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(54) FINGERPRINT SENSOR WITH GAIN CONTROL FEATURES AND ASSOCIATED METHODS

FINGERABDRUCKSENSOR MIT VERSTÄRKUNGSSTEUERUNGSMERKMALEN UND DAZUGEHÖRIGE VERFAHREN

CAPTEUR DACTYLOSCOPIQUE PRESENTANT DES CARACTERISTIQUES DE COMMANDE DE GAIN ET PROCEDES ASSOCIES

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- **PATENT ABSTRACTS OF JAPAN vol. 013, no. 407 (E-818), 8 September 1989 -& JP 01 146464 A (OKI ELECTRIC IND CO LTD), 8 June 1989**
- **PATENT ABSTRACTS OF JAPAN vol. 014, no. 185 (P-1036), 13 April 1990 -& JP 02 031377 A (RICOH CO LTD), 1 February 1990**

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Description

[0001] The present invention relates to the field of personal identification and verification, and, more particularly, to the field of fingerprint sensing and processing.

[0002] Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. In particular, a common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in a database to determine proper identification of a person, such as for verification purposes.

[0003] A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. The specification of US-A-4,210,899 discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. The specification of US-A-4,525,859 discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

[0004] WO 86/06527 discloses a skin pattern recognition device in which an image of the print of a skin pattern is projected onto a photo-detector device and the intensity variations of the print image in at least one region thereof is digitally processed to form a digital signal which is compared to a second signal derived from stored skin pattern information.

[0005] Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. in addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams.

[0006] The specification of US-A-4,353,056 discloses another approach to sensing a live fingerprint. In particular, it discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques.

[0007] Unfortunately, the resilient materials required for the sensor may suffer from long term reliability problems.

[0008] The specification of US-A-5,325,442 discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying portion of the finger surface which, in turn, is at ground potential. The sensor is fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes.

[0009] Unfortunately, driving the array of closely spaced sensing electrodes may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. The specification of USA-4,811,414 discloses methods for noise averaging, illumination equalizing, directional filtering, curvature correcting, and scale correcting for an optically generated fingerprint image.

[0010] JP-A-01146464 discloses an AGC circuit in a picture reader in which an analogue signal from a reader sensor is converted into a digital signal so as to apply digital processing and facilitate the setting of the AGC characteristic and eliminate dispersion of an AGC output.

[0011] JP-A-02031377 discloses an automatic level controller for sound recording and reproducing device in which the number of ports is reduced by using a Digital to Analogue converter to generate a reference voltage for an AD converter and automatically controlling the range of the AD converter.

[0012] EP 0 786 745 A2 published on 30 July 1997 and claiming a priority date of 26 January 1996 discloses an enhanced security fingerprint sensor package having A/D converters for converting analogue signals from an array of electric field sensing elements. A reference voltage of the A/D converters is under control of a processor so as to achieve a limited degree of dynamic contrast compensation.

[0013] An object of the present invention is to provide a fingerprint sensor and related methods so that the fingerprint sensor may accommodate variations in image signal intensities, such as between different fingers, for different sensing conditions, or based on manufacturing process variations, for example.

[0014] According to one aspect, the present invention consists in a fingerprint sensor comprising an array of fingerprint sensing elements, at least one analogue-to-digital (A/D) converter for converting an analogue signal from at least one fingerprint sensing element to a digital signal based upon at least one reference voltage for controlling the range of the A/D converter, the or each A/D converter having at least one reference voltage input for receiving the reference voltage, scanning means for operating said at least one AID converter and said array of fingerprint sensing elements to perform sequential A/D conversions of predetermined ones of said array of fingerprint sensing elements, and reference voltage determining and setting means for controlling the at least one reference voltage of the or each A/D converter based upon prior A/D conversions to thereby provide enhanced conversion resolution, said reference voltage determining and setting means comprising a processor including histogram generating means for generating a histogram based upon prior A/D conversions.

[0015] According to another aspect, the present invention consists in a method for operating a fingerprint sensor of a type comprising an array of fingerprint sensing elements, the method comprising the steps of, converting analogue signals from the array of fingerprint sensing elements to digital signals using at least one A/D converter having a controllable range, performing sequential A/D conversions of predetermined ones of the array of fingerprint sensing elements, and determining and controlling the range of the at least one A/D converter based upon prior A/D conversions to thereby provide enhanced conversion resolution, in which the range of the at least one A/D converter is controllable based upon at least one reference voltage, and the step of determining and controlling the range comprises controlling the at least one reference voltage, wherein the step of converting analogue signals comprises converting same using at least one amplifier having a controllable gain for permitting setting of the range, and the step of determining and controlling the range comprises controlling the range using the amplifier, generating a histogram based upon a prior A/D conversions, and setting a default range for initial ones of the fingerprint sensing elements.

[0016] The conversion resolution is enhanced despite variations in sensed fingers, conditions, or despite process variations resulting from manufacturing.

[0017] In one embodiment, the A/D conversion means preferably comprises a plurality or bank of A/D converters for simultaneously converting analogue signals from a corresponding plurality of fingerprint sensing elements. By enabling dynamic exploitation of the full resolution range of the A/D converters, the accuracy of the sensing can be significantly improved.

[0018] Accordingly, the range determining and setting means may include at least one digital-to-analogue converter connected between the processor and the at least one reference voltage input. In particular, the AID converters may typically include a first reference voltage input and a second reference voltage input for setting corresponding first and second range points thereby defining the range. Alternatively, or in addition thereto, the A/D conversion means may include at least one amplifier having a controllable gain for permitting setting of the range.

[0019] In addition, the range determining and setting means may comprise default setting means for setting a default range for initial ones of the fingerprint sensing elements.

[0020] Each of the fingerprint sensing elements may be provided by an electric field sensing electrode and an amplifier associated therewith. A shield electrode may also be associated with each electric field sensing electrode and be connected to a respective amplifier.

[0021] The invention will now be described, by way of example, with reference to the accompanying drawings in which:

FIG. 1 is a top plan view of a fingerprint sensor,
FIG. 2 is a schematic view of a circuit portion of the fingerprint sensor as shown in FIG.1,
FIG. 3 is a greatly enlarged top plan view of the sensing portion of the fingerprint sensor as shown in FIG.1,
FIG. 4 is a schematic diagram of another circuit portion of the fingerprint sensor as shown in FIG.1,
FIG. 5 is a greatly enlarged side cross-sectional view of a portion of the fingerprint sensor as shown in FIG.1,
FIG. 6 is a greatly enlarged side cross-sectional view of a portion of an alternate embodiment of the fingerprint sensor,
FIG. 7 is a greatly enlarged side cross-sectional view of another portion of the fingerprint sensor as shown in FIG.1,
FIG. 8 is a schematic block diagram of yet another circuit portion of the fingerprint sensor as shown in FIG.1.
FIG. 9 is a schematic circuit diagram of a portion of the circuit as shown in FIG. 8.
FIG. 10 is a schematic block diagram of still another circuit portion of the fingerprint sensor as shown in FIG. 1.
FIG. 11 is a schematic block diagram of an alternate embodiment of we circuit portion shown in FIG. 10.
FIG. 12 is a schematic block diagram of an additional circuit portion of the fingerprint sensor as shown in FIG. 1.
FIG. 13 is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. 12.

[0022] Referring to FIGS. 1-3 depict the fingerprint sensor **30** that includes a housing or package **51,** a dielectric layer **52** exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of output pins, not shown. A first conductive strip or external electrode **54** around the periphery of the dielectric layer **52**, and a second external electrode **53** provide contact electrodes for the finger **79**. The sensor **30** provides output signals in a range of sophistication levels depending on the level of processing.

[0023] The sensor **30** includes a plurality of individual pixels or sensing elements **30a** arranged in array pattern as perhaps best shown in FIG. **3**. These sensing elements are relatively small so as to be capable of sensing the ridges **59** and intervening valleys **60** of a typical fingerprint. Live fingerprint readings, as from the electric field sensor **30**, is less reliable than optical sensing, because the impedance of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate. In contrast, an optical sensor may be deceived by a readily deceived by a photograph or other similar image of a fingerprint, for example.

[0024] The sensor **30** includes a substrate **65**, and one or more active semiconductor devices formed thereon, such as the schematically illustrated amplifier **73.** A first metal layer **66** interconnects the active semiconductor devices. A second or ground plane electrode layer **68** is above the first metal layer **66** and separated therefrom by an insulating layer **67**. A third metal layer **71** is positioned over another dielectric layer **70**. The first external electrode **54** is connected to an excitation drive amplifier **74** which, in turn, drives the finger **79** with a signal which may be typically in the range of about 1 KHz to 1 MHz. The drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor **30** may be relatively low, while the reliability is great.

[0025] A circularly shaped electric field sensing electrode **78** is on the insulating layer **70**. The sensing electrode **78** may be connected to sensing integrated electronics, such as amplifier **73** formed adjacent the substrate **65** as schematically illustrated.

[0026] An annularly shaped shield electrode **80** surrounds the sensing electrode **78** in spaced relation therefrom. The sensing electrode **78** and its surrounding shield electrode **80** may have other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements **30a**. The shield electrode **80** is an active shield which is driven by a portion of the output of the amplifier **73** to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electric field sensing electrodes **78**.

[0027] The sensor **30** includes only three metal or electrically conductive layers **66,68**, and **71**. The sensor **30** can be made without requiring additional metal layers which would otherwise increase the manufacturing cost, and, perhaps, reduce yields. Accordingly, the sensor **30** is less expensive and may be more rugged and reliable than a sensor including four or more metal layers.

[0028] The amplifier **73** is operated at a gain of greater than about one to drive the shield electrode **80**. Stability problems do not adversely affect the operation of the amplifier **73**. Moreover, the common mode and general noise rejection are greatly enhanced. In addition, operating at again greater than one tends to focus the electric field with respect co the sensing electrode **78**.

[0029] The sensing elements **30a** operate at very low currants and at very high impedances. For example, the output signal from each sensing electrode **78** is desirably about **5** to **10** millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element **30a**, as defined by the outer dimensions of the shield electrode **80**, may be about **50.8** to **127** μm in diameter. The ground plane electrode **68** protects the active electronic devices from unwanted excitation. The various signal feed through conductors for the electrodes **78,80** to the active electronic circuitry may be readily formed.

[0030] The overall contact or sensing surface for the sensor 30 may desirably be about **12.7** by **12.7** mm - a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor **30** in accordance with the invention is also fairly tolerant of dead pixels or sensing elements **30a**. A typical sensor **30** includes an array of about **256** by **256** pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor **30** may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

[0031] FIG. 4 shows another aspect of the sensor **30**. The sensor may include power control means for controlling operation of active circuit portions **100** based upon sensing finger contact with the first external electrode **54** as determined by the finger sense block or circuit **101**. For example, the finger sense circuit **101** may operate based upon a change in impedance to an oscillator to thereby determine finger contact. Of course, other approaches for sensing contact with the finger are also contemplated by the invention. The power control means may include wake-up means for only powering active circuit portions upon sensing finger contact with the first external electrode to conserve power. Alternately or additionally, the power control means may further comprise protection means for grounding active circuit portions upon not sensing finger contact with the first external electrode. A combination of wake-up and protection controller circuits **101** are illustrated.

[0032] The fingerprint sensor **30** further comprise finger charge bleed means for bleeding a charge from a finger or other object upon contact therewith. The finger charge bleed means may be provided by the second external electrode **53** carried by the package **51** for contact by a finger, and a charge bleed resistor **104** connected between the second external electrode and an earth ground. As schematically illustrated in the upper right hand portion of FIG. 4, the second electrode may alternately be provided by a movable electrically conductive cover **53'** slidably connected to the package **51** for covering the opening to the exposed upper dielectric layer **52**. A pivotally connected cover is also contemplated by the present invention. Accordingly, under normal conditions, the charge would be bled from the finger as the cover **53'** is moved to expose the sensing portion of the sensor **30**.

[0033] In addition, the finger charge bleed means and power control means may be such that the active portions remain grounded until the charge bleed means can remove the charge on the finger before powering the active circuit portions, such as by providing a brief delay during wake-up sufficient to permit the charge to be discharged through the resistor **104**. Accordingly, power may be conserved in the sensor **30** and BSD protection provided by the sensor so that the sensor is relatively inexpensive, yet robust and conserves power.

[0034] FIG. 5 refers to another feature of the sensor **30**. The dielectric covering **52** comprise a z-axis anisotropic dielectric layer **110** for focusing an electric field, shown by the illustrated field lines, at each of the electric field sensing electrodes **78**.

[0035] The z-axis anisotropic dielectric layer **110** of the present invention, for example, may have a thickness in range of about **2.54** to **101.6** µm. Of course, the z-axis anisotropic dielectric layer **110** is also preferably chemically resistant and mechanically strong to withstand contact with fingers, and co permit periodic cleanings with solvents. The z-axis anisotropic dielectric layer **110** may preferably define an outermost protective surface for the integrated circuit die **120**. Accordingly, the overall dielectric covering **52** may further include at least one relatively thin oxide, nitride, carbide, or diamond layer **111** on the integrated circuit die **120** and beneath the z-axis anisotropic dielectric layer **110**. The thin layer **111** will typically be relatively hard, and the z-axis anisotropic dielectric layer **110** is desirably softer to thereby absorb more mechanical activity.

[0036] The 2-axis anisotropic dielectric layer **110** may be provided by a plurality of oriented dielectric particles in a cured matrix. For example, the z-axis anisotropic dielectric layer **110** may comprise barium titanate in a polyimide matrix.

[0037] FIG. 6 shows another variation of a z-axis dielectric cover **52'** by a plurality of high dielectric portions **112** aligned with corresponding electric field sensing electrodes **78**, and a surrounding matrix of lower dielectric portions **113**. This embodiment of the dielectric covering **52'** may be formed in a number of ways, such as by forming a layer of either the high dielectric or low dielectric portions, selectively etching same, and filling the openings with the opposite material. Another approach may be to use polarizable microcapsules and subjecting same to an electric field during curing of a matrix material. A material may be compressed to cause the z-axis anisotropy.

[0038] Another aspect of the invention relates to being able to completely cover and protect the entire upper surface of the integrated circuit die **120**, and still permit connection and communication with the external devices and circuits as now further explained with reference FIG. 7. The third metal layer **71** (FIG. 2) preferably further includes a plurality of capacitive coupling pads **116a-118a** for permitting capacitive coupling of the integrated circuit die **120.** Accordingly, the dielectric covering **52** is preferably continuous over the capacitive coupling pads **116a-118a** and the array of electric field sensing electrodes **78** of the pixels **30a** (FIG. 1). In sharp contrast to this feature of the present invention, it is conventional to create openings through an outer coating to electrically connect to the bond pads. Unfortunately, these openings would provide pathways for water and/ or other contaminants to come in contact with and damage the die.

[0039] A portion of the package **51** includes a printed circuit board **122** which carries corresponding pads **115b-118b.** A power modulation circuit **124** is coupled to pads **115b-116b**, while a signal modulation circuit **126** is illustrated coupled to pads **117b-118b.** Both power and signals may be coupled between the printed circuit board **122** and the integrated circuit die **120**, further using the illustrated power demodulation/regulator circuit **127**, and the signal demodulation circuit **128**. The z-axis anisotropic dielectric layer **110** also advantageously reduces cross-talk between adjacent capacitive coupling pads. This embodiment of the invention **30** presents no penetrations through the dielectric covering **52** for moisture to enter and damage the integrated circuit die **120**. In addition, another level of insulation is provided between the integrated circuit and the external environment.

[0040] For the sensor **30**, the package **51** has an opening aligned with the array of electric field sensing electrodes **78** (FIGS. **1-3**). The capacitive coupling and z-axis anisotropic layer **110** may be advantageously used in a number of applications in addition to the illustrated fingerprint sensor **30**, and particularly where it is desired to have a continuous film covering the upper surface of the integrated circuit die **120** and pads **116a-118a**.

[0041] Referring to FIGS. 8 and 9, impedance matrix filtering aspects of the invention are now described. In FIG. 8, the fingerprint sensor **30** may be considered as comprising an array of fingerprint sensing elements **130** and associated active circuits **131** for generating signals relating to the fingerprint image. The sensor **30** also includes an impedance matrix **135** connected to the active circuits for filtering the signals therefrom.

[0042] The impedance matrix **135** includes a plurality of impedance elements **136** with a respective impedance element connectable between each active circuit of a respective fingerprint sensing element as indicated by the central node **138**, and the other active circuits (outer nodes **140**). The impedance matrix **135** also includes a plurality of switches **137** with a respective switch connected in series with each impedance element **136.** An input signal may be supplied to the central node **138** via the illustrated switch **142** and its associated impedance element **143.** The impedance element may one or more of a resistor as illustrated, and a capacitor **134.**

[0043] Filter control means may operate the switches **137** to perform processing of the signals generated by the active circuits **131.** In one embodiment, the fingerprint sensing elements **130** may be electric field sensing electrodes **78,** and the active circuits **131** may be amplifiers **73** (FIG. 2).

[0044] Ridge flow determining means **145** may be provided for selectively operating the switches **137** of the matrix **135** to determine ridge flow directions of the fingerprint image. More particularly, the ridge flow determining means **145** may selectively operate the switches **137** for determining signal strength vectors relating to ridge flow directions of the fingerprint image.

[0045] The sensor **30** may include core location determining means **146** cooperating with the ridge flow determining means **145** for determining a core location of the fingerprint image. The position of the core is helpful, for example, in extracting and processing minutiae from the fingerprint image.

[0046] In FIG. 8, a binarizing filter **150** is provided for selectively operating the switches **137** to convert a gray scale fingerprint image to a binarized fingerprint image. Considered another way, the impedance matrix **135** may be used to provide dynamic image contrast enhancement. In addition, an edge smoothing filter **155** may be readily implemented to improve the image. As also schematically illustrated other spatial filters **152** may also be implemented using the impedance matrix **135** for selectively operating the switches **137** to spatially filter the fingerprint image. Accordingly, processing of the fingerprint image may be carried out at the sensor 30 and thereby reduce additional downstream computational requirements.

[0047] FIG. 9 shows the impedance matrix **135** that comprise a plurality of impedance elements with a respective impedance element **136** connectable between each active circuit for a given fingerprint sensing element **130** and eight other active circuits for respective adjacent fingerprint sensing elements.

[0048] The control means **153** is for sequentially powering sets of active circuits **131** to conserve power. Of course, the respective impedance elements **136** are desirably also sequentially connected to perform the filtering function. The powered active circuits **131** may be considered as defining a cloud or kernel. The power control means **153** may be operated in an adaptive fashion whereby the size of the area used for filtering is dynamically changed for preferred image characteristics. In addition, the power control means **153** may also power only certain ones of the active circuits corresponding to a predetermined area of the array of sensing elements **130.**

[0049] Reader control means **154** may be provided to read only predetermined subsets of each set of active circuits **131** so that a contribution from adjacent active circuits is used for filtering. In other words, only a subset of active circuits **131** are typically simultaneously read although adjacent active circuits **131** and associated impedance elements **136** are also powered and connected, respectively. For example, 16 impedance elements **136** could define a subset and be readily simultaneously read. The subset size could be optimized for different sized features to be determined.

[0050] Accordingly, the array of sense elements **130** can be quickly read, and power consumption substantially reduced since all of the active circuits **131** need not be powered for reading a given set of active circuits. For a typical sensor, the combination of the power control and impedance matrix features described herein may permit power savings by a factor of about 10 as compared to powering the full array.

[0051] Another advantage of the fingerprint sensor **30** is to guard against spoofing or deception of the sensor into incorrectly treating a simulated image as a live fingerprint image. For example, optical sensors may be deceived or spoofed by using a paper with a fingerprint image thereon. The electric field sensing of the fingerprint sensor **30** provides an effective approach to avoiding spoofing based upon the complex impedance of a finger.

[0052] In FIG. 10, the fingerprint sensor **30** may be considered as including an array of impedance sensing elements **160** for generating signals related to a finger **79** or other object positioned adjacent thereto. In the embodiment described herein, the impedance sensing elements **160** are provided by electric field sensing electrodes **78** and amplifiers **73** (FIG. 2) associated therewith. In addition, a guard shield **80** may be associated with each electric field sensing electrode **78** and connected to a respective amplifier **73.** Spoof reducing means **161** is provided for determining whether or not an impedance of the object positioned adjacent the array of impedance sensing elements **160** corresponds to a live finger **79** to thereby reduce spoofing of the fingerprint sensor by an object other than a live finger. A spoofing may be indicated, such as by the schematically illustrated lamp **163** and/or used to block further processing. Alternately, a live fingerprint determination may also be indicated by a lamp **164** and/or used to permit further processing of the fingerprint image.

[0053] In one embodiment, the spoof reducing means **161** may include impedance determining means 165 to detect a complex impedance having a phase angle in a range of about 10 to 60 degrees corresponding to a live finger **79**. Alternately, the spoof reducing means **161** may detect an impedance having a phase angle of about 0 degrees corresponding to some objects other than a live finger, such as a sheet of paper having an image thereon, for example. In addition, the spoof reducing means **161** may detect an impedance of 90 degrees corresponding to other objects.

[0054] Turning now to FIG. 11, another embodiment of spoof reducing means is explained. The fingerprint sensor **30** includes drive means for driving the array of impedance sensing elements **160**, such as the illustrated excitation amplifier **74** (FIG. 2). The sensor also includes synchronous demodulator means **170** for synchronously demodulating signals from the array of impedance sensing elements **160**. Accordingly, in one particularly advantageous embodiment of the invention, the spoof reducing means comprises means for operating the synchronous demodulator means **170** at at least one predetermined phase rotation angle. For example, the synchronous demodulator means **170** could be operated in a range of about 10 to 60 degrees, and the magnitude compared to a predetermined threshold indicative of a live fingerprint. A live fingerprint typically has a complex impedance within the range of 10 to 60 degrees.

[0055] Alternately, ratio generating and comparing means **172** may be provided for cooperating with the synchronous demodulator means **170** for synchronously demodulating signals at first and second phase angles θ_1, θ_2, generating an amplitude ratio thereof, and comparing the amplitude ratio to a predetermined threshold to determine whether the object is a live fingerprint or other object. Accordingly, the synchronous demodulator **170** may be readily used to generate the impedance information desired for reducing spoofing of the sensor **30** by an object other than a live finger. The first angle θ_1 and the second θ_2 may have a difference in a range of about 45 to 90 degrees, for example.

[0056] The fingerprint sensor **30** also includes an automatic gain control feature to account for a difference in intensity of the image signals generated by different fingers or under different conditions, and also to account for differences in sensor caused by process variations. It is important for accurately producing a fingerprint image, that the sensor can discriminate between the ridges and valleys of the fingerprint. Accordingly, the sensor **30** includes a gain control feature, a first embodiment of which is understood with reference to FIG. 12.

[0057] As shown in FIG. 12, the portion of the fingerprint sensor **30** includes an array of fingerprint sensing elements in the form of the electric field sensing electrodes **78** and surrounding shield electrodes **80** connected to the amplifiers **73.** Other fingerprint sensing elements may also benefit from the following automatic gain control implementations.

[0058] The signal processing circuitry of the sensor **30** includes a plurality of analog-to-digital (A/D) converters **180** as illustrated. Moreover, each of these A/D converters **180** may have a controllable scale. Scanning means **182** sequentially connects different elements to the bank of A/D converters **180.** The illustrated gain processor **185** provides range determining and setting means for controlling the range of the A/D converters **180** based upon prior A/D conversions to thereby provide enhanced conversion resolution. The A/D converters **180** may comprise the illustrated reference voltage input V_{ref} and offset voltage input V_{offset} for permitting setting of the range. Accordingly, the range determining and setting means may also comprise a first digital-to-analog D/A converter **186** connected between the gain processor **185** and the reference voltage V_{ref} inputs of the A/D converters **180.** In addition, a second D/A converter **189** is also illustratively connected to the offset voltage inputs V_{offset} from the gain processor **185.**

[0059] The gain processor **185** may comprise histogram generating means for generating a histogram, as described above, and based upon prior A/D conversions. The graph adjacent the gain processor **185** in FIG. 12 illustrates a typical histogram plot **191**. The histogram plot 191 includes two peaks corresponding to the sensed ridges and valleys of the fingerprint. By setting the range for the A/D converters **180**, the peaks can be readily positioned as desired to thereby account for the variations and use the full resolution of the A/D converters **180.**

[0060] Turning to FIG. 13, the A/D converters **180** may include an associated input amplifier for permitting setting of the range. In this variation, the range determining and setting means may also comprise the illustrated gain processor **185**, and wherein the amplifier is a programmable gain amplifier (PGA) **187** connected to the processor. A digital word output from the gain processor **185** sets the gain of the PGA **187** so that full use of the resolution of the A/D converters **180** is obtained for best accuracy. A second digital word output from the gain processor **185** and coupled to the amplifier **187** through the illustrated D/A converter **192** may also control the offset of the amplifier.

[0061] The range determining and setting means of the gain processor **185** may comprise default setting means for setting a default range for initial ones of the fingerprint sensing elements. The automatic gain control feature allows the D/A converters **180** to operate over their full resolution range to thereby increase the accuracy of the image signal processing.

[0062] A fingerprint sensor includes an array of fingerprint sensing elements; analog-to-digital (A/D) converters having a controllable range; a scanner to perform sequential A/D conversions of predetermined ones of the array of fingerprint sensing elements; and a range determining and setting circuit for controlling the range of the A/D converters based upon prior A/D conversions to thereby provide enhanced conversion resolution. A plurality of A/D converters are used for simultaneously converting analog signals from a corresponding plurality of fingerprint sensing elements. The A/D converters may include at least one reference voltage input for permitting setting of first and second points of the range. The range scale determining and setting circuit generate a histogram based upon prior A/D conversions.

Claims

1. A fingerprint sensor (30) comprising, a substrate (65),

   an array of electric field sensing elements (78,130), at least one analogue-to-digital (A/D) converter (180) for converting an analogue signal from at least one electric field sensing element (78,130) to a digital signal based upon at least one reference voltage for controlling the range of the A/D converter (180), the or each A/D converter (180) having at least one reference voltage input for receiving the reference voltage, scanning means (182) for operating said at least one A/D converter and said array of electric field sensing elements (78,130) to perform sequential A/D conversions of analogue signals from predetermined ones of said array of electric field sensing elements, and reference voltage determining and setting means (185) for controlling the at least one reference voltage of the or each A/D (180) converter based upon prior A/D conversions to thereby provide enhanced conversion resolution, said reference voltage determining and setting means comprising a processor (185) including histogram generating means for generating a histogram based upon prior A/D conversions.

2. A fingerprint sensor as claimed in claim 1, wherein said reference voltage determining and setting means further comprises at least one digital-to-analogue converter (186) connected between said processor (185) and said at least one reference voltage input.

3. A fingerprint sensor as claimed in claim 1, wherein said at least one A/D converter further comprises at least one amplifier (187) for permitting setting of the range.

4. A fingerprint sensor as claimed in claim 1, 2 or 3, wherein said at least one A/D converter (180) comprises a plurality of A/D converters (180) for simultaneously converting analogue signals from a corresponding plurality of electric field sensing elements (78,130).

5. A fingerprint sensor as claimed in any preceding claim, wherein said reference voltage determining and setting means comprises default setting means for setting at least one default reference voltage for initial ones of said electric field sensing elements, each of said electric field sensing elements comprises an electric field sensing electrode (78) and an amplifier (73) associated therewith, and further comprising a shield electrode (80) associated with each electric field sensing electrode (78) and connected to a respective amplifier (73).

6. A method for operating a fingerprint sensor (30) of a type comprising an array of electric field sensing elements (78,130), the method comprising the steps of:

converting analogue signals from the array of electric field sensing elements (78,130) to digital signals using at least one A/D converter (180) having a controllable range,
performing sequential A/D conversions of analogue signals from predetermined ones of the array of electric field sensing elements (78,130), and
determining and controlling the range of the at least one A/D converter (180) based upon prior AID conversions to thereby provide enhanced conversion resolution, in which the range of the at least one A/D converter (180) is controllable based upon at least one reference voltage, and the step of determining and controlling the range comprises controlling the at least one reference voltage,

wherein the step of converting analogue signals comprises converting same using at least one amplifier (187) having a controllable gain for permitting setting of the range, and the step of determining and controlling the range comprises controlling the range using the amplifier (187), generating a histogram based upon a prior A/D conversions, and setting a default range for initial ones of the electric field sensing elements (78,130).

Patentansprüche

1. Ein Fingerabdrucksensor (30), beinhaltend:

ein Substrat (65),

eine Anordnung/Matrix von Sensorelementen (78, 130) für ein elektrisches Feld,

mindestens einen analog-digital (A/D) Konverter (180), um ein analoges Signal von mindestens einer der elektrischen Feld-Sensorelemente (78, 130) zu einem digitalen Signal zu konvertieren, basierend auf mindestens einer Referenzspannung zur Regelung des Bereichs des A/D-Konverters (180), wobei der oder jeder A/D-Konverter (180) mindestens einen Referenzspannungseingang zur Einleitung der Referenzspannung besitzt,

Mittel zum Scannen (182) zum Betrieb des mindestens einen A/D-Konverters (180) und der Anordnung/Matrix der elektrischen Feld-Sensorelemente (78, 130), um sequentielle A/D-Konvertierungen von analogen Signalen von Vorbestimmten der Anordnung/Matrix der elektrischen Feld-Sensorelemente durchzuführen,

und Referenzspannungs-Bestimmungs- und -Einstellmittel (185) zur Regelung der mindestens einen Referenzspannung des oder jedes A/D-Konverters (180), basierend auf vorhergehenden A/D-Konvertierungen, um hierbei eine vergrößerte Konvertierungs-Auflösung zu liefern, wobei die Referenzspannungs-Bestimmungsund -Einstellmittel einen Prozessor (185) beinhalten, mit einem ein Histogramm erzeugenden Mittel, zur Erzeugung eines Histogramms, basierend auf vorhergehenden A/D-Konvertierungen.

2. Ein Fingerabdrucksensor wie in Anspruch 1 beansprucht, worin die Referenzspannungs-Bestimmungs- und -Einstellmittel weiterhin mindestens einen digital-analog Konverter (186) beinhalten, der zwischen dem besagten Prozessor (185) und dem besagten mindestens einen Referenzspannungseingang geschaltet ist.

3. Ein Fingerabdrucksensor wie in Anspruch 1 beansprucht, worin der mindestens eine A/D-Konverter weiterhin mindestens einen Verstärker (187) beinhaltet, um das Einstellen der Bereichs zu ermöglichen.

4. Ein Fingerabdrucksensor wie in einem der Ansprüche 1, 2 oder 3 beansprucht, worin der mindestens eine A/D-Konverter (180) eine Vielzahl von A/D-Konvertern (180) zur gleichzeitigen Konvertierung von analogen Signalen von einer zugehörigen Vielzahl von elektrischen Feld-Sensorelementen (78, 130) beinhaltet.

5. Ein Fingerabdrucksensor wie in einem der vorhergehenden Ansprüche beansprucht, worin die Referenzspannungs-Bestimmungs- und -Einstellmittel Fehlereinstellmittel beinhalten, um mindestens eine Fehler-Referenzspannung für Erste einer der elektrischen Feld-Sensorelemente einzustellen, wobei jede der elektrischen Feld-Sensorelemente eine Sensorelektrode (78) für ein elektrisches Feld und einen damit verbundenen Verstärker (80) beinhaltet, und weiterhin eine Schirmungselektrode (80) beinhaltet, die mit jeder elektrischen Feld-Sensorelektrode (78) verbunden ist und mit einem entsprechenden Verstärker (73) verbunden ist.

6. Ein Verfahren zum Betrieb eines Fingerabdrucksensors (30) eines Typs, beinhaltend eine Anordnung/Matrix von Sensorelementen (78, 130) für ein elektrisches Feld, wobei das Verfahren die Schritte beinhaltet:

Konvertieren analoger Signale von einer Anordnung/Matrix von elektrischen Feld-Sensorelementen (78, 130) in digitale Signale mittels mindestens eines A/D-Konverters (180) mit regelbarem Bereich,

Durchführen sequentieller A/D-Konvertierungen von analogen Signalen von Vorbestimmten der Anordnung/Matrix von elektrischen Feld-Sensorelementen (78, 130), und

Bestimmen und Regeln des Bereichs des mindestens einen A/D-Konverters (180), basierend auf vorhergehenden A/D-Konvertierungen, um hierbei eine vergrößerte Konvertierungs-Auflösung zu liefern, wobei der Bereich des mindestens einen A/D-Konverters (180) regelbar ist, basierend auf mindestens einer Referenzspannung, und der Schritt des Bestimmens und Regelns des Bereiches das Regeln der mindestens einen Referenzspannung beinhaltet,

wobei der Schritt des Konvertierens analoger Signale das Konvertieren derselben mittels mindestens eines Verstärkers (187) mit einer regelbaren Verstärkung beinhaltet, um das Einstellen des Bereiches zu ermöglichen, und der Schritt des Bestimmens und Regelns des Bereiches, das Regeln des Bereiches mittels Verstärkers (187) beinhaltet, wobei ein Histogramm erzeugt wird, basierend auf vorhergehenden A/D-Konvertierungen, und Einstellen eines Fehlerbereiches für Erste der elektrischen Feld-Sensorelemente (78, 130).

Revendications

1. Détecteur d'empreintes digitales (30), comprenant un substrat (65), une matrice d'éléments détecteurs d'un champ électrique (78, 130), au moins un convertisseur (180) analogique/numérique (A/N) permettant de convertir un signal analogique provenant d'au moins un élément détecteur d'un champ électrique (78, 130) en un signal numérique fondé sur au moins une tension de référence afin de commander la plage du convertisseur A/N (180), le (ou chaque) convertisseur A/N (180) ayant au moins une entrée de tension de référence afin de recevoir la tension de référence, un moyen formant scanner (182) permettant de faire fonctionner ledit au moins un convertisseur A/N et ladite matrice d'éléments détecteurs d'un champ électrique (78, 130) afin d'effectuer des conversions A/N séquentielles des signaux analogiques provenant d'éléments détecteurs prédéterminés parmi la matrice d'éléments détecteurs d'un champ électrique, et des moyens de détermination et de fixation d'une tension de référence (185) permettant de commander ladite au moins une tension de référence du (de chaque) convertisseur A/N (180) en se fondant sur les conversions A/N précédentes, afin de fournir ainsi une résolution de conversion améliorée, lesdits moyens de détermination et de fixation d'une tension de référence comprenant un processeur (185) incluant un moyen générateur d'histogramme afin de générer un histogramme fondé sur les conversions A/N précédentes.

2. Détecteur d'empreintes digitales selon la revendication 1, dans lequel lesdits moyens de détermination et de fixation d'une tension de référence comprennent en outre au moins un convertisseur numérique-analogique (186) connecté entre ledit processeur (185) et ladite au moins une entrée de tension de référence.

3. Détecteur d'empreintes digitales selon la revendication 1, dans lequel ledit au moins un convertisseur A/N comprend au moins un amplificateur (187) permettant de fixer la plage.

4. Détecteur d'empreintes digitales selon la revendication 1, 2 ou 3, dans lequel ledit au moins un convertisseur A/N (180) comprend une pluralité de convertisseurs A/N (180) permettant de convertir, simultanément, des signaux analogiques provenant d'une pluralité correspondante d'éléments détecteurs d'un champ électrique (78, 130).

5. Détecteur d'empreintes digitales selon l'une quelconque des revendications précédentes, dans lequel lesdits moyens de détermination et de fixation d'une tension de référence comprennent des moyens de fixation par défaut, afin de fixer au moins une tension de référence par défaut pour les éléments initiaux parmi lesdits éléments détecteurs d'un champ électrique, chacun desdits éléments détecteurs d'un champ électrique comprenant une électrode de détection d'un champ électrique (78) et un amplificateur (73) associé à celle-ci, et comprenant en outre une électrode blindée (80) associée à chacune des électrodes de détection d'un champ électrique (78) et connectée à un amplificateur respectif (73).

6. Procédé de fonctionnement d'un détecteur d'empreintes digitales (30) d'un type comprenant une matrice d'éléments détecteurs d'un champ électrique (78, 130), ce procédé comprenant les étapes de :

conversion des signaux analogiques provenant de la matrice d'éléments détecteurs d'un champ électrique (78, 130) en signaux numériques en utilisant au moins un convertisseur A/N (180) ayant une plage pouvant être commandée,
réalisation de conversions séquentielles A/N de signaux analogiques provenant d'éléments prédéterminés parmi la matrice d'éléments détecteurs d'un champ électrique (78, 130), et
détermination et commande de la plage dudit au moins un convertisseur A/N (180) en se fondant sur les conversions A/N précédentes afin de fournir une résolution de conversion améliorée, dans laquelle la plage dudit au moins un convertisseur A/N (180) peut être commandée en se fondant sur au moins une tension de référence, et l'étape de détermination et de commande de la plage comprend la commande de ladite au moins une tension de référence,

dans lequel l'étape de conversion des signaux analogiques comprend la conversion de ceux-ci en utilisant au moins un amplificateur (187) ayant un gain pouvant être commandé, afin de permettre la commande de la plage en utilisant l'amplificateur (187), la génération d'un histogramme en se fondant sur les conversions A/N précédentes, et la fixation d'une plage par défaut pour les éléments initiaux parmi les éléments détecteurs d'un champ électrique (78, 130).

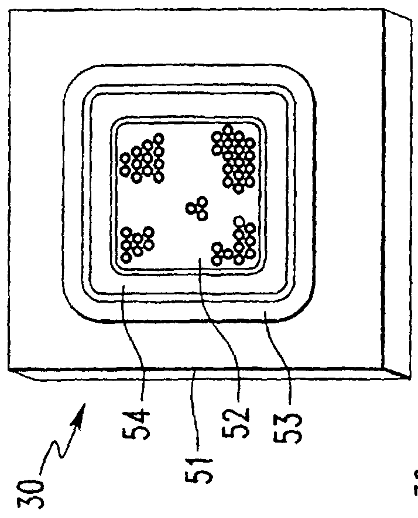

30
54
51
52
53

FIG. 1

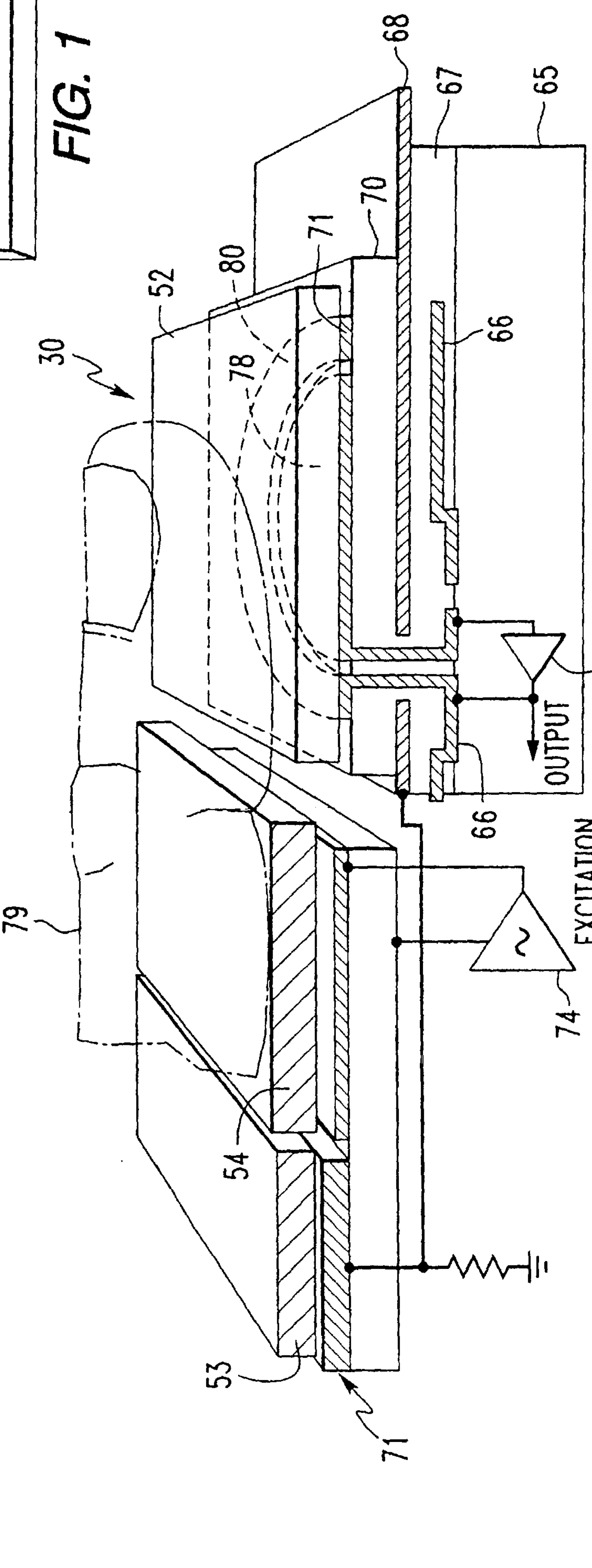

68
67
65
70
71
80
52
30
78
66
73
OUTPUT
EXCITATION DRIVE
74
79
54
53
71

FIG. 2

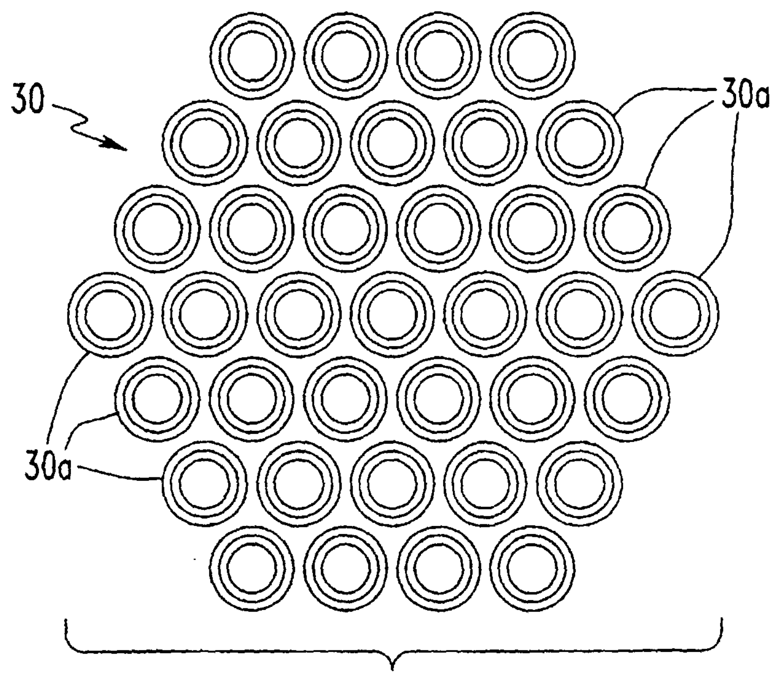

30
30a
30a
30a

FIG.3

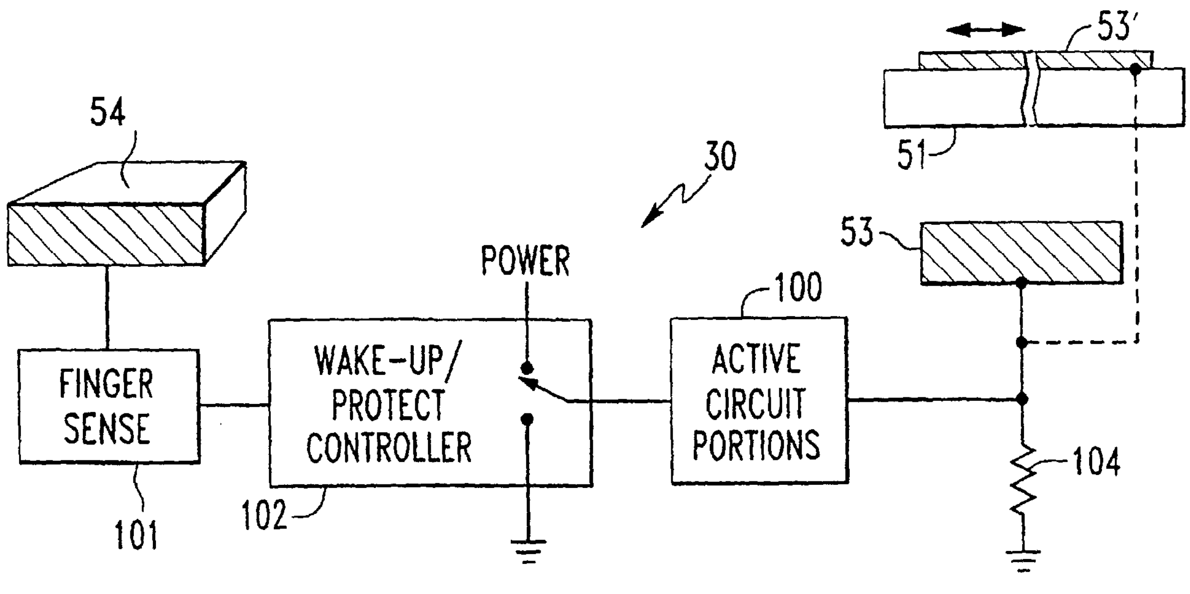

53′
51
54
30
53
POWER
100
FINGER
SENSE
WAKE-UP/
PROTECT
CONTROLLER
ACTIVE
CIRCUIT
PORTIONS
104
101
102

FIG.4

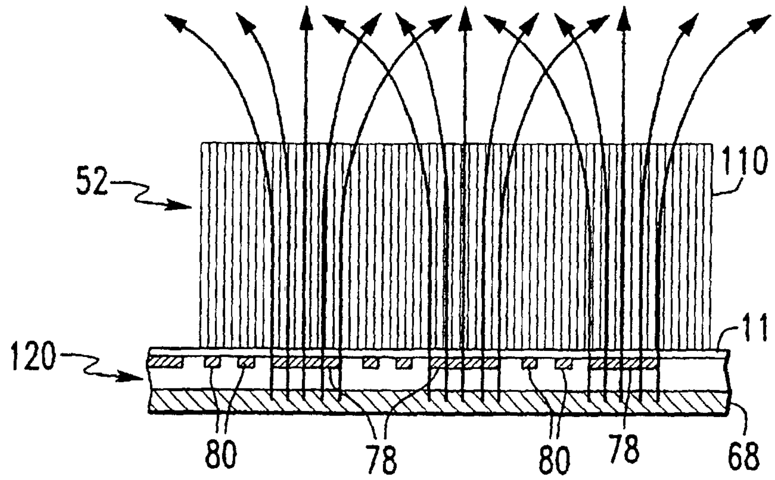


FIG. 5

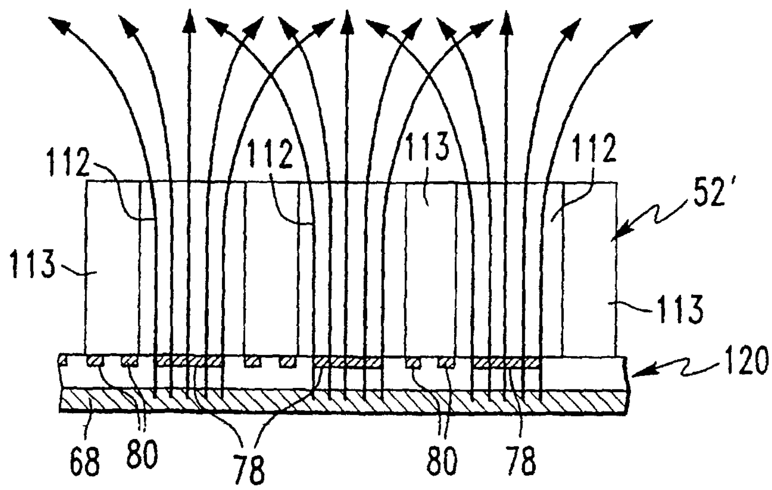


FIG. 6

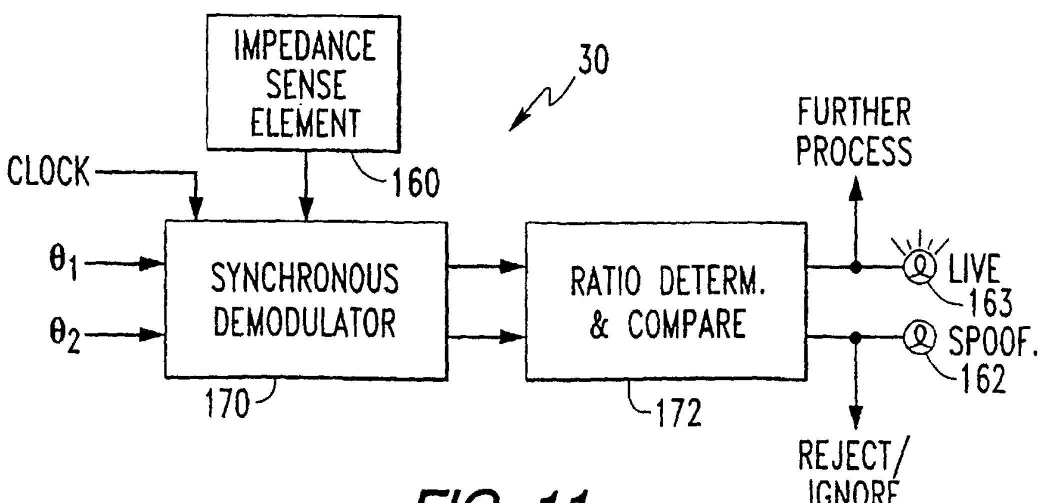
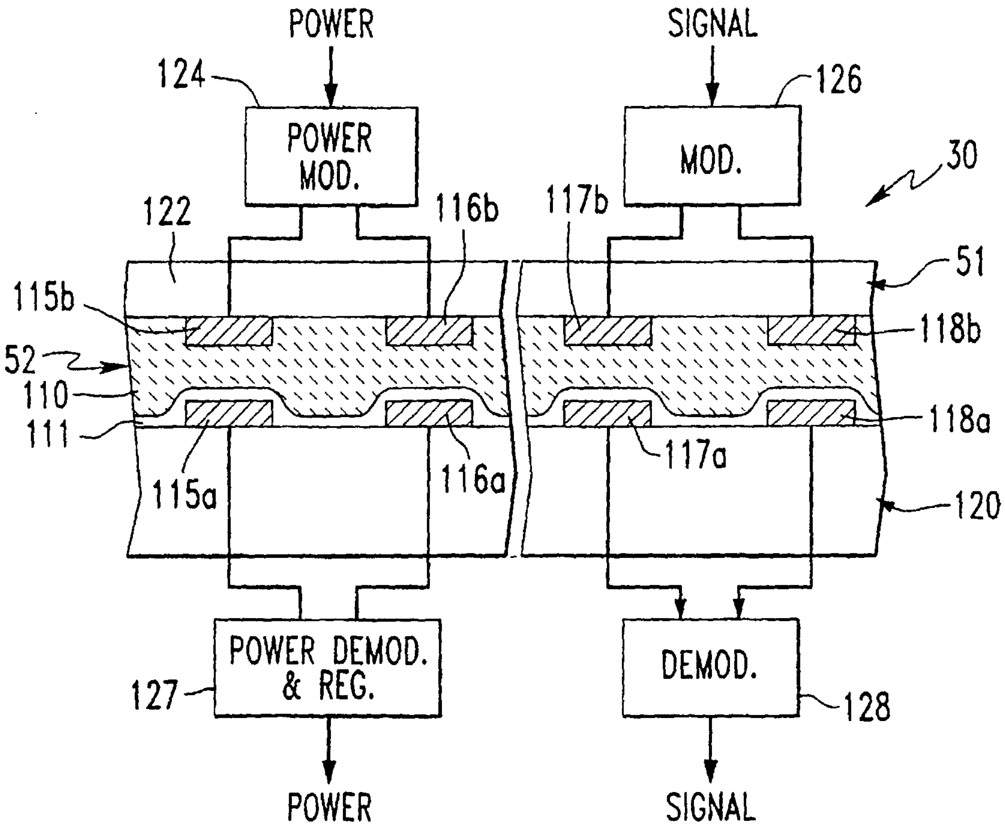
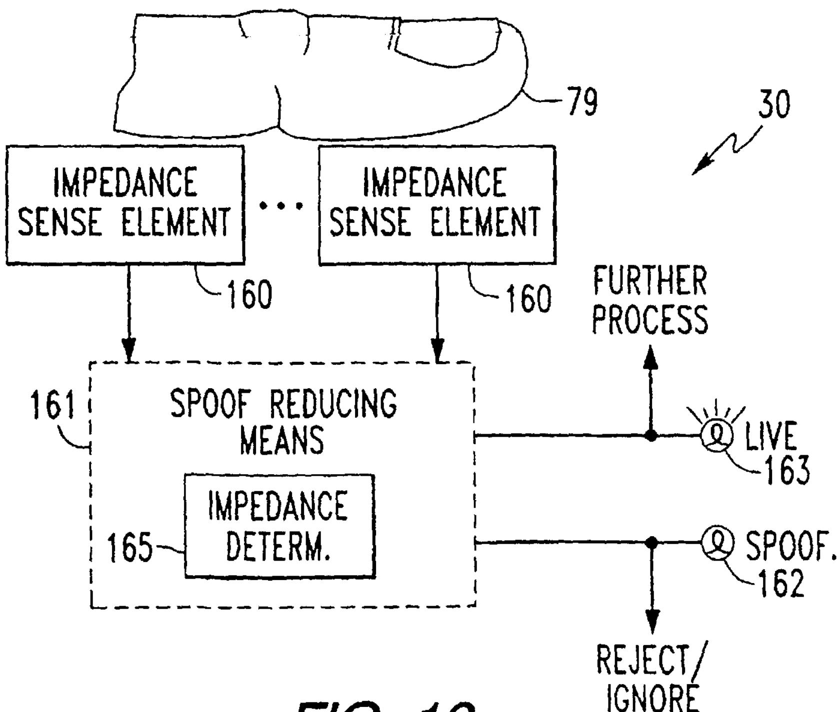


FIG. 11



POWER
124
POWER MOD.
SIGNAL
126
MOD.
30
122
116b
117b
51
115b
118b
52
110
111
118a
117a
115a
116a
120
POWER DEMOD. & REG.
127
DEMOD.
128
POWER
SIGNAL

FIG. 7



79
30
IMPEDANCE SENSE ELEMENT
IMPEDANCE SENSE ELEMENT
160
160
FURTHER PROCESS
161
SPOOF REDUCING MEANS
LIVE
163
IMPEDANCE DETERM.
165
SPOOF.
162
REJECT/ IGNORE

FIG. 10

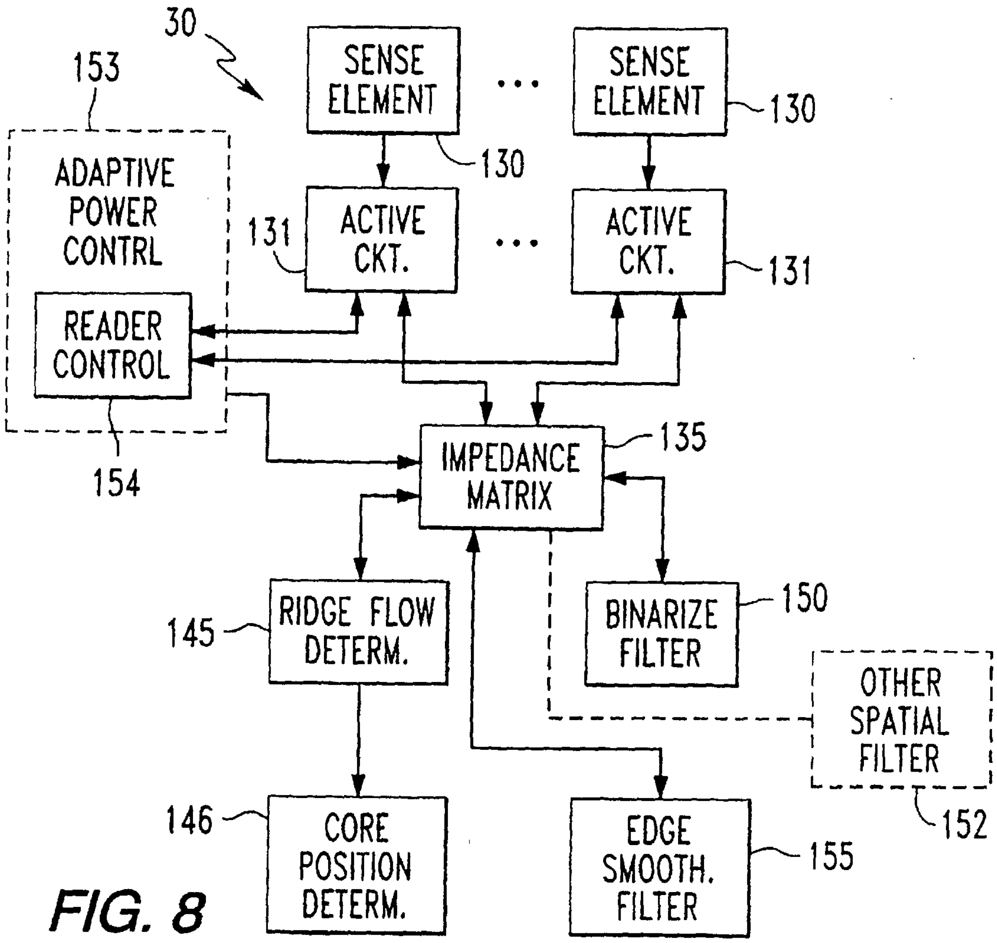

30
153
SENSE ELEMENT
SENSE ELEMENT
130
130
ADAPTIVE POWER CONTRL
131
ACTIVE CKT.
ACTIVE CKT.
131
READER CONTROL
IMPEDANCE MATRIX
135
154
RIDGE FLOW DETERM.
145
BINARIZE FILTER
150
OTHER SPATIAL FILTER
152
146
CORE POSITION DETERM.
EDGE SMOOTH. FILTER
155

FIG. 8

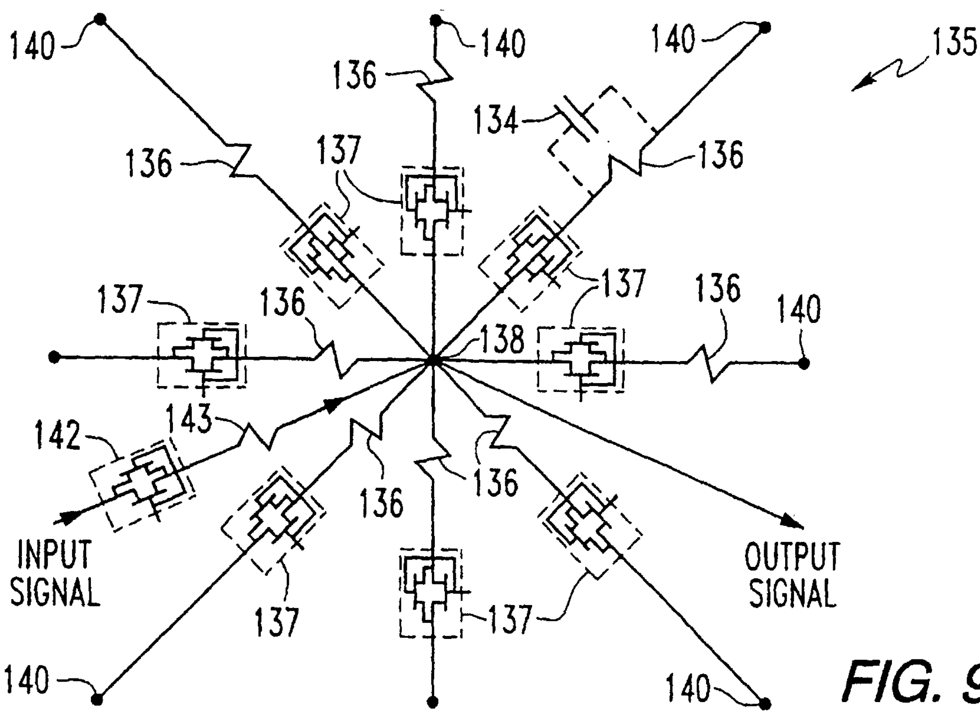
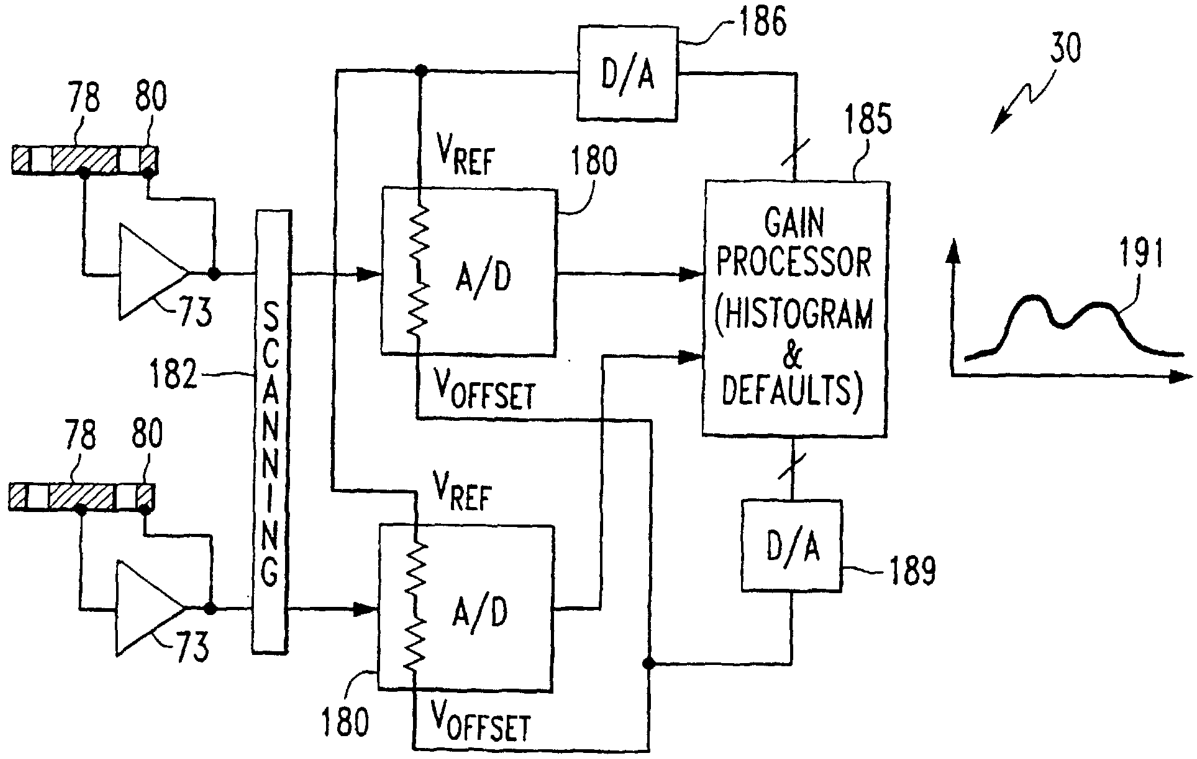
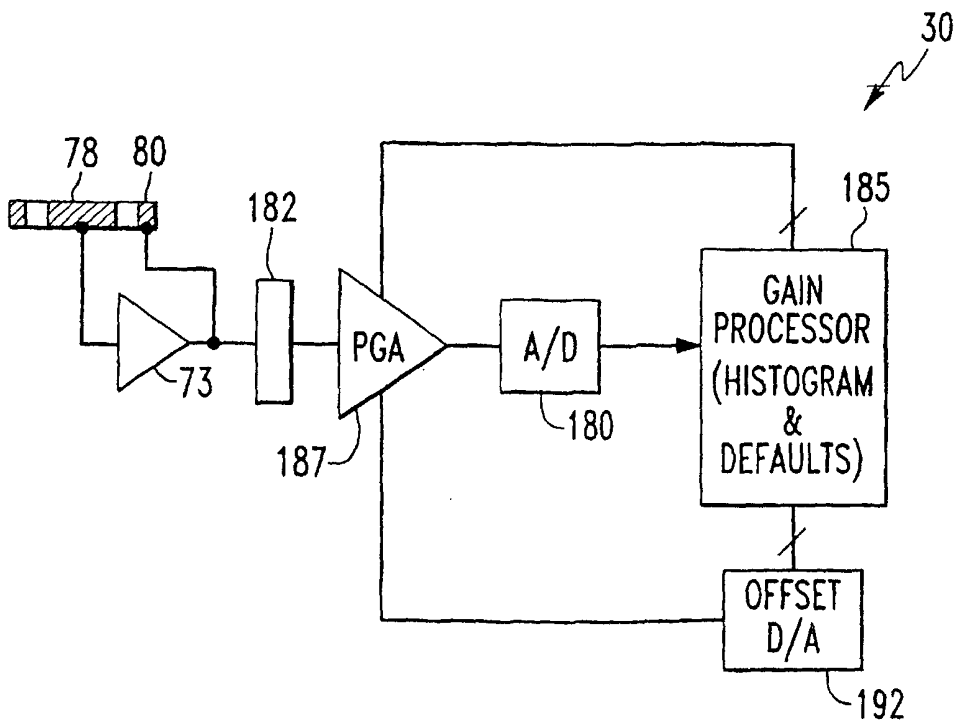

140
140
140
135
136
134
136
136
137
137
137
136
136
140
138
142
143
136
136
INPUT SIGNAL
OUTPUT SIGNAL
137
137
140
140

FIG. 9



186
D/A
30
78
80
185
VREF
180
GAIN
PROCESSOR
(HISTOGRAM
&
DEFAULTS)
A/D
191
73
SCANNING
182
VOFFSET
78
80
VREF
D/A
189
A/D
73
180
VOFFSET

FIG. 12



30
78
80
185
182
GAIN
PROCESSOR
(HISTOGRAM
&
DEFAULTS)
PGA
A/D
73
180
187
OFFSET
D/A
192

FIG. 13