

GESTURE-RESPONSIVE USER INTERFACE FOR AN ELECTRONIC DEVICE HAVING A COLOR CODED 3D SPACE

CROSS-REFERENCE TO RELATED APPLICATIONS

5 **[0001]** This application claims priority to U.S. Patent Application No. 13/308,263, filed on November 30, 2011 and entitled "GESTURE-RESPONSIVE USER INTERFACE FOR AN ELECTRONIC DEVICE HAVING A COLOR CODED 3D SPACE" (Attorney Docket QUALP075/ 103283), which is hereby incorporated by
10 reference in its entirety and for all purposes.

TECHNICAL FIELD

[0002] This disclosure relates to techniques for gesture recognition, and, more specifically, to an interactive display having a color coded 3-D space for providing a
15 user input/output interface controlled responsively to a user's gestures

DESCRIPTION OF THE RELATED TECHNOLOGY

[0003] Electromechanical systems (EMS) include devices having electrical and mechanical elements, actuators, transducers, sensors, optical components (such as
20 mirrors and optical film layers) and electronics. Electromechanical systems can be manufactured at a variety of scales including, but not limited to, microscales and nanoscales. For example, microelectromechanical systems (MEMS) devices can include structures having sizes ranging from about a micron to hundreds of microns or more. Nanoelectromechanical systems (NEMS) devices can include structures having
25 sizes smaller than a micron including, for example, sizes smaller than several hundred nanometers. Electromechanical elements may be created using deposition, etching, lithography, and/or other micromachining processes that etch away parts of substrates and/or deposited material layers, or that add layers to form electrical and electromechanical devices.

30 **[0004]** One type of electromechanical systems device is called an interferometric modulator (IMOD). As used herein, the term interferometric modulator or interferometric light modulator refers to a device that selectively absorbs and/or reflects light using the principles of optical interference. In some implementations, an interferometric modulator may include a pair of conductive plates, one or both of

which may be transparent and/or reflective, wholly or in part, and capable of relative motion upon application of an appropriate electrical signal. In an implementation, one plate may include a stationary layer deposited on a substrate and the other plate may include a reflective membrane separated from the stationary layer by an air gap.

5 The position of one plate in relation to another can change the optical interference of light incident on the interferometric modulator. Interferometric modulator devices have a wide range of applications, and are anticipated to be used in improving existing products and creating new products, especially those with display capabilities, such as personal computers and per personal electronic devices (PED's).

10 **[0005]** Increasingly, electronic devices such as personal computers and PED's provide for at least some user inputs to be provided by means other than physical buttons, keyboards, and point and click devices. For example, touchscreen displays are increasingly relied upon for common user input functions. Touchscreen displays such as resistive and capacitive "electronic-touch" touchscreens generally employ
15 transparent layers of indium tin oxide (ITO) stacked together and separated by a thin space. The ITO layers are relatively costly, tend to degrade screen clarity, and have poor durability. Electronic-touch devices commonly employ an embedded "grid" of thin electrodes that, while normally invisible to the naked eye, do noticeably reduce the brightness, contrast of the screen and may induce visually noticeable artifacts in
20 displayed image. Moreover, the display quality of touchscreen displays can be degraded by contamination from a user's touch. Finally, when the user's interaction with the device must be limited to a two dimensional space, as is normally the case with touchscreen displays, of, at least, PEDs, the user's input (touch) may be required to be very precisely located in order to achieve a desired result. This results in
25 slowing down or otherwise impairing the user's ability to interact with the device.

[0006] Accordingly, it is desirable to have an optical-touch interface that avoids the need for ITO layer while also being responsive, at least in part, to "gestures" by which is meant, the electronic device senses and reacts in a deterministic way to gross motions of a user's hand, digit, or an object worn or held by the user. The gestures
30 may be made proximate to, but, advantageously, not in direct physical contact with the electronic device. Known gesture responsive devices are bulky, expensive and power intensive, making them unsuitable for many electronic devices, particularly portable ones.

SUMMARY

[0007] The systems, methods and devices of the disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

5 [0008] One innovative aspect of the subject matter described in this disclosure includes an apparatus for determining a three dimensional position of an object. The apparatus includes a first radiating element configured to emit, first electromagnetic (EM) radiation toward a position-sensing volume, the first EM radiation having a first wavelength. A second radiating element is configured to emit second EM radiation
10 toward the position-sensing volume, the second EM radiation having a second wavelength different from the first wavelength. A radiation sensor is coupled to a processor and is configured to detect scattered radiation, the detected scattered radiation resulting from interaction of the emitted first and second EM radiation with an object located in the position-sensing volume. Characteristics of the detected
15 scattered radiation have a correlation with a position of the object in the position-sensing volume, and the processor is configured to determine, from the correlation, a three dimensional position of the object.

[0009] In some implementations, the apparatus may include a third radiating element configured to emit third EM radiation toward the three dimensional position-sensing volume, the third EM radiation having a third wavelength different from the
20 first wavelength and the second wavelength. The apparatus may further include a fourth radiating element configured to emit fourth EM radiation toward the three dimensional position-sensing volume, the fourth EM radiation having a fourth wavelength different from the first wavelength, the second wavelength, and the third
25 wavelength.

[0010] In some implementations, the first and second wavelengths may be in the visible light range, the first wavelength may correspond to a first color, and the second wavelength may correspond to a second color. The correlation may be based on the color of the detected scattered radiation. The first wavelength and the second
30 wavelength may be in a frequency range selected from the group consisting of: infrared radiation, visible light, and ultraviolet radiation. The radiating elements may be light emitting diodes (LEDs) or lasers.

[0011] In some implementations, the first radiating element and the second radiating element may be proximate to a respective light sensor. The object may have a known radiation scattering behavior.

5 [0012] The processor may be configured to determine a relative strength of a first scattered radiation compared to a second scattered radiation. The first scattered radiation may result from interaction of the emitted first EM radiation with the object and the second scattered radiation may result from interaction of the emitted second EM radiation with the object.

10 [0013] The apparatus may further include an interactive display providing an input/output (I/O) interface to a user. The processor may be configured to recognize, from the output of the radiation sensor, an instance of a user gesture, and to control the interactive display and/or the apparatus responsive to the user gesture. The object may not be in direct physical contact with the interactive display. The position-sensing volume may be proximate to and extend above an external surface of the
15 interactive display. The processor may be configured to communicate with the interactive display and to process image data. The apparatus may further include a memory device that is configured to communicate with the processor, wherein the interactive display is configured to receive input data and to communicate the input data to the processor. The apparatus may further include a driver circuit configured to
20 send at least one signal to the interactive display and/or a controller configured to send at least a portion of the image data to the driver circuit. The apparatus may further include an image source module that sends the image data to the processor. The image source module may include a receiver, a transceiver, and/or a transmitter.

25 [0014] In some implementations, the apparatus may include a plurality of first radiating elements, each configured to emit modulated first electromagnetic (EM) radiation toward a respective portion of a position-sensing volume, the modulated first EM radiation having a first wavelength, where each of the plurality of first radiating elements is modulated in a mutually distinct manner. The apparatus may further include a plurality of second radiating elements, each configured to emit modulated
30 second EM radiation toward a respective portion of the position-sensing volume, the modulated second EM radiation having a second wavelength different from the first wavelength, wherein each of the plurality of second radiating elements is modulated in a mutually distinct manner. At least one radiation sensor may detect scattered radiation, the detected scattered radiation resulting from interaction of the emitted

modulated first and second EM radiation with an object located in the position-sensing volume, characteristics of the detected scattered radiation having a correlation with a position of the object in the position-sensing volume, wherein the apparatus is configured to determine, from the correlation, a three dimensional position of the object. The processor may be configured to determine, from the correlation, a three dimensional position of at least two objects simultaneously present in the position-sensing region. Characteristics of the detected scattered radiation, resulting from a first intensity and a first duty cycle of the modulated first EM radiation and a second intensity and a second duty cycle of the modulated second EM radiation, may have a correlation with a position of one or more objects in the position-sensing volume, and the apparatus may be configured to determine, from the correlation, a three dimensional position of the one or more objects.

[0015] Details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims. Note that the relative dimensions of the following figures may not be drawn to scale.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Figure 1 shows an example of an isometric view depicting two adjacent pixels in a series of pixels of an interferometric modulator (IMOD) display device.

[0017] Figure 2 shows an example of a system block diagram illustrating an electronic device incorporating a 3x3 interferometric modulator display.

[0018] Figure 3 shows an example of a diagram illustrating movable reflective layer position versus applied voltage for the interferometric modulator of Figure 1.

[0019] Figure 4 shows an example of a table illustrating various states of an interferometric modulator when various common and segment voltages are applied.

[0020] Figure 5A shows an example of a diagram illustrating a frame of display data in the 3x3 interferometric modulator display of Figure 2.

[0021] Figure 5B shows an example of a timing diagram for common and segment signals that may be used to write the frame of display data illustrated in Figure 5A.

[0022] Figure 6A shows an example of a partial cross-section of the interferometric modulator display of Figure 1.

[0023] Figures 6B-6E show examples of cross-sections of varying implementations of interferometric modulators.

[0024] Figure 7 shows an example of a flow diagram illustrating a manufacturing process for an interferometric modulator.

5 [0025] Figures 8A-8E show examples of cross-sectional schematic illustrations of various stages in a method of making an interferometric modulator.

[0026] Figures 9A-9H show an example of an arrangement for determining a position of an object within a 2-D position-sensing region.

10 [0027] Figure 10 shows an example of the arrangement of Figures 9A and 9B illustrating how emitted radiation may interact with an object in a position-sensing volume.

[0028] Figure 11 shows an example of a flow diagram illustrating a method for determining a three dimensional position of an object.

15 [0029] Figures 12A and 12B show examples of system block diagrams illustrating a display device that includes a plurality of interferometric modulators.

[0030] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

20 [0031] The following description is directed to certain implementations for the purposes of describing the innovative aspects of this disclosure. However, a person having ordinary skill in the art will readily recognize that the teachings herein can be applied in a multitude of different ways. The described implementations may be implemented in any device or system that can be configured to display an image,
25 whether in motion (e.g., video) or stationary (e.g., still image), and whether textual, graphical or pictorial. More particularly, it is contemplated that the described implementations may be included in or associated with a variety of electronic devices such as, but not limited to: mobile telephones, multimedia Internet enabled cellular telephones, mobile television receivers, wireless devices, smartphones, Bluetooth®
30 devices, personal data assistants (PDAs), wireless electronic mail receivers, hand-held or portable computers, netbooks, notebooks, smartbooks, tablets, printers, copiers, scanners, facsimile devices, GPS receivers/navigators, cameras, MP3 players, camcorders, game consoles, wrist watches, clocks, calculators, television monitors, flat panel displays, electronic reading devices (i.e., e-readers), computer monitors,

auto displays (including odometer and speedometer displays, etc.), cockpit controls and/or displays, camera view displays (such as the display of a rear view camera in a vehicle), electronic photographs, electronic billboards or signs, projectors, architectural structures, microwaves, refrigerators, stereo systems, cassette recorders or players, DVD players, CD players, VCRs, radios, portable memory chips, washers, dryers, washer/dryers, parking meters, packaging (such as in electromechanical systems (EMS), microelectromechanical systems (MEMS) and non-MEMS applications), aesthetic structures (e.g., display of images on a piece of jewelry) and a variety of EMS devices. The teachings herein also can be used in non-display applications such as, but not limited to, electronic switching devices, radio frequency filters, sensors, accelerometers, gyroscopes, motion-sensing devices, magnetometers, inertial components for consumer electronics, parts of consumer electronics products, varactors, liquid crystal devices, electrophoretic devices, drive schemes, manufacturing processes and electronic test equipment. Thus, the teachings are not intended to be limited to the implementations depicted solely in the Figures, but instead have wide applicability as will be readily apparent to one having ordinary skill in the art.

[0032] Described herein below are new techniques for providing, on an interactive display, a gesture-responsive user input/output (I/O) interface for an electronic device. "Gesture" as used herein broadly refers to a gross motion of a user's hand, digit, or an object worn, held, or otherwise under control of the user. The motion may be made proximate to, but not necessarily in direct physical contact with the electronic device. In some implementations, the electronic device senses and reacts in a deterministic way to a user's gesture.

[0033] Using the present techniques, a three dimensional position-sensing volume is encoded whereby the interactive display is enabled to determine a three dimensional position of the object within the position-sensing volume from characteristics of radiation scattered from the object and received by a radiation sensor. The position-sensing volume is encoded by at least two radiating elements, each radiating element configured to emit EM radiation having a respective, different, wavelength toward the position-sensing volume. A processor may be configured to recognize, from the output of the radiation sensor, an instance of a user gesture, and to control the interactive display and/or the electronic device responsive to the user gesture.

[0034] Particular implementations of the subject matter described in this disclosure can be implemented to realize one or more of the following potential advantages. In some implementations, the user is enabled to interact with the electronic device in a "touchless" manner, thereby mitigating a screen contamination problem with conventional touchscreen devices. In some implementations, the use of ITO layers may be avoided, with a consequential reduction in cost of the electronic device. In some implementations, a gesture-responsive interface is provided for an electronic device using an arrangement that is attractively compact, low cost, and low power.

[0035] An example of a suitable display device, for which the techniques described herein below may be implemented, is a reflective EMS or MEMS-based display device. Reflective display devices can incorporate interferometric modulators (IMODs) to selectively absorb and/or reflect light incident thereon using principles of optical interference. IMODs can include an absorber, a reflector that is movable with respect to the absorber, and an optical resonant cavity defined between the absorber and the reflector. The reflector can be moved to two or more different positions, which can change the size of the optical resonant cavity and thereby affect the reflectance of the interferometric modulator. The reflectance spectrums of IMODs can create fairly broad spectral bands which can be shifted across the visible wavelengths to generate different colors. The position of the spectral band can be adjusted by changing the thickness of the optical resonant cavity. One way of changing the optical resonant cavity is by changing the position of the reflector.

[0036] Figure 1 shows an example of an isometric view depicting two adjacent pixels in a series of pixels of an interferometric modulator (IMOD) display device. The IMOD display device includes one or more interferometric MEMS display elements. In these devices, the pixels of the MEMS display elements can be in either a bright or dark state. In the bright ("relaxed," "open" or "on") state, the display element reflects a large portion of incident visible light, e.g., to a user. Conversely, in the dark ("actuated," "closed" or "off") state, the display element reflects little incident visible light. In some implementations, the light reflectance properties of the on and off states may be reversed. MEMS pixels can be configured to reflect predominantly at particular wavelengths allowing for a color display in addition to black and white.

[0037] The IMOD display device can include a row/column array of IMODs. Each IMOD can include a pair of reflective layers, i.e., a movable reflective layer and a fixed partially reflective layer, positioned at a variable and controllable distance from each other to form an air gap (also referred to as an optical gap or cavity). The movable reflective layer may be moved between at least two positions. In a first position, i.e., a relaxed position, the movable reflective layer can be positioned at a relatively large distance from the fixed partially reflective layer. In a second position, i.e., an actuated position, the movable reflective layer can be positioned more closely to the partially reflective layer. Incident light that reflects from the two layers can interfere constructively or destructively depending on the position of the movable reflective layer, producing either an overall reflective or non-reflective state for each pixel. In some implementations, the IMOD may be in a reflective state when unactuated, reflecting light within the visible spectrum, and may be in a dark state when unactuated, absorbing and/or destructively interfering light within the visible range. In some other implementations, however, an IMOD may be in a dark state when unactuated, and in a reflective state when actuated. In some implementations, the introduction of an applied voltage can drive the pixels to change states. In some other implementations, an applied charge can drive the pixels to change states.

[0038] The depicted portion of the pixel array in Figure 1 includes two adjacent interferometric modulators 12. In the IMOD 12 on the left (as illustrated), a movable reflective layer 14 is illustrated in a relaxed position at a predetermined distance from an optical stack 16, which includes a partially reflective layer. The voltage V_0 applied across the IMOD 12 on the left is insufficient to cause actuation of the movable reflective layer 14. In the IMOD 12 on the right, the movable reflective layer 14 is illustrated in an actuated position near or adjacent the optical stack 16. The voltage V_{bias} applied across the IMOD 12 on the right is sufficient to maintain the movable reflective layer 14 in the actuated position.

[0039] In Figure 1, the reflective properties of pixels 12 are generally illustrated with arrows 13 indicating light incident upon the pixels 12, and light 15 reflecting from the pixel 12 on the left. Although not illustrated in detail, it will be understood by a person having ordinary skill in the art that most of the light 13 incident upon the pixels 12 will be transmitted through the transparent substrate 20, toward the optical stack 16. A portion of the light incident upon the optical stack 16 will be transmitted through the partially reflective layer of the optical stack 16, and a portion will be

reflected back through the transparent substrate 20. The portion of light 13 that is transmitted through the optical stack 16 will be reflected at the movable reflective layer 14, back toward (and through) the transparent substrate 20. Interference (constructive or destructive) between the light reflected from the partially reflective layer of the optical stack 16 and the light reflected from the movable reflective layer 14 will determine the wavelength(s) of light 15 reflected from the pixel 12.

[0040] The optical stack 16 can include a single layer or several layers. The layer(s) can include one or more of an electrode layer, a partially reflective and partially transmissive layer and a transparent dielectric layer. In some implementations, the optical stack 16 is electrically conductive, partially transparent and partially reflective, and may be fabricated, for example, by depositing one or more of the above layers onto a transparent substrate 20. The electrode layer can be formed from a variety of materials, such as various metals, for example indium tin oxide (ITO). The partially reflective layer can be formed from a variety of materials that are partially reflective, such as various metals, such as chromium (Cr), semiconductors, and dielectrics. The partially reflective layer can be formed of one or more layers of materials, and each of the layers can be formed of a single material or a combination of materials. In some implementations, the optical stack 16 can include a single semi-transparent thickness of metal or semiconductor which serves as both an optical absorber and electrical conductor, while different, electrically more conductive layers or portions (e.g., of the optical stack 16 or of other structures of the IMOD) can serve to bus signals between IMOD pixels. The optical stack 16 also can include one or more insulating or dielectric layers covering one or more conductive layers or an electrically conductive/optically absorptive layer.

[0041] In some implementations, the layer(s) of the optical stack 16 can be patterned into parallel strips, and may form row electrodes in a display device as described further below. As will be understood by one having ordinary skill in the art, the term "patterned" is used herein to refer to masking as well as etching processes. In some implementations, a highly conductive and reflective material, such as aluminum (Al), may be used for the movable reflective layer 14, and these strips may form column electrodes in a display device. The movable reflective layer 14 may be formed as a series of parallel strips of a deposited metal layer or layers (orthogonal to the row electrodes of the optical stack 16) to form columns deposited on top of posts 18 and an intervening sacrificial material deposited between the posts

18. When the sacrificial material is etched away, a defined gap 19, or optical cavity, can be formed between the movable reflective layer 14 and the optical stack 16. In some implementations, the spacing between posts 18 may be approximately 1-1000 μm , while the gap 19 may be less than $< 10,000$ Angstroms (A).

- 5 [0042] In some implementations, each pixel of the IMOD, whether in the actuated or relaxed state, is essentially a capacitor formed by the fixed and moving reflective layers. When no voltage is applied, the movable reflective layer 14 remains in a mechanically relaxed state, as illustrated by the pixel 12 on the left in Figure 1, with the gap 19 between the movable reflective layer 14 and optical stack 16. However,
- 10 when a potential difference, a voltage, is applied to at least one of a selected row and column, the capacitor formed at the intersection of the row and column electrodes at the corresponding pixel becomes charged, and electrostatic forces pull the electrodes together. If the applied voltage exceeds a threshold, the movable reflective layer 14 can deform and move near or against the optical stack 16. A dielectric layer (not
- 15 shown) within the optical stack 16 may prevent shorting and control the separation distance between the layers 14 and 16, as illustrated by the actuated pixel 12 on the right in Figure 1. The behavior is the same regardless of the polarity of the applied potential difference. Though a series of pixels in an array may be referred to in some instances as "rows" or "columns," a person having ordinary skill in the art will readily
- 20 understand that referring to one direction as a "row" and another as a "column" is arbitrary. Restated, in some orientations, the rows can be considered columns, and the columns considered to be rows. Furthermore, the display elements may be evenly arranged in orthogonal rows and columns (an "array"), or arranged in non-linear configurations, for example, having certain positional offsets with respect to one
- 25 another (a "mosaic"). The terms "array" and "mosaic" may refer to either configuration. Thus, although the display is referred to as including an "array" or "mosaic," the elements themselves need not be arranged orthogonally to one another, or disposed in an even distribution, in any instance, but may include arrangements having asymmetric shapes and unevenly distributed elements.
- 30 [0043] Figure 2 shows an example of a system block diagram illustrating an electronic device incorporating a 3x3 interferometric modulator display. The electronic device includes a processor 21 that may be configured to execute one or more software modules. In addition to executing an operating system, the processor

21 may be configured to execute one or more software applications, including a web browser, a telephone application, an email program, or any other software application.

[0044] The processor 21 can be configured to communicate with an array driver 22. The array driver 22 can include a row driver circuit 24 and a column driver circuit 26 that provide signals to, for example, a display array or panel 30. The cross section of the IMOD display device illustrated in Figure 1 is shown by the lines 1-1 in Figure 2. Although Figure 2 illustrates a 3x3 array of IMODs for the sake of clarity, the display array 30 may contain a very large number of IMODs, and may have a different number of IMODs in rows than in columns, and vice versa.

[0045] Figure 3 shows an example of a diagram illustrating movable reflective layer position versus applied voltage for the interferometric modulator of Figure 1. For MEMS interferometric modulators, the row/column (i.e., common/segment) write procedure may take advantage of a hysteresis property of these devices as illustrated in Figure 3. An interferometric modulator may use, in one example implementation, about a 10-volt potential difference to cause the movable reflective layer, or mirror, to change from the relaxed state to the actuated state. When the voltage is reduced from that value, the movable reflective layer maintains its state as the voltage drops back below, in this example, 10 volts; however, the movable reflective layer does not relax completely until the voltage drops below 2 volts. Thus, a range of voltage, approximately 3 to 7 volts, in this example, as shown in Figure 3, exists where there is a window of applied voltage within which the device is stable in either the relaxed or actuated state. This is referred to herein as the "hysteresis window" or "stability window." For a display array 30 having the hysteresis characteristics of Figure 3, the row/column write procedure can be designed to address one or more rows at a time, such that during the addressing of a given row, pixels in the addressed row that are to be actuated are exposed to a voltage difference of about, in this example, 10 volts, and pixels that are to be relaxed are exposed to a voltage difference of near zero volts. After addressing, the pixels can be exposed to a steady state or bias voltage difference of approximately 5 volts in this example, such that they remain in the previous strobing state. In this example, after being addressed, each pixel sees a potential difference within the "stability window" of about 3-7 volts. This hysteresis property feature enables the pixel design, such as that illustrated in Figure 1, to remain stable in either an actuated or relaxed pre-existing state under the same applied voltage conditions. Since each IMOD pixel, whether in the actuated or relaxed state, is

essentially a capacitor formed by the fixed and moving reflective layers, this stable state can be held at a steady voltage within the hysteresis window without substantially consuming or losing power. Moreover, essentially little or no current flows into the IMOD pixel if the applied voltage potential remains substantially fixed.

5 [0046] In some implementations, a frame of an image may be created by applying data signals in the form of "segment" voltages along the set of column electrodes, in accordance with the desired change (if any) to the state of the pixels in a given row. Each row of the array can be addressed in turn, such that the frame is written one row at a time. To write the desired data to the pixels in a first row, segment voltages
10 corresponding to the desired state of the pixels in the first row can be applied on the column electrodes, and a first row pulse in the form of a specific "common" voltage or signal can be applied to the first row electrode. The set of segment voltages can then be changed to correspond to the desired change (if any) to the state of the pixels in the second row, and a second common voltage can be applied to the second row
15 electrode. In some implementations, the pixels in the first row are unaffected by the change in the segment voltages applied along the column electrodes, and remain in the state they were set to during the first common voltage row pulse. This process may be repeated for the entire series of rows, or alternatively, columns, in a sequential fashion to produce the image frame. The frames can be refreshed and/or updated with
20 new image data by continually repeating this process at some desired number of frames per second.

[0047] The combination of segment and common signals applied across each pixel (that is, the potential difference across each pixel) determines the resulting state of each pixel. Figure 4 shows an example of a table illustrating various states of an
25 interferometric modulator when various common and segment voltages are applied. As will be understood by one having ordinary skill in the art, the "segment" voltages can be applied to either the column electrodes or the row electrodes, and the "common" voltages can be applied to the other of the column electrodes or the row electrodes.

30 [0048] As illustrated in Figure 4 (as well as in the timing diagram shown in Figure 5B), when a release voltage $V_{C_{REL}}$ is applied along a common line, all interferometric modulator elements along the common line will be placed in a relaxed state, alternatively referred to as a released or unactuated state, regardless of the voltage applied along the segment lines, i.e., high segment voltage V_{S_H} and low segment

voltage V_{S_L} - In particular, when the release voltage $V_{C_{REL}}$ is applied along a common line, the potential voltage across the modulator pixels (alternatively referred to as a pixel voltage) is within the relaxation window (see Figure 3, also referred to as a release window) both when the high segment voltage V_{S_H} and the low segment voltage V_{S_L} are applied along the corresponding segment line for that pixel.

[0049] When a hold voltage is applied on a common line, such as a high hold voltage $V_{C_H O_{LD_H}}$ or a low hold voltage $V_{C_H O_{LD_L}}$, the state of the interferometric modulator will remain constant. For example, a relaxed IMOD will remain in a relaxed position, and an actuated IMOD will remain in an actuated position. The hold voltages can be selected such that the pixel voltage will remain within a stability window both when the high segment voltage V_{S_H} and the low segment voltage V_{S_L} are applied along the corresponding segment line. Thus, the segment voltage swing, i.e., the difference between the high V_{S_H} and low segment voltage V_{S_L} , is less than the width of either the positive or the negative stability window.

[0050] When an addressing, or actuation, voltage is applied on a common line, such as a high addressing voltage $V_{CA_{DD_H}}$ or a low addressing voltage $V_{CA_{DD_L}}$, data can be selectively written to the modulators along that line by application of segment voltages along the respective segment lines. The segment voltages may be selected such that actuation is dependent upon the segment voltage applied. When an addressing voltage is applied along a common line, application of one segment voltage will result in a pixel voltage within a stability window, causing the pixel to remain unactuated. In contrast, application of the other segment voltage will result in a pixel voltage beyond the stability window, resulting in actuation of the pixel. The particular segment voltage which causes actuation can vary depending upon which addressing voltage is used. In some implementations, when the high addressing voltage $V_{CA_{DD_H}}$ is applied along the common line, application of the high segment voltage V_{S_H} can cause a modulator to remain in its current position, while application of the low segment voltage V_{S_L} can cause actuation of the modulator. As a corollary, the effect of the segment voltages can be the opposite when a low addressing voltage $V_{CA_{DD_L}}$ is applied, with high segment voltage V_{S_H} causing actuation of the modulator, and low segment voltage V_{S_L} having no effect (i.e., remaining stable) on the state of the modulator.

[0051] In some implementations, hold voltages, address voltages, and segment voltages may be used which produce the same polarity potential difference across the

modulators. In some other implementations, signals can be used which alternate the polarity of the potential difference of the modulators from time to time. Alternation of the polarity across the modulators (that is, alternation of the polarity of write procedures) may reduce or inhibit charge accumulation which could occur after repeated write operations of a single polarity.

[0052] Figure 5A shows an example of a diagram illustrating a frame of display data in the 3x3 interferometric modulator display of Figure 2. Figure 5B shows an example of a timing diagram for common and segment signals that may be used to write the frame of display data illustrated in Figure 5A. The signals can be applied to a 3x3 array, similar to the array of Figure 2, which will ultimately result in the line time 60e display arrangement illustrated in Figure 5A. The actuated modulators in Figure 5A are in a dark-state, i.e., where a substantial portion of the reflected light is outside of the visible spectrum so as to result in a dark appearance to, for example, a viewer. Prior to writing the frame illustrated in Figure 5A, the pixels can be in any state, but the write procedure illustrated in the timing diagram of Figure 5B presumes that each modulator has been released and resides in an unactuated state before the first line time 60a.

[0053] During the first line time 60a: a release voltage 70 is applied on common line 1; the voltage applied on common line 2 begins at a high hold voltage 72 and moves to a release voltage 70; and a low hold voltage 76 is applied along common line 3. Thus, the modulators (common 1, segment 1), (1,2) and (1,3) along common line 1 remain in a relaxed, or unactuated, state for the duration of the first line time 60a, the modulators (2,1), (2,2) and (2,3) along common line 2 will move to a relaxed state, and the modulators (3,1), (3,2) and (3,3) along common line 3 will remain in their previous state. With reference to Figure 4, the segment voltages applied along segment lines 1, 2 and 3 will have no effect on the state of the interferometric modulators, as none of common lines 1, 2 or 3 are being exposed to voltage levels causing actuation during line time 60a (i.e., $V_{C_{REL}}$ - relax and $V_{C_H Q_{LD-L}}$ - stable).

[0054] During the second line time 60b, the voltage on common line 1 moves to a high hold voltage 72, and all modulators along common line 1 remain in a relaxed state regardless of the segment voltage applied because no addressing, or actuation, voltage was applied on the common line 1. The modulators along common line 2 remain in a relaxed state due to the application of the release voltage 70, and the

modulators (3,1), (3,2) and (3,3) along common line 3 will relax when the voltage along common line 3 moves to a release voltage 70.

[0055] During the third line time 60c, common line 1 is addressed by applying a high address voltage 74 on common line 1. Because a low segment voltage 64 is applied along segment lines 1 and 2 during the application of this address voltage, the pixel voltage across modulators (1,1) and (1,2) is greater than the high end of the positive stability window (i.e., the voltage differential exceeded a predefined threshold) of the modulators, and the modulators (1,1) and (1,2) are actuated. Conversely, because a high segment voltage 62 is applied along segment line 3, the pixel voltage across modulator (1,3) is less than that of modulators (1,1) and (1,2), and remains within the positive stability window of the modulator; modulator (1,3) thus remains relaxed. Also during line time 60c, the voltage along common line 2 decreases to a low hold voltage 76, and the voltage along common line 3 remains at a release voltage 70, leaving the modulators along common lines 2 and 3 in a relaxed position.

[0056] During the fourth line time 60d, the voltage on common line 1 returns to a high hold voltage 72, leaving the modulators along common line 1 in their respective addressed states. The voltage on common line 2 is decreased to a low address voltage 78. Because a high segment voltage 62 is applied along segment line 2, the pixel voltage across modulator (2,2) is below the lower end of the negative stability window of the modulator, causing the modulator (2,2) to actuate. Conversely, because a low segment voltage 64 is applied along segment lines 1 and 3, the modulators (2,1) and (2,3) remain in a relaxed position. The voltage on common line 3 increases to a high hold voltage 72, leaving the modulators along common line 3 in a relaxed state.

[0057] Finally, during the fifth line time 60e, the voltage on common line 1 remains at high hold voltage 72, and the voltage on common line 2 remains at a low hold voltage 76, leaving the modulators along common lines 1 and 2 in their respective addressed states. The voltage on common line 3 increases to a high address voltage 74 to address the modulators along common line 3. As a low segment voltage 64 is applied on segment lines 2 and 3, the modulators (3,2) and (3,3) actuate, while the high segment voltage 62 applied along segment line 1 causes modulator (3,1) to remain in a relaxed position. Thus, at the end of the fifth line time 60e, the 3x3 pixel array is in the state shown in Figure 5A, and will remain in that state as long

as the hold voltages are applied along the common lines, regardless of variations in the segment voltage which may occur when modulators along other common lines (not shown) are being addressed.

[0058] In the timing diagram of Figure 5B, a given write procedure (i.e., line times 60a-60e) can include the use of either high hold and address voltages, or low hold and address voltages. Once the write procedure has been completed for a given common line (and the common voltage is set to the hold voltage having the same polarity as the actuation voltage), the pixel voltage remains within a given stability window, and does not pass through the relaxation window until a release voltage is applied on that common line. Furthermore, as each modulator is released as part of the write procedure prior to addressing the modulator, the actuation time of a modulator, rather than the release time, may determine the line time. Specifically, in implementations in which the release time of a modulator is greater than the actuation time, the release voltage may be applied for longer than a single line time, as depicted in Figure 5B. In some other implementations, voltages applied along common lines or segment lines may vary to account for variations in the actuation and release voltages of different modulators, such as modulators of different colors.

[0059] The details of the structure of interferometric modulators that operate in accordance with the principles set forth above may vary widely. For example, Figures 6A-6E show examples of cross-sections of varying implementations of interferometric modulators, including the movable reflective layer 14 and its supporting structures. Figure 6A shows an example of a partial cross-section of the interferometric modulator display of Figure 1, where a strip of metal material, i.e., the movable reflective layer 14 is deposited on supports 18 extending orthogonally from the substrate 20. In Figure 6B, the movable reflective layer 14 of each IMOD is generally square or rectangular in shape and attached to supports at or near the corners, on tethers 32. In Figure 6C, the movable reflective layer 14 is generally square or rectangular in shape and suspended from a deformable layer 34, which may include a flexible metal. The deformable layer 34 can connect, directly or indirectly, to the substrate 20 around the perimeter of the movable reflective layer 14. These connections are herein referred to as support posts. The implementation shown in Figure 6C has additional benefits deriving from the decoupling of the optical functions of the movable reflective layer 14 from its mechanical functions, which are carried out by the deformable layer 34. This decoupling allows the structural design

and materials used for the reflective layer 14 and those used for the deformable layer 34 to be optimized independently of one another.

[0060] Figure 6D shows another example of an IMOD, where the movable reflective layer 14 includes a reflective sub-layer 14a. The movable reflective layer 14 rests on a support structure, such as support posts 18. The support posts 18 provide separation of the movable reflective layer 14 from the lower stationary electrode (i.e., part of the optical stack 16 in the illustrated IMOD) so that a gap 19 is formed between the movable reflective layer 14 and the optical stack 16, for example when the movable reflective layer 14 is in a relaxed position. The movable reflective layer 14 also can include a conductive layer 14c, which may be configured to serve as an electrode, and a support layer 14b. In this example, the conductive layer 14c is disposed on one side of the support layer 14b, distal from the substrate 20, and the reflective sub-layer 14a is disposed on the other side of the support layer 14b, proximal to the substrate 20. In some implementations, the reflective sub-layer 14a can be conductive and can be disposed between the support layer 14b and the optical stack 16. The support layer 14b can include one or more layers of a dielectric material, for example, silicon oxynitride (SiON) or silicon dioxide (SiO₂). In some implementations, the support layer 14b can be a stack of layers, such as, for example, a SiO₂/SiON/SiO₂ tri-layer stack. Either or both of the reflective sub-layer 14a and the conductive layer 14c can include, for example, an aluminum (Al) alloy with about 0.5% copper (Cu), or another reflective metallic material. Employing conductive layers 14a, 14c above and below the dielectric support layer 14b can balance stresses and provide enhanced conduction. In some implementations, the reflective sub-layer 14a and the conductive layer 14c can be formed of different materials for a variety of design purposes, such as achieving specific stress profiles within the movable reflective layer 14.

[0061] As illustrated in Figure 6D, some implementations also can include a black mask structure 23. The black mask structure 23 can be formed in optically inactive regions (such as between pixels or under posts 18) to absorb ambient or stray light. The black mask structure 23 also can improve the optical properties of a display device by inhibiting light from being reflected from or transmitted through inactive portions of the display, thereby increasing the contrast ratio. Additionally, the black mask structure 23 can be conductive and be configured to function as an electrical bussing layer. In some implementations, the row electrodes can be connected to the

black mask structure 23 to reduce the resistance of the connected row electrode. The black mask structure 23 can be formed using a variety of methods, including deposition and patterning techniques. The black mask structure 23 can include one or more layers. For example, in some implementations, the black mask structure 23 includes a molybdenum-chromium (MoCr) layer that serves as an optical absorber, a layer, and an aluminum alloy that serves as a reflector and a bussing layer, with a thickness in the range of about 30-80 Å, 500-1000 Å, and 500-6000 Å, respectively. The one or more layers can be patterned using a variety of techniques, including photolithography and dry etching, including, for example, carbon tetrafluoromethane (CF₄) and/or oxygen (O₂) for the MoCr and SiO₂ layers and chlorine (Cl₂) and/or boron trichloride (BCl₃) for the aluminum alloy layer. In some implementations, the black mask 23 can be an etalon or interferometric stack structure. In such interferometric stack black mask structures 23, the conductive absorbers can be used to transmit or bus signals between lower, stationary electrodes in the optical stack 16 of each row or column. In some implementations, a spacer layer 35 can serve to generally electrically isolate the absorber layer 16a from the conductive layers in the black mask 23.

[0062] Figure 6E shows another example of an IMOD, where the movable reflective layer 14 is self supporting. In contrast with Figure 6D, the implementation of Figure 6E does not include support posts 18. Instead, the movable reflective layer 14 contacts the underlying optical stack 16 at multiple locations, and the curvature of the movable reflective layer 14 provides sufficient support that the movable reflective layer 14 returns to the unactuated position of Figure 6E when the voltage across the interferometric modulator is insufficient to cause actuation. The optical stack 16, which may contain a plurality of several different layers, is shown here for clarity including an optical absorber 16a, and a dielectric 16b. In some implementations, the optical absorber 16a may serve both as a fixed electrode and as a partially reflective layer. In some implementations, the optical absorber 16a is an order of magnitude (ten times or more) thinner than the movable reflective layer 14. In some implementations, optical absorber 16a is thinner than reflective sub-layer 14a.

[0063] In implementations such as those shown in Figures 6A-6E, the IMODs function as direct-view devices, in which images are viewed from the front side of the transparent substrate 20, i.e., the side opposite to that upon which the modulator is arranged. In these implementations, the back portions of the device (that is, any

portion of the display device behind the movable reflective layer 14, including, for example, the deformable layer 34 illustrated in Figure 6C) can be configured and operated upon without impacting or negatively affecting the image quality of the display device, because the reflective layer 14 optically shields those portions of the device. For example, in some implementations a bus structure (not illustrated) can be included behind the movable reflective layer 14 which provides the ability to separate the optical properties of the modulator from the electromechanical properties of the modulator, such as voltage addressing and the movements that result from such addressing. Additionally, the implementations of Figures 6A-6E can simplify processing, such as, for example, patterning.

[0064] Figure 7 shows an example of a flow diagram illustrating a manufacturing process 80 for an interferometric modulator, and Figures 8A-8E show examples of cross-sectional schematic illustrations of corresponding stages of such a manufacturing process 80. In some implementations, the manufacturing process 80 can be implemented to manufacture an electromechanical systems device such as interferometric modulators of the general type illustrated in Figures 1 and 6. The manufacture of an electromechanical systems device can also include other blocks not shown in Figure 7. With reference to Figures 1, 6 and 7, the process 80 begins at block 82 with the formation of the optical stack 16 over the substrate 20. Figure 8A illustrates such an optical stack 16 formed over the substrate 20. The substrate 20 may be a transparent substrate such as glass or plastic, it may be flexible or relatively stiff and unbending, and may have been subjected to prior preparation processes, such as cleaning, to facilitate efficient formation of the optical stack 16. As discussed above, the optical stack 16 can be electrically conductive, partially transparent and partially reflective and may be fabricated, for example, by depositing one or more layers having the desired properties onto the transparent substrate 20. In Figure 8A, the optical stack 16 includes a multilayer structure having sub-layers 16a and 16b, although more or fewer sub-layers may be included in some other implementations. In some implementations, one of the sub-layers 16a and 16b can be configured with both optically absorptive and electrically conductive properties, such as the combined conductor/absorber sub-layer 16a. Additionally, one or more of the sub-layers 16a, 16b can be patterned into parallel strips, and may form row electrodes in a display device. Such patterning can be performed by a masking and etching process or another suitable process known in the art. In some implementations, one of the sub-

layers 16a, 16b can be an insulating or dielectric layer, such as sub-layer 16b that is deposited over one or more metal layers (e.g., one or more reflective and/or conductive layers). In addition, the optical stack 16 can be patterned into individual and parallel strips that form the rows of the display. It is noted that Figures 8A-8E may not be drawn to scale. For example, in some implementations, one of the sub-layers of the optical stack, the optically absorptive layer, may be very thin, although sub-layers 16a, 16b are shown somewhat thick in Figures 8A-8E.

[0065] The process 80 continues at block 84 with the formation of a sacrificial layer 25 over the optical stack 16. The sacrificial layer 25 is later removed (see block 90) to form the cavity 19 and thus the sacrificial layer 25 is not shown in the resulting interferometric modulators 12 illustrated in Figure 1. Figure 8B illustrates a partially fabricated device including a sacrificial layer 25 formed over the optical stack 16. The formation of the sacrificial layer 25 over the optical stack 16 may include deposition of a xenon difluoride (XeF_2)-etchable material such as molybdenum (Mo) or amorphous silicon (a-Si), in a thickness selected to provide, after subsequent removal, a gap or cavity 19 (see also Figures 1 and 8E) having a desired design size. Deposition of the sacrificial material may be carried out using deposition techniques such as physical vapor deposition (PVD, which includes many different techniques, such as sputtering), plasma-enhanced chemical vapor deposition (PECVD), thermal chemical vapor deposition (thermal CVD), or spin-coating.

[0066] The process 80 continues at block 86 with the formation of a support structure such as post 18, illustrated in Figures 1, 6 and 8C. The formation of the post 18 may include patterning the sacrificial layer 25 to form a support structure aperture, then depositing a material (such as a polymer or an inorganic material such as silicon oxide) into the aperture to form the post 18, using a deposition method such as PVD, PECVD, thermal CVD, or spin-coating. In some implementations, the support structure aperture formed in the sacrificial layer can extend through both the sacrificial layer 25 and the optical stack 16 to the underlying substrate 20, so that the lower end of the post 18 contacts the substrate 20 as illustrated in Figure 6A. Alternatively, as depicted in Figure 8C, the aperture formed in the sacrificial layer 25 can extend through the sacrificial layer 25, but not through the optical stack 16. For example, Figure 8E illustrates the lower ends of the support posts 18 in contact with an upper surface of the optical stack 16. The post 18, or other support structures, may be formed by depositing a layer of support structure material over the sacrificial layer

25 and patterning portions of the support structure material located away from apertures in the sacrificial layer 25. The support structures may be located within the apertures, as illustrated in Figure 8C, but also can, at least partially, extend over a portion of the sacrificial layer 25. As noted above, the patterning of the sacrificial layer 25 and/or the support posts 18 can be performed by a patterning and etching process, but also may be performed by alternative etching methods.

[0067] The process 80 continues at block 88 with the formation of a movable reflective layer or membrane such as the movable reflective layer 14 illustrated in Figures 1, 6 and 8D. The movable reflective layer 14 may be formed by employing one or more deposition steps including, for example, reflective layer (such as aluminum, aluminum alloy, or other reflective layer) deposition, along with one or more patterning, masking, and/or etching steps. The movable reflective layer 14 can be electrically conductive, and referred to as an electrically conductive layer. In some implementations, the movable reflective layer 14 may include a plurality of sub-layers 14a, 14b, 14c as shown in Figure 8D. In some implementations, one or more of the sub-layers, such as sub-layers 14a, 14c, may include highly reflective sub-layers selected for their optical properties, and another sub-layer 14b may include a mechanical sub-layer selected for its mechanical properties. Since the sacrificial layer 25 is still present in the partially fabricated interferometric modulator formed at block 88, the movable reflective layer 14 is typically not movable at this stage. A partially fabricated IMOD that contains a sacrificial layer 25 may also be referred to herein as an "unreleased" IMOD. As described above in connection with Figure 1, the movable reflective layer 14 can be patterned into individual and parallel strips that form the columns of the display.

[0068] The process 80 continues at block 90 with the formation of a cavity, such as cavity 19 illustrated in Figures 1, 6 and 8E. The cavity 19 may be formed by exposing the sacrificial material 25 (deposited at block 84) to an etchant. For example, an etchable sacrificial material such as Mo or amorphous Si may be removed by dry chemical etching, by exposing the sacrificial layer 25 to a gaseous or vaporous etchant, such as vapors derived from solid XeF_2 , for a period of time that is effective to remove the desired amount of material. The sacrificial material is typically selectively removed relative to the structures surrounding the cavity 19. Other etching methods, such as wet etching and/or plasma etching, also may be used. Since the sacrificial layer 25 is removed during block 90, the movable reflective layer

14 is typically movable after this stage. After removal of the sacrificial material 25, the resulting fully or partially fabricated IMOD may be referred to herein as a "released" IMOD.

[0069] According to one innovative aspect of the subject matter described in this disclosure, an interactive display, which may be associated with an IMOD display device as described hereinabove, provides an input/output (I/O) interface to a user, wherewith (i) an instance of a user gesture may be recognized, and (ii) the interactive display may be controlled responsive to the user gesture. Advantageously, an electronic device such as, for example, a handheld personal electronic device (PED) is enabled to sense and react in a deterministic way to gross motions of a user's hand, digit, or an object held or worn by the user. The gestures may be made proximate to, but, advantageously, not in direct physical contact with the electronic device. More generally, the present disclosure relates to gesture recognition by determining a three dimensional position of an object. As such, a large variety of applications are within the contemplation of the present inventors. For example, gesture recognition based on the present teachings may be applicable to, at least, portable and non-portable gaming platforms, video conferencing, industrial and home security, and telemedicine.

[0070] In some implementations each of two or more radiating elements emit a respective electromagnetic (EM) radiation toward a three dimensional position-sensing volume. In some implementations, the three dimensional position-sensing volume can be related to a display, for example images presented on a display device, or projected onto a floor, wall, or ceiling of the three dimensional position-sensing volume. However, other implementations have no relation to a display and simply sense the position of objects in the volume. EM radiation from a first radiating element is at a first wavelength and EM radiation from a second radiating element is at a second wavelength, different from the first wavelength. A radiation sensor detects scattered radiation, the detected scattered radiation resulting from interaction of the emitted first and second EM radiation with an object located in the position-sensing volume. Characteristics of the detected scattered radiation have a correlation with a position of the object in the position-sensing volume. The object may have a known radiation scattering behavior, but this is not necessarily so. The positioning determination arrangement is configured to determine, from the correlation, a three dimensional position of the object.

[0071] In some implementations, the position-sensing volume may be proximate to and extend from an external surface of an interactive display that provides an input/output (I/O) interface to a user. A processor coupled to the radiation sensor may be configured to determine three dimensional coordinates of the position of the object
5 in the position-sensing volume. Moreover, the processor may be configured to recognize, from the output of the radiation sensor, an instance of a user gesture, and to control the interactive display, and/or a related apparatus, responsive to the user gesture.

[0072] In other implementations, the position-sensing volume may be free-standing, and associated, for example, with a game playing space, a video
10 conferencing room, or an area under security surveillance.

[0073] Figures 9A and 9B show a plan view of an example of an arrangement 900 for determining a position of an object within a 3-D position-sensing volume associated with interactive display 910. A first radiating element 920 emits
15 electromagnetic (EM) radiation, having a first wavelength, toward a position-sensing volume that may, for example extend from and above a surface of interactive display 910. In the illustrated arrangement, for example, first radiating element 920 is a light emitting diode (LED) emitting visible light at a wavelength associated with red light. A second radiating element 930 emits EM radiation, having a second wavelength,
20 toward the position-sensing volume. In the illustrated implementation, for example, second radiating element 930 is an LED emitting visible light at a wavelength associated with blue light. A third radiating element 940 emits EM radiation, having a third wavelength, toward the position-sensing volume. In the illustrated implementation, for example, third radiating element 940 is an LED emitting visible
25 light at a wavelength associated with green light. It is to be understood that, while radiation elements 920, 930 and 940 may be described as emitting at a particular wavelength, practical radiating elements will actually emit a band of wavelengths about a given particular wavelength.

[0074] A radiation sensor 950 detects "scattered" radiation, the scattered radiation
30 resulting from interaction of the emitted EM radiation with an object (not shown) located in the position-sensing volume. In the illustrated implementation, for example, radiation sensor 950 is a color sensor that determines the color of the detected scattered radiation.

[0075] More generally, referring now to Figure 9C and 9D, which illustrate, respectively, a plan view and an isometric view of an example implementation, first radiating element 920 may be configured to emit first EM radiation at a first wavelength toward position-sensing volume 911. Second radiating element 930 may be configured to emit second EM radiation at a second wavelength different from the first wavelength toward position-sensing volume 911. Radiation sensor 950 may be configured to detect scattered radiation from the emitted radiation responsive to an object scattering the emitted radiation.

[0076] It is to be understood that, although the example implementations illustrated in Figures 9A, 9B, 9C, and 9D have emitters and sensors located proximate to a respective corner of a rectangular interactive display, other arrangements are within the contemplation of the present disclosure. For example, one or more of the emitters and/or detectors may be located near a mid-point of an edge of the position-sensing volume. Furthermore, the interactive display need not be rectangular.

[0077] As a further example, referring now to Figure 9E, an isometric view of position-sensing volume 911 according to one implementation is illustrated. Here, first radiating element 920 may be configured to emit first EM radiation at a first wavelength toward position-sensing volume 911. Second radiating element 930 may be configured to emit second EM radiation at a second wavelength different from the first wavelength toward position-sensing volume 911. Third radiating element 940 may be configured to emit third EM radiation at a third wavelength different from the first wavelength toward position-sensing volume 911. Radiation sensor 950 may be configured to detect scattered radiation from the emitted radiation responsive to an object scattering the emitted radiation. It will be understood that, although in the illustrated implementation three radiating elements are illustrated, two or four or more radiating elements may be provided. For example, additional radiating elements may be conveniently located at corners 911a, 911b, and/or 911c of position-sensing volume 911. Furthermore, one or more radiation sensor 950 may be disposed at any location within or proximate to position-sensing volume 911. Conveniently, for example, radiation sensor 950 may be located along an edge, at position 911d, for example of position-sensing volume 911, and/or proximate to a midpoint of one face or wall of position-sensing volume 911, at position 911e, for example.

[0078] Moreover, in some implementations, two or more radiation sensors 950 may be provided. For example, as illustrated in Figure 9F, a plan view of an

implementation, first radiation sensor 950a may be disposed on or near a mid-point of a first side of the interactive display, whereas second radiation sensor 950b may be disposed on or near a mid-point of a second side of the interactive display. Although illustrated with only two radiation sensors 950a and 950b, it is understood that in some implementations, more than two radiation sensors can be used, for example, three or four radiation sensors.

[0079] In some implementations, the position-sensing volume 911 may include all or portions of an enclosed room, in which case the two or more radiating elements may be located in corners of the enclosed room.

[0080] As a yet further example, in some implementations, one or more of the radiating elements 920, 930, and 940 may be proximate to, or integrated with a radiation sensor. In the implementation illustrated in Figure 9G, for example, radiating element 920 is integrated with radiation sensor 950a, radiating element 930 is integrated with radiation sensor 950b, and radiating element 940 is integrated with radiation sensor 950c. As a result, light emitted by, for example, radiating element 920 may be scattered back toward the integrated radiation sensor 950a and/or scattered toward all of radiation sensors 950a, 950b and 950c. Although illustrated with three radiating elements 920, 930 and 940, each integrated with a radiation sensor 950a, 950b and 950c, it will be understood that in some implementations, more than three radiating elements integrated with radiation sensors may be used. In one example, four radiating elements, each integrated with a radiation sensor may be used.

[0081] The position-sensing region may be associated with a display of an electronic device such as, but not limited to, mobile telephones, multimedia Internet enabled cellular telephones, smartphones, personal data assistants (PDAs), wireless electronic mail receivers, hand-held or portable computers, netbooks, notebooks, smartbooks, electronic reading devices (e.g., e-readers), computer monitors, and the like.

[0082] The wavelengths of the electromagnetic radiation emitted from the radiating elements may be in various frequency ranges, such as infrared (IR) radiation, visible light, and ultraviolet radiation, depending on the desired application. For example, as illustrated in Figure 9A, radiating elements in the form of three (3) different LEDs with respective saturated primary colors (Red, Green, and Blue) may be provided. Other electromagnetic radiation sources (with an appropriate wavelength discriminating radiation sensor) are also within the contemplation of the

present inventors. For example, lasers (which may be coupled with a diffuser or lens to diffuse the laser light over a portion of the 2-dimensional plane) may be used in addition to, or instead, of LEDs.

[0083] Radiation sensors (such as radiation sensor 950 of Figures 9A, 9B, 9C, 9D, 9E, and 9H, or radiation sensors 950a and 950b of Figure 9F, or radiation sensors 950a, 950b, and 950c of Figure 9G) may be any sensor capable of wavelength or color discrimination. In various implementations, a radiation sensor may include multiple photodiodes, where each photodiode is matched with a color filter so that the radiation sensor provides multiple outputs, each of the multiple outputs indicating the intensity of light for a given color. In some implementations, for example, each photodiode is matched with one of a Red, Green, or Blue color filter. In this example, each photodiode may then provide a reading of the intensity or strength of Red, Green, or Blue components in the scattered light. In alternative implementations, particularly implementations with multiple radiation sensors, each radiation sensor may include only one photodiode with only one color filter to provide only one output indicating the intensity of light for only color.

[0084] In some implementations, a display screen, which may be included in an IMOD display device as described hereinabove, may utilize the present 3-D position-sensing techniques. For example, the display screen may have an external surface proximate to a first border of the position-sensing volume. Advantageously, a viewable area of the display screen may be substantially co-extensive with the first border of the position-sensing volume. The display screen may be rectangular, in which case up to three radiating elements may each be disposed proximate to a respective corner, while a fourth corner may be occupied by radiation sensor 950. Additional radiation sensors (not illustrated) may be also be placed along sides of the position-sensing region or in corners, for example, adjacent to radiating elements 920, 930, and 940. Alternatively, however, one or more radiating elements and/or radiation sensor 950 may be disposed proximate to a respective side.

[0085] In an implementation, radiation sensor 950 may be located substantially in the same plane as radiating elements 920, 930, and 940 (if present). A processor 960 may be coupled to radiation sensor 950 and be configured to determine 3-D coordinates of the position of the object in the region of the plane based on the detected scattered radiation, as described in more detail herein below.

[0086] Due to the spatial separation of radiating elements 920, 930, and 940, each coordinate in the position-sensing region has a different characteristic "color", or band of wavelengths. Referring to Figure 9B, for example, it is illustrated how different light intensities of red, green, and blue light at a particular location depend upon the distance of each of the first, second, and third radiating elements 920, 930, and 940 from the location. The different light intensities, coupled with additive color mixing, results in a 3-D position-sensing region space that is color-coded. That is, each location, which may be defined by an (X, Y, Z) coordinate has a unique combination of color densities. Radiation scattered from an object at that coordinate will likewise have a unique characteristic. Put another way, characteristics of the scattered radiation will have a correlation with a position of the object in the position-sensing region.

[0087] Figure 10 shows an example of the arrangement of Figures 9A and 9B, illustrating how emitted radiation may interact with an object in a position-sensing region. When a finger or other object enters the position-sensing region, it scatters the emitted radiation. Some of the scattered emitted radiation will reach the radiation sensor 950. Characteristics of the radiation arriving at the radiation sensor (the "detected scattered radiation") may be analyzed by processor 960 to determine the X, Y, Z position of the object. For example, when the object touches region 1001 of position-sensing region 910, scattered light of a first particular color and intensity will be received by radiation sensor 960. When the object touches region 1002 of position-sensing volume 911, scattered light of a second particular color and intensity will be received by the radiation sensor. Thus, characteristics of the detected scattered radiation will have a correlation with the position touched by the object. Advantageously, the correlation may be used to determine the three dimensional position of the object. In one implementation, determination of the three dimensional position is accomplished by processor 960 coupled to radiation sensor 950. For example, processor 960 may determine a relative strength of radiation scattered from the object of each of a first EM radiation and a second EM radiation.

[0088] In some implementations, a three dimensional position determination of at least two objects simultaneously present in the position-sensing region may be facilitated. For example, two or more radiating elements may each be configured to emit a modulated first EM radiation of a first wavelength toward a respective portion of a position-sensing volume, such that each radiating element is modulated in a

mutually distinct manner. For example, one radiating element having the first wavelength may be pulsed on/off at a first duty cycle, whereas a second radiating element having the first wavelength may be pulsed on/off at different duty cycle. In an implementation illustrated in plan view, by Figure 9H, for example, radiating elements 920a and 920b may each emit light associated with a first color, and radiating element 920a may be modulated by, for example, a mutually distinct duty cycle from the duty cycle of radiating element 920b. Radiating elements 930a and 930b may each emit light associated with a second color, and each may be modulated by, for example, a mutually distinct duty cycle. Radiating elements 940a and 940b may each emit light associated with a second color, and be modulated by, for example, a mutually distinct duty cycle. Using the additional information provided by providing at least two radiating elements emitting light of a given color at a mutually distinct modulation, a processor may be configured to determine a three dimensional position of at least two objects simultaneously present in the position-sensing region.

[0089] Because the three dimensional position of an object is constantly determinable by the processor, according to the present teachings, it will be understood that the processor may further be enabled to identify motion of the object. Thus, an instance of a user gesture may be recognized by the processor, which may also be configured to control the interactive display and/or the apparatus, responsive to the user gesture. For example, the processor may be configured to cause an image displayed on the interactive display to be scrolled up or down, rotated, enlarged, or otherwise modified. Alternatively, or in addition, the processor may be configured to control other aspects of the electronic device, responsive to the user gesture. For example, the processor may be configured to change a volume setting, power off the electronic device, place or terminate a telephone call, launch or terminate a software application, etc., responsive to the user gesture.

[0090] In some implementations, normalization of the color field may be achieved with highly accurate control of the spectrum/intensity of each radiation emitter and the scattered light can be detected with a high resolution radiation sensor. As a result, the number of color coordinates can be very large, and the effective signal to noise ratio of the optical touch apparatus may be significantly improved.

[0091] Figure 11 shows an example of a flow diagram illustrating a method 1100 for determining a three dimensional position of an object. At block 1110 first and second EM radiation may be emitted, toward a position-sensing volume. The first

EM radiation may have a first wavelength or a first band of wavelengths about the first wavelength; the second EM radiation may have a second wavelength, or a second band of wavelengths about the second wavelength, the second wavelength being different from the first wavelength. For example, the first and second EM radiation may be emitted by a respective LED, emitting light at a visual, IR or UV wavelength.

[0092] At block 1120 radiation scattered from an object may be detected. The detected scattered radiation may result from interaction of the emitted first and second EM radiation with an object located in the position-sensing volume. Characteristics of the detected scattered radiation may have a correlation with a position of the object in the position-sensing volume.

[0093] At block 1130, a three dimensional position of the object may be determined from the correlation. For example, a position determination may be made by a processor receiving signals representative of detected scattered radiation from one or more radiation sensors.

[0094] Figures 12A and 12B show examples of system block diagrams illustrating a display device 40 that includes a plurality of interferometric modulators. The display device 40 can be, for example, a smart phone, a cellular or mobile telephone. However, the same components of the display device 40 or slight variations thereof are also illustrative of various types of display devices such as televisions, tablets, e-readers, hand-held devices and portable media players.

[0095] The display device 40 includes a housing 41, a display 30, an antenna 43, a speaker 45, an input device 48 and a microphone 46. The housing 41 can be formed from any of a variety of manufacturing processes, including injection molding, and vacuum forming. In addition, the housing 41 may be made from any of a variety of materials, including, but not limited to: plastic, metal, glass, rubber and ceramic, or a combination thereof. The housing 41 can include removable portions (not shown) that may be interchanged with other removable portions of different color, or containing different logos, pictures, or symbols.

[0096] The display 30 may be any of a variety of displays, including a bi-stable or analog display, as described herein. The display 30 also can be configured to include a flat-panel display, such as plasma, EL, OLED, STN LCD, or TFT LCD, or a non-flat-panel display, such as a CRT or other tube device. In addition, the display 30 can include an interferometric modulator display, as described herein.

[0097] The components of the display device 40 are schematically illustrated in Figure 12B. The display device 40 includes a housing 41 and can include additional components at least partially enclosed therein. For example, the display device 40 includes a network interface 27 that includes an antenna 43 which is coupled to a transceiver 47. The transceiver 47 is connected to a processor 21, which is connected to conditioning hardware 52. The conditioning hardware 52 may be configured to condition a signal (e.g., filter a signal). The conditioning hardware 52 is connected to a speaker 45 and a microphone 46. The processor 21 is also connected to an input device 48 and a driver controller 29. The driver controller 29 is coupled to a frame buffer 28, and to an array driver 22, which in turn is coupled to a display array 30. In some implementations, a power supply 50 can provide power to substantially all components in the particular display device 40 design.

[0098] The network interface 27 includes the antenna 43 and the transceiver 47 so that the display device 40 can communicate with one or more devices over a network.

The network interface 27 also may have some processing capabilities to relieve, for example, data processing requirements of the processor 21. The antenna 43 can transmit and receive signals. In some implementations, the antenna 43 transmits and receives RF signals according to the IEEE 16.1 1 standard, including IEEE 16.1 1(a), (b), or (g), or the IEEE 802.1 1 standard, including IEEE 802.1 1a, b, g, n, and further implementations thereof. In some other implementations, the antenna 43 transmits and receives RF signals according to the BLUETOOTH standard. In the case of a cellular telephone, the antenna 43 is designed to receive code division multiple access (CDMA), frequency division multiple access (FDMA), time division multiple access (TDMA), Global System for Mobile communications (GSM), GSM/General Packet Radio Service (GPRS), Enhanced Data GSM Environment (EDGE), Terrestrial Trunked Radio (TETRA), Wideband-CDMA (W-CDMA), Evolution Data Optimized (EV-DO), 1xEV-DO, EV-DO Rev A, EV-DO Rev B, High Speed Packet Access (HSPA), High Speed Downlink Packet Access (HSDPA), High Speed Uplink Packet Access (HSUPA), Evolved High Speed Packet Access (HSPA+), Long Term Evolution (LTE), AMPS, or other known signals that are used to communicate within a wireless network, such as a system utilizing 3G or 4G technology. The transceiver 47 can pre-process the signals received from the antenna 43 so that they may be received by and further manipulated by the processor 21. The transceiver 47 also can

process signals received from the processor 21 so that they may be transmitted from the display device 40 via the antenna 43.

[0099] In some implementations, the transceiver 47 can be replaced by a receiver. In addition, in some implementations, the network interface 27 can be replaced by an image source, which can store or generate image data to be sent to the processor 21. The processor 21 can control the overall operation of the display device 40. The processor 21 receives data, such as compressed image data from the network interface 27 or an image source, and processes the data into raw image data or into a format that is readily processed into raw image data. The processor 21 can send the processed data to the driver controller 29 or to the frame buffer 28 for storage. Raw data typically refers to the information that identifies the image characteristics at each location within an image. For example, such image characteristics can include color, saturation and gray-scale level.

[00100] The processor 21 can include a microcontroller, CPU, or logic unit to control operation of the display device 40. The conditioning hardware 52 may include amplifiers and filters for transmitting signals to the speaker 45, and for receiving signals from the microphone 46. The conditioning hardware 52 may be discrete components within the display device 40, or may be incorporated within the processor 21 or other components.

[00101] The driver controller 29 can take the raw image data generated by the processor 21 either directly from the processor 21 or from the frame buffer 28 and can re-format the raw image data appropriately for high speed transmission to the array driver 22. In some implementations, the driver controller 29 can re-format the raw image data into a data flow having a raster-like format, such that it has a time order suitable for scanning across the display array 30. Then the driver controller 29 sends the formatted information to the array driver 22. Although a driver controller 29, such as an LCD controller, is often associated with the system processor 21 as a stand-alone Integrated Circuit (IC), such controllers may be implemented in many ways. For example, controllers may be embedded in the processor 21 as hardware, embedded in the processor 21 as software, or fully integrated in hardware with the array driver 22.

[00102] The array driver 22 can receive the formatted information from the driver controller 29 and can re-format the video data into a parallel set of waveforms that are

applied many times per second to the hundreds, and sometimes thousands (or more), of leads coming from the display's x-y matrix of pixels.

[00103] In some implementations, the driver controller 29, the array driver 22, and the display array 30 are appropriate for any of the types of displays described herein.

5 For example, the driver controller 29 can be a conventional display controller or a bi-stable display controller (such as an IMOD controller). Additionally, the array driver 22 can be a conventional driver or a bi-stable display driver (such as an IMOD display driver). Moreover, the display array 30 can be a conventional display array or a bi-stable display array (such as a display including an array of IMODs). In some
10 implementations, the driver controller 29 can be integrated with the array driver 22. Such an implementation can be useful in highly integrated systems, for example, mobile phones, portable-electronic devices, watches or small-area displays.

[00104] In some implementations, the input device 48 can be configured to allow, for example, a user to control the operation of the display device 40. The input device
15 48 can include a keypad, such as a QWERTY keyboard or a telephone keypad, a button, a switch, a rocker, a touch-sensitive screen, a touch-sensitive screen integrated with display array 30, or a pressure- or heat-sensitive membrane. In some implementations, the input device 48 includes an instance of the optical touchscreen display techniques described above. The microphone 46 can be configured as an
20 input device for the display device 40. In some implementations, voice commands through the microphone 46 can be used for controlling operations of the display device 40.

[00105] The power supply 50 can include a variety of energy storage devices. For example, the power supply 50 can be a rechargeable battery, such as a nickel-cadmium battery or a lithium-ion battery. In implementations using a rechargeable
25 battery, the rechargeable battery may be chargeable using power coming from, for example, a wall socket or a photovoltaic device or array. Alternatively, the rechargeable battery can be wirelessly chargeable. The power supply 50 also can be a renewable energy source, a capacitor, or a solar cell, including a plastic solar cell or
30 solar-cell paint. The power supply 50 also can be configured to receive power from a wall outlet.

[00106] In some implementations, control programmability resides in the driver controller 29 which can be located in several places in the electronic display system. In some other implementations, control programmability resides in the array driver

22. The above-described optimization may be implemented in any number of hardware and/or software components and in various configurations.

[00107] The various illustrative logics, logical blocks, modules, circuits and algorithm steps described in connection with the implementations disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. The interchangeability of hardware and software has been described generally, in terms of functionality, and illustrated in the various illustrative components, blocks, modules, circuits and steps described above. Whether such functionality is implemented in hardware or software depends upon the particular application and design constraints imposed on the overall system.

[00108] The hardware and data processing apparatus used to implement the various illustrative logics, logical blocks, modules and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose single- or multi-chip processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, or, any conventional processor, controller, microcontroller, or state machine. A processor also may be implemented as a combination of computing devices, such as a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. In some implementations, particular steps and methods may be performed by circuitry that is specific to a given function.

[00109] In one or more aspects, the functions described may be implemented in hardware, digital electronic circuitry, computer software, firmware, including the structures disclosed in this specification and their structural equivalents thereof, or in any combination thereof. Implementations of the subject matter described in this specification also can be implemented as one or more computer programs, i.e., one or more modules of computer program instructions, encoded on a computer storage media for execution by, or to control the operation of, data processing apparatus.

[00110] If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. The steps of a method or algorithm disclosed herein may be implemented in a processor-

executable software module which may reside on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that can be enabled to transfer a computer program from one place to another. A storage media may be any available media that may be
5 accessed by a computer. By way of example, and not limitation, such computer-readable media may include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer. Also, any connection can be
10 properly termed a computer-readable medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above also may be included within the scope of computer-readable media. Additionally, the operations of a
15 method or algorithm may reside as one or any combination or set of codes and instructions on a machine readable medium and computer-readable medium, which may be incorporated into a computer program product.

[00111] Various modifications to the implementations described in this disclosure may be readily apparent to those skilled in the art, and the generic principles defined
20 herein may be applied to other implementations without departing from the spirit or scope of this disclosure. Thus, the claims are not intended to be limited to the implementations shown herein, but are to be accorded the widest scope consistent with this disclosure, the principles and the novel features disclosed herein. The word "exemplary" is used exclusively herein to mean "serving as an example, instance, or
25 illustration." Any implementation described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other possibilities or implementations. Additionally, a person having ordinary skill in the art will readily appreciate, the terms "upper" and "lower" are sometimes used for ease of describing the figures, and indicate relative positions corresponding to the orientation of the
30 figure on a properly oriented page, and may not reflect the proper orientation of an IMOD as implemented.

[00112] Certain features that are described in this specification in the context of separate implementations also can be implemented in combination in a single implementation. Conversely, various features that are described in the context of a

single implementation also can be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[00113] Similarly, while operations are depicted in the drawings in a particular order, a person having ordinary skill in the art will readily recognize that such operations need not be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Further, the drawings may schematically depict one more example processes in the form of a flow diagram. However, other operations that are not depicted can be incorporated in the example processes that are schematically illustrated. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the illustrated operations. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products. Additionally, other implementations are within the scope of the following claims. In some cases, the actions recited in the claims can be performed in a different order and still achieve desirable results.

CLAIMS

What is claimed is:

1. An apparatus comprising:

5 a first radiating element configured to emit first electromagnetic (EM) radiation toward a three dimensional position-sensing volume, the first EM radiation having a first wavelength;

 a second radiating element configured to emit second EM radiation toward the three dimensional position-sensing volume, the second EM radiation having a second
10 wavelength different from the first wavelength;

 a processor; and

 at least one radiation sensor coupled to the processor, and configured to (i) detect scattered radiation and (ii) output, to the processor, signals responsive to the detected scattered radiation, the detected scattered radiation resulting from interaction
15 of the emitted first and second EM radiation with an object located in the position-sensing volume, characteristics of the detected scattered radiation having a correlation with a position of the object in the position-sensing volume, wherein the processor is configured to determine, from the correlation, a three dimensional position of the object.

20 2. The apparatus as recited in claim 1, further comprising:

 a third radiating element configured to emit third EM radiation toward the three dimensional position-sensing volume, the third EM radiation having a third wavelength different from the first wavelength and the second wavelength.

3. The apparatus as recited in claim 1 or claim 2, further comprising:

25 a fourth radiating element configured to emit third EM radiation toward the three dimensional position-sensing volume, the fourth EM radiation having a fourth wavelength different from the first wavelength, the second wavelength, and the third wavelength.

4. The apparatus as recited in any one of claims 1-3, wherein:

the first and second wavelengths are in the visible light range, the first wavelength corresponds to a first color, and the second wavelength corresponds to a second color, and the correlation is based, at least in part, on the color of the detected scattered radiation.

5. The apparatus as recited in any one of claims 1-3, wherein the first wavelength and the second wavelength are in a frequency range of EM radiation, the frequency range selected from the group consisting of: infrared radiation, visible light, and ultraviolet radiation.

6. The apparatus as recited in any one of claims 1-5, wherein the radiating elements are light emitting diodes (LEDs) or lasers.

7. The apparatus as recited in claim 1, wherein each of the first radiating element and the second radiating element is proximate to a respective light sensor.

8. The apparatus as recited in claim 1, wherein the object has a known radiation scattering behavior.

9. The apparatus as recited in any one of claims 1-8, wherein the processor is configured to determine a relative strength of a first scattered radiation compared to a second scattered radiation based on the signals of the at least one radiation sensor, wherein the first scattered radiation results from interaction of the emitted first EM radiation with the object and the second scattered radiation results from interaction of the emitted second EM radiation with the object.

10. The apparatus as recited in claim 9, further comprising:

an interactive display providing an input/output (I/O) interface to a user; wherein

the processor is configured to recognize, from the signals of the at least one radiation sensor, an instance of a user gesture, and to control at least one of the interactive display and the apparatus responsive to the user gesture.

11. The apparatus as recited in claim 10, wherein the object is not in direct physical contact with the interactive display.
12. The apparatus as recited in claim 10, wherein the position-sensing volume is proximate to and extends from a surface of the interactive display.
- 5 13. The apparatus as recited in claim 12, wherein the processor is configured to communicate with the interactive display, the processor being configured to process image data; and the apparatus further including a memory device that is configured to communicate with the processor, wherein the interactive display is configured to receive input data and to communicate the input data to the processor.
- 10 14. The apparatus as recited in claim 13, further comprising:
a driver circuit configured to send at least one signal to the interactive display.
15. The apparatus as recited in claim 14, further comprising:
a controller configured to send at least a portion of the image data to the driver circuit.
- 15 16. The apparatus as recited in claim 14, further comprising:
an image source module configured to send the image data to the processor.
17. The apparatus as recited in claim 16, wherein the image source module includes at least one of a receiver, transceiver, and transmitter.
18. An apparatus comprising:
- 20 a first radiating element configured to emit first electromagnetic (EM) radiation toward a three dimensional position-sensing volume, the first EM radiation having a first wavelength;
a second radiating element configured to emit second EM radiation toward the three dimensional position-sensing volume, the second EM radiation having a second
25 wavelength different from the first wavelength; and

means for determining a three dimensional position of an object located in the position-sensing volume using scattered radiation resulting from interaction of the emitted first and second EM radiation with the object.

19. The apparatus as recited in claim 18, further comprising:

5 a third radiating element configured to emit third EM radiation toward the three dimensional position-sensing volume, the third EM radiation having a third wavelength different from the first wavelength and the second wavelength.

20. The apparatus as recited in claim 18 or claim 19, further comprising an interactive display configured to provide an input/output (I/O) interface to a user;
10 wherein the position-sensing volume is proximate to and extends from a surface of the interactive display.

21. A method comprising:

 emitting first electromagnetic (EM) radiation toward a three dimensional position-sensing volume, the first EM radiation having a first wavelength;

15 emitting second EM radiation toward the position-sensing volume, the second EM radiation having a second wavelength different from the first wavelength;

 detecting scattered radiation, the detected scattered radiation resulting from interaction of the emitted first and second EM radiation with an object located in the position-sensing volume, characteristics of the detected scattered radiation having a
20 correlation with a position of the object in the position-sensing volume; and

 determining, from the correlation, a three dimensional position of the object.

22. The method as recited in claim 21, wherein determining, from the correlation, a three dimensional position of the object includes determining, with a processor, a relative strength of a first scattered radiation compared to a second scattered radiation,
25 wherein the first scattered radiation results from interaction of the emitted first EM radiation with the object and the second scattered radiation results from interaction of the emitted second EM radiation with the object.

23. The method as recited in claim 21 or claim 22, further comprising:

emitting third EM radiation toward the position-sensing volume, the third EM radiation having a third wavelength different from the first wavelength and the second wavelength.

5 24. The method as recited in any one of claims 21-23, wherein a user interface surface of an interactive display is proximate to the position-sensing volume.

25. A non-transitory tangible computer-readable storage medium storing instructions executable by a computer to perform a process, the process comprising:

10 emitting first electromagnetic (EM) radiation toward a three dimensional position-sensing volume, the first EM radiation having a first wavelength;

emitting second EM radiation toward the position-sensing volume, the second EM radiation having a second wavelength different from the first wavelength;

15 detecting scattered radiation, the detected scattered radiation resulting from interaction of the emitted first and second EM radiation with an object located in the position-sensing volume, characteristics of the detected scattered radiation having a correlation with a position of the object in the position-sensing volume; and

determining, from the correlation, a three dimensional position of the object.

26. The non-transitory tangible computer-readable storage medium as recited in claim 25, wherein determining, from the correlation, a three dimensional position of
20 the object comprises determining, with a processor, a relative strength of a first scattered radiation compared to a second scattered radiation, wherein the first scattered radiation results from interaction of the emitted first EM radiation with the object and the second scattered radiation results from interaction of the emitted second EM radiation with the object. .

25 27. The non-transitory tangible computer-readable storage medium as recited in claim 25 or claim 26, the process further comprising:

emitting third EM radiation toward the position-sensing volume, the third EM radiation having a third wavelength different from the first wavelength and the second wavelength.

28. The non-transitory tangible computer-readable storage medium as recited in any one of claims 21-27, wherein a user interface surface of an interactive display is proximate to the position-sensing volume.

29. An apparatus comprising:

5 a plurality of first radiating elements, each configured to emit modulated first electromagnetic (EM) radiation toward a respective portion of a position-sensing volume, the modulated first EM radiation having a first wavelength, wherein each of the plurality of first radiating elements is modulated in a mutually distinct manner;

10 a plurality of second radiating elements, each configured to emit modulated second EM radiation toward a respective portion of the position-sensing volume, the modulated second EM radiation having a second wavelength different from the first wavelength, wherein each of the plurality of second radiating elements is modulated in a mutually distinct manner;

15 at least one radiation sensor configured to detect scattered radiation, the detected scattered radiation resulting from interaction of the emitted modulated first and second EM radiation with an object located in the position-sensing volume, characteristics of the detected scattered radiation having a correlation with a position of the object in the position-sensing volume, wherein the apparatus is configured to determine, from the correlation, a three dimensional position of the object.

20 30. The apparatus as recited in claim 29, further comprising:

a processor coupled to the radiation sensor, the processor configured to determine three dimensional coordinates of the position of the object in the position-sensing volume based on the correlation; and

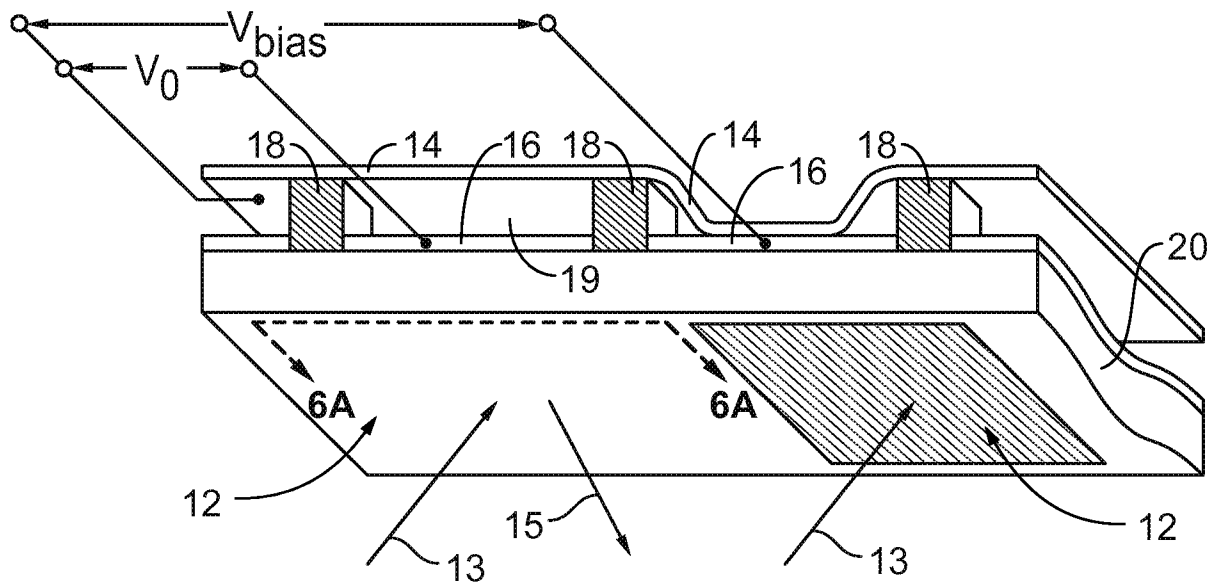
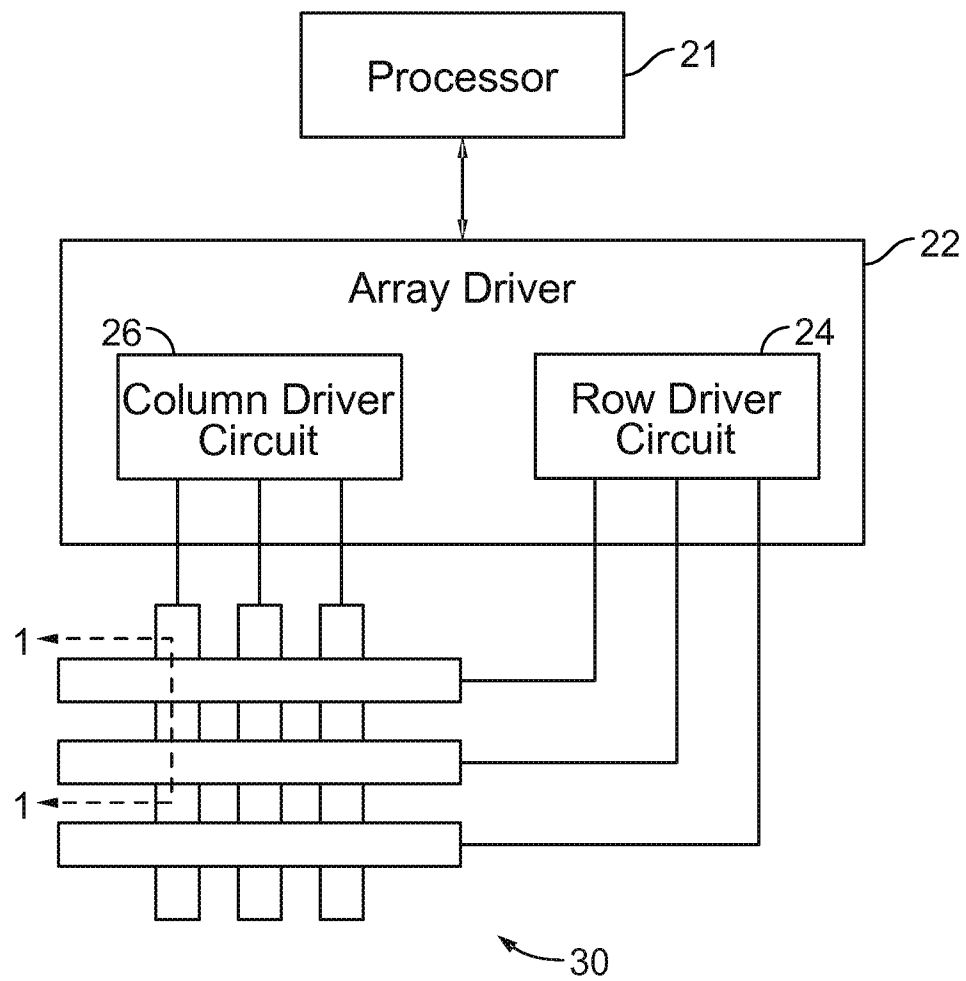
25 an interactive display providing an input/output (I/O) interface to a user; wherein

the processor is configured to recognize, from the output of the radiation sensor, an instance of a user gesture, and to control at least one of the interactive display and the apparatus responsive to the user gesture.

31. The apparatus as recited in claim 29 or claim 30, wherein the processor is configured to determine, from the correlation, a three dimensional position of at least two objects simultaneously present in the position-sensing region.

32. The apparatus as recited in any one of claims 29-31, wherein characteristics of
5 the detected scattered radiation, including first intensity and a first duty cycle of the modulated first EM radiation and a second intensity and a second duty cycle of the modulated second EM radiation, have a correlation with a position of one or more objects in the position-sensing volume, and the apparatus is configured to determine, from the correlation, a three dimensional position of the one or more objects.

10

**Figure 1****Figure 2**

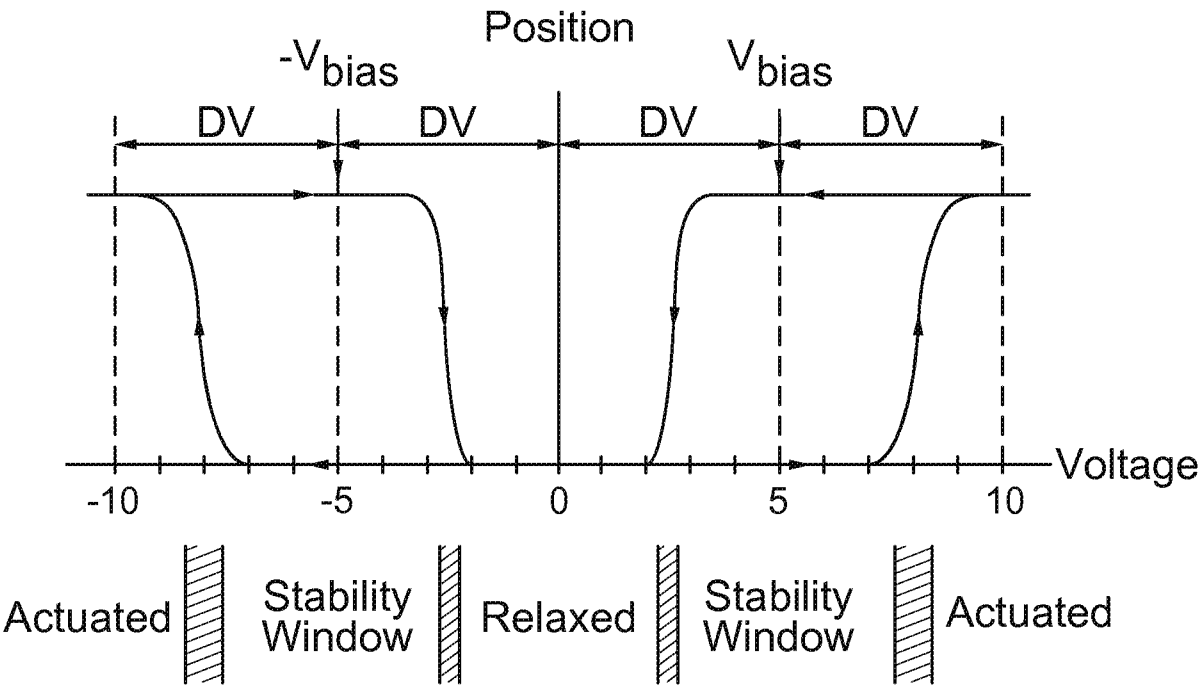
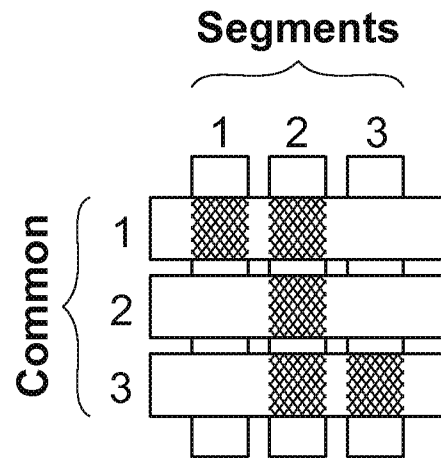
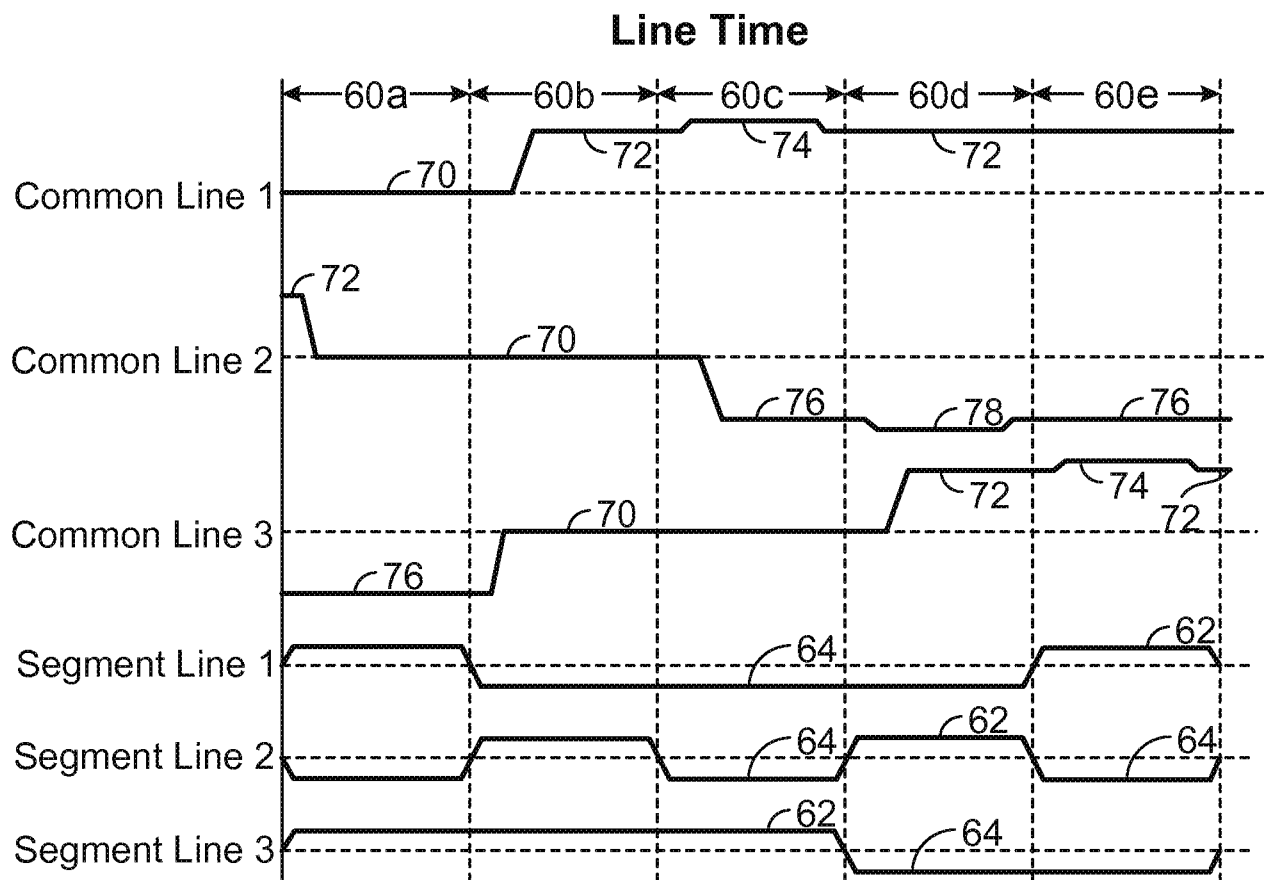


Figure 3

Common Voltages						
Segment Voltages		V_{CADD_H}	V_{CHOLD_H}	V_{CREL}	V_{CHOLD_L}	V_{CADD_L}
	V_{S_H}	Stable	Stable	Relax	Stable	Actuate
	V_{S_L}	Actuate	Stable	Relax	Stable	Stable

Figure 4

**Figure 5A****Figure 5B**

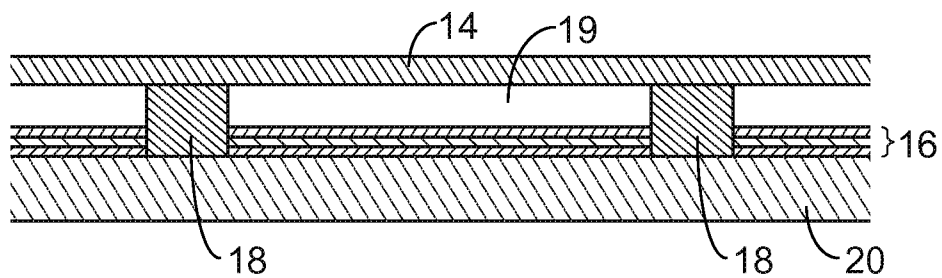


Figure 6A

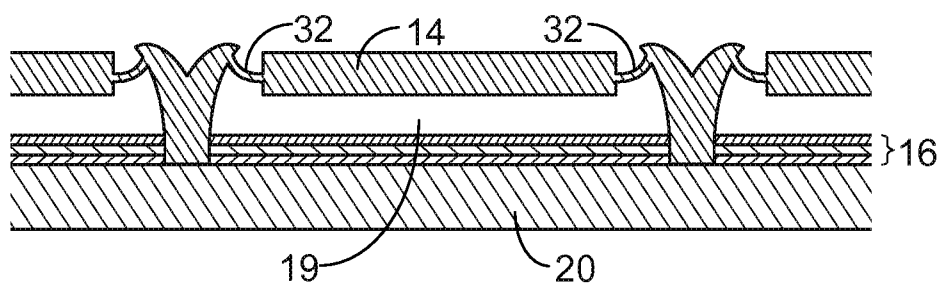


Figure 6B

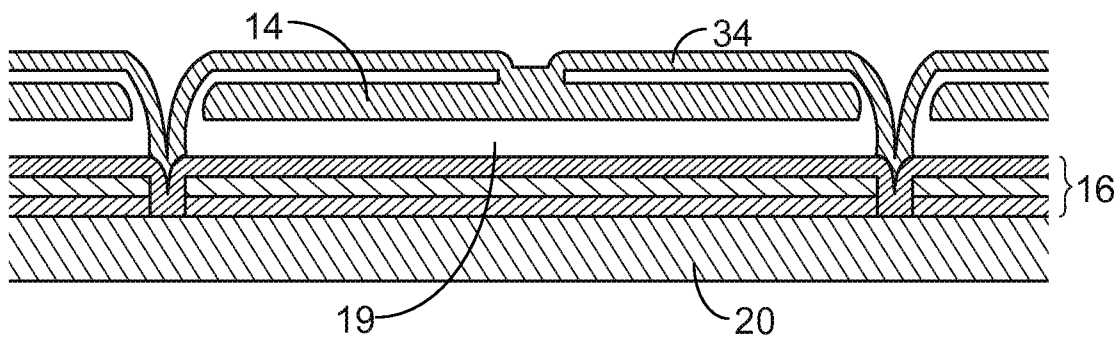


Figure 6C

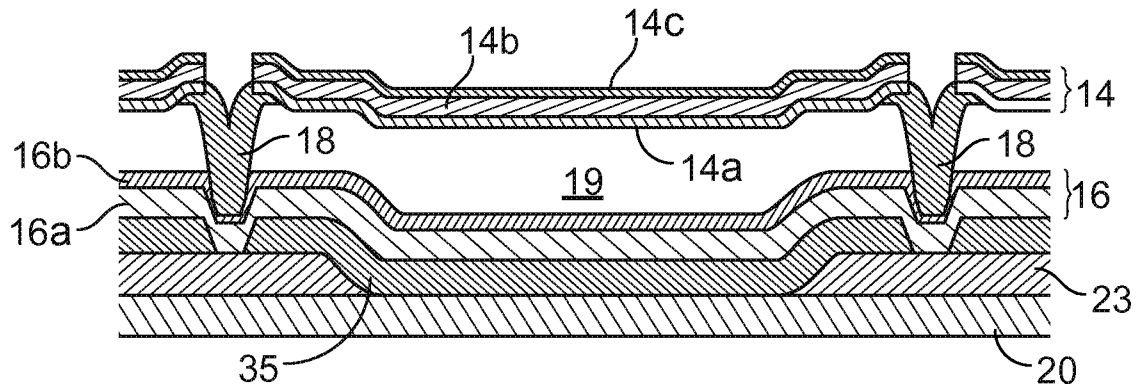


Figure 6D

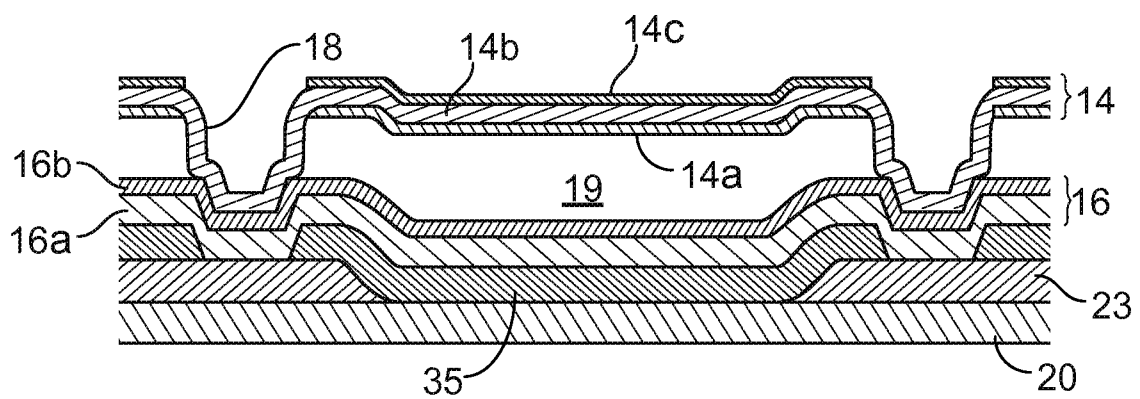
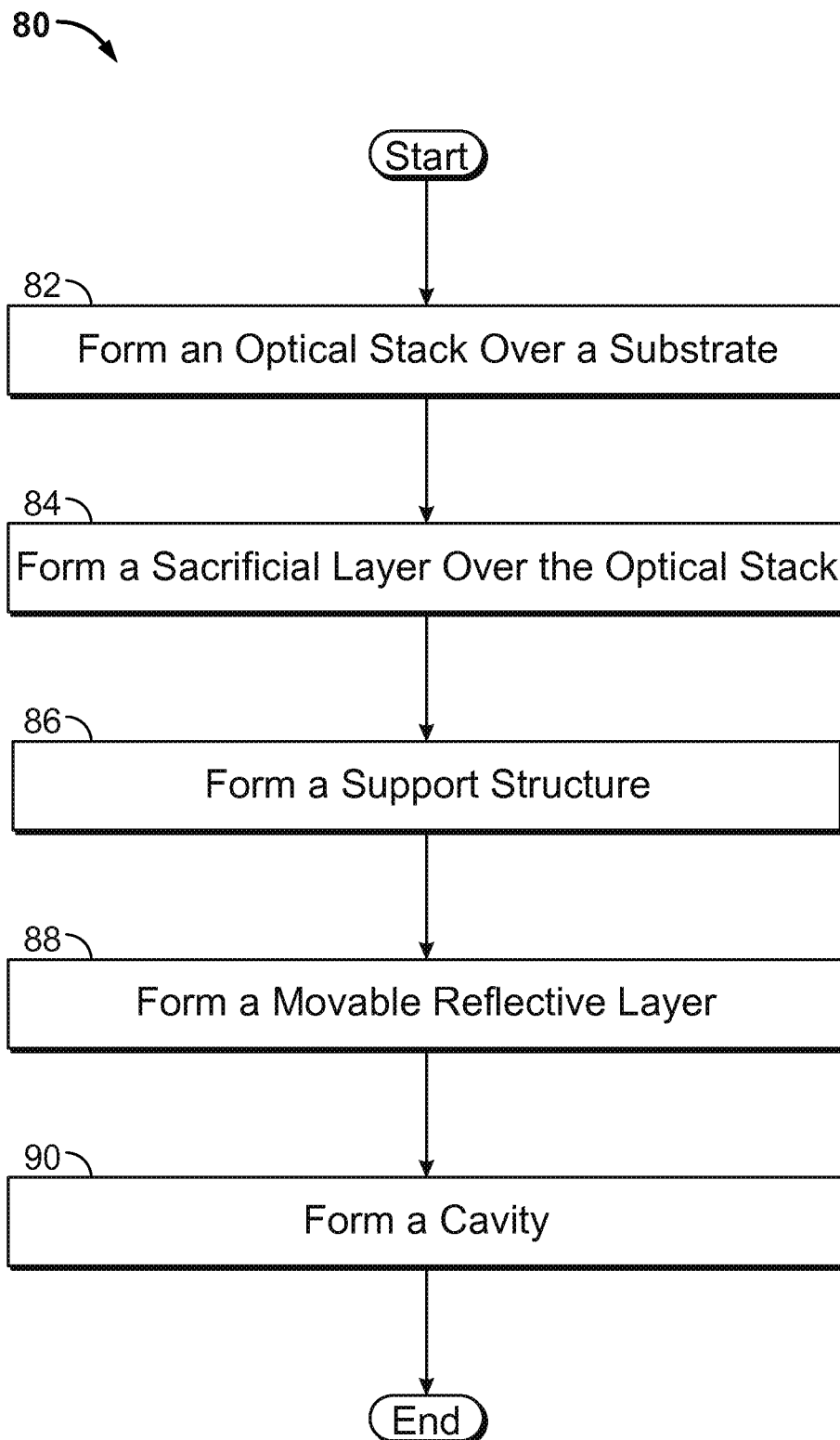


Figure 6E

**Figure 7**

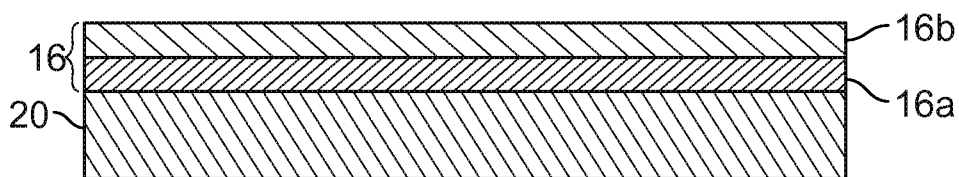


Figure 8A

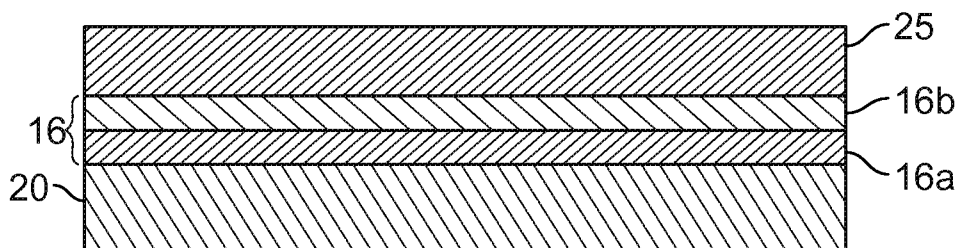


Figure 8B

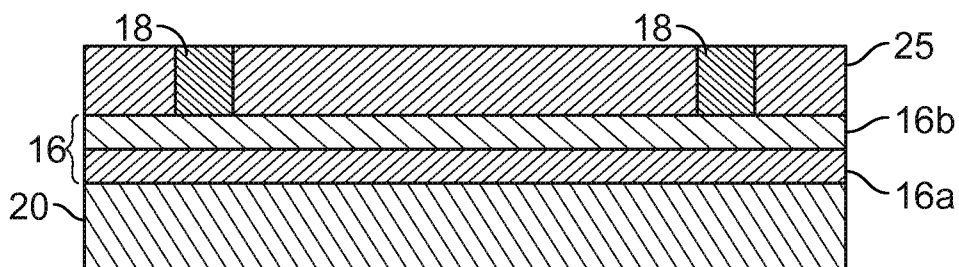


Figure 8C

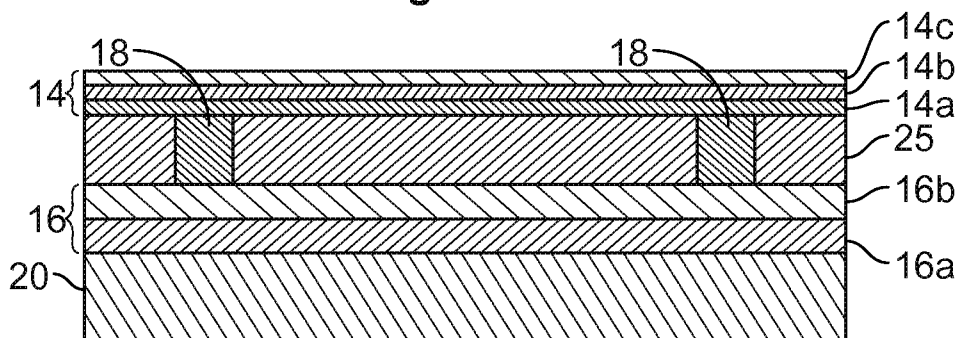


Figure 8D

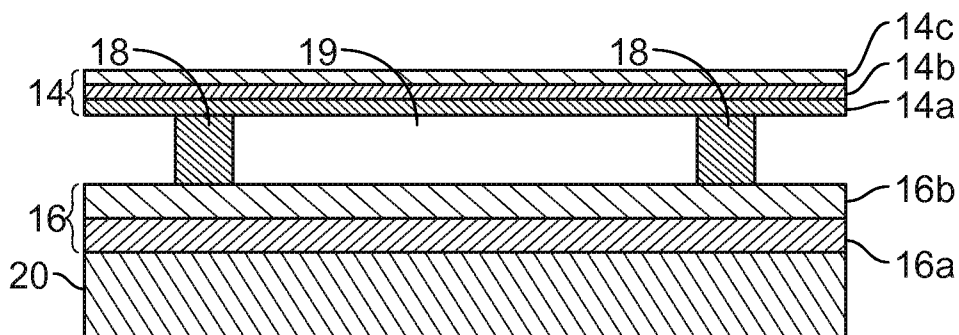


Figure 8E

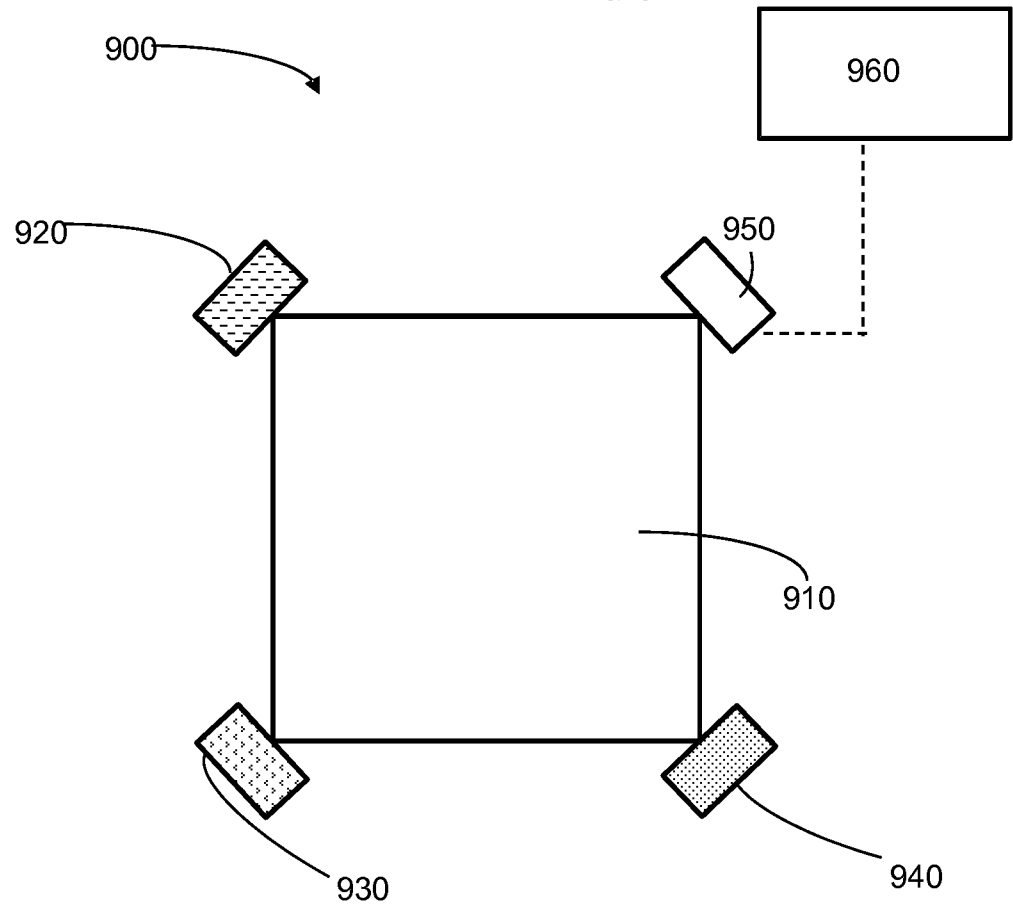


Figure 9A

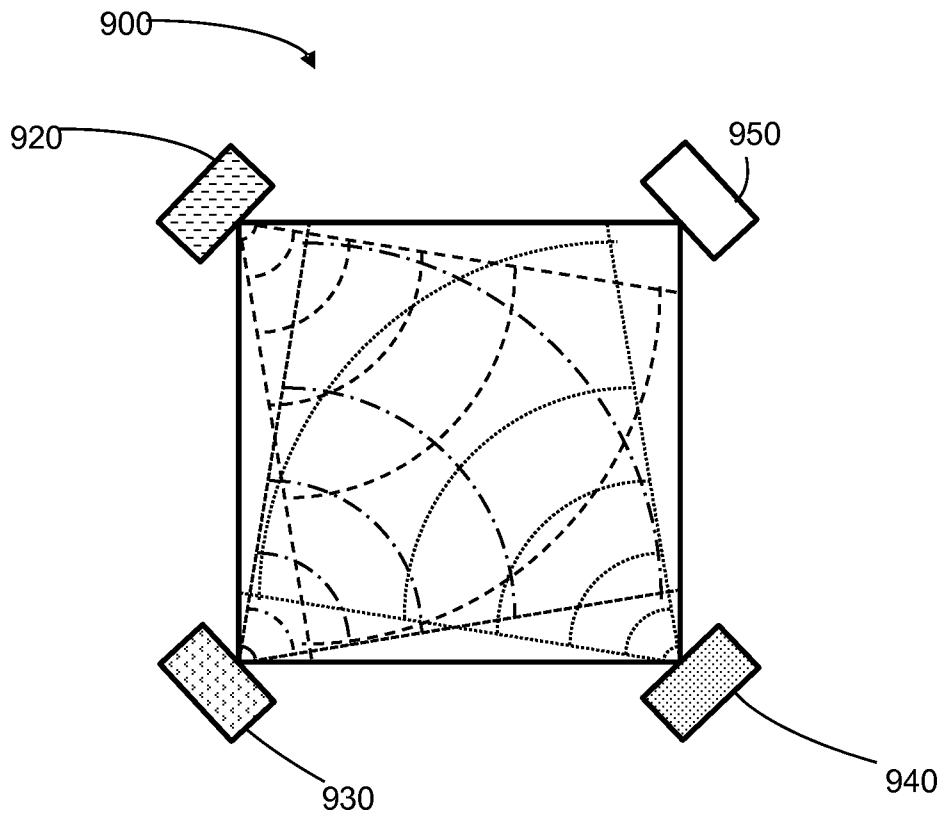
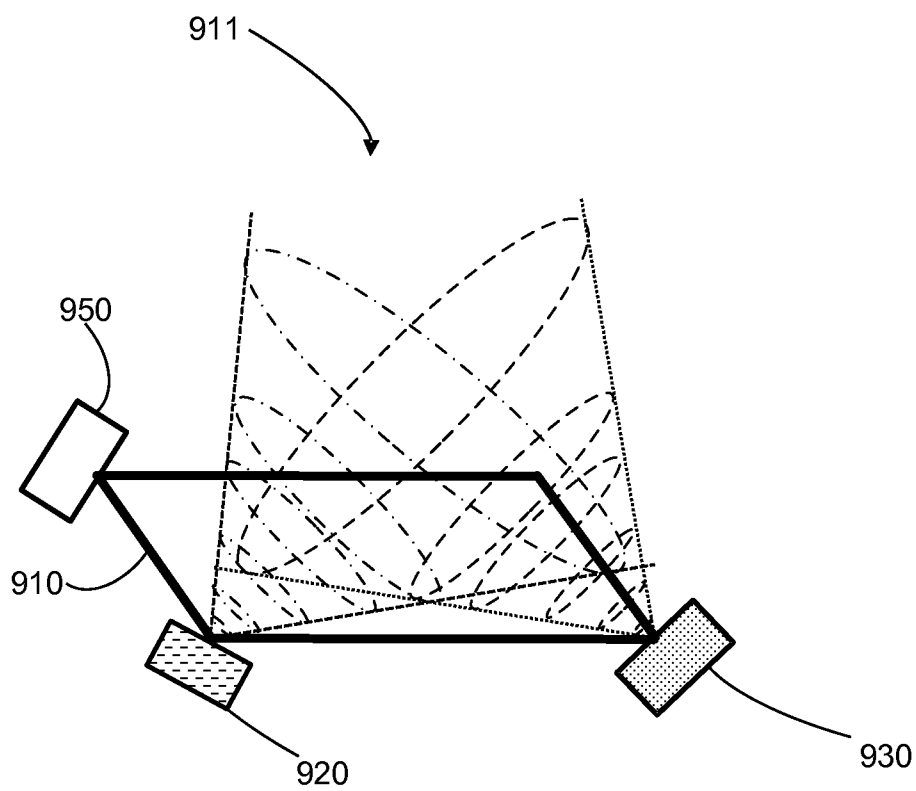
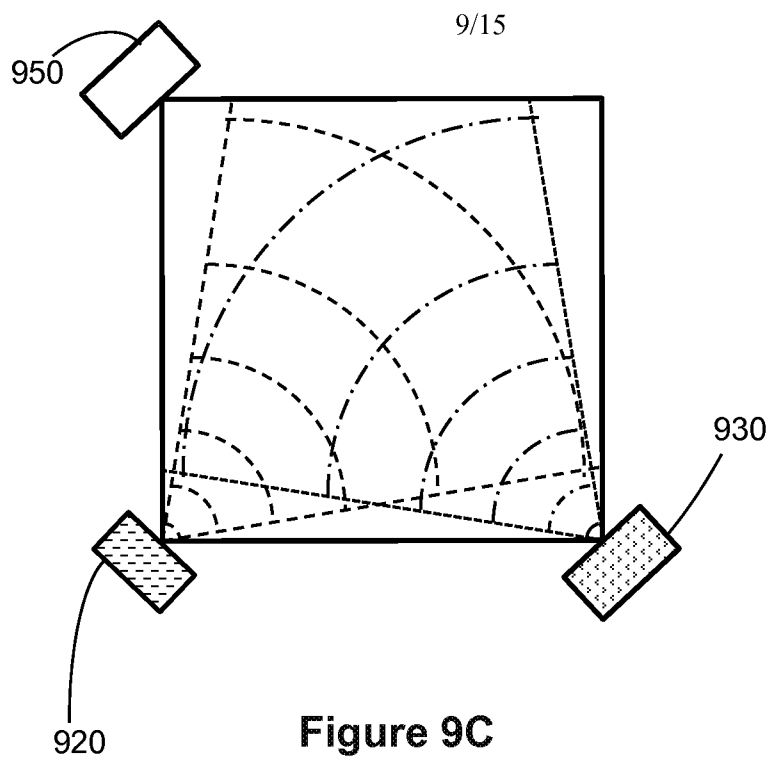


Figure 9B



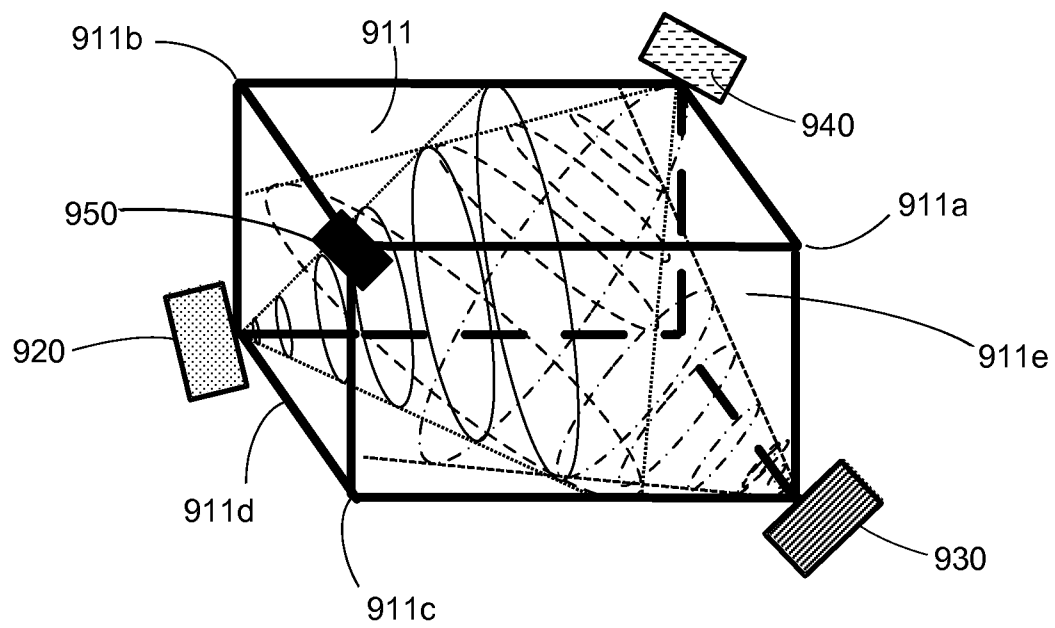


Figure 9E

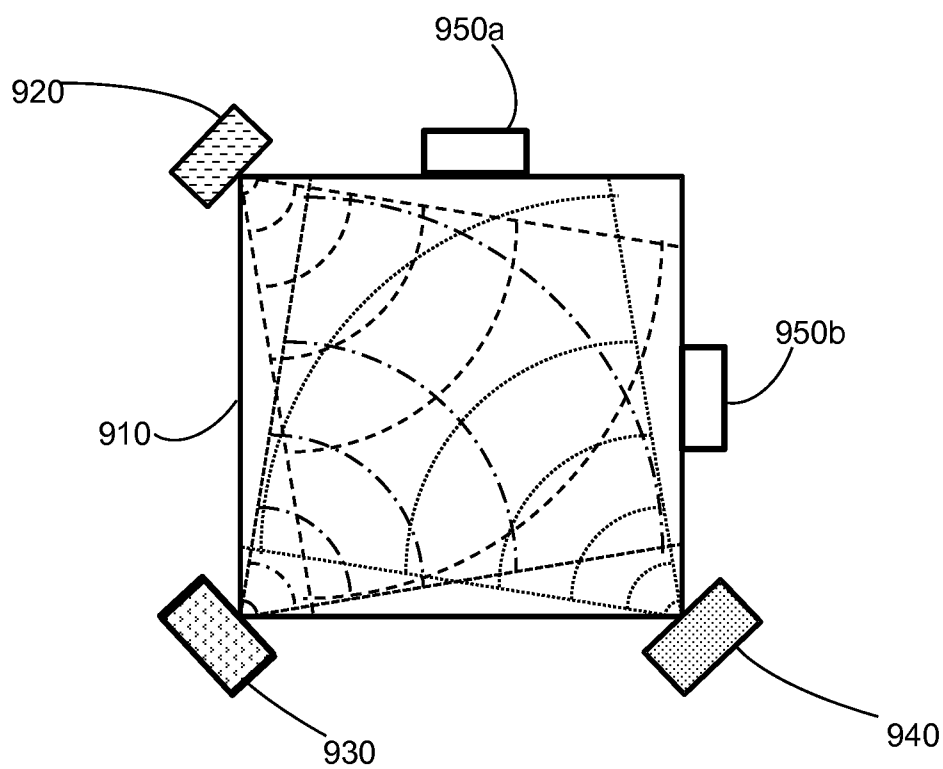


Figure 9F

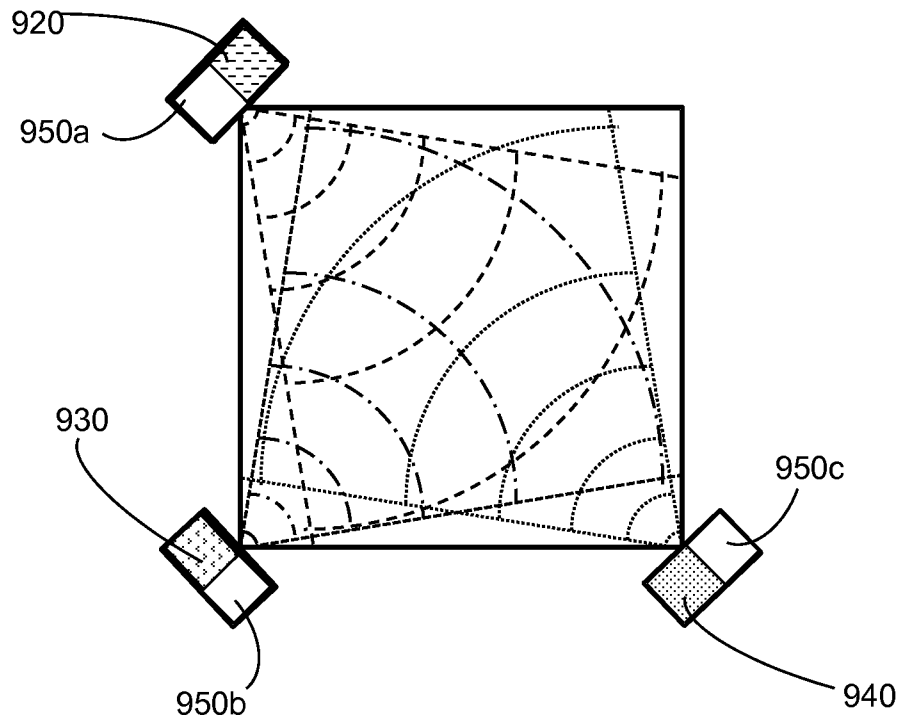


Figure 9G

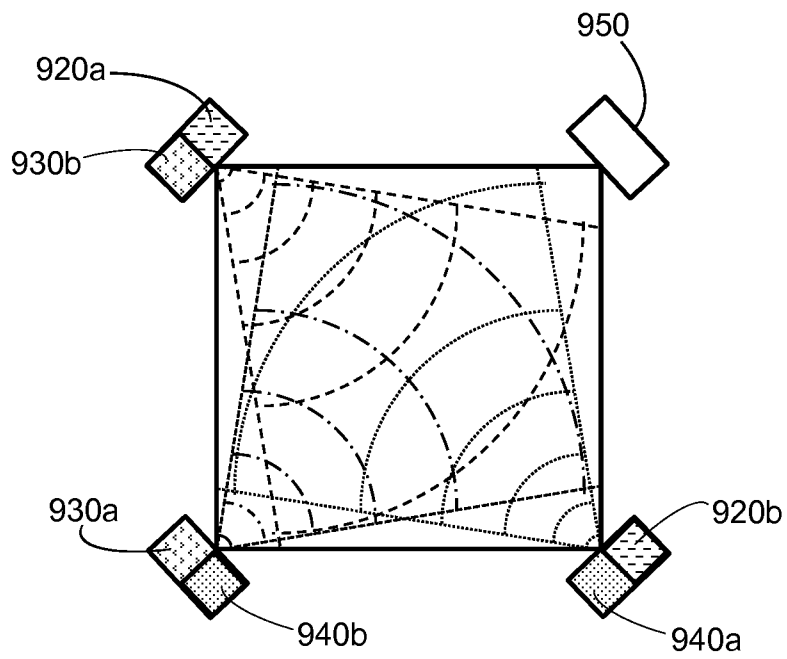


Figure 9H

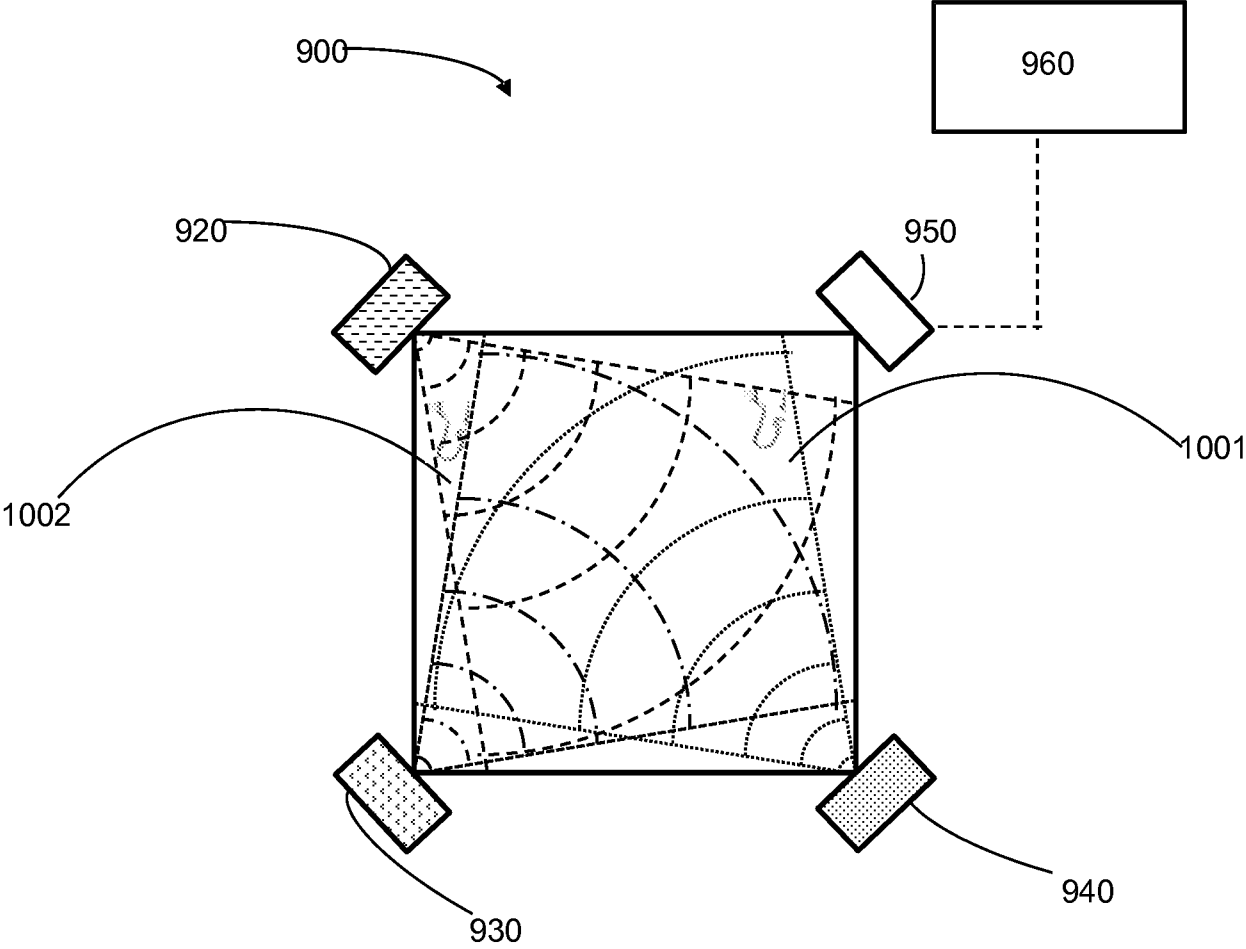


Figure 10

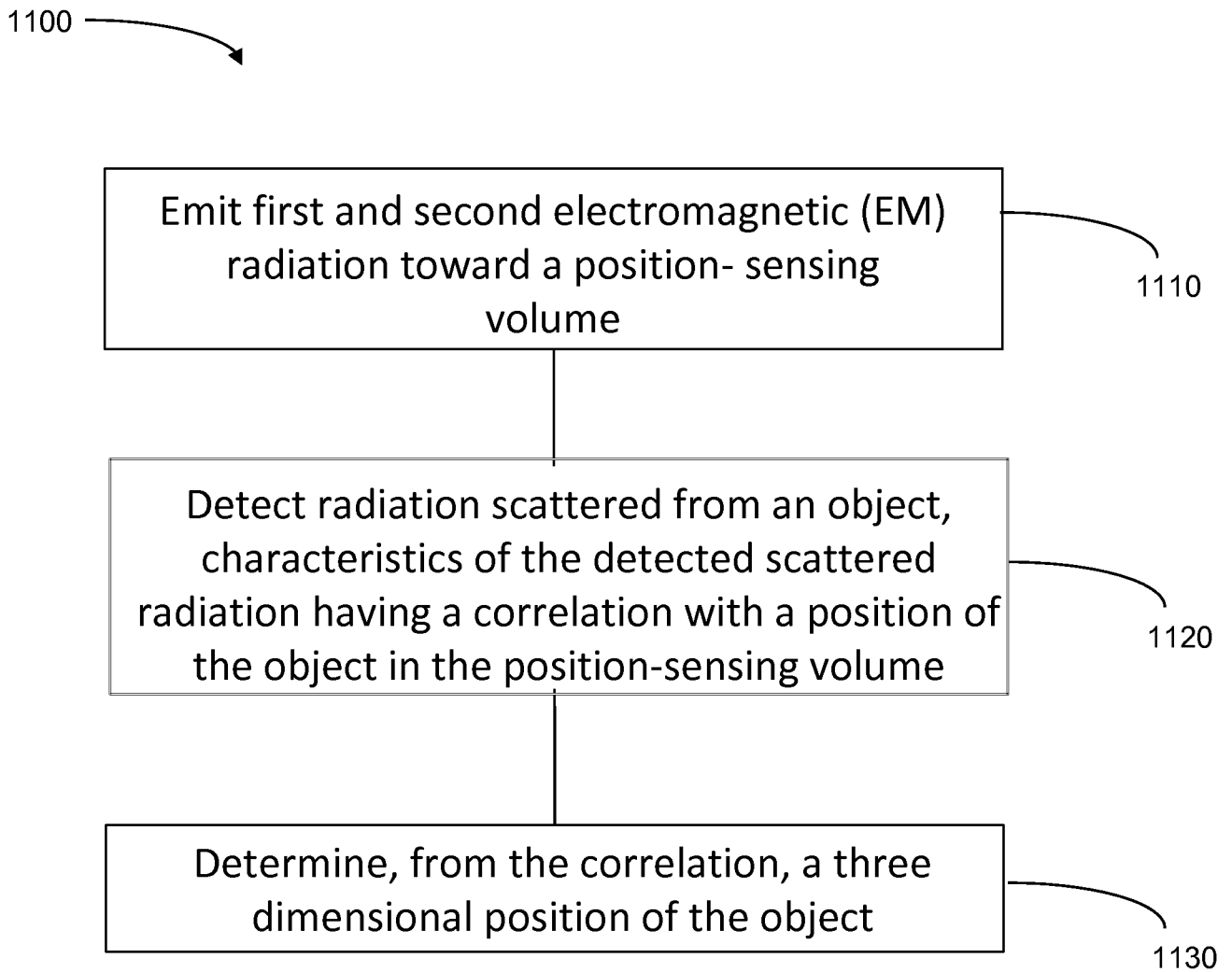
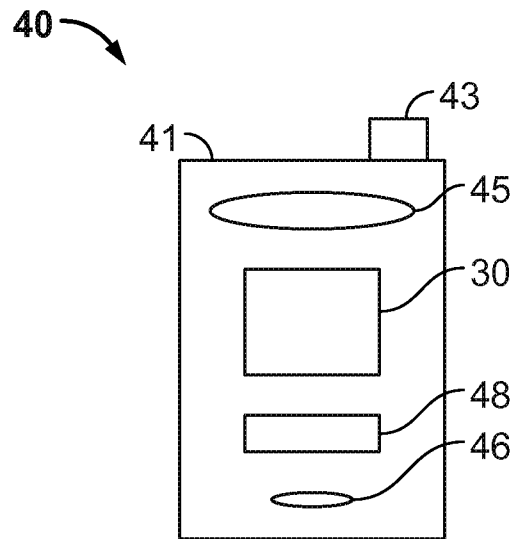
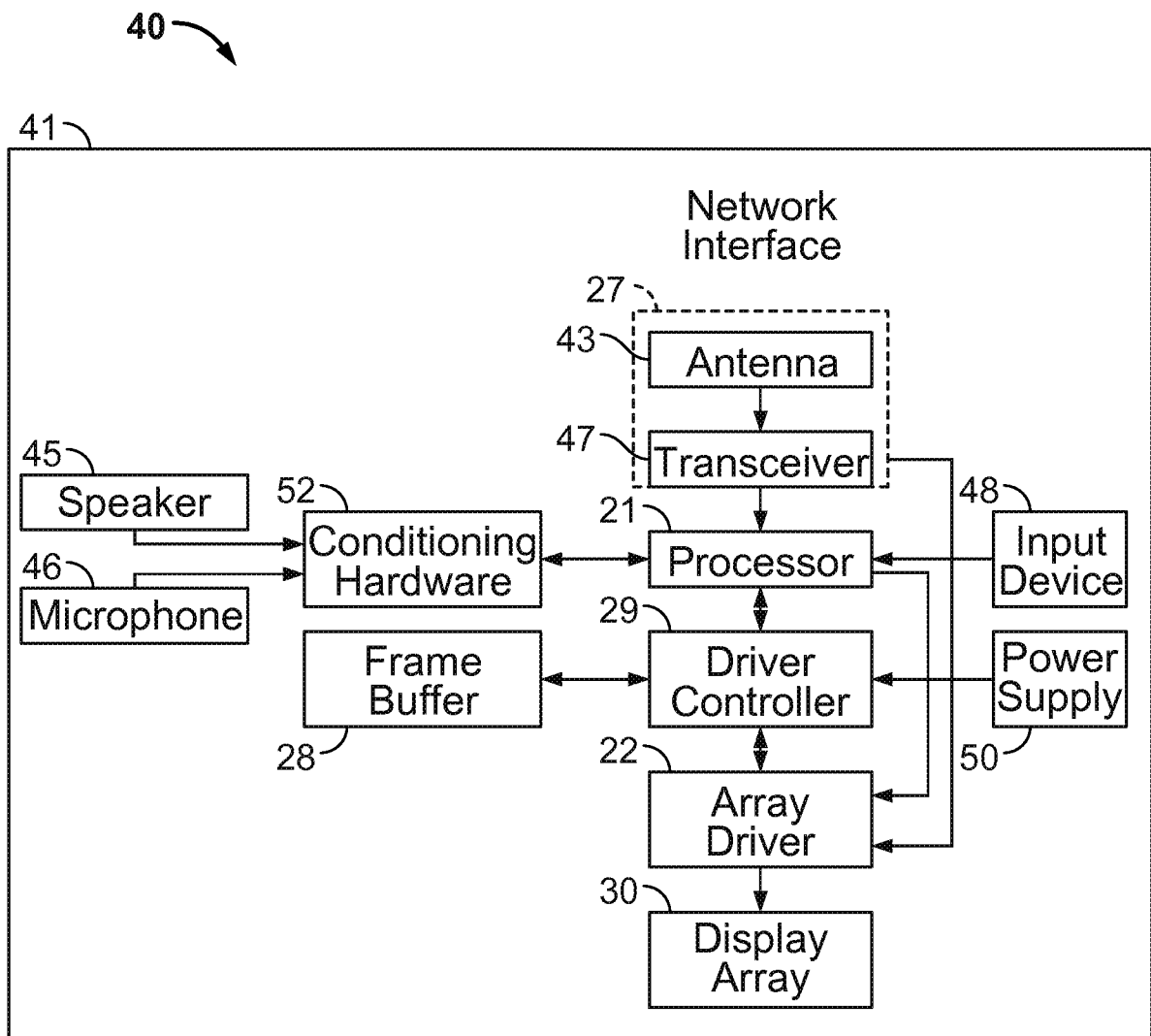


Figure 11

**Figure 12A****Figure 12B**

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/066664

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06F3/042 G06F3/03 GOIBII/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06F G01B

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

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

EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/299642 AI (MERRELL THOMAS [US] ET AL) 25 November 2010 (2010-11-25) paragraphs [0030] , [0033] , [0034] , [0035] paragraphs [0042] - [0047] paragraphs [0055] - [0061] paragraph [0079] -----	1-28



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

21 February 2013

Date of mailing of the international search report

01/03/2013

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

P i r i ou, Nomi noë

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/066664

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: **29-32**
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/21Q

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos. :

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 29-32

No search report has been established for claims 29-32, thus no opinion is established for claims 29-32 with regard to novelty, inventive step and industrial applicability. The subject-matter of claims 29-32 appears to be supported by the description, Article 6 PCT, specifically in the embodiment described in paragraph [0088] the description as originally filed. However in this embodiment, as is also the case in independent claim 29 and dependent claims 30-32, a plurality of first radiating elements emitting an electromagnetic radiation having a first wavelength, and a plurality of second radiating elements emitting an electromagnetic radiation having a second wavelength, are used to determine a three dimensional position of one (claim 29) or two objects (claim 30). The skilled person, in the field of optical position detection, is well aware of the fact that for detection of a three dimensional position, at least three emitters having different wavelengths are determined. In the embodiment of paragraph [0088], there is no provision for a plurality of third radiating elements emitting an electromagnetic radiation having third wavelength. There is also no basis in the application as originally filed from which the skilled person may directly and unambiguously deduce such feature. It is therefore considered that the description, in relation to the embodiment of paragraph [0088], therefore does not disclose the invention in a manner sufficiently clear and complete for the invention to be carried out by the person skilled in the art, contrary to the requirements of Article 5 PCT. As claims 29-32 are based on the embodiment of paragraph [0088], no search can be done with regard to those claims.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guideline C-VI, 8.2), should the problems which led to the Article 17(2) declaration be overcome.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2012/066664

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010299642	A1	25-11-2010	NONE
