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(54) **FINGERPRINT SENSING CIRCUIT HAVING PROGRAMMABLE SENSING PATTERNS**

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***G06K 9/00*** (2006.01)

(52) **U.S. Cl.**
CPC .................................. ***G06K 9/00013*** (2013.01)

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See application file for complete search history.

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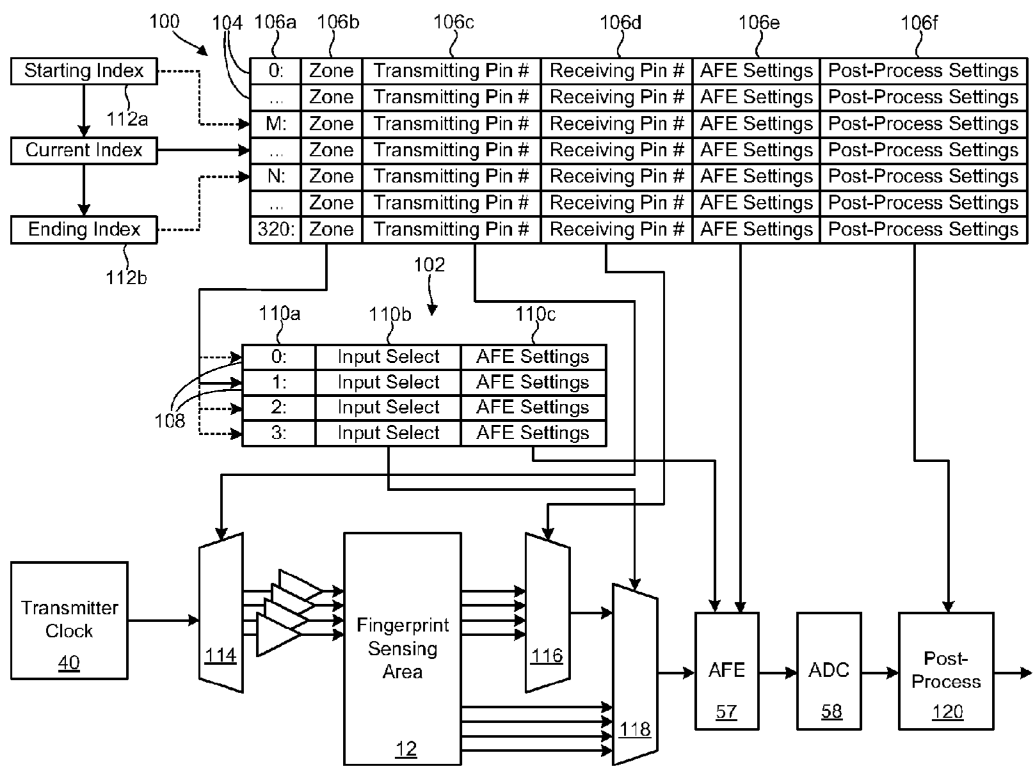
(57) **ABSTRACT**

A fingerprint sensor with programmable sensing patterns is disclosed in one embodiment of the invention as including a fingerprint sensing circuit having multiple I/O interconnects. The I/O interconnects are configured to sequentially drive a plurality of fingerprint sensing elements. A memory device may be operably coupled to the fingerprint sensing circuit. A programmable data structure, such as a table, file, character string, numeric value, array, or the like may be stored in the memory device to designate a pattern for driving the fingerprint sensing elements. The fingerprint sensing circuit is configured to drive the fingerprint sensing elements according to the designated pattern. In selected embodiments, the fingerprint sensing elements may include transmitting elements, receiving elements, or a combination thereof.

**21 Claims, 8 Drawing Sheets**



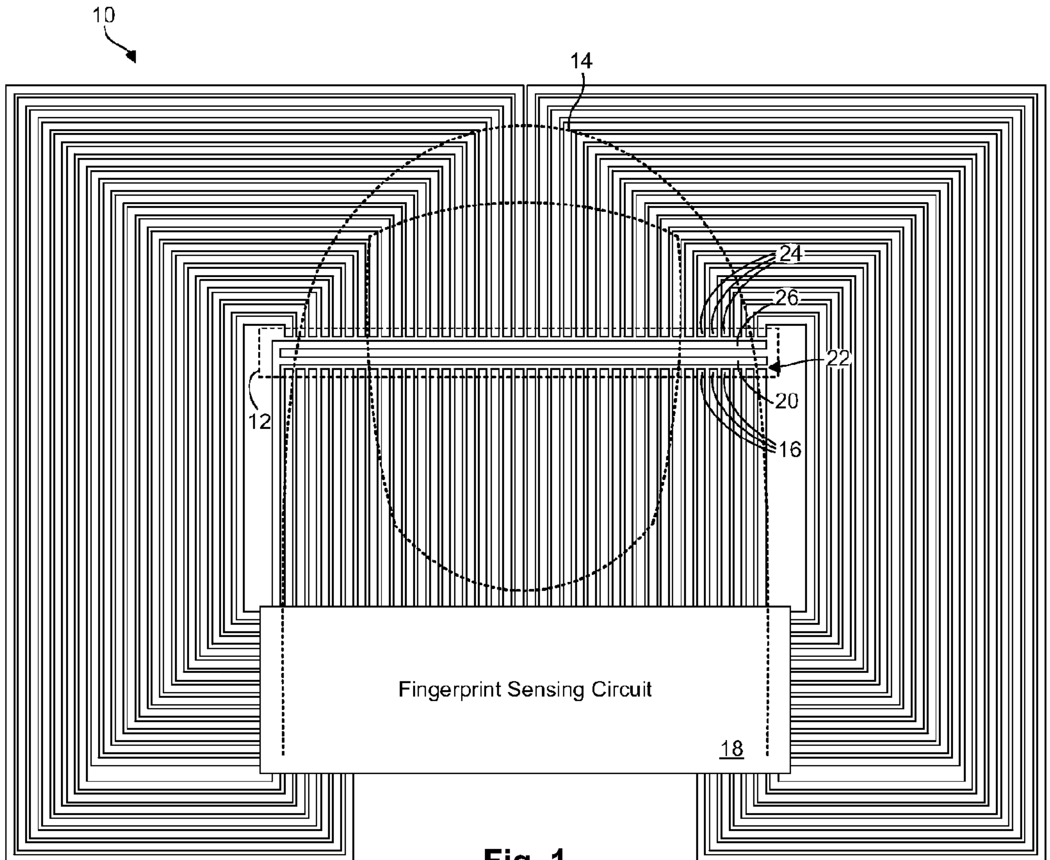



Fig. 1

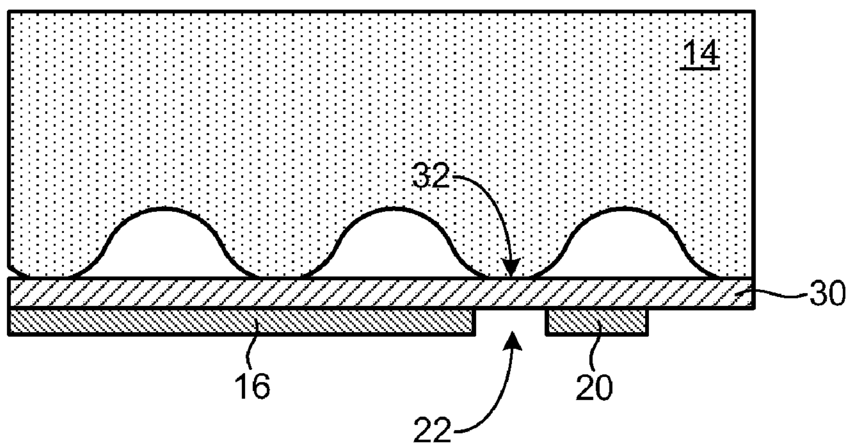



Fig. 2

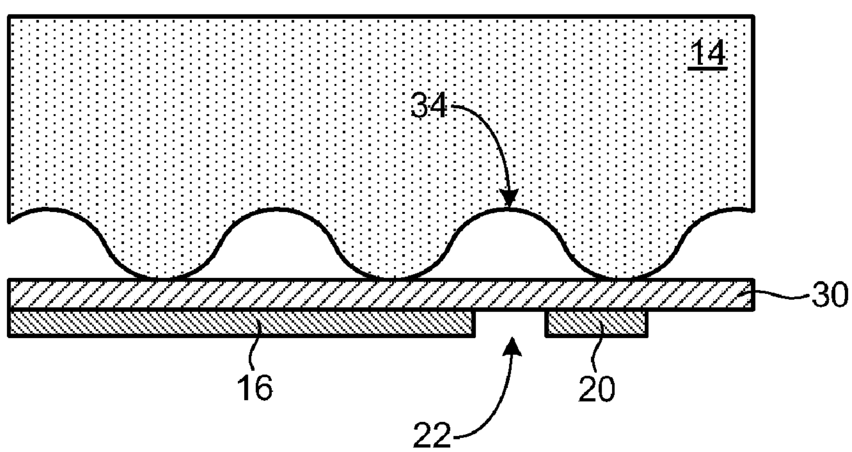



Fig. 3

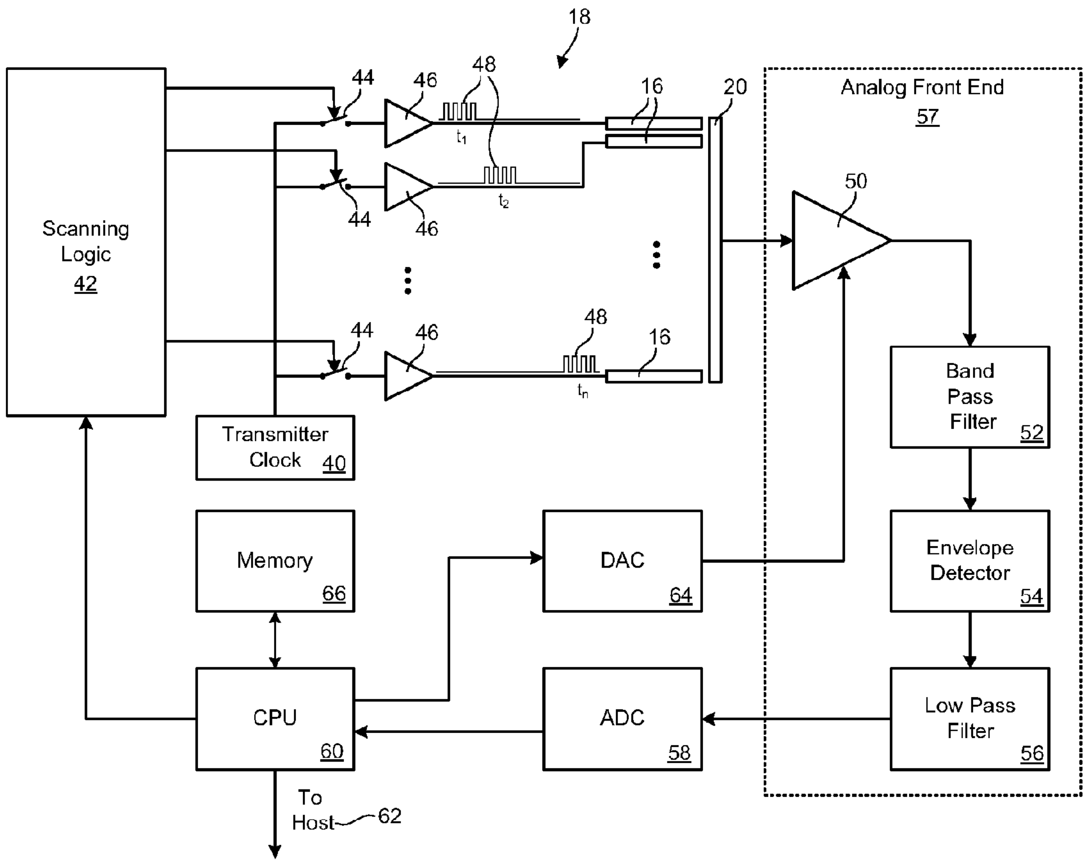

18
Scanning Logic 42
44
46
48
$t_1$
$t_2$
$t_n$
16
20
Analog Front End 57
50
Band Pass Filter 52
Envelope Detector 54
Low Pass Filter 56
Transmitter Clock 40
Memory 66
DAC 64
CPU 60
ADC 58
To Host 62

Fig. 4

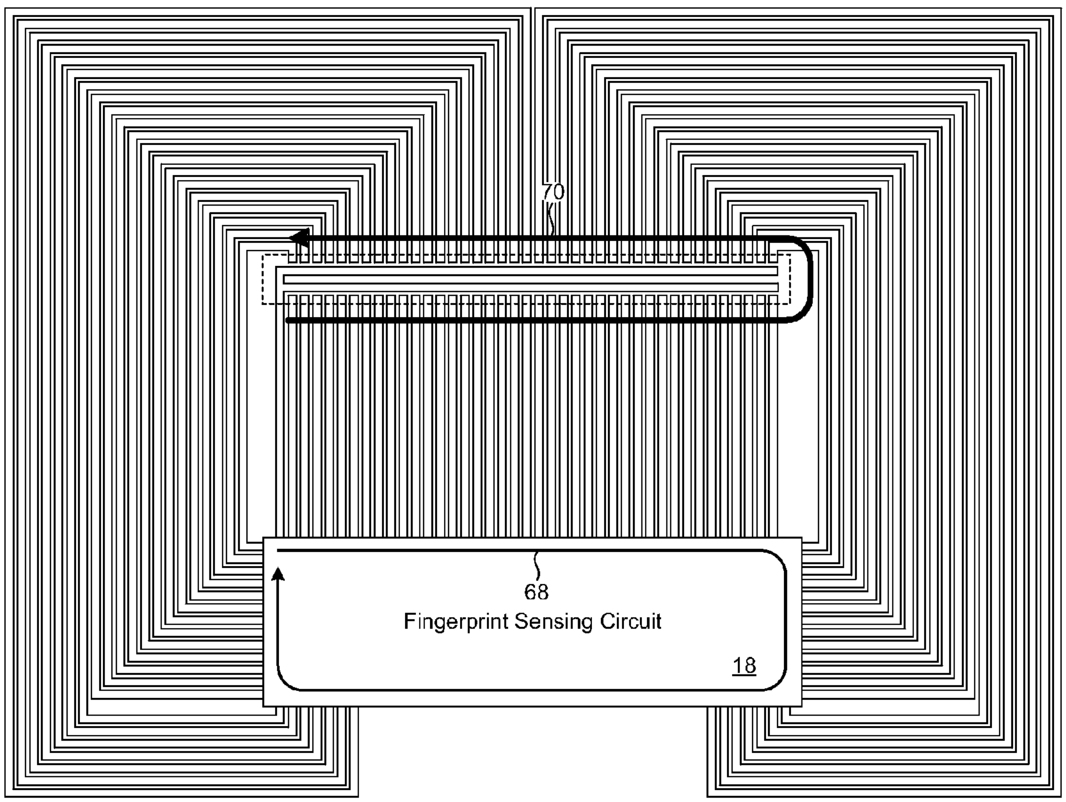



Fig. 5

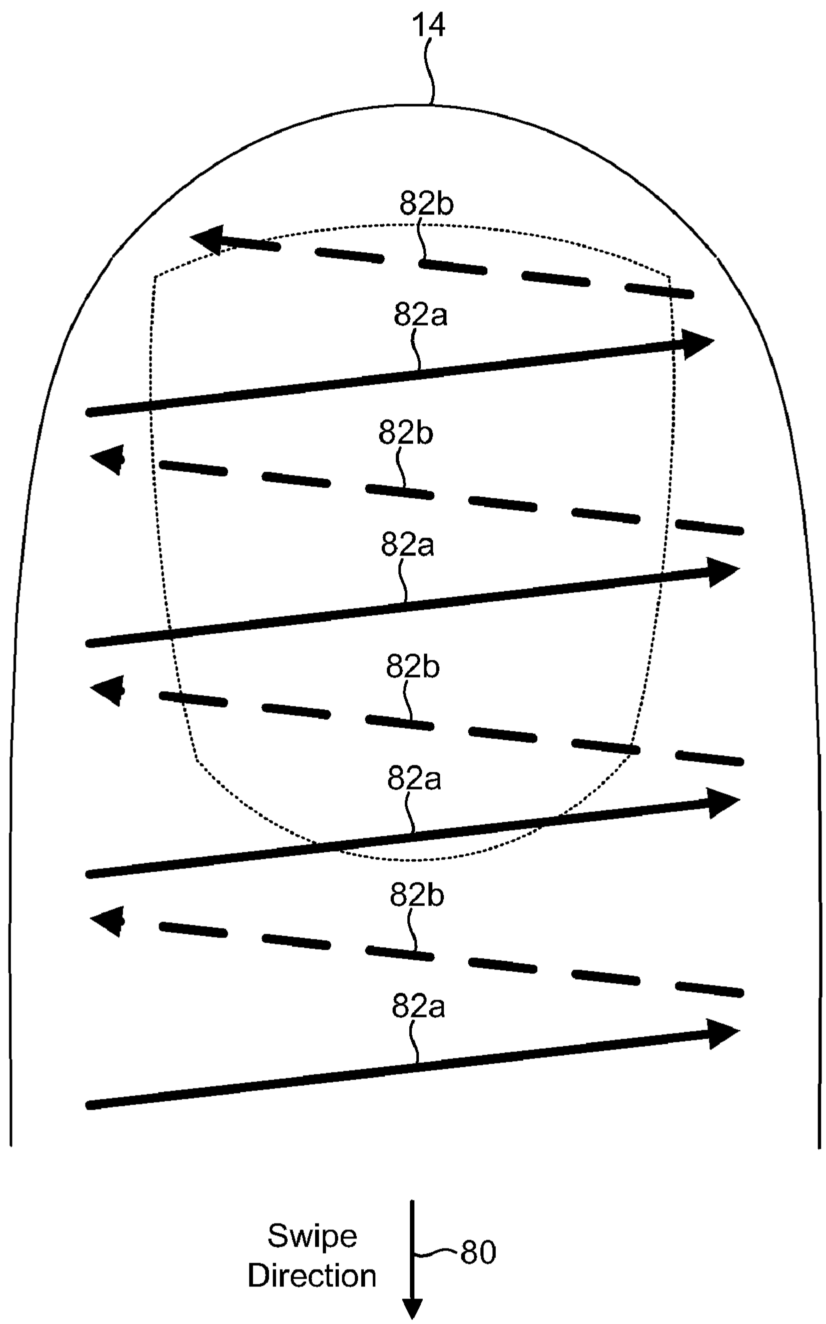



**Fig. 6**

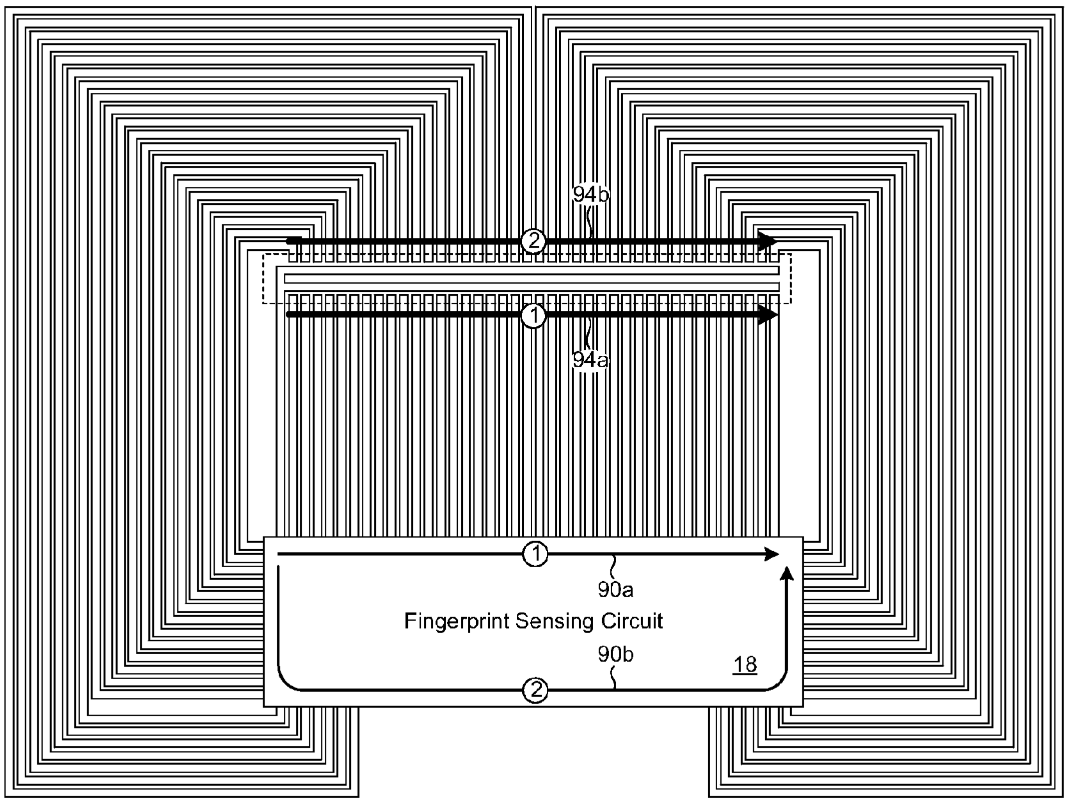



Fig. 7

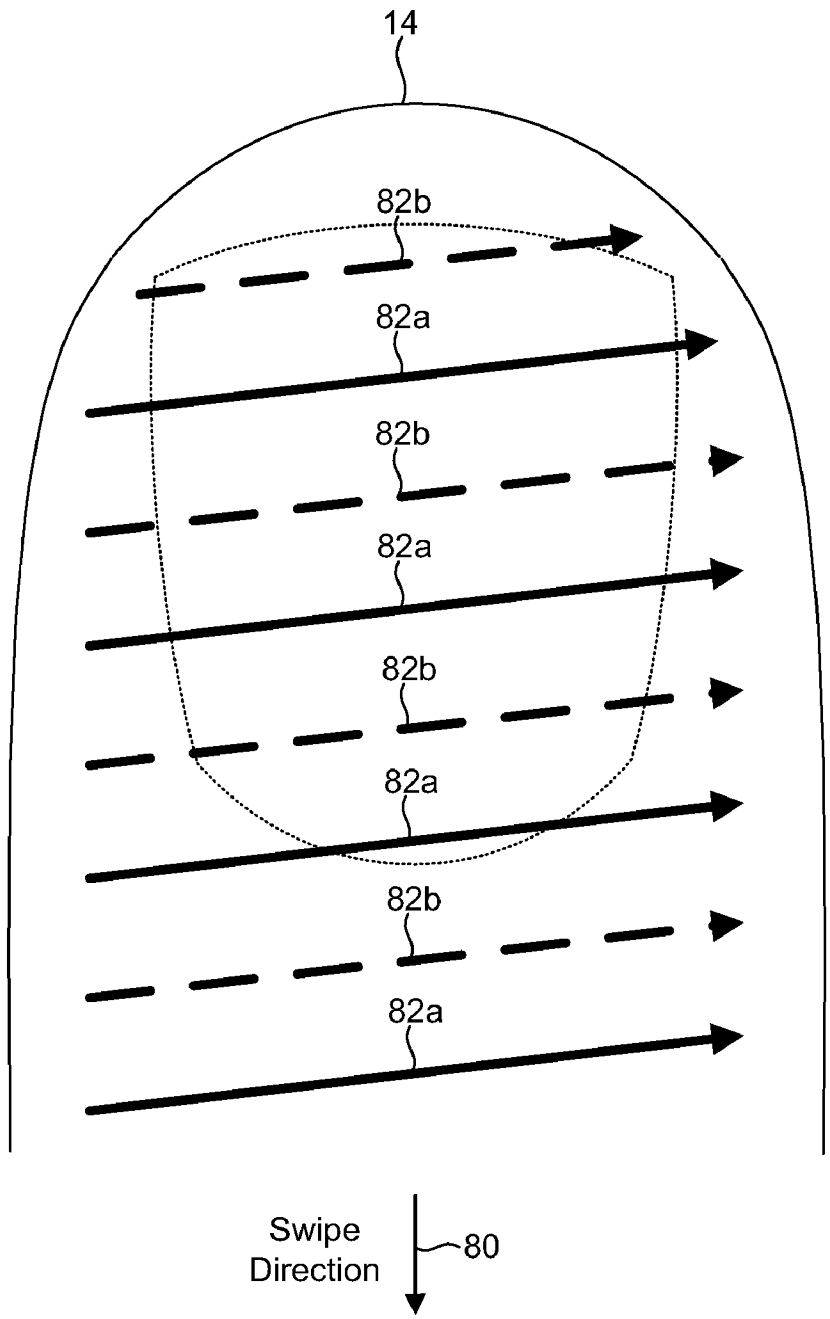



Fig. 8

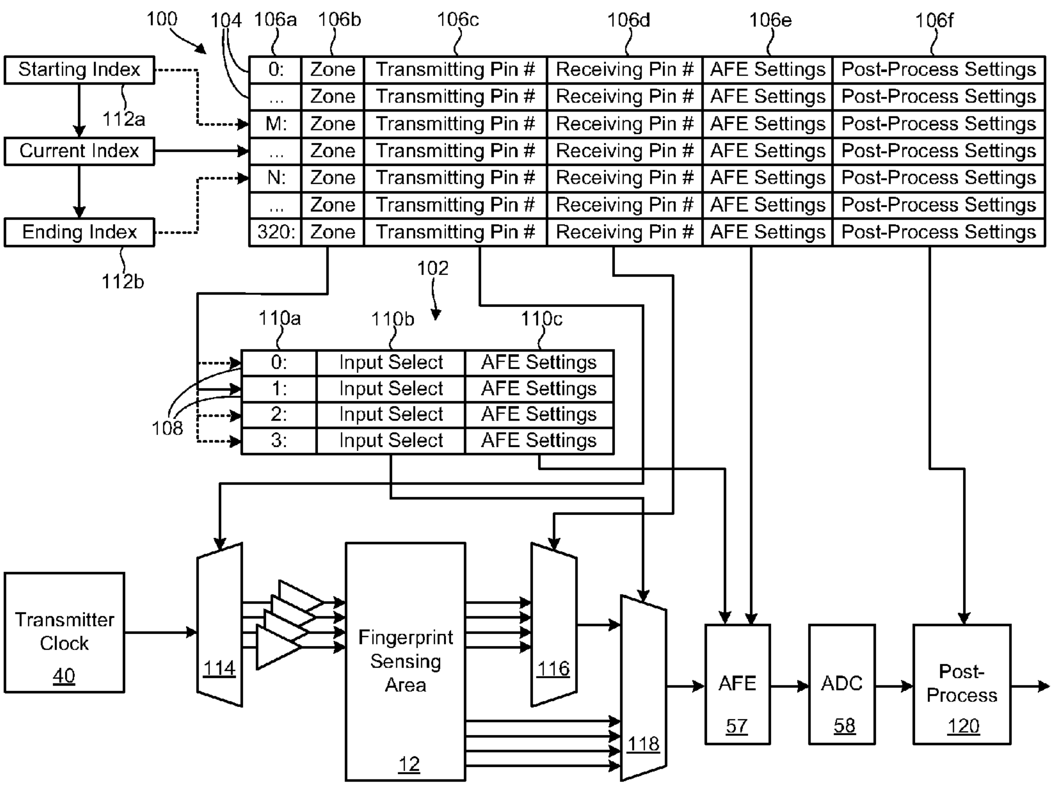

100
104
106a
106b
106c
106d
106e
106f
Starting Index
112a
Current Index
Ending Index
112b
0:
...
M:
N:
320:
Zone
Transmitting Pin #
Receiving Pin #
AFE Settings
Post-Process Settings
102
110a
110b
110c
108
1:
2:
3:
Input Select
Transmitter Clock
40
114
Fingerprint Sensing Area
12
116
118
AFE
57
ADC
58
Post-Process
120

Fig. 9

# FINGERPRINT SENSING CIRCUIT HAVING PROGRAMMABLE SENSING PATTERNS

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.**

## BACKGROUND

This invention relates to fingerprint sensing technology and more particularly to fingerprint sensing circuits that can be programmed with different sensing patterns.

Fingerprint sensing technology is increasingly recognized as a reliable, non-intrusive way to verify individual identity. Fingerprints, like various other biometric characteristics, are based on unalterable personal characteristics and thus are believed to be more reliable when identifying individuals. The potential applications for fingerprints sensors are myriad. For example, electronic fingerprint sensors may be used to provide access control in stationary applications, such as security checkpoints. Electronic fingerprint sensors may also be used to provide access control in portable applications, such as portable computers, personal data assistants (PDAs), cell phones, gaming devices, navigation devices, information appliances, data storage devices, and the like. Accordingly, some applications, particularly portable applications, may require electronic fingerprint sensing systems that are compact, highly reliable, and inexpensive.

Various electronic fingerprint sensing methods, techniques, and devices have been proposed or are currently under development. For example, optical and capacitive fingerprint sensing devices are currently on the market or under development. Like a digital camera, optical technology utilizes visible light to capture a digital image. In particular, optical technology may use a light source to illuminate an individual's finger while a charge-coupled device (CCD) captures an analog image. This analog image may then be converted to a digital image.

There are generally two types of capacitive fingerprint sensing technologies: passive and active. Both types of capacitive technologies utilize the same principles of capacitance to generate fingerprint images. Passive capacitive technology typically utilizes an array of plates to apply an electrical current to the finger. The voltage discharge is then measured through the finger. Fingerprint ridges will typically have a substantially greater discharge potential than valleys, which may have little or no discharge.

Active capacitive technology is similar to passive technology, but may require initial excitation of the epidermal skin layer of the finger by applying a voltage. Active capacitive sensors, however, may be adversely affected by dry or worn minutia, which may fail to drive the sensor's output amplifier. By contrast, passive sensors are typically capable of producing images regardless of contact resistance and require significantly less power.

One feature common to each of the above fingerprint-sensing technologies is that they typically use arrays of fingerprint sensing elements, or "pixels," to sense a fingerprint. For example, optical technology may use an array of solid state pixels (e.g., a charge-coupled device) to detect a fingerprint, whereas capacitive technology may use an array of capacitive-type sensors, or "pixels." Each of these pixels may interface with a fingerprint sensing circuit (e.g, a fingerprint-sensing IC) using pins, leads, or other interconnects. In certain cases, the pixels that are used for scanning, as well as the scanning sequence of the pixels, is fixed or difficult to change after the fingerprint-sensing circuit is designed and implemented. In certain cases, the pixels and their sequence may depend on which interconnects they connect to. This characteristic may limit the flexibility of the fingerprint sensing circuit.



Accordingly, it would be an advance in the art to provide a fingerprint sensing circuit with greater flexibility. Ideally, the sensing pattern of a fingerprint sensing circuit could be programmed to include different pixels or sequences of pixels. Such flexibility may allow a fingerprint-sensing circuit to be tailored to different applications or allow fingerprint sensing circuits to be optimized or improved after they have been designed and implemented.

## BRIEF DESCRIPTION OF THE DRAWINGS

In order that the advantages of the invention will be readily understood, a more particular description of the invention briefly described above will be rendered by reference to specific examples illustrated in the appended drawings. Understanding that these drawings depict only typical examples of the invention and are not therefore to be considered limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings, in which:

FIG. **1** is a high-level block diagram of one embodiment of a fingerprint sensing area containing an array of fingerprint sensing elements and interfacing with a fingerprint sensing circuit;

FIG. **2** is a partial cutaway profile view of a fingerprint sensing area showing the interaction between a finger and fingerprint sensing elements in a capacitive-type fingerprint sensor, with a fingerprint ridge lying substantially over the sensor gap;

FIG. **3** is a partial cutaway profile view of a fingerprint sensing area showing the interaction between a finger and fingerprint sensing elements in a capacitive-type fingerprint sensor, with a fingerprint valley lying substantially over the sensor gap;

FIG. **4** is a high-level block diagram of one embodiment of a fingerprint sensing circuit for use with the present invention;

FIG. **5** is a high-level block diagram showing one embodiment of a pattern for driving the I/O interconnects and "pixels" of a fingerprint sensing circuit;

FIG. **6** is a diagram showing one embodiment of a finger scanning pattern resulting from the pattern of FIG. **5**;

FIG. **7** is a high-level block diagram showing an alternative embodiment of a pattern for driving the I/O interconnects and "pixels" of a fingerprint sensing circuit;

FIG. **8** is a diagram showing a finger scanning pattern resulting from the pattern of FIG. **7**; and

FIG. **9** is a high-level block diagram showing one embodiment of a programmable data structure, in this example several tables, which may be used to designate a sensing pattern.

## DETAILED DESCRIPTION

The invention has been developed in response to the present state of the art, and in particular, in response to the problems and needs in the art that have not yet been fully solved by currently available fingerprint sensors. Accordingly, the invention has been developed to provide fingerprint sensing circuits with programmable sensing patterns. The features and advantages of the invention will become more fully apparent from the following description and appended claims and their equivalents, and also any subsequent claims or amendments presented, or may be learned by practice of the invention as set forth hereinafter.

Consistent with the foregoing, a fingerprint sensor with programmable sensing patterns is disclosed in one embodiment of the invention as including a fingerprint sensing circuit having multiple I/O interconnects. The I/O interconnects are configured to sequentially drive a plurality of fingerprint sensing elements (e.g., transmitting and/or receiving elements). A memory device is operably coupled to the fingerprint sensing circuit. A programmable data structure, such as a table, file, character string, numeric value, array, or the like is stored in the memory device and is configured to designate a pattern for driving the fingerprint sensing elements. The fingerprint sensing circuit is configured to drive the fingerprint sensing elements according to the designated pattern. In selected embodiments, the fingerprint sensing elements may include transmitting elements, receiving elements, or a combination thereof.

In certain embodiments, the programmable data structure may include entries associated with each timeslot in the pattern. The entries may identify I/O interconnects used for transmitting and receiving during each timeslot, analog settings associated with each timeslot, digital settings associated with each timeslot, indices uniquely identifying each timeslot, or the like. In certain embodiments, the entries may identify a zone associated with each timeslot. The zone may be associated with settings to be used with all entries belonging to the zone.

In another embodiment in accordance with the invention, a method for programming a fingerprint sensor with different sensing patterns may include providing a fingerprint sensing circuit having multiple I/O interconnects. The I/O interconnects may be configured to sequentially drive multiple fingerprint sensing elements. The method may further include reading a programmable data structure designating a pattern for driving the fingerprint sensing elements. The fingerprint sensing elements may then be driven according to the pattern.

It will be readily understood that the components of the present invention, as generally described and illustrated in the Figures herein, may be arranged and designed in a wide variety of different configurations. Thus, the following more detailed description of the embodiments of the systems and methods of the present invention, as represented in the Figures, is not intended to limit the scope of the invention, as claimed, but is merely representative of selected embodiments of the invention.

Some of the functional units or method steps described in this specification may be embodied or implemented as modules. For example, a module may be implemented as a hardware circuit comprising custom VLSI circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A module may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices, or the like.

Modules may also be implemented in software for execution by various types of processors. An identified module of executable code may, for instance, comprise one or more physical or logical blocks of computer instructions which may, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified module need not be physically located together, but may comprise disparate instructions stored in different locations which, when joined logically together, comprise the module and achieve the stated purpose of the module.

Indeed, a module of executable code could be a single instruction, or many instructions, and may even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within modules, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or may be distributed over different locations including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network.

Reference throughout this specification to "one embodiment," "an embodiment," or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment may be included in at least one embodiment of the present invention. Thus, appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment.

Furthermore, the described features, structures, or characteristics may be combined in any suitable manner in one or more embodiments. One skilled in the relevant art will recognize, however, that the invention can be practiced without one or more of the specific details, or with other methods, components, etc. In other instances, well-known structures, or operations are not shown or described in detail to avoid obscuring aspects of the invention.

The illustrated embodiments of the invention will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout. The following description is intended only by way of example, and simply illustrates certain selected embodiments of apparatus and methods that are consistent with the invention as claimed herein.

Referring to FIG. **1**, in selected embodiments, a fingerprint sensor **10** useable with an apparatus and method in accordance with the invention may include a fingerprint sensing area **12** to provide a surface onto which a user can swipe a fingerprint. A dotted outline of a finger **14** is shown superimposed over the fingerprint sensing area **12** to provide a general idea of the size and scale of one embodiment of a fingerprint sensing area **12**. The size and shape of the fingerprint sensing area **12** may vary, as needed, to accommodate different applications.

In certain embodiments, the fingerprint sensing area **12** may include an array of transmitting elements **16**, such as a linear array of transmitting elements **16**, to assist in scanning lines of "pixels" as a fingerprint is swiped across the fingerprint sensing area **12**. In this embodiment, the transmitting elements **16** are shown as a linear array of conductive traces **16** connected to a fingerprint sensing circuit **18**. The transmitting elements **16** are not drawn to scale and may include several hundred transmitting elements **16** arranged across the width of a fingerprint, one transmitting element **16** per pixel. A fingerprint image may be generated by scanning successive lines of pixels as a finger is swiped over the array. These lines may then be assembled to generate a fingerprint image, similar to the way a fax image is generated using line-by-line scanning.

In certain embodiments, the transmitting elements **16** are configured to sequentially emit, or burst, a probing signal, one after the other. As will be explained in more detail hereafter, the probing signal may include a burst of probing pulses, such as a burst of square waves. This probing signal may be sensed on the receiving end by a receiving element **20**. Like the transmitting elements **16**, the receiving element **20** is shown as a conductive trace **20** connected to the fingerprint sensing circuit **18**. Although shown as a single receiving element **20**, in other embodiments, pairs of receiving elements **20** may be used to differentially cancel out noise.

At the receiving element **20**, a response signal may be generated in response to the probing signal. The magnitude of the response signal may depend on factors such as whether a finger is present over the fingerprint sensing area **12** and, more particularly, whether a ridge or valley of a fingerprint is immediately over the gap **22** between a transmitting element **16** and the receiving element **20**. The magnitude of the signal generated at the receiving element **20** may be directly related to the RF impedance of a finger ridge or valley placed over the gap **22** between the corresponding transmitting element **16** and receiving element **20**.

By using a single receiving element **20** (or a small number of receiving elements **20**) and a comparatively larger number of transmitting elements **16**, a receiver that is coupled to the receiving element **20** may be designed to be very high quality and with a much better dynamic range than would be possible using an array of multiple receiving elements. This design differs from many conventional fingerprint sensors, which may employ a single large transmitting element with a large array of receiving elements and receivers. Nevertheless, the apparatus and methods described herein are not limited to the illustrated transmitter and receiver design. Indeed, the apparatus and methods disclosed herein may be used with fingerprint sensors using a small number of transmitting elements and a relatively large number of receiving elements, a large number of transmitting elements and a relatively small number of receiving element, or a roughly equal number of transmitting and receiving elements.

As shown in FIG. **1**, the fingerprint sensing area **12** (including the transmitting and receiving elements **16**, **20**) may be physically decoupled from the fingerprint sensing circuit **18**. Positioning the sensing elements **16**, **20** off the silicon die may improve the reliability of the fingerprint sensor **10** by reducing the sensor's susceptibility to electrostatic discharge, wear, and breakage. This may also allow the cost of the sensor **10** to be reduced over time by following a traditional die-shrink roadmap. This configuration provides a distinct advantage over direct contact sensors (sensors that are integrated onto the silicon die) which cannot be shrunk to less than the width of an industry standard fingerprint. Nevertheless, the apparatus and methods disclosed herein are applicable to fingerprint sensors with sensing elements that are located either on or off the silicon die.

In certain embodiments in accordance with the invention, a second array of transmitting elements **24** may be provided adjacent to the first array of transmitting elements **16**. This second array of transmitting elements **24** may communicate with a second receiving element **26**, which may, in certain embodiments, electrically connect to the first receiving element **20**, as shown in FIG. **1**. In certain embodiments, the second array of transmitting elements **24** may be used in combination with the first array of transmitting elements **16** to determine the velocity of a finger as it is swiped over the fingerprint sensing area **12**. That is, lines of fingerprint data scanned by the second array may be compared to lines of fingerprint data scanned by the first array to determine the velocity of the finger. This velocity measurement may be important to generate an accurate non-distorted fingerprint image.

Referring generally to FIGS. **2** and **3**, in selected embodiments, the transmitting and receiving elements **16**, **20** discussed above may be adhered to a non-conductive substrate **30**. For example, the substrate **30** may be constructed of a flexible polyimide material marketed under the trade name Kapton® and with a thickness of between about 25 and 100 μm. The Kapton® polymer may allow the fingerprint sensor **10** to be applied to products such as touchpads and molded plastics having a variety of shapes and contours while providing exceptional durability and reliability.

In selected embodiments, a user's finger may be swiped across the side of the substrate **30** opposite the transmitting and receiving elements **16**, **20**. Thus, the substrate **30** may electrically and mechanically isolates a user's finger from the transmitting element **16** and receiving element **20**, thereby providing some degree of protection from electrostatic discharge (ESD) and mechanical abrasion.

The capacitive coupling between the transmitting element **16** and the receiving element **20** may change depending on whether a fingerprint ridge or valley is immediately over the gap **22**. This is because the dielectric constant of a finger is typically ten to twenty times greater than the dielectric constant of air. The dielectric constant of the ridges of a finger may vary significantly from finger to finger and person to person, explaining the significant range of dielectric constants. Because a fingerprint ridge has a dielectric constant that differs significantly from that of air, the capacitive coupling between the transmitting element **16** and receiving element **20** may vary significantly depending on whether a ridge or valley is present over the sensor gap **22**.

For example, referring to FIG. **2**, when a fingerprint ridge **32** is over the gap **22**, the capacitive coupling between the transmitting element **16** and receiving element **20** may be increased such that the probing signal emitted by the transmitting element **16** is detected at the receiving element **20** as a stronger response signal. It follows that a stronger response signal at the receiving element **20** indicates the presence of a ridge **32** over the gap **22**. On the other hand, as shown in FIG. **3**, the capacitive coupling between the transmitting element **16** and receiving element **20** may decrease when a valley is present over the gap **22**. Thus, a weaker response signal at the receiving element **20** may indicate that a valley **34** is over the gap **22**. By measuring the magnitude of the response signal at the receiving element **20**, ridges and valleys may be detected as a user swipes his or her finger across the sensing area **12**, allowing a fingerprint image to be generated.

Referring to FIG. **4**, in certain embodiments, a fingerprint sensing circuit **18** useable with an apparatus and method in accordance with the invention may include a transmitter clock **40** configured to generate an oscillating signal, such as an oscillating square-wave signal. Scanning logic **42** may be used to sequentially route the oscillating signal to buffer amplifiers **46**, one after the other, using switches **44**. The buffer amplifiers **46** may amplify the oscillating signal to generate the probing signal. As shown, the buffer amplifiers **46** may sequentially burst the probing signal **48** to each of the transmitting elements **16**, one after the other. A response signal, generated in response to the probing signal **48**, may be sensed at the receiving element **20** and may be routed to a variable-gain amplifier **50** to amplify the response signal. The amplified response signal may then be passed to a band pass filter **52** centered at the frequency of the transmitter clock **40**.

The output from the band pass filter **52** may then be supplied to an envelope detector **54**, which may detect the envelope of the response signal. This envelope may provide a baseband signal, the amplitude of which may vary depending on whether a ridge or valley is over the sensor gap **22**. The baseband signal may be passed to a low pass filter **56** to remove unwanted higher frequencies. The variable-gain amplifier **50**, band pass filter **52**, envelope detector **54**, low pass filter **56**, as well as other analog components may be collectively referred to as an analog front end **57**.

The output from the low pass filter **56** may be passed to an analog-to-digital converter (ADC) **58**, which may convert the analog output to a digital value. The ADC **58** may have, for example, a resolution of 8 to 12 bits and may be capable of resolving the output of the low pass filter **56** to 256 to 4096 values. The magnitude of the digital value may be proportional to the signal strength measured at the receiving element **20**. Likewise, as explained above, the signal strength may be related to the capacitive coupling between the transmitting element **16** and receiving element **20**, which may depend on the RF impedance of the feature over the sensor gap **22**.

The resulting digital value may be passed to a CPU **60** or other digital components (e.g., memory **66**), which may eventually pass digital fingerprint data to a host system **62**. The host system **62**, in selected embodiments, may process the fingerprint data using various matching algorithms in order to authenticate a user's fingerprint.

In addition to processing the digital data, the CPU **60** may control the gain of the variable-gain amplifier **50** using a digital-to-analog converter (DAC) **64**. The gain may be adjusted to provide a desired output power or amplitude in the presence of variable sensing conditions. For example, in selected embodiments, the gain of the variable-gain amplifier **50** may be adjusted to compensate for variations in the impedance of different fingers. In selected embodiments, the CPU **60** may also control the operation of the scanning logic **42**.

Referring to FIG. **5**, while continuing to refer generally to FIG. **1**, in selected embodiments, the interconnects that are used to connect the fingerprint sensing circuit **18** to the transmitting elements **16** may be configured to drive the transmitting elements **16** in a particular order. For example, if the order begins with the interconnect at the upper left-hand corner of the fingerprint sensing circuit **18** and then follows a generally clock-wise path **68** around the fingerprint sensing circuit **18**, the transmitting elements **16**, **24** may be driven in a sensing pattern **70**. That is the first array of transmitting elements **16** may be driven in a rightward direction, after which the second array of transmitting elements **24** may be driven in a leftward direction. Although effective, this sensing pattern **70** is not optimal for sensing fingerprints due to the motion of the user's finger.

For example, referring to FIG. **6**, while continuing to refer to FIGS. **1** and **5**, when scanning a fingerprint, a user may swipe his or her finger **14** across the fingerprint sensing area **12** in a direction **80**. Because the finger **14** is moving while it is being scanned, the acquired scan lines may be represented as slanted lines **82**a, **82**b across the user's finger. That is, the movement of the finger **14** combined with the rightward or leftward driving direction of the transmitting elements **16**, **24** may generate scan lines **82**a, **82**b that are not aligned across the width of the finger (perpendicular to the swipe direction **80**), but rather are slanted in one of two directions. The angles of the slanted scan lines **82**a, **82**b are exaggerated for illustration purposes.

For example, when a first array of transmitting elements **16** is scanning in a rightward direction, as shown in FIG. **5**, scan lines **82**a generated by the first array may be slanted upward to the right. Similarly, when a second array of transmitting elements **24** are scanning in a leftward direction, scan lines **82**b generated by the second array may be slanted upward to the left. Thus, the scanning pattern **70** illustrated in FIG. **5** may generate scan lines **82**a, **82**b that are slanted in opposite directions. This scanning pattern **70** may be non-ideal where two lines are scanned and compared to one another to determine finger velocity. Ideally, the scan lines **82**a, **82**b would be parallel or as close to parallel as possible.

Referring to FIG. **7**, in certain embodiments, it may advantageous to provide a fingerprint sensing circuit **18** that can drive the transmitting elements **16**, **24** in an order modifiable through programming or other means. For example, if the order illustrated in FIG. **5** could be modified such that it begins with the interconnect at the upper left-hand corner of the fingerprint sensing circuit **18** and proceeds in a rightward direction (as indicated by the path **90**a) and then returns to the upper left-hand corner and proceeds in a counter-clock-wise direction (as indicated by the path **90**b), the transmitting elements **16**, **24** may be driven in an improved sensing pattern **94**a, **94**b. Specifically, the first array of transmitting elements **16** may be driven in a rightward direction (as indicated by the path **94**a), after which the second array of transmitting elements **24** may also be driven in a rightward direction (as indicated by the path **94**b).

For example, referring to FIG. **8**, while continuing to refer to FIGS. **1** and **7**, when a user swipes his or her finger across the fingerprint sensing area **12** in a direction **80**, the acquired scan lines **82**a, **82**b may be slanted in the same direction, as opposed to opposite directions. Specifically, as the first array of transmitting elements **16** scans in a rightward direction **94**a, as shown in FIG. **7**, the acquired scan lines **82**a may be slanted upward to the right. Similarly, when the second array of transmitting elements **24** scans in a rightward direction **94**b, the acquired scan lines **82**b may also be slanted upward to the right. This generates scan lines **82**a, **82**b that are substantially parallel to one another, facilitating the comparing of the lines **82**a, **82**b for velocity sensing purposes.

Referring to FIG. **9**, in selected embodiments in accordance with the invention, a data structure **100**, **102** may be stored in memory **66** (e.g., RAM, ROM, PROM, EPROM, etc.) of the fingerprint sensing circuit **18** to designate a sensing pattern for driving the transmitting elements **16**, **24** and receiving elements **20**, **26**. In certain embodiments, this data structure **100**, **102** may be programmed to set or alter the sensing pattern, or may be programmed to contain several different sensing patterns, one or more of which may be selected. As shown in FIG. **9**, the data structure **100**, **102** is provided in the form of one or more tables **100**, **102**. However, the data structure **100**, **102** is not limited to any specific form or structure, but may include, for example, tables, files, character strings, numeric values, arrays, or the like. Alternatively, the sensing pattern may be programmed with a field programmable gate array or other programmable logic. In this embodiment, the programmable data structure would be deemed to include programming information for logic gates or other programmable logic blocks.

Where tables **100**, **102** are used as the data structure **100**, **102**, in certain embodiments, the tables **100**, **102** may include a timeslot table **100** and a zone configuration table **102**. The timeslot table **100** may include entries **104**, each represented by a row **104** in the table **100**. Each row **104** may correspond to a different "timeslot." For the purposes of this disclosure, a "timeslot" may refer to the time that is allocated to each "pixel" of the fingerprint sensor **10** when scanning a fingerprint. In the illustrated example, a timeslot may refer to the time that is allocated to each transmitting element **16**, **24** as it emits the probing signal.

In certain embodiments, the timeslot table **100** may include multiple columns **106**, providing fields for each of the entries **104**. For example, the timeslot table **100** may include columns to store an index **106**a, a zone **106**b, a transmitting pin number **106**c, a receiving pin number **106**d, analog front end settings **106**e, and post-process settings **106**f for each of the entries **104**. In certain embodiments, the index **106**a is provided to uniquely identify a timeslot. In certain embodiments, the fingerprint sensing circuit **18** may be configured to step from one timeslot to another in the order of the indices **106**a, as will be explained in more detail hereafter.

In certain embodiments, each of the entries **104** may identify a transmitting pin number **106**c, which may identify which pin (or interconnect) of the fingerprint sensing circuit **18** is used to transmit the probing signal during the respective timeslot. Similarly, the entries **104** may identify a receiving pin number **106**d to identify which pin (or interconnect) is used to sense (or receive) during the same timeslot. In selected embodiments, the fingerprint sensing circuit **18** may be configured such that various of the interconnects may be used for either transmitting or receiving purposes, thereby increasing the flexibility of the circuit **18** and enabling various different sensing patterns.

Each of the entries **104** may also include analog-front-end setting **106**e, which may identify settings such as gain or filter settings associated with the analog portion **57** of the fingerprint sensing circuit **18** and associated with the timeslot. These settings **106**e may be important, for example, if the fingerprint sensor **10** is being used for different applications, such as fingerprint sensing, calibration, or for tasks such as navigation (e.g., the fingerprint sensor doubles as a navigation device such as a touchpad). The entries **104** may also include post-process settings **106**f associated with the digital portion of the circuit **18**. These post-process settings **106**f may, for example, identify how many bits are used to represent data from each pixel, or settings such as whether a pixel is used for velocity sensing or fingerprint sensing purposes, or whether a pixel is used in association with culling redundant fingerprint data.

In selected embodiments, a zone column **106**b may identify a zone associated with a timeslot. Because groups of pixels may be used for the same purpose (e.g., fingerprint sensing, velocity sensing, calibration, navigation, etc.), groups of pixels may share common settings. A zone configuration table **102**, containing zone entries **108**, may identify settings that are common to groups, or "zones," of pixels such that the settings do not have to be stored for each individual pixel, or timeslot **104**. This can significantly reduce the amount of memory that is required to store settings for each individual pixel. Thus, by identifying a zone **106**b, a timeslot entry **104** may be assigned settings that are common to the zone.

In certain embodiments, zone entries **108** may include an index field **110**a, uniquely identifying a zone, an input select field **110**b, and an analog-front-end settings field **110**c, among other fields. In selected embodiments, an input select field **110**b may identify an interconnect used as an input for the zone. This input may include a dedicated interconnect (an interconnect used only for receiving) or an interconnect that can be used for either transmitting or receiving. Similarly, analog-front-end settings **110**c may identify analog settings that are common to the zone.

In operation, a sensing pattern may be defined by a starting index **112**a and an ending index **112**b in the timeslot table **100**. The control logic of the fingerprint sensing circuit **18** may step through the indices **106**a, beginning with the starting index **112**a and terminating with the ending index **112**b. As the control logic steps through the indices **106**a, a demultiplexer **114** may route the probing signal (from the transmitter clock **40**) to the transmitting pin **106**c identified in the timeslot table **100**. This will drive the transmitting element **16**, **24** connected to the transmitting pin **106**c. This probing signal may be detected (in the form of a response signal) by a receiver element **20**, **26** identified in the timeslot table **100** and selected by a multiplexer **116**. In certain embodiments, the probing signal may be detected by a receiving element **20** coupled to a dedicated analog input, as discussed previously. The input select **110**b may be coupled to a multiplexer **118** to select whether a dedicated or non-dedicated interconnect is used for receiving the probing signal.

The resulting response signal may be routed to the analog-front-end **57**. The analog-front-end **57** may be tuned and adjusted according to the analog-front-end settings **106**e, **110** c stored in the timeslot table **100** and/or zone configuration table **102**. The output from the AFE **57** may then be passed to the ADC **58**, where it may be converted to a digital value. The resulting digital value may be processed according to the post-process settings **106**f stored in the timeslot table **100**.

The programmable data structure, one embodiment of which is illustrated in FIG. **9**, is not limited to the fingerprint sensing circuit **18** nor the fingerprints sensing patterns illustrated herein. Indeed, the data structure may be used to impart greater flexibility to a wide variety of different fingerprint-sensing technologies, including capacitive, optical, and ultrasonic sensors. Each of these technologies may benefit from having programmable interconnects and/or programmable sequences for driving the interconnects.

One advantage of the present invention becomes apparent in cases where the fingerprint sensing area **12** and the fingerprint sensing circuit **18** are developed somewhat independently. In such cases, the geometry of the fingerprint sensing area **12**, including the placement of the transmitting and receiving elements **16**, **20**, **24**, **26** and the sequence for driving them, may not be fully known at the time the fingerprint sensing circuit **18** is developed. By making the interconnects and the sequence for driving the interconnects programmable, the fingerprint sensing circuit **18** may be developed and then programmed once the geometry of the fingerprint sensing area **12** is known.

Another advantage of the present invention is that different sensing patterns may be stored concurrently in the programmable data structure. For example, different sensing patterns may be used for fingerprint sensing, velocity sensing, calibration, or navigation purposes. Each of these patterns may be stored in different index ranges of the data structure. By properly selecting the starting and ending indices **112**a, **112**b, the fingerprint sensing area **12** may implement different sensing patterns without the need to reprogram the data structure.

The invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described examples are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

The invention claimed is:

**1**. A fingerprint sensor providing programmable sensing patterns, the fingerprint sensor comprising:

a fingerprint sensing circuit comprising a plurality of I/O interconnects, the I/O interconnects configured to sequentially drive a plurality of fingerprint sensing elements;

a memory device operably coupled to the fingerprint sensing circuit;

at least one programmable table stored in the memory device to designate a pattern for driving the fingerprint sensing elements; and

the fingerprint sensing circuit further configured to drive the fingerprint sensing elements according to the pattern.

**2**. The fingerprint sensor of claim **1**, wherein the fingerprint sensing elements comprise at least one of transmitting elements and receiving elements.

**3**. The fingerprint sensor of claim **1**, wherein the programmable data structure comprises entries, each entry associated with a timeslot in the pattern.

**4**. The fingerprint sensor of claim **3**, wherein each entry identifies an I/O interconnect used for transmitting.

**5**. The fingerprint sensor of claim **3**, wherein each entry identifies an I/O interconnect used for receiving.

**6**. The fingerprint sensor of claim **3**, wherein each entry identifies analog settings associated with a corresponding timeslot.

**7**. The fingerprint sensor of claim **3**, wherein each entry identifies digital settings associated with a corresponding timeslot.

**8**. The fingerprint sensor of claim **3**, wherein each entry includes an index uniquely identifying the entry.

**9**. The fingerprint sensor of claim **3**, wherein each entry identifies a zone associated with the corresponding timeslot, the zone identifying settings to be used with all entries associated with the zone.

**10**. The fingerprint sensor of claim **1**, wherein the data structure is configured to concurrently store multiple patterns for driving the fingerprint sensing elements.

**11**. A method for programming a fingerprint sensor with different sensing patterns, the method comprising:

providing a fingerprint sensing circuit comprising a plurality of I/O interconnects, the I/O interconnects configured to sequentially drive a plurality of fingerprint sensing elements;

reading at least one programmable table designating a pattern for driving the fingerprint sensing elements; and

driving the plurality of fingerprint sensing elements according to the pattern.

**12**. The method of claim **11**, wherein driving the plurality of fingerprint sensing elements comprises driving at least one of transmitting elements and receiving elements.

**13**. The method of claim **11**, wherein reading at least one programmable table comprises reading entries, each entry associated with a timeslot in the pattern.

**14**. The method of claim **13**, wherein reading an entry comprises identifying an I/O interconnect used for transmitting.

**15**. The method of claim **13**, wherein reading an entry comprises identifying an I/O interconnect used for receiving.

**16**. The method of claim **13**, wherein reading an entry comprises identifying analog settings associated with a corresponding timeslot.

**17**. The method of claim **13**, wherein reading an entry comprises identifying digital settings associated with a corresponding timeslot.

**18**. The method of claim **13**, wherein reading an entry comprises reading an index uniquely identifying the entry.

**19**. The method of claim **13**, wherein reading an entry comprises reading a zone associated with the corresponding timeslot, the zone identifying settings to be used with all entries associated with the zone.

**20**. The method of claim **11**, wherein reading a programmable data structure comprises reading at least one of a table, a file, a character string, a numeric value, and an array.

*21. The fingerprint sensor of claim 1, wherein the plurality of fingerprint sensing elements comprise a combination of transmitting elements and receiving elements.*

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