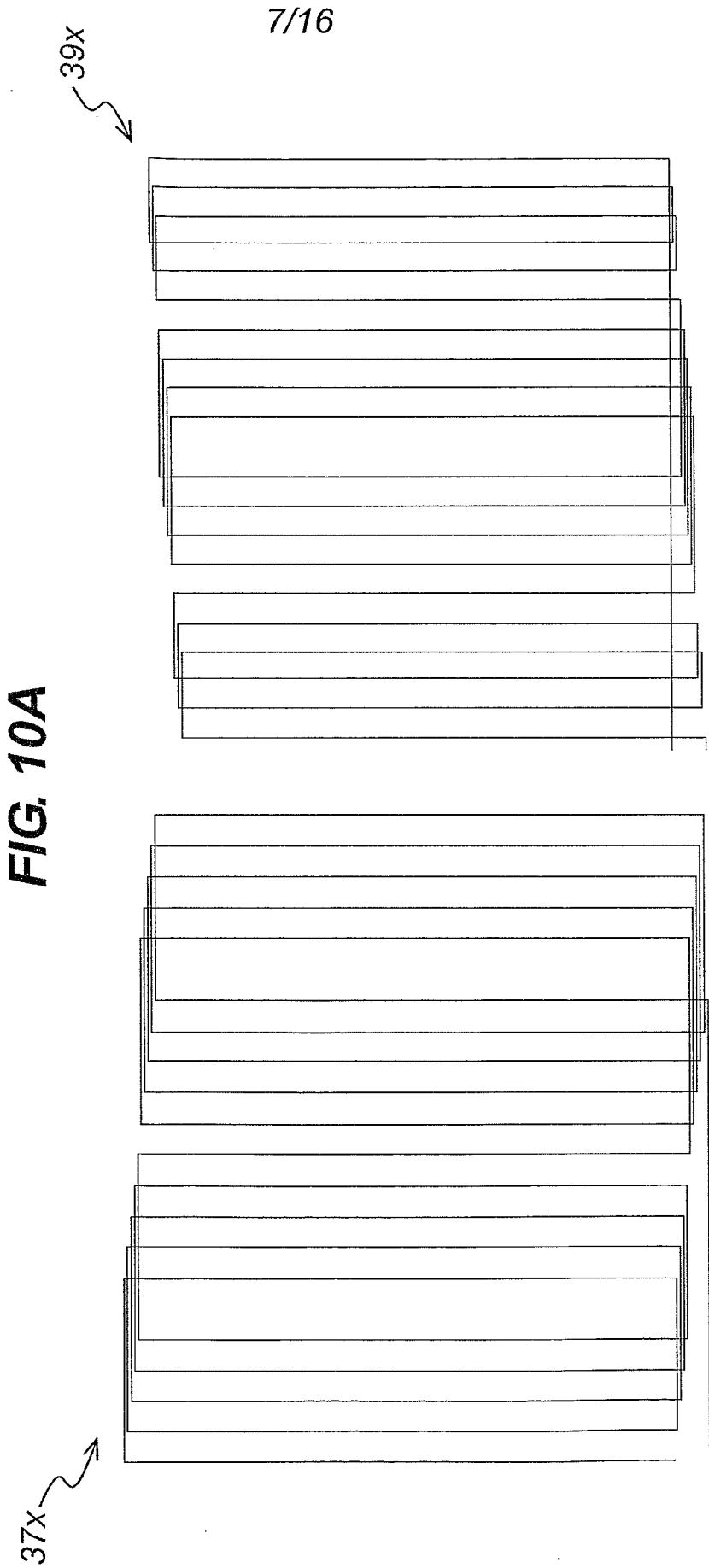


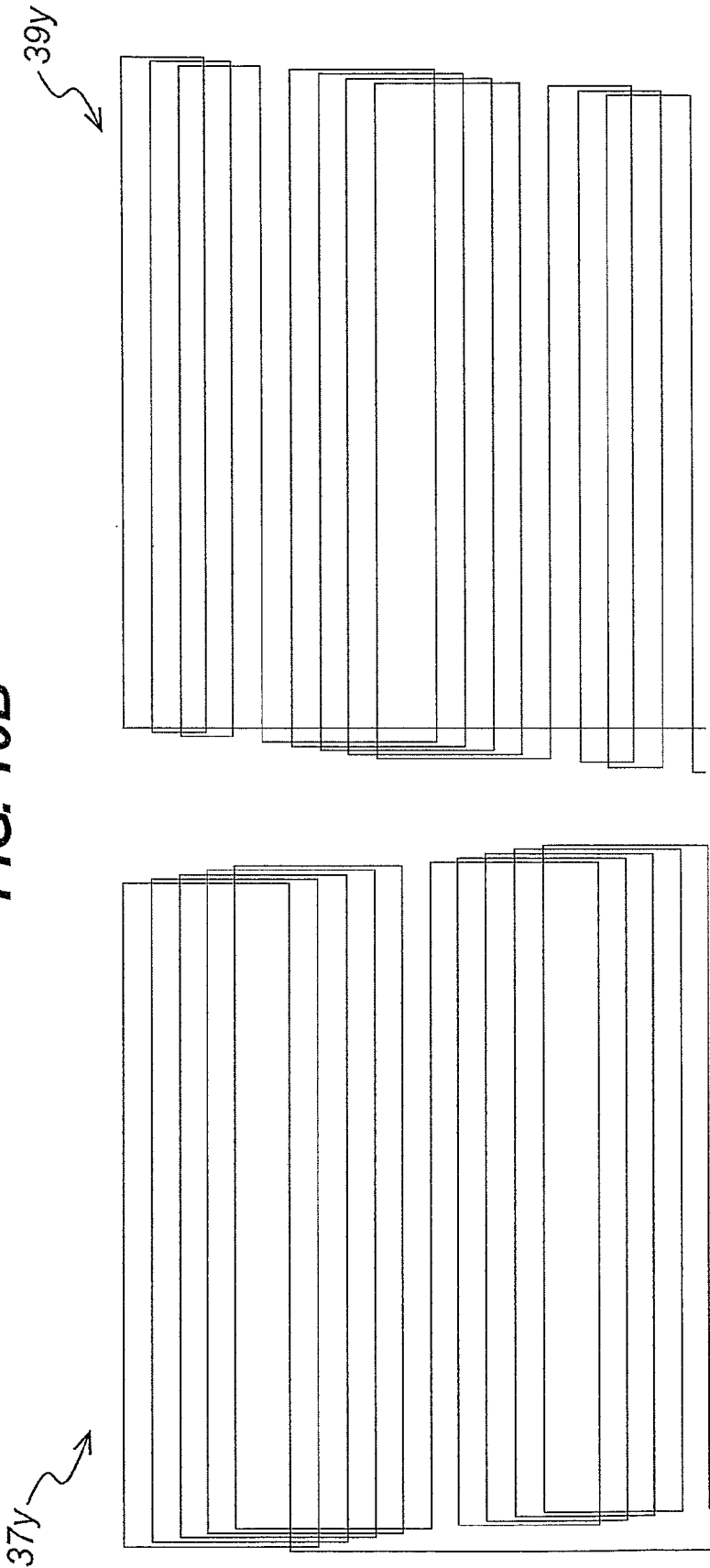
FIG. 9





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FIG. 10B



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FIG. 10C

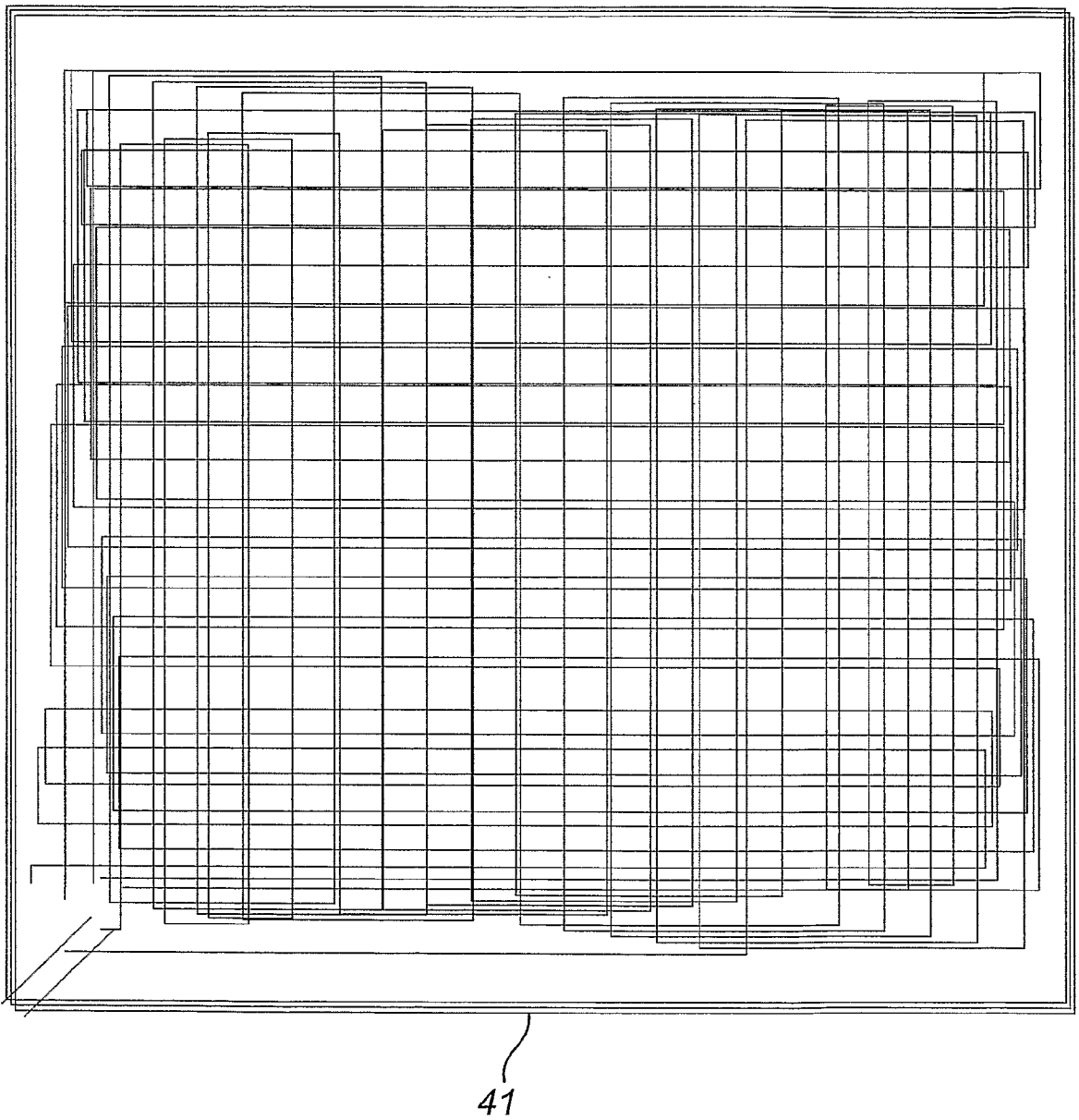


FIG. 11A

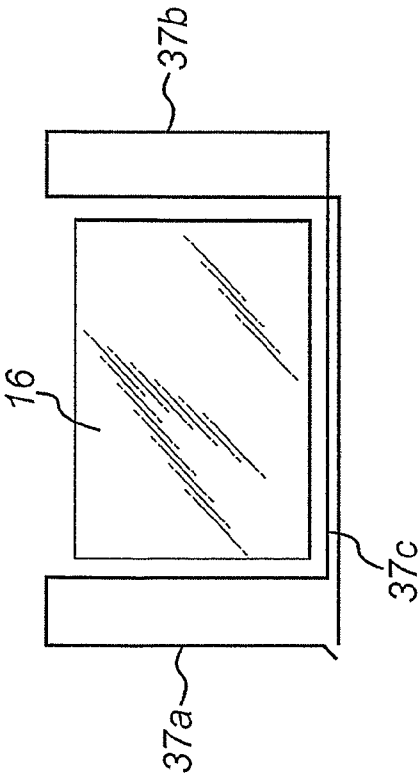


FIG. 11B

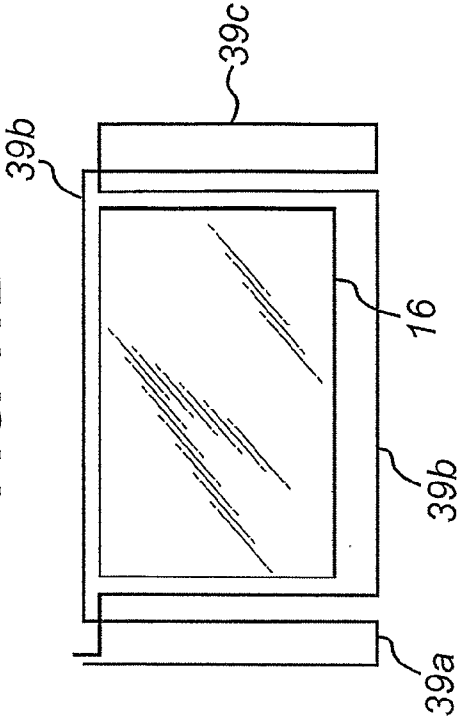
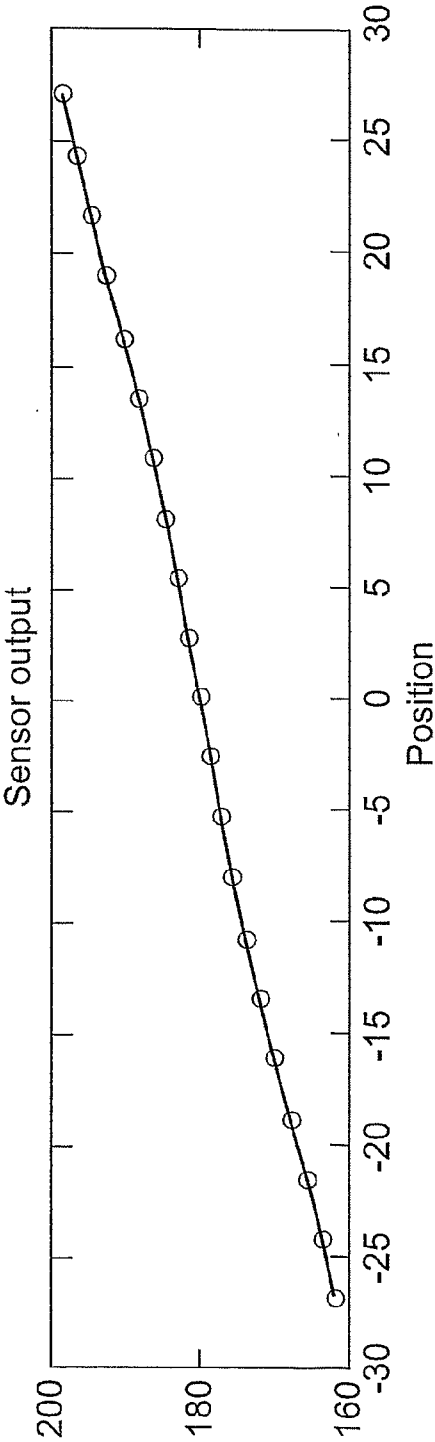
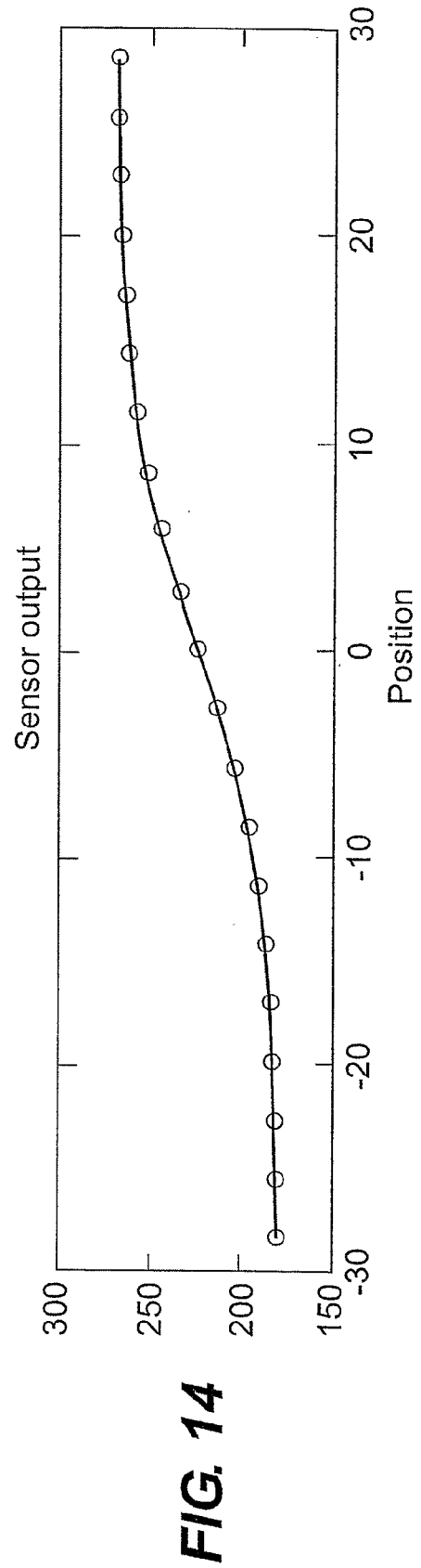
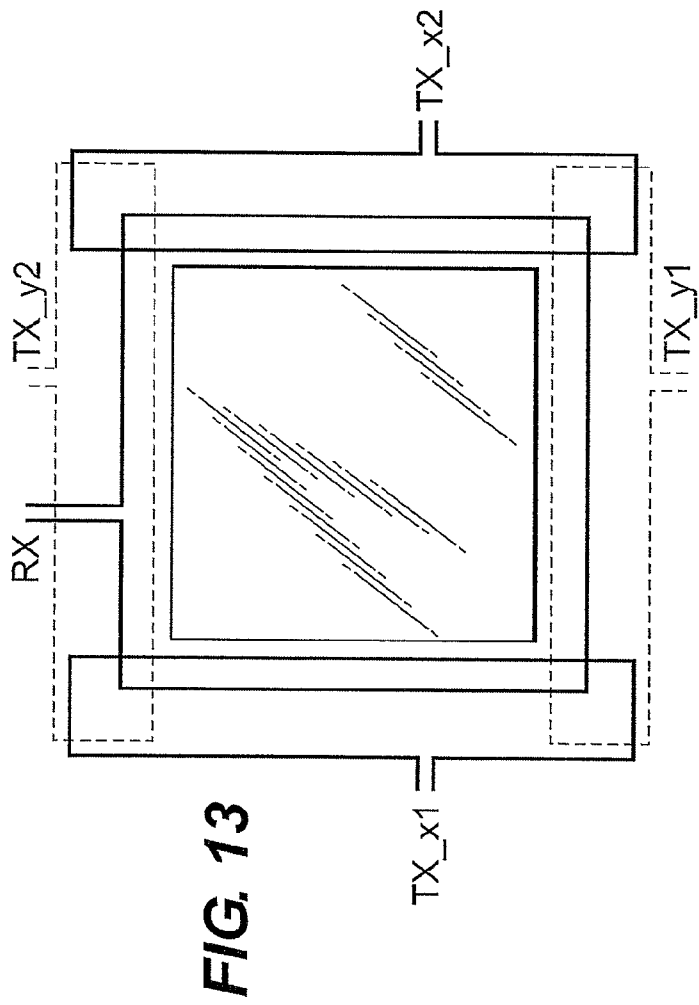


FIG. 12





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FIG. 15A

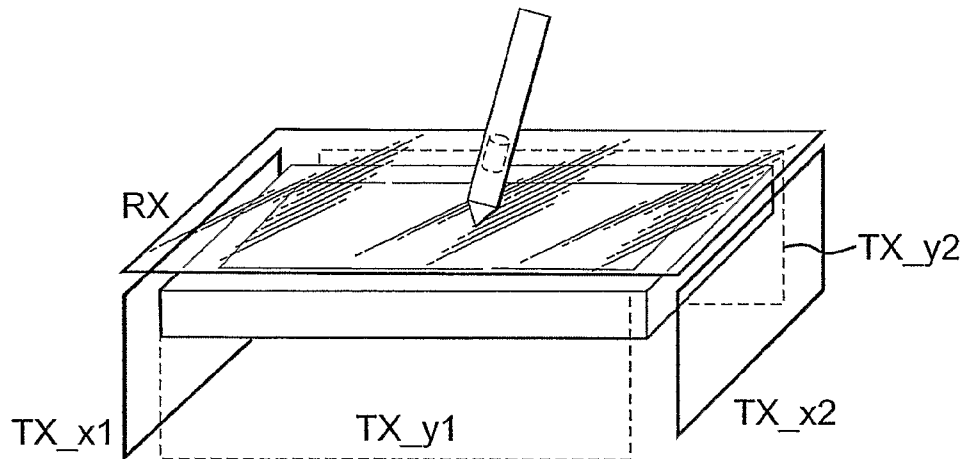
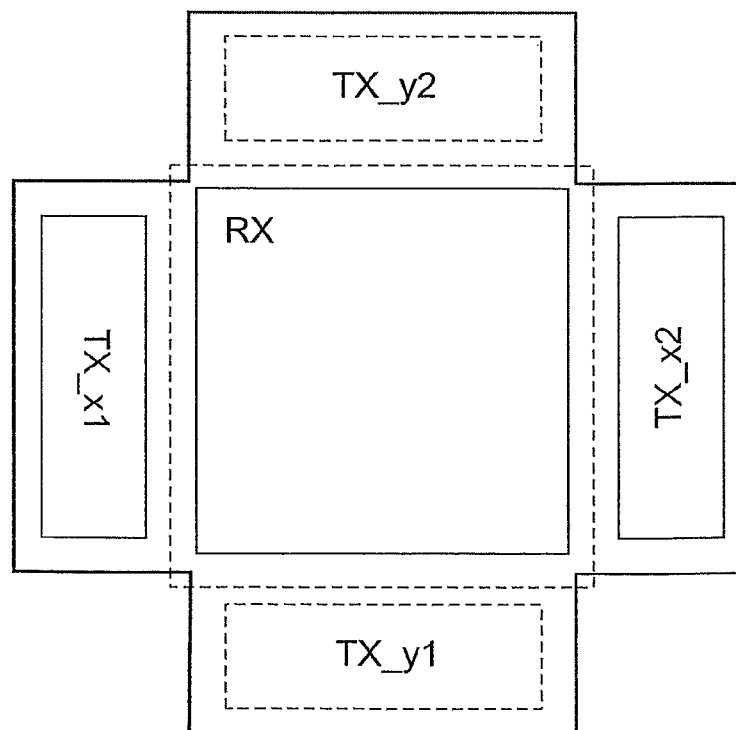


FIG. 15B



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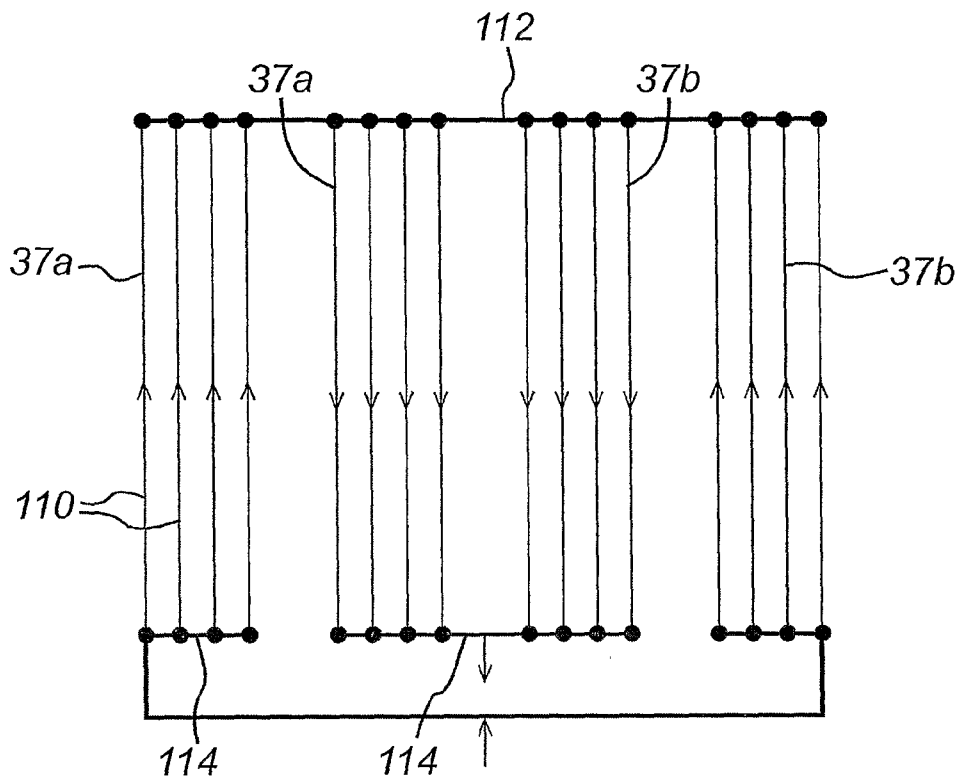
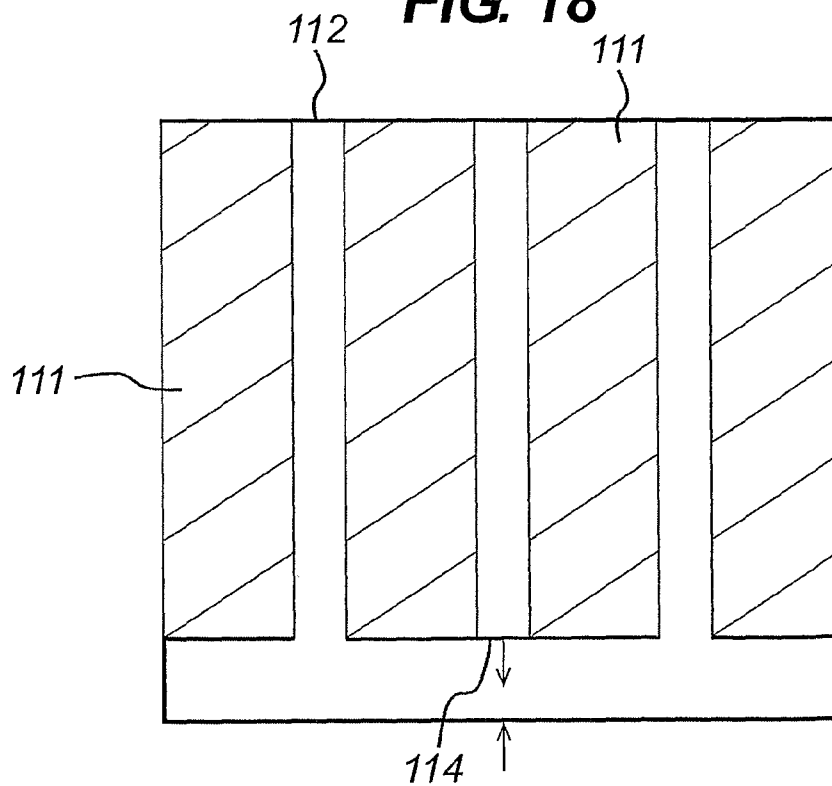
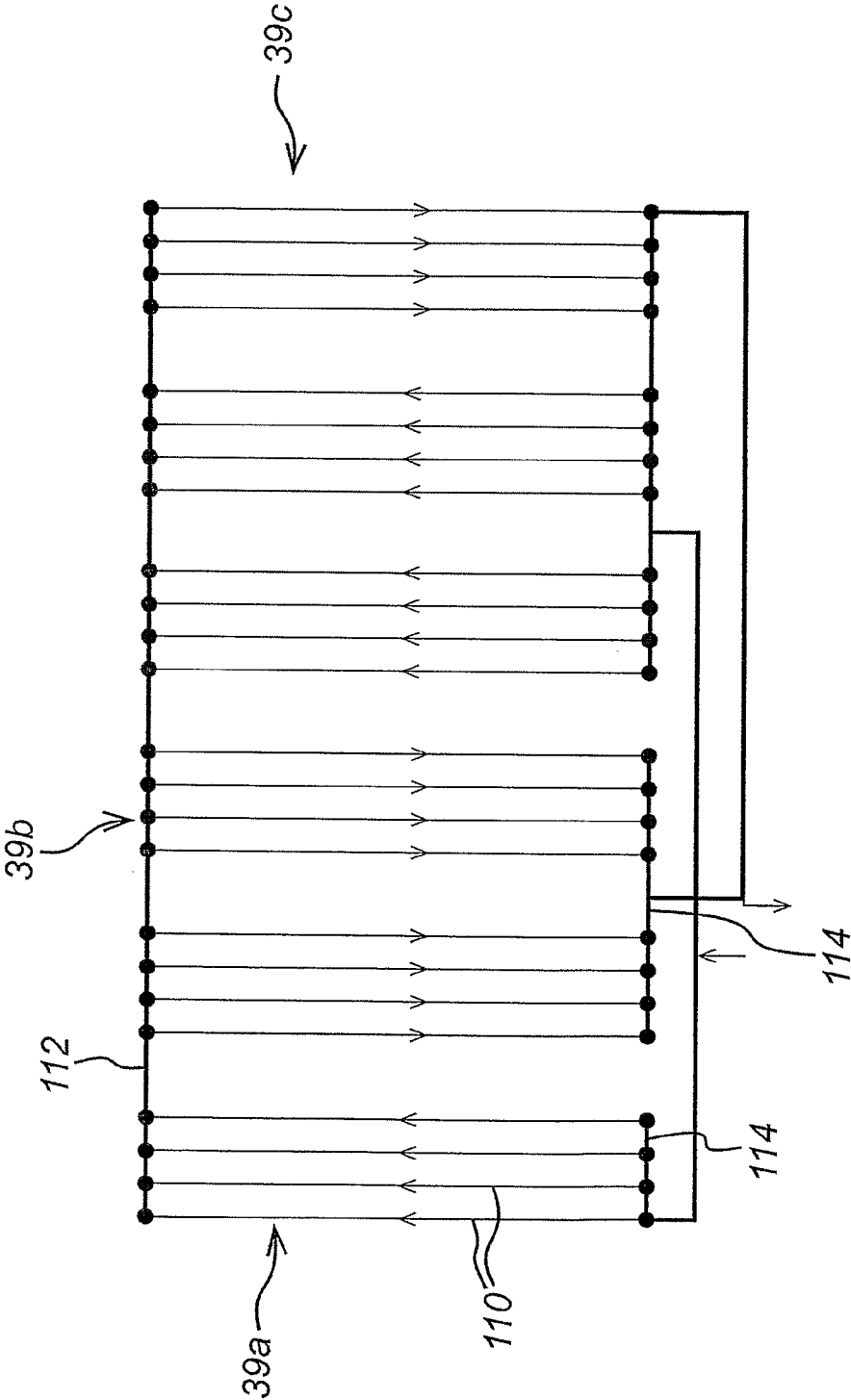
FIG. 16**FIG. 18**

FIG. 17



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FIG. 19

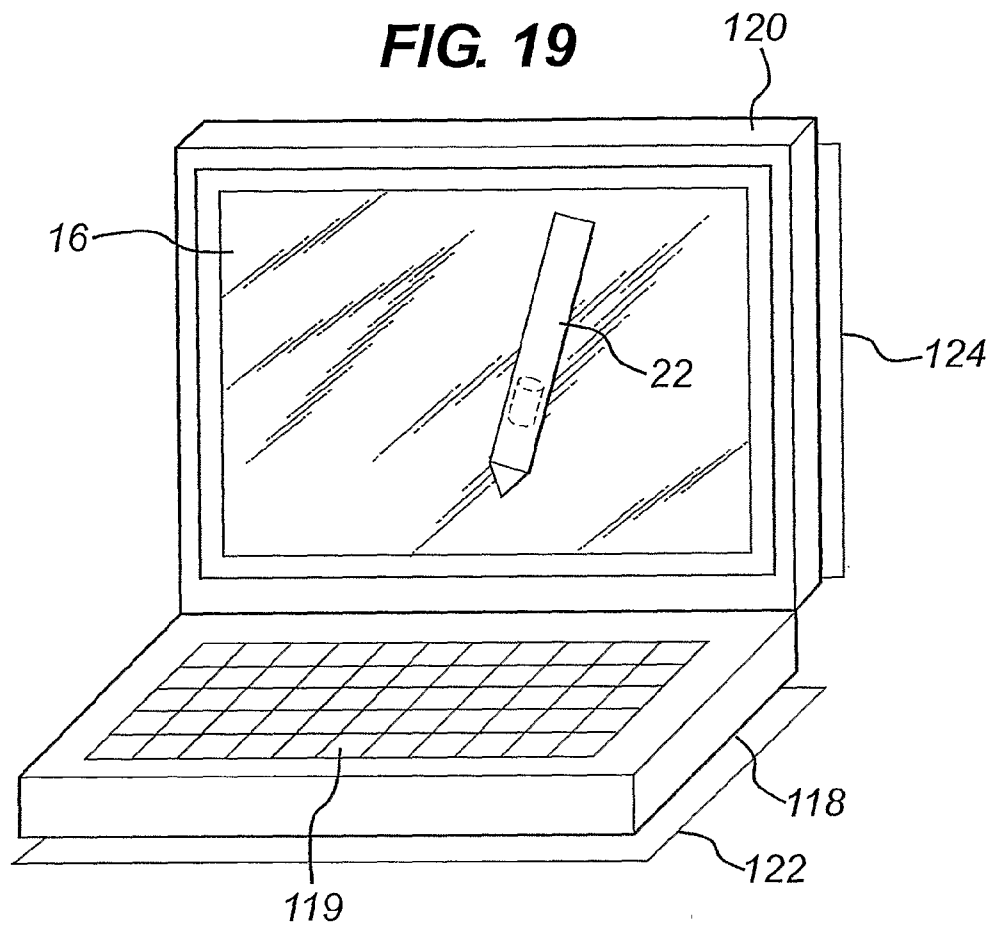


FIG. 20

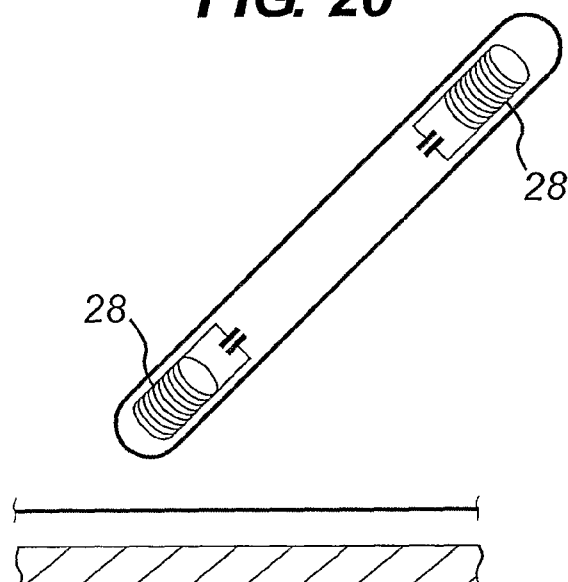


FIG. 21

