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**Beyhs**

(10) **Patent No.: US 11,941,175 B2**
(45) **Date of Patent: *Mar. 26, 2024**

(54) **SKIN-TO-SKIN CONTACT DETECTION**


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(73) Assignee: **Apple Inc.**, Cupertino, CA (US)


( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.


(21) Appl. No.: **18/194,514**

(22) Filed: **Mar. 31, 2023**

(65) **Prior Publication Data**

US 2023/0251711 A1 Aug. 10, 2023

**Related U.S. Application Data**

(63) Continuation of application No. 17/814,826, filed on Jul. 25, 2022, now Pat. No. 11,625,098, which is a continuation of application No. 17/218,038, filed on Mar. 30, 2021, now Pat. No. 11,397,468, which is a continuation-in-part of application No. 16/836,552, filed on Mar. 31, 2020, now Pat. No. 11,397,466.

(51) **Int. Cl.**
***G06F 3/01*** (2006.01)

(52) **U.S. Cl.**
CPC .............. ***G06F 3/014*** (2013.01); ***G06F 3/017*** (2013.01)

(58) **Field of Classification Search**
CPC ................................. G06F 3/014; G06F 3/017
See application file for complete search history.


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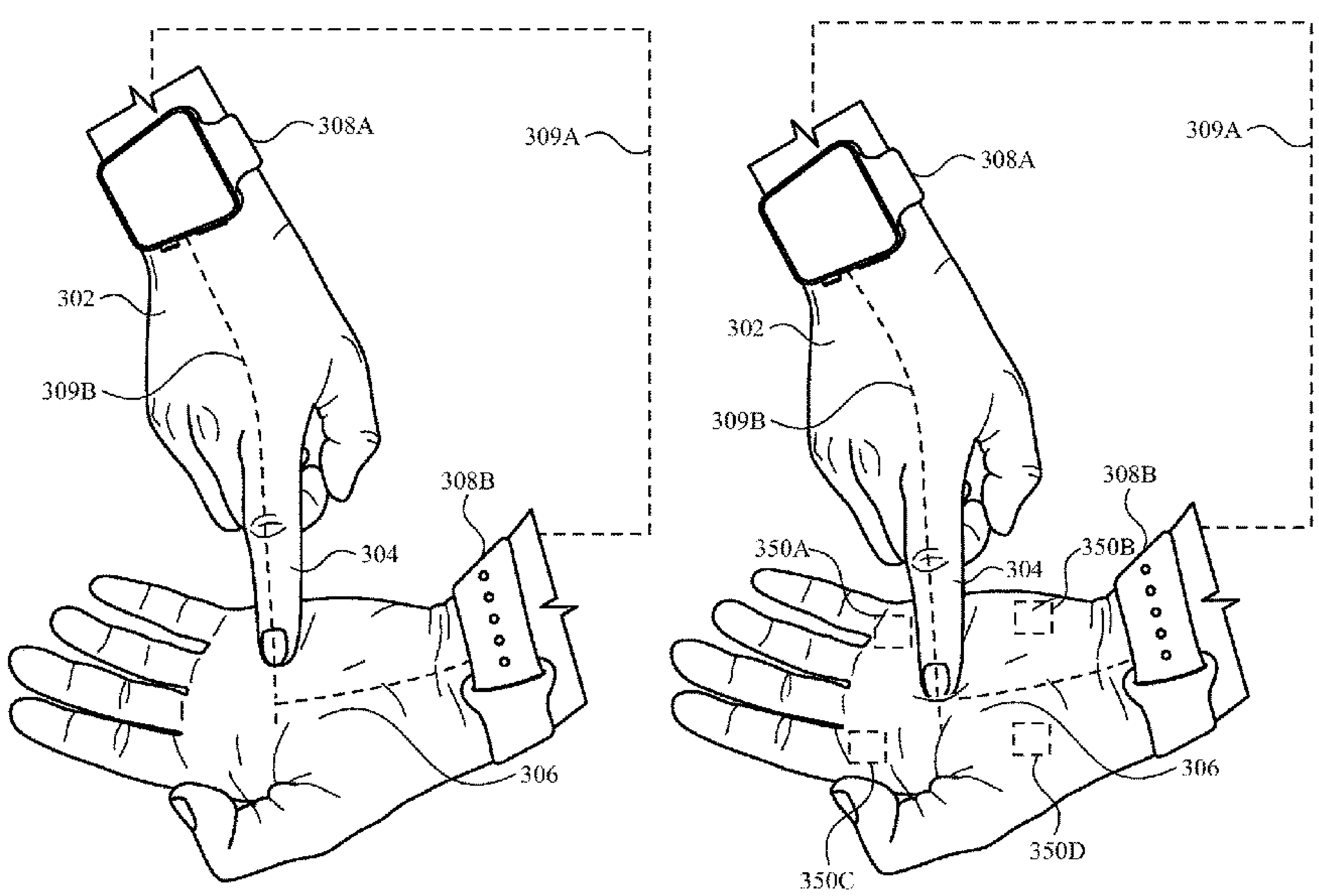
*Primary Examiner* — Eric J. Bycer
(74) *Attorney, Agent, or Firm* — Kubota & Basol LLP

(57) **ABSTRACT**


Contact or movement gestures between a first body part and a second body part can be detected. Sense circuitry can be configured to sense a signal at the sense electrode (e.g., configured to contact the second body part) in response to a drive signal applied to the drive electrode (e.g., configured to contact the first body part). Processing circuitry can be configured to detect contact in accordance with a determination that one or more criteria are met (e.g., an amplitude criterion and a non-distortion criterion). Additionally or alternatively, processing circuitry can be configured to detect a movement gesture in accordance with a determination that one or more criteria are met (e.g., a contact criterion and a movement criterion).


**20 Claims, 16 Drawing Sheets**



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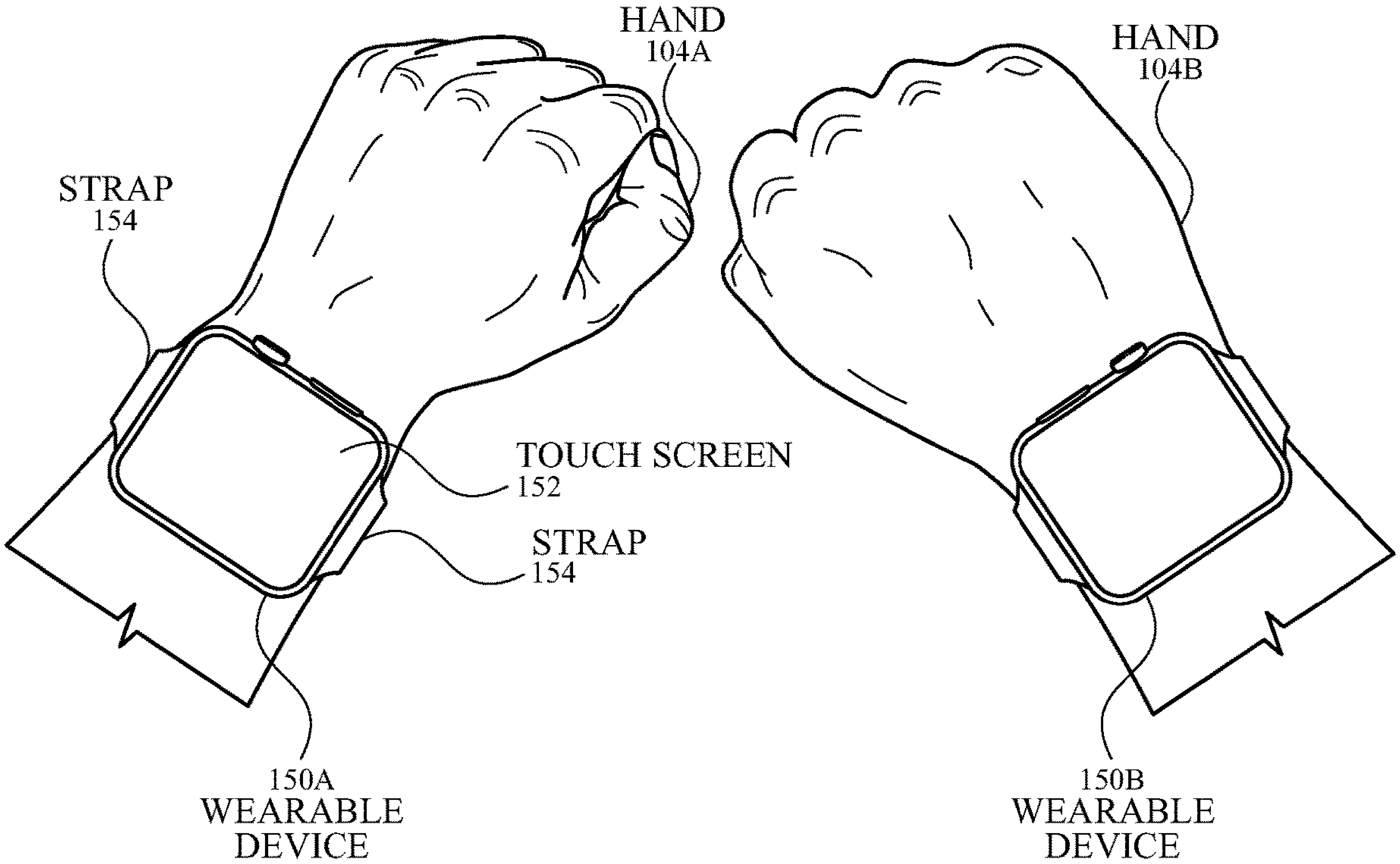
HAND
104A
HAND
104B
STRAP
154
TOUCH SCREEN
152
STRAP
154
150A
WEARABLE
DEVICE
150B
WEARABLE
DEVICE

*FIG. 1A*

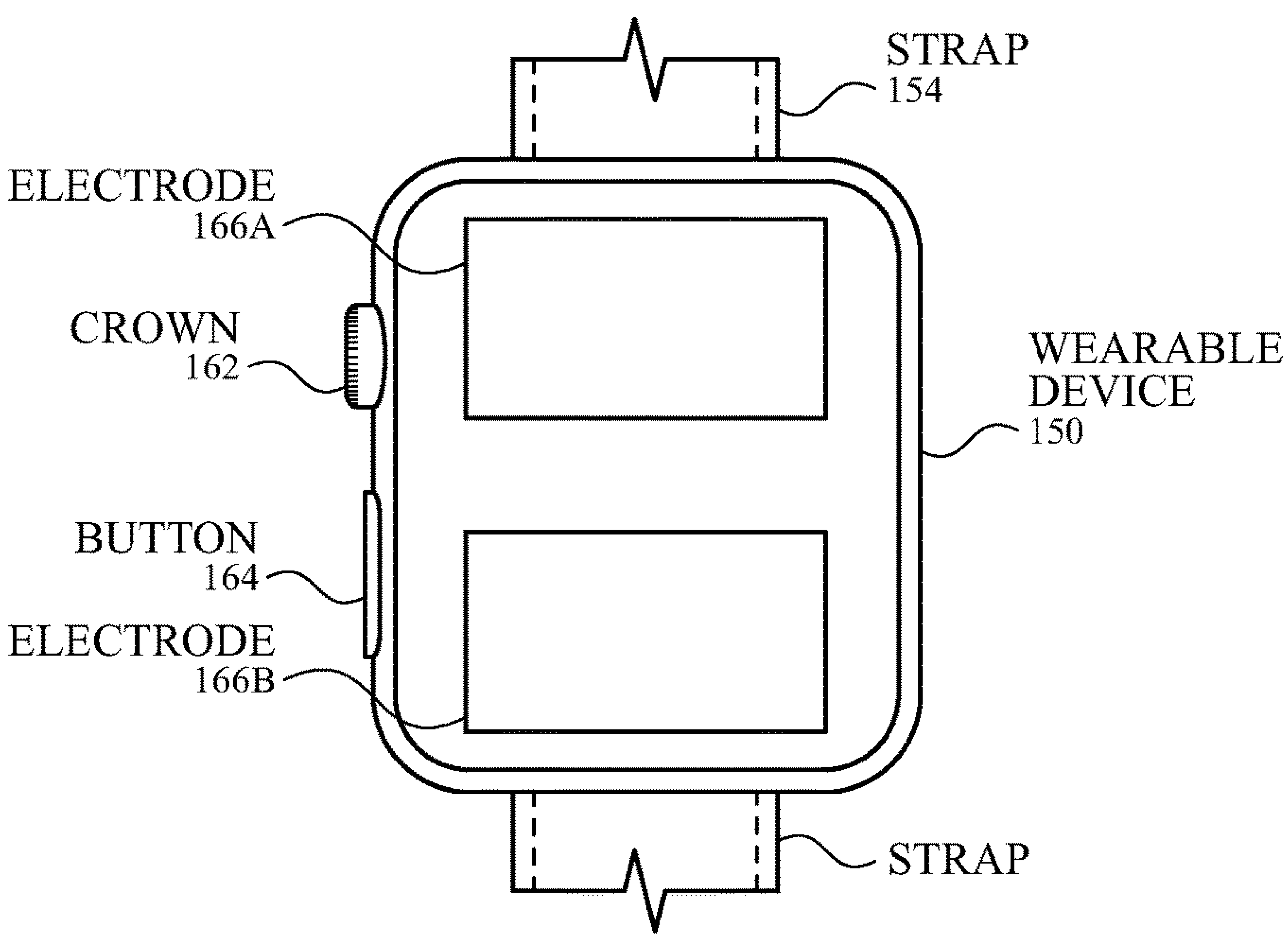
STRAP
154
ELECTRODE
166A
CROWN
162
WEARABLE
DEVICE
150
BUTTON
164
ELECTRODE
166B
STRAP

*FIG. 1B*

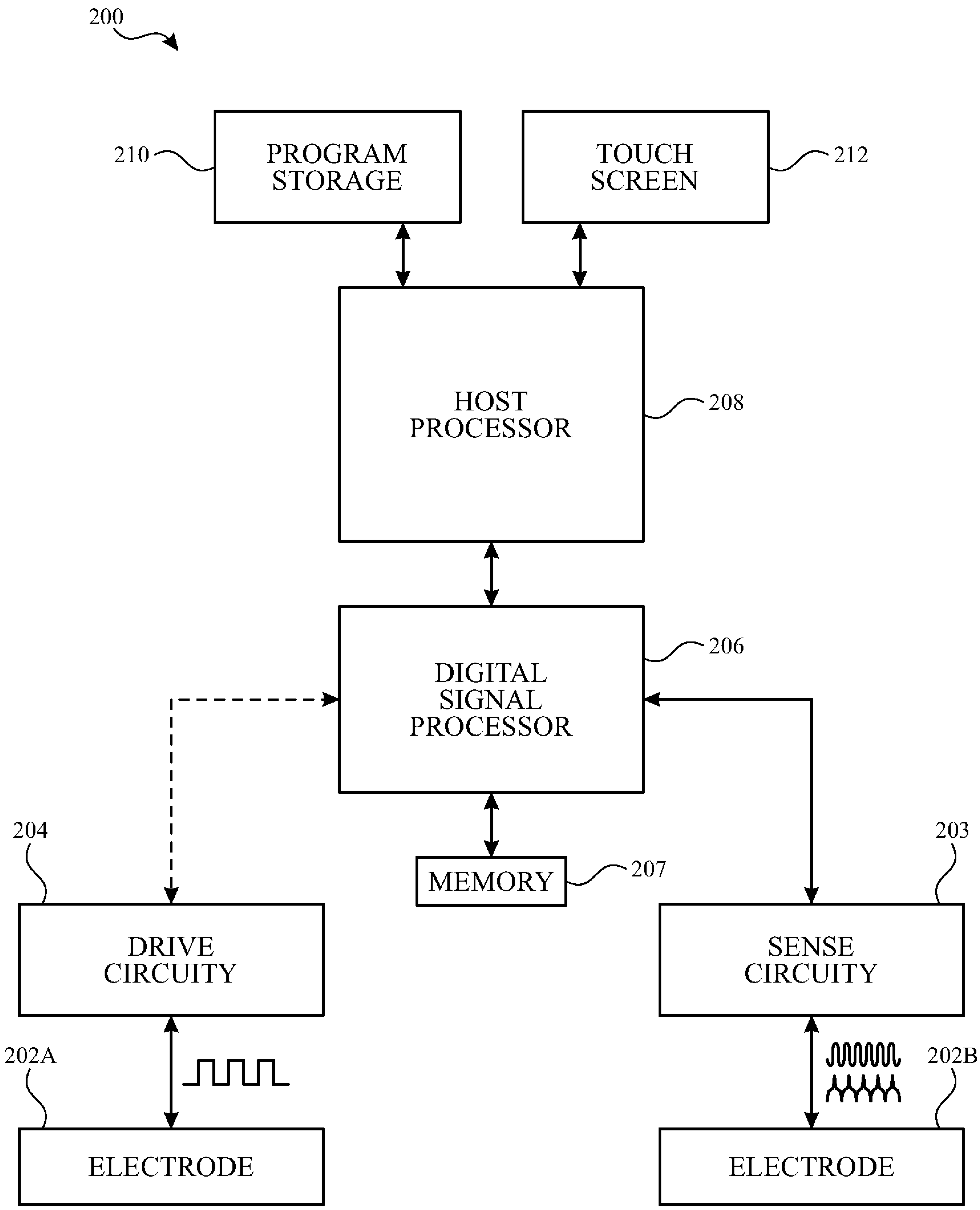
200
210
PROGRAM STORAGE
TOUCH SCREEN
212
HOST PROCESSOR
208
206
DIGITAL SIGNAL PROCESSOR
204
203
MEMORY
207
DRIVE CIRCUITY
SENSE CIRCUITY
202A
202B
ELECTRODE
ELECTRODE

*FIG. 2*

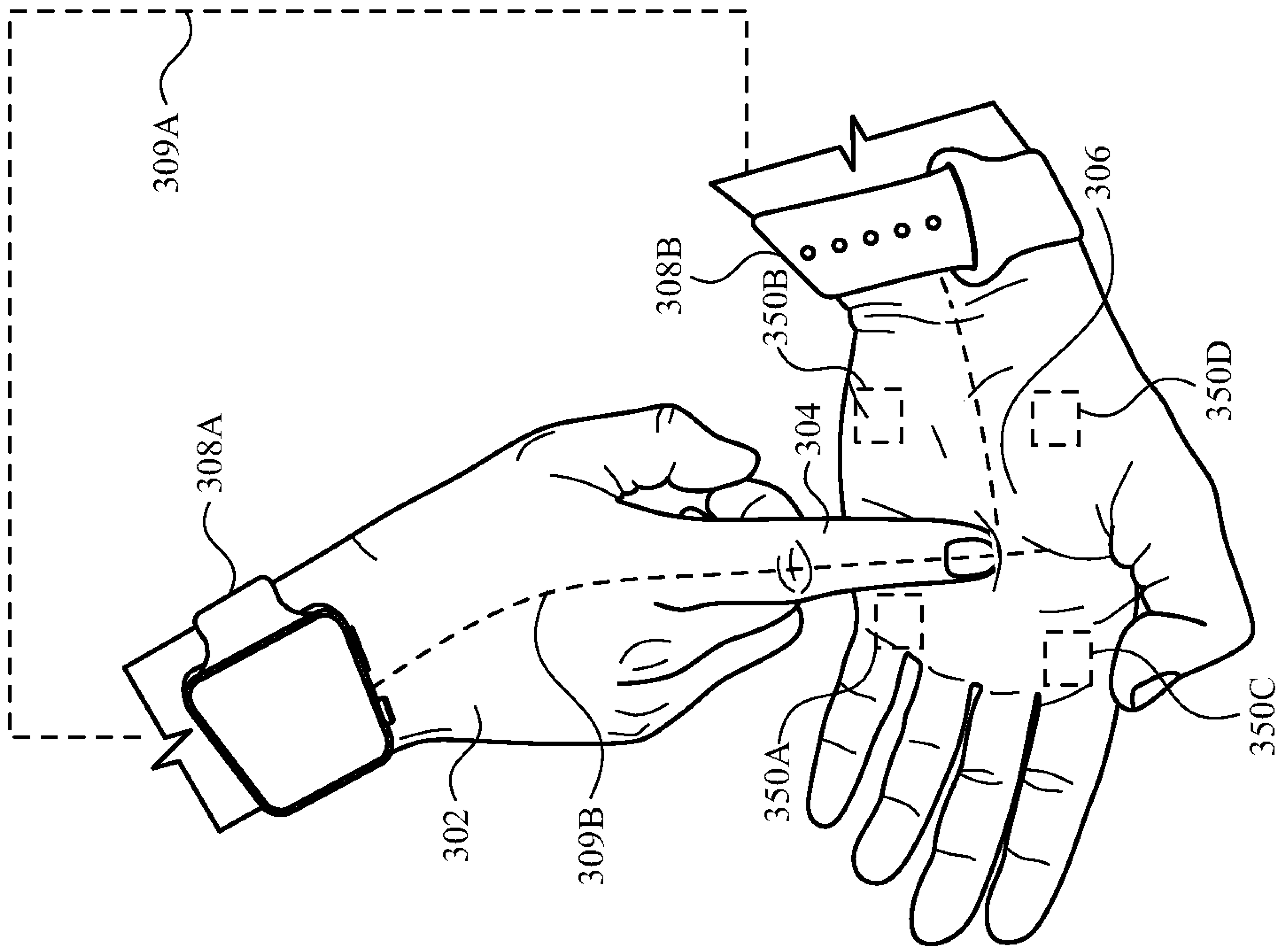
309A
308A
308B
350B
304
306
350D
350A
350C
302
309B

FIG. 3B

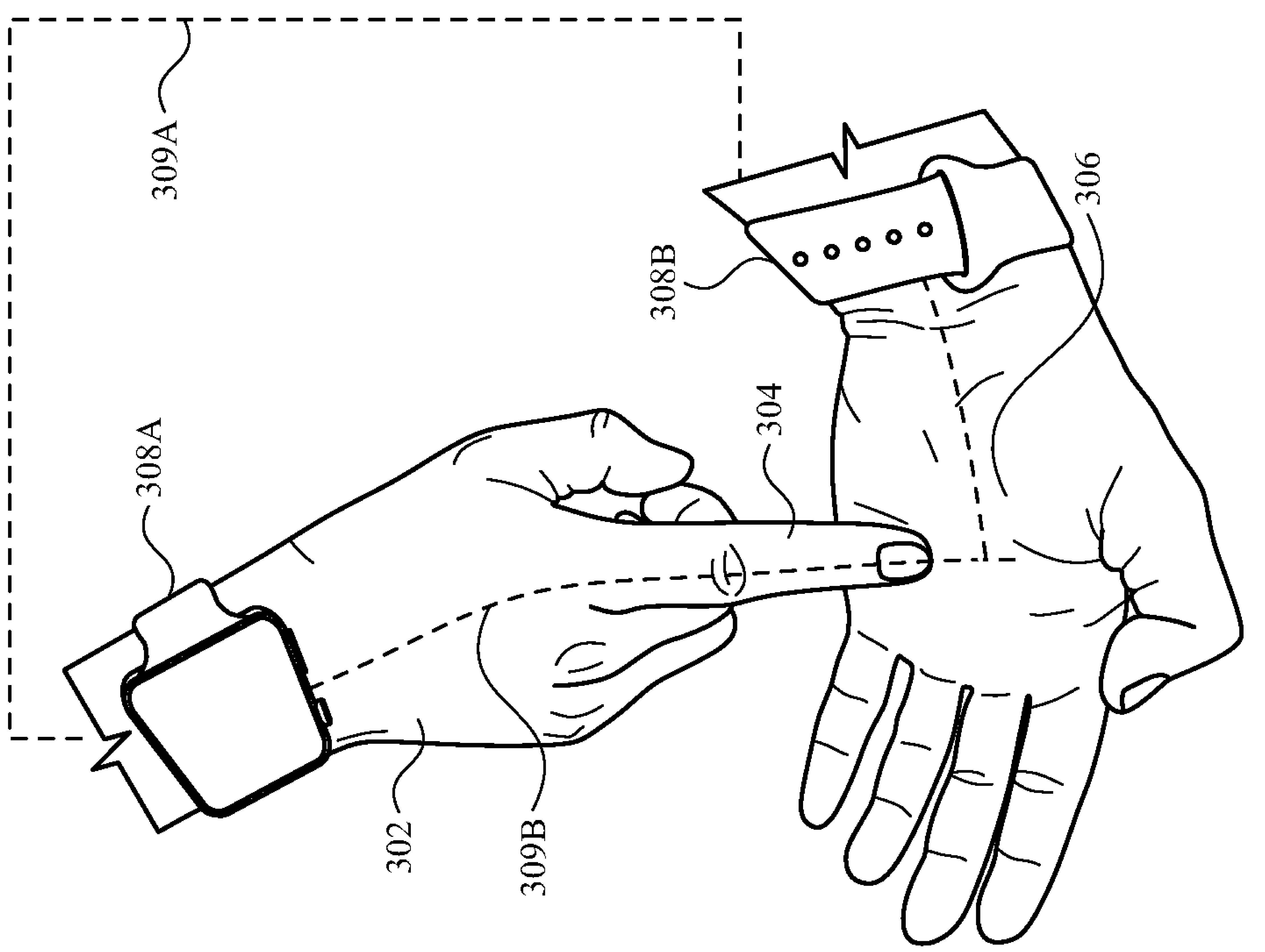
309A
308A
308B
304
306
302
309B

FIG. 3A

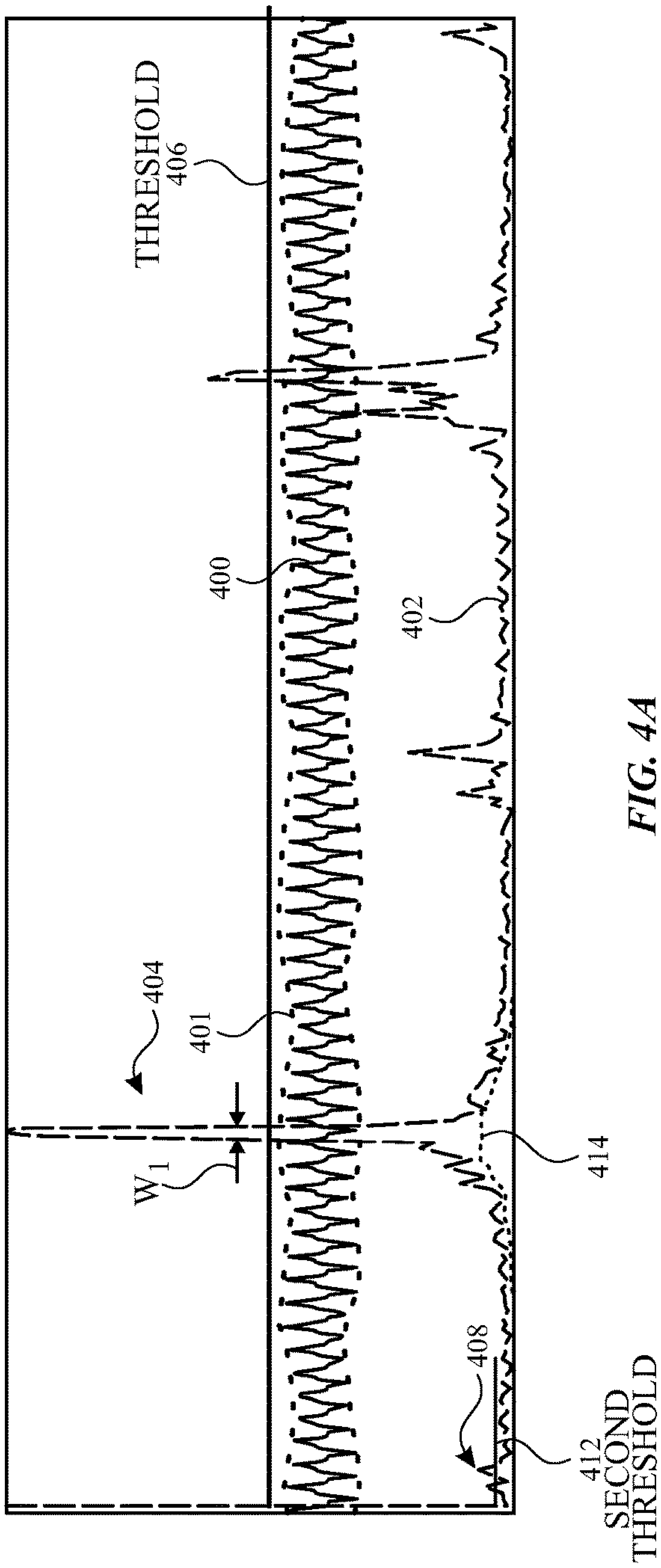
THRESHOLD
406
400
401
402
404
$W_1$
414
408
412
SECOND
THRESHOLD

FIG. 4A

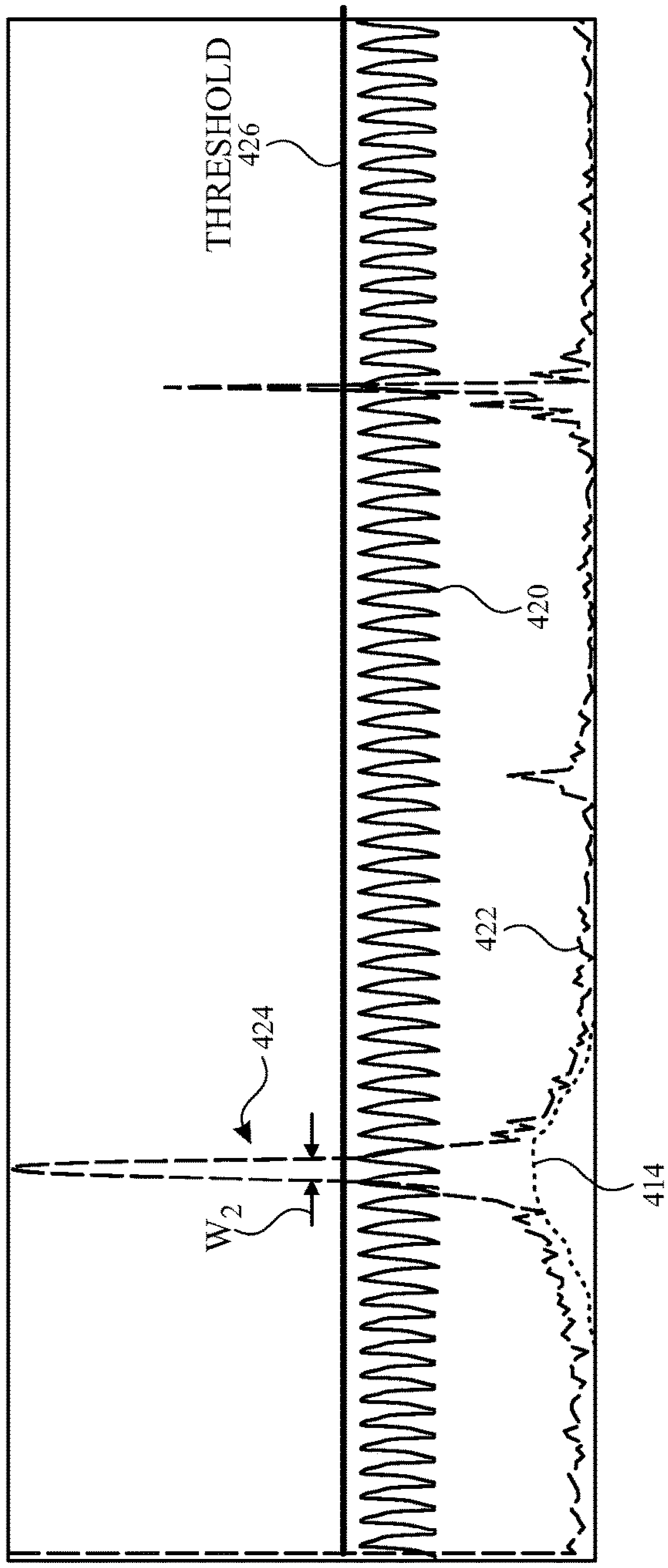
THRESHOLD
426
420
422
424
$W_2$
414

FIG. 4B

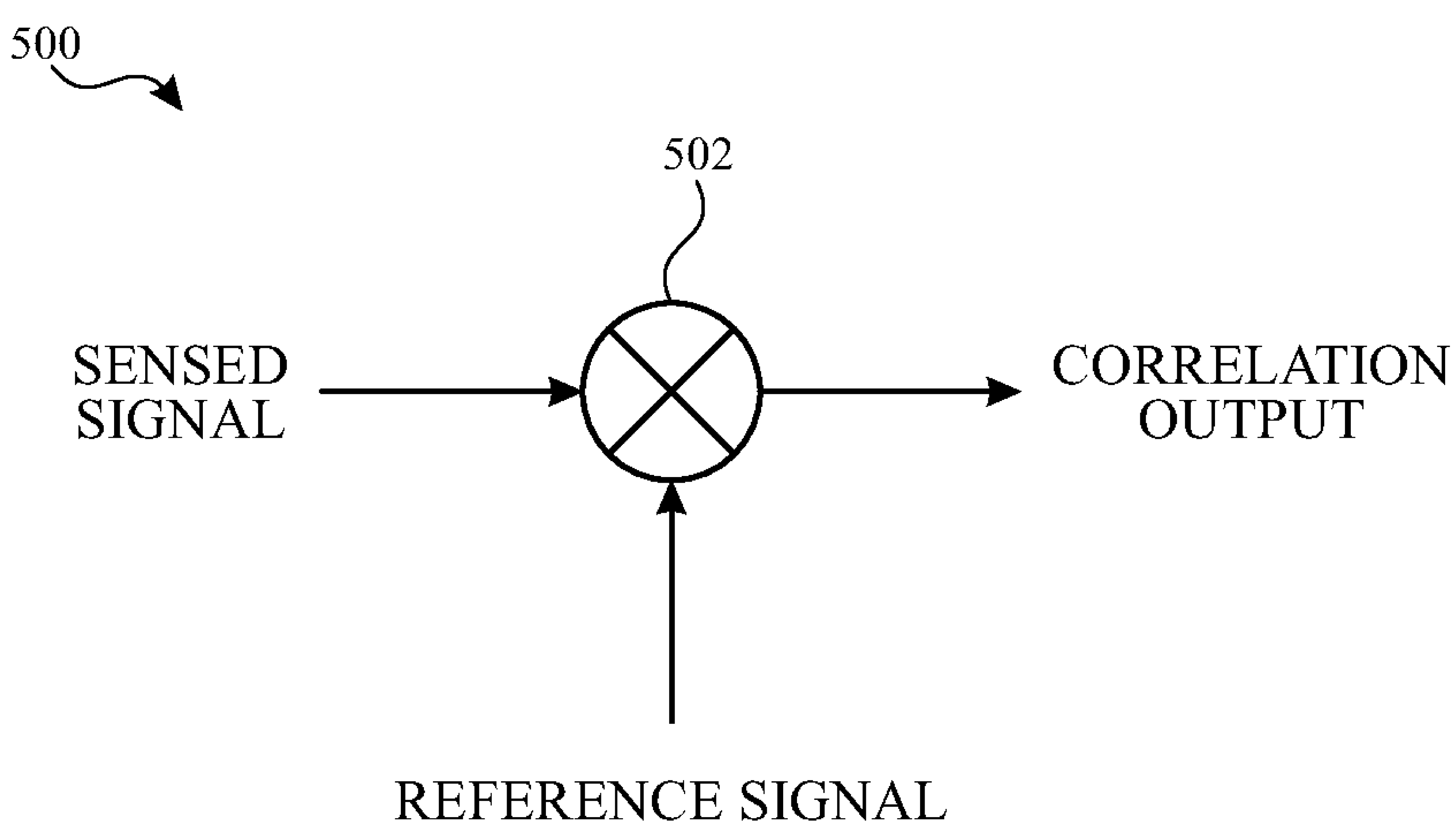
500
502
SENSED SIGNAL
CORRELATION OUTPUT
REFERENCE SIGNAL

*FIG. 5*

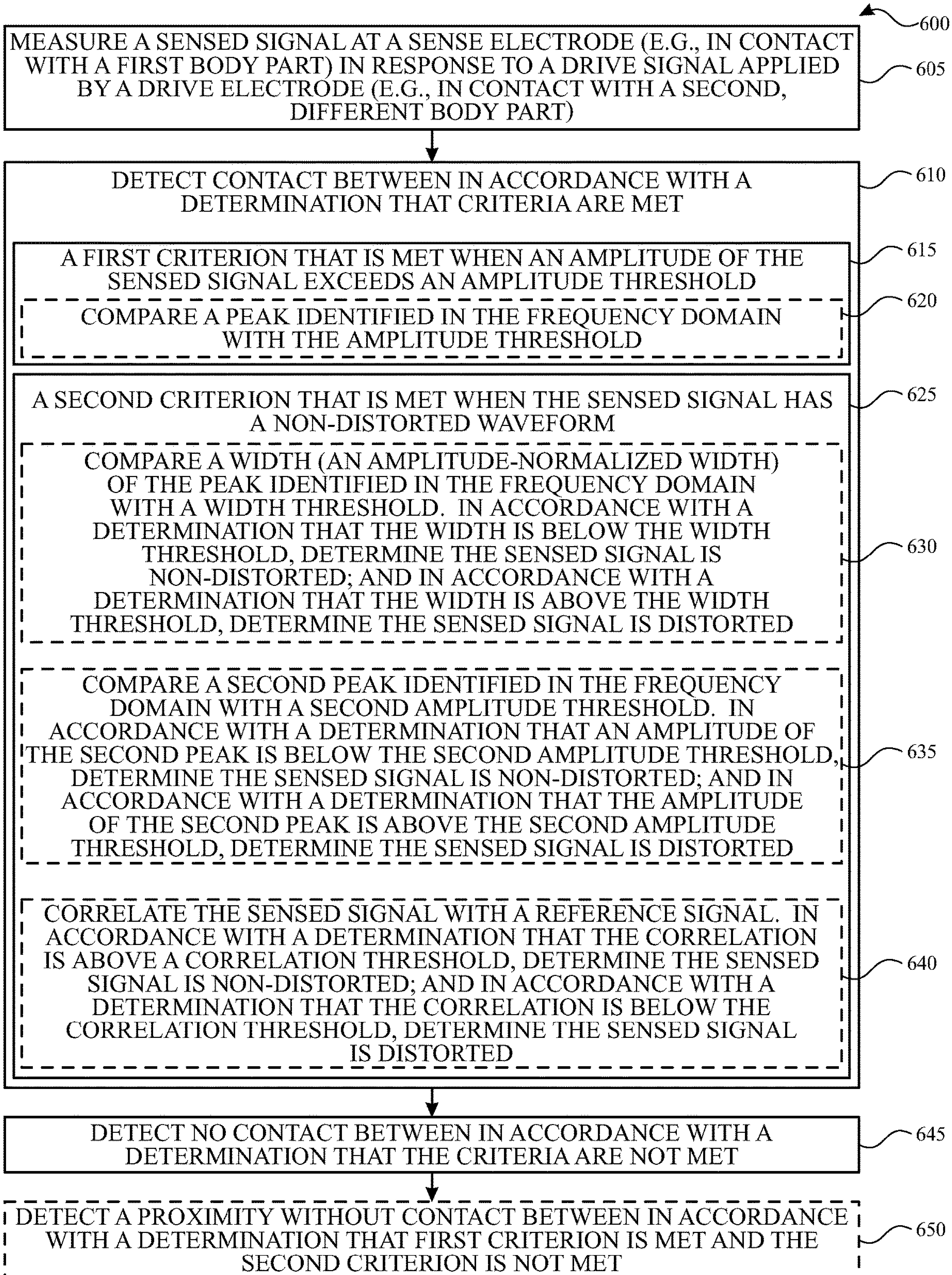
600
MEASURE A SENSED SIGNAL AT A SENSE ELECTRODE (E.G., IN CONTACT WITH A FIRST BODY PART) IN RESPONSE TO A DRIVE SIGNAL APPLIED BY A DRIVE ELECTRODE (E.G., IN CONTACT WITH A SECOND, DIFFERENT BODY PART)
605
DETECT CONTACT BETWEEN IN ACCORDANCE WITH A DETERMINATION THAT CRITERIA ARE MET
610
A FIRST CRITERION THAT IS MET WHEN AN AMPLITUDE OF THE SENSED SIGNAL EXCEEDS AN AMPLITUDE THRESHOLD
615
COMPARE A PEAK IDENTIFIED IN THE FREQUENCY DOMAIN WITH THE AMPLITUDE THRESHOLD
620
A SECOND CRITERION THAT IS MET WHEN THE SENSED SIGNAL HAS A NON-DISTORTED WAVEFORM
625
COMPARE A WIDTH (AN AMPLITUDE-NORMALIZED WIDTH) OF THE PEAK IDENTIFIED IN THE FREQUENCY DOMAIN WITH A WIDTH THRESHOLD. IN ACCORDANCE WITH A DETERMINATION THAT THE WIDTH IS BELOW THE WIDTH THRESHOLD, DETERMINE THE SENSED SIGNAL IS NON-DISTORTED; AND IN ACCORDANCE WITH A DETERMINATION THAT THE WIDTH IS ABOVE THE WIDTH THRESHOLD, DETERMINE THE SENSED SIGNAL IS DISTORTED
630
COMPARE A SECOND PEAK IDENTIFIED IN THE FREQUENCY DOMAIN WITH A SECOND AMPLITUDE THRESHOLD. IN ACCORDANCE WITH A DETERMINATION THAT AN AMPLITUDE OF THE SECOND PEAK IS BELOW THE SECOND AMPLITUDE THRESHOLD, DETERMINE THE SENSED SIGNAL IS NON-DISTORTED; AND IN ACCORDANCE WITH A DETERMINATION THAT THE AMPLITUDE OF THE SECOND PEAK IS ABOVE THE SECOND AMPLITUDE THRESHOLD, DETERMINE THE SENSED SIGNAL IS DISTORTED
635
CORRELATE THE SENSED SIGNAL WITH A REFERENCE SIGNAL. IN ACCORDANCE WITH A DETERMINATION THAT THE CORRELATION IS ABOVE A CORRELATION THRESHOLD, DETERMINE THE SENSED SIGNAL IS NON-DISTORTED; AND IN ACCORDANCE WITH A DETERMINATION THAT THE CORRELATION IS BELOW THE CORRELATION THRESHOLD, DETERMINE THE SENSED SIGNAL IS DISTORTED
640
DETECT NO CONTACT BETWEEN IN ACCORDANCE WITH A DETERMINATION THAT THE CRITERIA ARE NOT MET
645
DETECT A PROXIMITY WITHOUT CONTACT BETWEEN IN ACCORDANCE WITH A DETERMINATION THAT FIRST CRITERION IS MET AND THE SECOND CRITERION IS NOT MET
650

*FIG. 6*

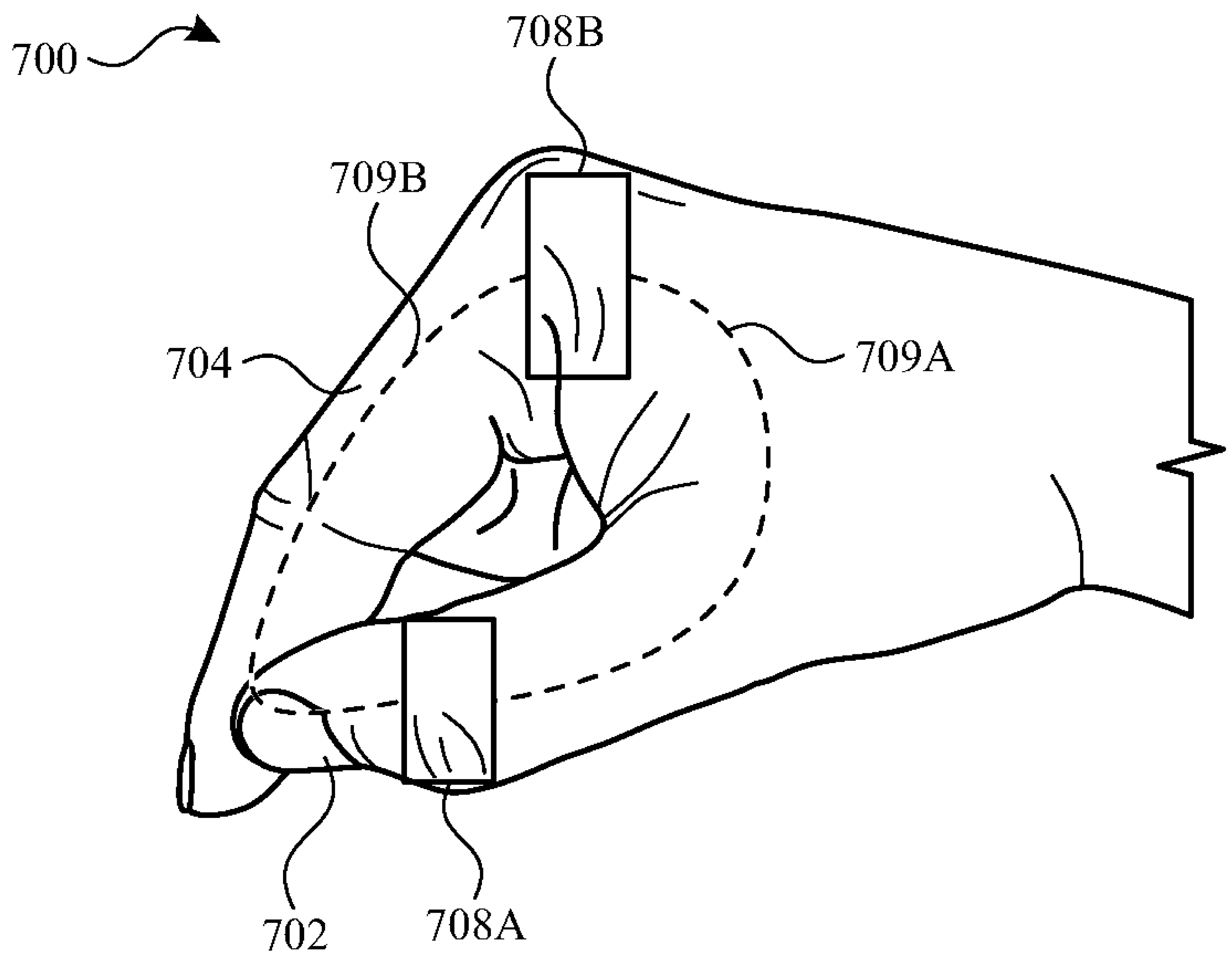
700
708B
709B
704
709A
702
708A

*FIG. 7A*

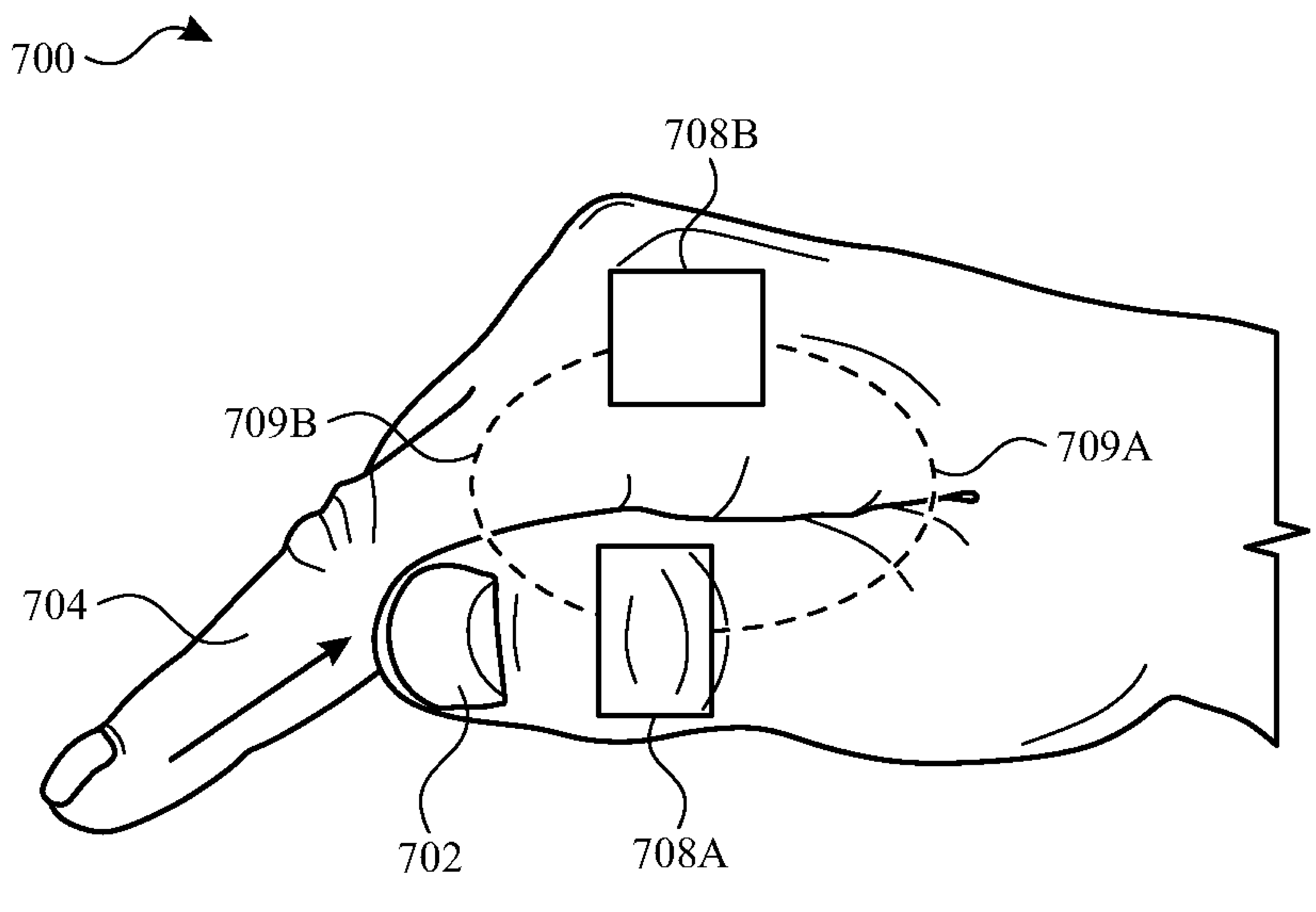
700
708B
709B
709A
704
702
708A

*FIG. 7B*

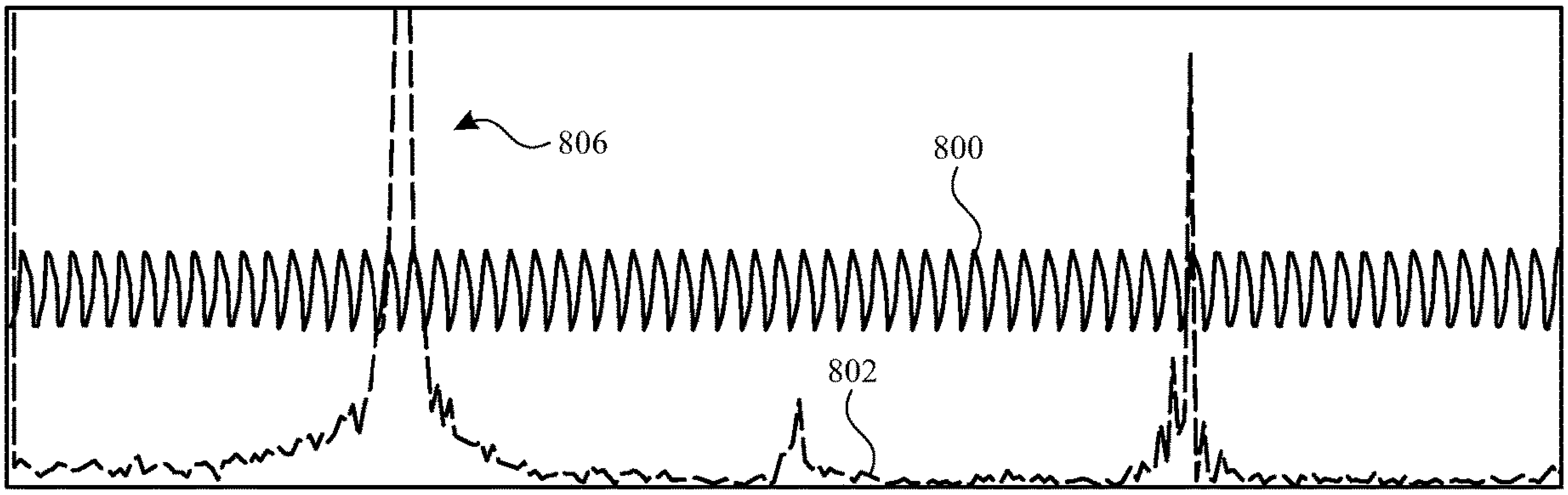


*FIG. 8A*

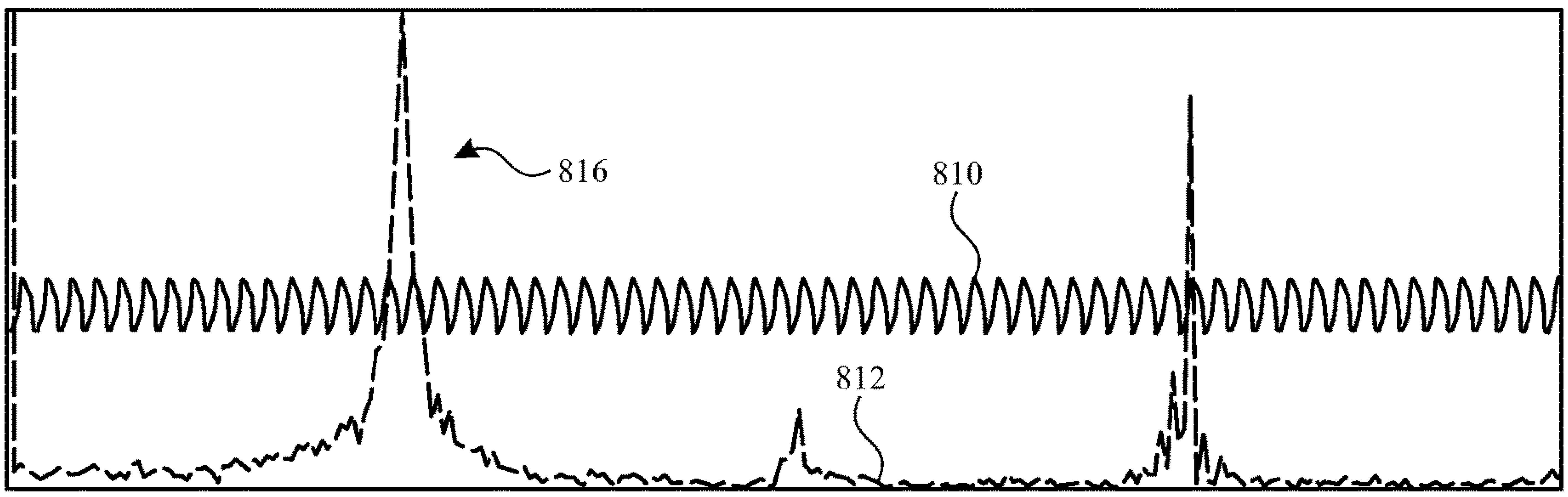


*FIG. 8B*

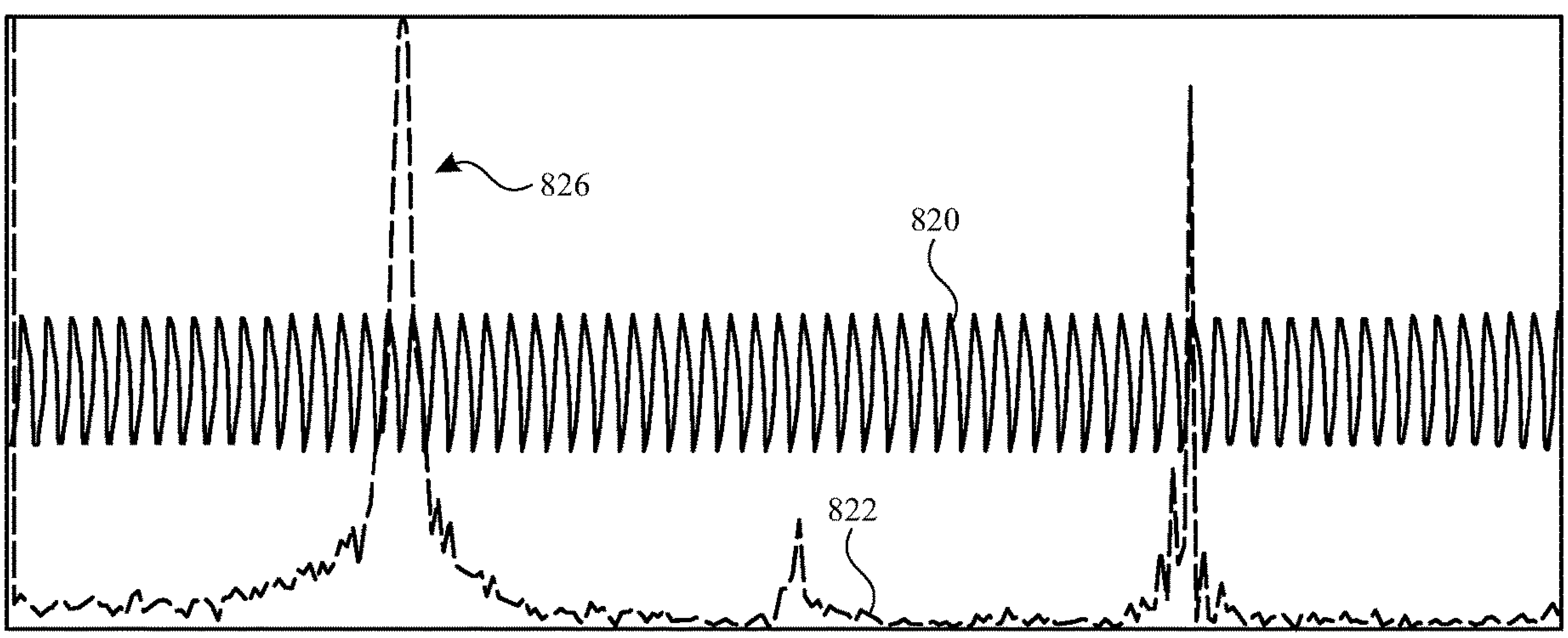


*FIG. 8C*

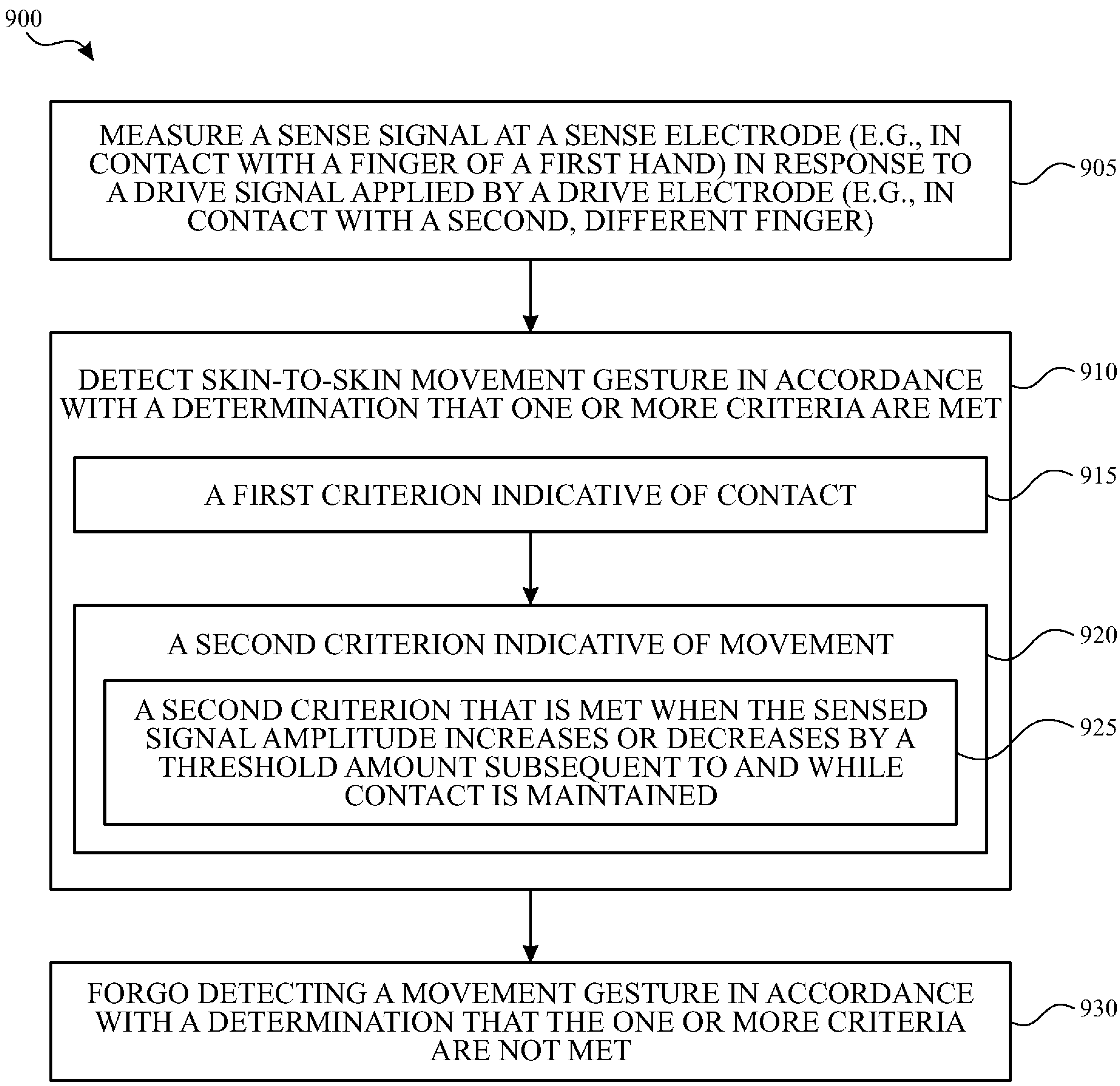
900
MEASURE A SENSE SIGNAL AT A SENSE ELECTRODE (E.G., IN CONTACT WITH A FINGER OF A FIRST HAND) IN RESPONSE TO A DRIVE SIGNAL APPLIED BY A DRIVE ELECTRODE (E.G., IN CONTACT WITH A SECOND, DIFFERENT FINGER)
905
DETECT SKIN-TO-SKIN MOVEMENT GESTURE IN ACCORDANCE WITH A DETERMINATION THAT ONE OR MORE CRITERIA ARE MET
910
A FIRST CRITERION INDICATIVE OF CONTACT
915
A SECOND CRITERION INDICATIVE OF MOVEMENT
920
A SECOND CRITERION THAT IS MET WHEN THE SENSED SIGNAL AMPLITUDE INCREASES OR DECREASES BY A THRESHOLD AMOUNT SUBSEQUENT TO AND WHILE CONTACT IS MAINTAINED
925
FORGO DETECTING A MOVEMENT GESTURE IN ACCORDANCE WITH A DETERMINATION THAT THE ONE OR MORE CRITERIA ARE NOT MET
930

*FIG. 9*

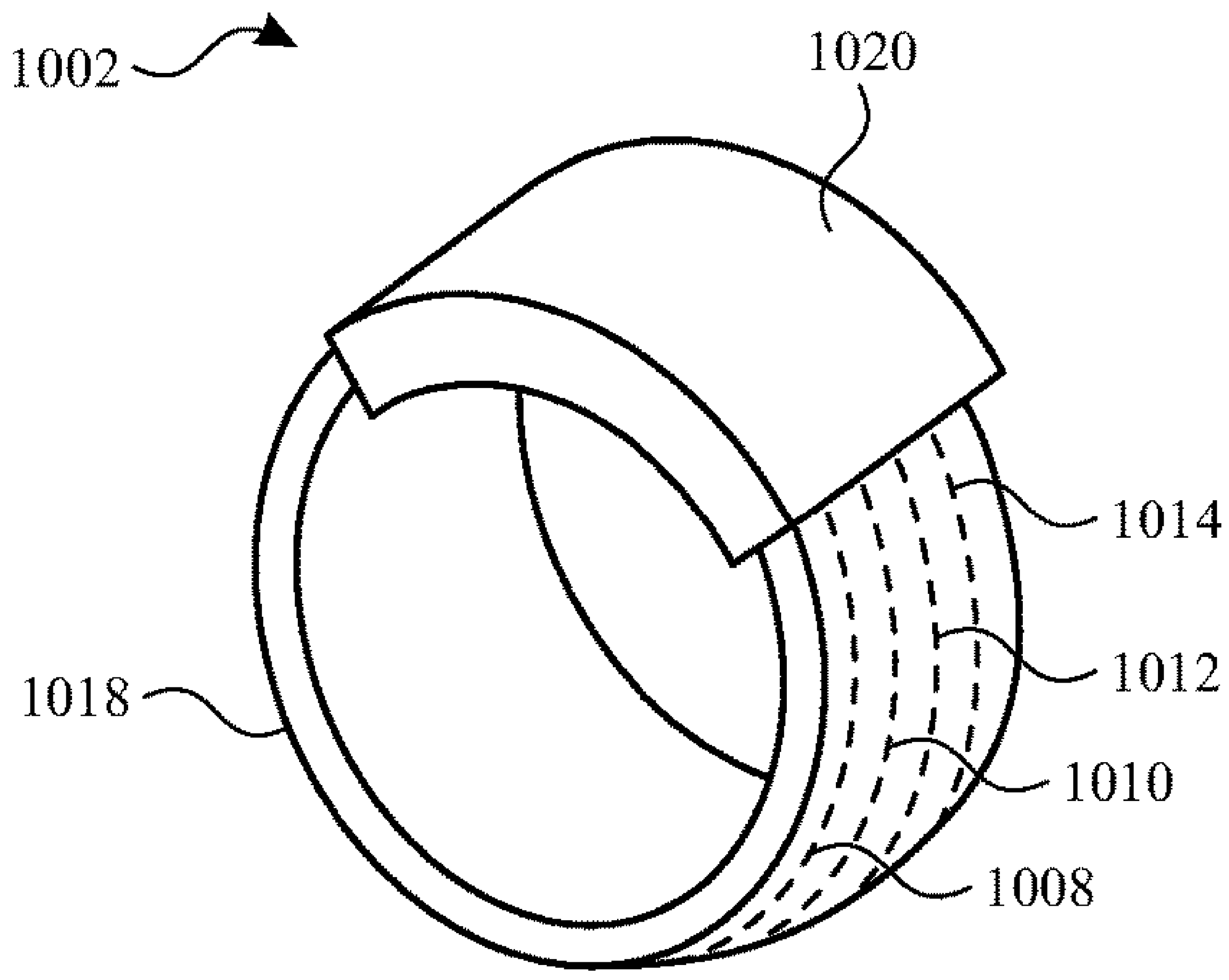
1002
1020
1014
1012
1018
1010
1008

*FIG. 10*

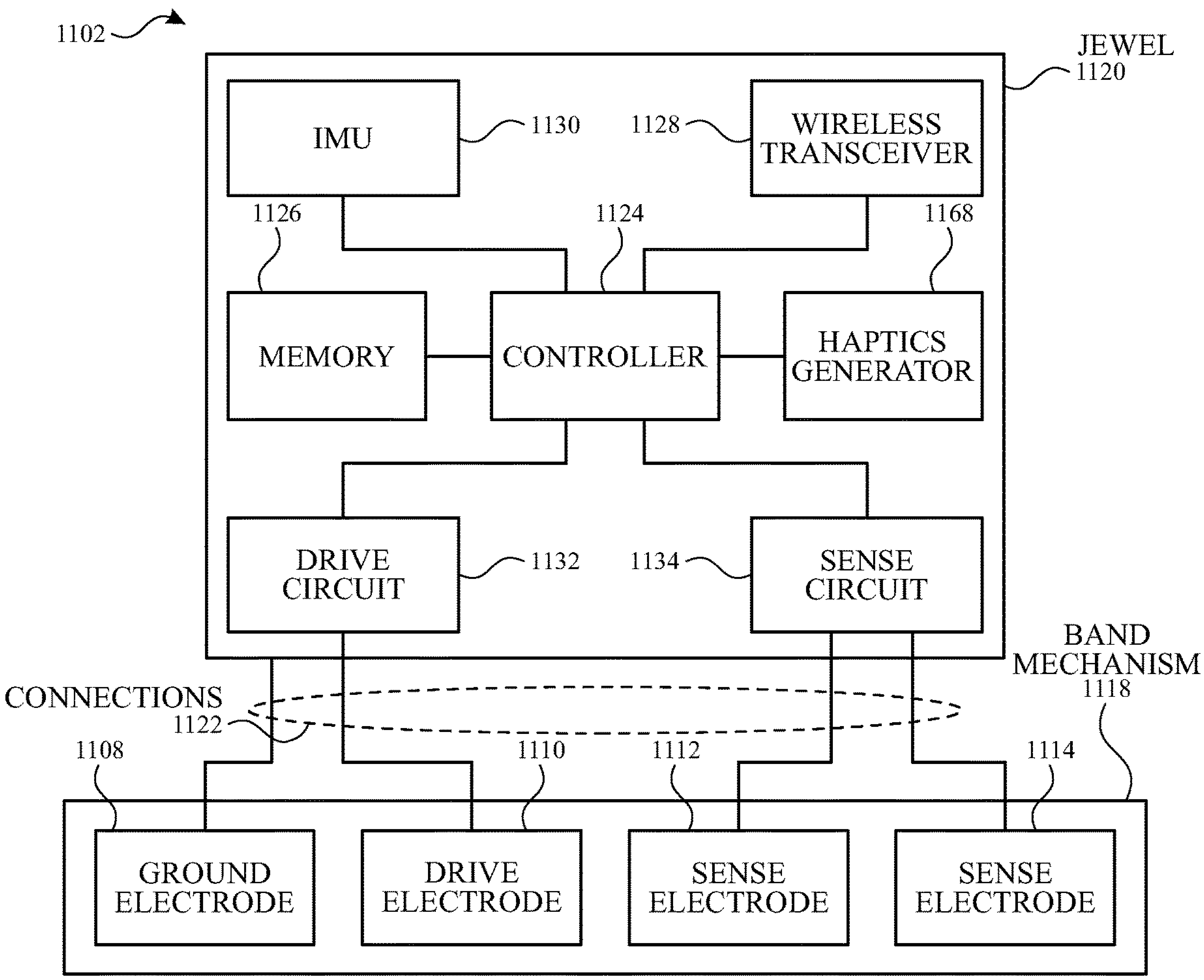
1102
JEWEL
1120
IMU
1130
1128
WIRELESS TRANSCEIVER
1126
1124
1168
MEMORY
CONTROLLER
HAPTICS GENERATOR
DRIVE CIRCUIT
1132
1134
SENSE CIRCUIT
BAND MECHANISM
1118
CONNECTIONS
1122
1108
1110
1112
1114
GROUND ELECTRODE
DRIVE ELECTRODE
SENSE ELECTRODE
SENSE ELECTRODE

*FIG. 11*

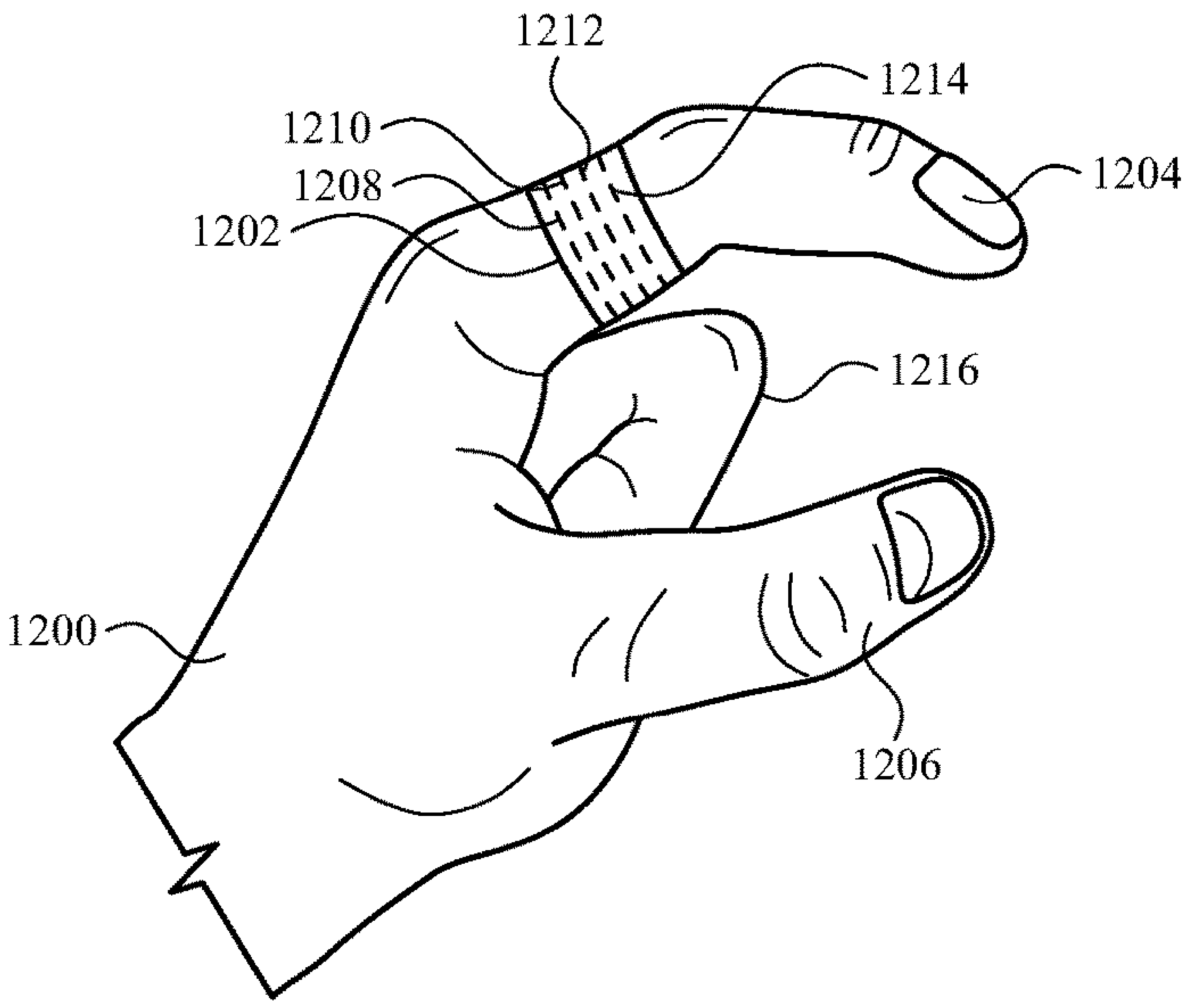


FIG. 12A

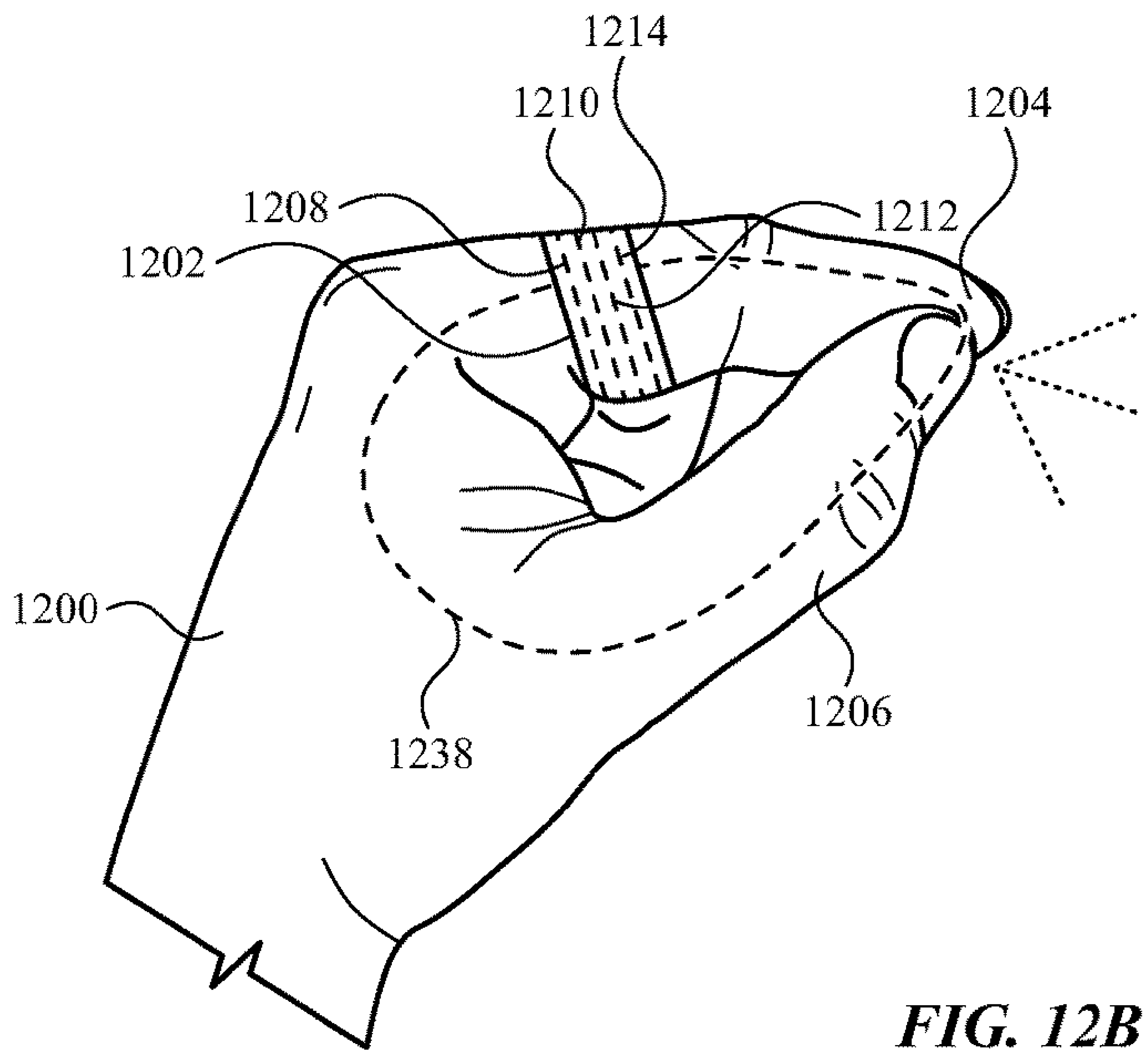


FIG. 12B

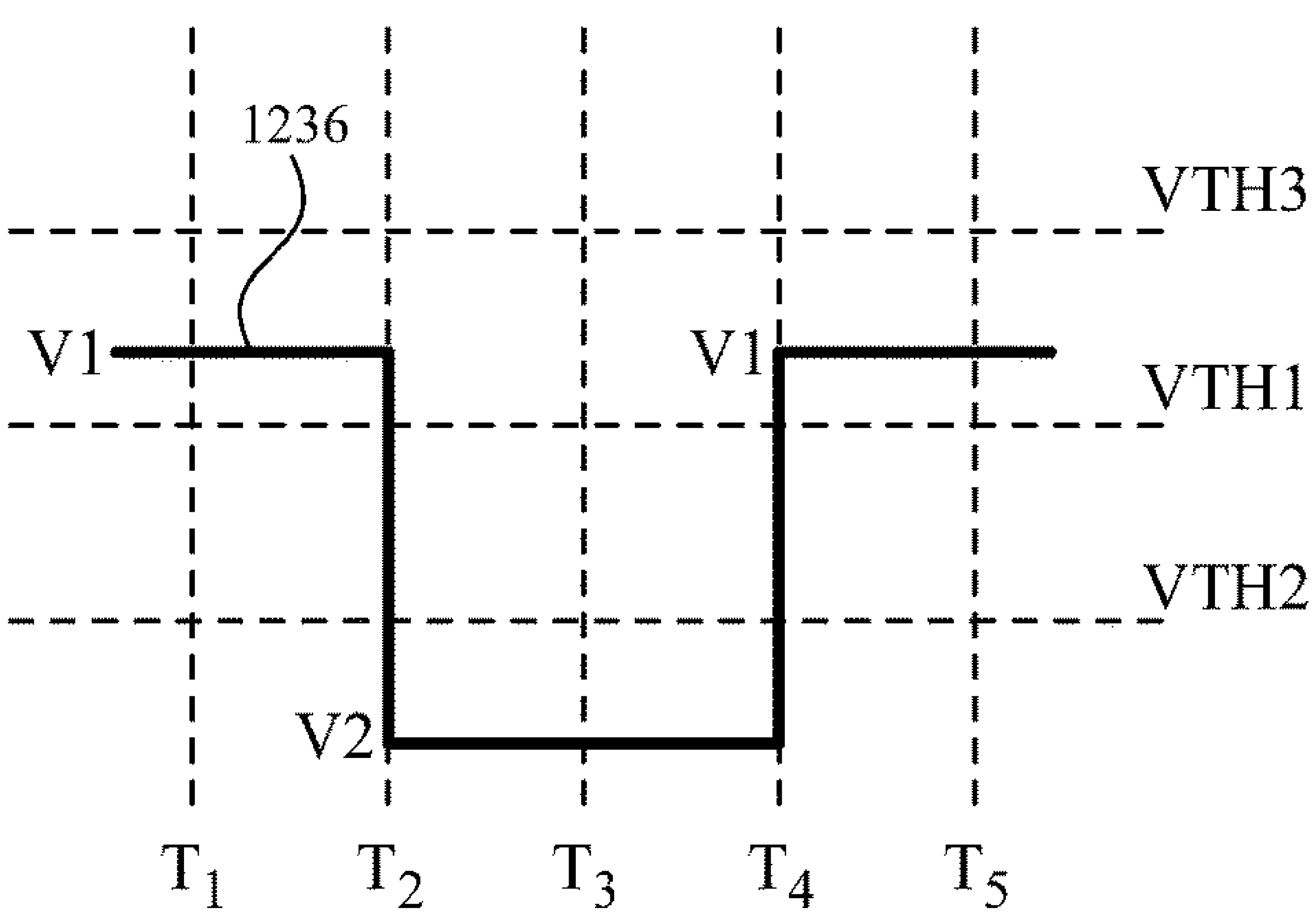


FIG. 12C

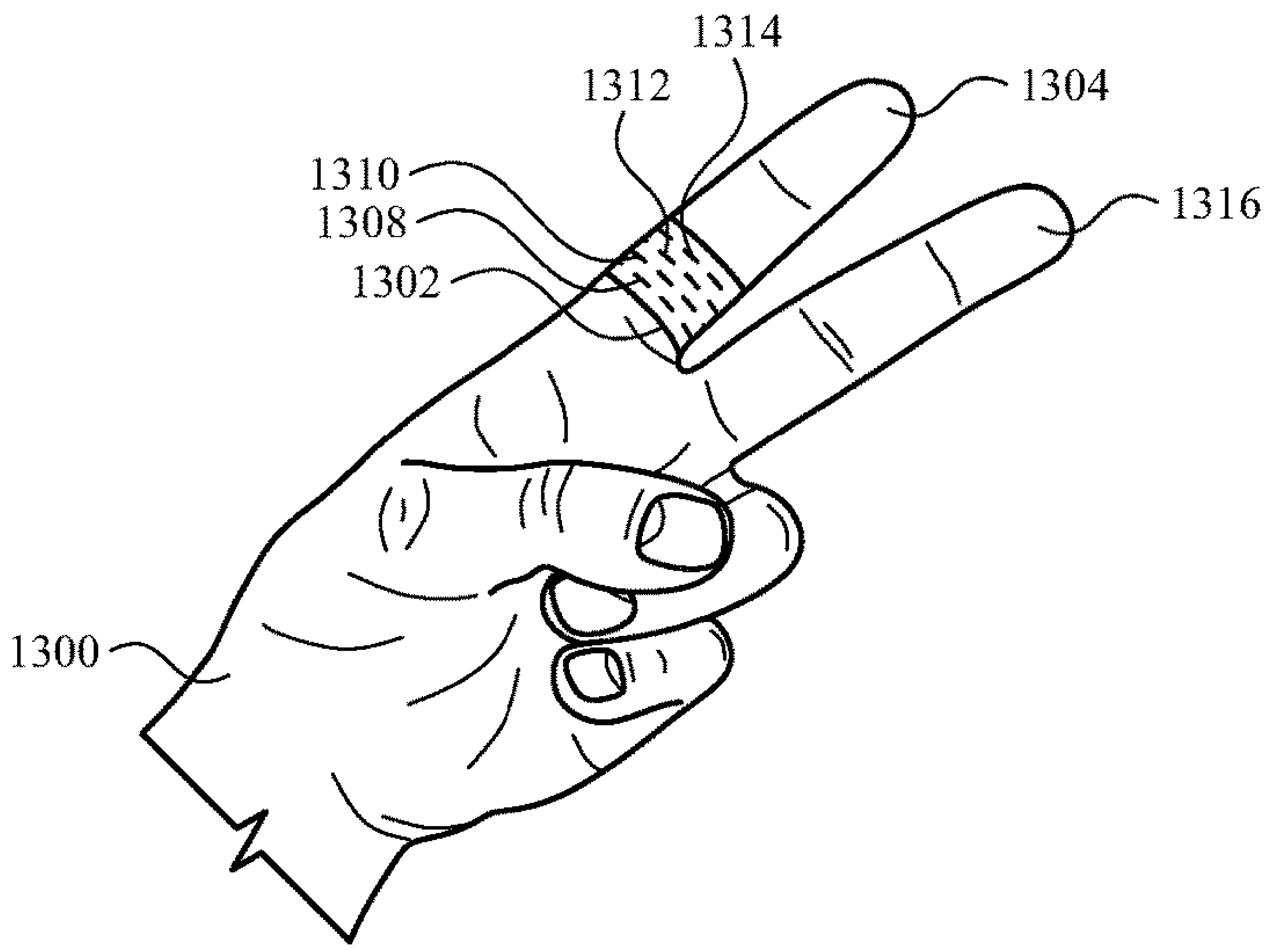


*FIG. 13A*

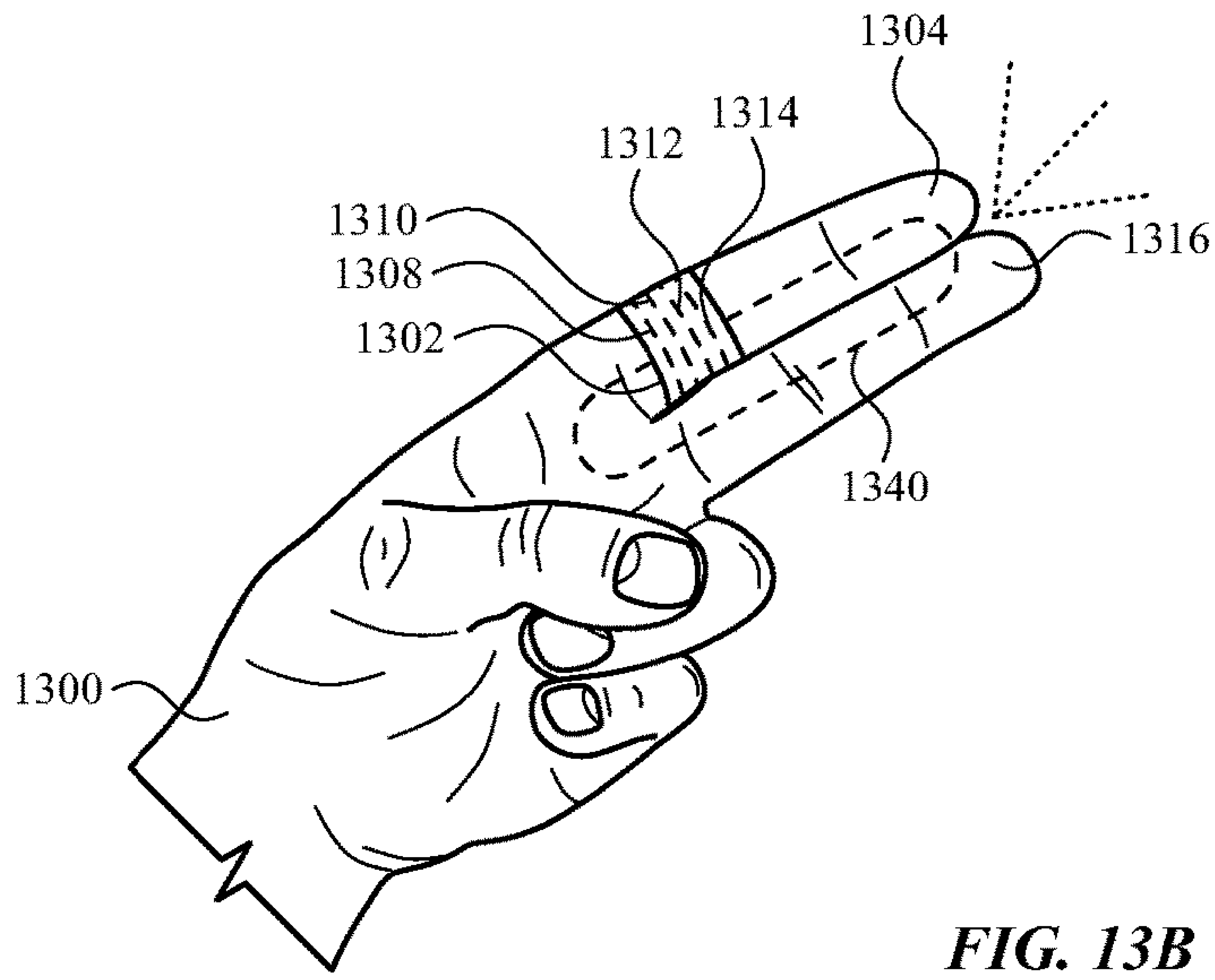


*FIG. 13B*

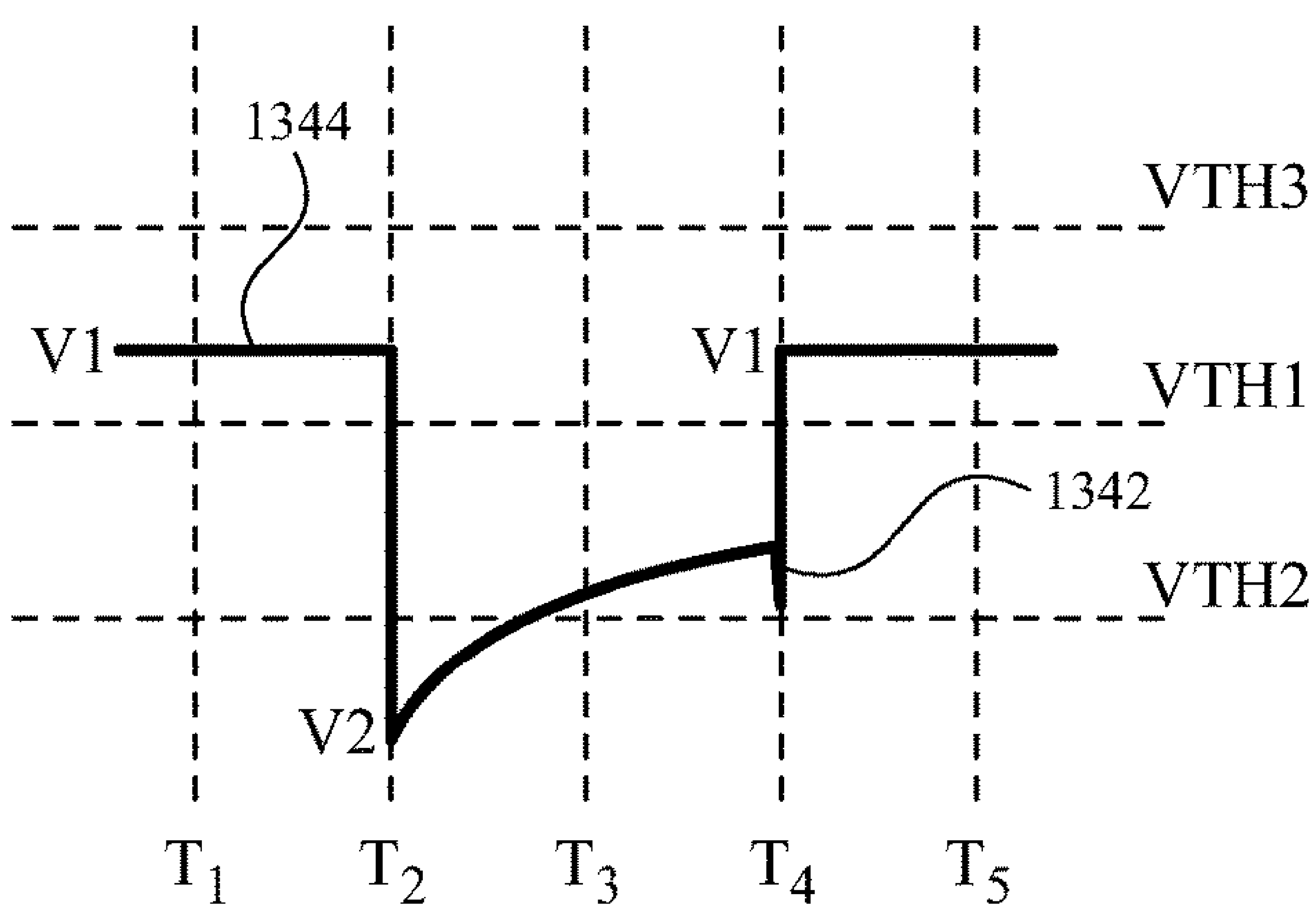


*FIG. 13C*

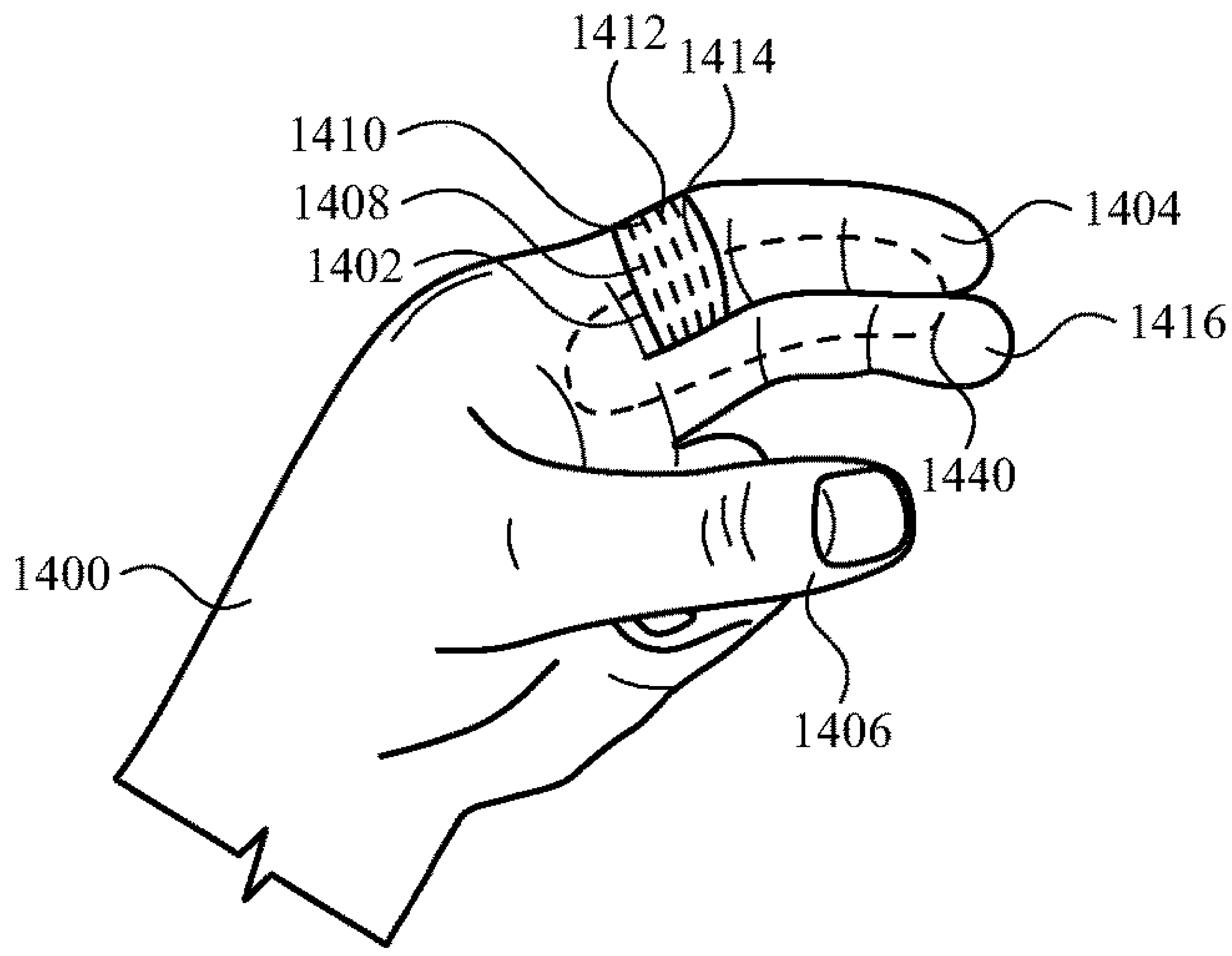


*FIG. 14A*

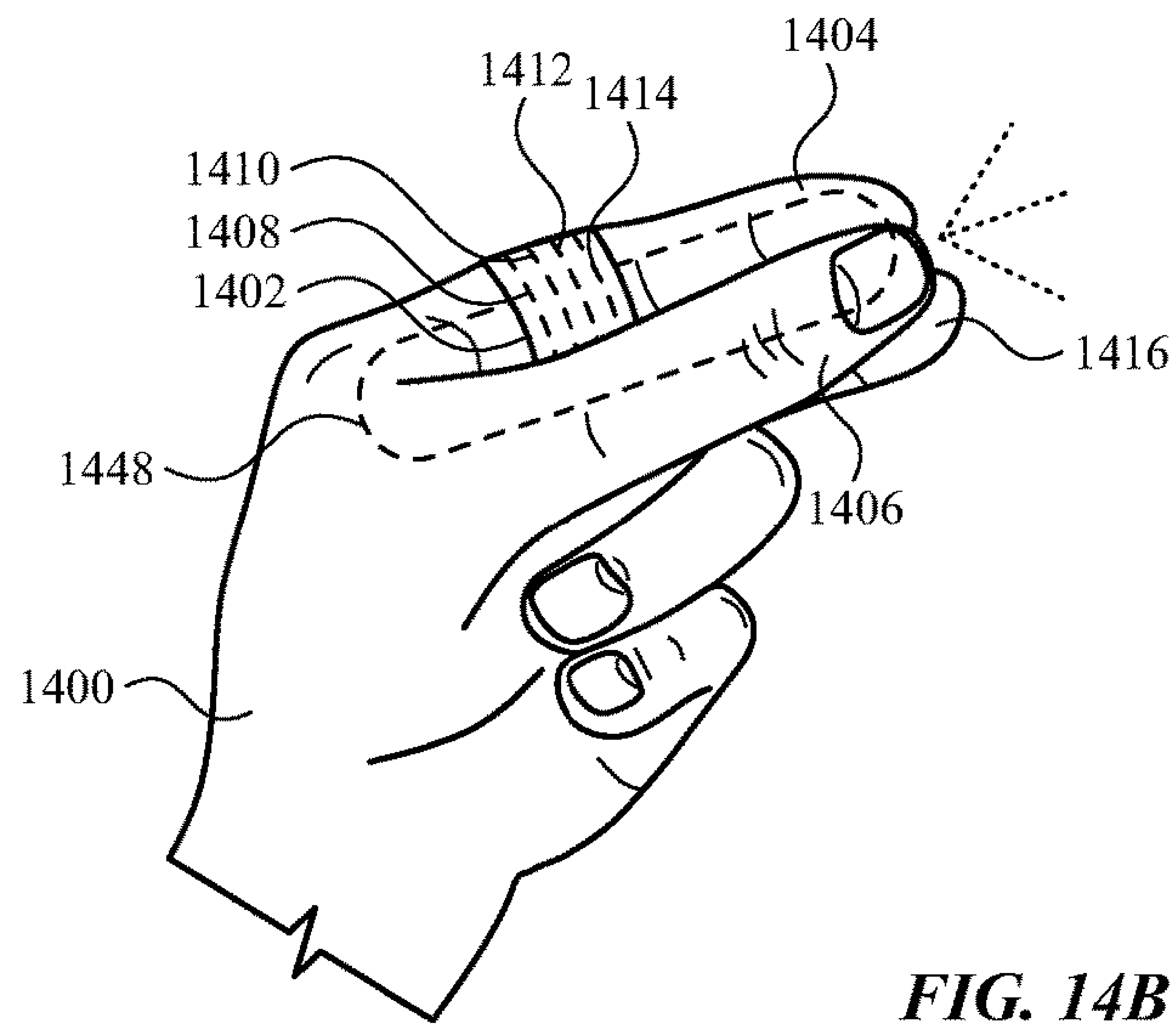


*FIG. 14B*

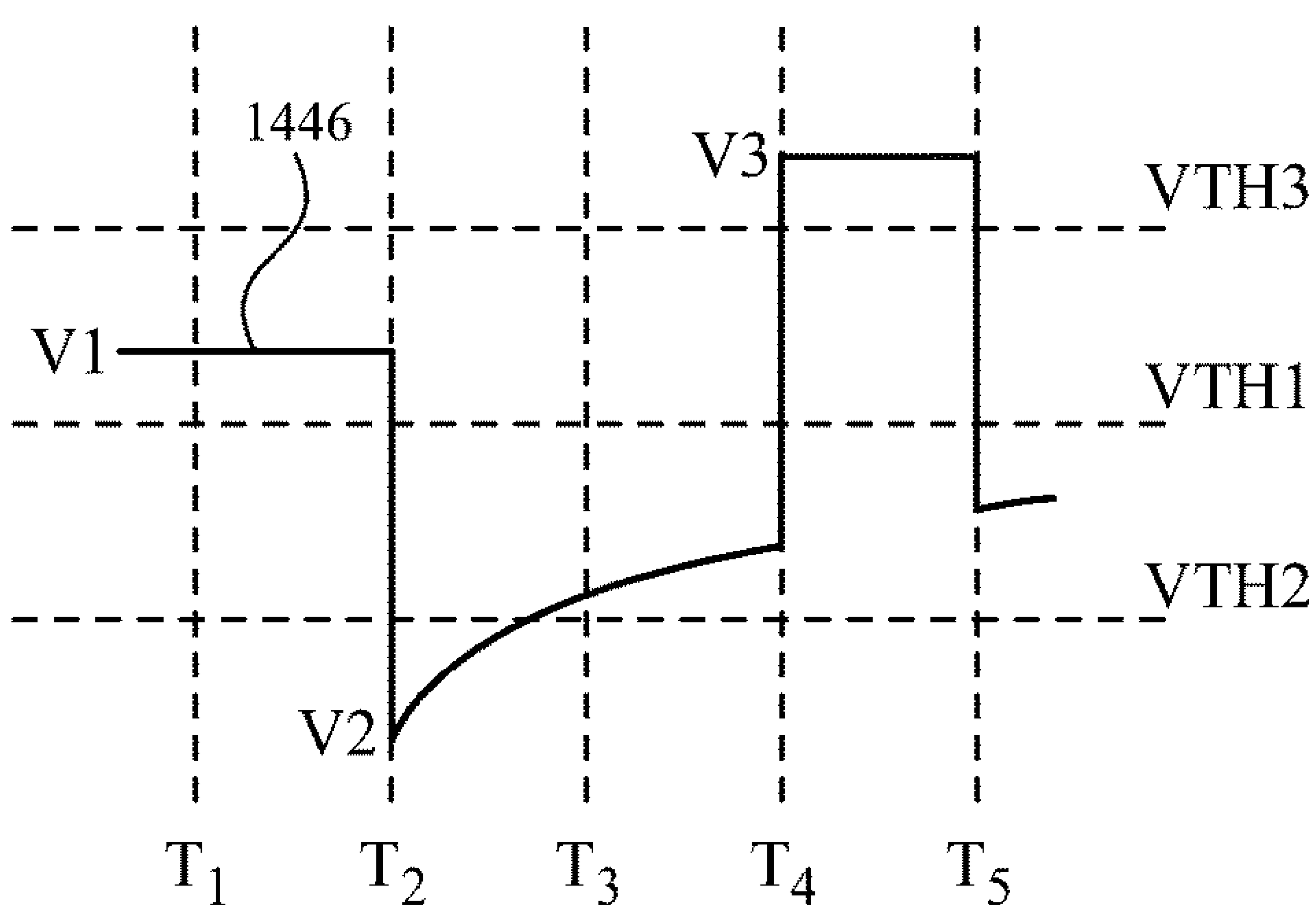


*FIG. 14C*

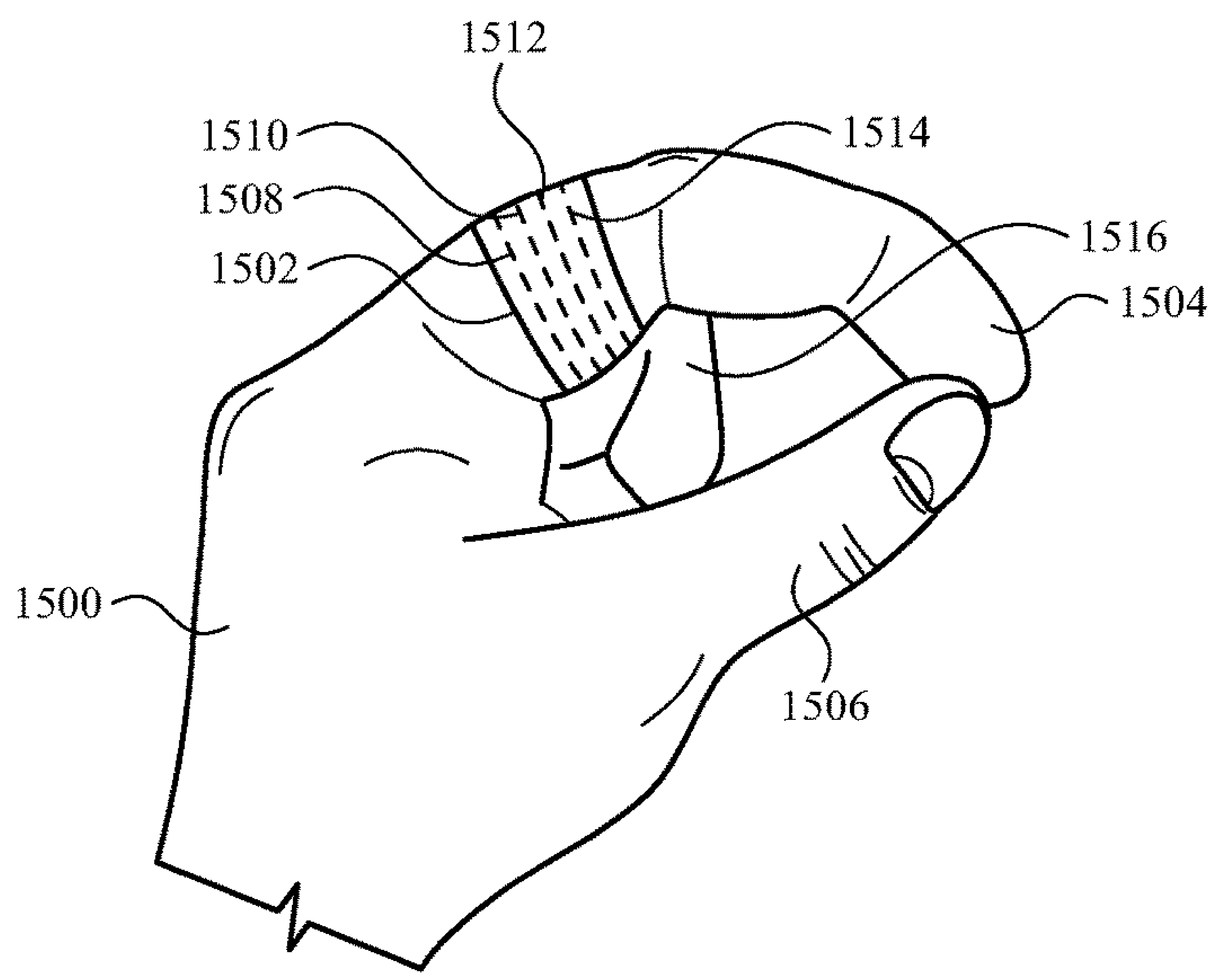


FIG. 15A

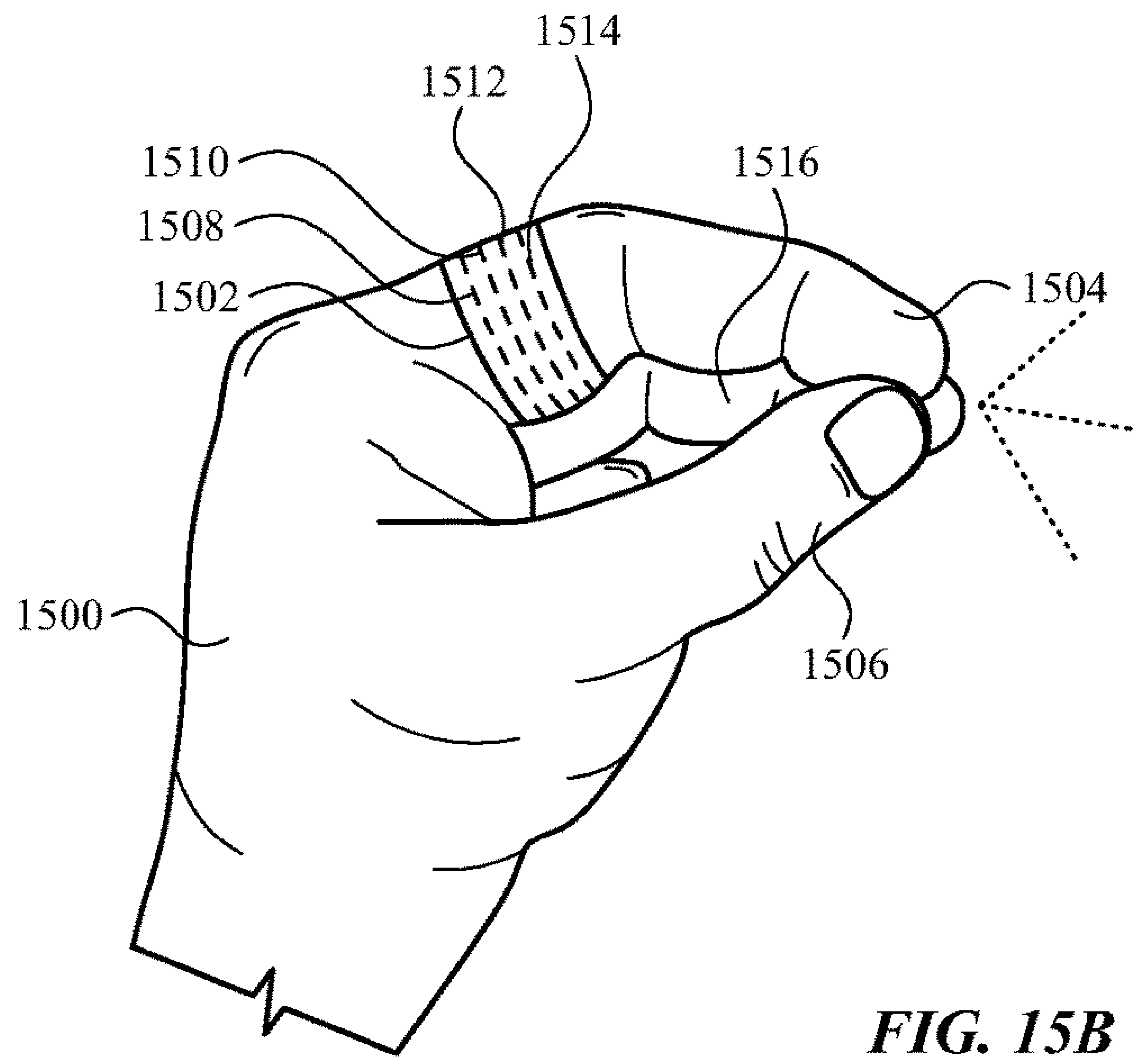


FIG. 15B

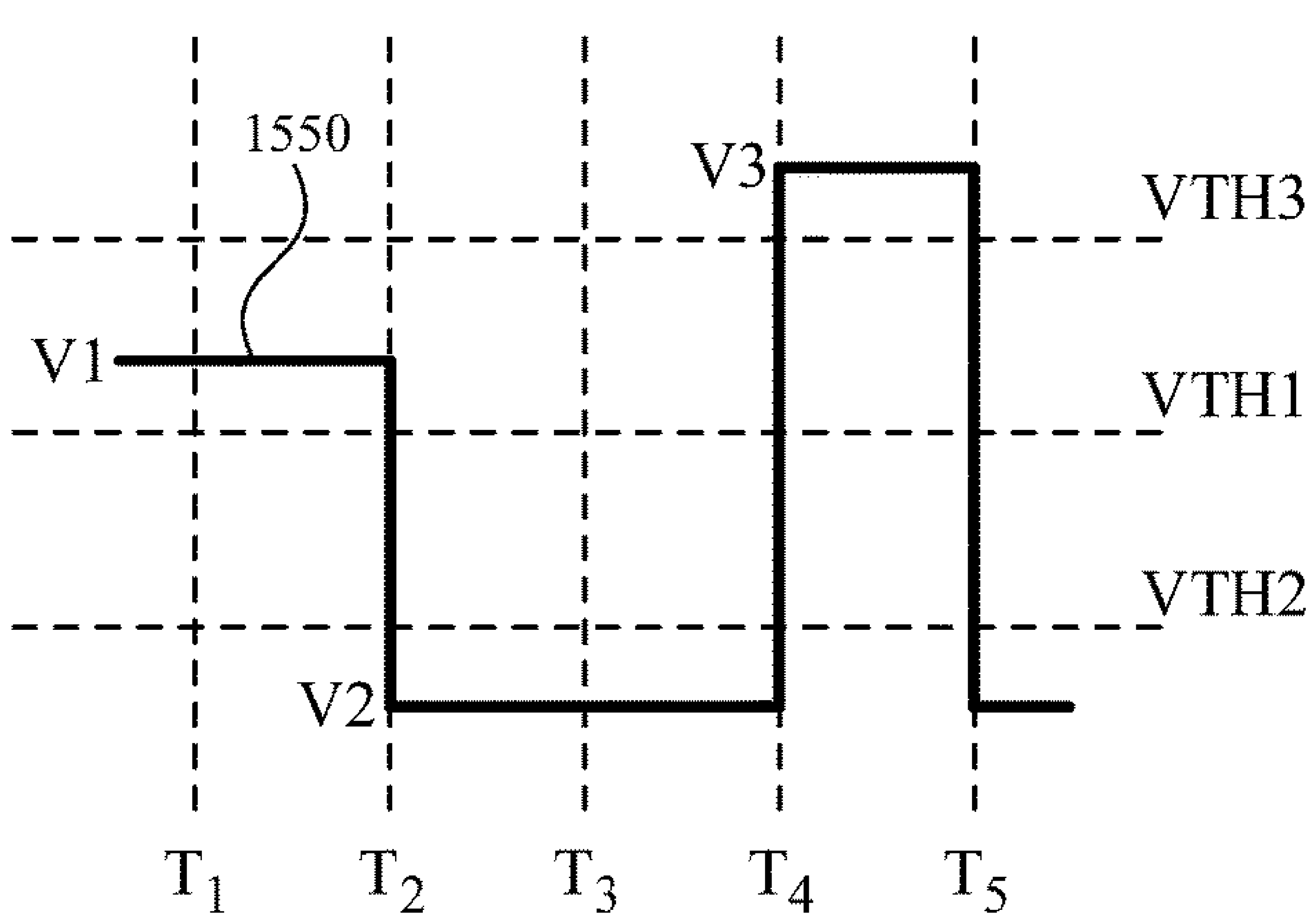


FIG. 15C

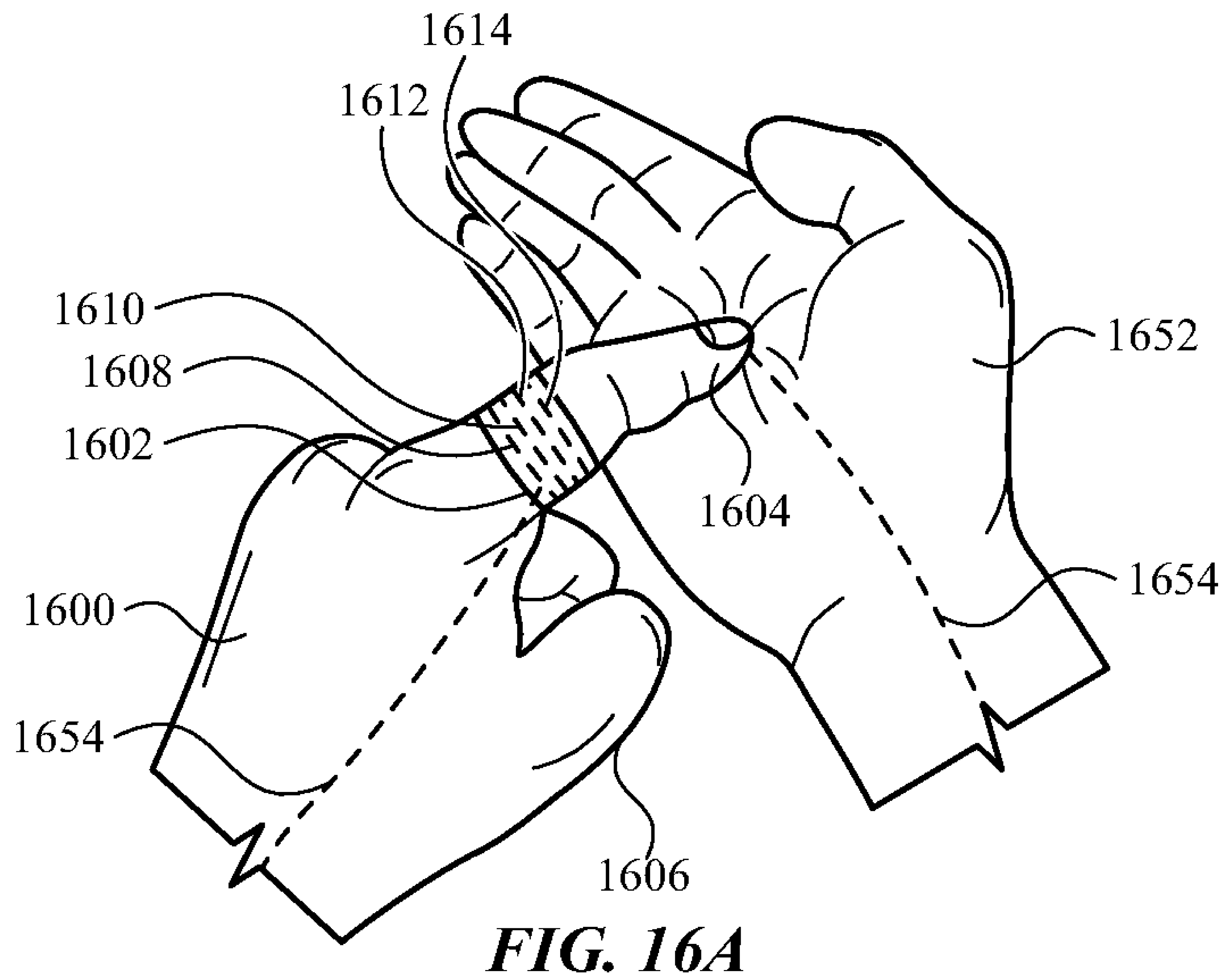


*FIG. 16A*

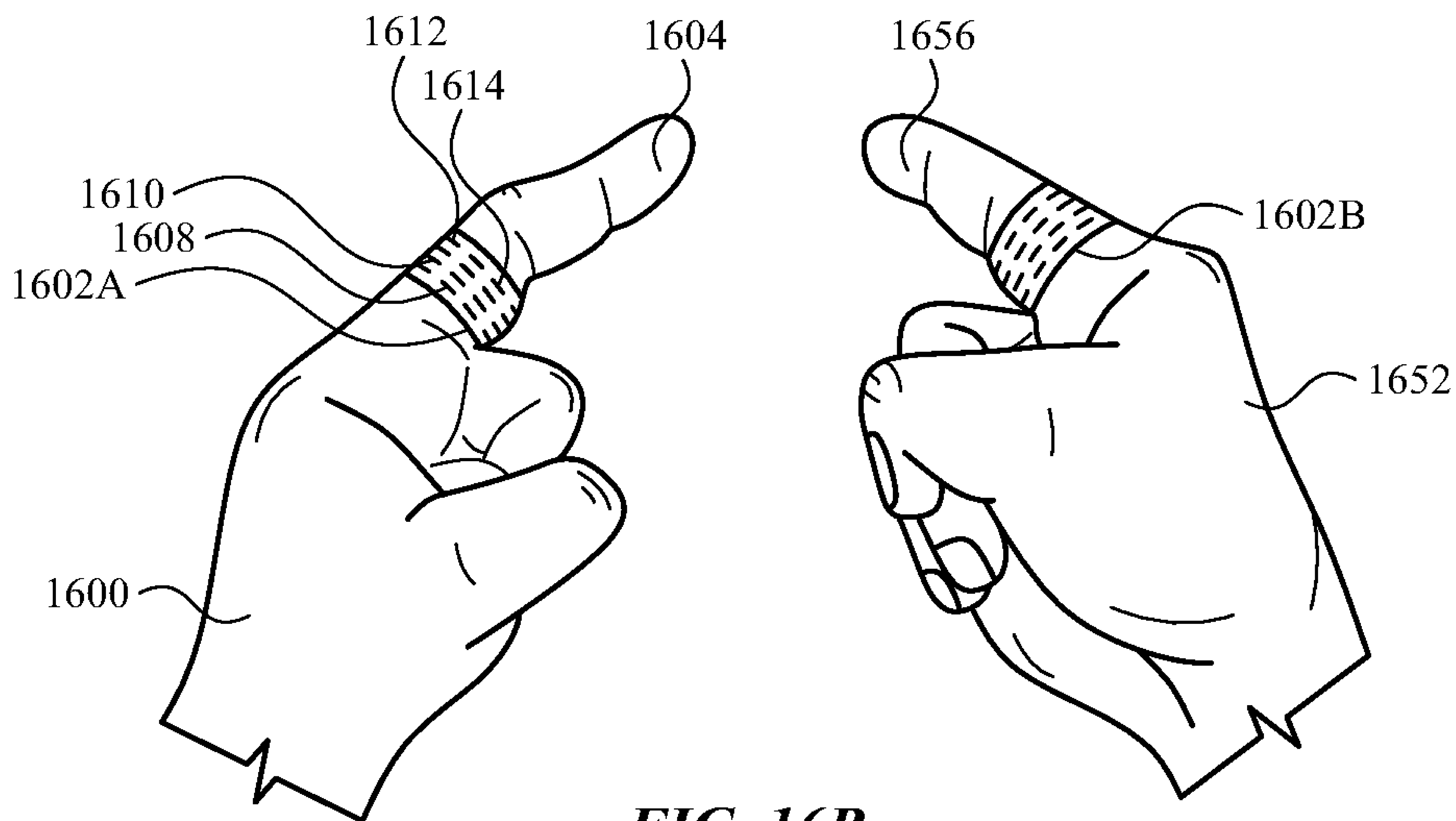


*FIG. 16B*

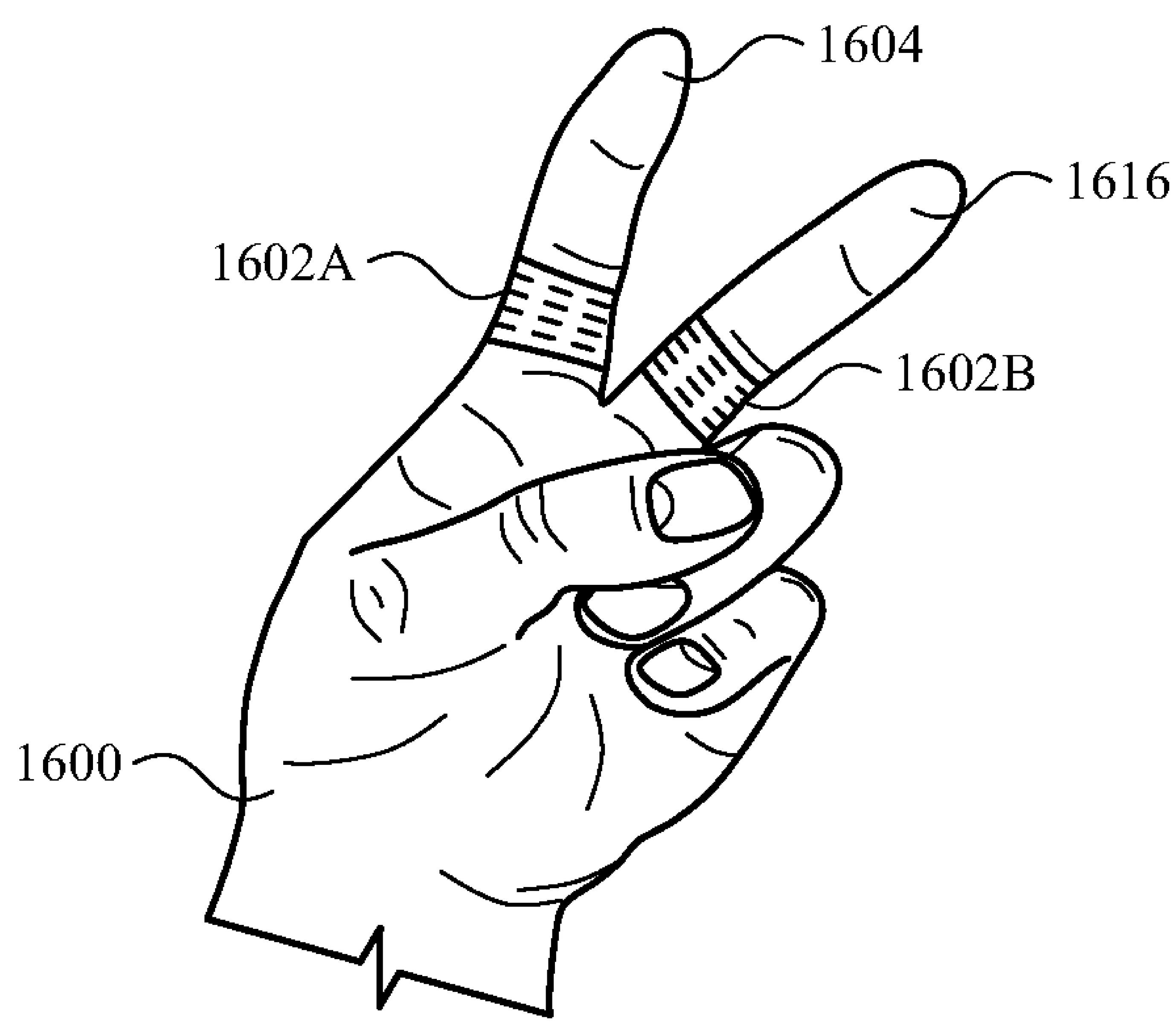


*FIG. 16C*

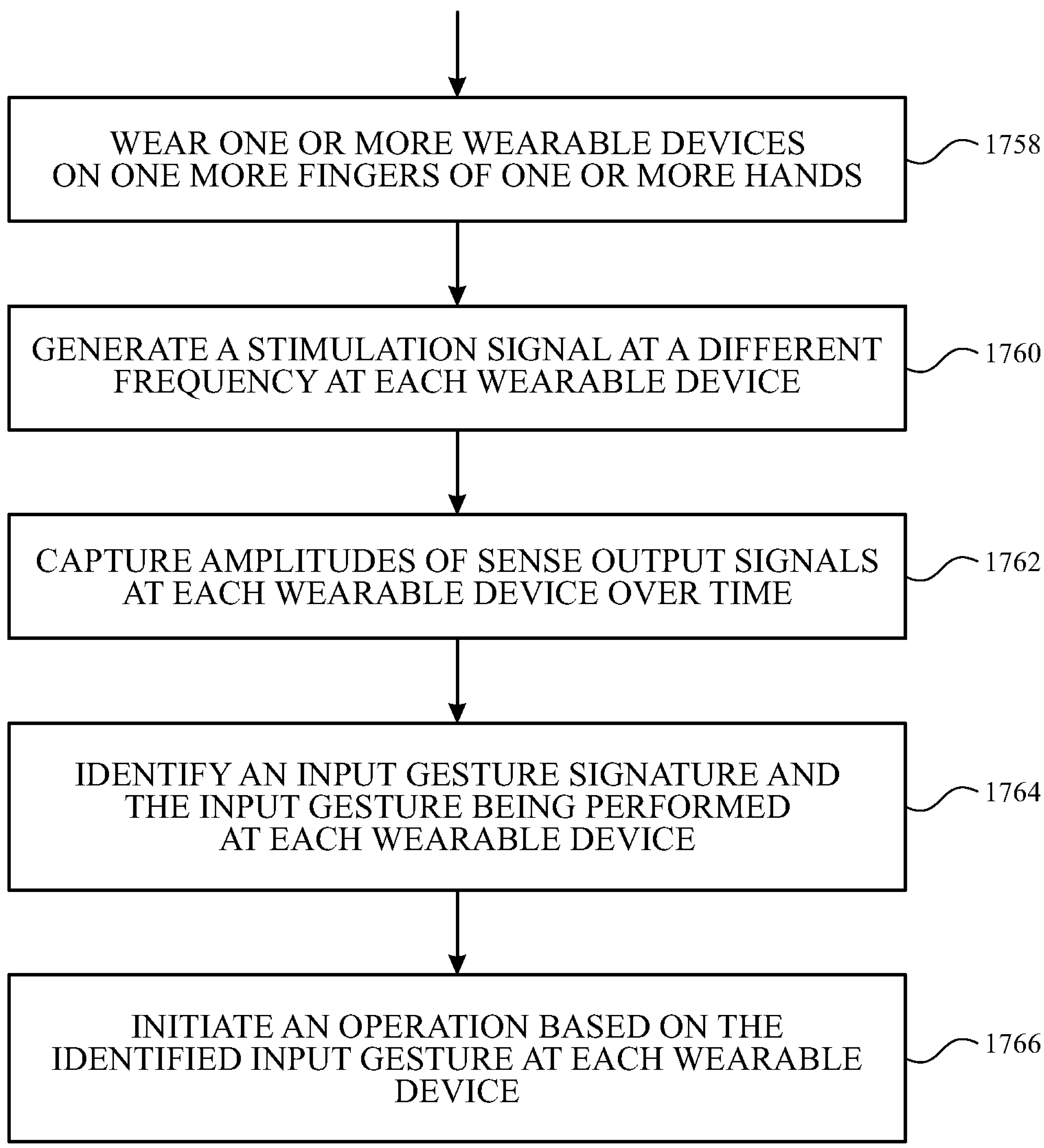
WEAR ONE OR MORE WEARABLE DEVICES ON ONE MORE FINGERS OF ONE OR MORE HANDS
1758
GENERATE A STIMULATION SIGNAL AT A DIFFERENT FREQUENCY AT EACH WEARABLE DEVICE
1760
CAPTURE AMPLITUDES OF SENSE OUTPUT SIGNALS AT EACH WEARABLE DEVICE OVER TIME
1762
IDENTIFY AN INPUT GESTURE SIGNATURE AND THE INPUT GESTURE BEING PERFORMED AT EACH WEARABLE DEVICE
1764
INITIATE AN OPERATION BASED ON THE IDENTIFIED INPUT GESTURE AT EACH WEARABLE DEVICE
1766

*FIG. 17*

# SKIN-TO-SKIN CONTACT DETECTION

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 17/814,826 now U.S. Pat. No. 11,625,098 issued on Apr. 11, 2023), filed on Jul. 25, 2022, which is a continuation of U.S. patent application Ser. No. 17/218,038 (now U.S. Pat. No. 11,397,468 issued on Jul. 26, 2022), filed on Mar. 30, 2021, which is a continuation-in-part (CIP) of U.S. patent application Ser. No. 16/836,552 (now U.S. Pat. No. 11,397,466 issued on Jul. 26, 2022), filed on Mar. 31, 2020, the contents of which are incorporated herein by reference in their entireties for all purposes.

## FIELD

This relates generally to systems and methods of detecting skin-to-skin contact, and more particularly, to detecting contact between two hands or between two fingers for input in virtual reality or augmented reality environments.

## BACKGROUND

Many types of input devices are presently available for performing operations in a computing system, such as buttons or keys, mice, trackballs, joysticks, touch sensor panels, touch screens and the like. In some examples, contact between two different parts of a user's body may be used for input. For example, cameras in a head-mounted display can be used to track movement of fingers to detect a finger in contact with an opposite hand, or to track movement of a finger along an opposite hand surface. Additionally or alternatively, a radiofrequency-based system can be used to detect a finger in contact with an opposite hand, or to track movement of a finger along an opposite hand surface. However, camera-based systems and/or radiofrequency-based systems may have difficulty detecting the difference between a finger touching the opposite hand or proximate to without contacting (hovering above) the opposite hand. Additionally, camera-based systems require the finger and opposite hand be in the field of view of the cameras for operation.

## SUMMARY

This relates to devices and methods of detecting contact between a first body part and a second body part. Sense circuitry can be configured to sense a signal at the sense electrode (e.g., configured to contact the second body part) in response to a drive signal applied to the drive electrode (e.g., configured to contact the first body part). Processing circuitry can be configured to detect contact in accordance with a determination that one or more criteria are met. The one or more criteria can include a first criterion that is met when an amplitude of the sensed signal exceeds an amplitude threshold and a second criterion that is met when the sensed signal has a non-distorted waveform. Using a robust set of criteria, including an evaluation of the quality of the waveform (e.g., whether it is distorted or not), can improve the disambiguation between a skin-to-skin contact event and a proximity event.

This also relates to devices and methods of detecting a movement gesture using contact between two fingers of the same hand (e.g., to enable one-handed skin-to-skin input gestures). Sense circuitry can be configured to sense a signal at a sense electrode (e.g., configured to contact a finger of a hand) in response to a drive signal applied to a drive electrode (e.g., configured to contact a different finger of the hand). Processing circuitry can be configured to detect a movement gesture (e.g., a slide gesture) in accordance with a determination that one or more criteria are met. The one or more criteria can include a first criterion indicative of contact between a first finger and a second finger and a second criterion indicative of movement of the first finger along the second finger.

This further relates to devices and methods of detecting gestures between a finger of one hand and other body parts (e.g., other fingers or a thumb on the same hand, or the opposing hand) using a single device (e.g., a ring) on the finger of the hand. Sense circuitry in the device can be configured to sense a signal at one or more sense electrodes in the device in response to a drive signal applied to a drive electrode in the device. Processing circuitry can be configured to detect contact or a movement gesture (e.g., a slide gesture) in accordance with a determination that one or more criteria are met. The one or more criteria can include various amplitude criteria, in some instances evaluated over a certain time period. When a particular gesture is detected, an operation can be initiated.

This also relates to devices and methods of detecting gestures between a finger of one hand and other body parts (e.g., other fingers or a thumb on the same hand, or the opposing hand) using a device (e.g., a ring) on each of multiple fingers of the same hand, or on fingers of different hands. Sense circuitry in each device can be configured to sense a signal at one or more sense electrodes in the device in response to drive signals applied to a drive electrode in each of the devices. When a particular gesture is detected, an operation can be initiated.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A-**1**B illustrate an example system for skin-to-skin contact detection according to examples of the disclosure.

FIG. **2** illustrates a block diagram of an example computing system **200** for skin-to-skin contact detection according to examples of the disclosure.

FIGS. **3**A-**3**B illustrate a proximity and a contact, respectively, between a first body part and a second body part according to examples of the disclosure.

FIGS. **4**A-**4**B illustrate time domain and frequency domain representations of the sensed signal corresponding to the proximity or the contact according to examples of the disclosure.

FIG. **5** illustrates a block diagram of a correlation circuit **500** according to examples of the disclosure.

FIG. **6** illustrates an example process of skin-to-skin contact detection according to examples of the disclosure.

FIGS. **7**A-**7**B illustrate an example system for detection of a skin-to-skin gesture according to examples of the disclosure.

FIGS. **8**A-**8**C illustrate time domain representations and frequency domain representations of the sensed signal corresponding to a finger-to-finger slide gesture according to examples of the disclosure.

FIG. **9** illustrates an example process of skin-to-skin gesture detection according to examples of the disclosure.

FIG. **10** illustrates a wearable device in the form of a ring according to examples of the disclosure.

FIG. **11** is a system block diagram of a wearable device according to examples of the disclosure.

FIG. **12**A illustrates a hand with an index finger supporting a wearable device (e.g., a ring) but not making contact with a thumb according to examples of the disclosure.

FIG. **12**B illustrates the hand of FIG. **12**A, except that the index finger is now making contact with the thumb according to examples of the disclosure.

FIG. **12**C illustrates a sense output signal when the index finger and thumb make and break contact as shown in FIGS. **12**B and **12**A according to examples of the disclosure.

FIG. **13**A illustrates a hand with an index finger supporting a wearable device (e.g., a ring) but not making contact with a middle finger according to examples of the disclosure.

FIG. **13**B illustrates the hand of FIG. **13**A, except that the index finger is now making contact with the middle finger according to examples of the disclosure.

FIG. **13**C illustrates a sense output signal when the index finger and middle finger make and break contact as shown in FIGS. **13**B and **13**A according to examples of the disclosure.

FIG. **14**A illustrates a hand with an index finger supporting a wearable device (e.g., a ring) and in contact with a middle finger according to examples of the disclosure.

FIG. **14**B illustrates the hand of FIG. **14**A, except that the thumb is now making contact with the already touching index finger and middle finger according to examples of the disclosure.

FIG. **14**C illustrates a sense output signal when the thumb makes and breaks contact with the already touching index finger and middle finger as shown in FIGS. **14**B and **14**A according to examples of the disclosure.

FIG. **15**A illustrates a hand with an index finger supporting a wearable device (e.g., a ring) and making contact with a thumb according to examples of the disclosure.

FIG. **15**B illustrates the hand of FIG. **15**A, except that the middle finger is now making contact with the already touching index finger and thumb according to examples of the disclosure.

FIG. **15**C illustrates a sense output signal when the middle finger makes and breaks contact with the already touching index finger and thumb as shown in FIGS. **15**B and **15**A according to examples of the disclosure.

FIG. **16**A illustrates a hand with an index finger supporting a wearable device (e.g., a ring) and making contact with an opposite hand according to examples of the disclosure.

FIG. **16**B illustrates a left hand with an index finger supporting a wearable device (e.g., a ring) and also a right hand with an index finger supporting another wearable device (e.g., a ring) according to examples of the disclosure.

FIG. **16**C illustrates a hand with an index finger supporting a wearable device (e.g., a ring) and a middle finger supporting another wearable device (e.g., a ring) according to examples of the disclosure.

FIG. **17** illustrates a flowchart for detecting input gestures using one or more devices according to examples of the disclosure.

## DETAILED DESCRIPTION

In the following description of examples, reference is made to the accompanying drawings which form a part hereof, and in which it is shown by way of illustration specific examples that can be practiced. It is to be understood that other examples can be used and structural changes can be made without departing from the scope of the disclosed examples.

This relates to devices and methods of detecting contact between a first body part and a second body part. Sense circuitry can be configured to sense a signal at the sense electrode (e.g., configured to contact the second body part) in response to a drive signal applied to the drive electrode (e.g., configured to contact the first body part). Processing circuitry can be configured to detect contact in accordance with a determination that one or more criteria are met. The one or more criteria can include a first criterion that is met when an amplitude of the sensed signal exceeds an amplitude threshold and a second criterion that is met when the sensed signal has a non-distorted waveform. Using a robust set of criteria, including an evaluation of the quality of the waveform (e.g., whether it is distorted or not), can improve the disambiguation between a skin-to-skin contact event and a proximity event.

This also relates to devices and methods of detecting a movement gesture using contact between two fingers of the same hand (e.g., to enable one-handed skin-to-skin input gestures). Sense circuitry can be configured to sense a signal at a sense electrode (e.g., configured to contact a finger of a hand) in response to a drive signal applied to a drive electrode (e.g., configured to contact a different finger of the hand). Processing circuitry can be configured to detect a movement gesture (e.g., a slide gesture) in accordance with a determination that one or more criteria are met. The one or more criteria can include a first criterion indicative of contact between a first finger and a second finger and a second criterion indicative of movement of the first finger along the second finger.

This further relates to devices and methods of detecting gestures between a finger of one hand and other body parts (e.g., other fingers or a thumb on the same hand, or the opposing hand) using a single device (e.g., a ring) on the finger of the hand. Sense circuitry in the device can be configured to sense a signal at one or more sense electrodes in the device in response to a drive signal applied to a drive electrode in the device. Processing circuitry can be configured to detect contact or a movement gesture (e.g., a slide gesture) in accordance with a determination that one or more criteria are met. The one or more criteria can include various amplitude criteria, in some instances evaluated over a certain time period. When a particular gesture is detected, an operation can be initiated.

This also relates to devices and methods of detecting gestures between a finger of one hand and other body parts (e.g., other fingers or a thumb on the same hand, or the opposing hand) using a device (e.g., a ring) on each of multiple fingers of the same hand, or on fingers of different hands. Sense circuitry in each device can be configured to sense a signal at one or more sense electrodes in the device in response to drive signals applied to a drive electrode in each of the devices. When a particular gesture is detected, an operation can be initiated.

FIGS. **1**A-**1**B illustrate an example system for skin-to-skin contact detection according to examples of the disclosure. FIG. **1**A illustrates a system including two wrist-worn wearable devices **150**A, **150**B, each including at least one electrode to establish electrical contact between the wearable device and the wearer's skin. An electrode of a first wearable device **150**A can be used to drive a drive signal (sometimes referred to as a "stimulation signal") into the wearer's body via the electrode's contact with the wrist of right hand **104**A. An electrode of a second wearable device **150**B can be used to sense a signal (sometimes referred to as a "sensed signal" or "received signal") from the wearer's body via contact with the wrist of left hand **104**B. As described herein, without contact between hands **104**A-**104**B, a conductive path through the body can allow for propagation of the drive signal and reception of the sensed signal. Proximity or contact between hands **104**A-**104**B can form a second conductive path through the contact or proximity for propagation of the drive signal and reception of the sensed signal that can change characteristics of the sensed signal. These characteristics can be monitored and analyzed (e.g., by processing circuitry) and used to determine whether skin-to-skin contact has been made as discussed in more detail herein.

In some examples, as illustrated in FIG. **1**A, the wearable devices **150**A-**105**B can be watches (optionally including crown **162** and/or button **164**) that can each be fastened to a user via strap **154** or any other suitable fastener. One or both of the wearable devices **150**A-**105**B can include a touch screen **152**. It is understood that although wearable devices **150**A-**150**B are illustrated as including a touch screen **152**, that the skin-to-skin contact detection can be achieved without a touch screen or display integrated with wearable devices **150**A-**150**B. Additionally or alternatively, each wearable device can include processing circuitry, drive circuitry sense circuitry, and/or more than one electrode (e.g., to enable the various drive, sense and processing functionalities to be performed by either or both wearable devices). For example, FIG. **1**B illustrates a backside of wearable device **150** with two electrodes **166**A-B, though fewer or more electrodes is possible. For example, some devices device can include a single electrode (for single-ended driving and/or sensing capability), two electrodes (e.g., for single-ended driving or sensing and/or for differential driving or sensing), three electrodes (e.g., for single-ended driving and differential sensing and/or for differential driving and single-ended sensing) or four electrodes (e.g., for differential driving and/or differential sensing), etc. It should be understood that each of the watches can include all of the components above, or that the watches may include fewer components or different components. It should be understood that although watches are illustrated in FIGS. **1**A-**1**B that different devices are possible and/or different placement of the devices is possible. For example, watches **150**A-**150**B can be replaced with two wristbands; one wristband can include an electrode and drive circuitry and one wristband can include an electrode and sense circuitry. The control of the drive and sense circuitry and/or the processing of the signals received by the sense circuitry can be performed by circuitry within each respective wristband or by circuitry within another device (e.g., a smartphone or other computing device) based on wired or wireless communication between such a device and the wristbands. In some examples, one watch may be used for sensing and processing the sensed signal, and the drive circuitry and electrode can be implemented in another type of device (e.g., a ring). In some examples, one or both devices (e.g., for driving the drive signal and/or sensing the sensed signal) can be implemented in a glove, finger cuff, bracelet, necklace, head-mounted device, necklace, armband, headphones or ear buds. Although primarily described as wearable devices, in some examples, one or both devices can be a non-wearable device such as a handheld controller. Additionally, although primarily described as being implemented in two devices on two hands, it is understood that in some examples that two devices can be implement on one hand (e.g., as illustrated in FIGS. **7**A-**7**B), and optionally integrated together in one device (e.g., in a glove).

FIG. **2** illustrates a block diagram of an example computing system **200** for skin-to-skin contact detection according to examples of the disclosure. Computing system **200** can include electrodes **202**A-**202**B, sense circuitry **203**, drive circuitry **204** to stimulate first body part with drive signals and measure sensed signals from a second body part. In some examples, the drive circuitry can include a voltage source or (constant) current source to generate the stimulation signal. In some examples, the stimulation signal can have a square waveform. In some examples, the stimulation signal can have a frequency greater than 500 kHz. In some examples, the stimulation signal can be between 1 MHz and 10 Mhz. The drive signal can be applied as a single-ended stimulus via one drive electrode or as a differential signal referenced to a second drive electrode (a floating or ground reference). In some examples, the sense circuitry can include an amplifier (with a feedback network between the input(s) and output(s)). In some examples, the amplifier can be single-ended with the inverting input coupled to the sense electrode and the non-inverting input coupled to a reference electrode (e.g., a ground electrode or a floating electrode). In some examples, the amplifier can be differential with the inverting input coupled to a first sense electrode and the non-inverting input coupled to a second sense electrode. A ground electrode can be coupled between the two sense electrodes. In some examples, the sense circuitry can include multiple amplifiers to sense signals received a multiple sense electrodes (in a single-ended or differential manner). Additionally, computing system **200** can include a digital signal processor (DSP) **206** to analyze and process the sensed signals for skin-to-skin contact detection (and/or gesture detection), and optionally memory **207** to store the data from sense circuitry **203** and/or store configuration data or instructions for DSP **206**. In some examples, computing system **200** can also include host processor **208**, program storage **210** and touch screen **212** (or other display) to perform display or other operations (e.g., in response to skin-to-skin contact). The components of computing system **200** are described in more detail below.

Host processor **208** can be connected to program storage **210** to execute instructions stored in program storage **210** (e.g., a non-transitory computer-readable storage medium). Host processor **208** can, for example, provide control and data signals to generate a display image on touch screen **212** (or other display devices), such as a display image of a user interface (UI). Host processor **208** can also receive outputs from DSP **206** (e.g., detection of skin-to-skin contact and/or gestures as touch input) and perform actions based on the outputs (e.g., selection of content or scroll content in a real-world, virtual reality or mixed reality environment, etc.). Host processor **208** can also receive outputs (touch input) from touch screen **212** (or a touch controller, not shown). The input (e.g., touch input from touch screen **212** or skin-to-skin contact/gesture input from DSP **206**) can be used by computer programs stored in program storage **210** to perform actions. The actions can include, but are not limited to, moving an object such as a cursor or pointer, scrolling or panning, adjusting control settings, opening a file or document, viewing a menu, making a selection, executing instructions, operating a peripheral device connected to the host device, answering a telephone call, placing a telephone call, terminating a telephone call, changing the volume or audio settings, storing information related to telephone communications such as addresses, frequently dialed numbers, received calls, missed calls, logging onto a computer or a computer network, permitting authorized individuals access to restricted areas of the computer or computer network, loading a user profile associated with a user's preferred arrangement of the computer desktop, permitting access to web content, launching a particular program, encrypting or decoding a message, and/or the like.

Host processor **208** can also perform additional functions that may not be related to touch processing and display.

Note that one or more of the functions described herein, including the analysis and processing of sensed signals for skin-to-skin contact detection, can be performed by firmware stored in memory **207** and executed by one or more processors (e.g., in DSP **206**), or stored in program storage **210** and executed by host processor **208**. The firmware can also be stored and/or transported within any non-transitory computer-readable storage medium for use by or in connection with an instruction execution system, apparatus, or device, such as a computer-based system, processor-containing system, or other system that can fetch the instructions from the instruction execution system, apparatus, or device and execute the instructions. In the context of this document, a "non-transitory computer-readable storage medium" can be any medium (excluding signals) that can contain or store the program for use by or in connection with the instruction execution system, apparatus, or device. The computer-readable storage medium can include, but is not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus or device, a portable computer diskette (magnetic), a random access memory (RAM) (magnetic), a read-only memory (ROM) (magnetic), an erasable programmable read-only memory (EPROM) (magnetic), a portable optical disc such a CD, CD-R, CD-RW, DVD, DVD-R, or DVD-RW, or flash memory such as compact flash cards, secured digital cards, USB memory devices, memory sticks, and the like.

The firmware can also be propagated within any transport medium for use by or in connection with an instruction execution system, apparatus, or device, such as a computer-based system, processor-containing system, or other system that can fetch the instructions from the instruction execution system, apparatus, or device and execute the instructions. In the context of this document, a "transport medium" can be any medium that can communicate, propagate or transport the program for use by or in connection with the instruction execution system, apparatus, or device. The transport medium can include, but is not limited to, an electronic, magnetic, optical, electromagnetic or infrared wired or wireless propagation medium.

It is to be understood that the computing system **200** is not limited to the components and configuration of FIG. **2**, but can include other or additional components (or omit components) in multiple configurations according to various examples. For example, an analog-to-digital converter (ADC) may be included as part of the sense circuitry **203** or between sense circuitry **203** and DSP **206** to convert the signals to the digital domain from the analog domain. As another example, touch screen **212** can be omitted and the input information from the analysis and processing by DSP **206** can be relayed to another device (e.g., a tablet, laptop, smartphone, computer, server, etc.) via wired or wireless connection that can include a display (e.g., a real-world or virtual or mixed reality display). Additionally, the components of computing system **200** can be included within a single device, or duplicated in part or in whole in multiple devices in a system (e.g., as illustrated in and described with reference to FIG. **1**A), or can be distributed between multiple devices. In some examples, the drive circuitry **204** and/or sense circuitry **203** can be in separated from the electrodes such that the drive/sense circuitry can be implemented in a device worn on the wrist (or a first part of the body, generally) and the electrodes can be worn on or near the fingers (e.g., as part of devices **708**A-**708**B) or palms (or a second different part of the body, generally).

Referring back to sense circuitry **203**, sense circuitry **203** can measure sensed signals and can be in communication with DSP **206** to provide the sensed signals to DSP **206**. In some examples, the sensed signals can be stored in memory **207** (e.g., acting as a data buffer) and the DSP **206** can acquire a buffered sample of the sensed signal waveform for analysis as described herein. In some examples, memory **207** can be implemented as part of DSP **206**. It should be understood that although a DSP is described, other processing circuits could be used to implement the analysis and processing described herein including a microprocessor, central processing unit (CPU), programmable logic device (PLD), and/or the like.

FIGS. **3**A-**3**B illustrate a proximity and a contact, respectively, between a first body part and a second body part according to examples of the disclosure. FIGS. **4**A-**4**B illustrate time domain representations **400**, **420** and frequency domain representations **402**, **422** of the sensed signal corresponding to the proximity or the contact according to examples of the disclosure. With or without contact or proximity, the stimulation generated by wearable device **308**A (e.g., corresponding to wearable device **150**, drive circuitry **204** and electrode **202**A) can propagate through the body via a first path **309**A, and can be received by wearable device **308**B (e.g., corresponding to wearable device **150**, sense circuitry **203** and electrode **202**B). A second path **309**B can be formed between wearable devices **308**A-**308**B due to contact or proximity between index finger **304** and/or right hand **302** and left hand **306**. The second path **309**B can cause changes to the sensed signal when contact or proximity between index finger **304** and left hand **306** occurs compared with the expected sensed signal from first path **309**A. FIG. **3**A illustrates that a second path **309**B can be formed between index finger **304** of right hand **302** in proximity to the palm of left hand **306** (e.g., a capacitive path). FIG. **3**B illustrates that a second path **309**B can be formed between index finger **304** of right hand **302** in contact with the palm of left hand **306**. The differences in the sensed waveform can be used to distinguish between skin-to-skin touch and skin-to-skin proximity.

In particular, as shown in FIGS. **4**A-**4**B, the amplitude of a frequency domain peak (e.g., peak **404** in FIG. **4**A and peak **424** in FIG. **4**B) can increase relative to reference peak **414** due to proximity or contact. Thus, an amplitude criterion can be used to detect skin-to-skin contact or proximity. For example, when the peak **404**, **424** exceeds a threshold **406**, **426**, the processing circuitry (e.g., DSP **206**) can detect contact or proximity. When peak **404**, **424** is below the threshold **406**, **426**, the processing circuitry (e.g., DSP **206**) can detect an absence of contact or proximity. In some examples, threshold **406** and threshold **426** illustrated in FIGS. **4**A-**4**B can be the same threshold, and one or more additional criteria can be used to differentiate between a touch event and a proximity event, as described in more detail below. Although shown as frequency domain thresholds, it should be understood that time domain thresholds can be used instead for time domain representations **400**, **420**, in some examples. In some examples, thresholds **406** and **426** can be different thresholds, and can be used to differentiate between a touch event and a proximity event. For example, the relative amplitude increase of peak **404** corresponding to a proximity event can be less than the amplitude increase of peak **424** corresponding to a touch event. A first, higher threshold can be set to detect a touch event, and a second, lower threshold can be set to detect a proximity event (e.g., when the amplitude is less than the first threshold but above the second threshold).

Relying on an amplitude criterion alone for differentiation between a touch and hover, however, may be inaccurate (false detection of touch and/or proximity events) because the amplitude may be a function of more than the distance between the two body parts (the difference between touch versus proximity). For example, the capacitive nature of the second path **309**B for a proximity event (without contact) can result in amplitude changes in the sensed signal that can be a function of the distance between two body parts (e.g., a distance between left hand **306** and index finger **304**/right hand **302**) and also the size of the body parts (e.g., the size of finger **304** as compared with the hand **302**). Likewise, the second path **309**B for a contact event can see amplitude changes based on the size contact, which can change based on the amount of force applied or the number of fingers making contact, for example. As a result, the approach of index finger **304** of right hand **302** and the proximity of right hand **302** and left hand **306** can result in an amplitude spike indicative of contact based on the amplitude threshold before index finger **304** makes contact with left hand **306**. This can cause a false detection of contact (e.g., detecting contact while the finger hovers), and even if contact occurs subsequently, the amplitude spike can mask the contact of index finger **304** (because the subsequent amplitude change may be a relatively small change compared with the proximity of the larger hands). Additionally, the timing of the moment of contact (even if it can be differentiated from proximity) may be imprecise.

As described herein, one or more additional criteria can be used to improve skin-to-skin contact or proximity detection. The one or more additional criteria can be related to other characteristics of the sensed signal. In some examples, the one or more additional criteria can correspond to whether the sensed signal has a distorted waveform or not. For example, time domain representation **400** corresponding to a proximity event can include distortion compared with the time domain representation corresponding to a touch event. The waveform can appear more similar to a saw-tooth waveform (distorted in FIG. **4**A) than a sine waveform (non-distorted in FIG. **4**B).

In some examples, the sensed signal can be correlated with a reference waveform. For example, a reference waveform can be a sine waveform corresponding to the sensed signal without contact or proximity events. For example, FIG. **5** illustrates a block diagram of a correlation circuit **500** according to examples of the disclosure. Correlator **502** of correlation circuit **500** can receive the sensed signal as a first input and a reference signal as a second signal, and can output a correlation of the input signals. The sensed signal can be provided by sense circuitry **203** directly or from storage in memory **207**, for example. The reference signal can be stored in memory **207**. Correlator **502** can be implemented, in some examples, in DSP **206**. When the correlation is high (above a threshold) between the sensed signal and the reference waveform, the processing circuitry (e.g., DSP **206**) can determine that the signal has a non-distorted waveform and/or detect a skin-to-skin contact event. When the correlation is low (below the threshold) between the sensed signal and the reference waveform, the processing circuitry (e.g., DSP **206**) can determine that the signal has a distorted waveform and/or detect a proximity event (without contact). In some examples, the reference waveform can be a saw-tooth waveform, and the conventions can be reversed with respect to the threshold (e.g., high correlation corresponds to distortion/proximity and low correlation corresponds to contact). It should be understood that the sensed signal and reference signal waveforms illustrated correspond to a square wave stimulation applied to the body. However, a different stimulation signal, sensed signal, and reference signal can be used in other examples. Although described as a correlation of the time domain representations, correlation can also be performed on frequency domain representations.

In some examples, a second criterion can be based on the width of a frequency domain peak. The width of the peak **404**, **424** ($W_1$, $W_2$ respectively) in the frequency domain can provide an indication of distortion. For example, a frequency domain representation of a pure sine wave at one frequency can be spike at that frequency. The narrower the width of the peak, the closer the sensed signal is to a sine wave. Thus, a width threshold can be used to determine whether the sensed signal is distorted or non-distorted based on how the width of the peak compares with the width threshold. When the width of peak **404**, **424** is below the threshold, the processing circuitry (e.g., DSP **206**) can determine that the signal has a non-distorted waveform and/or detect a skin-to-skin contact event. When the width of peak **404**, **424** is above the threshold, the processing circuitry (e.g., DSP **206**) can determine that the signal has a distorted waveform and/or detect a proximity event (without contact).

In some examples, the width of the peak can be measured at a fixed point (e.g., at a fixed amplitude point). For example, the width can be measured at the amplitude threshold **406**, **426**, or at another fixed point. In some examples, the width measurement can be normalized according to the amplitude of the peak (because peaks may widen as the amplitude increases). The amplitude-normalized width of the peak can be used with the amplitude-normalized width threshold in a similar manner as described above. In some examples, the width can be measured at a midpoint of the amplitude of the peak. In some examples, the amplitude-normalized width can be a ratio of the width at a fixed amplitude point to the maximum amplitude at the peak (e.g., scaled according to maximum amplitude) that can be compared to an amplitude-normalized width threshold.

In some examples, a second criterion can be based on an envelope of the sensed signal. As illustrated in FIG. **4**A, time domain representation **400** of the sensed signal includes an envelope **401** when a proximity event occurs, whereas as illustrated in FIG. **4**B the envelope can be essentially flattened when a contact event occurs. In some examples, the envelope can appear as a second, low-frequency peak **408** (relative to peak **404**) in the frequency domain representation **402**. When the amplitude of the second peak **408** is above a second amplitude threshold **412** (different and lower than amplitude threshold **406**), the processing circuitry (e.g., DSP **206**) can determine that the signal has a distorted waveform and/or detect a proximity event (without contact). When the second peak **408** is below threshold **412** (or non-existent), the processing circuitry (e.g., DSP **206**) can determine that the signal has a non-distorted waveform and/or detect a skin-to-skin contact event. Although described as frequency domain processing to identify the existence of the envelope in a beat frequency, alternatively processing can be performed in the time domain using the time domain representation of the envelope with a threshold based on the flatness of the envelope function.

In some examples, the second criterion can be based on a phase shift between the stimulation signal and the sensed signal. For example, in addition to receiving the sensed signal, the processing circuitry (e.g., DSP **206**) can also receive the drive signal. The processing circuitry can calculate the phase shift. Thus, a phase shift threshold can be used to determine whether the sensed signal is distorted or non-distorted based on how the calculated phase shift compares with the phase shift threshold. In some examples, when the phase shift is below the threshold, the processing circuitry (e.g., DSP **206**) can determine that the signal has a non-distorted waveform and/or detect a skin-to-skin contact event. When the phase shift is above the threshold, the processing circuitry (e.g., DSP **206**) can determine that the signal has a distorted waveform and/or detect a proximity event (without contact).

In some examples, the one or more criteria can include a third criterion. For example, when hands are within the field of view of a camera or cameras (not shown in FIG. **2**), processing circuitry can receive an input stream from the camera(s) and can estimate whether a contact or proximity event occurs using the camera input. In some examples, the camera may provide useful information about the size, position and orientation of the body parts, which may used to differentiate between an amplitude spike caused by large objects in proximity (e.g., two parallel palms) versus contact between two smaller objects (e.g., two finger tips). However, it is understood that the detection of and differentiation between skin-to-skin contact events and proximity events can be performed even without the use of a camera. Detection without the camera(s) may be particularly advantageous when one or both hands are out of the field of view of the camera(s) or one of the hands occludes the other of the hands (making optical detection of whether objects are touching or in proximity difficult).

FIG. **6** illustrates an example process **600** of skin-to-skin contact detection according to examples of the disclosure. At **605**, a sensed signal can be measured at a sense electrode (e.g., in contact with a first body part) in response to a drive signal applied by a drive electrode (e.g., in contact with a second body part, different from the first body part). In some examples, the drive signal can be a square wave with a frequency greater than 500 kHz. In some examples, the drive signal can be a square wave with a frequency between 1 MHz and 10 MHz. The sensed signal can be processed to detect skin-to-skin contact between two body parts. In some examples, the processing can include transforming the sensed signal from a time domain to a frequency domain (e.g., using a fast Fourier transform (FFT) or other suitable technique). In some examples, the processing can be performed entirely in the time domain without transforming the sensed signal to the frequency domain. The processing can include, at **610**, detecting contact between the first body part and the second body part in accordance with a determination that one or more criteria are met. The one or more criteria can include a first criterion that is met when an amplitude of the sensed signal exceeds an amplitude threshold (**615**). For example, determining whether the amplitude of the sensed signal exceeds the amplitude threshold for evaluating the first criterion can include comparing a peak identified in the frequency domain with the amplitude threshold (**620**). The one or more criteria can include a second criterion that is met when the sensed signal has a non-distorted waveform (**625**). Evaluating the second criterion can include, in some examples, comparing a width (in some examples an amplitude-normalized width) of the peak identified in the frequency domain with a width threshold (**630**). In accordance with a determination that the width is below the width threshold, determining that the sensed signal has the non-distorted waveform (the second criterion is met); and in accordance with a determination that the width is above the width threshold, determining that the sensed signal has a distorted waveform (the second criterion is not met). Evaluating the second criterion can include, in some examples, comparing a second, low-frequency peak identified in the frequency domain with a second amplitude threshold (**635**). In accordance with a determination that an amplitude of the second peak is below the second amplitude threshold (or in the absence of a second peak at the lower frequency), the processing circuitry can determine that the sensed signal has the non-distorted waveform (the second criterion is met). In accordance with a determination that the amplitude of the second peak is above the second amplitude threshold, the processing circuitry can determine that the sensed signal has a distorted waveform (the second criterion is not met). Evaluating the second criterion can include, in some examples, correlating the sensed signal with a reference signal (**640**). In accordance with a determination that the correlation is above a correlation threshold, determining that the sensed signal has the non-distorted waveform (the second criterion is met); and in accordance with a determination that the correlation is below the correlation threshold, determining that the sensed signal has a distorted waveform (the second criterion is not met). Process **600** can include, at **645**, detecting no contact between the first body part and the second body part in accordance with a determination that the one or more criteria are not met. Process **600** can include, at **650**, detecting a proximity without contact between the first body part and the second body part in accordance with a determination that first criterion is met and that the second criterion is not met.

It is understood that process **600** is an example process and that some of the processing mentioned above can be omitted or different processing may be performed. For example, the second criterion can be evaluated using processing of **630**, **635** or **640**. In some examples, the second criterion can met when multiple characteristics indicate non-distortion of the waveform (e.g., using processing of **630**, **635** and/or **640**).

In some examples, in addition to detecting skin-to-skin contact, skin-to-skin gestures can be detected as well. For example, the gestures enabled by skin-to-skin contact can include a tap, double tap, tap-and-hold (long press) and the like. In additional, other skin-to-skin contact gestures can be enabled based on movement subsequent to contact. For example, a sliding gesture can be detected based on skin-to-skin contact followed on-skin movement (e.g., prior to breaking skin-to-skin contact). In some examples, the skin-to-skin contact can be between two fingers on the same hand and the sliding gesture can be one finger sliding along a second finger on the same hand.

FIGS. **7A-7B** illustrate an example system for detection of a skin-to-skin gesture according to examples of the disclosure. In particular, FIGS. **7A-7B** illustrate a slide gesture between a first finger and a second finger of the same hand according to examples of the disclosure. The system can use a computing system including the same or similar components as described with reference to computing system **200**. FIGS. **8A-8C** illustrate time domain representations **800**, **810** and **820** and frequency domain representations **802**, **812**, **822** of the sensed signal corresponding to a finger-to-finger slide gesture according to examples of the disclosure. As illustrated in FIGS. **7A-7B**, a first wearable device **708A** (e.g., corresponding to wearable device **150**, drive circuitry **204** and electrode **202A**) can be coupled on a first finger, thumb **702**, and a second wearable device **708B** (e.g., corresponding to wearable device **150**, sense circuitry **203** and electrode **202B**) can be coupled on a second finger, index finger **704**. In some examples, the first wearable device **708A** can be disposed at or near (within a threshold distance of) the midpoint of thumb **702** (e.g., at or near the boundary between the distal bone and the proximal bone). In some examples, the first wearable device **708**A can be disposed at or near (within a threshold distance of) the base of thumb **702** (e.g., at or near the base of the metacarpal bone). In some examples, the second wearable device **708**B can be disposed at or near (within a threshold distance of) the base of index finger **704** (e.g., at or near the base of the metacarpal bone). In some examples, the first wearable device **708**A can be finger cuff and the second wearable device **708**B can be a ring. In some examples, the first and second wearable devices can be implemented as part of a glove.

With or without the contact between thumb **702** and index finger **704** shown in FIGS. **7**A-**7**B, the stimulation generated by wearable device **708**A can propagate through the body via a first path **709**A, and can be received by wearable device **708**B. A second path **709**B can be formed between wearable devices **708**A-**708**B due to contact between thumb **702** and index finger **704**. The second path **709**B can cause changes to the sensed signal compared with the expected sensed signal from first path **709**A when contact between thumb **702** and index finger **704** occurs. The changes to the sensed signal can be different depending upon the location of thumb **702** on index finger **704**. In particular, the closer the tip of thumb **702** is to the tip of index finger **704**, the higher the resistance of the second path and the lower the resulting amplitude spike due to contact. In a similar manner, the closer the tip of thumb **702** is to the base of index finger **704** (and wearable device **708**B), the lower the resistance of the second path and the larger the resulting amplitude spike due to contact. The changes in the sensed waveform (e.g., the difference in amplitude spike) can be used to identify movement of the contact location between the two fingers to identify a gesture (e.g., a slide gesture).

The detection of a movement gesture can include the detection of contact between the first finger and the second finger (e.g., thumb **702** and index finger **704**) and the detection of movement of the first finger along the second finger. The skin-to-skin contact of thumb **702** and index finger **704** can be detected via the one or more criteria (e.g., including an amplitude criterion and a non-distortion criterion) as discussed above and not repeated here for brevity. The movement of the contact can be detected by an increase or decrease in amplitude of the sensed signal (relative to the initial amplitude at contact) while skin-to-skin contact is maintained.

FIG. **8**A, for example, shows a frequency domain peak **806** corresponding to an initial contact (e.g., corresponding to the position of the fingers shown in FIG. **7**A). FIGS. **8**B and **8**C show the corresponding frequency domain peaks corresponding to a subsequent contact. FIG. **8**B, for example, shows a frequency domain peak **816** corresponding to a subsequent contact with a decreased amplitude peak indicative of movement away from the base of the finger (e.g., away from wearable device **708**B). FIG. **8**C, for example, shows a frequency domain peak **826** corresponding to a subsequent contact with an increased amplitude peak, indicative of movement toward the base of the finger (e.g., toward from wearable device **708**B, corresponding to the position of the fingers shown in FIG. **7**B). Detection of movement away from the base of the finger can correspond to a slide-away gesture, and detection of movement toward the base of the finger can correspond to a slide-toward gesture. The slide-away and slide-toward gestures can provide different inputs to a system. In some examples, the opposite directions of the slide inputs can correspond to opposite functionality (e.g., raising vs. lowering volume, moving a slider control in opposite directions, etc.). Although shown as frequency domain peaks, it should be understood that changes of amplitude in the time domain can be used instead for detection of movement and determining a direction of sliding.

In some examples, in order to detect a slide gesture, the amount of movement must be a threshold amount of movement in order to avoid false positives when a change in amplitude detected may due to other reasons other than a change in position (e.g., movement). For example, the other reasons may include a change in the size of the contact (e.g., by adding/removing fingers, pressing with more/less force with the finger, or changing the orientation of the finger) or adding moisture. Additionally or alternatively to requiring a threshold amount of movement to identify a movement gesture, in some examples, information from another sensor can be used to exclude these external causes. For example, camera(s) or other optical sensor(s), a force sensor or moisture sensor can be used to exclude other causes of the change in the amplitude of the finger. For example, camera(s)/optical sensor(s) can be used to exclude the change in number of fingers or the orientation or force of the finger. A force sensor can be used to exclude the change in applied force. A moisture sensor can be used to exclude a change in moisture.

Additionally or alternatively, in some examples, one or more additional sense electrodes and corresponding sense circuitry can be used to record multiple measurements along a finger (e.g., along index finger **704**). For example, an additional sense electrode and/or sense circuitry can be located at or near the distal bone of index finger **704** in addition to the electrode and/or sense circuitry at or near the base of the metacarpal bone of index finger **704**. In some examples, the slide of thumb **702** can be detected based on both the increase in the sensed signal at one sense electrode and the decrease in the sensed signal at the other sense electrode (or visa versa). In some examples, a differential measurement of the signal sensed from the two sense electrodes can be taken and the increase or decrease in the differential sensed signal can be used to detect a slide gesture. Such a differential measurement can improve rejection of alternative sources of signal amplitude change that may be common mode. For example, the change in amplitude due to applied force can appear as common mode at both sense electrodes and thus may be removed by a differential measurement (thereby reducing false positive detection of force as a gesture). It is understood that the differential measurement can provide a similar benefit to reducing false positives in skin-to-skin contact detection as described herein (e.g., not limited to reducing false positives for gesture detection).

Although movement gestures are described herein primarily with respect to finger-to-finger gestures, it should be understood that gestures may be detected using other body parts. For example, using the wearable devices of FIGS. **3**A-**3**B, a sliding gesture may be detected of one finger on one hand sliding along a second finger of the other hand. Additionally or alternatively, a sliding gesture may be detected of one finger along a palm of the other hand. In some examples, multiple sense electrodes (and corresponding sensing circuitry) can be located at different parts of the palm. For example, as shown in FIG. **3**B, four sensing electrodes **350**A-**350**D can be disposed at approximately four corners of the palm (e.g., in a glove for example) and can be sensed with corresponding sensing circuitry (e.g., co-located or located elsewhere, such as on the backside of the palm or in wearable device **308**B). Based on the relative changes in amplitude at the multiple sense electrodes, the processing circuitry can determine relative movement of the index finger **304**. As a result, multiple directional slide gestures can be enabled (e.g., slide up, slide down, slide left, slide right, diagonal slides, etc.). The sensed signals may be differential between sense electrodes to reduce common mode changes to signal amplitude due to applied force as described above.

FIG. **9** illustrates an example process **900** of skin-to-skin gesture detection according to examples of the disclosure. At **905**, a sensed signal can be measured at a sense electrode (e.g., in contact with a finger of a hand) in response to a drive signal applied by a drive electrode (e.g., in contact with a different finger of the same hand). In some examples, the drive signal can be a square wave with a frequency greater than 500 kHz. In some examples, the drive signal can be a square wave with a frequency between 1 MHz and 10 MHz. At **910**, the sensed signal can be processed to detect a skin-to-skin contact gesture in accordance with a determination that one or more criteria are met. In some examples, the processing can include, at **915**, detecting skin-to-skin contact between the two fingers in accordance with a determination that one or more contact criteria are met (e.g., as described above with respect to process **900**, and not repeated here for brevity). The processing can include, at **920**, detecting movement of a first finger along a second finger. Detecting movement of the first finger along the second finger can be based on an increase or decrease in amplitude of the sensed signal subsequent to and while contact is made between the first and second fingers (**925**). In some examples, the increase or decrease in amplitude (relative to the initial amplitude upon contact) can be based on the time domain sensed signal. In some examples, the increase or decrease in amplitude can be based on the frequency domain sensed signal (e.g., such that the processing may include a frequency domain transformation). An increase in amplitude from an initial amplitude upon contact can be indicative of a slide-toward gesture. A decrease in amplitude from the initial amplitude upon contact can be indicative of a slide-away gesture. In some examples, to reduce false positive detection of a gesture, that a threshold amount of increase or decrease in amplitude may be required (corresponding to a threshold amount of movement) to detect a gesture. In some examples, to reduce false positive detection of a gesture, an additional sensor may be used to exclude another source of the increase or decrease (e.g., a camera, force sensor, etc.). At **930**, in accordance with a determination that the one or more criteria are not met, the processing circuitry (e.g., DSP **206**) can forgo detecting the movement gesture. It is understood that process **900** is an example and that some of the processing mentioned above can be omitted or different processing may be performed.

Although examples of the disclosure presented above utilize at least two separate devices, including one device to generate a drive signal and another device to receive a sense signal, in other examples a single device (e.g., a ring) can be used to both generate a drive signal and receive a sense signal to detect contact and/or movement gestures between a finger of one hand and other body parts (e.g., other fingers or a thumb on the same hand, or the opposing hand). For example, a single device can detect a same-hand index finger and thumb touch (pinch or tap), an index finger and middle finger touch (pinch or tap), an index finger and middle finger touch followed by the addition of the thumb, an index finger and thumb touch followed by the addition of the middle finger, an index finger touching or tapping an opposite hand, or the thumb sliding along the index finger, and other gesture inputs. These gesture inputs can be detected and advantageously used to initiate operations using a single unobtrusive device, such as a ring, that may be commonly worn by a user for AR/VR and smart home operations. In still other examples, multiple devices, each capable of generating a different stimulation frequency and receiving a sense signal, can be utilized to unambiguously detect a finger touching an opposite hand, detect finger pinches using the thumb and multiple fingers of the same hand performed at different times or simultaneously, or detect gestures performed on two hands at different times or simultaneously.

FIG. **10** illustrates wearable device **1002** in the form of a ring according to examples of the disclosure. In the example of FIG. **10**, wearable device **1002** can include band mechanism **1018** electrically coupled to electronic jewel system (jewel) **1020**, although in other examples the jewel may be integrated within the band mechanism. Band mechanism **1018** can include ground electrode **1008**, drive electrode **1010**, and differential sense electrodes **1012** and **1014**. In some examples, these electrodes can be wrapped fully or almost entirely around the circumference of band mechanism **1018**. In other examples, the electrodes can be discrete electrode patches.

FIG. **11** is a system block diagram of wearable device **1102** according to examples of the disclosure. In the example of FIG. **11**, which may correspond to device **1002** in FIG. **10**, band mechanism **1118** can be electrically coupled to jewel **1120** through connections **1122**, which in some examples can be so-called "pogo pins," which are spring-loaded electrical connectors that press into, and make electrical contact with, conductive areas (lands or targets). Band mechanism **1118** can include ground electrode **1108**, drive electrode **1110**, and sense electrodes **1112** and **1114**.

Jewel **1120** can include controller **1124** coupled to memory and/or storage **1126**. Controller **1124** may correspond to DSP **206** described above and shown in FIG. **2**, and can include one or more processors capable of executing programs stored in memory **1126** to perform various functions. In some examples of the disclosure, controller **1124** can be connected to wireless transmitter or transceiver **1128** and one or more of inertial measurement unit (IMU) **1130** and haptics generator **1168**. Memory **1126** may correspond to memory **207** and/or program storage **210** described above and shown in FIG. **2**, and can include, but is not limited to, random access memory (RAM) or other types of memory or storage, watchdog timers and the like. In some examples, controller **1124** can include drive circuitry **1132** configured for applying a stimulation signal to drive electrode **1110**, and/or sense circuitry **1134** configured for sensing signals on sense electrodes **1112** and **1114**. Drive circuitry **1132** and sense circuitry **1134** may correspond to drive circuitry **204** and sense circuitry **203** described above and shown in FIG. **2**, respectively. In some examples, drive circuitry **1132** can be separate from controller **1124** include a frequency source or generator, an amplifier, a pulse-width modulator (PWM) or the like for generating a stimulation signal. In some examples, the stimulation signal can be in the range of about 100 kHz to 10 MHz, because higher frequencies can pass more easily through the capacitive nature of a user's body. In some examples, the stimulation signal can be in the range of 3.3V, which can be advantageously provided directly from some microcontrollers without the need for level shifters. In some examples, sense circuitry **1134** can be separate from controller **1124**, and can include an instrumentation amplifier that can perform differential sensing across two inputs, each coupled to a different sense electrode

**1112** and **1114**. In some examples, sensing can be performed at about 5 megasamples per second (MS/s). Controller **1124** can also be communicatively coupled to IMU **1130** to process signals from the IMU to determine parameters such as the angular rate, orientation, position, and velocity of wearable device **1102**. In some examples, controller **1124** can be communicatively coupled to haptics generator **1168** to initiate haptic feedback. Controller **1124** can also be communicatively coupled to wireless transmitter or transceiver **1128** to wirelessly send and receive data and other information. In some examples, wireless transmitter or transceiver **1128** can communicate wirelessly with desktop, laptop and tablet computing devices, smartphones, media players, other wearables such as watches and health monitoring devices, smart home control and entertainment devices, headphones and ear buds, and devices for computer-generated environments such as augmented reality, mixed reality, or virtual reality environments, and the like.

It should be apparent that the architecture shown in FIG. **11** is only one example architecture of band mechanism **1118** and jewel **1120**, and that the system could have more or fewer components than shown, or a different configuration of components. For example, some of the processing of jewel **1120** can be offloaded to separate devices such as those mentioned above, and the jewel can contain reduced controller functionality along with wireless transceiver **1128** to enable communication with those separate devices. Regardless of where they are located, the various components shown in FIG. **11** can be implemented in hardware, software, firmware or any combination thereof, including one or more signal processing and/or application specific integrated circuits.

FIG. **12**A illustrates hand **1200** with index finger **1204** supporting wearable device (e.g., ring) **1202** but not making contact with thumb **1206** according to examples of the disclosure. Although the example of FIG. **12**A shows device **1202** worn over index finger **1204**, it should be understood that in other examples device **1202** can be worn over other fingers such as middle finger **1216**, or over thumb **1206**. Device **1202** can include ground electrode **1208**, drive electrode **1210**, differential sense electrodes **1212** and **1214**, and other electronics not shown in FIG. **12**A. The order of ground electrode **1208**, drive electrode **1210**, and differential sense electrodes **1212** and **1214** need not be as shown in the example of FIG. **12**A, and in other examples the order of electrodes can be rearranged. In addition, in other examples a single-ended sense electrode can be utilized instead of differential sense electrodes **1212** and **1214**.

FIG. **12**B illustrates the hand of FIG. **12**A, except that index finger **1204** is now making contact with thumb **1206** according to examples of the disclosure.

FIG. **12**C illustrates sense output signal **1236** detected at device **1202** when index finger **1204** and thumb **1206** make and break contact as shown in FIGS. **12**B and **12**A according to examples of the disclosure. In the example of FIG. **12**C, sense output signal **1236** can be derived from an output of an instrumentation amplifier or other circuitry in device **1202**. For example, raw differential sense signals can be received at sense electrodes **1212** and **1214**, and sense output signal **1236** can be a selected peak of a Fast Fourier Transform (FFT) of the raw differential sense signals over time. In other examples, as an alternative to the FFT signal processing described above, an envelope of the raw differential signals can be captured over time. The amplitude modulated (AM) raw differential sense signals can be high-pass or band-pass filtered using a filter tuned to the stimulation signal frequency to remove RF frequencies that can distort the envelope. The filtered signals can then be rectified (e.g., using a rectifier circuit) and passed through an envelope detector (e.g., using an envelope detector circuit) to produce output signal **1236** without RF components. If multiple stimulation signal frequencies are employed, tuned filters, rectification and envelope detection can be separately performed at each frequency. Sense output signal **1236** can represent a "signature" of index finger **1204** coming into contact with thumb **1206**, and therefore detection of this signature can enable device **1202** to determine that an input gesture comprised of an index finger and thumb pinch has been received.

At time t**1**, index finger **1204** and thumb **1206** are not touching (the "break contact" condition as shown in FIG. **12**A), and a stimulation signal generated at drive electrode **1210** can propagate through index finger **1204** to differential sense electrodes **1212** and **1214**, producing voltage v**1** on sense output signal **1236**. At time t**2**, index finger **1204** and thumb **1206** contact each other (the "make contact" condition as shown in FIG. **12**B), which can provide grounding path **1238** between sense electrode **1214** and ground electrode **1208** through the thumb. Grounding path **1238** can result in a greater voltage difference between differential sense electrodes **1212** and **1214**, which can cause a resultant drop in the amplitude of sense output signal **1236** to v**2**. It should be noted that if thumb **1206** does not contact index finger **1204** but instead contacts the middle, ring or pinky fingers, grounding path **1238** would not exist and no voltage drop to v**2** would occur. At time t**4**, index finger **1204** and thumb **1206** separate (break contact), and because grounding path **1238** is no longer present, sense output signal **1236** returns to v**1**.

In some examples, circuitry within device **1202** (e.g., an analog-to-digital converter (ADC) or other circuitry) can be used to capture voltage levels and determine when the sense output is above, below or within various voltage thresholds, such as above voltage threshold vth**1** or below voltage threshold vth**2**. However, because voltage levels by themselves may not be sufficient to unambiguously identify a signature and determine that a particular gesture has occurred, in some examples time durations can also be monitored. Time durations can be determined and monitored using timing circuits and/or algorithms within device **1102** to evaluate signal transition times, shapes, durations, etc. For example, at time periods t**2** and t**4**, sense output signal **1236** can be evaluated to confirm that it transitions between expected voltage levels or crosses expected voltage thresholds within a certain time period (i.e., to detect expected steep transitions in the sense output signal as compared to gradual increases or decreases indicative of other behavior).

In the example of FIG. **12**C, when sense output signal **1236** is determined to be above vth**1** at time t**1**, a timer can be started (e.g., clock cycles can be counted, a capacitance can be charged, etc.) to confirm that the sense output signal remains above vth**1** for a first time period (e.g., until time t**2**), which can indicate a steady state "break" condition where index finger **1204** is not touching any other finger or thumb. At time t**2**, when sense output signal **1236** drops from v**1** to v**2**, it can be determined whether the sense output signal has fallen with a requisite steepness. When the voltage level is confirmed to have dropped below vth**2** with a requisite steepness, it can then be determined how long the sense output signal stays below voltage threshold vth**2**. In one example, when the sense output signal falls below voltage threshold vth**2** with a certain steepness and stays below voltage threshold vth**2** for a second time period until at least time t**3**, it can be determined that an index finger

**1204** and thumb **1206** contact (e.g., an index finger-thumb pinch) has occurred. When sense output signal **1236** returns to a voltage level above voltage threshold vth**1** at time t**4** with a requisite steepness and stays at that level for a third time period (e.g., to time t**5**), it can be determined that index finger **1204** and thumb **1206** have separated and returned to the steady state condition.

In some examples, the single device **1202** can be utilized to detect a slide gesture. For example, if thumb **1206** contacts index finger **1204** near the tip of the index finger, a certain voltage drop at sense output signal **1236** can be produced (e.g., a voltage drop to a level below vth**2**). However, if thumb **1206** contacts index finger at a location closer to device **1202**, a reduced voltage drop can be produced on sense output signal **1236** (but still below vth**2** in the example of FIG. **12**C). Thus, for example, if thumb **1206** initially touches the tip of index finger **1204**, then slides along the index finger towards device **1202**, the voltage at sense output signal **1236** may initially be at v**2**, but increase towards vth**2** as the thumb slides towards the device. In some examples, different voltages at sense output signal **1236** can be mapped to different locations along index finger **1204**, or voltage changes at the sense output can be converted to relative slide distances. In other examples, capturing the voltage level of sense output signal **1236** over time can allow for a determination of slide velocity or acceleration. These slide detection parameters can be used as control inputs for various operations.

Although FIG. **12**C illustrates a voltage drop when index finger **1204** contacts thumb **1206**, in other examples the amplitude of sense output signal **1236** may rise when the index finger contacts the thumb. In general, for the example of FIG. **12**C and any of the subsequently disclosed examples, the direction and amount of change in the sense output signal for a given gesture can be a function of the order in which the sense electrodes are arranged, and/or the configuration of the sense circuit within the device. Thus, it should be understood that the voltage levels and the direction of voltage changes described and illustrated herein are for purposes of illustration only, and that in other examples the voltage levels can be different, and signals can be "inverted." Accordingly, for example, a voltage above first voltage threshold vth**1** can be said to "satisfy" that threshold in FIG. **12**C, but if FIG. **12**C were inverted due to a different circuit configuration, a voltage below vth**1** can also be said to "satisfy" that threshold.

FIG. **13**A illustrates hand **1300** with index finger **1304** supporting wearable device (e.g., ring) **1302** but not making contact with middle finger **1316** according to examples of the disclosure. Device **1302** can include ground electrode **1308**, drive electrode **1310**, differential sense electrodes **1312** and **1314**, and other electronics not shown in FIG. **13**A. The order of ground electrode **1308**, drive electrode **1310**, and differential sense electrodes **1312** and **1314** need not be as shown in the example of FIG. **13**A, and in other examples the order of electrodes can be rearranged. In addition, in other examples a single-ended sense electrode can be utilized instead of differential sense electrodes **1312** and **1314**.

FIG. **13**B illustrates the hand of FIG. **13**A, except that index finger **1304** is now making contact with middle finger **1316** according to examples of the disclosure.

FIG. **13**C illustrates sense output signal **1344** detected at device **1302** when index finger **1304** and middle finger **1316** make and break contact as shown in FIGS. **13**B and **13**A according to examples of the disclosure. In the example of FIG. **13**C, sense output signal **1344** can be derived from an output of an instrumentation amplifier or other circuitry in device **1302**. For example, raw differential sense signals can be received at sense electrodes **1312** and **1314**, and sense output signal **1344** can be a selected peak of an FFT of the raw differential sense signals over time. Alternatively, filtering, rectification and envelope detection as described above can also be used to generate sense output signal **1344**. Sense output signal **1344** can represent a "signature" of index finger **1304** coming into contact with middle finger **1316**, and therefore detection of this signature can enable device **1302** to determine that an input gesture comprised of an index finger coming into contact with a middle finger has been received.

At time t**1**, index finger **1304** and middle finger **1316** are not touching (the "break contact" condition as shown in FIG. **13**A), and a stimulation signal generated at drive electrode **1310** can propagate through index finger **1304** to differential sense electrodes **1312** and **1314**, producing voltage v**1** on sense output signal **1344**. At time t**2**, index finger **1304** and middle finger **1316** contact each other (the "make contact" condition as shown in FIG. **13**B), which can provide grounding path **1340** between sense electrode **1314** and ground electrode **1308** through the middle finger. Grounding path **1340** can result in a greater voltage difference between differential sense electrodes **1312** and **1314**, which can cause a resultant drop in the amplitude of sense output signal **1344** to v**2**. After time t**2**, sense output signal **1344** can gradually increase over time in what can appear to be a roughly logarithmic curve until time t**4**, when index finger **1304** and middle finger **1316** separate (break contact). In some examples, this gradual voltage increase can be caused by a gradual increase in moisture between index finger **1304** and middle finger **1316**. In other examples, this gradual voltage increase can be caused by a gradual increase in resistance or impedance between index finger **1304** and middle finger **1316**. At time t**4**, after a temporary downward voltage spike at **1342**, the amplitude of sense output signal **1344** returns to v**1** because grounding path **1340** is no longer present.

In some examples, circuitry within device **1302** (e.g., an ADC or other circuitry) can be used to capture voltage levels and determine when the sense output is above, below or within various voltage thresholds, such as above voltage threshold vth**1** or below voltage threshold vth**2**. However, because voltage levels by themselves may not be sufficient to unambiguously identify a signature and determine that a particular gesture has occurred, in some examples time durations can also be monitored. Time durations can be determined and monitored using timing circuits and/or algorithms within device **1302** to evaluate signal transition times, shapes, durations, etc.

In the example of FIG. **13**C, when sense output signal **1344** is determined to be above vth**1** at time t**1**, a timer can be started (e.g., clock cycles can be counted, a capacitance can be charged, etc.) to confirm that the sense output signal remains above vth**1** for a first time period (e.g., until time t**2**), which can indicate a steady state "break" condition where index finger **1304** is not touching any other finger or thumb. At time t**2**, when sense output signal **1344** drops from v**1** to v**2**, it can be determined whether the sense output signal has fallen with a requisite steepness. When the voltage level is confirmed to have dropped below vth**2** with a requisite steepness, it can then be determined how long the sense output signal stays below voltage threshold vth**2**. In one example, when the sense output falls below voltage threshold vth**2** with a requisite steepness, but only for a second time period less than the time from t**2** to t**3**, it can be determined that index finger **1304** and middle finger **1316** contact has occurred. When sense output signal **1344** returns to a voltage level above voltage threshold vth**1** at time t**4** with a requisite steepness and stays at that level for a third time period, it can be determined that index finger **1304** and middle finger **1316** have separated and returned to the steady state condition.

FIG. **14**A illustrates hand **1400** with index finger **1404** supporting wearable device (e.g., ring) **1402** and in contact with middle finger **1416** according to examples of the disclosure. Device **1402** can include ground electrode **1408**, drive electrode **1410**, differential sense electrodes **1412** and **1**, and other electronics not shown in FIG. **14**A. Grounding path **1440** can be generated between sense electrode **1414** and ground electrode **1408** through middle finger **1416**. The order of ground electrode **1408**, drive electrode **1410**, differential sense electrodes **1412** and **1414** need not be as shown in the example of FIG. **14**A, and in other examples the order of electrodes can be rearranged. In addition, in other examples a single-ended sense electrode can be utilized instead of differential sense electrodes **1412** and **1414**.

FIG. **14**B illustrates the hand of FIG. **14**A, except that thumb **1406** is now making contact with already touching index finger **1404** and middle finger **1416** according to examples of the disclosure. Grounding path **1448** can be formed between sense electrode **1414** and ground electrode **1408** through thumb **1406**.

FIG. **14**C illustrates sense output signal **1446** detected at device **1402** when thumb **1406** makes and breaks contact with already touching index finger **1404** and middle finger **1416** according to examples of the disclosure. In the example of FIG. **14**C, sense output signal **1446** can be derived from an output of an instrumentation amplifier or other circuitry in device **1402**. For example, raw differential sense signals can be received at sense electrodes **1412** and **1414**, and sense output signal **1446** can be a selected peak of an FFT of the raw differential sense signals over time. Alternatively, filtering, rectification and envelope detection as described above can also be used to generate sense output signal **1446**. Sense output signal **1446** can represent a "signature" of thumb **1406** coming into contact with already touching index finger **1404** and middle finger **1416**, and therefore detection of this signature can enable device **1402** to determine that an input gesture comprised of a thumb coming into contact with already touching index and middle fingers has been received.

At time t**1**, index finger **1404** and middle finger **1416** are not touching (as shown in FIG. **13**A), and a stimulation signal generated at drive electrode **1410** can propagate through index finger **1404** to differential sense electrodes **1412** and **1414**, producing voltage v**1** on sense output signal **1446**. At time t**2**, index finger **1404** and middle finger **1416** contact each other (as shown in FIG. **14**A), which can provide grounding path **1440** between sense electrode **1414** and ground electrode **1408** through the middle finger. Grounding path **1440** (hidden in FIG. **14**B) can result in a greater voltage difference between differential sense electrodes **1412** and **1414**, which can cause a resultant drop in the amplitude of sense output signal **1446** to v**2**. After time t**2**, sense output signal **1446** can increase over time in what can appear to be a roughly logarithmic curve until time t**4**, when thumb **1406** comes into contact with touching index finger **1404** and middle finger **1416**.

At time t**4**, with thumb **1406** now in contact with touching index finger **1404** and middle finger **1416**, an abrupt rise in the amplitude of sense output signal **1446** to v**3** (above vth**3**) can occur, where v**3** can be greater than v**1**. At time t**5**, thumb **1406** can separate from touching index finger **1404** and middle finger **1416**, resulting in sense output signal **1446** returning to a voltage level between vth**1** and vth**2**.

In some examples, circuitry within device **1402** (e.g., ADC or other circuitry) can be used to capture voltage levels and determine when the sense output is above, below or within various voltage thresholds vth**1**, vth**2** or vth**3**. However, because voltage levels by themselves may not be sufficient to unambiguously identify a signature and determine that a particular gesture has occurred, in some examples time durations can also be monitored. Time durations can be determined and monitored using timing circuits and/or algorithms within device **1402** to evaluate signal transition times, shapes, durations, etc.

In the example of FIG. **14**C, when sense output signal **1446** is determined to be above vth**1** at time t**1**, a timer can be started (e.g., clock cycles can be counted, a capacitance can be charged, etc.) to confirm that the sense output signal remains above vth**1** for a first time period (e.g., until time t**2**), which can indicate a steady state "break" condition where index finger **1404** is not touching any other finger or thumb. At time t**2**, when sense output signal **1446** drops from v**1** to v**2**, it can be determined whether the sense output signal has fallen with a requisite steepness. When the voltage level is confirmed to have fallen below voltage threshold vth**2** with a requisite steepness, it can then be determined how long the sense output signal stays below voltage threshold vth**2**. In one example, when the amplitude of sense output signal **1446** falls below voltage threshold vth**2** with a requisite steepness, but only for a second timer period less than the time from t**2** to t**3**, it can be determined that index finger **1404** and middle finger **1416** contact has occurred. While sense output signal **1446** is between vth**1** and vth**2** (indicative of touching index finger **1404** and middle finger **1416**), if the amplitude of sense output signal **1446** then rises at time t**4** with a requisite steepness to a voltage v**3** such that it exceeds voltage threshold vth**3**, it can further be determined that thumb **1406** has been added to the touching index and middle fingers. If sense output signal **1446** then drops back down at time t**5** to between vth**1** and vth**2** with a requisite steepness, it can further be determined that thumb **1406** has broken contact with touching index finger **1404** and middle finger **1416**.

FIG. **15**A illustrates hand **1500** with index finger **1504** supporting wearable device (e.g., ring) **1502** and making contact with thumb **1506** according to examples of the disclosure. Device **1502** can include ground electrode **1508**, drive electrode **1510**, differential sense electrodes **1512** and **1514**, and other electronics not shown in FIG. **15**A. The order of ground electrode **1508**, drive electrode **1510**, differential sense electrodes **1512** and **1514** need not be as shown in the example of FIG. **15**A, and in other examples the order of electrodes can be rearranged. In addition, in other examples a single-ended sense electrode can be utilized instead of differential sense electrodes **1512** and **1514**.

FIG. **15**B illustrates the hand of FIG. **15**A, except that middle finger **1516** is now making contact with already touching index finger **1504** and thumb **1506** according to examples of the disclosure.

FIG. **15**C illustrates sense output signal **1550** detected at device **1502** when middle finger **1516** makes and breaks contact with already touching index finger **1504** and thumb **1506** according to examples of the disclosure. In the example of FIG. **15**C, sense output signal **1550** can be derived from an output of an instrumentation amplifier or other circuitry in device **1502**. For example, raw differential sense signals can be received at sense electrodes **1512** and **1514**, and sense output signal **1550** can be a selected peak of an FFT of the raw differential sense signals over time. Alternatively, filtering, rectification and envelope detection as described above can also be used to generate sense output signal **1550**. Sense output signal **1550** can represent a "signature" of middle finger **1516** coming into contact with already touching index finger **1504** and thumb **1506**, and therefore detection of this signature can enable device **1502** to determine that an input gesture comprised of a middle finger coming into contact with already touching index finger and thumb has been received.

At time t**1**, index finger **1504** and thumb **1506** are not touching, and a stimulation signal generated at drive electrode **1510** can propagate through index finger **1504** to differential sense electrodes **1512** and **1514**, producing voltage v**1** on sense output signal **1550** at the output of the sense circuitry in device **1502**. At time t**2**, index finger **1504** and thumb **1506** contact each other (as shown in FIG. **15**A), which can provide a grounding path between sense electrode **1514** and ground electrode **1508** through the thumb. The grounding path can result in a greater voltage difference between differential sense electrodes **1512** and **1514**, which can cause a resultant drop in the amplitude of sense output signal **1550** to v**2**. At time t**3**, middle finger **1516** can come into contact with touching index finger **1504** and thumb **1506**, and an abrupt rise in the amplitude of sense output signal **1550** to v**3** can occur. At time t**4**, middle finger **1516** can separate from touching index finger **1504** and thumb **1506**, resulting in the amplitude of sense output signal **1550** returning to a voltage level less than vth**2**.

In some examples, circuitry within device **1502** (e.g., ADC or other circuitry) can be used to capture voltage levels and determine when the sense output is above, below or between any of voltage thresholds vth**1**, vth**2** or vth**3**. However, because voltage levels by themselves may not be sufficient to unambiguously identify a signature and determine that a particular gesture has occurred, in some examples time durations can also be monitored.

In the example of FIG. **15**C, when sense output signal **1550** is determined to be above vth**1** and time t**1**, a timer can be started (e.g., clock cycles can be counted, a capacitance can be charged, etc.) to confirm that the sense output signal remains above vth**1** for a first time period (e.g., until time t**2**), which can indicate a steady state "break" condition where index finger **1504** is not touching any other finger or thumb. At time t**2**, when sense output signal **1550** drops from v**1** to v**2**, it can be determined whether the sense output signal has fallen with a requisite steepness. When the voltage level is confirmed to have dropped below voltage threshold vth**2** with a requisite steepness, it can then be determined how long the sense output stays below voltage threshold vth**2**. In one example, when the sense output signal falls below voltage threshold vth**2** with a certain steepness and stays below voltage threshold vth**2** for a second time period until at least time t**3**, it can be determined that an index finger **1504** and thumb **1506** contact (e.g., an index finger-thumb pinch) has occurred. At time t**4**, middle finger **1516** can come into contact with touching index finger **1504** and thumb **1506**, and an abrupt rise in sense output signal **1550** to v**3** (greater than v**1**) can occur. At time t**5**, middle finger **1516** can separate from touching index finger **1504** and thumb **1506**, resulting in the amplitude of sense output signal **1550** returning to a voltage level less than vth**2**.

FIG. **16**A illustrates left hand **1600** with index finger **1604** supporting wearable device (e.g., ring) **1602** and making contact with opposite, right hand **1652** according to examples of the disclosure. Although the example of FIG. **16**A shows device **1602** over index finger **1604**, it should be understood that in other examples device **1602** can be worn over other fingers such as middle finger **1616**. Device **1602** can include ground electrode **1608**, drive electrode **1610**, differential sense electrodes **1612** and **1614**, and other electronics not shown in FIG. **16**A. The order of ground electrode **1608**, drive electrode **1610**, differential sense electrodes **1612** and **1614** need not be as shown in the example of FIG. **16**A, and in other examples the order of electrodes can be rearranged. In addition, in other examples a single-ended sense electrode can be utilized instead of differential sense electrodes **1612** and **1614**.

Although index finger **1604** in the example of FIG. **16**A is not touching thumb **1606** (as in FIG. **12**B), nevertheless the sense output signal "signature" can be similar to that shown in FIG. **12**C, because a similar grounding path **1654** (similar to grounding path **1238** in FIG. **12**B) can be present between sense electrode **1614** and ground electrode **1608** via the user's body. Accordingly, in some examples a separate camera can be employed to distinguish between the gesture of FIG. **12**B and the gesture of FIG. **16**A.

FIG. **16**B illustrates left hand **1600** with index finger supporting wearable device (e.g., ring) **1602**A and also right hand **1652** with index finger **1656** supporting wearable device (e.g., ring) **1602**B according to examples of the disclosure. Although the example of FIG. **16**B shows device **1602**A over index finger **1604** of left hand **1600**, and device **1602**B over index finger **1656** of right hand **1652**, it should be understood that in other examples the devices can be worn over other fingers on the left and right hands. Having devices **1602**A and **1602**B on both hands can enable a user to provide the gesture inputs described above with either hand, either separately or simultaneously.

In addition, in some examples, the stimulation frequency applied to the drive electrode of device **1602**A can be different from the stimulation frequency applied to the drive electrode of device **1602**B. By providing different stimulation frequencies on devices **1602**A and **1602**B, the ambiguity presented by receiving a similar output waveform "signature" from the index finger-thumb gesture of FIG. **12**B and also the index finger-opposite hand gesture of FIG. **16**A can be resolved without requiring a camera. For example, if device **1602**A generates a 5 MHz stimulation signal and device **1602**B generates an 8 MHz stimulation signal, then an index finger-thumb input gesture generated by device **1602**A on left hand **1600** can produce the sense output signature of FIG. **12**C at 5 MHz at device **1602**A. However, if index finger **1604** of left hand **1600** touches right hand **1652**, the 8 MHz stimulation signal generated by device **1602**B of the right hand can couple onto device **1602**A of the left hand, and the sense output signal at device **1602**A can be a composite signal having both 5 MHz and 8 MHz components. These frequency components can be separately detected to unambiguously determine that index finger **1604** of left hand **1600** is touching right hand **1652** (rather than left thumb **1606**).

FIG. **16**C illustrates left hand **1600** with index finger **1604** supporting wearable device (e.g., ring) **1602**A and middle finger **1616** supporting wearable device (e.g., ring) **1602**B according to examples of the disclosure. Wearing devices on two fingers of the same hand can allow a user to perform additional input gestures using a single hand, such as a middle finger-thumb pinch gesture similar to the index finger-thumb pinch gesture of FIGS. **12**A-**12**C. Although FIG. **16**C shows devices on index finger **1604** and middle finger **1616**, in other examples devices can be worn on any combination of index, middle, ring, and pinky fingers to provide additional input gesture possibilities.

FIG. **17** illustrates a flowchart for detecting input gestures using one or more devices according to examples of the disclosure. In the example of FIG. **17**, at block **1758** one or more devices can be worn on one or more fingers of one or both hands. At block **1760**, each device can generate a stimulation signal at a different frequency. At block **1762**, sense output signal amplitudes can be captured at each device over time. At block **1764**, the amplitudes of sense output signals can be compared to various voltage and time thresholds/windows to identify an input gesture signature and the gesture being performed. At block **1766**, different operations can be initiated, controlled or performed based on the identified gesture.

Therefore, according to the above, some examples of the disclosure are directed to a system. The system can comprise sense circuitry and processing circuitry. The sense circuitry can be coupled to a sense electrode, the sense circuitry configured to sense a signal at the sense electrode in response to a drive signal applied to a first body part. The sense electrode can be configured to contact a second body part, different from the first body part. The processing circuitry can be configured to: in accordance with a determination that one or more criteria are met, detect contact between the first body part and the second body part; and in accordance with a determination that the one or more criteria are not met, detect no contact between the first body part and the second body part. The one or more criteria can include a first criterion that is met when an amplitude of the sensed signal exceeds an amplitude threshold and a second criterion that is met when the sensed signal has a non-distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the processing circuitry can be further configured to: in accordance with a determination that the first criteria is met and that the second criterion is not met, detecting proximity of the first body part to the second body part without contact between the first body part and the second body part. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the system can further comprise: drive circuitry coupled to a drive electrode. The drive circuitry can be configured to apply the drive signal to the drive electrode, and the drive electrode can be configured to contact the first body part. Additionally or alternatively to one or more of the examples disclosed above, in some examples, determining whether the amplitude of the sensed signal exceeds the amplitude threshold can comprise identifying a peak in a frequency domain representation of the sensed signal and comparing the peak identified in the frequency domain with the amplitude threshold in the frequency domain. Additionally or alternatively to one or more of the examples disclosed above, in some examples, determining whether the sensed signal has a non-distorted waveform can comprise comparing a width of the peak identified in the frequency domain with a width threshold. In accordance with a determination that the width is below the width threshold, determining that the sensed signal has the non-distorted waveform; and in accordance with a determination that the width is above the width threshold, determining that the sensed signal has a distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, determining whether the sensed signal has a non-distorted waveform can comprise comparing an amplitude-normalized width of the peak identified in the frequency domain with a width threshold. In accordance with a determination that the amplitude-normalized width is below the width threshold, determining that the sensed signal has the non-distorted waveform; and in accordance with a determination that the amplitude-normalized width is above the width threshold, determining that the sensed signal has a distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, determining whether the received sensed has a non-distorted waveform can comprise identifying a second peak in the frequency domain representation of the sensed signal, the second peak at a lower frequency than the first peak, and comparing the second peak identified in the frequency domain with a second amplitude threshold in the frequency domain. In accordance with a determination that an amplitude of the second peak is below the second amplitude threshold, determining that the sensed signal has the non-distorted waveform; and in accordance with a determination that the amplitude of the second peak is above the second amplitude threshold, determining that the sensed signal has a distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, determining whether the sensed signal has a non-distorted waveform can comprise correlating the sensed signal with a reference signal. In accordance with a determination that the correlation is above a correlation threshold, determining that the sensed signal has the non-distorted waveform; and in accordance with a determination that the correlation is below the correlation threshold, determining that the sensed signal has a distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the drive signal can have a frequency greater than 500 kHz or between 1-10 MHz. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the drive signal can be a square wave. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the first body part can comprise a first wrist and hand and the second body part can comprise a second wrist and hand. Additionally or alternatively to one or more of the examples disclosed above, in some examples, detecting contact between the first body part and the second body part can comprise detecting contact between a finger of a first hand and a palm or a finger of a second hand.

Some examples of the disclosure are directed to a method. The method can comprise: at a device comprising sense circuitry and processing circuitry: sensing, via sense circuitry, a signal at a sense electrode configured to contact a first body part, in response to a drive signal applied by a drive electrode configured to contact a second body part, different from the first body part; and in accordance with a determination that one or more criteria are met, detecting contact between the first body part and the second body part; and in accordance with a determination that the one or more criteria are not met, detecting no contact between the first body part and the second body part. The one or more criteria can include a first criterion that is met when an amplitude of the sensed signal exceeds an amplitude threshold and a second criterion that is met when the sensed signal has a non-distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the method can further comprise: in accordance with a determination that the first criteria is met and that the second criterion is not met, detecting proximity of the first body part to the second body part without contact between the first body part and the second body part. Additionally or alternatively to one or more of the examples disclosed above, in some examples, determining whether the amplitude of the sensed signal exceeds the amplitude threshold can comprise identifying a peak in a frequency domain representation of the sensed signal and comparing the peak identified in the frequency domain with the amplitude threshold in the frequency domain. Additionally or alternatively to one or more of the examples disclosed above, in some examples, determining whether the sensed signal has a non-distorted waveform can comprise comparing a width of the peak identified in the frequency domain with a width threshold. In accordance with a determination that the width is below the width threshold, determining that the sensed signal has the non-distorted waveform; and in accordance with a determination that the width is above the width threshold, determining that the sensed signal has a distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, determining whether the sensed signal has a non-distorted waveform can comprise comparing an amplitude-normalized width of the peak identified in the frequency domain with a width threshold. In accordance with a determination that the amplitude-normalized width is below the width threshold, determining that the sensed signal has the non-distorted waveform; and in accordance with a determination that the amplitude-normalized width is above the width threshold, determining that the sensed signal has a distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, determining whether the received sensed has a non-distorted waveform can comprise identifying a second peak in the frequency domain representation of the sensed signal, the second peak at a lower frequency than the first peak, and comparing the second peak identified in the frequency domain with a second amplitude threshold in the frequency domain. In accordance with a determination that an amplitude of the second peak is below the second amplitude threshold, determining that the sensed signal has the non-distorted waveform; and in accordance with a determination that the amplitude of the second peak is above the second amplitude threshold, determining that the sensed signal has a distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, determining whether the sensed signal has a non-distorted waveform can comprise correlating the sensed signal with a reference signal. In accordance with a determination that the correlation is above a correlation threshold, determining that the sensed signal has the non-distorted waveform; and in accordance with a determination that the correlation is below the correlation threshold, determining that the sensed signal has a distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the drive signal can have a frequency greater than 500 kHz or between 1-10 MHz. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the drive signal can be a square wave. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the first body part can comprise a first wrist and hand and the second body part can comprise a second wrist and hand. Additionally or alternatively to one or more of the examples disclosed above, in some examples, detecting contact between the first body part and the second body part can comprise detecting contact between a finger of a first hand and a palm or a finger of a second hand. Some examples of the disclosure are directed to a non-transitory computer readable storage medium. The non-transitory computer readable storage medium can store instructions (e.g., one or more programs), which when executed by one or more processors of an electronic device, can cause the electronic device to perform any of the above methods.

Some examples of the disclosure are directed to a system. The system can comprise sense circuitry and processing circuitry. The sense circuitry can be coupled to a sense electrode, the sense circuitry configured to sense a signal at the sense electrode in response to a drive signal applied to a first finger of a hand, and the sense electrode configured to contact a second finger of the hand, different from the first finger. The processing circuitry can be configured to: in accordance with a determination that one or more criteria are met, detect a movement gesture; and in accordance with a determination that the one or more criteria are not met, forgo detecting the movement gesture. The one or more criteria can include a first criterion indicative of contact between the first finger and the second finger and a second criterion indicative of movement of the first finger along the second finger. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the first criterion can be met when an amplitude of the sensed signal exceeds an amplitude threshold. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the first criterion can be met when an amplitude of the sensed signal exceeds an amplitude threshold and when the sensed signal has a non-distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the second criterion can be met when an amplitude of the sensed signal increases or decreases by a threshold amount subsequent to and while the first criterion is met. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the movement gesture can be a slide gesture. Additionally or alternatively to one or more of the examples disclosed above, in some examples, in accordance with a determination that an amplitude of the sensed signal increases from an initial value (by a threshold amount), the detected movement gesture can be a slide-toward gesture. Additionally or alternatively to one or more of the examples disclosed above, in some examples, in accordance with a determination that an amplitude of the sensed signal decreases from an initial value (by a threshold amount), the detected movement gesture can be a slide-away gesture. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the first electrode can be configured to contact the first finger at or near the base of the first finger and the second electrode can be configured to contact the second finger at or near the base of the second finger. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the first finger can be a thumb and the second finger can be an index finger. The first electrode can be configured to contact the first finger at or near the middle of the thumb, and the second electrode can be configured to contact the index finger at or near the base of the index finger.

Some examples of the disclosure are directed to a method. The method can comprise: at a device comprising sense circuitry and processing circuitry: sensing, via sense circuitry, a signal at a sense electrode in response to a drive signal applied by a drive electrode configured to contact a first finger of a hand, the sense electrode configured to contract a second finger of the hand, different from the first finger; and in accordance with a determination that one or more criteria are met, detect a movement gesture; and in accordance with a determination that the one or more criteria are not met, forgo detecting the movement gesture. The one or more criteria can include a first criterion indicative of contact between the first finger and the second finger and a second criterion indicative of movement of the first finger along the second finger. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the first criterion can be met when an amplitude of the sensed signal exceeds an amplitude threshold. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the first criterion can be met when an amplitude of the sensed signal exceeds an amplitude threshold and when the sensed signal has a non-distorted waveform. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the second criterion can be met when an amplitude of the sensed signal increases or decreases by a threshold amount subsequent to and while the first criterion is met. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the movement gesture can be a slide gesture. Additionally or alternatively to one or more of the examples disclosed above, in some examples, in accordance with a determination that an amplitude of the sensed signal increases from an initial value (by a threshold amount), the detected movement gesture can be a slide-toward gesture. Additionally or alternatively to one or more of the examples disclosed above, in some examples, in accordance with a determination that an amplitude of the sensed signal decreases from an initial value (by a threshold amount), the detected movement gesture can be a slide-away gesture. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the first electrode can be configured to contact the first finger at or near the base of the first finger and the second electrode can be configured to contact the second finger at or near the base of the second finger. Additionally or alternatively to one or more of the examples disclosed above, in some examples, the first finger can be a thumb and the second finger can be an index finger. The first electrode can be configured to contact the first finger at or near the middle of the thumb, and the second electrode can be configured to contact the index finger at or near the base of the index finger. Some examples of the disclosure are directed to a non-transitory computer readable storage medium. The non-transitory computer readable storage medium can store instructions (e.g., one or more programs), which when executed by one or more processors of an electronic device, can cause the electronic device to perform any of the above methods.

Some examples of the disclosure are directed to a wearable device for detecting gestures, comprising drive circuitry coupled to a drive electrode and configured to generate a stimulation signal, the drive electrode positioned at a first location in the device for contacting a first finger of a first hand, sense circuitry coupled to at least one sense electrode and configured to generate a sense output signal based on one or more sense signals received at the at least one sense electrode in response to the stimulation signal, the at least one sense electrode positioned at a second location in the device for contacting the first finger of the first hand, and a processor communicatively coupled to the drive and sense circuitry and configured for capturing an amplitude of the sense output signal over time, and in accordance with a determination that a first set of amplitude and time criteria are met, detecting a making of contact of the first finger with an adjacent second finger of the first hand. Additionally or alternatively to one or more of the examples disclosed above, in some examples the processor is further configured for, in accordance with a determination that a second set of amplitude and time criteria are met following the determination that the first set of amplitude and time criteria are met, detecting a breaking of contact of the first finger and the adjacent second finger. Additionally or alternatively to one or more of the examples disclosed above, in some examples the processor is further configured for, in accordance with a determination that a second set of amplitude and time criteria are met following the determination that the first set of amplitude and time criteria are met, detecting a making of contact of a thumb of the first hand with the touching first and second fingers. Additionally or alternatively to one or more of the examples disclosed above, in some examples the processor is further configured for, in accordance with a determination that a third set of amplitude and time criteria are met following the determination that the second set of amplitude and time criteria are met, detecting a breaking of contact of the thumb of the first hand with the touching first finger and second fingers. Additionally or alternatively to one or more of the examples disclosed above, in some examples the determination that the first set of amplitude and time criteria are met comprises determining that the sense output signal satisfies a first voltage threshold during a first time period between a first time and a second time, determining that the sense output signal changes to satisfy a second voltage threshold at the second time, determining that the sense output signal changes and approaches the second voltage threshold while continuing to satisfy the second voltage threshold during a portion of a second time period between the second time and a third time, and determining that the sense output signal no longer satisfies the second voltage threshold at the third time. Additionally or alternatively to one or more of the examples disclosed above, in some examples the processor is further configured for, in accordance with a determination that a second set of amplitude and time criteria are met following the determination that the first set of amplitude and time criteria are met, detecting a breaking of contact of the first finger and the adjacent second finger, wherein the determination that the second set of amplitude and time criteria are met comprises determining that the sense output signal changes to satisfy the first voltage threshold at a fourth time. Additionally or alternatively to one or more of the examples disclosed above, in some examples the processor is further configured for, in accordance with a determination that a second set of amplitude and time criteria are met following the determination that the first set of amplitude and time criteria are met, detecting a making of contact of a thumb of the first hand with the touching first and second fingers, wherein the determination that the second set of amplitude and time criteria are met comprises determining that the sense output signal changes to satisfy a third voltage threshold at a fourth time. Additionally or alternatively to one or more of the examples disclosed above, in some examples the processor is further configured for, in accordance with a determination that a third set of amplitude and time criteria are met following the determination that the second set of amplitude and time criteria are met, detecting a breaking of contact of the thumb and the touching first finger and second fingers, wherein the determination that the third set of amplitude and time criteria are met comprises determining that the sense output signal changes to a voltage between the first voltage threshold and the second voltage threshold at a fifth time. Additionally or alternatively to one or more of the examples disclosed above, in some examples the at least one sense electrode comprises two differential sense electrodes, and the device further comprises a ground electrode positioned at a third location in the device for contacting the first finger of the first hand, wherein the ground electrode, the drive electrode, and the two differential sense electrodes are arranged in order in the device.

Some examples of the disclosure are directed to a method for detecting gestures, the method performed at a wearable device including drive circuitry, sense circuitry, and processing circuitry, the method comprising generating a stimulation signal for propagating through a first finger of a first hand, generating a sense output signal based on one or more sense signals received from the first finger of the first hand in response to the stimulation signal, capturing an amplitude of the sense output signal over time, and in accordance with a determination that a first set of amplitude and time criteria are met, detecting a making of contact of the first finger with an adjacent second finger of the first hand. Additionally or alternatively to one or more of the examples disclosed above, in some examples the method further comprises, in accordance with a determination that a second set of amplitude and time criteria are met following the determination that the first set of amplitude and time criteria are met, detecting a breaking of contact of the first finger and the adjacent second finger. Additionally or alternatively to one or more of the examples disclosed above, in some examples the method further comprises, in accordance with a determination that a second set of amplitude and time criteria are met following the determination that the first set of amplitude and time criteria are met, detecting a making of contact of a thumb of the first hand with the touching first and second fingers. Additionally or alternatively to one or more of the examples disclosed above, in some examples the method further comprises, in accordance with a determination that a third set of amplitude and time criteria are met following the determination that the second set of amplitude and time criteria are met, detecting a breaking of contact of the thumb of the first hand and the touching first finger and second fingers. Additionally or alternatively to one or more of the examples disclosed above, in some examples the determination that the first set of amplitude and time criteria are met comprises determining that the sense output signal satisfies a first voltage threshold during a first time period between a first time and a second time, determining that the sense output signal changes to satisfy a second voltage threshold at the second time, determining that the sense output signal changes and approaches the second voltage threshold while continuing to satisfy the second voltage threshold during a portion of a second time period between the second time and a third time, and determining that the sense output signal no longer satisfies the second voltage threshold at the third time. Additionally or alternatively to one or more of the examples disclosed above, in some examples the method further comprises, in accordance with a determination that a second set of amplitude and time criteria are met following the determination that the first set of amplitude and time criteria are met, detecting a breaking of contact of the first finger and the adjacent second finger, wherein the determination that the second set of amplitude and time criteria are met comprises determining that the sense output signal changes to satisfy the first voltage threshold at a fourth time. Additionally or alternatively to one or more of the examples disclosed above, in some examples the method further comprises, in accordance with a determination that a second set of amplitude and time criteria are met following the determination that the first set of amplitude and time criteria are met, detecting a making of contact of a thumb of the first hand with the touching first and second fingers, wherein the determination that the second set of amplitude and time criteria are met comprises determining that the sense output signal changes to satisfy a third voltage threshold at a fourth time. Additionally or alternatively to one or more of the examples disclosed above, in some examples the method further comprises, in accordance with a determination that a third set of amplitude and time criteria are met following the determination that the second set of amplitude and time criteria are met, detecting a breaking of contact of the thumb and the touching first finger and second fingers, wherein the determination that the third set of amplitude and time criteria are met comprises determining that the sense output signal changes to a voltage between the first voltage threshold and the second voltage threshold at a fifth time.

Some examples of the disclosure are directed to a wearable device for detecting gestures, comprising drive circuitry coupled to a drive electrode and configured to generate a stimulation signal, the drive electrode positioned at a first location in the device for contacting a first finger of a first hand, sense circuitry coupled to at least one sense electrode and configured to generate a sense output signal based on one or more sense signals received at the at least one sense electrode in response to the stimulation signal, the at least one sense electrode positioned at a second location in the device for contacting the first finger of the first hand, and a processor communicatively coupled to the drive and sense circuitry and configured for capturing an amplitude of the sense output signal over time, in accordance with a determination that a first set of amplitude and time criteria are met, detecting a making of contact of the first finger with a thumb of the first hand, and in accordance with a determination that a second set of amplitude and time criteria are met following the determination that the first set of amplitude and time criteria are met, detecting a making of contact of a second finger adjacent to the first finger of the first hand with the touching first finger and thumb. Additionally or alternatively to one or more of the examples disclosed above, in some examples the processor is further configured for, in accordance with a determination that a third set of amplitude and time criteria are met following the determination that the second set of amplitude and time criteria are met, detecting a breaking of contact of the second finger with the touching first finger and thumb.

Some examples of the disclosure are directed to a method for detecting gestures, the method performed at a wearable device including drive circuitry, sense circuitry, and processing circuitry, the method comprising generating a stimulation signal for propagating through a first finger of a first hand, generating a sense output signal based on one or more sense signals received from the first finger of the first hand in response to the stimulation signal, capturing an amplitude of the sense output signal over time, in accordance with a determination that a first set of amplitude and time criteria are met, detecting a making of contact of the first finger with a thumb of the first hand, and in accordance with a determination that a second set of amplitude and time criteria are met following the determination that the first set of amplitude and time criteria are met, detecting a making of contact of a second finger adjacent to the first finger of the first hand with the touching first finger and thumb.

Although examples of this disclosure have been fully described with reference to the accompanying drawings, it is to be noted that various changes and modifications will become apparent to those skilled in the art. Such changes and modifications are to be understood as being included within the scope of examples of this disclosure as defined by the appended claims.

The invention claimed is:

**1**. A wearable system for detecting gestures, comprising:

a wearable device, comprising:

drive circuitry coupled to a drive electrode and configured to generate a stimulation signal, the drive electrode positioned at a first location in the wearable device for contacting a first finger of a first hand; and sense circuitry coupled to a sense electrode and configured to generate a sense output signal based on one or more sense signals received at the sense electrode in response to the stimulation signal, the sense electrode positioned at a second location in the wearable device for contacting the first finger of the first hand; and

a processor communicatively coupled to the drive circuitry and the sense circuitry of the wearable device, and configured for:

capturing an amplitude of the sense output signal over time, and

in accordance with a determination that first criteria are met, the first criteria comprising first amplitude and time criteria evaluated for the sense output signal, detecting a making of contact of the first finger of the first hand with a body part different from the first finger of the first hand.

**2**. The wearable system of claim **1**, wherein:

the body part different from the first finger of the first hand is a second hand that is different from the first hand.

**3**. The wearable system of claim **1**, further comprising:

an optical sensor in communication with the processor, wherein the first criteria further comprise:

a criterion for an output of the optical sensor that is met when the output of the optical sensor indicates the making of contact of the first finger with the body part different than the first hand.

**4**. The wearable system of claim **3**, wherein the processor is further configured for:

in accordance a determination that the output of the optical sensor indicates a making of contact of the first finger with another finger or thumb of the first hand, detecting the making of contact of the first finger with another finger or thumb of the first hand.

**5**. The wearable system of claim **1**, wherein the wearable device is a first wearable device, wherein the drive electrode is a first drive electrode, wherein the stimulation signal is a first stimulation signal, wherein the sense electrode is a first sense electrode, wherein the sense output signal is a first sense output signal, and wherein the wearable system further comprises:

a second wearable device, comprising:

drive circuitry coupled to a second drive electrode and configured to generate a second stimulation signal, the drive electrode positioned at a first location in the second wearable device for contacting a first finger of a second hand; and

sense circuitry coupled to a second sense electrode and configured to generate a second sense output signal, the second sense electrode positioned at a second location in the second wearable device for contacting the first finger of the second hand, wherein:

the first stimulation signal has a first frequency selected from a first set of stimulation frequencies; and

the second stimulation signal has a second frequency selected from a second set of stimulation frequencies, the second set of stimulation frequencies being different from the first set of stimulation frequencies.

**6**. The wearable system of claim **5**, wherein:

the processor is configured for detecting the making of contact of the first finger of the first hand with the body part different than the first hand in further accordance with a determination that the first sense output signal has a first component corresponding to the first frequency and has a second component corresponding to the second frequency.

**7**. The wearable system of claim **6**, wherein the processor is communicatively coupled to the drive circuitry and the sense circuitry of the second wearable device, and further configured for:

capturing an amplitude of the second sense output signal over time; and

in accordance with a determination that second criteria are met, the second criteria comprising the first amplitude and time criteria evaluated for the second sense output signal, detecting a making of contact of the first finger of the second hand with the first hand.

**8**. The wearable system of claim **7**, wherein the second criteria further comprise:

a criterion for the second sense output signal that is met when the second sense output signal has a first component corresponding to the first frequency and has a second component corresponding to the second frequency.

**9**. The wearable system of claim **5**, wherein the processor is communicatively coupled to the drive circuitry and the sense circuitry of the second wearable device, and further configured for:

in accordance with a determination that the first amplitude and time criteria evaluated for the first sense output signal are met, and a determination that the first sense output signal only corresponds to the first frequency, detecting a making of contact of the first finger of the first hand with a thumb of the first hand; and

in accordance with a determination that the first amplitude and time criteria evaluated for the second sense output signal are met, and a determination that the second sense output signal only corresponds to the second frequency, detecting a making of contact of the first finger of the second hand with a thumb of the second hand.

**10**. The wearable system of claim **5**, wherein the processor is communicatively coupled to the drive circuitry and the sense circuitry of the second wearable device, and further configured for:

in accordance with a determination that second amplitude and time criteria evaluated for the first sense output signal are met, and a determination that the first sense output signal only corresponds to the first frequency, detecting a making of contact of the first finger of the first hand with another finger or thumb of the first hand; and

in accordance with a determination that the second amplitude and time criteria evaluated for the second sense output signal are met, and a determination that the second sense output signal only corresponds to the second frequency, detecting a making of contact of the first finger of the second hand with another finger or thumb of the second hand.

**11**. The wearable system of claim **10**, wherein:

the second amplitude and time criteria include the first amplitude and time criteria.

**12**. The wearable system of claim **10**, wherein the processor is further configured for:

in accordance with a determination that third amplitude and time criteria evaluated for the first sense output signal are met, following the determination that the second amplitude and time criteria evaluated for the first sense output signal are met, detecting a breaking of contact of the first finger of the first hand with the another finger or thumb of the first hand; and

in accordance with a determination that the third amplitude and time criteria evaluated for second sense output signal are met, following the determination that the second amplitude and time criteria evaluated for the second sense output signal are met, detecting a breaking of contact of the first finger of the second hand with the another finger or thumb of the second hand.

**13**. The wearable system of claim **1**, wherein the determination that the first amplitude and time criteria evaluated for the sense output signal are met comprises:

determining that the sense output signal satisfies a first voltage threshold during a first time period between a first time and a second time; and

determining that the sense output signal changes to satisfy a second voltage threshold at the second time.

**14**. The wearable system of claim **1**, wherein the wearable device is a first wearable device, wherein the drive electrode is a first drive electrode, wherein the stimulation signal is a first stimulation signal, wherein the sense electrode is a first sense electrode, wherein the sense output signal is a first sense output signal, and wherein the wearable system further comprises:

a second wearable device, comprising:

drive circuitry coupled to a second drive electrode and configured to generate a second stimulation signal, the drive electrode positioned at a first location in the second wearable device for contacting a second finger of the first hand; and

sense circuitry coupled to a second sense electrode and configured to generate a second sense output signal, the second sense electrode positioned at a second location in the second wearable device for contacting the second finger of the first hand, wherein the processor is communicatively coupled to the drive circuitry and the sense circuitry of the second wearable device, and further configured for:

capturing an amplitude of the second sense output signal over time; and

in accordance with a determination that the first amplitude and time evaluated for the second sense output signal are met, detecting a making of contact of the second finger of the first hand with a body part different than the second finger of the first hand.

**15**. The wearable system of claim **14**, wherein:

the body part different than the second finger of the first hand is a thumb of the first hand.

**16**. The wearable system of claim **14**, wherein:

the body part different than the second finger of the first hand is a second hand that is different from the first hand.

**17**. A method for detecting gestures, the method performed at a wearable device including drive circuitry, sense circuitry, and processing circuitry, the method comprising:

generating a stimulation signal for propagating through a first finger of a first hand;

generating a sense output signal based on one or more sense signals received from the first finger of the first hand in response to the stimulation signal;

capturing an amplitude of the sense output signal over time; and

in accordance with a determination that first amplitude and time criteria are met by the sense output signal, detecting a making of contact of the first finger of the first hand with a body part different than the first finger of the first hand.

**18**. The method of claim **17**, wherein detecting the making of contact of the first finger of the first hand with the body part different than the first finger of the first hand comprises:

detecting the making of contact of the first finger of the first hand with a thumb of the first hand; or

detecting the making of contact of the first finger of the first hand with a second hand that is different from the first hand.

**19**. The method of claim **17**, wherein the determination that the first amplitude and time criteria are met by the sense output signal comprises:

determining that the sense output signal satisfies a first voltage threshold during a first time period between a first time and a second time; and

determining that the sense output signal changes to satisfy a second voltage threshold at the second time.

**20**. A wearable device for detecting gestures, comprising:

drive circuitry comprising a drive electrode positioned within the wearable device to contact a first finger of a first hand;

sense circuitry comprising a sense electrode and configured to generate a sense output signal;

a processor communicatively coupled to the drive circuitry and the sense circuitry and configured for:

capturing an amplitude of the sense output signal over time; and

in accordance with a determination that first amplitude and time criteria are met by the sense output signal, detecting a making of contact of the first finger of the first hand with a body part different than first finger of the first hand.

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