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Audio Output Devices for Head Mounted Display Devices

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Abstract

A head mounted display (HMD) device may include a first audio output device, or speaker, installed at a first side of the housing, and a second audio output device, or speaker, installed at a second side of the housing. The first and second audio output devices may be mounted proximate to optical components of the HMD, with audio output respectively directed toward the user's ears. This may allow the user to be immersed in the sound output by the audio output devices. An HMD equipped in this manner may provide for a mobile, portable electronic device that can output an immersive audio and visual experience from a single mobile/portable unit.

A head mounted display (HMD) device may be worn on a head of the user, to view and interact with visual content displayed on a display of the HMD. The visual content displayed on the display of the HMD may be accompanied by audio content, or sound, to enhance the user's experience of and interaction with the visual content. An HMD may be operated in connection with a Virtual Reality (VR) system and/or an Augmented Reality (AR) system to generate an immersive virtual environment including visual content and audio content to be experienced by the user via the HMD.

An HMD may display image content on a display of the HMD to engage a user's visual senses, substantially fully capturing the user's field of vision, while audio content may engage the user's auditory senses, to generate an immersive virtual experience. This type of immersive virtual experience, in which the user's visual and auditory senses are essentially equally stimulated, may enhance the user's overall experience. Depending on

a configuration of the HMD, directing sound to the user's ear(s) to create three-dimensional (3D) digital spatial effects may be challenging. For example, headphones, earbuds, and other types of ancillary audio output devices may be connected to the HMD to deliver audio output, or sound, associated with the immersive visual content displayed by the HMD, essentially directly to the user's ears. However, once the HMD is positioned on the user's head and the physical environment outside the HMD is no longer visible to the user, and/or the physical environment is darkened, it may be difficult to locate and/or connect these types of headphones, earbuds, and other types of ancillary equipment to the HMD and/or place these devices in the user's ears.

In some situations, audio output devices in the physical environment operating, for example, in conjunction with a media system in communication with the HMD, including, for example, down firing speakers mounted in the physical environment, may provide audio output, or sound, in the physical environment that may be heard by the user. This may provide for audio output, or sound, that does not require the user to locate and/or connect an ancillary device to the HMD. However, in this arrangement, the sound output by speakers arranged in this manner cannot make use of the natural shape of the human pinna (the outer ear) to reflect sound into the user's ear canal. This type of arrangement may generate a virtual sound floor that appears to be above the user, rather than generating an immersive audio experience to accompany the immersive visual experience.

In an HMD to be described in more detail below, one or more audio output devices may be provided in the HMD, mounted proximate to optical components of the HMD, and directed toward, for example, the user's pinna, tragus, etc., allowing the user

to be immersed in the sound output by the audio output device(s). Additional 3D spatialization effects may make use of reflective qualities to add a widening quality to the sound that surrounds the user, further enhancing the immersive effect. This may provide for a mobile, portable electronic device that can output an immersive audio and visual experience from a single mobile/portable unit.

In some situations, the user may interact with one or more external computing devices that are operably coupled with, and communicate with, the HMD. Such external computing devices may include, for example, handheld computing devices such as smartphones or controllers, desktop or laptop computers in the physical space, smart media devices including, for example, a smart TV, a media entertainment system, a set top box, a router, and the like. Operable coupling between the HMD and one or more external computing devices may provide for communication between and the exchange of data between the HMD and the external device(s). This may allow some, or all, of the components of the immersive virtual environment, to be transmitted between the external device(s) and the HMD, so that the immersive audio and visual experience may be output by the HMD.

Figures 1A through 1G illustrate an example HMD 100 that can be configured to implement the features described. In particular, Figure 1A is a front perspective view of an example HMD 100, Figures 1B and 1C are front and rear views of a housing 110 of the example HMD 100 shown in Figure 1A, Figure 1D is a rear perspective view of the example HMD 100 shown in Figure 1A, Figure 1E is an exploded perspective view of the example HMD 100 shown in Figures1A through 1D, Figure 1F is a partial view of an audio output device 130 of the example HMD 100, with a top portion of a housing 110 of

the HMD 100 removed, and Figure 1G is partial view of the audio output device 130 of the example HMD 100, with the housing 110 of the HMD 100 illustrated in shadow.

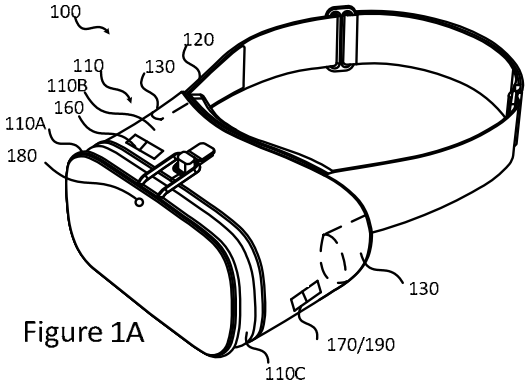


Figure 1A

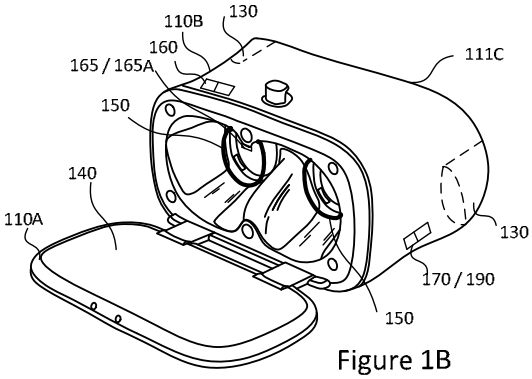


Figure 1B

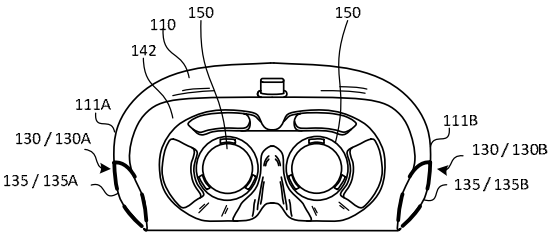


Figure 1C

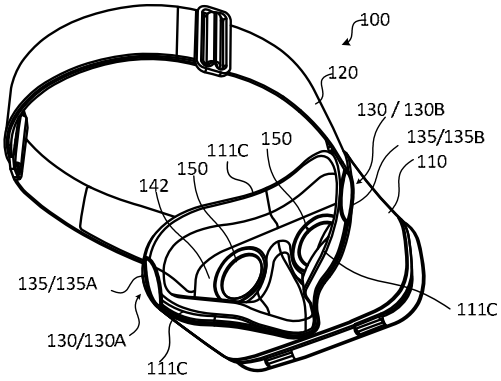


Figure 1D

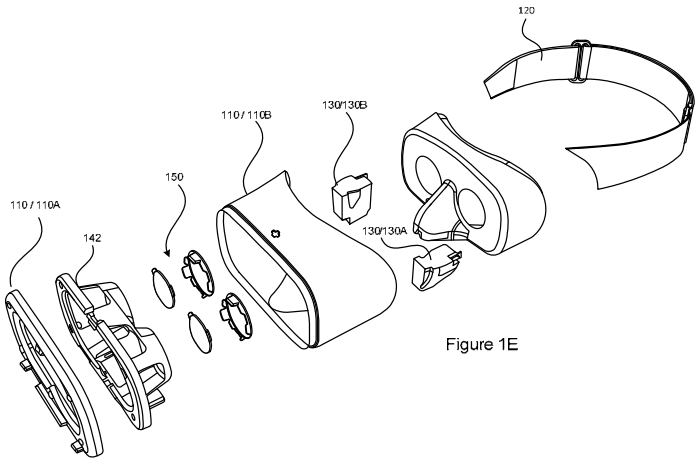


Figure 1E

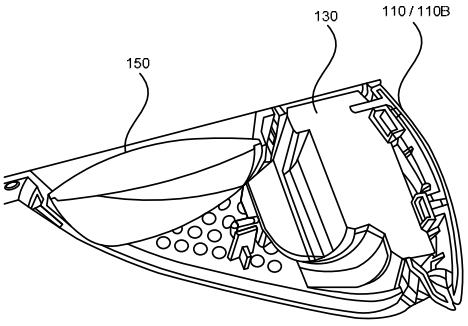


Figure 1F

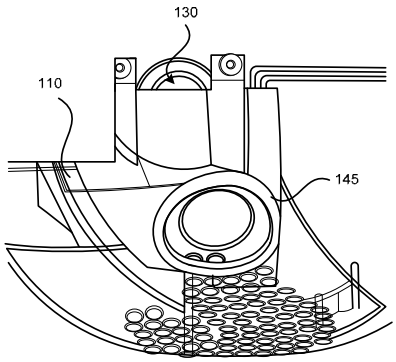


Figure 1G

Figure 2 illustrates the example HMD 100 shown in Figures 1A through 1G, worn on the head of a user.

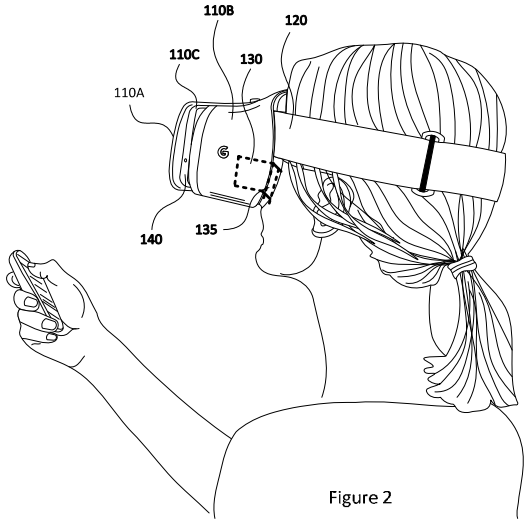


Figure 2

Figure 3 is a block diagram of an example electronic device 300 such as, for example, an HMD as shown in Figures 1A through 1G, that can deliver both visual content and audio content to a user.

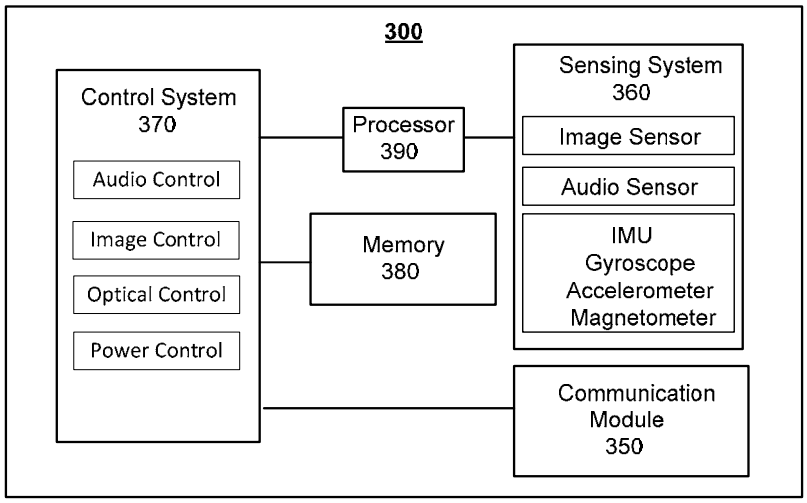


Figure 3

In the example HMD 100 shown in Figures 1A through 1G, the housing 110 is coupled to a frame 120, or a band 120, allowing the HMD 100 to be worn on the user's head. The front portion 110A of the housing 110 is coupled to the base portion 110B of the housing 110. A display 140 may be positioned at an interior facing side of the front portion 110A of the housing 110. The display 140 may be an installed component in the housing 110, or may be included in a separate electronic device, such as, for example, a smartphone, that may be removably coupled to (e.g., inserted into, removed from) the housing 110 of the HMD 100. For example, a separate electronic device including the display 140 may be slidably inserted into a slot 110C formed in the housing 110 of the HMD 100, such as, for example, between the front portion 110A and the base portion 110B of the housing 110, as shown in Figure 1A. The front portion 110A of the housing 110 may be moveable, such as for example, rotatable, with respect to the base portion 110B of the housing 110, as shown in Figure 1B. In this arrangement, the front portion 110A may be moved, for example, rotated, with respect to the base portion 110B of the housing 110 to allow an electronic device including the display 140 to be inserted into the

housing 110. The front portion 110A of the housing 110 may be returned to the closed position against the base portion 110B of the housing 110 so that the electronic device can be at least partially enclosed within the housing 110.

Optical components 150, such as, for example, lenses 150, may be mounted in the housing 110, between the user's eyes and the display 140 when the front portion 110A is in the closed position against the base portion 110B of the housing 110. The HMD 100 may include a sensing system 160 including various sensors such as, for example, audio sensor(s), image/light sensor(s), positional sensors (e.g., inertial measurement unit including gyroscope and accelerometer), and the like. The HMD 100 may also include a control system 170 including a processor 190 and various control system devices to facilitate operation of the HMD 100. The HMD 100 may include a camera 180 to capture still and moving images. The images captured by the camera 180 may be used to help track a physical position of the user wearing the HMD 100 in the physical space, and/or may be displayed to the user on the display 140 in a pass through mode. The HMD 100 may include a gaze tracking device 165 including one or more image sensors 165A to detect and track an eye gaze of the user, which may be processed as a user input.

Audio components, such as, for example, multiple audio output devices 130, or speakers 130, may be included in the HMD 100, for example, in the housing 110, to direct audio output toward the ears of the user when the HMD 100 is worn by the user, as shown in Figure 2.

As shown in Figure 3, the electronic device 300 may include a sensing system 360 and a control system 370, which may be similar to the sensing system 160 and the control system 170, respectively, of the example HMD 100 shown in Figures 1A and 1B.

The sensing system 360 may include, for example, a light sensor, an audio sensor, an image sensor, a distance/proximity sensor, a positional sensor, and/or other sensors and/or different combination(s) of sensors. The control system 370 may include, for example, a power/pause control device, audio and video control devices, an optical control device, a transition control device, and/or other such devices and/or different combination(s) of devices. The sensing system 360 and/or the control system 370 may include more, or fewer, devices, depending on a particular application, and may have a different physical arrangement that shown. A processor 390 may be in communication with the sensing system 360 and the control system 370, a memory 380, and a communication module 350 may provide for communication between the electronic device 300 and one or more external device(s) as discussed above

Returning to the HMD 100 shown in Figures 1A through 1G, the audio output device 130 of the HMD 100 may include a first audio output device 130A positioned at a first side, for example, the left side, of the optical components 150 in the housing 110, and a second audio output device 130B is positioned at a second side, for example, the right side, of the optical components in the housing 110. The first audio output device 130A may be adjacent to a first lateral wall 111A of the housing 110, with an output port 135A of the first audio output device 130A shaped and oriented so as to direct sound to the user's left ear. The second audio output device 130B may be adjacent to a second lateral wall 111B of the housing 110 opposite the first lateral wall 111A, with an output port 135B of the second audio output device 130B shaped and oriented to direct sound to the user's right ear.

The frame 120 of the HMD 100 may be adjustable, allowing a position of the

HMD 100 on the head of the user to be adjusted so as further facilitate the direction of sound from the audio output devices 130 to the ears of the user. When the system is operating to generate and display, for example, a virtual reality environment to the user on the display 140 of the HMD 100, the housing 110 of the HMD 100 may be in contact with, or seated against, the user's face. The HMD 100 may define, or form, a seal or barrier, for example, along a peripheral edge portion 111C of the housing 110 that contacts the user's head and/or face, or by a peripheral edge portion of the support portion 142 of the optical components 150 seated against the face of the user. This seal may inhibit, or block, light from entering the interior confines of the housing 110 of the HMD 100.

With the peripheral edge portion 111C of the housing 110 seated against the user's face, the walls of the housing 110 may form a barrier that provides for physical separation of the first and second audio output devices 130A, 130B positioned at opposite lateral sides 111A, 111B of the housing 110. In particular, this barrier may inhibit, or block, sound generated by the first audio output device 130A from mixing with sound generated by the second audio output device 130B. This barrier may also inhibit sound output by the first audio output device 130A from reaching the user's right ear, and may inhibit sound output by the second audio output device 130B from reaching the user's left ear. The audio barrier formed between the first and second audio output devices 130A, 130B in this manner may provide for stereo separation between the first and second audio output devices 130A, 130B, while directing sound toward a respective one of the user's ears, thus enhancing the immersive experience provided by the HMD 100.

The housing 110 of the HMD 100 protrudes forward, in front of, or beyond, the

user's face. Positioning the first audio output device 130A as close to the user's left ear as possible, and the second audio output device 130B as close to the user's right ear as possible, may direct the sound output by the first and second audio output devices 130A, 130B around a respective peripheral portion of the HMD 100, and increase an associated echo delay.

In the example HMD 100 shown in Figures 1A through 1G, at least a portion of the housing of the HMD 100 can define a back volume. In general, in generating sound to be output by an audio output device, or speaker, construction of the back volume (of the speaker enclosure) greatly affects the ability of the speaker to push sound waves against the back volume and project sound out through the front volume (of the speaker enclosure). These aspects can affect overall sound quality and performance of the speaker.

In the example HMD 100 shown in Figures 1A through 1G, the lateral walls 111A and 111B of the housing 110, together with the support portion 142 of the optical components 150 in the housing 110, can define, at least in part, the back volume for the audio output devices 130. The use of the lateral walls 111A, 111B of the housing 110 of the HMD 100 to at least partially define a back volume may eliminate the need for a completely separate enclosure assembly to define the back volume of the audio output devices 130. The use of the walls 111A, 111B of the housing 110 as a back volume can reduce a number of redundant wall structures in the HMD 100, allowing a greater back volume to be accommodated with less structure. The use of the walls 111A, 111B of the housing 110 as a back volume can also reduce the overall weight of the HMD 100 (when compared to an HMD including audio output devices having separate audio subsystems

coupled to the HMD). This arrangement may also enhance the structural integrity of the HMD 100.

As shown in Figures 1E through 1G, each audio output device 130 may be coupled in the housing 110, between a corresponding portion of the housing 110 and the structural support 140 for the optical components 150. For example, each audio output device 130 may be coupled to a corresponding interior wall portion of the housing 110, and/or to a corresponding portion of the structural portion 142 of the optical components 150. A seal 145 may be positioned in the housing 110 to enclose the back volume of the audio output device 130. Thus, in this arrangement, the audio enclosure may be defined in part by the interior wall(s) of the housing 110, the seal 145, and the structural portion 142 of the optical components 150. The first and second audio output devices 130A and 130B can be enclosed in two separate, independent, sealed chambers that are coupled to the structural portion 142 of the optical components 150. Thus, in some arrangements, the back volumes of the first and second audio output devices 130A and 130B may be defined, at least in part, by interior wall(s) of the housing 110 and/or structural portion(s) 142 of the optical components 150. In other arrangements, the back volumes of the first and second audio output devices 130A and 130B may be, essentially, self-enclosed by their own respective structures, as shown in Figures 1F and 1G.

The HMD 100 may include a mechanism for adjusting an inter-pupillary distance (IPD), or a distance between the respective optical centers of the optical components 150, or lenses 150, corresponding to a distance between the respective centers of the pupils of the user's left and right eyes. Adjustment of the IPD of the optical components 150 may bias the first and second audio output devices 130A, 130B in front of the left and right

ears of the user. That is, as the user adjusts the optical components 150 to adapt to a particular IPD/corresponding head size, a position of the audio output devices 130 (coupled to the optical components 150 via the structural support 140) may also be adjusted to the corresponding ear position/head size.

In an HMD including audio output devices, as described above, the audio output devices 130 may be integrated into the housing 110, proximate the structural support 140 for the optical components 150, where electronics are readily accessible for easy wiring and connection. In an HMD including audio output devices, as described above, existing walls of the structural portion 142 of the optical components 150 and/or the housing 110 may define a relatively large, sealed back volume for the audio output devices 130. This may allow relatively small audio output devices 130 to generate relatively low frequency (for example, approximately 100 Hz) bass response while occupying a relatively small amount of space in the housing 110 of the HMD 100, while adding relatively little to the overall weight of the HMD 100.

In an HMD including audio output devices, as described above, the central portion of the audio output port 135 of each of the audio output devices may be targeted substantially directly at the tragus and reflecting off the pinna, providing for enhanced/optimum 3D sound spatialization. In an HMD including audio output devices, as described above, sound output by the audio output devices 130 is directed toward the respective ears of the user wearing the HMD 100, without being inserted into the user's ears This may allow the user to experience an immersive audio and visual environment, while still maintaining some level of presence in and awareness of the physical environment. An HMD including audio output devices, as described above, provides a

mobile, portable system that can provide an immersive audio and visual experience without relying on auxiliary devices to generate and output sound. In an HMD including audio output devices, as described above, the audio output devices 130 may be contained within the interior of the housing 110, and essentially not visible from an exterior of the HMD 100. This may provide for a sleek, more appealing, exterior appearance.

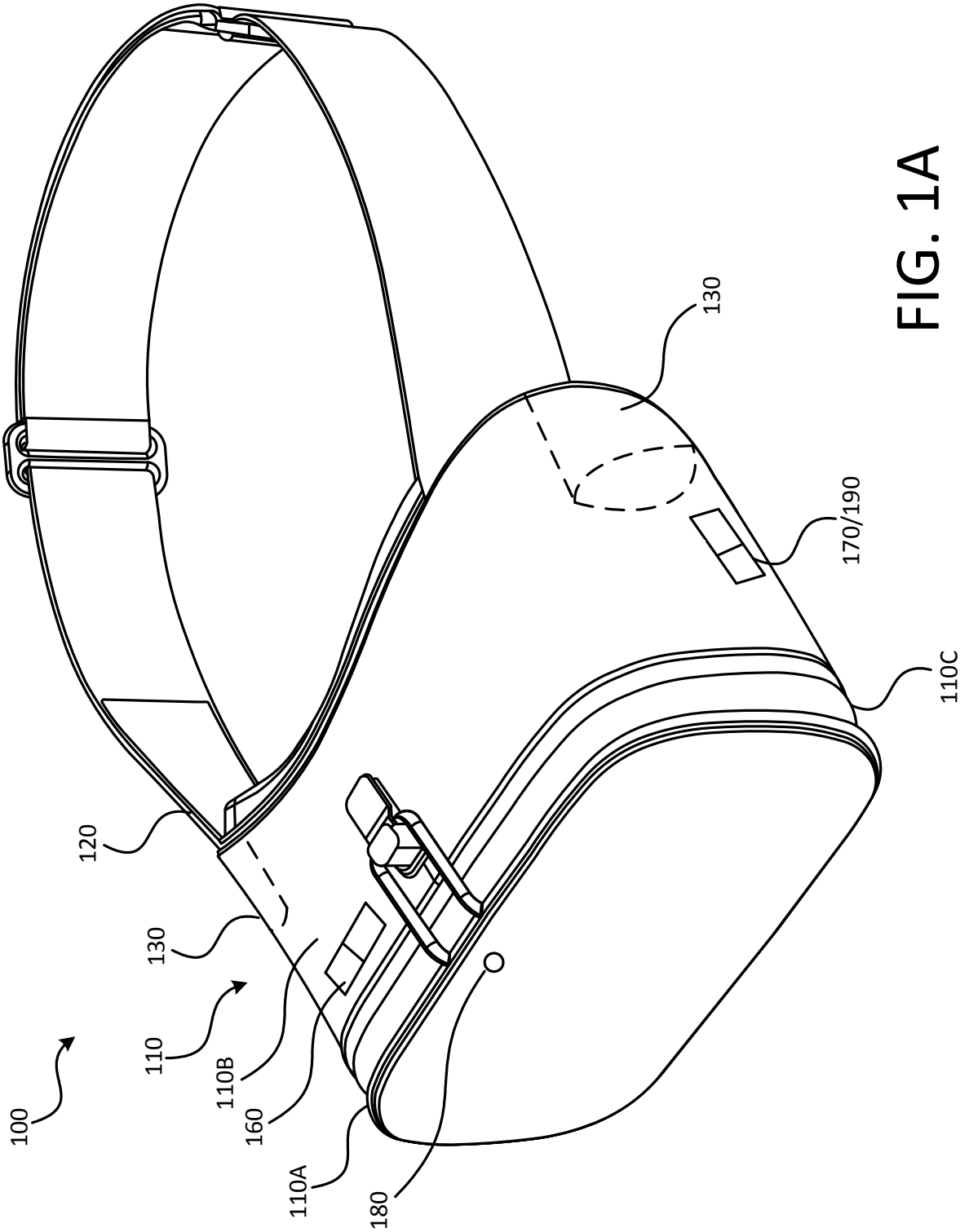


FIG. 1A

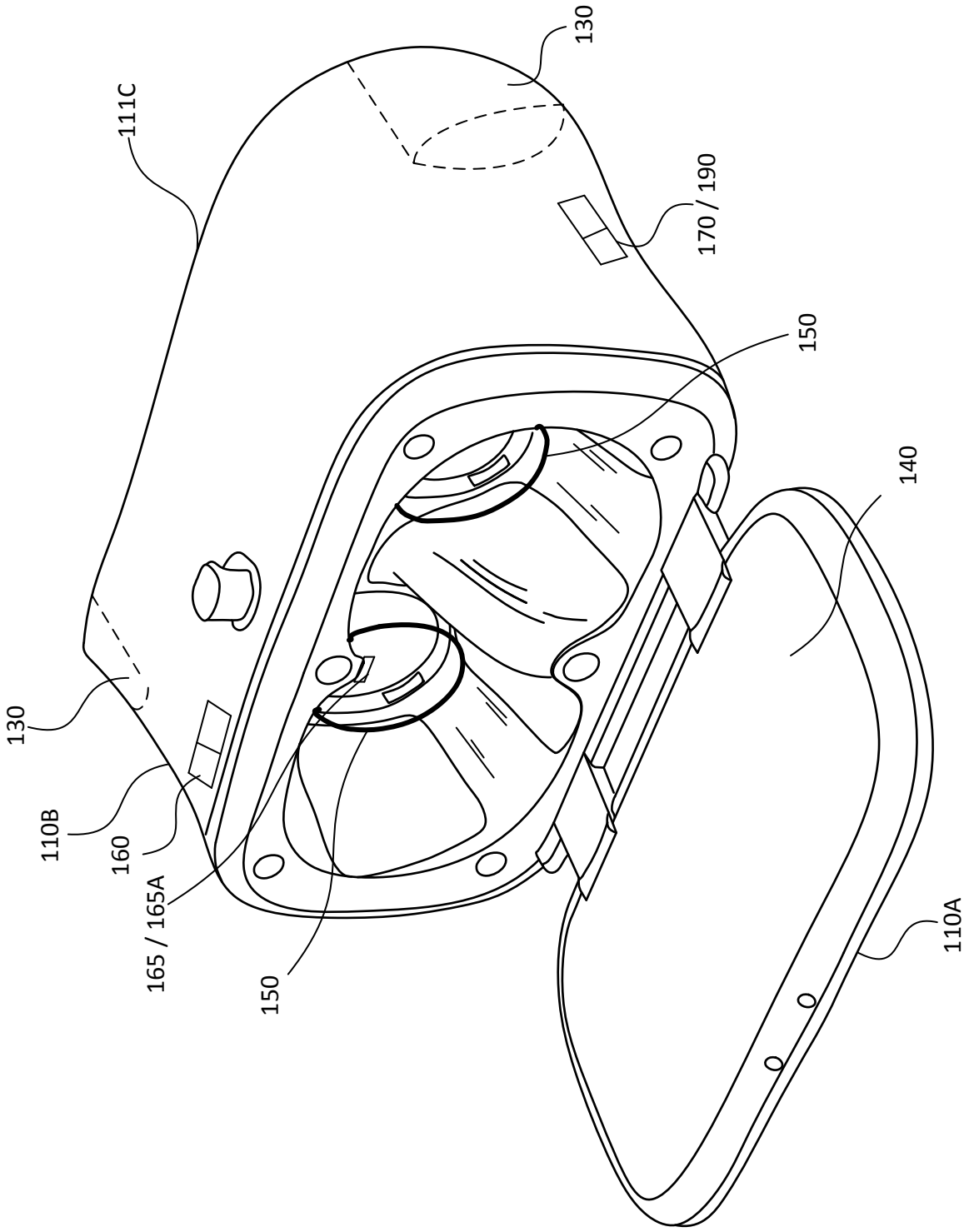


FIG. 1B

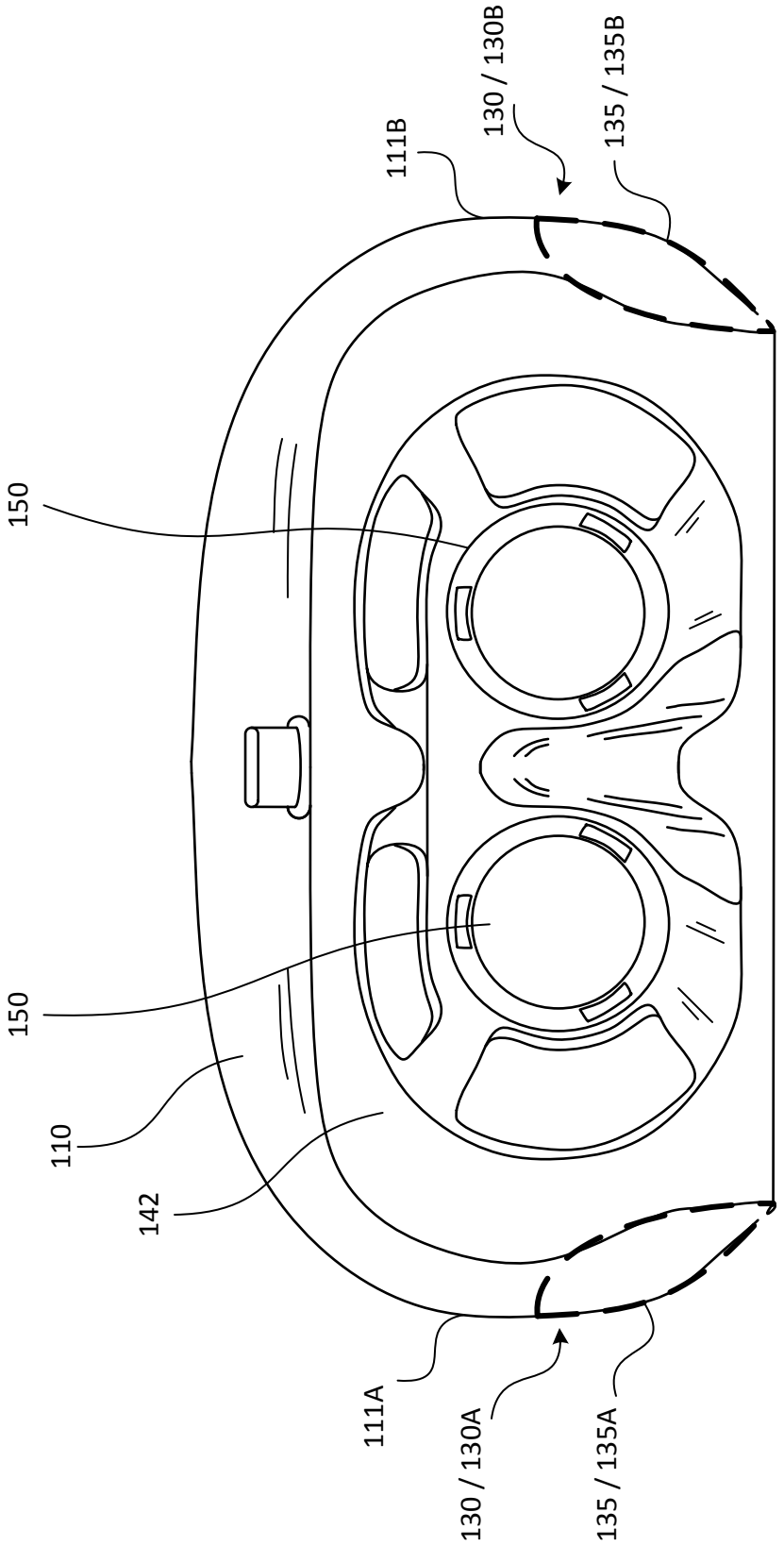
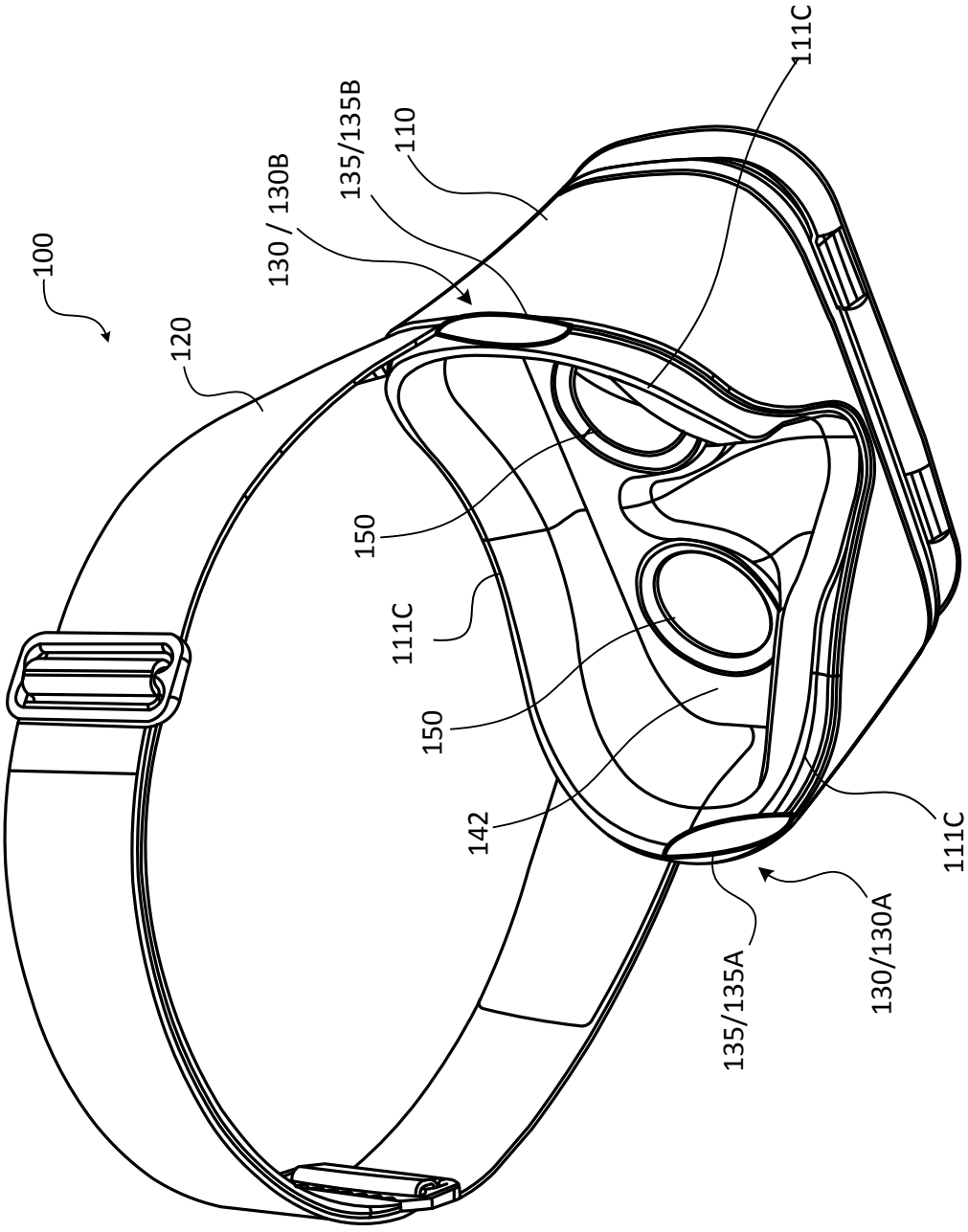


FIG. 1C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142
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FIG. 1D

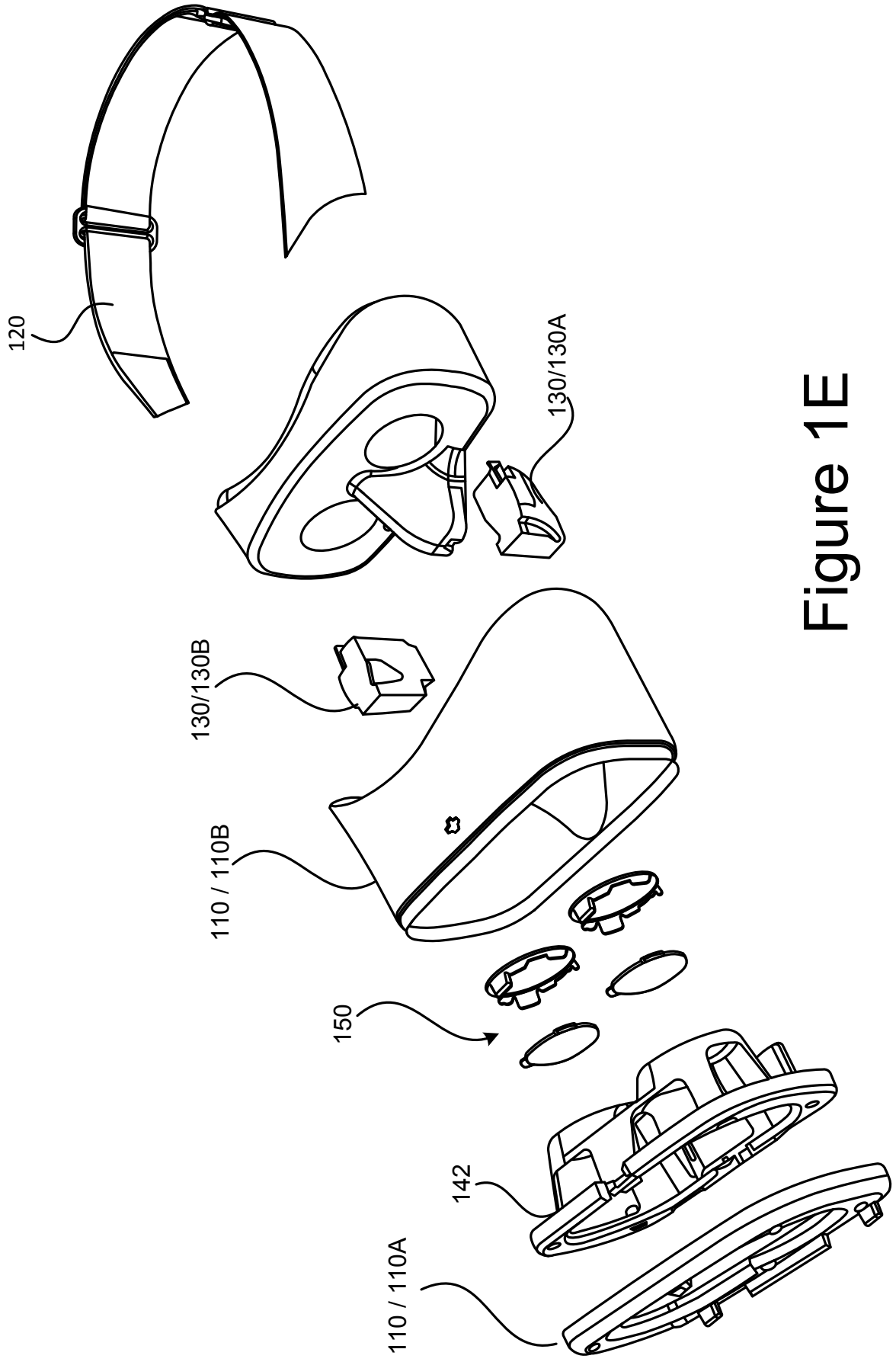


Figure 1E

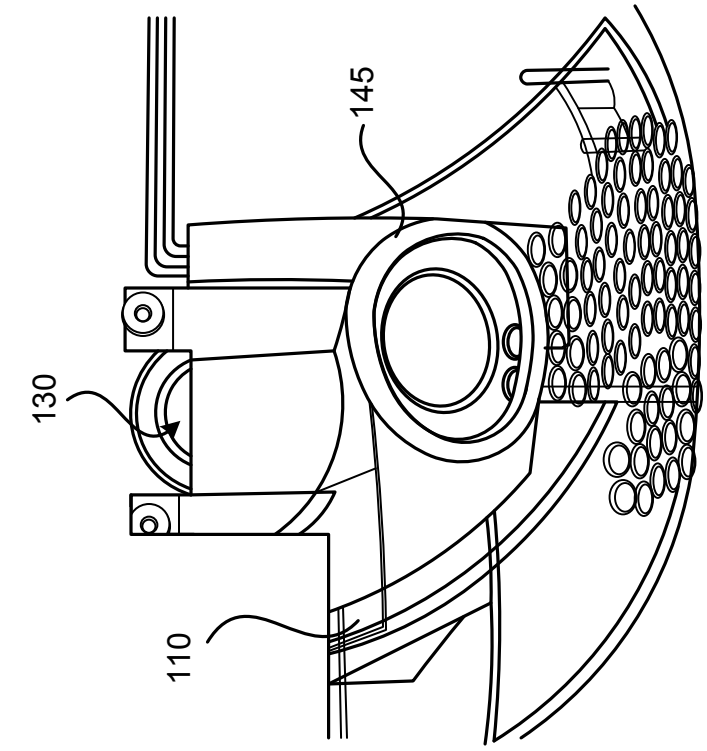


Figure 1G

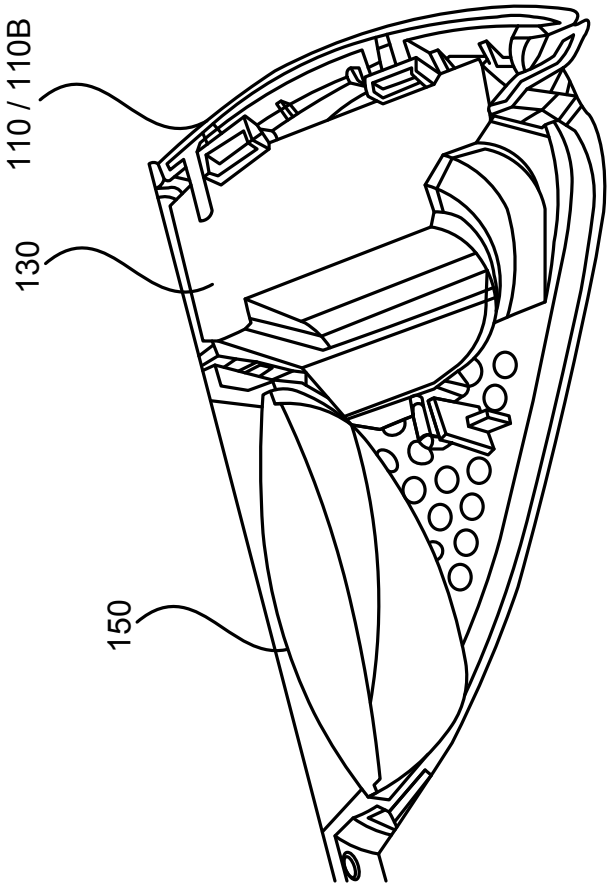


Figure 1F

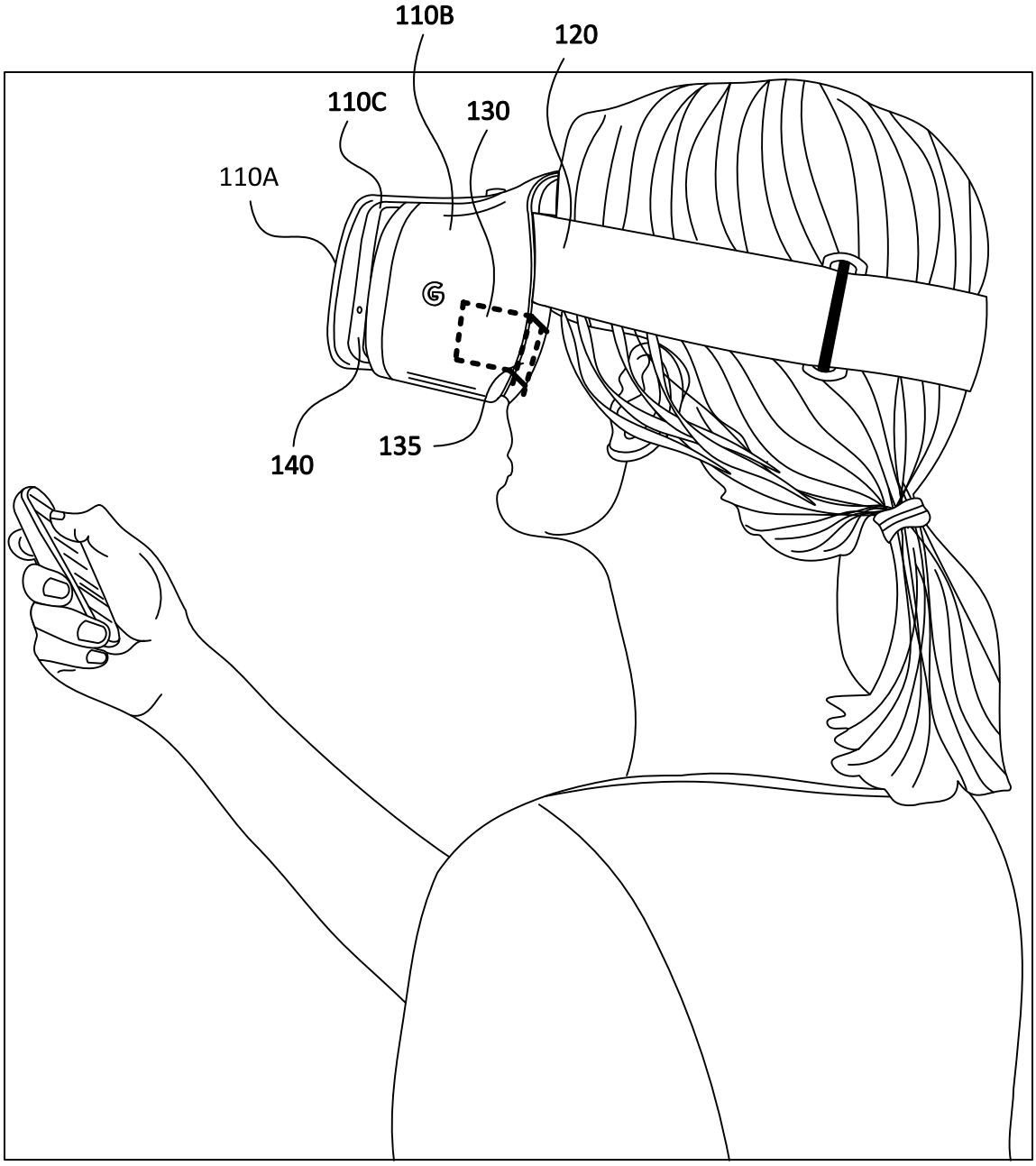
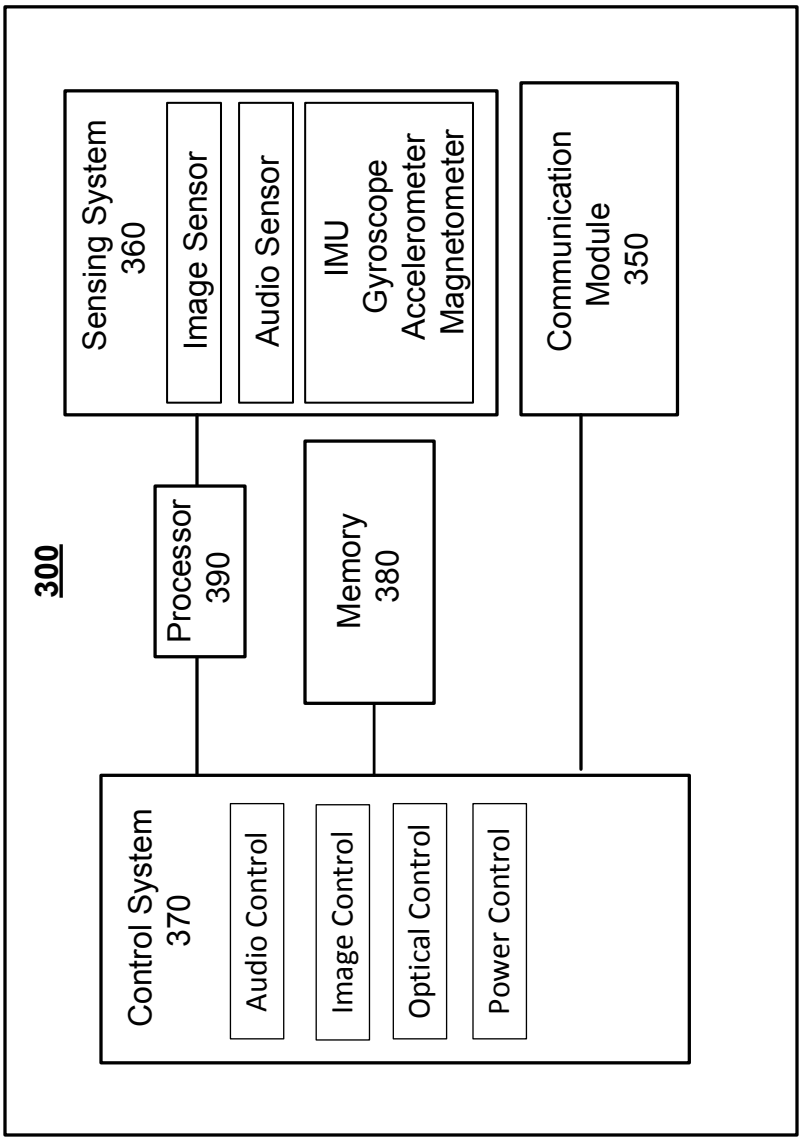


FIG. 2


300
Sensing System
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Audio Sensor
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Accelerometer
Magnetometer
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Processor
390
Memory
380
Control System
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Audio Control
Image Control
Optical Control
Power Control

FIG. 3

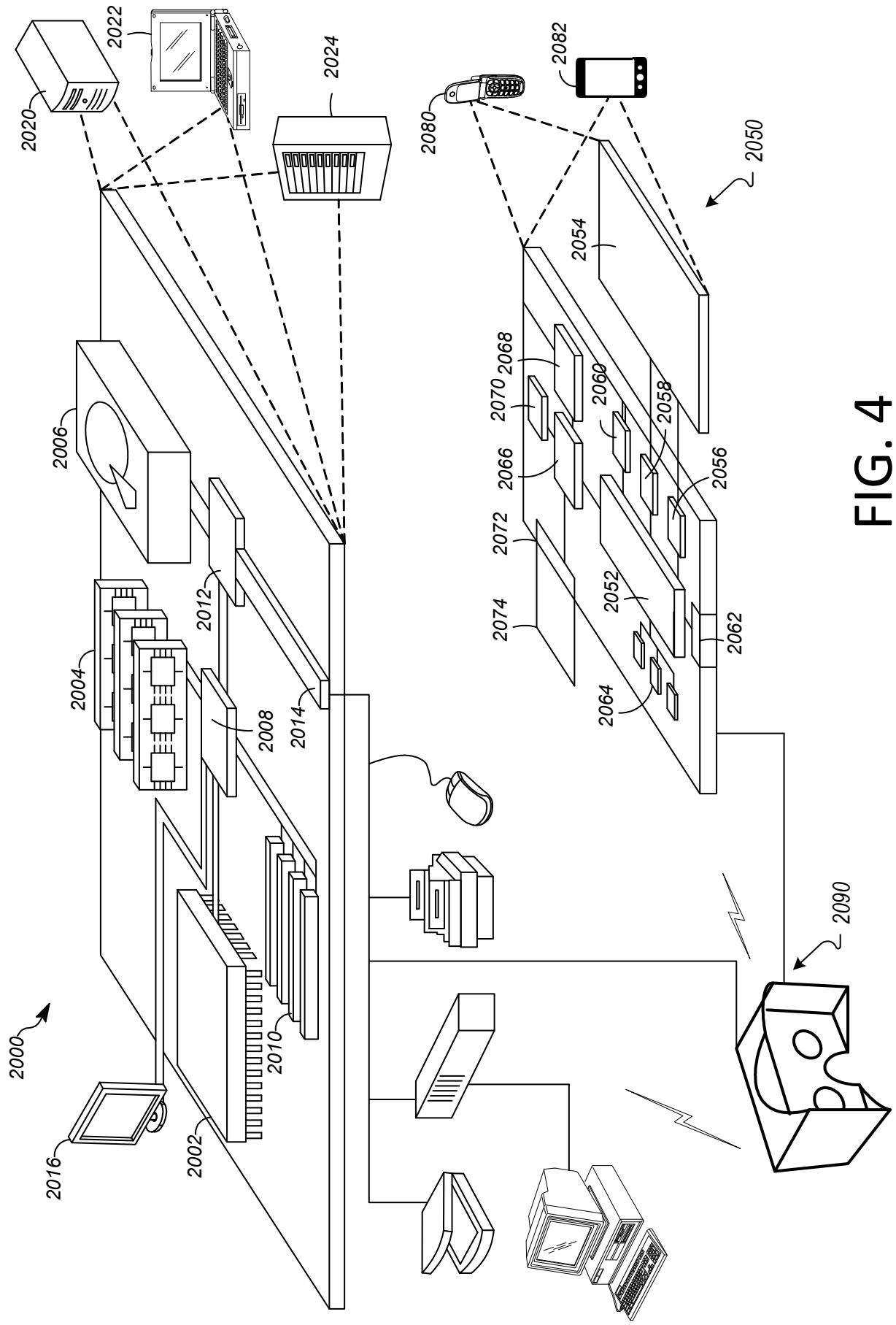
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FIG. 4