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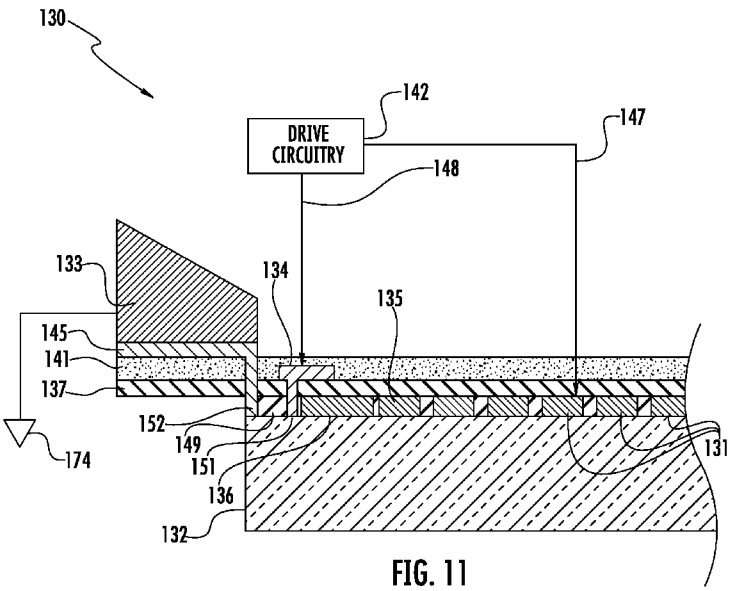


FIG. 11

(57) Abstract: An electronic device may include a housing and circuitry carried by the housing and having a device ground associated therewith. The electronic device may also include an array of biometric finger sensing pixel electrodes and an array shielding electrode outside the array of biometric finger sensing pixels. A finger coupling electrode may be outside the array shielding electrode and coupled to the device ground. The electronic device may also include drive circuitry capable of generating a drive signal for the array of biometric finger sensing pixel electrodes and a compensating drive signal for the array shielding electrode.

WO 2014/099514 A1

ELECTRONIC DEVICE INCLUDING DEVICE GROUND COUPLED FINGER COUPLING ELECTRODE AND ARRAY SHIELDING ELECTRODE AND RELATED METHODS

Field of the Invention

[0001] The present invention relates to the field of electronics, and, more particularly, to finger sensing devices and related methods.

Background of the Invention

[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 particularly advantageous approach to fingerprint sensing is disclosed in U.S. Patent No. 5,953,441 to Setlak and assigned to the assignee of the present invention, the entire contents of which are herein incorporated by reference. The fingerprint sensor is an integrated circuit sensor that drives the user's finger with an electric field signal and senses the electric field with an array of electric field sensing pixels on the integrated circuit substrate.

[0004] U.S. Patent No. 6,289,114 to Mainguet, which is assigned to the assignee of the present invention and is incorporated in its entirety by reference, discloses a fingerprint sensor that includes a finger sensing integrated circuit (IC). The finger sensing IC includes a layer of piezoelectric or pyroelectric material placed between upper and lower electrodes to provide electric signals representative of an image of the ridges and valleys of the fingerprint.

[0005] A particularly advantageous approach to multi-biometric fingerprint sensing is disclosed in U.S. Patent No. 7,361,919 to Setlak, which is assigned to the assignee of the present invention and is incorporated in its entirety by reference. The Setlak patent discloses a multi-biometric finger sensor sensing different biometric characteristics of a user's finger that have different matching selectivities.

[0006] A fingerprint sensor may be particularly advantageous for verification and/or authentication in an electronic device, and more particularly, a portable device, for example. Such a fingerprint sensor may be carried by the housing of a portable electronic device, for example, and may be sized to sense a fingerprint from a single-finger. For example, the AES3400 sensor from AuthenTec, Inc. of Melbourne, Florida, the assignee of the present invention, is widely used in a variety of notebooks, desktops and PC peripherals. Other fingerprint sensors, for example, the AES850, also from AuthenTec, Inc. of Melbourne, Florida, is a multi-function smart sensor that expands touch-based functionality of touchscreen and QWERTY smartphones with a reduced impact on sensor performance or durability. Thus, a fingerprint sensor may be particularly advantageous for providing more convenient access to the electronic device without a password, for example, and, more particularly, without having to type the password, which is often time consuming. A fingerprint sensor may also be particularly advantageous for starting one or more applications on the electronic device.

[0007] U.S. Patent Application Publication No. 2011/0175703 to Benkley, III discloses an electronic imager using an impedance sensor grid array mounted on or about a switch. More particularly, Benkley, III discloses a switch being incorporated into a sensor assembly that allows integration of sensor operations, such as, fingerprint sensor operations. A fingerprint sensor can be used for authentication while being used together with a power switch or navigation selection switch. The authentication may be used to access the device entirely or access different levels of information.

[0008] U.S. Patent Application Publication No. 2009/0083850 to Fadell et al. discloses an embedded authentication system in an electronic device. More particularly, Fadell et al. discloses authenticating a user via a fingerprint to provide access to resources or content that was previously not available. The electronic device may allow a user to authenticate for a particular amount of time for accessing restricted resources.

[0009] U.S. Patent No. 7,809,168 to Abiko et al. discloses a biometric information input device. More particularly, Abiko et al. discloses a movement direction detection means for detecting a movement direction of a finger with respect to the fingerprint sensor, based on partial fingerprint images collected by the fingerprint sensor.

[0010] Moreover, while a fingerprint sensor used in an electronic device may be particularly advantageous for authentication, navigation, etc., these finger sensors generally require the user's finger to be placed in a very close proximity to the array of finger sensing pixels. The need for close proximity to the user's finger typically makes the mechanical packaging and the integration of a fingerprint sensor into the electronic device more difficult and more costly.

[0011] Some approaches to address packaging of an electronic device include a special molded package with an opening in the molding allowing the finger a close approach to the finger sensing array. Specialized packaging increases the cost of these sensors.

[0012] The desire for the user's finger to be close to the array of finger sensing pixels may limit the thickness of the material that can be placed over the array of finger sensing pixels, which may increasingly restrict the use of both protective and cosmetic coatings over the array area. Mechanically integrating these sensors into their host devices typically requires that the finger sensor project through a hole in the electronic device's case, so that the array of finger sensing pixels can be located about flush with the external surface of the case.

[0013] However, a negative aspect of these mounting arrangements may include increased difficultly and cost to seal the opening for the finger

sensor in the electronic device case or housing against the ingress of moisture, dust, and other contaminants. Additionally, the opening in the case or housing with the finger sensor protruding may be cosmetically unacceptable to the intended appearance of the electronic device, and mounting the finger sensor in an opening in the case may be difficult and costly in some devices.

[0014] It may be desirable to extend the range of electric field based finger sensors so that they can image fingers through significantly thicker dielectric materials such as molded plastic structures. Using an increased thickness material layer over the array of finger sensing pixels may result in increased power consumption. More particularly, an increased thickness material layer generally requires a greater drive voltage to be driven into the user's finger. The greater distance from the array of finger sensing pixels and the increased drive voltage may result in increased noise of a finger image, which may be undesirable for authentication, for example.

Summary

[0015] In view of the foregoing background, it is therefore an object of the present invention to provide an electronic device that may generate a reduced noise finger image from a finger positioned at a relatively large distance from the array of biometric finger sensing pixel electrodes.

[0016] This and other objects, features, and advantages in accordance with the present invention are provided by an electronic device that may include a housing and circuitry carried by the housing and having a device ground associated therewith. The electronic device may include an array of biometric finger sensing pixel electrodes, and an array shielding electrode outside the array of biometric finger sensing pixels, for example. The electronic device may also include a finger coupling electrode outside the array shielding electrode and coupled to the device ground. The electronic device may further include drive circuitry capable of generating a drive signal for the array of biometric finger sensing pixel electrodes and a compensating drive signal for the array shielding electrode, for example. Accordingly, the electronic device may generate a reduced noise finger

image from a finger positioned at a relatively large distance from the array of finger sensing pixels.

[0017] The drive circuitry may be capable of generating the compensating drive signal comprising a scaled replica of the drive signal. The electronic device may further include sense amplifier circuitry coupled to the array of biometric finger sensing pixel electrodes and having a circuit reference associated therewith different than the device ground. The drive circuitry may be capable of generating the drive signal between the device ground and the circuit reference, for example.

[0018] The array shielding electrode may include a plurality of shielding pixel electrodes, for example. The electronic device may further include a reference electrode between the array shielding electrode and the array of biometric finger sensing pixel electrodes. The electronic device may further include a dummy biometric finger sensing pixel electrode area between the array of biometric finger sensing pixel electrodes and the reference electrode, for example.

[0019] The electronic device may include a dielectric cap over the array of biometric finger sensing pixel electrodes. A semiconductor substrate may carry the array of biometric finger sensing pixel electrodes.

[0020] The circuitry may include wireless communications circuitry capable of performing at least one wireless communications function, for example. An input device may carry the array of biometric finger sensing pixel electrodes. The drive circuitry may be capable of generating the drive signal as a square wave at an amplitude in a range of 10 to 20 volts and at a frequency of 1 to 5 MHz, for example.

[0021] A method aspect is directed to a method of making an electronic device that may include circuitry having a device ground associated therewith. The method may include forming an array shielding electrode outside an array of biometric finger sensing pixel electrodes and forming a finger coupling electrode outside the array shielding electrode and coupled to the device ground. The method may also include forming drive circuitry capable of generating a drive signal for the array of biometric

finger sensing pixels and a compensating drive signal for the array shielding electrode, for example.

Brief Description of the Drawings

[0022] FIG. 1 is a plan view of an electronic device including a biometric finger sensor in accordance with the present invention.

[0023] FIG. 2 is a schematic block diagram of the electronic device and biometric finger sensor of FIG. 1.

[0024] FIG. 3 is a top view of the biometric finger sensor of FIG. 1.

[0025] FIG. 4 is a cross-sectional view of a portion of the biometric finger sensor of FIG. 3.

[0026] FIG. 5 is an enlarged cross-sectional view of a portion of the biometric finger sensor of FIG. 1.

[0027] FIG. 6 is a cross-sectional view of a portion of a biometric finger sensor in accordance with another embodiment of the present invention.

[0028] FIG. 7 is a graph of simulated voltage for a biometric finger sensor without an array shielding electrode.

[0029] FIG. 8 is a graph of simulated voltage for a biometric finger sensor in accordance with the present invention.

[0030] FIG. 9 is a plan view of an electronic device including a biometric finger sensor in accordance with another embodiment of the present invention.

[0031] FIG. 10 is a schematic block diagram of the electronic device and biometric finger sensor of FIG. 9.

[0032] FIG. 11 is a cross-sectional view of a portion of the biometric finger sensor of FIG. 9.

[0033] FIG. 12 is a schematic circuit diagram illustrating the finger coupling electrode coupled to the device ground in accordance with the present invention.

Detailed Description of the Preferred Embodiments

[0034] The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which

preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime notation and numbers in increments of 100 are used to refer to like elements in different embodiments.

[0035] Referring initially to FIGS. 1 and 2, an electronic device **20** is now described. The electronic device **20** illustratively includes a portable housing **21** and a processor **22** carried by the portable housing. The electronic device **20** is illustratively a mobile wireless communications device, for example, a cellular telephone or smartphone. The electronic device **20** may be another type of electronic device, for example, a tablet computer, laptop computer, etc.

[0036] A wireless transceiver **25** is also carried within the portable housing **21** and is coupled to the processor **22**. The wireless transceiver **25** cooperates with the processor **22** to perform at least one wireless communications function, for example, for voice and/or data communication. In some embodiments, the electronic device **20** may not include a wireless transceiver **25** or other wireless communications circuitry.

[0037] A display **23** is also carried by the portable housing **21** and is coupled to the processor **22**. The display **23** may be a liquid crystal display (LCD), for example, or may be another type of display, as will be appreciated by those skilled in the art.

[0038] A finger-operated input device, illustratively in the form of a pushbutton switch **24**, is also carried by the portable housing **21** and is coupled to the processor **22**. The pushbutton switch **24** cooperates with the processor **22** to perform one or more device functions in response to operation of the pushbutton switch. For example, a device function may include a powering on or off of the electronic device **20**, initiating

communication via the wireless communications circuitry **25**, and/or performing a menu function.

[0039] More particularly, with respect to a menu function, the processor **22** may change the display **23** to show a menu of available applications based upon pressing of the pushbutton switch **24**. In other words, the pushbutton switch **24** may be a home switch or button, or key. The processor **22** may also toggle between applications executed by the processor based upon pressing of the pushbutton switch **24**. Of course, other device functions may be performed based upon the pushbutton switch **24** for example, finger biometric data enrollment and/or finger biometric data matching. In some embodiments, the finger-operated input device **24** may be a different type of finger-operated input device, for example, forming part of a touch screen display. Other or additional finger-operated input devices may be carried by the portable housing **21**.

[0040] Referring now additionally to FIGS. 3-5, a biometric finger sensor **30** is carried by the pushbutton switch **24** to sense a user's finger **40**. The finger sensor **30** is carried by the pushbutton switch **24** so that when a user contacts and/or presses downward on the pushbutton switch, finger biometric data from the user's finger **40** is acquired, for example, for finger matching and/or finger enrollment to be stored and later used for matching.

[0041] The finger biometric data may include fingerprint minutae data, ridge and/or valley fingerprint image data, ridge flow data, finger pore data, etc. For example, the biometric finger sensor **30** may be a finger sensor as described in U.S. Patent No. 5,953,441 to Setlak and/or as described in U.S. Patent No. 6,927,581 to Gozzini, and assigned to the assignee of the present invention and the entire contents of which are herein incorporated by reference.

[0042] The biometric finger sensor **30** includes an array of biometric finger sensing pixels **31** to receive a user's finger **40** adjacent thereto. The array of finger biometric sensing pixels **31** are carried by a semiconductor substrate **32**, for example, a silicon substrate. The array of finger sensing

pixels **31** may be any array size, as will be appreciated by those skilled in the art, but may be particularly sized to be carried by the pushbutton switch **24**. The array of biometric finger sensing pixels **31** are illustratively in the shape of a square. In some embodiments, the array of biometric finger sensing pixels **31** may have a different shape.

[0043] Each biometric finger sensing pixel **31** may be an electric-field sensing pixel, and more particularly, a high impedance electric field sensing pixel. In some embodiments, each finger sensing pixel may be a capacitive sensing pixel, for example, or other type of sensing pixel. As will be appreciated by those skilled in the art, each finger sensing pixel **31** includes a finger sensing electrode.

[0044] The biometric finger sensor **30** further includes a dummy biometric finger sensing pixel area **35** carried by the semiconductor substrate **32** and laterally outside the array of biometric finger sensing pixels **31**. The dummy biometric finger sensing pixel area **35** includes dummy pixels which are unused for biometric finger sensing. The dummy pixels of the dummy biometric finger sensing pixel area **35** may be coupled a voltage reference, for example a ground, or may be electrically floating.

[0045] A ground electrode **36** is also carried by the semiconductor substrate **32** and laterally outside the array of biometric finger sensing pixels **31**, or more particularly, outside the dummy biometric finger sensing pixel area **35**. In other words, the dummy biometric finger sensing pixel area **35** is laterally between the ground electrode **36** and the array of biometric finger sensing pixels **31**. The dummy biometric finger sensing pixel area **35** and the ground electrode **36** are illustratively in the shape of a square ring following the square shape of the array of biometric finger sensing pixels **31**. In some embodiments, the dummy biometric finger sensing pixel area **35** and the ground electrode **36** may not be square and/or ring-shaped, for example, each of the dummy biometric finger sensing pixel area and the ground electrode may be a circular ring and/or may have one or more discontinuities therein.

[0046] A dielectric routing substrate **37** is over the array of biometric finger sensing pixels, the dummy pixel area **35**, and the ground electrode **36**. More particularly, the array of biometric finger sensing pixels, the dummy pixel area **35**, and the ground electrode **36** are adjacent a bottom surface of the dielectric routing substrate **37**.

[0047] The biometric finger sensor **30** includes an array shielding electrode **34** laterally outside the array of biometric finger sensing pixels **31** and is carried by an upper surface of the dielectric routing substrate **37**. The array shielding electrode **34** is also illustratively in the shape of a square ring and may have a size **ε** of about 0.2mm, for example (FIG. 5). Of course, in some embodiments, the array shielding electrode **34** may not be in the shape of a square ring and/or may have one or more discontinuities therein, and may have a different size.

[0048] The array shielding electrode **34** is coupled by a through-via **51** in the dielectric routing substrate **37**. The array shielding electrode **34** is partially over the ground electrode **36**.

[0049] The biometric finger sensor **30** illustratively includes a finger drive electrode **33** laterally outside the array shielding electrode **34**. The finger drive electrode **33** is coupled by a conductive finger drive electrode pad **45** between the finger drive electrode **33** and the top surface of the dielectric routing substrate **37**. In other words, the finger drive electrode **33** is carried by and coupled to the conductive finger drive electrode pad **45** which extends to the semiconductor substrate **32** by a through-via **52**. A distance **δ** of about 0.1mm may be between the finger drive electrode **33** and the array shielding electrode **34**. An adhesive layer **41** may secure the finger drive electrode **33** to the dielectric routing substrate **37**. In other words, the adhesive layer **41** is between the dielectric routing substrate **37** and the finger drive electrode **33**.

[0050] The finger drive electrode **33** is also illustratively in the shape of a ring. Of course, in some embodiments, the finger drive electrode **33** may not be in the shape of a ring and/or may have one or discontinuities therein. A dielectric material **49** fills any open spaces between the

components and connections (i.e. the array of finger sensing pixels **30**, the dummy biometric finger sensing pixel area **35**, the ground electrode **36**, and the through-vias **51**, **52**).

[0051] A dielectric cap **38** is over the array of biometric finger sensing pixels **31**, the dummy finger sensing pixel area **35**, the ground electrode **36**, the array shielding electrode **34**, and the finger drive electrode **33**. The dielectric cap **38** may be plastic, for example, and may be contoured for the user's finger. In other words, the dielectric cap **38** may have a curved upper surface **46** for receiving the user's finger **40** thereon during operation of the pushbutton switch **24**. For example, the dielectric cap **38** may have a radius of curvature of 70 mm. In some embodiments, the finger drive electrode **33** may also have a curved upper surface, which may be particularly advantageous because the finger drive electrode is relatively close to the user's finger **40**.

[0052] Of course, in some embodiments, the dielectric cap **38** may not have a curved upper surface or may have a relatively flat upper surface. Where, for example, the dielectric cap **38** has a flat upper surface, a dielectric material layer may be carried by the flat upper surface. The dielectric material may be z-axis anisotropic dielectric material, for example. Further details of a z-axis anisotropic dielectric material as it relates to a finger sensor are described in U.S. Patent No. 6,088,471, which has a common inventor with and is assigned to the assignee of the present application, and the entire contents of which are herein incorporated by reference.

[0053] In some embodiments, the finger drive electrode **33** may be carried by or integrally formed with the dielectric cap **38**. Thus, when the dielectric cap **38** is positioned over the array of biometric finger sensing pixels **31**, the dummy finger sensing pixel area **35**, the ground electrode **36**, the array shielding electrode **34**, and the conductive finger drive electrode pad **45**, the finger drive electrode **33** contacts or couples to the conductive finger drive electrode pad.

[0054] The finger drive electrode **33** is configured to couple a finger drive signal through the user's finger **40** to the array of biometric finger sensing pixels **31**. Of course, the finger drive electrode **33** may couple a finger drive signal through more than one user's finger, and more than one finger drive electrode may be used.

[0055] Finger drive circuitry **42** is coupled to finger drive electrode **33**. The finger drive circuitry **42** may include a radio frequency drive signal generator, for example. The finger drive circuitry **42** generates the finger drive signal **47**, which may be a 2 MHz finger drive signal. In some embodiments, the finger drive signal may be near 5 MHz, for example.

[0056] The finger drive circuitry **42** is also coupled to the array shielding electrode **34** and generates a compensating finger drive signal **48** for the array shielding electrode. The compensating finger drive signal **48** may have a different magnitude or offset with respect to the finger drive signal. In one particularly advantageous embodiment, the compensating finger drive signal **48** is in the form of an inverted finger drive signal for the array shielding electrode **34**. In other words, the inverted finger drive signal is about 180-degrees out of phase with the finger drive signal for the finger drive electrode **33**, as will be explained in further detail below.

[0057] As will be appreciated by those skilled in the art, the finger biometric sensing device **20** operates by injecting a small electrical signal, the finger drive signal **47**, from the finger drive electrode **33** into the conductive layer of the skin of the user's finger **40**. The shape of the electric field generated by that conductive layer of skin is then measured.

[0058] The finger drive electrode **33** is configured to inject the small electrical signal into the users' finger by operating as an insulated electrode finger drive, since the user's finger **40** does not come in direct contact with the finger drive electrode **33**. In other words, the finger drive electrode **33** is separated from the surface of the user's finger **40** by a thickness of the dielectric cap **38**. Electrical signals on an insulated finger drive electrode **33** couple capacitively to nearby skin surfaces. Signal attenuation due to coupling depends on the combination of several parameters including the

area of the region of skin close to the electrode, the thickness of the dielectric cap **38** (i.e., the thickness of dielectric material between the finger drive electrode **33** and the user's finger **40**), the electrical properties of the dielectric cap, and the electrical properties of the finger skin itself.

[0059] It may be important to note that the dielectric cap **38** being over the finger drive electrode **33**, i.e., an insulated finger drive system, tends to reduce the variation in drive signal attenuation between the dry, thick skinned fingers and the moist, thin skinned fingers, for example, because of the increased distance between the user's finger **40** and the finger drive electrode. To address the difference in average attenuation, the voltage of the finger drive signal applied to the finger drive electrode **33** from the finger drive circuitry **42** may be increased. A typical voltage of the finger drive voltage may be upwards of 18 volts, for example. However, the biometric finger sensor **30** may demand significantly less dynamic range to be able to handle finger skin variation.

[0060] Moreover, because of the relatively small size of the biometric finger sensor **30**, for example, so that it may be carried by the pushbutton switch **24** of the electronic device **20**, voltage, for example, the finger drive signal, may leak from the finger drive electrode **33**. This may cause distortion in the sensing field, and thus the biometric data sensed by the array of biometric finger sensing pixels **31**. The finger drive circuitry **42** advantageously generates the inverted finger drive signal for the array shielding electrode **34** to reduce or cancel the leakage from the finger drive electrode **33**. In other words, the array shielding electrode **34** reduces the field distortion or noise generated from the relatively close proximity of the finger drive electrode **33** to the array of biometric finger sensing pixels **31**. Additionally, the ground electrode **36** reduces or blocks leakage from the array shielding electrode **34**.

[0061] As will be appreciated by those skilled in the art, the above-described arrangement may be particularly advantageous for a relatively small-sized finger biometric sensor, for example, for use in a mobile electronic device. For example, an exemplary size **α** of the array of finger

biometric sensing pixels **30** may be about 4.8mm (FIG. 3). The length **β** of the biometric finger sensor **30** up to the finger drive electrode **33** may be 5.8mm (FIG. 3). In other words, there may be a 1mm between the array of finger biometric finger sensing pixels **30** and the finger drive electrode **33**. The overall size or diameter **γ** of the biometric finger sensor **30** may be about 10.9mm (FIG. 3). In other words the size of the finger drive electrode at its thickest part may be about 5.1mm.

[0062] In some embodiments, the finger drive circuitry **42** may perform voltage balancing based upon a given one of the user's fingers. As will be appreciated by those skilled in the art, different fingers have different leakage profiles. The finger drive circuitry **42** may adjust the voltage of the finger drive signal and the inverted finger drive signal based upon the finger type. Of course, the finger drive circuitry **42** may perform other and/or additional balancing or compensation functions.

[0063] Referring now to FIG. 6, in another embodiment, the array shielding electrode may be in the form of shielding pixels **34'**. More particularly, the dummy biometric finger sensing pixel area and the ground electrode described above with respect to FIGS. 3-5, are replaced with shielding pixels **34'** carried by the semiconductor substrate **32'** and laterally outside the array of biometric finger sensing pixels **31'**. The shielding pixels **34'** are structurally similar to the biometric sensing pixels **31'**, but are configured so that they do no perform the function of sensing finger biometrics.

[0064] The finger drive circuitry **42'**, in addition to being coupled to the finger drive electrode **33'**, is coupled to the shielding pixels **34'** and generates a compensating finger drive signal for the array shielding electrode. Similar to the embodiments described above, the compensating finger drive signal may have a different magnitude or offset with respect to the finger drive signal, and may be the form of an inverted finger drive signal for the shielding pixels **34'**.

[0065] Referring now to the graph **70** in FIG. 7, a pixel profile **71** is illustrated. Each horizontal flat spot in the profile is a pixel plate, as will be

appreciated by those skilled in the art. The peaks correspond to ridges in the user's finger **40**. The pixel profile illustrated is for a dry finger with no elevated field shaping electrode or array shielding electrode **34**. It should be noted that the voltage corresponding to between 0 and about 0.4mm is the effect of leakage from the drive signal. In other words, the voltage between 0 and 0.4mm is undesirable. The remaining pixel profile in terms of voltage, from 0.4mm to 2.5mm rises because of the curvature of the substrate, as will be appreciated by those skilled in the art.

[0066] Referring now to the graph **80** in FIG. 8, another pixel profile **81** is illustrated. The pixel profile is for a dry finger with an array shielding electrode **34** such that $V_{shield} = 0.02 * V_{drive}$. As will be appreciated by those skilled in the art, voltage leakage from the finger drive electrode is reduced.

[0067] A method aspect is directed to a method of making a biometric finger sensor **30**. The method includes forming an array shielding electrode **34** outside an array of biometric finger sensing pixels **31** and forming a finger drive electrode **33** outside the array shielding electrode. The method further includes coupling finger drive circuitry **42** to generate a finger drive signal for the finger drive electrode **33** and generate an inverted finger drive signal for the array shielding electrode **34**.

[0068] Referring now to FIGS. 9-12, in another embodiment, the electronic device **120** includes circuitry **175** carried by the housing **121**, for example, which may include the processor **122**, the display **123**, and the wireless communications circuitry **125** capable of performing at least one wireless communications function. Of course the circuitry **175** may include other or additional circuitry. The circuitry **175** has a device ground **174** associated therewith.

[0069] The electronic device **120** also includes a finger biometric sensor **130** that includes an array of biometric finger sensing pixel electrodes **131**, for example as described above. An input device, for example in the form of a pushbutton switch **124**, may carry the array of biometric finger sensing pixel electrodes **131**.

[0070] An array shielding electrode **134** is outside the array of biometric finger sensing pixels. The array shielding electrode in other embodiments may be provided by shielding pixel electrodes, as will be appreciated by those skilled in the art, for example, as described above with respect to FIG. 6.

[0071] A finger coupling electrode **133** is outside the array shielding electrode **134** and coupled to the device ground **173**. Sense amplifier circuitry **173** is coupled to the array of biometric finger sensing pixel electrodes **131** and has a circuit reference **172** associated therewith different than the device ground **174**. Similar to the embodiments described above, the finger coupling electrode **133** may be carried by and coupled to a conductive finger coupling electrode pad **145** which extends to the semiconductor substrate **132** by the through via **152**. Of course, other coupling arrangements may be used, as will be appreciated by those skilled in the art, including a two integrated circuit (IC) approach.

[0072] Drive circuitry **142** is capable of generating a drive signal **147** for the array of biometric finger sensing pixel electrodes **131**. The drive signal **147** may be generated as a square wave at an amplitude in a range of 10 to 20 volts and at a frequency of 1 to 5 MHz, for example. In other words, in contrast to the embodiments described above, the drive circuitry **142** drives the array of biometric finger sensing pixel electrodes **131** and the sense amplifier circuitry **173** as opposed to the finger coupling electrode **133**.

[0073] This arrangement of the array of biometric finger sensing pixel electrodes **142** being driven is illustrated more particularly in FIG. 12. The finger coupling electrode **133** is coupled to the device ground **174** so that the drive circuitry **142** drives the circuit reference **172** with respect to the finger coupling electrode and the device ground. A finger coupling electrode impedance **Ze** is defined between the user's finger **140** and the finger coupling electrode **133**, which in turn, is coupled to the device ground **174**. A finger impedance **Zf** exists between the user's finger **140** and the biometric finger sensing pixel electrode **131**. A reference impedance **Zg**

exists between the biometric finger sensing pixel electrode **131** and the substrate **132a** of a first IC. A reference impedance **Zr** exists between the circuit ground **172** of a second IC and the non-inverting input of the amplifier included within the sense circuitry **173** also on the second IC. A voltage regulator **177** may also be coupled to between the voltage supply **Vcc** and the circuit ground **172** or device ground **174**.

[0074] In contrast to driving the finger coupling electrode **133**, the relatively high voltage drive signal may not be seen by the sense amplifier circuitry **173** between its inputs and its ground. Small difference voltages may be visible to the sense amplifier circuitry **173**. However, an output signal from the sense amplifier circuitry **173** may not be ground referenced, but may be riding on top of the internal excitation signal or drive signal **147** as described in further detail below. Active level shifting circuitry may be applied in the subsequent signal path to remove the drive signal and generate a ground referenced output.

[0075] When the circuit reference **172** associated with the sense amplifier circuitry **173** is driven high, for example, the sense amplifier circuitry recognizes that the device grounded finger coupling electrode **133** went negative, hence it may be desirable that the array shielding electrode **134** be positive with respect to the circuit reference for it to appear inverted to the sense amplifier circuitry. Thus, the drive circuitry **142** is also capable of generating a compensating drive signal **148** for the array shielding electrode **134** and between the device ground **174** and the circuit reference **172**. The compensating drive signal **148** includes a scaled replica of the drive signal **147**. More particularly, the compensating drive signal **148** includes a scaled replica of the signal **147** driving the array of biometric finger sensing pixels **131** with respect to the circuit reference associated with the sense amplifier circuitry **173.** And with respect to device ground **174**, the compensating drive signal **148** "rides on top of the" drive signal **147**. Hence the compensating signal **148** appears in phase with and larger than the drive signal **147**. As will be appreciated by those skilled in the art, the compensating drive signal **148** may reduce noise since coupling the

finger coupling electrode **133** coupled to the device ground **174** may cause increased noise or leakage from the array of biometric finger sensing pixel electrodes **131** with respect to the finger coupling electrode **134**.

[0076] Similar to the embodiments described above with respect to FIG. 1-5, a reference electrode **136** is between the array shielding electrode **134** and the array of biometric finger sensing pixel electrodes **131**. A dummy biometric finger sensing pixel electrode area **135** may be between the array of biometric finger sensing pixel electrodes **131** and the reference electrode **136**. An adhesive layer **141** is between the dielectric layer routing substrate **137** and the finger coupling electrode **133**, and a dielectric material **149** fills opens spaces between components and connections, e.g. the array of biometric finger sensing pixel electrode **135**, the ground electrode **136**, and the through-vias **151**, **152**, also as described above. A dielectric cap is over the array of biometric finger sensing pixel electrodes **131** (FIG. 5), and a semiconductor substrate **132** may carry the array of biometric finger sensing pixel electrodes.

[0077] A method aspect is directed to a method of making an electronic device **120**. The electronic device **120** includes circuitry **175** having a device ground **174** associated therewith. The method includes forming an array shielding electrode **134** outside an array of biometric finger sensing pixel electrodes **131**. The method also includes forming a finger coupling electrode **133** outside the array shielding electrode **134** and coupled to the device ground **174**. The method also includes forming drive circuitry **142** capable of generating a drive signal **147** for the array of biometric finger sensing pixel electrodes **131** and a compensating drive signal **148** for the array shielding electrode **134**.

[0078] It should be noted that the biometric finger sensor described herein may be included within any electronic device, or may be used as a standalone biometric finger sensor to be coupled to or used in conjunction with other devices or circuitry. Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the

associated drawings. Therefore, it is understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

THAT WHICH IS CLAIMED IS:

1. An electronic device comprising:

a housing;

circuitry carried by said housing and having a device ground associated therewith;

an array of biometric finger sensing pixel electrodes;

an array shielding electrode outside said array of biometric finger sensing pixels;

a finger coupling electrode outside said array shielding electrode and coupled to the device ground; and

drive circuitry capable of generating a drive signal for said array of biometric finger sensing pixel electrodes and a compensating drive signal for said array shielding electrode.

2. The electronic device of Claim 1, wherein said drive circuitry is capable of generating the compensating drive signal comprising a scaled replica of the drive signal.

3. The electronic device of Claim 1, further comprising sense amplifier circuitry coupled to said array of biometric finger sensing pixel electrodes and having a circuit reference associated therewith different than the device ground; and wherein said drive circuitry is capable of generating the drive signal between the device ground and the circuit reference.

4. The electronic device of Claim 1, wherein said array shielding electrode comprises a plurality of shielding pixel electrodes.

5. The electronic device of Claim 1, further comprising a reference electrode between said array shielding electrode and said array of biometric finger sensing pixel electrodes.

6. The electronic device of Claim 5, further comprising a dummy biometric finger sensing pixel electrode area between said array of biometric finger sensing pixel electrodes and said reference electrode.

7. The electronic device of Claim 1, further comprising a dielectric cap over said array of biometric finger sensing pixel electrodes.

8. The electronic device of Claim 1, further comprising a semiconductor substrate carrying said array of biometric finger sensing pixel electrodes.

9. The electronic device of Claim 1, wherein said circuitry comprises wireless communications circuitry capable of performing at least one wireless communications function.

10. The electronic device of Claim 1, further comprising an input device carrying said array of biometric finger sensing pixel electrodes.

11. The electronic device of Claim 1, wherein said drive circuitry is capable of generating the drive signal as a square wave at an amplitude in a range of 10 to 20 volts and at a frequency of 1 to 5 MHz.

12. A finger biometric sensor to be coupled to circuitry carried by a housing of an electronic device, the circuitry having a device ground associated therewith, the finger biometric sensor comprising:

an array of biometric finger sensing pixel electrodes;

an array shielding electrode outside said array of biometric finger sensing pixels;

a finger coupling electrode outside said array shielding electrode and coupled to the device ground; and

drive circuitry capable of generating a drive signal for said array of biometric finger sensing pixel electrodes and a compensating drive signal for said array shielding electrode.

13. The finger biometric sensor of Claim 12, wherein said drive circuitry is capable of generating the compensating drive signal comprising a scaled replica of the drive signal.

14. The finger biometric sensor of Claim 12, further comprising sense amplifier circuitry coupled to said array of biometric finger sensing pixel electrodes and having a circuit reference associated therewith different than the device ground; and wherein said drive circuitry

is capable of generating the drive signal between the device ground and the circuit reference.

15. The finger biometric sensor of Claim 12, wherein said array shielding electrode comprises a plurality of shielding pixel electrodes.

16. The finger biometric sensor of Claim 12, further comprising a reference electrode between said array shielding electrode and said array of biometric finger sensing pixel electrodes.

17. The finger biometric sensor of Claim 16, further comprising a dummy biometric finger sensing pixel electrode area between said array of biometric finger sensing pixel electrodes and said reference electrode.

18. The finger biometric sensor of Claim 12, further comprising a dielectric cap over said array of biometric finger sensing pixel electrodes.

19. The finger biometric sensor of Claim 12, further comprising a semiconductor substrate carrying said array of biometric finger sensing pixel electrodes.

20. The finger biometric sensor of Claim 12, wherein said drive circuitry is capable of generating the drive signal as a square wave at an amplitude in a range of 10 to 20 volts and at a frequency of 1 to 5 MHz.

21. A method of making an electronic device comprising circuitry having a device ground associated therewith, the method comprising:

forming an array shielding electrode outside an array of biometric finger sensing pixel electrodes;

forming a finger coupling electrode outside the array shielding electrode and coupled to the device ground; and

forming drive circuitry capable of generating a drive signal for the array of biometric finger sensing pixels and a compensating drive signal for the array shielding electrode.

22. The method of Claim 21, wherein forming the drive circuitry comprises forming the drive circuitry to be capable of generating

the compensating drive signal comprising a scaled replica of the drive signal.

23. The method of Claim 21, further comprising forming sense amplifier circuitry coupled to the array of biometric finger sensing pixel electrodes and having a circuit reference associated therewith different than the device ground; and wherein the drive circuitry is capable of generating the drive signal between the device ground and the circuit reference.

24. The method of Claim 21, wherein forming the array shielding electrode comprises forming a plurality of shielding pixel electrodes.

25. The method of Claim 21, further comprising forming a reference electrode between the array shielding electrode and the array of biometric finger sensing pixel electrodes.

26. The method of Claim 25, further comprising a forming dummy biometric finger sensing pixel electrode area between the array of biometric finger sensing pixel electrodes and the reference electrode.

27. The method of Claim 21, further comprising positioning a dielectric cap over the array of biometric finger sensing pixel electrodes.

28. The method of Claim 21, wherein forming the drive circuitry comprises forming the drive circuitry to be capable of generating the drive signal as a square wave at an amplitude in a range of 10 to 20 volts and at a frequency of 1 to 5 MHz.

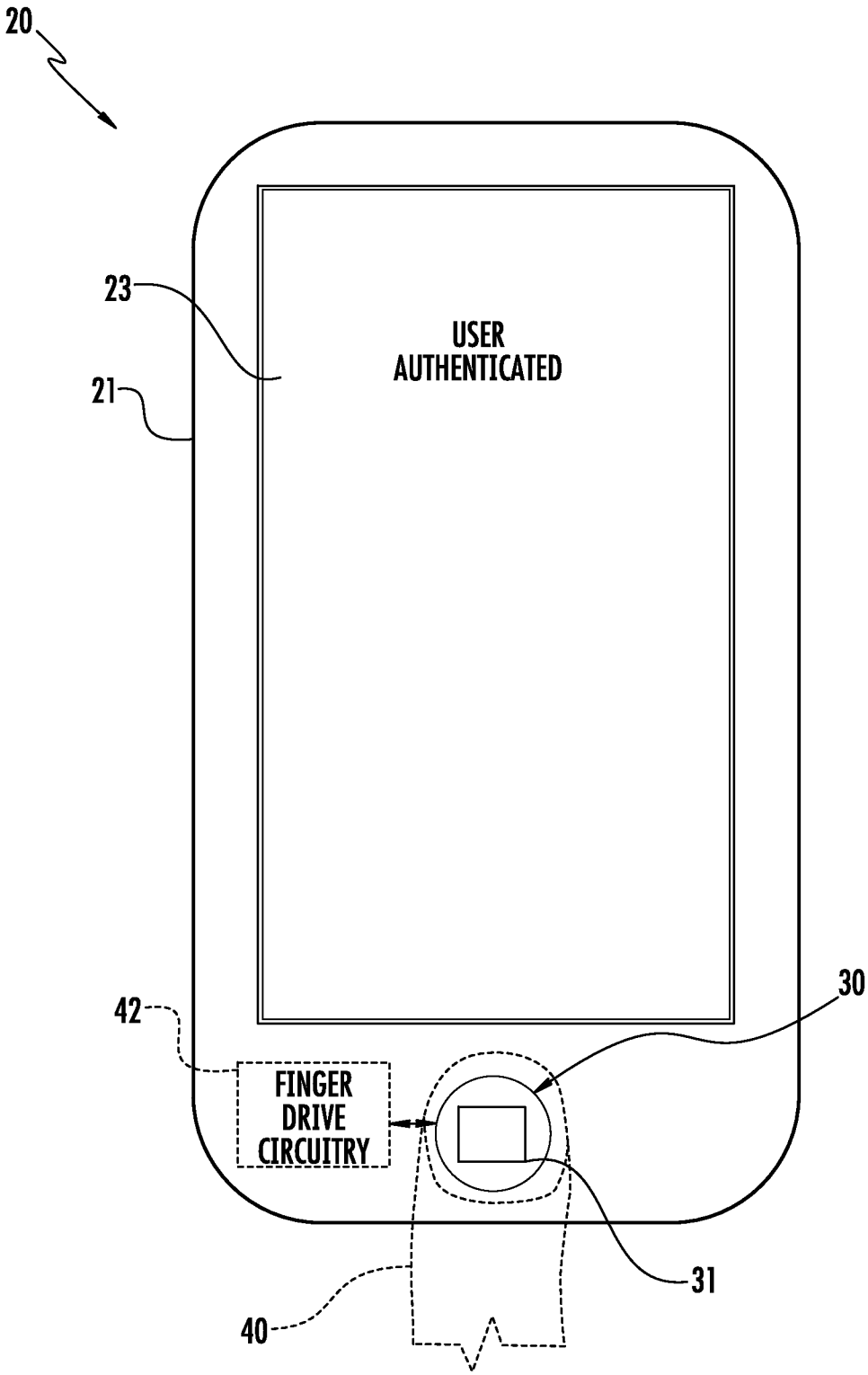

20
23
21
USER
AUTHENTICATED
42
30
FINGER
DRIVE
CIRCUITRY
31
40

FIG. 1

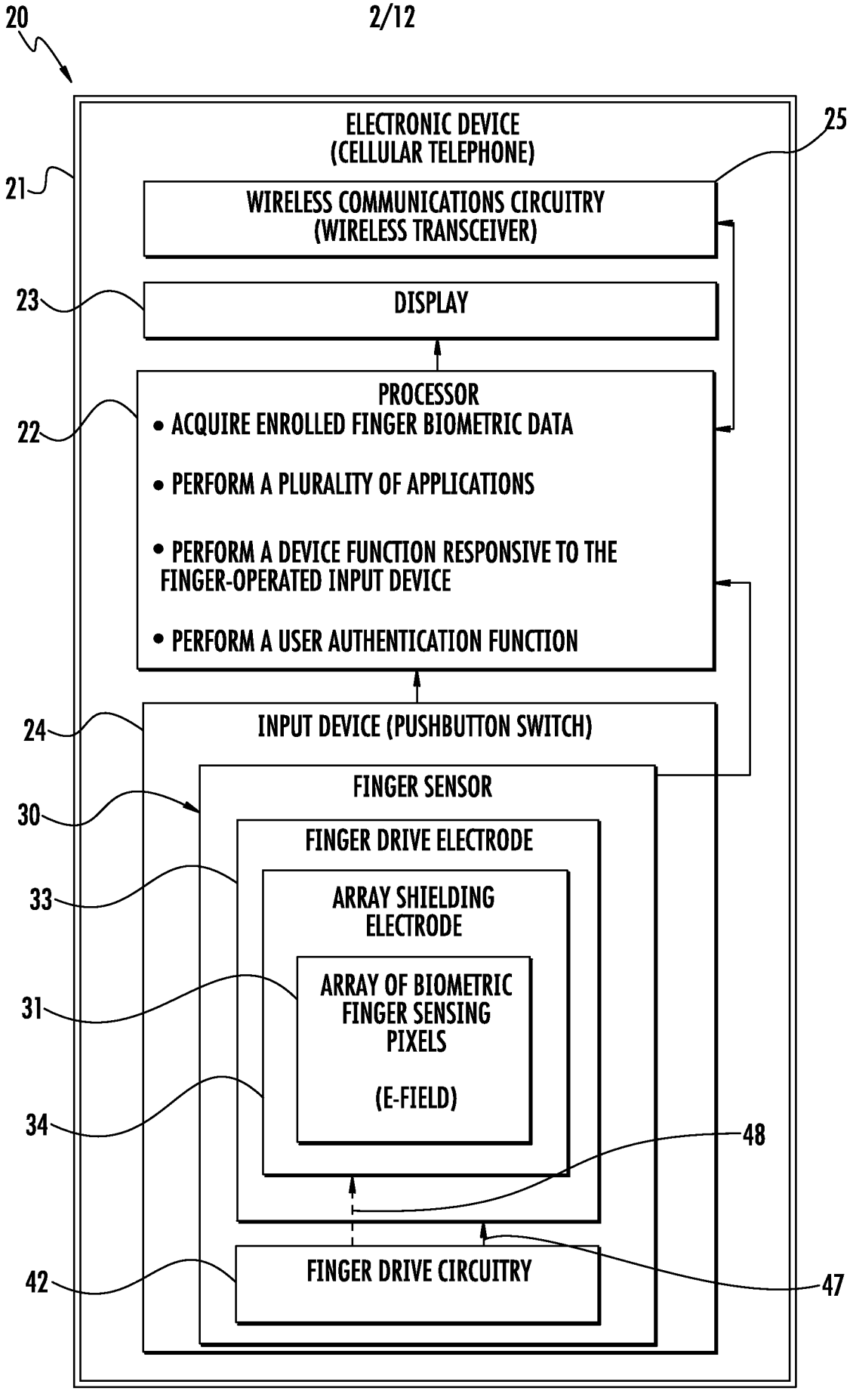

20
ELECTRONIC DEVICE
(CELLULAR TELEPHONE)
25
21
WIRELESS COMMUNICATIONS CIRCUITRY
(WIRELESS TRANSCEIVER)
23
DISPLAY
PROCESSOR
22
• ACQUIRE ENROLLED FINGER BIOMETRIC DATA
• PERFORM A PLURALITY OF APPLICATIONS
• PERFORM A DEVICE FUNCTION RESPONSIVE TO THE FINGER-OPERATED INPUT DEVICE
• PERFORM A USER AUTHENTICATION FUNCTION
24
INPUT DEVICE (PUSHBUTTON SWITCH)
FINGER SENSOR
30
FINGER DRIVE ELECTRODE
33
ARRAY SHIELDING ELECTRODE
31
ARRAY OF BIOMETRIC FINGER SENSING PIXELS
(E-FIELD)
34
48
42
FINGER DRIVE CIRCUITRY
47

FIG. 2

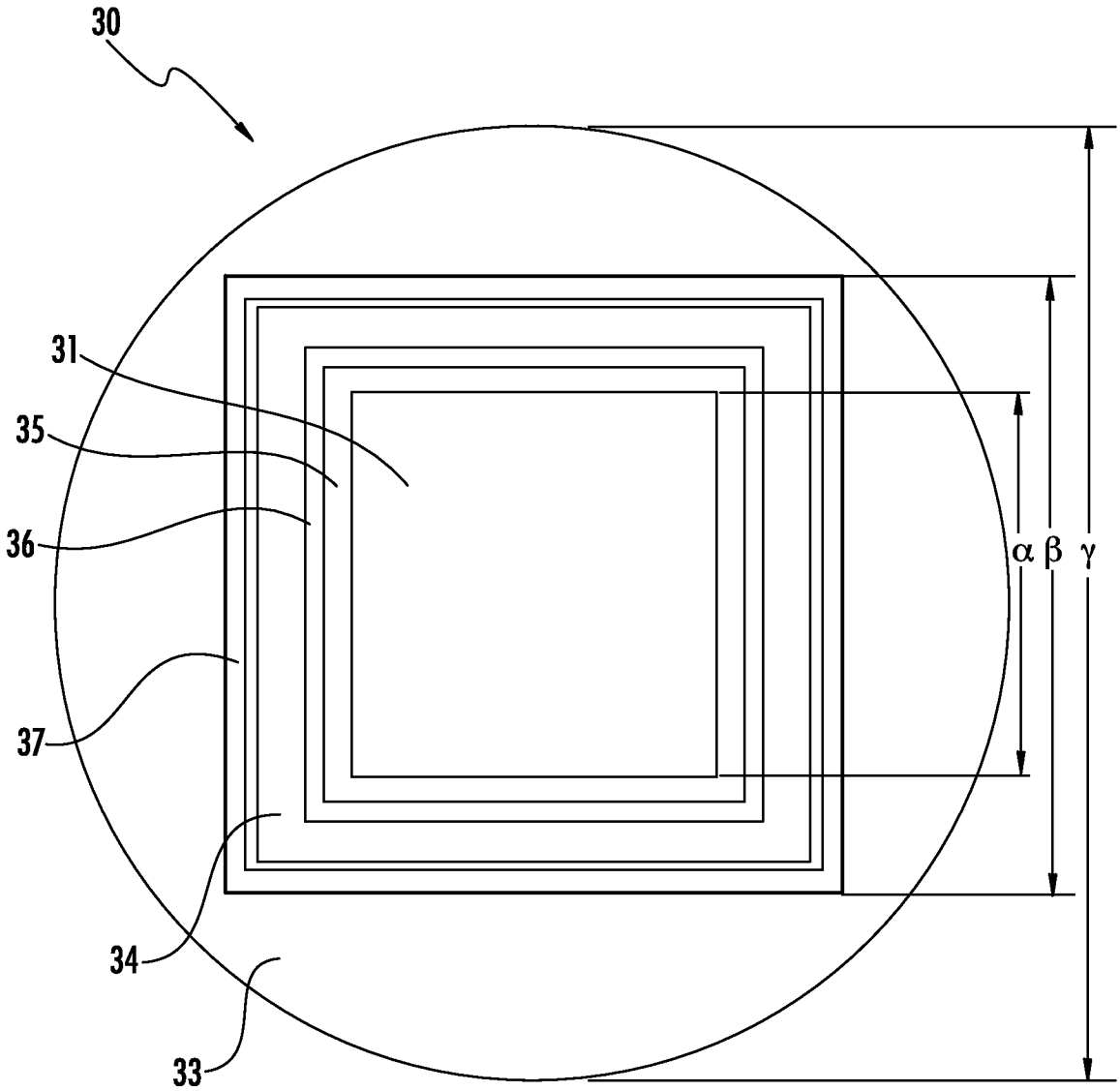


FIG. 3

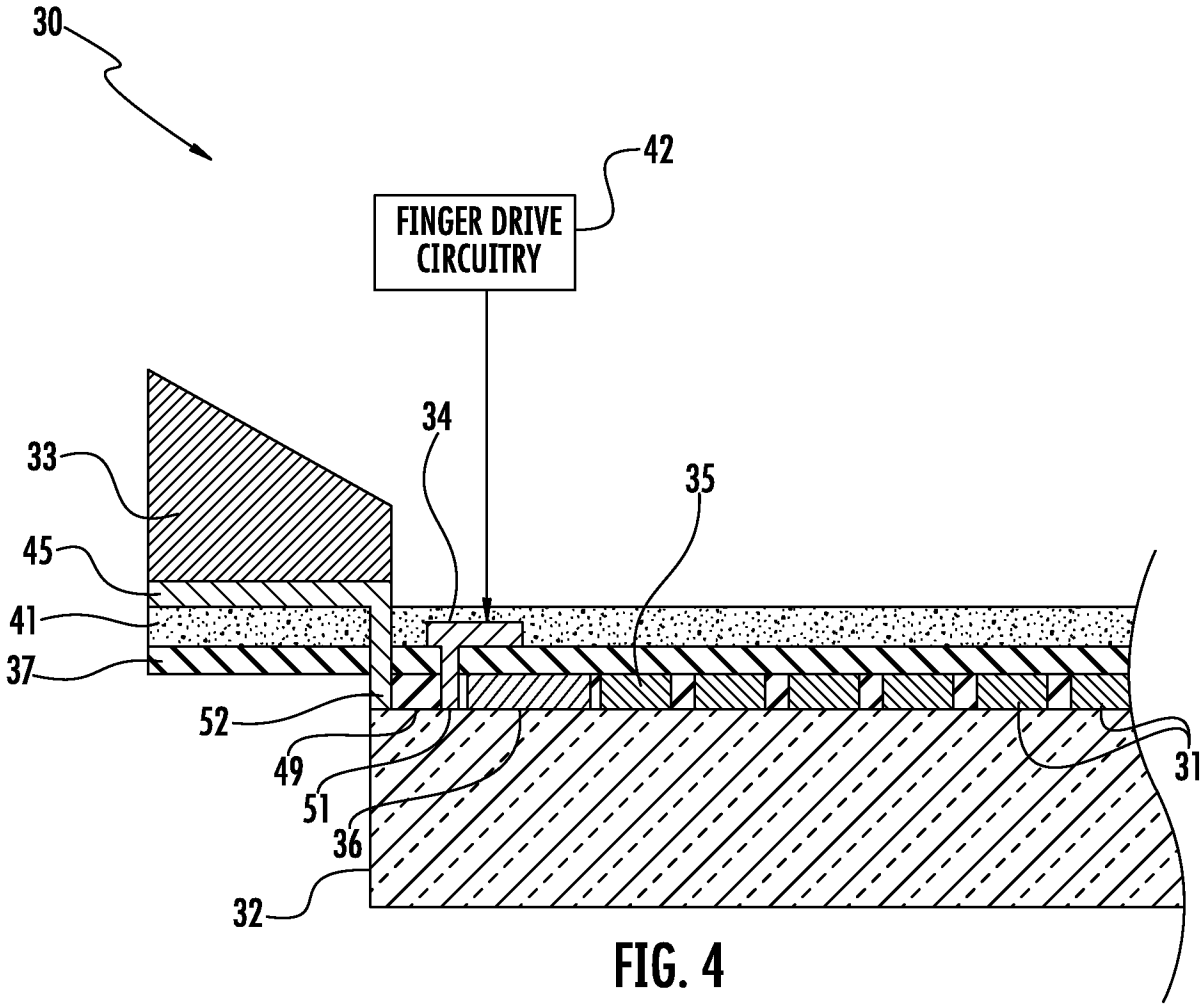


FIG. 4

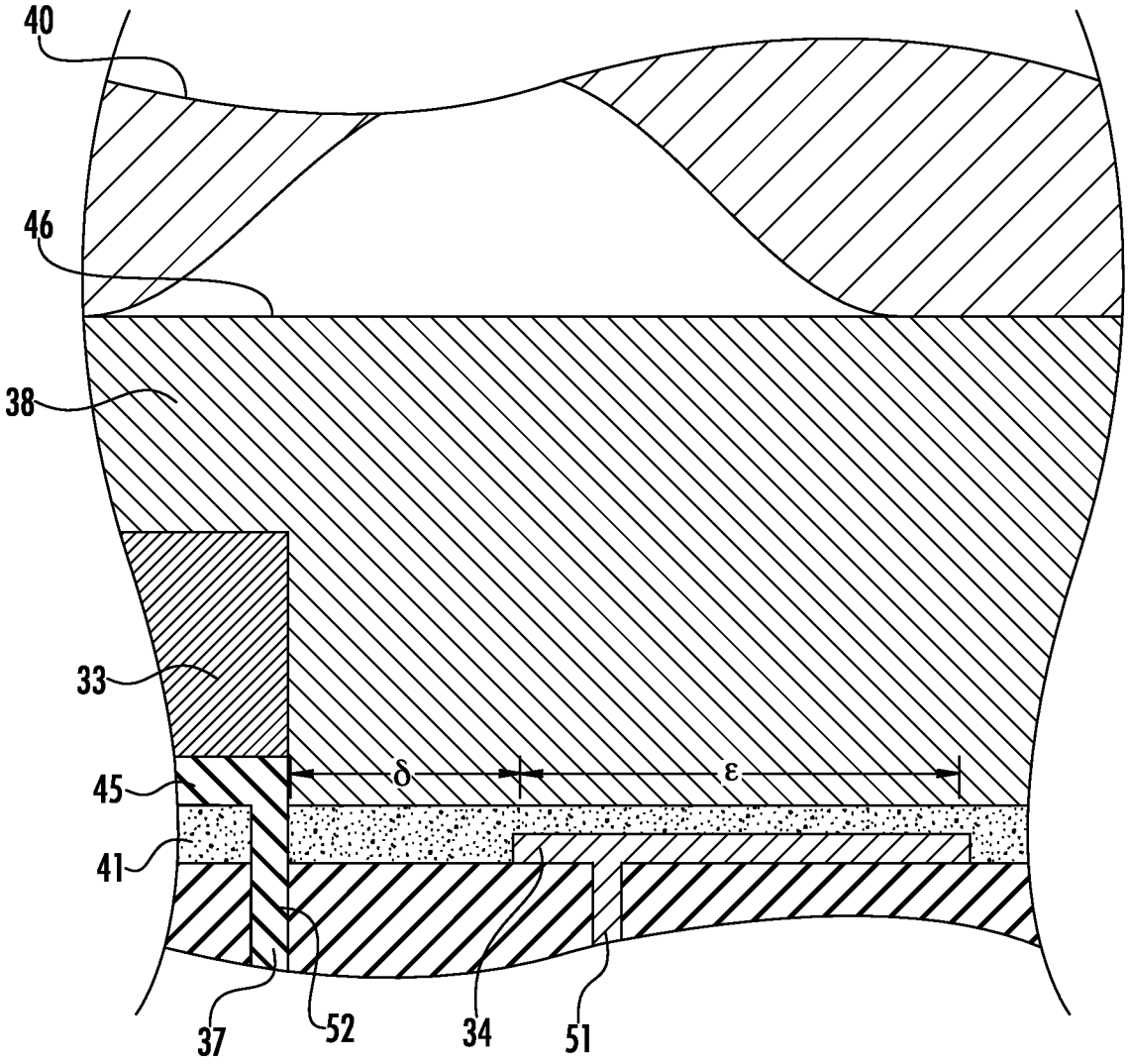


FIG. 5

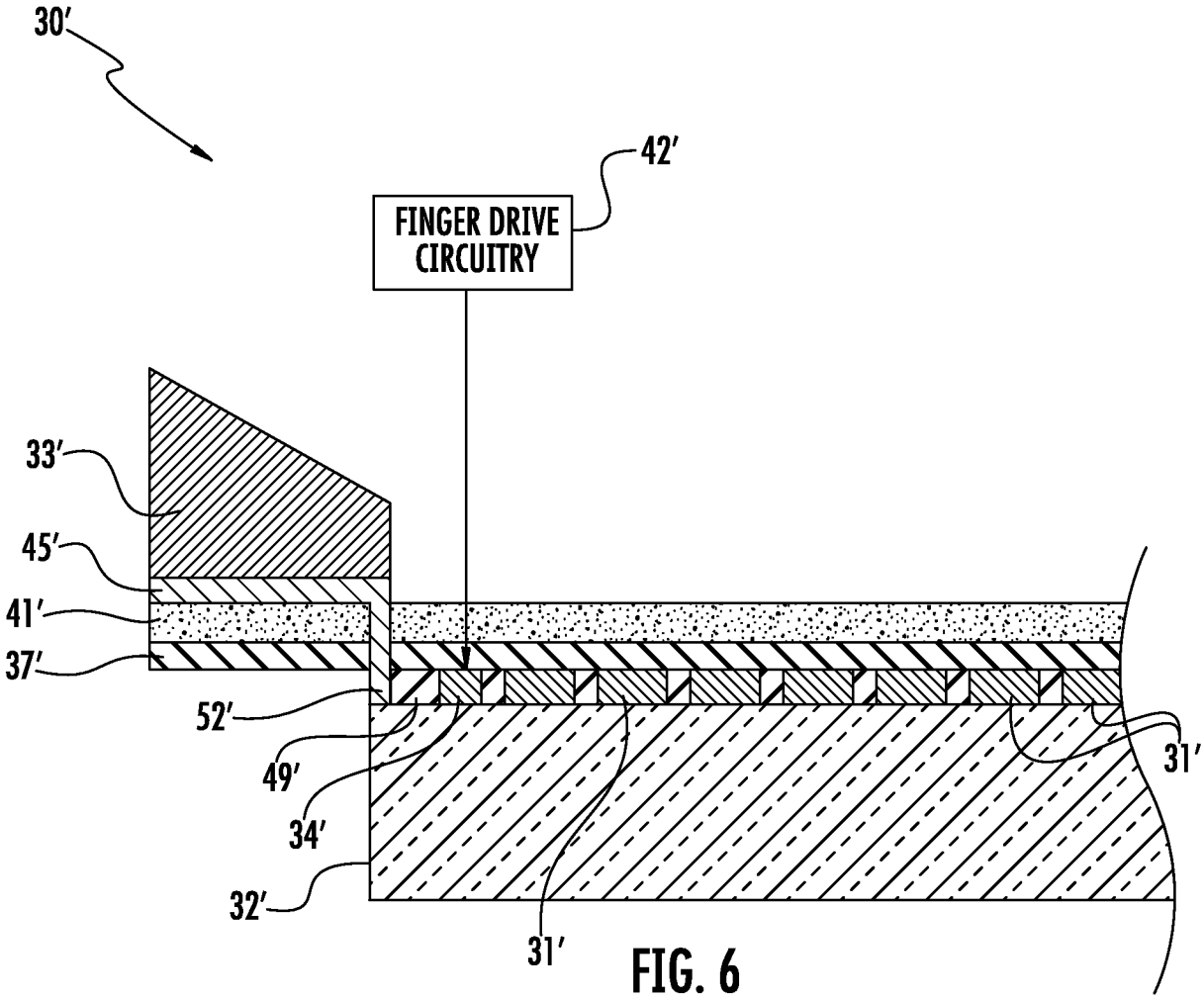


FIG. 6

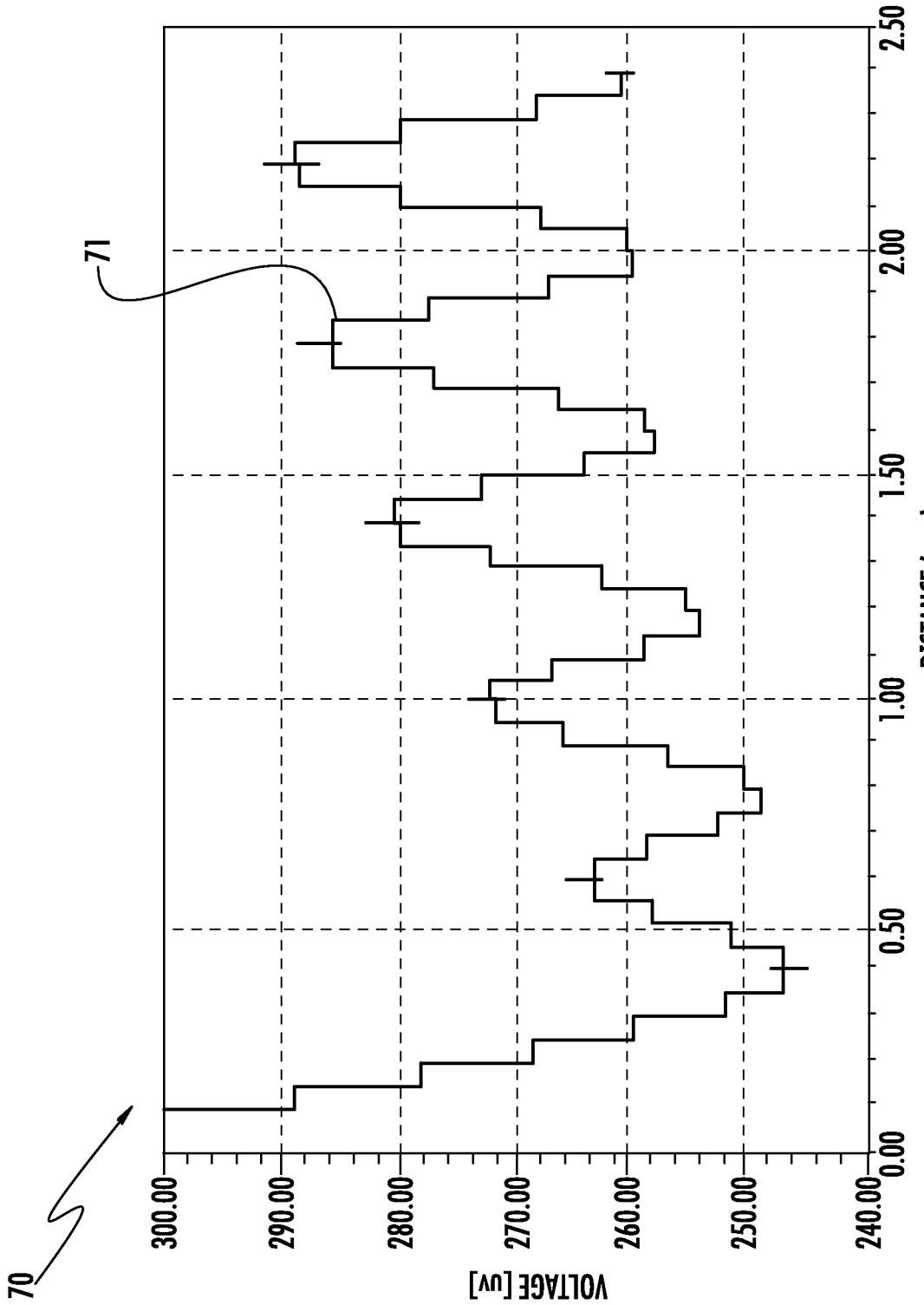

70
71
VOLTAGE [uv]
300.00
290.00
280.00
270.00
260.00
250.00
240.00
0.00
0.50
1.00
1.50
2.00
2.50
DISTANCE (mm)

FIG. 7

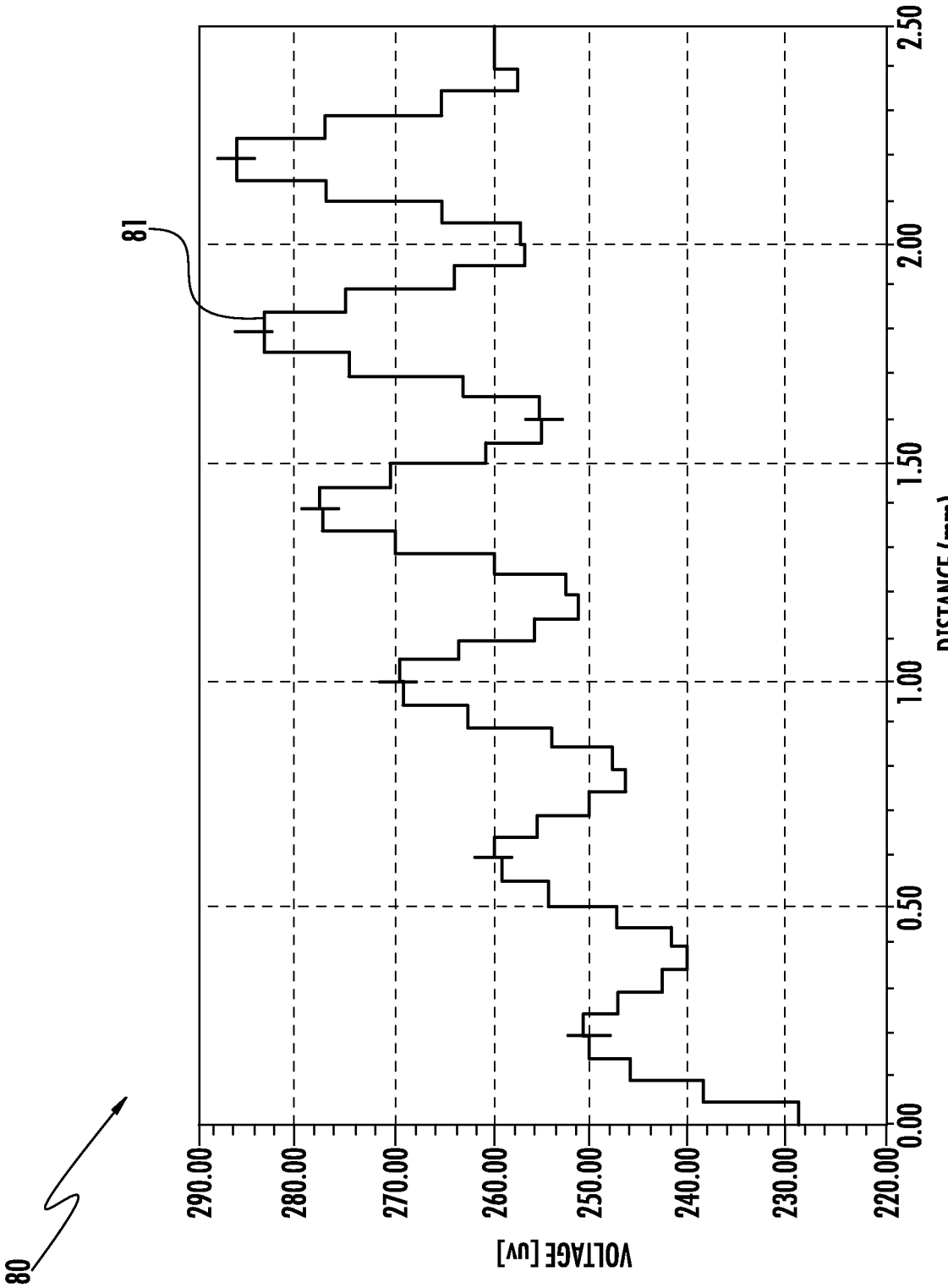

80
81
290.00
280.00
270.00
260.00
250.00
240.00
230.00
220.00
VOLTAGE [uv]
0.00
0.50
1.00
1.50
2.00
2.50
DISTANCE (mm)

FIG. 8

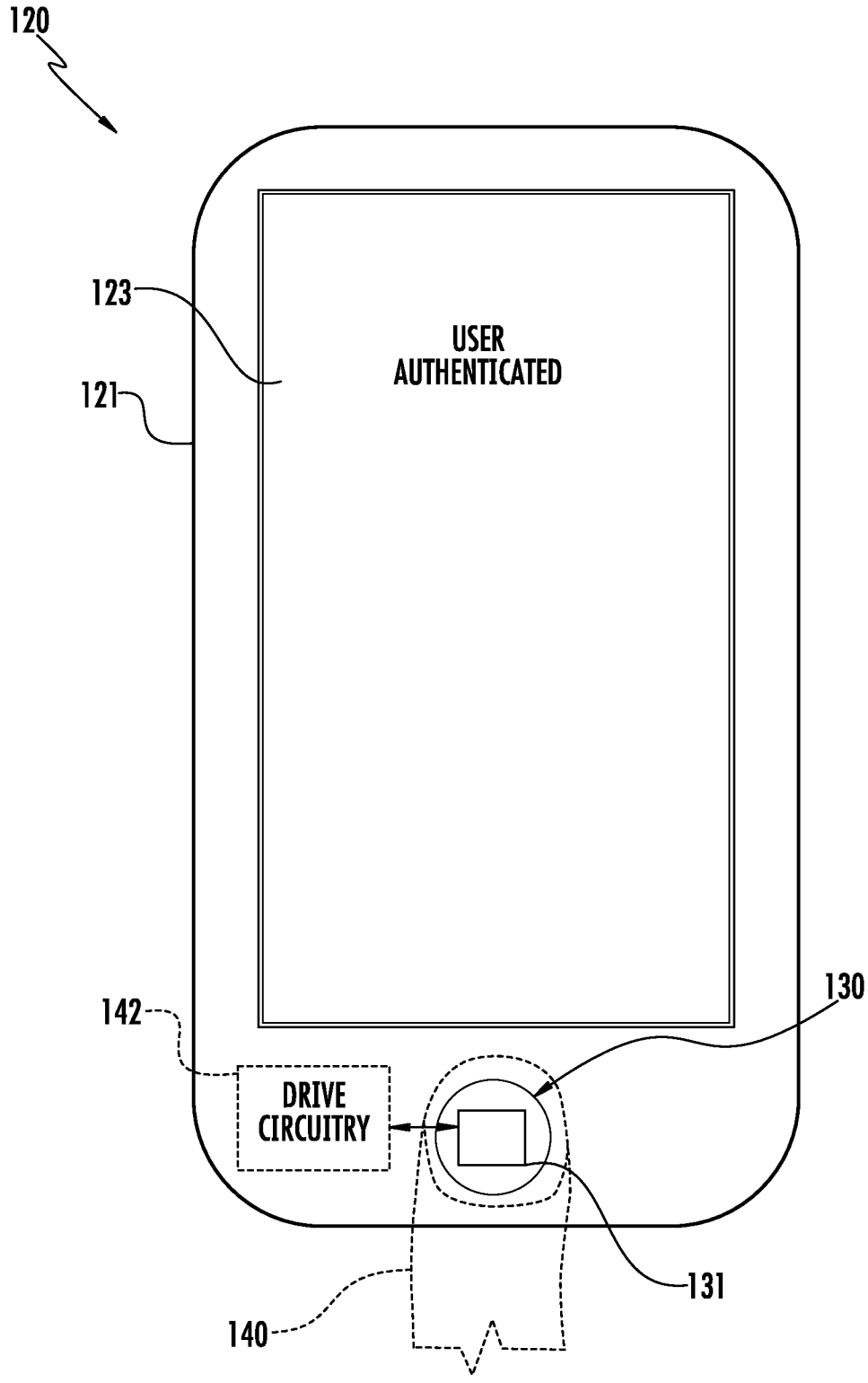

120
123
121
USER
AUTHENTICATED
142
130
DRIVE
CIRCUITRY
131
140

FIG. 9

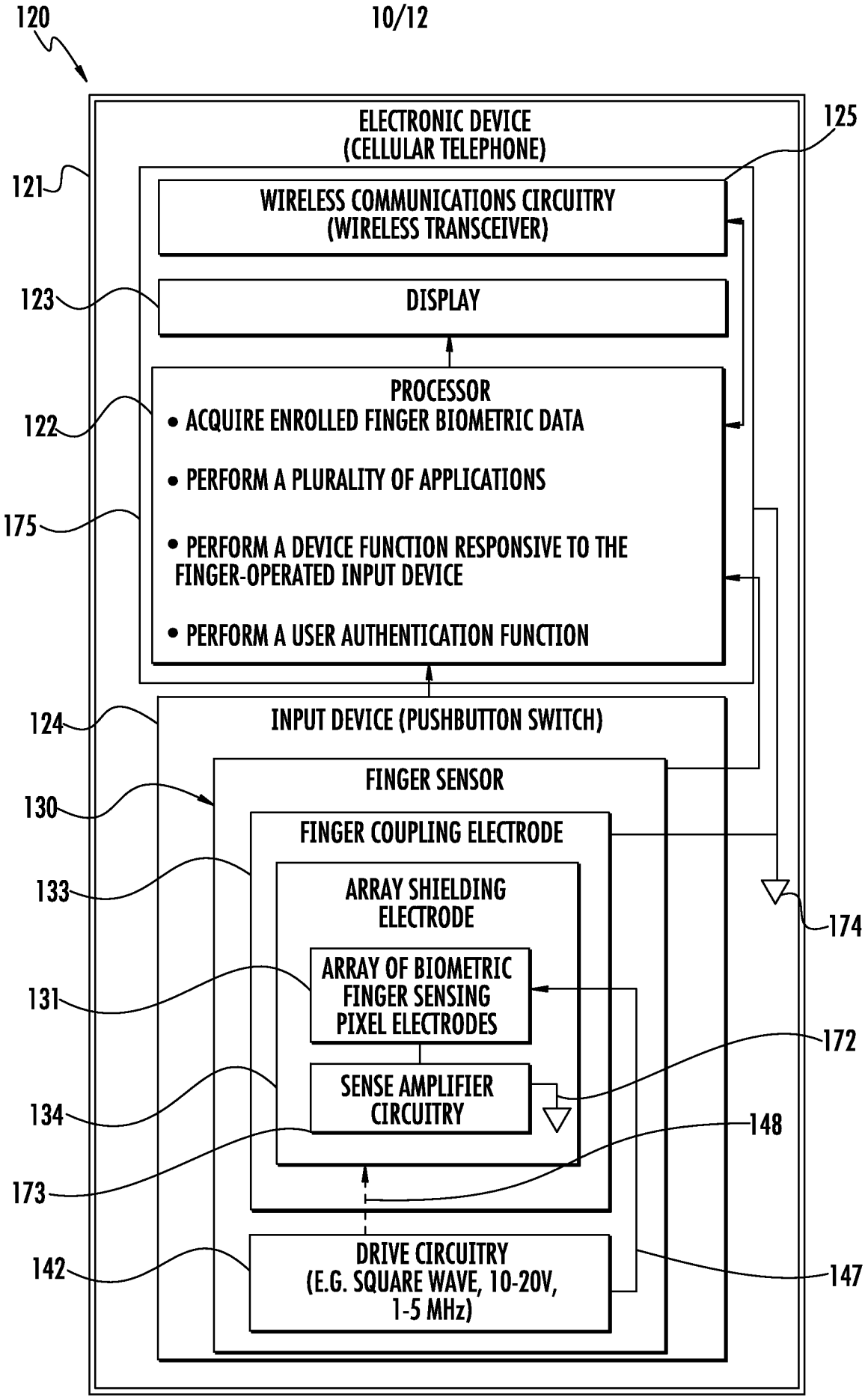

120
ELECTRONIC DEVICE
(CELLULAR TELEPHONE)
125
121
WIRELESS COMMUNICATIONS CIRCUITRY
(WIRELESS TRANSCEIVER)
123
DISPLAY
PROCESSOR
122
• ACQUIRE ENROLLED FINGER BIOMETRIC DATA
• PERFORM A PLURALITY OF APPLICATIONS
175
• PERFORM A DEVICE FUNCTION RESPONSIVE TO THE FINGER-OPERATED INPUT DEVICE
• PERFORM A USER AUTHENTICATION FUNCTION
124
INPUT DEVICE (PUSHBUTTON SWITCH)
FINGER SENSOR
130
FINGER COUPLING ELECTRODE
133
ARRAY SHIELDING ELECTRODE
174
131
ARRAY OF BIOMETRIC FINGER SENSING PIXEL ELECTRODES
172
134
SENSE AMPLIFIER CIRCUITRY
148
173
142
DRIVE CIRCUITRY
(E.G. SQUARE WAVE, 10-20V, 1-5 MHz)
147

FIG. 10

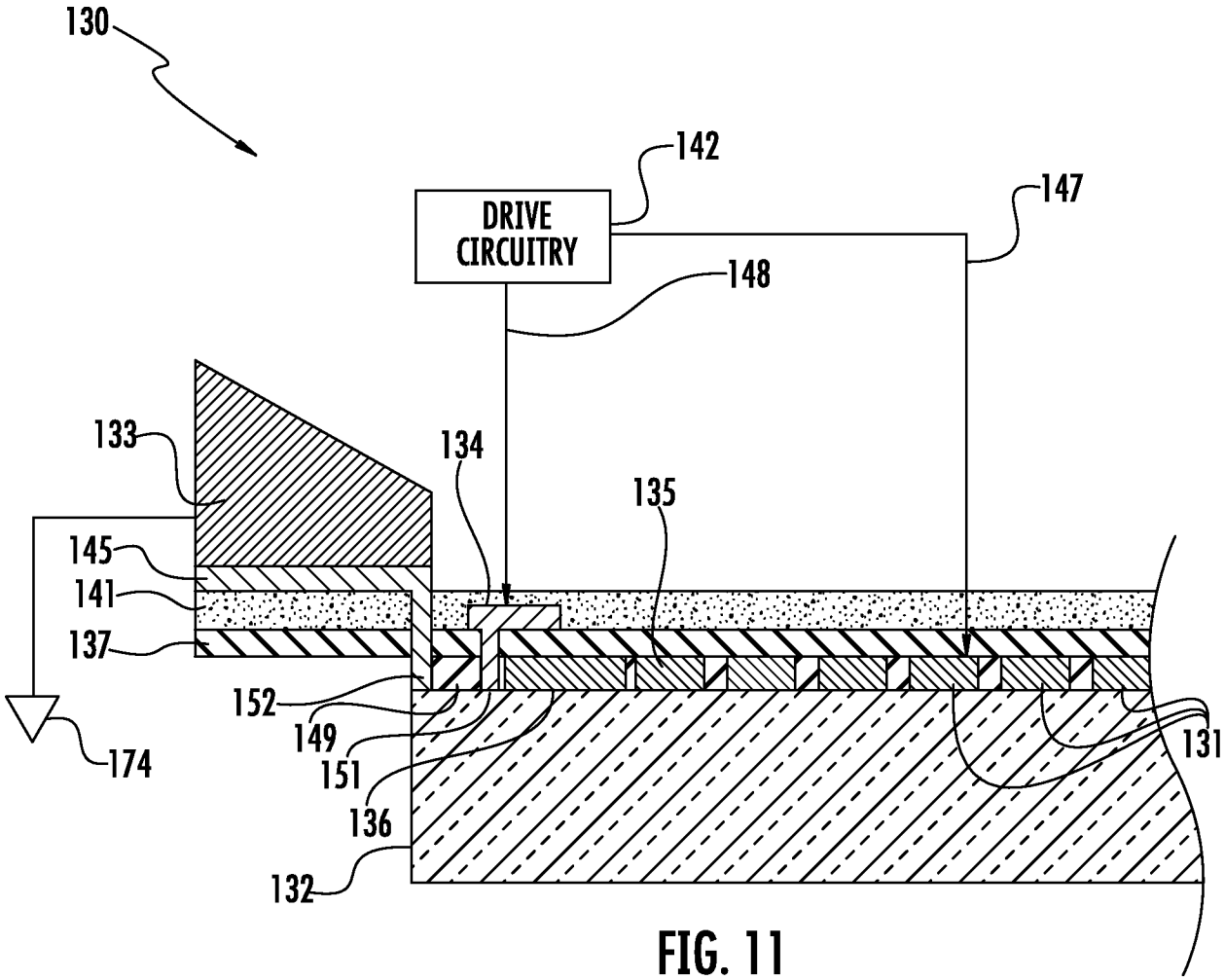

130
142
DRIVE CIRCUITRY
147
148
133
134
135
145
141
137
152
149
151
136
132
174
131

FIG. 11

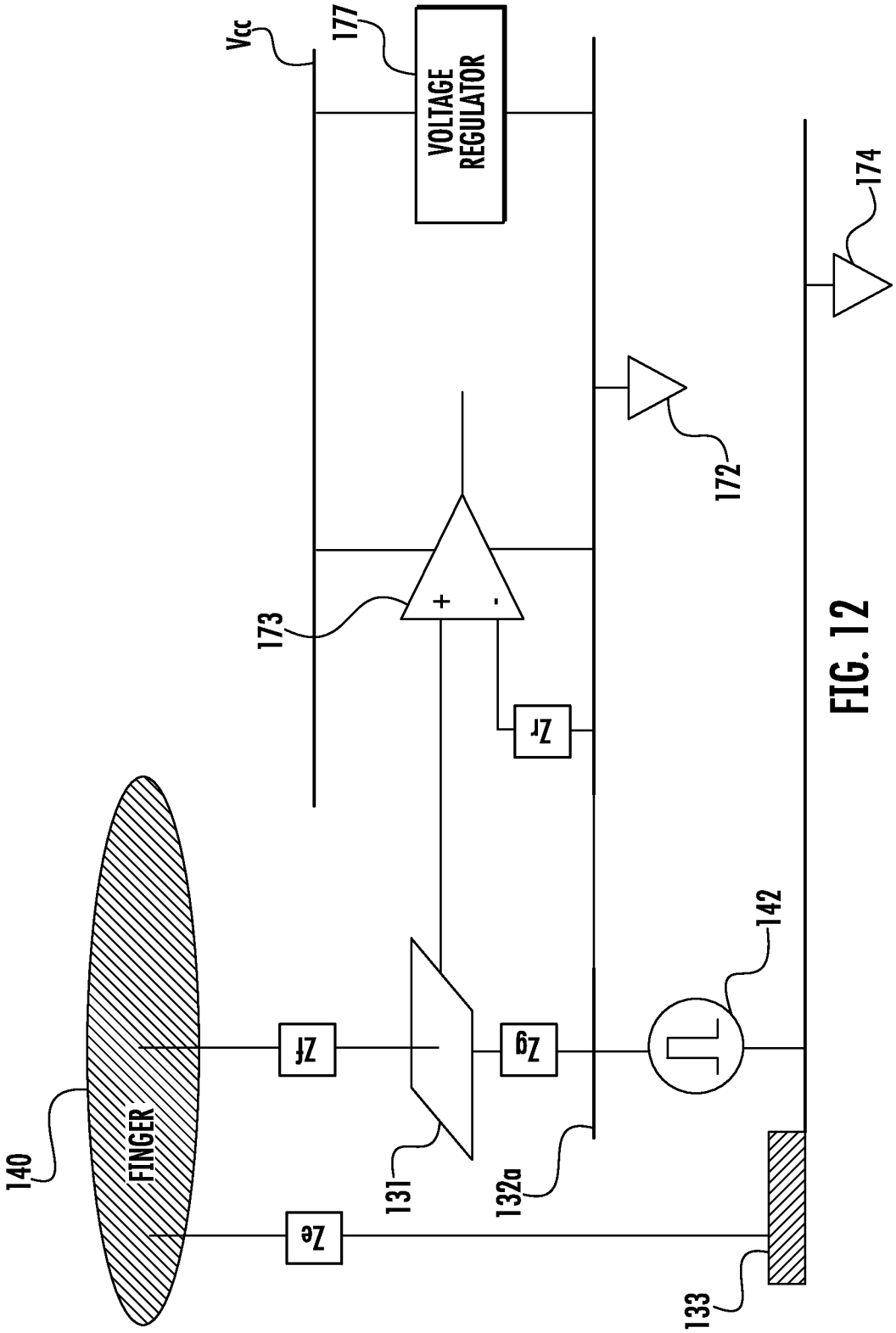

Vcc
177
VOLTAGE REGULATOR
174
172
173
+
-
Zr
142
Zf
Zg
FINGER
140
131
132a
Ze
133

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/074250

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06K9/00
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)
G06K

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

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X	EP 0 791 899 A2 (HARRIS CORP [US] AUTHENTEC INC [US]) 27 August 1997 (1997-08-27)	1-4, 7-15, 18-24, 27,28
Y	abstract; figures column 5, line 6 - column 7, line 4	5,6,16, 17,25,26
Y	US 2005/253598 A1 (KAWAHATA KEN [JP]) 17 November 2005 (2005-11-17) paragraph [0087] - paragraph [0088]	5,16,25
Y	EP 1 406 069 A1 (SONY CORP [JP]) 7 April 2004 (2004-04-07) paragraph [0030]	6,17,26
A	US 6 097 195 A (ACKLAND BRYAN D [US] ET AL) 1 August 2000 (2000-08-01) the whole document	1-28

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"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	Date of mailing of the international search report
20 March 2014	27/03/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Isa, Sabine

1

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/074250

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2005/124659 A1 (FINGERPRINT CARDS AB [SE]; RIEDIJK FRANK [NL]; HAMMERSBERG JOHAN [SE]) 29 December 2005 (2005-12-29) the whole document -----	1-28

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/074250

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