



- (51) **International Patent Classification:**
G02B 27/01 (2006.01) *F21V 8/00* (2006.01)
- (21) **International Application Number:**
PCT/US2024/056197
- (22) **International Filing Date:**
15 November 2024 (15.11.2024)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
63/611,927 19 December 2023 (19.12.2023) US
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- (81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,

HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

- (84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— with international search report (Art. 21(3))

(54) **Title:** ACHROMATIC OUTCOUPLING OF LIGHT FROM A PHOTONIC INTEGRATED CIRCUIT

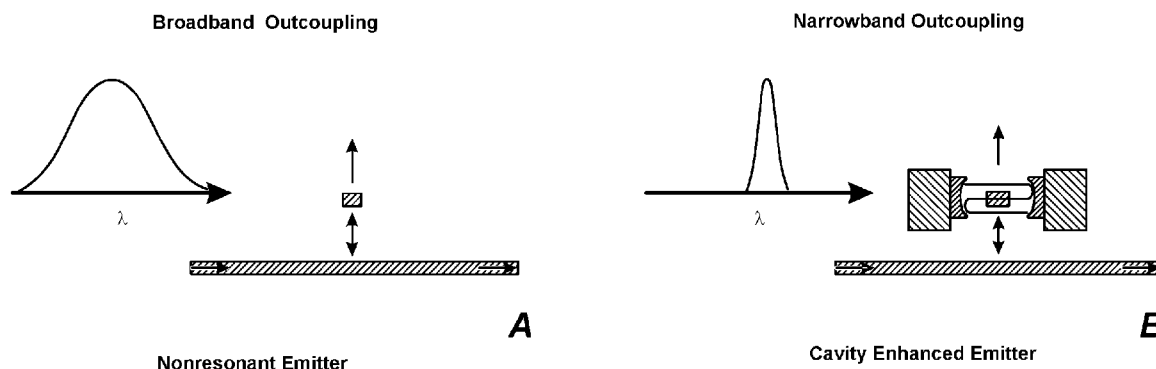


FIG. 1

(57) **Abstract:** A display includes an illumination source, a light propagation body optically coupled to the illumination source extending from an input end to an output end and configured to guide light by total internal reflection from the input end to the output end, and an output coupling element located proximate to the output end for coupling light out of the light propagation body, where the output coupling element includes an emitter disposed between two mutually opposing resonator mirrors and is configured to outcouple red, green, and blue light at a constant chief ray angle.



ACHROMATIC OUTCOUPLING OF LIGHT FROM A PHOTONIC INTEGRATED CIRCUIT**CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims benefit of and priority to U.S. provisional patent application Ser. No. 63/611,927 filed December 19, 2023.

BACKGROUND

[0002] Virtual reality (VR) and augmented reality (AR) eyewear devices and headsets enable users to experience events, such as interactions with people in a computer-generated simulation of a three-dimensional world or viewing data superimposed on a real-world view. Superimposing information onto a field of view may be achieved through an optical head-mounted display (OHMD) or by using embedded wireless glasses with a transparent heads-up display (HUD) or augmented reality overlay. VR/AR eyewear devices and headsets may be used for a variety of purposes. Governments may use such devices for military training, medical professionals may use such devices to simulate surgery, and engineers may use such devices as design visualization aids.

[0003] Virtual reality and augmented reality devices and headsets typically include an optical system having a microdisplay and imaging optics. The microdisplay may be configured to provide an image to be viewed either directly or indirectly using, for example, a micro OLED/LED display or by illuminating a liquid-crystal based display such as a liquid crystal on silicon (LCoS) microdisplay/liquid crystal display (LCD). Liquid crystal on silicon is a miniaturized reflective active-matrix display having a liquid crystal layer disposed over a silicon backplane.

SUMMARY

[0004] In accordance with a first aspect of the present disclosure, there is provided a display comprising: an illumination source; and an illuminator, wherein the illuminator comprises: a light propagation body optically coupled to the illumination source and extending from an input end to an output end and configured to guide light received from the illumination source by total internal reflection from the input end to the output end; a first output coupling element located proximate to the output end for coupling red light out of the light propagation body; a second output coupling element located proximate to the output end for coupling green light out of the light propagation body; and a third output coupling element located proximate to the output end for coupling blue light out of the light propagation body, wherein the first, second, and third output coupling elements each

1 comprise an emitter disposed between a respective pair of opposing resonator mirrors, such
2 that the first, second, and third output coupling elements outcouple the red, green, and blue
3 light at a constant chief ray angle.

4 [0005] In some embodiments, the illumination source comprises a red laser, a
5 green laser, and a blue laser.

6 [0006] In some embodiments, the first, second, and third output coupling
7 elements each comprise a surface relief grating.

8 [0007] In some embodiments, the first, second, and third output coupling
9 elements are configured to simultaneously outcouple the red, green, and blue light.

10 [0008] In some embodiments, the light propagation body is configured to
11 distribute light received from the illumination source over a two-dimensional display area.

12 [0009] In some embodiments, each emitter comprises a cavity enhanced emitter.

13 [0010] In some embodiments, the first output coupling element is configured to
14 outcouple red light to the exclusion of green light and blue light; the second output coupling
15 element is configured to outcouple green light to the exclusion of red light and blue light; and
16 the third output coupling element is configured to outcouple blue light to the exclusion of red
17 light and green light.

18 [0011] In some embodiments, the display further comprises a display panel
19 overlapping the illuminator, wherein the display panel is configured to receive the red, green,
20 and blue light outcoupled from the light propagation body.

21 [0012] In some embodiments, the display further comprises a dispersion
22 compensation layer overlying the output end of the light propagation body.

23 [0013] In some embodiments, the dispersion compensation layer comprises a
24 metasurface, a polarization volume hologram, or a volumetric Bragg grating.

25 [0014] In accordance with a second aspect of the present disclosure, there is
26 provided a display comprising: an illumination source; a light propagation body optically
27 coupled to the illumination source extending from an input end to an output end and
28 configured to guide light by total internal reflection from the input end to the output end;
29 and an output coupling element located proximate to the output end for coupling light out of
30 the light propagation body, wherein the output coupling element comprises an emitter
31 disposed between two mutually opposing resonator mirrors and is configured to outcouple
32 red, green, and blue light at a constant chief ray angle.

1 **[0015]** In some embodiments, the illumination source comprises a red laser, a
2 green laser, and a blue laser.

3 **[0016]** In some embodiments, the light propagation body is configured to
4 distribute light received from the illumination source over a two-dimensional display area.

5 **[0017]** In some embodiments, each emitter comprises a cavity enhanced emitter.

6 **[0018]** In some embodiments, the first output coupling element is configured to
7 outcouple red light to the exclusion of green light and blue light; the second output coupling
8 element is configured to outcouple green light to the exclusion of red light and blue light; and
9 the third output coupling element is configured to outcouple blue light to the exclusion of red
10 light and green light.

11 **[0019]** In some embodiments, the display further comprises a display panel
12 overlapping the illuminator, wherein the display panel is configured to receive the red, green,
13 and blue light outcoupled from the light propagation body.

14 **[0020]** In some embodiments, the display further comprises a dispersion
15 compensation layer overlying the output end of the light propagation body.

16 **[0021]** In some embodiments, the dispersion compensation layer comprises a
17 metasurface, a polarization volume hologram, or a volumetric Bragg grating.

18 **[0022]** In accordance with a third aspect of the present disclosure, there is
19 provided a display comprising: an illumination source; a light propagation body optically
20 coupled to the illumination source extending from an input end to an output end and
21 configured to guide light by total internal reflection from the input end to the output end; an
22 output coupling element located proximate to the output end for coupling light out of the
23 light propagation body; a dispersion compensation layer overlying the output end of the light
24 propagation body; and a display panel for receiving red, green, and blue light outcoupled from
25 the light propagation body, wherein the dispersion compensation layer is configured to direct
26 the red, green, and blue light to the display panel at a constant chief ray angle.

27 **[0023]** In some embodiments, the dispersion compensation layer comprises a
28 metasurface, a polarization volume hologram, or a volumetric Bragg grating.

29 **BRIEF DESCRIPTION OF THE DRAWINGS**

30 **[0024]** The accompanying drawings illustrate a number of exemplary
31 embodiments and are a part of the specification. Together with the following description,
32 these drawings demonstrate and explain various principles of the present disclosure.

1 **[0025]** FIG. 1 illustrates the outcoupling band profile of a cavity-enhanced
2 outcoupling element according to some embodiments.

3 **[0026]** FIG. 2 depicts an example spatial arrangement of plural cavity-enhanced
4 outcoupling elements on a bus waveguide according to certain embodiments.

5 **[0027]** FIG. 3 shows modeled performance data for a cavity-enhanced outcoupling
6 element according to some embodiments.

7 **[0028]** FIG. 4 illustrates example cavity-enhanced outcoupling element
8 architectures according to particular embodiments.

9 **[0029]** FIG. 5 describes various component configurations for a cavity-enhanced
10 outcoupling element according to some embodiments.

11 **[0030]** FIG. 6 shows example sub-pixel arrangements for a cavity-enhanced
12 outcoupling element according to certain embodiments.

13 **[0031]** FIG. 7 illustrates bus waveguide architectures according to various
14 embodiments.

15 **[0032]** FIG. 8 depicts a single white pixel configuration according to some
16 embodiments.

17 **[0033]** FIG. 9 depicts a single white pixel configuration according to further
18 embodiments.

19 **[0034]** FIG. 10 shows the co-integration of an external compensation layer with a
20 cavity-enhanced outcoupling element according to certain embodiments.

21 **[0035]** FIG. 11 shows the co-integration of an external compensation layer with a
22 cavity-enhanced outcoupling element according to further embodiments.

23 **[0036]** FIG. 12 illustrates the effects of mode index engineering on diffraction
24 angle uniformity according to some embodiments.

25 **[0037]** FIG. 13 is an illustration of an example artificial-reality system according to
26 some embodiments of this disclosure.

27 **[0038]** FIG. 14 is an illustration of an example artificial-reality system with a
28 handheld device according to some embodiments of this disclosure.

29 **[0039]** FIG. 15A is an illustration of example user interactions within an artificial-
30 reality system according to some embodiments of this disclosure.

31 **[0040]** FIG. 15B is an illustration of example user interactions within an artificial-
32 reality system according to some embodiments of this disclosure.

1 **[0041]** FIG. 16A is an illustration of example user interactions within an artificial-
2 reality system according to some embodiments of this disclosure.

3 **[0042]** FIG. 16B is an illustration of example user interactions within an artificial-
4 reality system according to some embodiments of this disclosure.

5 **[0043]** FIG. 17 is an illustration of an example wrist-wearable device of an artificial-
6 reality system according to some embodiments of this disclosure.

7 **[0044]** FIG. 18 is an illustration of an example wearable artificial-reality system
8 according to some embodiments of this disclosure.

9 **[0045]** FIG. 19 is an illustration of an example augmented-reality system according
10 to some embodiments of this disclosure.

11 **[0046]** FIG. 20A is an illustration of an example virtual-reality system according to
12 some embodiments of this disclosure.

13 **[0047]** FIG. 20B is an illustration of another perspective of the virtual-reality
14 system shown in FIG. 20A.

15 **[0048]** FIG. 21 is a block diagram showing system components of example
16 artificial- and virtual-reality systems.

17 **[0049]** Throughout the drawings, identical reference characters and descriptions
18 indicate similar, but not necessarily identical, elements. While the exemplary embodiments
19 described herein are susceptible to various modifications and alternative forms, specific
20 embodiments have been shown by way of example in the drawings and will be described in
21 detail herein. However, the exemplary embodiments described herein are not intended to be
22 limited to the particular forms disclosed. Rather, the present disclosure covers all
23 modifications, equivalents, and alternatives falling within the scope of the appended claims.

24 **DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS**

25 **[0050]** Virtual reality (VR) and augmented reality (AR) eyewear devices and
26 headsets enable users to experience events, such as interactions with people in a computer-
27 generated simulation of a three-dimensional world or viewing data superimposed on a real-
28 world view. Superimposing information onto a field of view may be achieved through an
29 optical head-mounted display (OHMD) or by using embedded wireless glasses with a
30 transparent heads-up display (HUD) or augmented reality overlay. VR/AR eyewear devices
31 and headsets may be used for a variety of purposes. Governments may use such devices for
32 military training, medical professionals may use such devices to simulate surgery, and

1 engineers may use such devices as design visualization aids.

2 [0051] Virtual reality and augmented reality devices and headsets typically include
3 an optical system having a microdisplay and imaging optics. The microdisplay may be
4 configured to provide an image to be viewed either directly or indirectly using, for example,
5 a micro OLED/LED display or by illuminating a liquid-crystal based display such as a liquid
6 crystal on silicon (LCoS) microdisplay/liquid crystal display (LCD). Liquid crystal on silicon is a
7 miniaturized reflective active-matrix display having a liquid crystal layer disposed over a
8 silicon backplane.

9 [0052] In an LCoS display, a liquid crystal (LC) layer is sandwiched between a sheet
10 of glass and a pixelated reflective CMOS die. The CMOS circuitry may be configured to accept
11 standard video signals and convert the signals into digital voltages that are independently
12 applied to each of the pixel regions. The pixels create a field across the LC and depending on
13 the direction of the field on each pixel, polarized light passing through the LC and reflected
14 off the pixelated regions is either rotated or not rotated. Each individual pixel is controlled by
15 the silicon, and only one polarization is sent to the viewer's eye.

16 [0053] In some instantiations, a liquid crystal display may include ferroelectric
17 liquid crystals (FLCs). In contrast to nematic liquid crystals, which are capable of switching
18 speeds in the range of approximately 10 msec, FLCs may switch at high speeds of less than
19 approximately 100 μ sec. An LCoS-based projector, such as a ferroelectric liquid crystal on
20 silicon (FLCoS) projector, typically uses three (F)LCoS chips, one each to modulate light in the
21 red, green, and blue channels. An LCoS projector may be configured to deliver the red, green,
22 and blue components of image light simultaneously, which may result in a projected image
23 having rich and well-saturated colors. As will be appreciated, an LCoS display may be
24 configured for wavelength selective switching, structured illumination, optical pulse shaping,
25 in addition to near-eye displays.

26 [0054] Due at least in part to inherent high resolution and high fill factors (minimal
27 inter-pixel spacing), visible pixelation on an LCoS machine may be essentially nonexistent
28 resulting in a high fidelity, continuous image. Moreover, in contrast to micro-mirror based
29 projection systems that can generate high frequencies that accentuate their digital nature,
30 LCoS pixel edges tend to be smoother, which may give them an analog-like response resulting
31 in a more natural image.

32 [0055] In a (F)LCoS display, an embedded photonic integrated circuit (PIC)

operative as a front-light illuminator may provide advantages in terms of resolution, power consumption, and form factor. Advantageously, the (F)LCoS+PIC display may function across the entire visible spectrum, where the PIC illuminator may be configured to emit RGB light while maintaining a desired polarization, chief ray angle, numerical aperture, and emission cone angle with a high collection efficiency. However, due to dispersion phenomena, different chief ray angles may be produced across the optical spectrum.

[0056] A light source may generate red, green, and blue light, and a laser illuminator may be configured to direct and distribute the generated light at prescribed angles onto the display panel. In certain embodiments, the generated light may be modulated by the PIC to form an array of achromatic pixels across the display.

[0057] Notwithstanding recent developments, in an (F)LCoS display with an embedded photonic integrated circuit (PIC) illuminator, it would be advantageous to provide outcoupling elements that support an achromatic outcoupling of light from the PIC while preserving a constant chief ray angle (CRA). Light outcoupled from the illuminator may be directed onto a display panel.

[0058] Disclosed are cavity-based outcoupling elements. For RGB operation, a cavity-based outcoupling element may be configured to selectively outcouple one wavelength band from a waveguide. Full RGB operation may be achieved by placing plural outcoupling elements at different spatial locations. According to further embodiments, each cavity-based outcoupling element may be configured to simultaneously outcouple red, green, or blue light with the same CRA. Such an approach may be used for color sequential operation, optionally with the co-integration of an additional dispersion compensation layer, such as a metasurface lens, a micro ball lens, etc. Within a cavity-based outcoupling element, dispersion across a given wavelength band can be managed. Furthermore, example waveguides may be engineered to decrease negative dispersion so as to decrease CRA deviation. Such waveguides may include low dispersion materials such as doped silica or alumina, or low dispersion waveguide structures.

[0059] As used herein, an optical cavity (or optical resonator) includes a configuration of elements arranged to circulate a beam of light in a closed path. A cavity-based outcoupling element may include a standing wave resonator, for example.

[0060] The following will provide, with reference to FIGS. 1-21, detailed descriptions of devices and related methods associated with the design, manufacture, and

1 operation of a cavity-based outcoupling element. By integrating the disclosed cavity-based
2 outcoupling elements with a PIC illuminator, red, green, and blue light guided by the PIC
3 illuminator may be outcoupled having the same chief ray angle. The discussion associated
4 with FIGS. 1-12 includes a description of example coupling element architectures and
5 associated component configurations. The discussion associated with FIGS. 13-21 relates to
6 exemplary virtual reality and augmented reality devices that may include one or more cavity-
7 based outcoupling elements as disclosed herein.

8 **[0061]** Broadband and narrowband coupling are depicted schematically in FIG. 1.
9 Referring to FIG. 1A, a comparative non-resonant outcoupling element has a relatively
10 broadband response. It may be adapted to outcouple RGB simultaneously, but usually with
11 uncontrollable and undesired dispersion. Red, green, and blue light may be outcoupled at
12 different angles. In contrast, as depicted in FIG. 1B, by placing the outcoupling element inside
13 a cavity, color-selective narrowband outcoupling can be achieved. A cavity-enhanced emitter
14 can selectively diffract one single color while leaving other colors unperturbed.

15 **[0062]** Color-selective cavity-enhanced outcoupling elements have many unique
16 advantages. In an example system, and with reference to FIG. 2, cavity-enhanced outcoupling
17 elements may be co-integrated with a single bus waveguide and configured to outcouple
18 R/G/B at different locations. In this manner, desired outcoupling responses such as cone angle
19 and outcoupling strength can be engineered separately for red, green, and blue light.
20 Furthermore, achromatic outcoupling from a PIC may allow tuning of an optical delay
21 between emitters, which may mitigate the creation of coherent optical artifacts.

22 **[0063]** Referring to FIG. 3, simulation results demonstrate color-selective
23 outcoupling. According to various embodiments, outcoupling strength may be determined by
24 the distance between a bus waveguide and each respective grating, the cavity mirror
25 reflectivity, and the grating/emitter intrinsic scattering strength. Performance data are shown
26 in FIG. 3A, cavity modes in linear and log scales are depicted in FIG. 3B, and a profile showing
27 far-field cavity radiation is depicted in FIG. 3C.

28 **[0064]** Turning to FIG. 4, shown are example configurations for a cavity-enhanced
29 outcoupling element. A cavity-enhanced emitter may include a bus waveguide, a pair of
30 reflectors defining an optical cavity, and an emitter located within the cavity. In certain
31 implementations, the cavity/emitter architecture may be configured to outcouple a selected
32 wavelength band to the exclusion of unselected wavelength bands, i.e., via constructive

1 interference of the selected wavelength band within the cavity.

2 [0065] According to various embodiments, the cavity and the emitter can be
3 etched into the bus waveguide, located on a side of the bus waveguide as depicted in FIG. 4A,
4 or formed on a separate layer located proximate to the waveguide as depicted in FIG. 4B.

5 [0066] With reference to FIG. 5, which are top-down views of example cavity-
6 enhanced outcoupling elements, the various components may be independently designed.
7 The bus waveguide may include, for example, a ridge waveguide, a rib waveguide, a diffused
8 waveguide, a buried waveguide, and the like. Example reflectors may include distributed
9 Bragg reflectors (DBRs) or photonic crystal (PhC) reflectors. Suitable emitters may include a
10 simple defect (e.g., notched or empty section), a short grating, or inversely-designed freeform
11 nanostructures.

12 [0067] Referring to FIG. 6, the RGB pixel arrangement may have any suitable
13 architecture. One advantage of cavity-enhanced emitters is that the color-selective
14 outcoupling elements can be displaced from the bus waveguide. Another advantage may
15 include an overall smaller footprint relative to comparative outcoupling elements. For
16 instance, RGB cavity emitters (i.e., wavelength selective output coupling elements) and the
17 bus waveguide can be located either side-by-side (parallel) or in an overlapping (serial)
18 configuration, as illustrated in FIG. 6A and FIG. 6B, respectively, although further
19 configurations are contemplated. Furthermore, the RGB subpixels may be arrayed on any
20 suitable lattice, e.g., rectangular, pentagonal, hexagonal, etc.

21 [0068] Depending on the pixel pitch requirements, a light engine may include one
22 or more bus waveguides, i.e., a single bus waveguide for RGB or a pair of bus waveguides for
23 improved efficiency and optical uniformity.

24 [0069] With reference to FIG. 7, in one example, RGB can share the same bus
25 waveguide with the spatial arrangement of the cavity-enhanced outcoupling elements (e.g.,
26 R and BG) arranged differently for different colors or color combinations. According to a
27 further example, the red channel may include a dedicated conventional outcoupling grating
28 coupled to a first bus waveguide, and green and blue light may share a second bus waveguide
29 with a cavity-enhanced outcoupling element designed for blue light and operative as a
30 traditional grating for green light. In particular embodiments, emission from the outcoupling
31 gratings may or may not overlap proximate to the center of the LC panel, as shown in FIGS.
32 7A and 7B, respectively.

1 **[0070]** A further advantage of cavity-enhanced emitters is that the chief ray angle
2 (CRA) is always directed toward the surface normal of the liquid crystal display panel at the
3 resonant condition. This is because light is trapped as a standing wave with counter-
4 propagating components inside the cavity, which breaks away from the usual diffraction
5 dispersion. As shown schematically in FIG. 8, based on this principle, a single white pixel can
6 be designed to operate for all RGB wavelengths instead of designing separate color-selective
7 cavity-enhanced outcoupling elements. Such an approach may be used for color sequential
8 operation.

9 **[0071]** According to certain embodiments, a single cavity-based outcoupling
10 element may be configured to simultaneously outcouple red, green, or blue light with the
11 same CRA. With reference to FIG. 9, the photonic crystals of the cavity-enhanced outcoupling
12 elements may be configured with 2 bandgaps (e.g., blue and green) and may emit red as a
13 conventional outcoupling element. If provided, a DBR/resonator may be configured with
14 resonant wavelengths and a free-spectral range (FSR) to align with input red, green, and blue
15 wavelengths.

16 **[0072]** According to further embodiments, a metasurface, volume Bragg grating
17 (VBG), polarization volume hologram (PVH), or analogous compensating structure may be
18 incorporated into an external layer located proximate to a waveguide. A compensating
19 structure may be adapted to correct for chief ray angle deviation across different wavelengths
20 such that RGB are each directed to a normal angle relative to a display panel. Such a
21 compensating structure may be co-integrated with a cavity-enhanced outcoupling element
22 or, as shown in FIG. 10, implemented independent of a cavity-enhanced outcoupling element.
23 With reference to FIG. 11, an external lens such as a doublet lens may include one or more
24 meta surfaces and may be configured to compensate for chromatic aberration and focusing.
25 Metasurface lenses may be monolithically integrated within the PIC backlight unit.

26 **[0073]** According to still further embodiments, and with reference to FIG. 12, the
27 dispersion characteristics of red, green, and blue light may be tuned by controlling the
28 effective mode index within a waveguide. For instance, through mode index engineering, a
29 waveguide may be sized and dimensioned to support higher order modes of propagation for
30 each wavelength band. By defining respective modes of propagation for each of red, green,
31 and blue light, achromatic outcoupling may be achieved at a constant CRA.

32 **[0074]** The grating equation (1) shows a strong correlation between the diffraction

angle and both the wavelength of light and the index of the guided mode and may be used to determine the diffraction angle of the grating emitter. By utilizing different order modes for each of the three RGB wavelengths, wavelength differences may be compensated to ensure that the diffraction angle is uniform.

$$k_0 n_{eff}(\lambda_0) = k_0 n_c(\lambda_0) \sin \theta_0 + \frac{2\pi}{\Lambda} \quad (1)$$

[0075] With n_{eff}/λ constant or essentially constant across RGB for positively dispersive materials or high confinement waveguide structures, such as with the presently-disclosed cavity-enhanced outcoupling elements, the grating CRA may be essentially constant.

[0076] By way of example, using a 120 nm thick and 600 nm wide SiC waveguide with silicon dioxide cladding, a sufficiently large index difference between the fundamental and high-order modes may be obtained to match the diffraction angle for RGB light. For a grating pitch of 293 nm, for example, diffraction angles are equal to -1.1° , -4.0° , and 3.5° for red (635 nm), green (518 nm), and blue (460 nm) light, respectively, which approximate normal emission. Symmetrical normal emission may be obtained by injecting light from both sides of the waveguide using two sets of RGB lasers.

Example Embodiments

[0077] Example 1: A display includes an illumination source and an illuminator, where the illuminator has: a light propagation body optically coupled to the illumination source and extending from an input end to an output end and configured to guide light received from the illumination source by total internal reflection from the input end to the output end, a first output coupling element located proximate to the output end for coupling red light out of the light propagation body, a second output coupling element located proximate to the output end for coupling green light out of the light propagation body, and a third output coupling element located proximate to the output end for coupling blue light out of the light propagation body, where the first, second, and third output coupling elements each include an emitter disposed between a respective pair of opposing resonator mirrors, such that the first, second, and third output coupling elements outcouple the red, green, and blue light at a constant chief ray angle.

[0078] Example 2: The display of Example 1, where the illumination source

1 includes a red laser, a green laser, and a blue laser.

2 **[0079]** Example 3: The display of any of Examples 1 and 2, where the first, second,
3 and third output coupling elements each include a surface relief grating.

4 **[0080]** Example 4: The display of any of Examples 1-3, where the first, second, and
5 third output coupling elements are configured to simultaneously outcouple the red, green,
6 and blue light.

7 **[0081]** Example 5: The display of any of Examples 1-4, where the light propagation
8 body is configured to distribute light received from the illumination source over a two-
9 dimensional display area.

10 **[0082]** Example 6: The display of any of Examples 1-5, where each emitter includes
11 a cavity enhanced emitter.

12 **[0083]** Example 7: The display of any of Examples 1-6, where the first output
13 coupling element is configured to outcouple red light to the exclusion of green light and blue
14 light, the second output coupling element is configured to outcouple green light to the
15 exclusion of red light and blue light, and the third output coupling element is configured to
16 outcouple blue light to the exclusion of red light and green light.

17 **[0084]** Example 8: The display of any of Examples 1-7, further including a display
18 panel overlapping the illuminator, where the display panel is configured to receive the red,
19 green, and blue light outcoupled from the light propagation body.

20 **[0085]** Example 9: The display of any of Examples 1-8, further including a
21 dispersion compensation layer overlying the output end of the light propagation body.

22 **[0086]** Example 10: The display of Example 9, where the dispersion compensation
23 layer includes a metasurface, a polarization volume hologram, or a volumetric Bragg grating.

24 **[0087]** Example 11: A display includes an illumination source, a light propagation
25 body optically coupled to the illumination source extending from an input end to an output
26 end and configured to guide light by total internal reflection from the input end to the output
27 end, and an output coupling element located proximate to the output end for coupling light
28 out of the light propagation body, where the output coupling element includes an emitter
29 disposed between two mutually opposing resonator mirrors and is configured to outcouple
30 red, green, and blue light at a constant chief ray angle.

31 **[0088]** Example 12: The display of Example 11, where the illumination source
32 includes a red laser, a green laser, and a blue laser.

1 **[0089]** Example 13: The display of any of Examples 11 and 12, where the light
2 propagation body is configured to distribute light received from the illumination source over
3 a two-dimensional display area.

4 **[0090]** Example 14: The display of any of Examples 11-13, where each emitter
5 includes a cavity enhanced emitter.

6 **[0091]** Example 15: The display of any of Examples 11-14, where the first output
7 coupling element is configured to outcouple red light to the exclusion of green light and blue
8 light, the second output coupling element is configured to outcouple green light to the
9 exclusion of red light and blue light, and the third output coupling element is configured to
10 outcouple blue light to the exclusion of red light and green light.

11 **[0092]** Example 16: The display of any of Examples 11-15, further including a
12 display panel overlapping the illuminator, where the display panel is configured to receive the
13 red, green, and blue light outcoupled from the light propagation body.

14 **[0093]** Example 17: The display of any of Examples 11-16, further including a
15 dispersion compensation layer overlying the output end of the light propagation body.

16 **[0094]** Example 18: The display of Example 17, where the dispersion
17 compensation layer includes a metasurface, a polarization volume hologram, or a volumetric
18 Bragg grating.

19 **[0095]** Example 19: A display includes an illumination source, a light propagation
20 body optically coupled to the illumination source extending from an input end to an output
21 end and configured to guide light by total internal reflection from the input end to the output
22 end, an output coupling element located proximate to the output end for coupling light out
23 of the light propagation body, a dispersion compensation layer overlying the output end of
24 the light propagation body, and a display panel for receiving red, green, and blue light
25 outcoupled from the light propagation body, wherein the dispersion compensation layer is
26 configured to direct the red, green, and blue light to the display panel at a constant chief ray
27 angle.

28 **[0096]** Example 20: The display of Example 19, where the dispersion
29 compensation layer includes a metasurface, a polarization volume hologram, or a volumetric
30 Bragg grating.

31 **[0097]** Embodiments of the present disclosure may include or be implemented in
32 conjunction with various types of Artificial-Reality (AR) systems. AR may be any superimposed

1 functionality and/or sensory-detectable content presented by an artificial-reality system
2 within a user's physical surroundings. In other words, AR is a form of reality that has been
3 adjusted in some manner before presentation to a user. AR can include and/or represent
4 virtual reality (VR), augmented reality, mixed AR (MAR), or some combination and/or
5 variation of these types of realities. Similarly, AR environments may include VR environments
6 (including non-immersive, semi-immersive, and fully immersive VR environments),
7 augmented-reality environments (including marker-based augmented-reality environments,
8 markerless augmented-reality environments, location-based augmented-reality
9 environments, and projection-based augmented-reality environments), hybrid-reality
10 environments, and/or any other type or form of mixed- or alternative-reality environments.

11 **[0098]** AR content may include completely computer-generated content or
12 computer-generated content combined with captured (e.g., real-world) content. Such AR
13 content may include video, audio, haptic feedback, or some combination thereof, any of
14 which may be presented in a single channel or in multiple channels (such as stereo video that
15 produces a three-dimensional (3D) effect to the viewer). Additionally, in some embodiments,
16 AR may also be associated with applications, products, accessories, services, or some
17 combination thereof, that are used to, for example, create content in an artificial reality
18 and/or are otherwise used in (e.g., to perform activities in) an artificial reality.

19 **[0099]** AR systems may be implemented in a variety of different form factors and
20 configurations. Some AR systems may be designed to work without near-eye displays (NEDs).
21 Other AR systems may include a NED that also provides visibility into the real world (such as,
22 e.g., VR system 2000 in FIGS. 20A and 20B). While some AR devices may be self-contained
23 systems, other AR devices may communicate and/or coordinate with external devices to
24 provide an AR experience to a user. Examples of such external devices include handheld
25 controllers, mobile devices, desktop computers, devices worn by a user, devices worn by one
26 or more other users, and/or any other suitable external system.

27 **[0100]** FIGS. 13-16B illustrate example artificial-reality (AR) systems in accordance
28 with some embodiments. FIG. 13 shows a first AR system 1300 and first example user
29 interactions using a wrist-wearable device 1302, a head-wearable device (e.g., AR system
30 1900), and/or a handheld intermediary processing device (HIPD) 1306. FIG. 14 shows a second
31 AR system 1400 and second example user interactions using a wrist-wearable device 1402,
32 AR glasses 1404, and/or an HIPD 1406. FIGS. 15A and 15B show a third AR system 1500 and

1 third example user 1508 interactions using a wrist-wearable device 1502, a head-wearable
2 device (e.g., VR headset 1550), and/or an HIPD 1506. FIGS. 16A and 16B show a fourth AR
3 system 1600 and fourth example user 1608 interactions using a wrist-wearable device 1630,
4 VR headset 1620, and/or a haptic device 1660 (e.g., wearable gloves).

5 **[0101]** A wrist-wearable device 1700, which can be used for wrist-wearable device
6 1302, 1402, 1502, 1630, and one or more of its components, are described below in reference
7 to FIGS. 17 and 18. AR system 1900 and VR system 2000, which can respectively be used for
8 AR glasses 1304, 1404 or VR headset 1550, 1620, and their one or more components are
9 described below in reference to FIGS. 19-21.

10 **[0102]** Referring to FIG. 13, wrist-wearable device 1302, AR glasses 1304, and/or
11 HIPD 1306 can communicatively couple via a network 1325 (e.g., cellular, near field, Wi-Fi,
12 personal area network, wireless LAN, etc.). Additionally, wrist-wearable device 1302, AR
13 glasses 1304, and/or HIPD 1306 can also communicatively couple with one or more servers
14 1330, computers 1340 (e.g., laptops, computers, etc.), mobile devices 1350 (e.g.,
15 smartphones, tablets, etc.), and/or other electronic devices via network 1325 (e.g., cellular,
16 near field, Wi-Fi, personal area network, wireless LAN, etc.).

17 **[0103]** In FIG. 13, a user 1308 is shown wearing wrist-wearable device 1302 and
18 AR glasses 1304 and having HIPD 1306 on their desk. The wrist-wearable device 1302, AR
19 glasses 1304, and HIPD 1306 facilitate user interaction with an AR environment. In particular,
20 as shown by first AR system 1300, wrist-wearable device 1302, AR glasses 1304, and/or HIPD
21 1306 cause presentation of one or more avatars 1310, digital representations of contacts
22 1312, and virtual objects 1314. As discussed below, user 1308 can interact with one or more
23 avatars 1310, digital representations of contacts 1312, and virtual objects 1314 via wrist-
24 wearable device 1302, AR glasses 1304, and/or HIPD 1306.

25 **[0104]** User 1308 can use any of wrist-wearable device 1302, AR glasses 1304,
26 and/or HIPD 1306 to provide user inputs. For example, user 1308 can perform one or more
27 hand gestures that are detected by wrist-wearable device 1302 (e.g., using one or more EMG
28 sensors and/or IMUs, described below in reference to FIGS. 17 and 18) and/or AR glasses 1304
29 (e.g., using one or more image sensor or camera, described below in reference to FIGS. 19-
30 10) to provide a user input. Alternatively, or additionally, user 1308 can provide a user input
31 via one or more touch surfaces of wrist-wearable device 1302, AR glasses 1304, HIPD 1306,
32 and/or voice commands captured by a microphone of wrist-wearable device 1302, AR glasses

1 1304, and/or HIPD 1306. In some embodiments, wrist-wearable device 1302, AR glasses 1304,
2 and/or HIPD 1306 include a digital assistant to help user 1308 in providing a user input (e.g.,
3 completing a sequence of operations, suggesting different operations or commands,
4 providing reminders, confirming a command, etc.). In some embodiments, user 1308 can
5 provide a user input via one or more facial gestures and/or facial expressions. For example,
6 cameras of wrist-wearable device 1302, AR glasses 1304, and/or HIPD 1306 can track eyes of
7 user 1308 for navigating a user interface.

8 **[0105]** Wrist-wearable device 1302, AR glasses 1304, and/or HIPD 1306 can
9 operate alone or in conjunction to allow user 1308 to interact with the AR environment. In
10 some embodiments, HIPD 1306 is configured to operate as a central hub or control center for
11 the wrist-wearable device 1302, AR glasses 1304, and/or another communicatively coupled
12 device. For example, user 1308 can provide an input to interact with the AR environment at
13 any of wrist-wearable device 1302, AR glasses 1304, and/or HIPD 1306, and HIPD 1306 can
14 identify one or more back-end and front-end tasks to cause the performance of the requested
15 interaction and distribute instructions to cause the performance of the one or more back-end
16 and front-end tasks at wrist-wearable device 1302, AR glasses 1304, and/or HIPD 1306. In
17 some embodiments, a back-end task is a background processing task that is not perceptible
18 by the user (e.g., rendering content, decompression, compression, etc.), and a front-end task
19 is a user-facing task that is perceptible to the user (e.g., presenting information to the user,
20 providing feedback to the user, etc.). As described below, HIPD 1306 can perform the back-
21 end tasks and provide wrist-wearable device 1302 and/or AR glasses 1304 operational data
22 corresponding to the performed back-end tasks such that wrist-wearable device 1302 and/or
23 AR glasses 1304 can perform the front-end tasks. In this way, HIPD 1306, which has more
24 computational resources and greater thermal headroom than wrist-wearable device 1302
25 and/or AR glasses 1304, performs computationally intensive tasks and reduces the computer
26 resource utilization and/or power usage of wrist-wearable device 1302 and/or AR glasses
27 1304.

28 **[0106]** In the example shown by first AR system 1300, HIPD 1306 identifies one or
29 more back-end tasks and front-end tasks associated with a user request to initiate an AR video
30 call with one or more other users (represented by avatar 1310 and the digital representation
31 of contact 1312) and distributes instructions to cause the performance of the one or more
32 back-end tasks and front-end tasks. In particular, HIPD 1306 performs back-end tasks for

1 processing and/or rendering image data (and other data) associated with the AR video call
2 and provides operational data associated with the performed back-end tasks to AR glasses
3 1304 such that the AR glasses 1304 perform front-end tasks for presenting the AR video call
4 (e.g., presenting avatar 1310 and digital representation of contact 1312).

5 **[0107]** In some embodiments, HIPD 1306 can operate as a focal or anchor point
6 for causing the presentation of information. This allows user 1308 to be generally aware of
7 where information is presented. For example, as shown in first AR system 1300, avatar 1310
8 and the digital representation of contact 1312 are presented above HIPD 1306. In particular,
9 HIPD 1306 and AR glasses 1304 operate in conjunction to determine a location for presenting
10 avatar 1310 and the digital representation of contact 1312. In some embodiments,
11 information can be presented a predetermined distance from HIPD 1306 (e.g., within 5
12 meters). For example, as shown in first AR system 1300, virtual object 1314 is presented on
13 the desk some distance from HIPD 1306. Similar to the above example, HIPD 1306 and AR
14 glasses 1304 can operate in conjunction to determine a location for presenting virtual object
15 1314. Alternatively, in some embodiments, presentation of information is not bound by
16 HIPD 1306. More specifically, avatar 1310, digital representation of contact 1312, and virtual
17 object 1314 do not have to be presented within a predetermined distance of HIPD 1306.

18 **[0108]** User inputs provided at wrist-wearable device 1302, AR glasses 1304,
19 and/or HIPD 1306 are coordinated such that the user can use any device to initiate, continue,
20 and/or complete an operation. For example, user 1308 can provide a user input to AR glasses
21 1304 to cause AR glasses 1304 to present virtual object 1314 and, while virtual object 1314 is
22 presented by AR glasses 1304, user 1308 can provide one or more hand gestures via wrist-
23 wearable device 1302 to interact and/or manipulate virtual object 1314.

24 **[0109]** FIG. 14 shows a user 1408 wearing a wrist-wearable device 1402 and AR
25 glasses 1404, and holding an HIPD 1406. In second AR system 1400, the wrist-wearable device
26 1402, AR glasses 1404, and/or HIPD 1406 are used to receive and/or provide one or more
27 messages to a contact of user 1408. In particular, wrist-wearable device 1402, AR glasses
28 1404, and/or HIPD 1406 detect and coordinate one or more user inputs to initiate a messaging
29 application and prepare a response to a received message via the messaging application.

30 **[0110]** In some embodiments, user 1408 initiates, via a user input, an application
31 on wrist-wearable device 1402, AR glasses 1404, and/or HIPD 1406 that causes the application
32 to initiate on at least one device. For example, in second AR system 1400, user 1408 performs

1 a hand gesture associated with a command for initiating a messaging application (represented
2 by messaging user interface 1416), wrist-wearable device 1402 detects the hand gesture and,
3 based on a determination that user 1408 is wearing AR glasses 1404, causes AR glasses 1404
4 to present a messaging user interface 1416 of the messaging application. AR glasses 1404 can
5 present messaging user interface 1416 to user 1408 via its display (e.g., as shown by a field of
6 view 1418 of user 1408). In some embodiments, the application is initiated and executed on
7 the device (e.g., wrist-wearable device 1402, AR glasses 1404, and/or HIPD 1406) that detects
8 the user input to initiate the application, and the device provides another device operational
9 data to cause the presentation of the messaging application. For example, wrist-wearable
10 device 1402 can detect the user input to initiate a messaging application, initiate and run the
11 messaging application, and provide operational data to AR glasses 1404 and/or HIPD 1406 to
12 cause presentation of the messaging application. Alternatively, the application can be
13 initiated and executed at a device other than the device that detected the user input. For
14 example, wrist-wearable device 1402 can detect the hand gesture associated with initiating
15 the messaging application and cause HIPD 1406 to run the messaging application and
16 coordinate the presentation of the messaging application.

17 **[0111]** Further, user 1408 can provide a user input provided at wrist-wearable
18 device 1402, AR glasses 1404, and/or HIPD 1406 to continue and/or complete an operation
19 initiated at another device. For example, after initiating the messaging application via wrist-
20 wearable device 1402 and while AR glasses 1404 present messaging user interface 1416, user
21 1408 can provide an input at HIPD 1406 to prepare a response (e.g., shown by the swipe
22 gesture performed on HIPD 1406). Gestures performed by user 1408 on HIPD 1406 can be
23 provided and/or displayed on another device. For example, a swipe gestured performed on
24 HIPD 1406 is displayed on a virtual keyboard of messaging user interface 1416 displayed by
25 AR glasses 1404.

26 **[0112]** In some embodiments, wrist-wearable device 1402, AR glasses 1404, HIPD
27 1406, and/or any other communicatively coupled device can present one or more
28 notifications to user 1408. The notification can be an indication of a new message, an
29 incoming call, an application update, a status update, etc. User 1408 can select the
30 notification via wrist-wearable device 1402, AR glasses 1404, and/or HIPD 1406 and can cause
31 presentation of an application or operation associated with the notification on at least one
32 device. For example, user 1408 can receive a notification that a message was received at

1 wrist-wearable device 1402, AR glasses 1404, HIPD 1406, and/or any other communicatively
2 coupled device and can then provide a user input at wrist-wearable device 1402, AR glasses
3 1404, and/or HIPD 1406 to review the notification, and the device detecting the user input
4 can cause an application associated with the notification to be initiated and/or presented at
5 wrist-wearable device 1402, AR glasses 1404, and/or HIPD 1406.

6 **[0113]** While the above example describes coordinated inputs used to interact
7 with a messaging application, user inputs can be coordinated to interact with any number of
8 applications including, but not limited to, gaming applications, social media applications,
9 camera applications, web-based applications, financial applications, etc. For example, AR
10 glasses 1404 can present to user 1408 game application data, and HIPD 1406 can be used as
11 a controller to provide inputs to the game. Similarly, user 1408 can use wrist-wearable device
12 1402 to initiate a camera of AR glasses 1404, and user 308 can use wrist-wearable device
13 1402, AR glasses 1404, and/or HIPD 1406 to manipulate the image capture (e.g., zoom in or
14 out, apply filters, etc.) and capture image data.

15 **[0114]** Users may interact with the devices disclosed herein in a variety of ways.
16 For example, as shown in FIGS. 15A and 15B, a user 1508 may interact with an AR system
17 1500 by donning a VR headset 1550 while holding HIPD 1506 and wearing wrist-wearable
18 device 1502. In this example, AR system 1500 may enable a user to interact with a game 1510
19 by swiping their arm. One or more of VR headset 1550, HIPD 1506, and wrist-wearable device
20 1502 may detect this gesture and, in response, may display a sword strike in game 1510.
21 Similarly, in FIGS. 16A and 16B, a user 1608 may interact with an AR system 1600 by donning
22 a VR headset 1620 while wearing haptic device 1660 and wrist-wearable device 1630. In this
23 example, AR system 1600 may enable a user to interact with a game 1610 by swiping their
24 arm. One or more of VR headset 1620, haptic device 1660, and wrist-wearable device 1630
25 may detect this gesture and, in response, may display a spell being cast in game 1510.

26 **[0115]** Having discussed example AR systems, devices for interacting with such AR
27 systems and other computing systems more generally will now be discussed in greater detail.
28 Some explanations of devices and components that can be included in some or all of the
29 example devices discussed below are explained herein for ease of reference. Certain types of
30 the components described below may be more suitable for a particular set of devices, and
31 less suitable for a different set of devices. But subsequent reference to the components
32 explained here should be considered to be encompassed by the descriptions provided.

1 **[0116]** In some embodiments discussed below, example devices and systems,
2 including electronic devices and systems, will be addressed. Such example devices and
3 systems are not intended to be limiting, and one of skill in the art will understand that
4 alternative devices and systems to the example devices and systems described herein may be
5 used to perform the operations and construct the systems and devices that are described
6 herein.

7 **[0117]** An electronic device may be a device that uses electrical energy to perform
8 a specific function. An electronic device can be any physical object that contains electronic
9 components such as transistors, resistors, capacitors, diodes, and integrated circuits.
10 Examples of electronic devices include smartphones, laptops, digital cameras, televisions,
11 gaming consoles, and music players, as well as the example electronic devices discussed
12 herein. As described herein, an intermediary electronic device may be a device that sits
13 between two other electronic devices and/or a subset of components of one or more
14 electronic devices and facilitates communication, data processing, and/or data transfer
15 between the respective electronic devices and/or electronic components.

16 **[0118]** An integrated circuit may be an electronic device made up of multiple
17 interconnected electronic components such as transistors, resistors, and capacitors. These
18 components may be etched onto a small piece of semiconductor material, such as silicon.
19 Integrated circuits may include analog integrated circuits, digital integrated circuits, mixed
20 signal integrated circuits, and/or any other suitable type or form of integrated circuit.
21 Examples of integrated circuits include application-specific integrated circuits (ASICs),
22 processing units, central processing units (CPUs), co-processors, and accelerators.

23 **[0119]** Analog integrated circuits, such as sensors, power management circuits,
24 and operational amplifiers, may process continuous signals and perform analog functions
25 such as amplification, active filtering, demodulation, and mixing. Examples of analog
26 integrated circuits include linear integrated circuits and radio frequency circuits.

27 **[0120]** Digital integrated circuits, which may be referred to as logic integrated
28 circuits, may include microprocessors, microcontrollers, memory chips, interfaces, power
29 management circuits, programmable devices, and/or any other suitable type or form of
30 integrated circuit. In some embodiments, examples of integrated circuits include central
31 processing units (CPUs),

32 **[0121]** Processing units, such as CPUs, may be electronic components that are

1 responsible for executing instructions and controlling the operation of an electronic device
2 (e.g., a computer). There are various types of processors that may be used interchangeably,
3 or may be specifically required, by embodiments described herein. For example, a processor
4 may be: (i) a general processor designed to perform a wide range of tasks, such as running
5 software applications, managing operating systems, and performing arithmetic and logical
6 operations; (ii) a microcontroller designed for specific tasks such as controlling electronic
7 devices, sensors, and motors; (iii) an accelerator, such as a graphics processing unit (GPU),
8 designed to accelerate the creation and rendering of images, videos, and animations (e.g.,
9 virtual-reality animations, such as three-dimensional modeling); (iv) a field-programmable
10 gate array (FPGA) that can be programmed and reconfigured after manufacturing and/or can
11 be customized to perform specific tasks, such as signal processing, cryptography, and machine
12 learning; and/or (v) a digital signal processor (DSP) designed to perform mathematical
13 operations on signals such as audio, video, and radio waves. One or more processors of one
14 or more electronic devices may be used in various embodiments described herein.

15 **[0122]** Memory generally refers to electronic components in a computer or
16 electronic device that store data and instructions for the processor to access and manipulate.
17 Examples of memory can include: (i) random access memory (RAM) configured to store data
18 and instructions temporarily; (ii) read-only memory (ROM) configured to store data and
19 instructions permanently (e.g., one or more portions of system firmware, and/or boot
20 loaders) and/or semi-permanently; (iii) flash memory, which can be configured to store data
21 in electronic devices (e.g., USB drives, memory cards, and/or solid-state drives (SSDs)); and/or
22 (iv) cache memory configured to temporarily store frequently accessed data and instructions.
23 Memory, as described herein, can store structured data (e.g., SQL databases, MongoDB
24 databases, GraphQL data, JSON data, etc.). Other examples of data stored in memory can
25 include (i) profile data, including user account data, user settings, and/or other user data
26 stored by the user, (ii) sensor data detected and/or otherwise obtained by one or more
27 sensors, (iii) media content data including stored image data, audio data, documents, and the
28 like, (iv) application data, which can include data collected and/or otherwise obtained and
29 stored during use of an application, and/or any other types of data described herein.

30 **[0123]** Controllers may be electronic components that manage and coordinate
31 the operation of other components within an electronic device (e.g., controlling inputs,
32 processing data, and/or generating outputs). Examples of controllers can include: (i)

1 microcontrollers, including small, low-power controllers that are commonly used in
2 embedded systems and Internet of Things (IoT) devices; (ii) programmable logic controllers
3 (PLCs) that may be configured to be used in industrial automation systems to control and
4 monitor manufacturing processes; (iii) system-on-a-chip (SoC) controllers that integrate
5 multiple components such as processors, memory, I/O interfaces, and other peripherals into
6 a single chip; and/or (iv) DSPs.

7 **[0124]** A power system of an electronic device may be configured to convert
8 incoming electrical power into a form that can be used to operate the device. A power system
9 can include various components, such as (i) a power source, which can be an alternating
10 current (AC) adapter or a direct current (DC) adapter power supply, (ii) a charger input, which
11 can be configured to use a wired and/or wireless connection (which may be part of a
12 peripheral interface, such as a USB, micro-USB interface, near-field magnetic coupling,
13 magnetic inductive and magnetic resonance charging, and/or radio frequency (RF) charging),
14 (iii) a power-management integrated circuit, configured to distribute power to various
15 components of the device and to ensure that the device operates within safe limits (e.g.,
16 regulating voltage, controlling current flow, and/or managing heat dissipation), and/or (iv) a
17 battery configured to store power to provide usable power to components of one or more
18 electronic devices.

19 **[0125]** Peripheral interfaces may be electronic components (e.g., of electronic
20 devices) that allow electronic devices to communicate with other devices or peripherals and
21 can provide the ability to input and output data and signals. Examples of peripheral interfaces
22 can include (i) universal serial bus (USB) and/or micro-USB interfaces configured for
23 connecting devices to an electronic device, (ii) Bluetooth interfaces configured to allow
24 devices to communicate with each other, including Bluetooth low energy (BLE), (iii) near field
25 communication (NFC) interfaces configured to be short-range wireless interfaces for
26 operations such as access control, (iv) POGO pins, which may be small, spring-loaded pins
27 configured to provide a charging interface, (v) wireless charging interfaces, (vi) GPS interfaces,
28 (vii) Wi-Fi interfaces for providing a connection between a device and a wireless network,
29 and/or (viii) sensor interfaces.

30 **[0126]** Sensors may be electronic components (e.g., in and/or otherwise in
31 electronic communication with electronic devices, such as wearable devices) configured to
32 detect physical and environmental changes and generate electrical signals. Examples of

sensors can include (i) imaging sensors for collecting imaging data (e.g., including one or more cameras disposed on a respective electronic device), (ii) biopotential-signal sensors, (iii) inertial measurement units (e.g., IMUs) for detecting, for example, angular rate, force, magnetic field, and/or changes in acceleration, (iv) heart rate sensors for measuring a user's heart rate, (v) SpO2 sensors for measuring blood oxygen saturation and/or other biometric data of a user, (vi) capacitive sensors for detecting changes in potential at a portion of a user's body (e.g., a sensor-skin interface), and/or (vii) light sensors (e.g., time-of-flight sensors, infrared light sensors, visible light sensors, etc.).

[0127] Biopotential-signal-sensing components may be devices used to measure electrical activity within the body (e.g., biopotential-signal sensors). Some types of biopotential-signal sensors include (i) electroencephalography (EEG) sensors configured to measure electrical activity in the brain to diagnose neurological disorders, (ii) electrocardiography (ECG or EKG) sensors configured to measure electrical activity of the heart to diagnose heart problems, (iii) electromyography (EMG) sensors configured to measure the electrical activity of muscles and to diagnose neuromuscular disorders, and (iv) electrooculography (EOG) sensors configured to measure the electrical activity of eye muscles to detect eye movement and diagnose eye disorders.

[0128] An application stored in memory of an electronic device (e.g., software) may include instructions stored in the memory. Examples of such applications include (i) games, (ii) word processors, (iii) messaging applications, (iv) media-streaming applications, (v) financial applications, (vi) calendars, (vii) clocks, and (viii) communication interface modules for enabling wired and/or wireless connections between different respective electronic devices (e.g., IEEE 1902.15.4, Wi-Fi, ZigBee, 6LoWPAN, Thread, Z-Wave, Bluetooth Smart, ISA100.11a, WirelessHART, or MiWi), custom or standard wired protocols (e.g., Ethernet or HomePlug), and/or any other suitable communication protocols).

[0129] A communication interface may be a mechanism that enables different systems or devices to exchange information and data with each other, including hardware, software, or a combination of both hardware and software. For example, a communication interface can refer to a physical connector and/or port on a device that enables communication with other devices (e.g., USB, Ethernet, HDMI, Bluetooth). In some embodiments, a communication interface can refer to a software layer that enables different software programs to communicate with each other (e.g., application programming

1 interfaces (APIs), protocols like HTTP and TCP/IP, etc.).

2 [0130] A graphics module may be a component or software module that is
3 designed to handle graphical operations and/or processes and can include a hardware
4 module and/or a software module.

5 [0131] Non-transitory computer-readable storage media may be physical devices
6 or storage media that can be used to store electronic data in a non-transitory form (e.g., such
7 that the data is stored permanently until it is intentionally deleted or modified).

8 [0132] FIGS. 17 and 18 illustrate an example wrist-wearable device 1700 and an
9 example computer system 1800, in accordance with some embodiments. Wrist-wearable
10 device 1700 is an instance of wearable device 1302 described in FIG. 13 herein, such that the
11 wearable device 1302 should be understood to have the features of the wrist-wearable device
12 1700 and vice versa. FIG. 18 illustrates components of the wrist-wearable device 1700, which
13 can be used individually or in combination, including combinations that include other
14 electronic devices and/or electronic components.

15 [0133] FIG. 17 shows a wearable band 1710 and a watch body 1720 (or capsule)
16 being coupled, as discussed below, to form wrist-wearable device 1700. Wrist-wearable
17 device 1700 can perform various functions and/or operations associated with navigating
18 through user interfaces and selectively opening applications as well as the functions and/or
19 operations described above with reference to FIGS. 13-16B.

20 [0134] As will be described in more detail below, operations executed by wrist-
21 wearable device 1700 can include (i) presenting content to a user (e.g., displaying visual
22 content via a display 1705), (ii) detecting (e.g., sensing) user input (e.g., sensing a touch on
23 peripheral button 1723 and/or at a touch screen of the display 1705, a hand gesture detected
24 by sensors (e.g., biopotential sensors)), (iii) sensing biometric data (e.g., neuromuscular
25 signals, heart rate, temperature, sleep, etc.) via one or more sensors 1713, messaging (e.g.,
26 text, speech, video, etc.); image capture via one or more imaging devices or cameras 1725,
27 wireless communications (e.g., cellular, near field, Wi-Fi, personal area network, etc.),
28 location determination, financial transactions, providing haptic feedback, providing alarms,
29 providing notifications, providing biometric authentication, providing health monitoring,
30 providing sleep monitoring, etc.

31 [0135] The above-example functions can be executed independently in watch
32 body 1720, independently in wearable band 1710, and/or via an electronic communication

1 between watch body 1720 and wearable band 1710. In some embodiments, functions can be
2 executed on wrist-wearable device 1700 while an AR environment is being presented (e.g.,
3 via one of AR systems 1300 to 1600). The wearable devices described herein can also be used
4 with other types of AR environments.

5 **[0136]** Wearable band 1710 can be configured to be worn by a user such that an
6 inner surface of a wearable structure 1711 of wearable band 1710 is in contact with the user's
7 skin. In this example, when worn by a user, sensors 1713 may contact the user's skin. In some
8 examples, one or more of sensors 1713 can sense biometric data such as a user's heart rate,
9 a saturated oxygen level, temperature, sweat level, neuromuscular signals, or a combination
10 thereof. One or more of sensors 1713 can also sense data about a user's environment
11 including a user's motion, altitude, location, orientation, gait, acceleration, position, or a
12 combination thereof. In some embodiment, one or more of sensors 1713 can be configured
13 to track a position and/or motion of wearable band 1710. One or more of sensors 1713 can
14 include any of the sensors defined above and/or discussed below with respect to FIG. 17.

15 **[0137]** One or more of sensors 1713 can be distributed on an inside and/or an
16 outside surface of wearable band 1710. In some embodiments, one or more of sensors 1713
17 are uniformly spaced along wearable band 1710. Alternatively, in some embodiments, one or
18 more of sensors 1713 are positioned at distinct points along wearable band 1710. As shown
19 in FIG. 17, one or more of sensors 1713 can be the same or distinct. For example, in some
20 embodiments, one or more of sensors 1713 can be shaped as a pill (e.g., sensor 1713a), an
21 oval, a circle a square, an oblong (e.g., sensor 1713c) and/or any other shape that maintains
22 contact with the user's skin (e.g., such that neuromuscular signal and/or other biometric data
23 can be accurately measured at the user's skin). In some embodiments, one or more sensors
24 of 1713 are aligned to form pairs of sensors (e.g., for sensing neuromuscular signals based on
25 differential sensing within each respective sensor). For example, sensor 1713b may be aligned
26 with an adjacent sensor to form sensor pair 1714a and sensor 1713d may be aligned with an
27 adjacent sensor to form sensor pair 1714b. In some embodiments, wearable band 1710 does
28 not have a sensor pair. Alternatively, in some embodiments, wearable band 1710 has a
29 predetermined number of sensor pairs (one pair of sensors, three pairs of sensors, four pairs
30 of sensors, six pairs of sensors, sixteen pairs of sensors, etc.).

31 **[0138]** Wearable band 1710 can include any suitable number of sensors 1713. In
32 some embodiments, the number and arrangement of sensors 1713 depends on the particular

1 application for which wearable band 1710 is used. For instance, wearable band 1710 can be
2 configured as an armband, wristband, or chest-band that include a plurality of sensors 1713
3 with different number of sensors 1713, a variety of types of individual sensors with the
4 plurality of sensors 1713, and different arrangements for each use case, such as medical use
5 cases as compared to gaming or general day-to-day use cases.

6 **[0139]** In accordance with some embodiments, wearable band 1710 further
7 includes an electrical ground electrode and a shielding electrode. The electrical ground and
8 shielding electrodes, like the sensors 1713, can be distributed on the inside surface of the
9 wearable band 1710 such that they contact a portion of the user's skin. For example, the
10 electrical ground and shielding electrodes can be at an inside surface of a coupling mechanism
11 1716 or an inside surface of a wearable structure 1711. The electrical ground and shielding
12 electrodes can be formed and/or use the same components as sensors 1713. In some
13 embodiments, wearable band 1710 includes more than one electrical ground electrode and
14 more than one shielding electrode.

15 **[0140]** Sensors 1713 can be formed as part of wearable structure 1711 of
16 wearable band 1710. In some embodiments, sensors 1713 are flush or substantially flush with
17 wearable structure 1711 such that they do not extend beyond the surface of wearable
18 structure 1711. While flush with wearable structure 1711, sensors 1713 are still configured to
19 contact the user's skin (e.g., via a skin-contacting surface). Alternatively, in some
20 embodiments, sensors 1713 extend beyond wearable structure 1711 a predetermined
21 distance (e.g., 0.1 – 2 mm) to make contact and depress into the user's skin. In some
22 embodiments, sensors 1713 are coupled to an actuator (not shown) configured to adjust an
23 extension height (e.g., a distance from the surface of wearable structure 1711) of sensors
24 1713 such that sensors 1713 make contact and depress into the user's skin. In some
25 embodiments, the actuators adjust the extension height between 0.01 mm – 1.2 mm. This
26 may allow a user to customize the positioning of sensors 1713 to improve the overall comfort
27 of the wearable band 1710 when worn while still allowing sensors 1713 to contact the user's
28 skin. In some embodiments, sensors 1713 are indistinguishable from wearable structure 1711
29 when worn by the user.

30 **[0141]** Wearable structure 1711 can be formed of an elastic material, elastomers,
31 etc., configured to be stretched and fitted to be worn by the user. In some embodiments,
32 wearable structure 1711 is a textile or woven fabric. As described above, sensors 1713 can be

1 formed as part of a wearable structure 1711. For example, sensors 1713 can be molded into
2 the wearable structure 1711, be integrated into a woven fabric (e.g., sensors 1713 can be
3 sewn into the fabric and mimic the pliability of fabric and can and/or be constructed from a
4 series woven strands of fabric).

5 [0142] Wearable structure 1711 can include flexible electronic connectors that
6 interconnect sensors 1713, the electronic circuitry, and/or other electronic components
7 (described below in reference to FIG. 18) that are enclosed in wearable band 1710. In some
8 embodiments, the flexible electronic connectors are configured to interconnect sensors 1713,
9 the electronic circuitry, and/or other electronic components of wearable band 1710 with
10 respective sensors and/or other electronic components of another electronic device (e.g.,
11 watch body 1720). The flexible electronic connectors are configured to move with wearable
12 structure 1711 such that the user adjustment to wearable structure 1711 (e.g., resizing,
13 pulling, folding, etc.) does not stress or strain the electrical coupling of components of
14 wearable band 1710.

15 [0143] As described above, wearable band 1710 is configured to be worn by a
16 user. In particular, wearable band 1710 can be shaped or otherwise manipulated to be worn
17 by a user. For example, wearable band 1710 can be shaped to have a substantially circular
18 shape such that it can be configured to be worn on the user's lower arm or wrist. Alternatively,
19 wearable band 1710 can be shaped to be worn on another body part of the user, such as the
20 user's upper arm (e.g., around a bicep), forearm, chest, legs, etc. Wearable band 1710 can
21 include a retaining mechanism 1712 (e.g., a buckle, a hook and loop fastener, etc.) for
22 securing wearable band 1710 to the user's wrist or other body part. While wearable band
23 1710 is worn by the user, sensors 1713 sense data (referred to as sensor data) from the user's
24 skin. In some examples, sensors 1713 of wearable band 1710 obtain (e.g., sense and record)
25 neuromuscular signals.

26 [0144] The sensed data (e.g., sensed neuromuscular signals) can be used to detect
27 and/or determine the user's intention to perform certain motor actions. In some examples,
28 sensors 1713 may sense and record neuromuscular signals from the user as the user performs
29 muscular activations (e.g., movements, gestures, etc.). The detected and/or determined
30 motor actions (e.g., phalange (or digit) movements, wrist movements, hand movements,
31 and/or other muscle intentions) can be used to determine control commands or control
32 information (instructions to perform certain commands after the data is sensed) for causing

1 a computing device to perform one or more input commands. For example, the sensed
2 neuromuscular signals can be used to control certain user interfaces displayed on display
3 1705 of wrist-wearable device 1700 and/or can be transmitted to a device responsible for
4 rendering an artificial-reality environment (e.g., a head-mounted display) to perform an
5 action in an associated artificial-reality environment, such as to control the motion of a virtual
6 device displayed to the user. The muscular activations performed by the user can include
7 static gestures, such as placing the user's hand palm down on a table, dynamic gestures, such
8 as grasping a physical or virtual object, and covert gestures that are imperceptible to another
9 person, such as slightly tensing a joint by co-contracting opposing muscles or using sub-
10 muscular activations. The muscular activations performed by the user can include symbolic
11 gestures (e.g., gestures mapped to other gestures, interactions, or commands, for example,
12 based on a gesture vocabulary that specifies the mapping of gestures to commands).

13 **[0145]** The sensor data sensed by sensors 1713 can be used to provide a user with
14 an enhanced interaction with a physical object (e.g., devices communicatively coupled with
15 wearable band 1710) and/or a virtual object in an artificial-reality application generated by
16 an artificial-reality system (e.g., user interface objects presented on the display 1705, or
17 another computing device (e.g., a smartphone)).

18 **[0146]** In some embodiments, wearable band 1710 includes one or more haptic
19 devices 1846 (e.g., a vibratory haptic actuator) that are configured to provide haptic feedback
20 (e.g., a cutaneous and/or kinesthetic sensation, etc.) to the user's skin. Sensors 1713 and/or
21 haptic devices 1846 (shown in FIG. 18) can be configured to operate in conjunction with
22 multiple applications including, without limitation, health monitoring, social media, games,
23 and artificial reality (e.g., the applications associated with artificial reality).

24 **[0147]** Wearable band 1710 can also include coupling mechanism 1716 for
25 detachably coupling a capsule (e.g., a computing unit) or watch body 1720 (via a coupling
26 surface of the watch body 1720) to wearable band 1710. For example, a cradle or a shape of
27 coupling mechanism 1716 can correspond to shape of watch body 1720 of wrist-wearable
28 device 1700. In particular, coupling mechanism 1716 can be configured to receive a coupling
29 surface proximate to the bottom side of watch body 1720 (e.g., a side opposite to a front side
30 of watch body 1720 where display 1705 is located), such that a user can push watch body
31 1720 downward into coupling mechanism 1716 to attach watch body 1720 to coupling
32 mechanism 1716. In some embodiments, coupling mechanism 1716 can be configured to

1 receive a top side of the watch body 1720 (e.g., a side proximate to the front side of watch
2 body 1720 where display 1705 is located) that is pushed upward into the cradle, as opposed
3 to being pushed downward into coupling mechanism 1716. In some embodiments, coupling
4 mechanism 1716 is an integrated component of wearable band 1710 such that wearable band
5 1710 and coupling mechanism 1716 are a single unitary structure. In some embodiments,
6 coupling mechanism 1716 is a type of frame or shell that allows watch body 1720 coupling
7 surface to be retained within or on wearable band 1710 coupling mechanism 1716 (e.g., a
8 cradle, a tracker band, a support base, a clasp, etc.).

9 **[0148]** Coupling mechanism 1716 can allow for watch body 1720 to be detachably
10 coupled to the wearable band 1710 through a friction fit, magnetic coupling, a rotation-based
11 connector, a shear-pin coupler, a retention spring, one or more magnets, a clip, a pin shaft, a
12 hook and loop fastener, or a combination thereof. A user can perform any type of motion to
13 couple the watch body 1720 to wearable band 1710 and to decouple the watch body 1720
14 from the wearable band 1710. For example, a user can twist, slide, turn, push, pull, or rotate
15 watch body 1720 relative to wearable band 1710, or a combination thereof, to attach watch
16 body 1720 to wearable band 1710 and to detach watch body 1720 from wearable band 1710.
17 Alternatively, as discussed below, in some embodiments, the watch body 1720 can be
18 decoupled from the wearable band 1710 by actuation of a release mechanism 1729.

19 **[0149]** Wearable band 1710 can be coupled with watch body 1720 to increase the
20 functionality of wearable band 1710 (e.g., converting wearable band 1710 into wrist-wearable
21 device 1700, adding an additional computing unit and/or battery to increase computational
22 resources and/or a battery life of wearable band 1710, adding additional sensors to improve
23 sensed data, etc.). As described above, wearable band 1710 and coupling mechanism 1716
24 are configured to operate independently (e.g., execute functions independently) from watch
25 body 1720. For example, coupling mechanism 1716 can include one or more sensors 1713
26 that contact a user's skin when wearable band 1710 is worn by the user, with or without
27 watch body 1720 and can provide sensor data for determining control commands.

28 **[0150]** A user can detach watch body 1720 from wearable band 1710 to reduce
29 the encumbrance of wrist-wearable device 1700 to the user. For embodiments in which watch
30 body 1720 is removable, watch body 1720 can be referred to as a removable structure, such
31 that in these embodiments wrist-wearable device 1700 includes a wearable portion (e.g.,
32 wearable band 1710) and a removable structure (e.g., watch body 1720).

1 **[0151]** Turning to watch body 1720, in some examples watch body 1720 can have
2 a substantially rectangular or circular shape. Watch body 1720 is configured to be worn by
3 the user on their wrist or on another body part. More specifically, watch body 1720 is sized
4 to be easily carried by the user, attached on a portion of the user's clothing, and/or coupled
5 to wearable band 1710 (forming the wrist-wearable device 1700). As described above, watch
6 body 1720 can have a shape corresponding to coupling mechanism 1716 of wearable band
7 1710. In some embodiments, watch body 1720 includes a single release mechanism 1729 or
8 multiple release mechanisms (e.g., two release mechanisms 1729 positioned on opposing
9 sides of watch body 1720, such as spring-loaded buttons) for decoupling watch body 1720
10 from wearable band 1710. Release mechanism 1729 can include, without limitation, a button,
11 a knob, a plunger, a handle, a lever, a fastener, a clasp, a dial, a latch, or a combination
12 thereof.

13 **[0152]** A user can actuate release mechanism 1729 by pushing, turning, lifting,
14 depressing, shifting, or performing other actions on release mechanism 1729. Actuation of
15 release mechanism 1729 can release (e.g., decouple) watch body 1720 from coupling
16 mechanism 1716 of wearable band 1710, allowing the user to use watch body 1720
17 independently from wearable band 1710 and vice versa. For example, decoupling watch body
18 1720 from wearable band 1710 can allow a user to capture images using rear-facing camera
19 1725b. Although release mechanism 1729 is shown positioned at a corner of watch body
20 1720, release mechanism 1729 can be positioned anywhere on watch body 1720 that is
21 convenient for the user to actuate. In addition, in some embodiments, wearable band 1710
22 can also include a respective release mechanism for decoupling watch body 1720 from
23 coupling mechanism 1716. In some embodiments, release mechanism 1729 is optional and
24 watch body 1720 can be decoupled from coupling mechanism 1716 as described above (e.g.,
25 via twisting, rotating, etc.).

26 **[0153]** Watch body 1720 can include one or more peripheral buttons 1723 and
27 1727 for performing various operations at watch body 1720. For example, peripheral buttons
28 1723 and 1727 can be used to turn on or wake (e.g., transition from a sleep state to an active
29 state) display 1705, unlock watch body 1720, increase or decrease a volume, increase or
30 decrease a brightness, interact with one or more applications, interact with one or more user
31 interfaces, etc. Additionally or alternatively, in some embodiments, display 1705 operates as
32 a touch screen and allows the user to provide one or more inputs for interacting with watch

1 body 1720.

2 [0154] In some embodiments, watch body 1720 includes one or more sensors
3 1721. Sensors 1721 of watch body 1720 can be the same or distinct from sensors 1713 of
4 wearable band 1710. Sensors 1721 of watch body 1720 can be distributed on an inside and/or
5 an outside surface of watch body 1720. In some embodiments, sensors 1721 are configured
6 to contact a user's skin when watch body 1720 is worn by the user. For example, sensors 1721
7 can be placed on the bottom side of watch body 1720 and coupling mechanism 1716 can be
8 a cradle with an opening that allows the bottom side of watch body 1720 to directly contact
9 the user's skin. Alternatively, in some embodiments, watch body 1720 does not include
10 sensors that are configured to contact the user's skin (e.g., including sensors internal and/or
11 external to the watch body 1720 that are configured to sense data of watch body 1720 and
12 the surrounding environment). In some embodiments, sensors 1721 are configured to track
13 a position and/or motion of watch body 1720.

14 [0155] Watch body 1720 and wearable band 1710 can share data using a wired
15 communication method (e.g., a Universal Asynchronous Receiver/Transmitter (UART), a USB
16 transceiver, etc.) and/or a wireless communication method (e.g., near field communication,
17 Bluetooth, etc.). For example, watch body 1720 and wearable band 1710 can share data
18 sensed by sensors 1713 and 1721, as well as application and device specific information (e.g.,
19 active and/or available applications, output devices (e.g., displays, speakers, etc.), input
20 devices (e.g., touch screens, microphones, imaging sensors, etc.).

21 [0156] In some embodiments, watch body 1720 can include, without limitation, a
22 front-facing camera 1725a and/or a rear-facing camera 1725b, sensors 1721 (e.g., a biometric
23 sensor, an IMU, a heart rate sensor, a saturated oxygen sensor, a neuromuscular signal
24 sensor, an altimeter sensor, a temperature sensor, a bioimpedance sensor, a pedometer
25 sensor, an optical sensor (e.g., imaging sensor 1863), a touch sensor, a sweat sensor, etc.). In
26 some embodiments, watch body 1720 can include one or more haptic devices 1876 (e.g., a
27 vibratory haptic actuator) that is configured to provide haptic feedback (e.g., a cutaneous
28 and/or kinesthetic sensation, etc.) to the user. Sensors 1821 and/or haptic device 1876 can
29 also be configured to operate in conjunction with multiple applications including, without
30 limitation, health monitoring applications, social media applications, game applications, and
31 artificial reality applications (e.g., the applications associated with artificial reality).

32 [0157] As described above, watch body 1720 and wearable band 1710, when

1 coupled, can form wrist-wearable device 1700. When coupled, watch body 1720 and
2 wearable band 1710 may operate as a single device to execute functions (operations,
3 detections, communications, etc.) described herein. In some embodiments, each device may
4 be provided with particular instructions for performing the one or more operations of wrist-
5 wearable device 1700. For example, in accordance with a determination that watch body
6 1720 does not include neuromuscular signal sensors, wearable band 1710 can include
7 alternative instructions for performing associated instructions (e.g., providing sensed
8 neuromuscular signal data to watch body 1720 via a different electronic device). Operations
9 of wrist-wearable device 1700 can be performed by watch body 1720 alone or in conjunction
10 with wearable band 1710 (e.g., via respective processors and/or hardware components) and
11 vice versa. In some embodiments, operations of wrist-wearable device 1700, watch body
12 1720, and/or wearable band 1710 can be performed in conjunction with one or more
13 processors and/or hardware components.

14 **[0158]** As described below with reference to the block diagram of FIG. 18,
15 wearable band 1710 and/or watch body 1720 can each include independent resources
16 required to independently execute functions. For example, wearable band 1710 and/or watch
17 body 1720 can each include a power source (e.g., a battery), a memory, data storage, a
18 processor (e.g., a central processing unit (CPU)), communications, a light source, and/or
19 input/output devices.

20 **[0159]** FIG. 18 shows block diagrams of a computing system 1830 corresponding
21 to wearable band 1710 and a computing system 1860 corresponding to watch body 1720
22 according to some embodiments. Computing system 1800 of wrist-wearable device 1700 may
23 include a combination of components of wearable band computing system 1830 and watch
24 body computing system 1860, in accordance with some embodiments.

25 **[0160]** Watch body 1720 and/or wearable band 1710 can include one or more
26 components shown in watch body computing system 1860. In some embodiments, a single
27 integrated circuit may include all or a substantial portion of the components of watch body
28 computing system 1860 included in a single integrated circuit. Alternatively, in some
29 embodiments, components of the watch body computing system 1860 may be included in a
30 plurality of integrated circuits that are communicatively coupled. In some embodiments,
31 watch body computing system 1860 may be configured to couple (e.g., via a wired or wireless
32 connection) with wearable band computing system 1830, which may allow the computing

1 systems to share components, distribute tasks, and/or perform other operations described
2 herein (individually or as a single device).

3 **[0161]** Watch body computing system 1860 can include one or more processors
4 1879, a controller 1877, a peripherals interface 1861, a power system 1895, and memory
5 (e.g., a memory 1880).

6 **[0162]** Power system 1895 can include a charger input 1896, a power-
7 management integrated circuit (PMIC) 1897, and a battery 1898. In some embodiments, a
8 watch body 1720 and a wearable band 1710 can have respective batteries (e.g., battery 1898
9 and 1859) and can share power with each other. Watch body 1720 and wearable band 1710
10 can receive a charge using a variety of techniques. In some embodiments, watch body 1720
11 and wearable band 1710 can use a wired charging assembly (e.g., power cords) to receive the
12 charge. Alternatively, or in addition, watch body 1720 and/or wearable band 1710 can be
13 configured for wireless charging. For example, a portable charging device can be designed to
14 mate with a portion of watch body 1720 and/or wearable band 1710 and wirelessly deliver
15 usable power to battery 1898 of watch body 1720 and/or battery 1859 of wearable band
16 1710. Watch body 1720 and wearable band 1710 can have independent power systems (e.g.,
17 power system 1895 and 1856, respectively) to enable each to operate independently. Watch
18 body 1720 and wearable band 1710 can also share power (e.g., one can charge the other) via
19 respective PMICs (e.g., PMICs 1897 and 1858) and charger inputs (e.g., 1857 and 1896) that
20 can share power over power and ground conductors and/or over wireless charging antennas.

21 **[0163]** In some embodiments, peripherals interface 1861 can include one or more
22 sensors 1821. Sensors 1821 can include one or more coupling sensors 1862 for detecting
23 when watch body 1720 is coupled with another electronic device (e.g., a wearable band
24 1710). Sensors 1821 can include one or more imaging sensors 1863 (e.g., one or more of
25 cameras 1825, and/or separate imaging sensors 1863 (e.g., thermal-imaging sensors)). In
26 some embodiments, sensors 1821 can include one or more SpO2 sensors 1864. In some
27 embodiments, sensors 1821 can include one or more biopotential-signal sensors (e.g., EMG
28 sensors 1865, which may be disposed on an interior, user-facing portion of watch body 1720
29 and/or wearable band 1710). In some embodiments, sensors 1821 may include one or more
30 capacitive sensors 1866. In some embodiments, sensors 1821 may include one or more heart
31 rate sensors 1867. In some embodiments, sensors 1821 may include one or more IMU sensors
32 1868. In some embodiments, one or more IMU sensors 1868 can be configured to detect

1 movement of a user's hand or other location where watch body 1720 is placed or held.

2 [0164] In some embodiments, one or more of sensors 1821 may provide an
3 example human-machine interface. For example, a set of neuromuscular sensors, such as
4 EMG sensors 1865, may be arranged circumferentially around wearable band 1710 with an
5 interior surface of EMG sensors 1865 being configured to contact a user's skin. Any suitable
6 number of neuromuscular sensors may be used (e.g., between 2 and 20 sensors). The number
7 and arrangement of neuromuscular sensors may depend on the particular application for
8 which the wearable device is used. For example, wearable band 1710 can be used to generate
9 control information for controlling an augmented reality system, a robot, controlling a
10 vehicle, scrolling through text, controlling a virtual avatar, or any other suitable control task.

11 [0165] In some embodiments, neuromuscular sensors may be coupled together
12 using flexible electronics incorporated into the wireless device, and the output of one or more
13 of the sensing components can be optionally processed using hardware signal processing
14 circuitry (e.g., to perform amplification, filtering, and/or rectification). In other embodiments,
15 at least some signal processing of the output of the sensing components can be performed in
16 software such as processors 1879. Thus, signal processing of signals sampled by the sensors
17 can be performed in hardware, software, or by any suitable combination of hardware and
18 software, as aspects of the technology described herein are not limited in this respect.

19 [0166] Neuromuscular signals may be processed in a variety of ways. For example,
20 the output of EMG sensors 1865 may be provided to an analog front end, which may be
21 configured to perform analog processing (e.g., amplification, noise reduction, filtering, etc.)
22 on the recorded signals. The processed analog signals may then be provided to an analog-to-
23 digital converter, which may convert the analog signals to digital signals that can be processed
24 by one or more computer processors. Furthermore, although this example is as discussed in
25 the context of interfaces with EMG sensors, the embodiments described herein can also be
26 implemented in wearable interfaces with other types of sensors including, but not limited to,
27 mechanomyography (MMG) sensors, sonomyography (SMG) sensors, and electrical
28 impedance tomography (EIT) sensors.

29 [0167] In some embodiments, peripherals interface 1861 includes a near-field
30 communication (NFC) component 1869, a global-position system (GPS) component 1870, a
31 long-term evolution (LTE) component 1871, and/or a Wi-Fi and/or Bluetooth communication
32 component 1872. In some embodiments, peripherals interface 1861 includes one or more

1 buttons 1873 (e.g., peripheral buttons 1723 and 1727 in FIG. 17), which, when selected by a
2 user, cause operation to be performed at watch body 1720. In some embodiments, the
3 peripherals interface 1861 includes one or more indicators, such as a light emitting diode
4 (LED), to provide a user with visual indicators (e.g., message received, low battery, active
5 microphone and/or camera, etc.).

6 **[0168]** Watch body 1720 can include at least one display 1705 for displaying visual
7 representations of information or data to a user, including user-interface elements and/or
8 three-dimensional virtual objects. The display can also include a touch screen for inputting
9 user inputs, such as touch gestures, swipe gestures, and the like. Watch body 1720 can include
10 at least one speaker 1874 and at least one microphone 1875 for providing audio signals to the
11 user and receiving audio input from the user. The user can provide user inputs through
12 microphone 1875 and can also receive audio output from speaker 1874 as part of a haptic
13 event provided by haptic controller 1878. Watch body 1720 can include at least one camera
14 1825, including a front camera 1825a and a rear camera 1825b. Cameras 1825 can include
15 ultra-wide-angle cameras, wide angle cameras, fish-eye cameras, spherical cameras,
16 telephoto cameras, depth-sensing cameras, or other types of cameras.

17 **[0169]** Watch body computing system 1860 can include one or more haptic
18 controllers 1878 and associated componentry (e.g., haptic devices 1876) for providing haptic
19 events at watch body 1720 (e.g., a vibrating sensation or audio output in response to an event
20 at the watch body 1720). Haptic controllers 1878 can communicate with one or more haptic
21 devices 1876, such as electroacoustic devices, including a speaker of the one or more speakers
22 1874 and/or other audio components and/or electromechanical devices that convert energy
23 into linear motion such as a motor, solenoid, electroactive polymer, piezoelectric actuator,
24 electrostatic actuator, or other tactile output generating components (e.g., a component that
25 converts electrical signals into tactile outputs on the device). Haptic controller 1878 can
26 provide haptic events to that are capable of being sensed by a user of watch body 1720. In
27 some embodiments, one or more haptic controllers 1878 can receive input signals from an
28 application of applications 1882.

29 **[0170]** In some embodiments, wearable band computing system 1830 and/or
30 watch body computing system 1860 can include memory 1880, which can be controlled by
31 one or more memory controllers of controllers 1877. In some embodiments, software
32 components stored in memory 1880 include one or more applications 1882 configured to

1 perform operations at the watch body 1720. In some embodiments, one or more applications
2 1882 may include games, word processors, messaging applications, calling applications, web
3 browsers, social media applications, media streaming applications, financial applications,
4 calendars, clocks, etc. In some embodiments, software components stored in memory 1880
5 include one or more communication interface modules 1883 as defined above. In some
6 embodiments, software components stored in memory 1880 include one or more graphics
7 modules 1884 for rendering, encoding, and/or decoding audio and/or visual data and one or
8 more data management modules 1885 for collecting, organizing, and/or providing access to
9 data 1887 stored in memory 1880. In some embodiments, one or more of applications 1882
10 and/or one or more modules can work in conjunction with one another to perform various
11 tasks at the watch body 1720.

12 **[0171]** In some embodiments, software components stored in memory 1880 can
13 include one or more operating systems 1881 (e.g., a Linux-based operating system, an
14 Android operating system, etc.). Memory 1880 can also include data 1887. Data 1887 can
15 include profile data 1888A, sensor data 1889A, media content data 1890, and application data
16 1891.

17 **[0172]** It should be appreciated that watch body computing system 1860 is an
18 example of a computing system within watch body 1720, and that watch body 1720 can have
19 more or fewer components than shown in watch body computing system 1860, can combine
20 two or more components, and/or can have a different configuration and/or arrangement of
21 the components. The various components shown in watch body computing system 1860 are
22 implemented in hardware, software, firmware, or a combination thereof, including one or
23 more signal processing and/or application-specific integrated circuits.

24 **[0173]** Turning to the wearable band computing system 1830, one or more
25 components that can be included in wearable band 1710 are shown. Wearable band
26 computing system 1830 can include more or fewer components than shown in watch body
27 computing system 1860, can combine two or more components, and/or can have a different
28 configuration and/or arrangement of some or all of the components. In some embodiments,
29 all, or a substantial portion of the components of wearable band computing system 1830 are
30 included in a single integrated circuit. Alternatively, in some embodiments, components of
31 wearable band computing system 1830 are included in a plurality of integrated circuits that
32 are communicatively coupled. As described above, in some embodiments, wearable band

1 computing system 1830 is configured to couple (e.g., via a wired or wireless connection) with
2 watch body computing system 1860, which allows the computing systems to share
3 components, distribute tasks, and/or perform other operations described herein (individually
4 or as a single device).

5 **[0174]** Wearable band computing system 1830, similar to watch body computing
6 system 1860, can include one or more processors 1849, one or more controllers 1847
7 (including one or more haptics controllers 1848), a peripherals interface 1831 that can
8 includes one or more sensors 1813 and other peripheral devices, a power source (e.g., a
9 power system 1856), and memory (e.g., a memory 1850) that includes an operating system
10 (e.g., an operating system 1851), data (e.g., data 1854 including profile data 1888B, sensor
11 data 1889B, etc.), and one or more modules (e.g., a communications interface module 1852,
12 a data management module 1853, etc.).

13 **[0175]** One or more of sensors 1813 can be analogous to sensors 1821 of watch
14 body computing system 1860. For example, sensors 1813 can include one or more coupling
15 sensors 1832, one or more SpO2 sensors 1834, one or more EMG sensors 1835, one or more
16 capacitive sensors 1836, one or more heart rate sensors 1837, and one or more IMU sensors
17 1838.

18 **[0176]** Peripherals interface 1831 can also include other components analogous
19 to those included in peripherals interface 1861 of watch body computing system 1860,
20 including an NFC component 1839, a GPS component 1840, an LTE component 1841, a Wi-Fi
21 and/or Bluetooth communication component 1842, and/or one or more haptic devices 1846
22 as described above in reference to peripherals interface 1861. In some embodiments,
23 peripherals interface 1831 includes one or more buttons 1843, a display 1833, a speaker 1844,
24 a microphone 1845, and a camera 1855. In some embodiments, peripherals interface 1831
25 includes one or more indicators, such as an LED.

26 **[0177]** It should be appreciated that wearable band computing system 1830 is an
27 example of a computing system within wearable band 1710, and that wearable band 1710
28 can have more or fewer components than shown in wearable band computing system 1830,
29 combine two or more components, and/or have a different configuration and/or
30 arrangement of the components. The various components shown in wearable band
31 computing system 1830 can be implemented in one or more of a combination of hardware,
32 software, or firmware, including one or more signal processing and/or application-specific

1 integrated circuits.

2 **[0178]** Wrist-wearable device 1700 with respect to FIG. 17 is an example of
3 wearable band 1710 and watch body 1720 coupled together, so wrist-wearable device 1700
4 will be understood to include the components shown and described for wearable band
5 computing system 1830 and watch body computing system 1860. In some embodiments,
6 wrist-wearable device 1700 has a split architecture (e.g., a split mechanical architecture, a
7 split electrical architecture, etc.) between watch body 1720 and wearable band 1710. In other
8 words, all of the components shown in wearable band computing system 1830 and watch
9 body computing system 1860 can be housed or otherwise disposed in a combined wrist-
10 wearable device 1700 or within individual components of watch body 1720, wearable band
11 1710, and/or portions thereof (e.g., a coupling mechanism 1716 of wearable band 1710).

12 **[0179]** The techniques described above can be used with any device for sensing
13 neuromuscular signals but could also be used with other types of wearable devices for sensing
14 neuromuscular signals (such as body-wearable or head-wearable devices that might have
15 neuromuscular sensors closer to the brain or spinal column).

16 **[0180]** In some embodiments, wrist-wearable device 1700 can be used in
17 conjunction with a head-wearable device (e.g., AR system 1900 and VR system 2000) and/or
18 an HIPD, and wrist-wearable device 1700 can also be configured to be used to allow a user to
19 control any aspect of the artificial reality (e.g., by using EMG-based gestures to control user
20 interface objects in the artificial reality and/or by allowing a user to interact with the
21 touchscreen on the wrist-wearable device to also control aspects of the artificial reality).
22 Having thus described example wrist-wearable devices, attention will now be turned to
23 example head-wearable devices, such AR system 1900 and VR system 2000.

24 **[0181]** FIGS. 19 to 21 show example artificial-reality systems, which can be used
25 as or in connection with wrist-wearable device 1700. In some embodiments, AR system 1900
26 includes an eyewear device 1902, as shown in FIG. 19. In some embodiments, VR system 2000
27 includes a head-mounted display (HMD) 2012, as shown in FIGS. 20A and 20B. In some
28 embodiments, AR system 1900 and VR system 2000 can include one or more analogous
29 components (e.g., components for presenting interactive artificial-reality environments, such
30 as processors, memory, and/or presentation devices, including one or more displays and/or
31 one or more waveguides), some of which are described in more detail with respect to FIG. 21.
32 As described herein, a head-wearable device can include components of eyewear device 1902

1 and/or head-mounted display 2012. Some embodiments of head-wearable devices do not
2 include any displays, including any of the displays described with respect to AR system 1900
3 and/or VR system 2000. While the example artificial-reality systems are respectively
4 described herein as AR system 1900 and VR system 2000, either or both of the example AR
5 systems described herein can be configured to present fully-immersive virtual-reality scenes
6 presented in substantially all of a user's field of view or subtler augmented-reality scenes that
7 are presented within a portion, less than all, of the user's field of view.

8 **[0182]** FIG. 19 show an example visual depiction of AR system 1900, including an
9 eyewear device 1902 (which may also be described herein as augmented-reality glasses,
10 and/or smart glasses). AR system 1900 can include additional electronic components that are
11 not shown in FIG. 19, such as a wearable accessory device and/or an intermediary processing
12 device, in electronic communication or otherwise configured to be used in conjunction with
13 the eyewear device 1902. In some embodiments, the wearable accessory device and/or the
14 intermediary processing device may be configured to couple with eyewear device 1902 via a
15 coupling mechanism in electronic communication with a coupling sensor 2124 (FIG. 21),
16 where coupling sensor 2124 can detect when an electronic device becomes physically or
17 electronically coupled with eyewear device 1902. In some embodiments, eyewear device
18 1902 can be configured to couple to a housing 2190 (FIG. 21), which may include one or more
19 additional coupling mechanisms configured to couple with additional accessory devices. The
20 components shown in FIG. 19 can be implemented in hardware, software, firmware, or a
21 combination thereof, including one or more signal-processing components and/or
22 application-specific integrated circuits (ASICs).

23 **[0183]** Eyewear device 1902 includes mechanical glasses components, including a
24 frame 1904 configured to hold one or more lenses (e.g., one or both lenses 1906-1 and 1906-
25 2). One of ordinary skill in the art will appreciate that eyewear device 1902 can include
26 additional mechanical components, such as hinges configured to allow portions of frame 1904
27 of eyewear device 1902 to be folded and unfolded, a bridge configured to span the gap
28 between lenses 1906-1 and 1906-2 and rest on the user's nose, nose pads configured to rest
29 on the bridge of the nose and provide support for eyewear device 1902, earpieces configured
30 to rest on the user's ears and provide additional support for eyewear device 1902, temple
31 arms configured to extend from the hinges to the earpieces of eyewear device 1902, and the
32 like. One of ordinary skill in the art will further appreciate that some examples of AR system

1 1900 can include none of the mechanical components described herein. For example, smart
2 contact lenses configured to present artificial reality to users may not include any
3 components of eyewear device 1902.

4 **[0184]** Eyewear device 1902 includes electronic components, many of which will
5 be described in more detail below with respect to FIG. 21. Some example electronic
6 components are illustrated in FIG. 19, including acoustic sensors 1925-1, 1925-2, 1925-3,
7 1925-4, 1925-5, and 1925-6, which can be distributed along a substantial portion of the frame
8 1904 of eyewear device 1902. Eyewear device 1902 also includes a left camera 1939A and a
9 right camera 1939B, which are located on different sides of the frame 1904. Eyewear device
10 1902 also includes a processor 1948 (or any other suitable type or form of integrated circuit)
11 that is embedded into a portion of the frame 1904.

12 **[0185]** FIGS. 20A and 20B show a VR system 2000 that includes a head-mounted
13 display (HMD) 2012 (e.g., also referred to herein as an artificial-reality headset, a head-
14 wearable device, a VR headset, etc.), in accordance with some embodiments. As noted, some
15 artificial-reality systems (e.g., AR system 1900) may, instead of blending an artificial reality
16 with actual reality, substantially replace one or more of a user's visual and/or other sensory
17 perceptions of the real world with a virtual experience (e.g., AR systems 1500 and 1600).

18 **[0186]** HMD 2012 includes a front body 2014 and a frame 2016 (e.g., a strap or
19 band) shaped to fit around a user's head. In some embodiments, front body 2014 and/or
20 frame 2016 include one or more electronic elements for facilitating presentation of and/or
21 interactions with an AR and/or VR system (e.g., displays, IMUs, tracking emitter or detectors).
22 In some embodiments, HMD 2012 includes output audio transducers (e.g., an audio
23 transducer 2018), as shown in FIG. 20B. In some embodiments, one or more components,
24 such as the output audio transducer(s) 2018 and frame 2016, can be configured to attach and
25 detach (e.g., are detachably attachable) to HMD 2012 (e.g., a portion or all of frame 2016,
26 and/or audio transducer 2018), as shown in FIG. 20B. In some embodiments, coupling a
27 detachable component to HMD 2012 causes the detachable component to come into
28 electronic communication with HMD 2012.

29 **[0187]** FIGS. 20A and 20B also show that VR system 2000 includes one or more
30 cameras, such as left camera 2039A and right camera 2039B, which can be analogous to left
31 and right cameras 1939A and 1939B on frame 1904 of eyewear device 1902. In some
32 embodiments, VR system 2000 includes one or more additional cameras (e.g., cameras 2039C

1 and 2039D), which can be configured to augment image data obtained by left and right
2 cameras 2039A and 2039B by providing more information. For example, camera 2039C can
3 be used to supply color information that is not discerned by cameras 2039A and 2039B. In
4 some embodiments, one or more of cameras 2039A to 2039D can include an optional IR cut
5 filter configured to remove IR light from being received at the respective camera sensors.

6 **[0188]** FIG. 21 illustrates a computing system 2120 and an optional housing 2190,
7 each of which show components that can be included in AR system 1900 and/or VR system
8 2000. In some embodiments, more or fewer components can be included in optional housing
9 2190 depending on practical restraints of the respective AR system being described.

10 **[0189]** In some embodiments, computing system 2120 can include one or more
11 peripherals interfaces 2122A and/or optional housing 2190 can include one or more
12 peripherals interfaces 2122B. Each of computing system 2120 and optional housing 2190 can
13 also include one or more power systems 2142A and 2142B, one or more controllers 2146
14 (including one or more haptic controllers 2147), one or more processors 2148A and 2148B (as
15 defined above, including any of the examples provided), and memory 2150A and 2150B,
16 which can all be in electronic communication with each other. For example, the one or more
17 processors 2148A and 2148B can be configured to execute instructions stored in memory
18 2150A and 2150B, which can cause a controller of one or more of controllers 2146 to cause
19 operations to be performed at one or more peripheral devices connected to peripherals
20 interface 2122A and/or 2122B. In some embodiments, each operation described can be
21 powered by electrical power provided by power system 2142A and/or 2142B.

22 **[0190]** In some embodiments, peripherals interface 2122A can include one or
23 more devices configured to be part of computing system 2120, some of which have been
24 defined above and/or described with respect to the wrist-wearable devices shown in FIGS. 17
25 and 18. For example, peripherals interface 2122A can include one or more sensors 2123A.
26 Some example sensors 2123A include one or more coupling sensors 2124, one or more
27 acoustic sensors 2125, one or more imaging sensors 2126, one or more EMG sensors 2127,
28 one or more capacitive sensors 2128, one or more IMU sensors 2129, and/or any other types
29 of sensors explained above or described with respect to any other embodiments discussed
30 herein.

31 **[0191]** In some embodiments, peripherals interfaces 2122A and 2122B can
32 include one or more additional peripheral devices, including one or more NFC devices 2130,

1 one or more GPS devices 2131, one or more LTE devices 2132, one or more Wi-Fi and/or
2 Bluetooth devices 2133, one or more buttons 2134 (e.g., including buttons that are slidable
3 or otherwise adjustable), one or more displays 2135A and 2135B, one or more speakers
4 2136A and 2136B, one or more microphones 2137, one or more cameras 2138A and 2138B
5 (e.g., including the left camera 2139A and/or a right camera 2139B), one or more haptic
6 devices 2140, and/or any other types of peripheral devices defined above or described with
7 respect to any other embodiments discussed herein.

8 **[0192]** AR systems can include a variety of types of visual feedback mechanisms
9 (e.g., presentation devices). For example, display devices in AR system 1900 and/or VR system
10 2000 can include one or more liquid-crystal displays (LCDs), light emitting diode (LED) displays,
11 organic LED (OLED) displays, and/or any other suitable types of display screens. Artificial-
12 reality systems can include a single display screen (e.g., configured to be seen by both eyes),
13 and/or can provide separate display screens for each eye, which can allow for additional
14 flexibility for varifocal adjustments and/or for correcting a refractive error associated with a
15 user's vision. Some embodiments of AR systems also include optical subsystems having one
16 or more lenses (e.g., conventional concave or convex lenses, Fresnel lenses, or adjustable
17 liquid lenses) through which a user can view a display screen.

18 **[0193]** For example, respective displays 2135A and 2135B can be coupled to each
19 of the lenses 1906-1 and 1906-2 of AR system 1900. Displays 2135A and 2135B may be
20 coupled to each of lenses 1906-1 and 1906-2, which can act together or independently to
21 present an image or series of images to a user. In some embodiments, AR system 1900
22 includes a single display 2135A or 2135B (e.g., a near-eye display) or more than two displays
23 2135A and 2135B. In some embodiments, a first set of one or more displays 2135A and 2135B
24 can be used to present an augmented-reality environment, and a second set of one or more
25 display devices 2135A and 2135B can be used to present a virtual-reality environment. In
26 some embodiments, one or more waveguides are used in conjunction with presenting
27 artificial-reality content to the user of AR system 1900 (e.g., as a means of delivering light
28 from one or more displays 2135A and 2135B to the user's eyes). In some embodiments, one
29 or more waveguides are fully or partially integrated into the eyewear device 1902.
30 Additionally, or alternatively to display screens, some artificial-reality systems include one or
31 more projection systems. For example, display devices in AR system 1900 and/or VR system
32 2000 can include micro-LED projectors that project light (e.g., using a waveguide) into display

1 devices, such as clear combiner lenses that allow ambient light to pass through. The display
2 devices can refract the projected light toward a user's pupil and can enable a user to
3 simultaneously view both artificial-reality content and the real world. Artificial-reality systems
4 can also be configured with any other suitable type or form of image projection system. In
5 some embodiments, one or more waveguides are provided additionally or alternatively to the
6 one or more display(s) 2135A and 2135B.

7 **[0194]** Computing system 2120 and/or optional housing 2190 of AR system 1900
8 or VR system 2000 can include some or all of the components of a power system 2142A and
9 2142B. Power systems 2142A and 2142B can include one or more charger inputs 2143, one
10 or more PMICs 2144, and/or one or more batteries 2145A and 2144B.

11 **[0195]** Memory 2150A and 2150B may include instructions and data, some or all
12 of which may be stored as non-transitory computer-readable storage media within the
13 memories 2150A and 2150B. For example, memory 2150A and 2150B can include one or more
14 operating systems 2151, one or more applications 2152, one or more communication
15 interface applications 2153A and 2153B, one or more graphics applications 2154A and 2154B,
16 one or more AR processing applications 2155A and 2155B, and/or any other types of data
17 defined above or described with respect to any other embodiments discussed herein.

18 **[0196]** Memory 2150A and 2150B also include data 2160A and 2160B, which can
19 be used in conjunction with one or more of the applications discussed above. Data 2160A and
20 2160B can include profile data 2161, sensor data 2162A and 2162B, media content data
21 2163A, AR application data 2164A and 2164B, and/or any other types of data defined above
22 or described with respect to any other embodiments discussed herein.

23 **[0197]** In some embodiments, controller 2146 of eyewear device 1902 may
24 process information generated by sensors 2123A and/or 2123B on eyewear device 1902
25 and/or another electronic device within AR system 1900. For example, controller 2146 can
26 process information from acoustic sensors 1925-1 and 1925-2. For each detected sound,
27 controller 2146 can perform a direction of arrival (DOA) estimation to estimate a direction
28 from which the detected sound arrived at eyewear device 1902 of AR system 1900. As one or
29 more of acoustic sensors 2125 (e.g., the acoustic sensors 1925-1, 1925-2) detects sounds,
30 controller 2146 can populate an audio data set with the information (e.g., represented in FIG.
31 21 as sensor data 2162A and 2162B).

32 **[0198]** In some embodiments, a physical electronic connector can convey

1 information between eyewear device 1902 and another electronic device and/or between
2 one or more processors 1948, 2148A, 2148B of AR system 1900 or VR system 2000 and
3 controller 2146. The information can be in the form of optical data, electrical data, wireless
4 data, or any other transmittable data form. Moving the processing of information generated
5 by eyewear device 1902 to an intermediary processing device can reduce weight and heat in
6 the eyewear device, making it more comfortable and safer for a user. In some embodiments,
7 an optional wearable accessory device (e.g., an electronic neckband) is coupled to eyewear
8 device 1902 via one or more connectors. The connectors can be wired or wireless connectors
9 and can include electrical and/or non-electrical (e.g., structural) components. In some
10 embodiments, eyewear device 1902 and the wearable accessory device can operate
11 independently without any wired or wireless connection between them.

12 **[0199]** In some situations, pairing external devices, such as an intermediary
13 processing device (e.g., HIPD 1306, 1406, 1506) with eyewear device 1902 (e.g., as part of AR
14 system 1900) enables eyewear device 1902 to achieve a similar form factor of a pair of glasses
15 while still providing sufficient battery and computation power for expanded capabilities.
16 Some, or all, of the battery power, computational resources, and/or additional features of AR
17 system 1900 can be provided by a paired device or shared between a paired device and
18 eyewear device 1902, thus reducing the weight, heat profile, and form factor of eyewear
19 device 1902 overall while allowing eyewear device 1902 to retain its desired functionality. For
20 example, the wearable accessory device can allow components that would otherwise be
21 included on eyewear device 1902 to be included in the wearable accessory device and/or
22 intermediary processing device, thereby shifting a weight load from the user's head and neck
23 to one or more other portions of the user's body. In some embodiments, the intermediary
24 processing device has a larger surface area over which to diffuse and disperse heat to the
25 ambient environment. Thus, the intermediary processing device can allow for greater battery
26 and computation capacity than might otherwise have been possible on eyewear device 1902
27 standing alone. Because weight carried in the wearable accessory device can be less invasive
28 to a user than weight carried in the eyewear device 1902, a user may tolerate wearing a lighter
29 eyewear device and carrying or wearing the paired device for greater lengths of time than the
30 user would tolerate wearing a heavier eyewear device standing alone, thereby enabling an
31 artificial-reality environment to be incorporated more fully into a user's day-to-day activities.

32 **[0200]** AR systems can include various types of computer vision components and

1 subsystems. For example, AR system 1900 and/or VR system 2000 can include one or more
2 optical sensors such as two-dimensional (2D) or three-dimensional (3D) cameras, time-of-
3 flight depth sensors, structured light transmitters and detectors, single-beam or sweeping
4 laser rangefinders, 3D LiDAR sensors, and/or any other suitable type or form of optical sensor.
5 An AR system can process data from one or more of these sensors to identify a location of a
6 user and/or aspects of the user's real-world physical surroundings, including the locations of
7 real-world objects within the real-world physical surroundings. In some embodiments, the
8 methods described herein are used to map the real world, to provide a user with context
9 about real-world surroundings, and/or to generate digital twins (e.g., interactable virtual
10 objects), among a variety of other functions. For example, FIGS. 20A and 20B show VR system
11 2000 having cameras 2039A to 2039D, which can be used to provide depth information for
12 creating a voxel field and a two-dimensional mesh to provide object information to the user
13 to avoid collisions.

14 **[0201]** In some embodiments, AR system 1900 and/or VR system 2000 can include
15 haptic (tactile) feedback systems, which may be incorporated into headwear, gloves, body
16 suits, handheld controllers, environmental devices (e.g., chairs or floormats), and/or any
17 other type of device or system, such as the wearable devices discussed herein. The haptic
18 feedback systems may provide various types of cutaneous feedback, including vibration,
19 force, traction, shear, texture, and/or temperature. The haptic feedback systems may also
20 provide various types of kinesthetic feedback, such as motion and compliance. The haptic
21 feedback may be implemented using motors, piezoelectric actuators, fluidic systems, and/or
22 a variety of other types of feedback mechanisms. The haptic feedback systems may be
23 implemented independently of other artificial-reality devices, within other artificial-reality
24 devices, and/or in conjunction with other artificial-reality devices.

25 **[0202]** In some embodiments of an artificial reality system, such as AR system
26 1900 and/or VR system 2000, ambient light (e.g., a live feed of the surrounding environment
27 that a user would normally see) can be passed through a display element of a respective head-
28 wearable device presenting aspects of the AR system. In some embodiments, ambient light
29 can be passed through a portion less than all of an AR environment presented
30 within a user's field of view (e.g., a portion of the AR environment co-located with a physical
31 object in the user's real-world environment that is within a designated boundary (e.g., a
32 guardian boundary) configured to be used by the user while they are interacting with the AR

1 environment). For example, a visual user interface element (e.g., a notification user interface
2 element) can be presented at the head-wearable device, and an amount of ambient light (e.g.,
3 15-50% of the ambient light) can be passed through the user interface element such that the
4 user can distinguish at least a portion of the physical environment over which the user
5 interface element is being displayed.

6 **[0203]** The process parameters and sequence of the steps described and/or
7 illustrated herein are given by way of example only and can be varied as desired. For example,
8 while the steps illustrated and/or described herein may be shown or discussed in a particular
9 order, these steps do not necessarily need to be performed in the order illustrated or
10 discussed. The various exemplary methods described and/or illustrated herein may also omit
11 one or more of the steps described or illustrated herein or include additional steps in addition
12 to those disclosed.

13 **[0204]** The preceding description has been provided to enable others skilled in the
14 art to best utilize various aspects of the exemplary embodiments disclosed herein. This
15 exemplary description is not intended to be exhaustive or to be limited to any precise form
16 disclosed. Many modifications and variations are possible without departing from the scope
17 of the present disclosure. The embodiments disclosed herein should be considered in all
18 respects illustrative and not restrictive. Reference should be made to the appended claims
19 and their equivalents in determining the scope of the present disclosure.

20 **[0205]** Unless otherwise noted, the terms “connected to” and “coupled to” (and
21 their derivatives), as used in the specification and claims, are to be construed as permitting
22 both direct and indirect (i.e., via other elements or components) connection. In addition, the
23 terms “a” or “an,” as used in the specification and claims, are to be construed as meaning “at
24 least one of.” Finally, for ease of use, the terms “including” and “having” (and their
25 derivatives), as used in the specification and claims, are interchangeable with and have the
26 same meaning as the word “comprising.”

27 **[0206]** It will be understood that when an element such as a layer or a region is
28 referred to as being formed on, deposited on, or disposed “on” or “over” another element, it
29 may be located directly on at least a portion of the other element, or one or more intervening
30 elements may also be present. In contrast, when an element is referred to as being “directly
31 on” or “directly over” another element, it may be located on at least a portion of the other
32 element, with no intervening elements present.

1 **[0207]** As used herein, the term “approximately” in reference to a particular
2 numeric value or range of values may, in certain embodiments, mean and include the stated
3 value as well as all values within 10% of the stated value. Thus, by way of example, reference
4 to the numeric value “50” as “approximately 50” may, in certain embodiments, include values
5 equal to 50 ± 5 , i.e., values within the range 45 to 55.

6 **[0208]** As used herein, the term “substantially” in reference to a given parameter,
7 property, or condition may mean and include to a degree that one of ordinary skill in the art
8 would understand that the given parameter, property, or condition is met with a small degree
9 of variance, such as within acceptable manufacturing tolerances. By way of example,
10 depending on the particular parameter, property, or condition that is substantially met, the
11 parameter, property, or condition may be at least approximately 90% met, at least
12 approximately 95% met, or even at least approximately 99% met.

13 **[0209]** While various features, elements or steps of particular embodiments may
14 be disclosed using the transitional phrase “comprising,” it is to be understood that alternative
15 embodiments, including those that may be described using the transitional phrases
16 “consisting of” or “consisting essentially of,” are implied. Thus, for example, implied
17 alternative embodiments to a lens that comprises or includes polycarbonate include
18 embodiments where a lens consists essentially of polycarbonate and embodiments where a
19 lens consists of polycarbonate.

1 What is claimed is:

2 1. A display comprising:

3 an illumination source; and

4 an illuminator, wherein the illuminator comprises:

5 a light propagation body optically coupled to the illumination source and
6 extending from an input end to an output end and configured to guide light received
7 from the illumination source by total internal reflection from the input end to the
8 output end;

9 a first output coupling element located proximate to the output end for
10 coupling red light out of the light propagation body;

11 a second output coupling element located proximate to the output end for
12 coupling green light out of the light propagation body; and

13 a third output coupling element located proximate to the output end for
14 coupling blue light out of the light propagation body, wherein the first, second, and
15 third output coupling elements each comprise an emitter disposed between a
16 respective pair of opposing resonator mirrors, such that the first, second, and third
17 output coupling elements outcouple the red, green, and blue light at a constant chief
18 ray angle.

19 2. The display of claim 1, wherein the illumination source comprises a red laser, a
20 green laser, and a blue laser.

21 3. The display according to any of the preceding claims, wherein the first, second, and
22 third output coupling elements each comprise a surface relief grating.

23 4. The display according to any of the preceding claims, wherein the first, second, and
24 third output coupling elements are configured to simultaneously outcouple the red, green,
25 and blue light.

26 5. The display according to any of the preceding claims, wherein the light propagation
27 body is configured to distribute light received from the illumination source over a two-
28 dimensional display area.

29 6. The display according to any of the preceding claims, wherein each emitter
30 comprises a cavity enhanced emitter.

31 7. The display according to any of the preceding claims, wherein:

32 the first output coupling element is configured to outcouple red light to the exclusion

1 of green light and blue light;

2 the second output coupling element is configured to outcouple green light to the
3 exclusion of red light and blue light; and

4 the third output coupling element is configured to outcouple blue light to the
5 exclusion of red light and green light; and/or preferably the display further comprising a
6 display panel overlapping the illuminator, wherein the display panel is configured to receive
7 the red, green, and blue light outcoupled from the light propagation body.

8 8. The display according to any of the preceding claims, further comprising a
9 dispersion compensation layer overlying the output end of the light propagation body; and/or
10 preferably wherein the dispersion compensation layer comprises a metasurface, a
11 polarization volume hologram, or a volumetric Bragg grating.

12 9. A display comprising:

13 an illumination source;

14 a light propagation body optically coupled to the illumination source extending from
15 an input end to an output end and configured to guide light by total internal reflection from
16 the input end to the output end; and

17 an output coupling element located proximate to the output end for coupling light
18 out of the light propagation body, wherein the output coupling element comprises an
19 emitter disposed between two mutually opposing resonator mirrors and is configured to
20 outcouple red, green, and blue light at a constant chief ray angle.

21 10. The display of claim 9, wherein the illumination source comprises a red laser, a
22 green laser, and a blue laser.

23 11. The display of claim 9 or 10, wherein the light propagation body is configured to
24 distribute light received from the illumination source over a two-dimensional display area;
25 and/or preferably wherein each emitter comprises a cavity enhanced emitter.

26 12. The display according to any of the claims 9 to 11, wherein:

27 the first output coupling element is configured to outcouple red light to the exclusion
28 of green light and blue light;

29 the second output coupling element is configured to outcouple green light to the
30 exclusion of red light and blue light; and

31 the third output coupling element is configured to outcouple blue light to the
32 exclusion of red light and green light; and/or preferably further comprising a display panel

1 overlapping the illuminator, wherein the display panel is configured to receive the red, green,
2 and blue light outcoupled from the light propagation body.

3 13. The display according to any of the claims 9 to 12, further comprising a dispersion
4 compensation layer overlying the output end of the light propagation body; and/or preferably
5 wherein the dispersion compensation layer comprises a metasurface, a polarization volume
6 hologram, or a volumetric Bragg grating.

7 14. A display comprising:

8 an illumination source;

9 a light propagation body optically coupled to the illumination source extending from
10 an input end to an output end and configured to guide light by total internal reflection from
11 the input end to the output end;

12 an output coupling element located proximate to the output end for coupling light
13 out of the light propagation body;

14 a dispersion compensation layer overlying the output end of the light propagation
15 body; and

16 a display panel for receiving red, green, and blue light outcoupled from the light
17 propagation body, wherein the dispersion compensation layer is configured to direct the
18 red, green, and blue light to the display panel at a constant chief ray angle.

19 15. The display of claim 14, wherein the dispersion compensation layer comprises a
20 metasurface, a polarization volume hologram, or a volumetric Bragg grating.

21

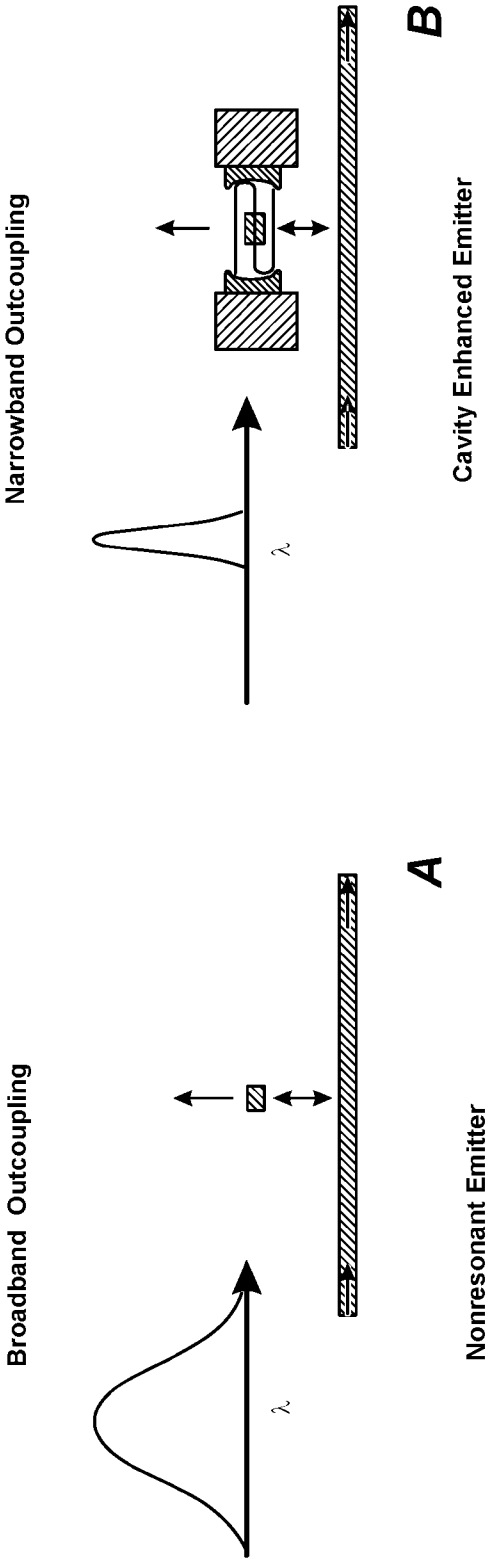


FIG. 1

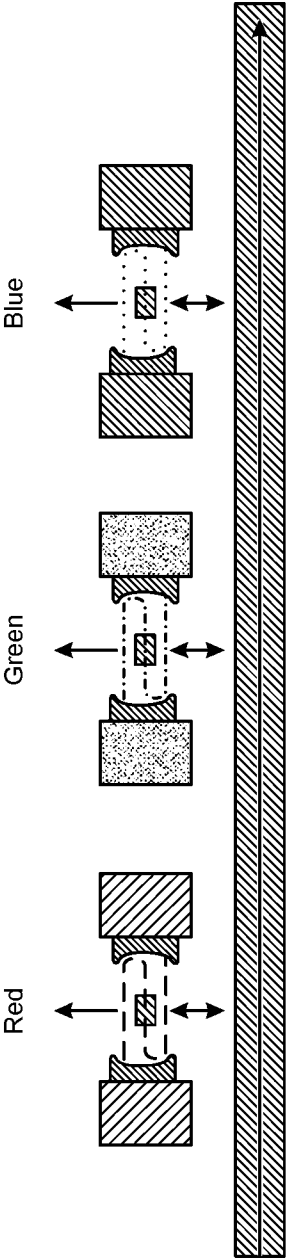


FIG. 2

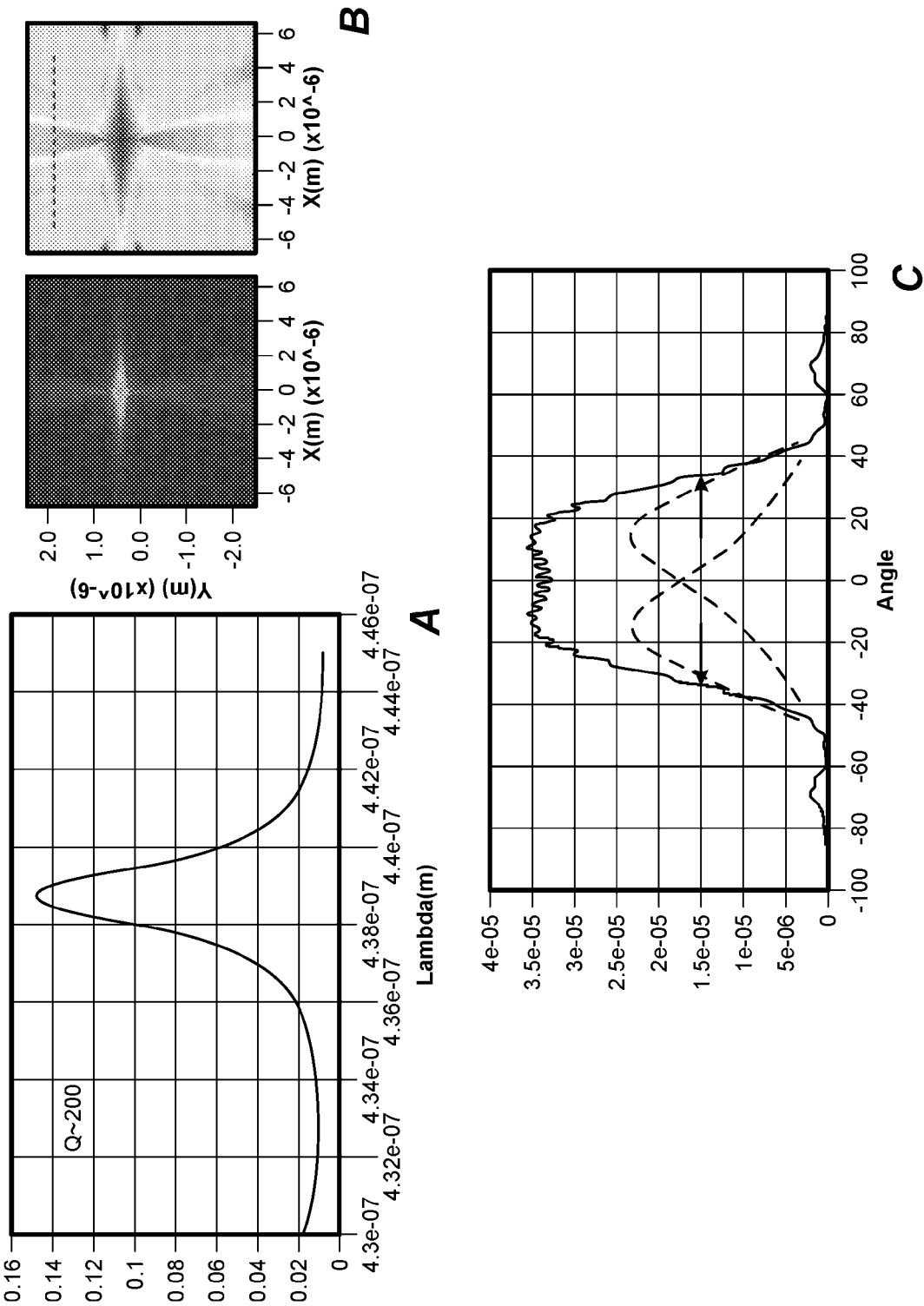


FIG. 3

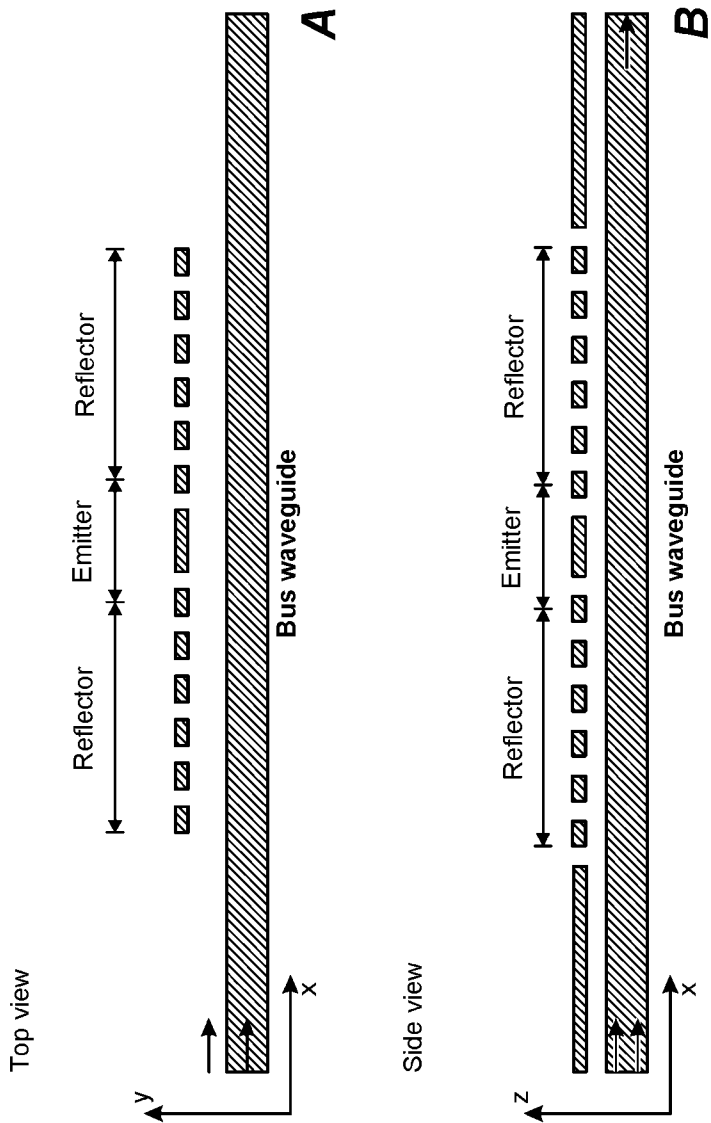


FIG. 4

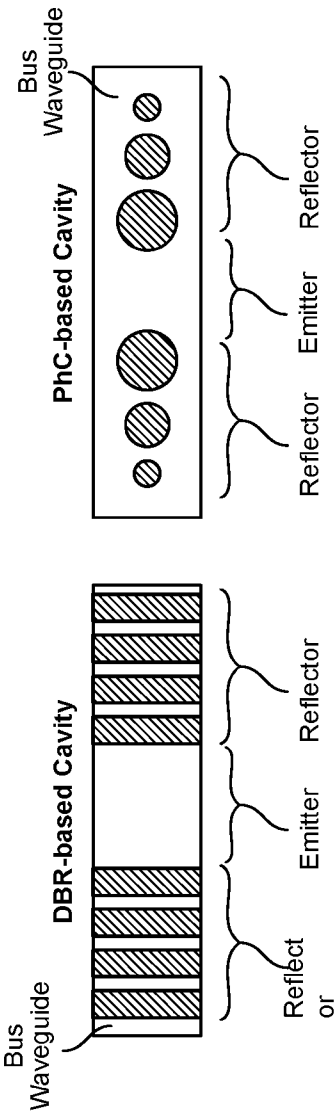
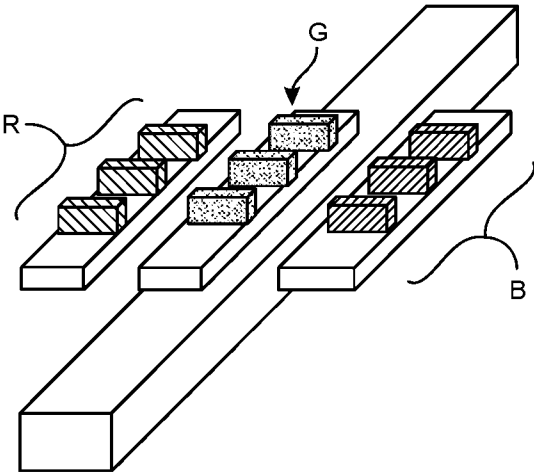
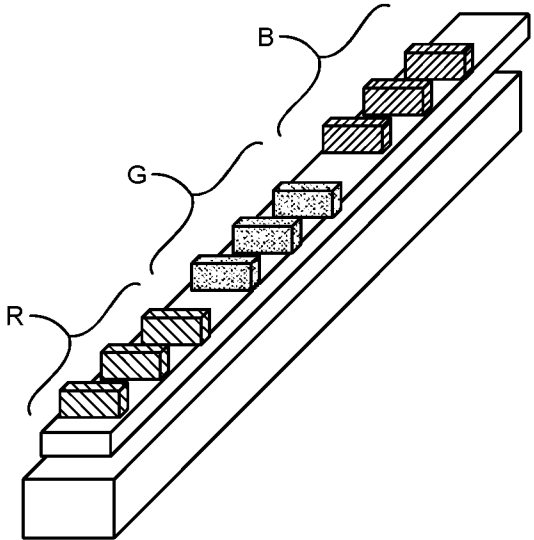


FIG. 5



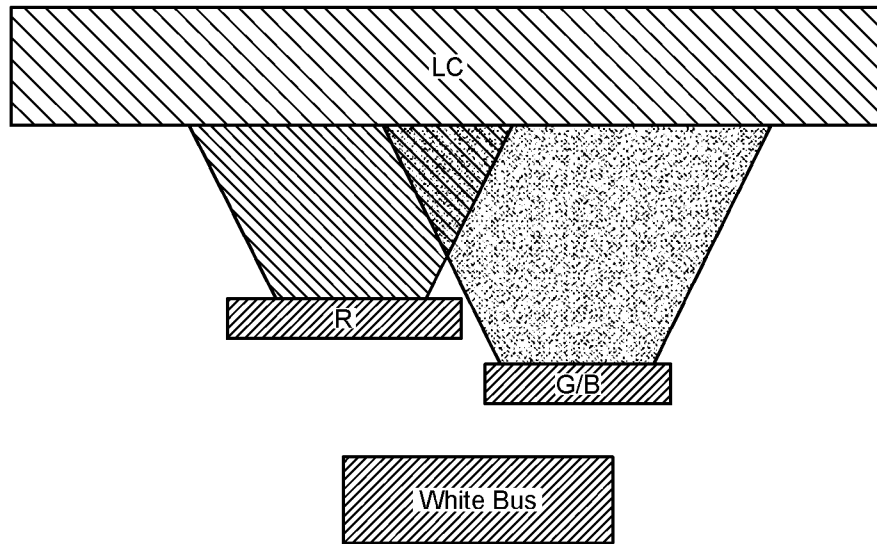
A



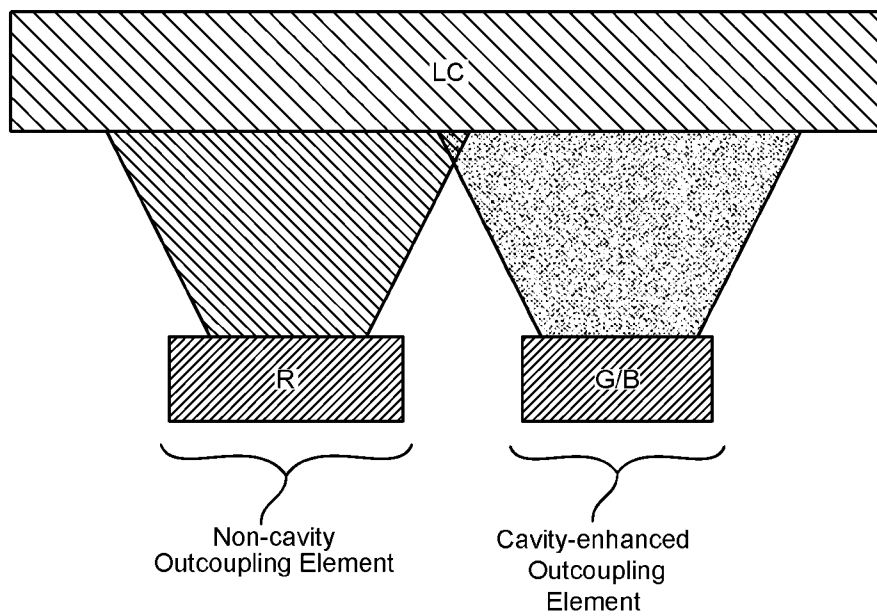
B

FIG. 6

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A



B

FIG. 7

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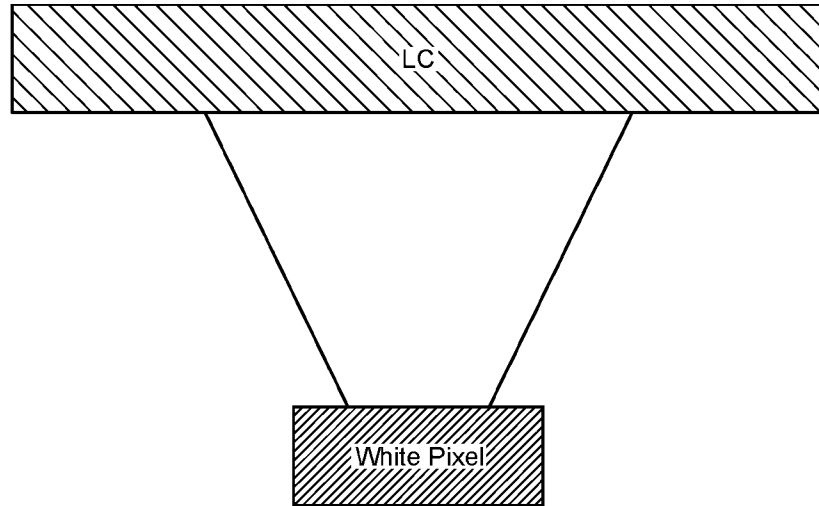


FIG. 8

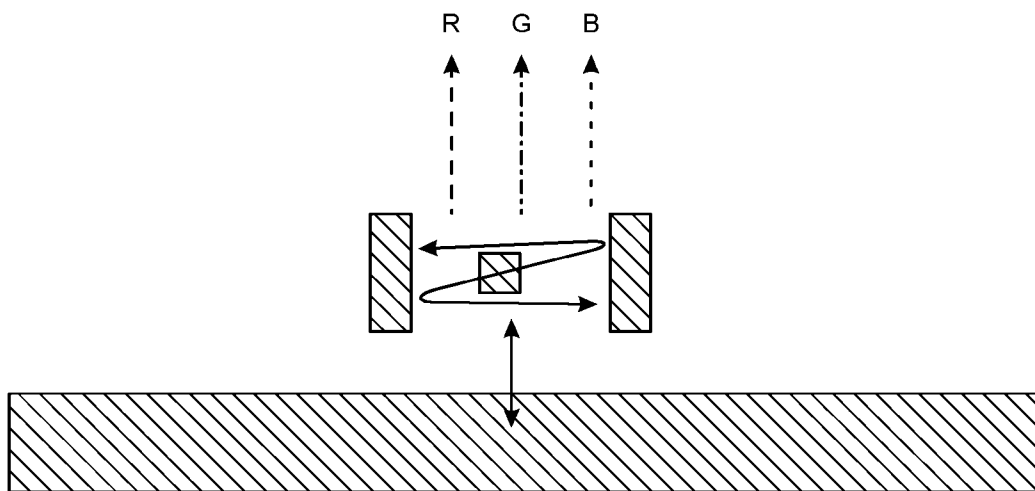


FIG. 9

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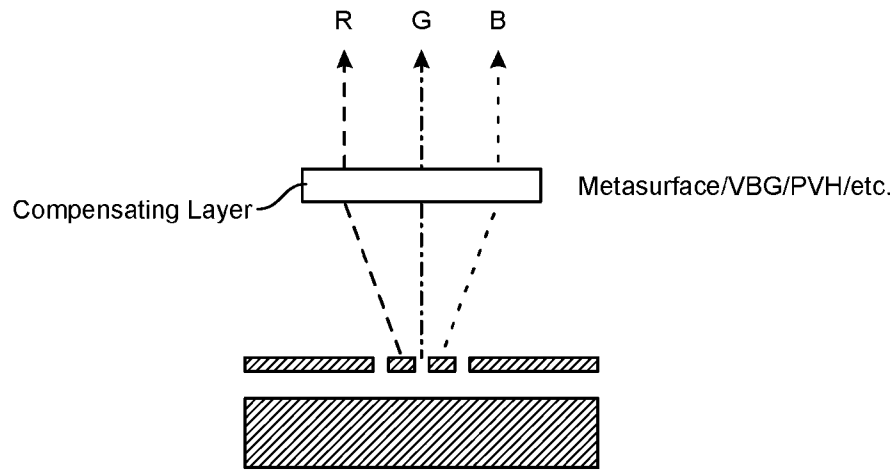


FIG. 10

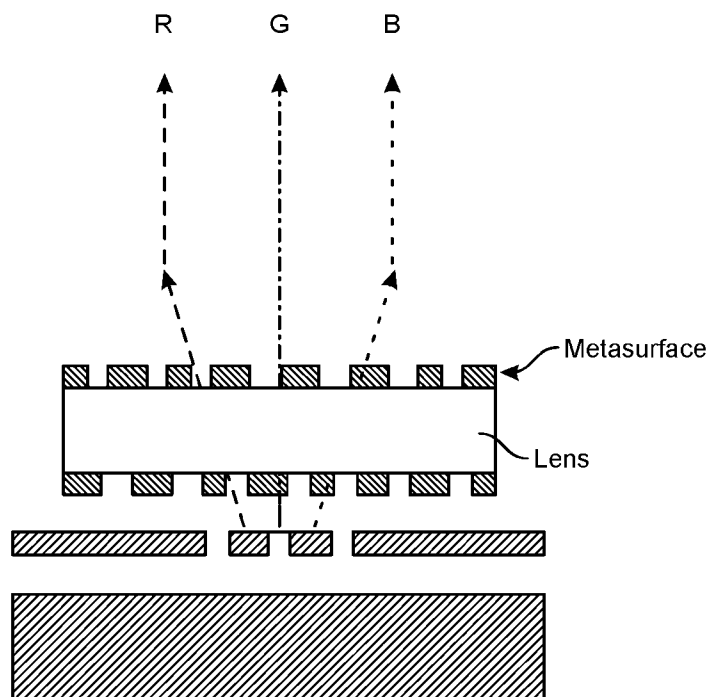


FIG. 11

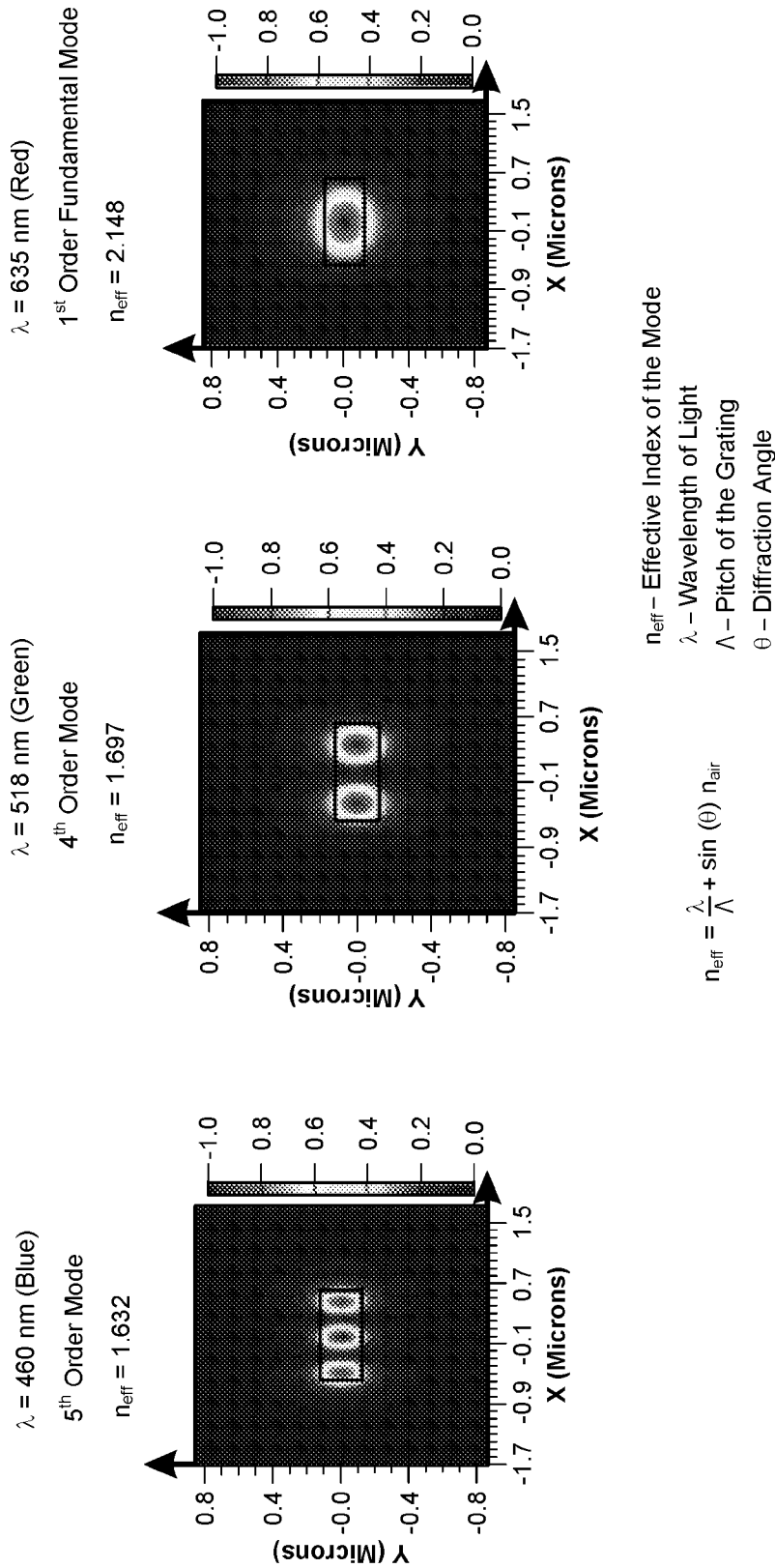


FIG. 12

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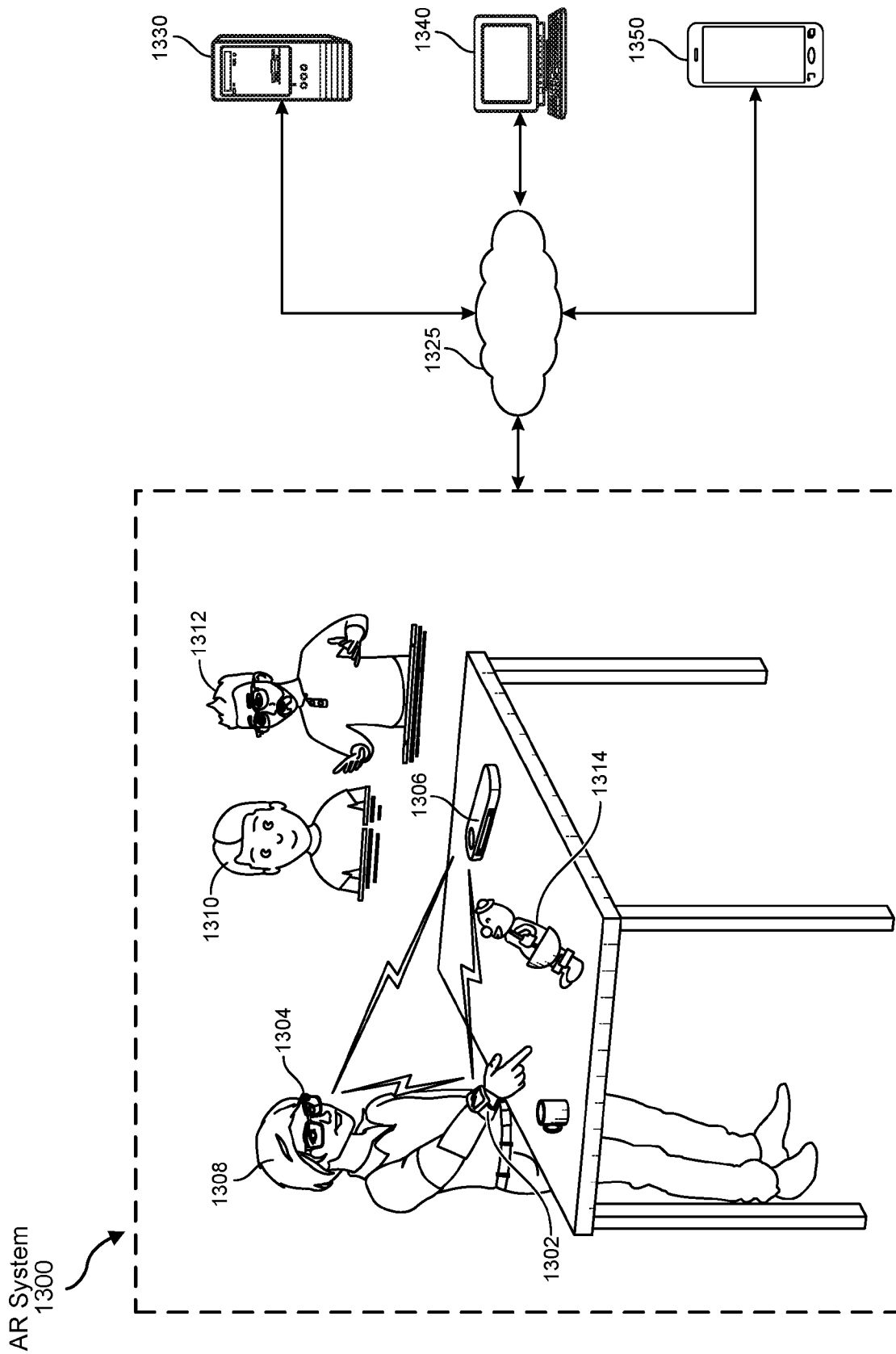


FIG. 13

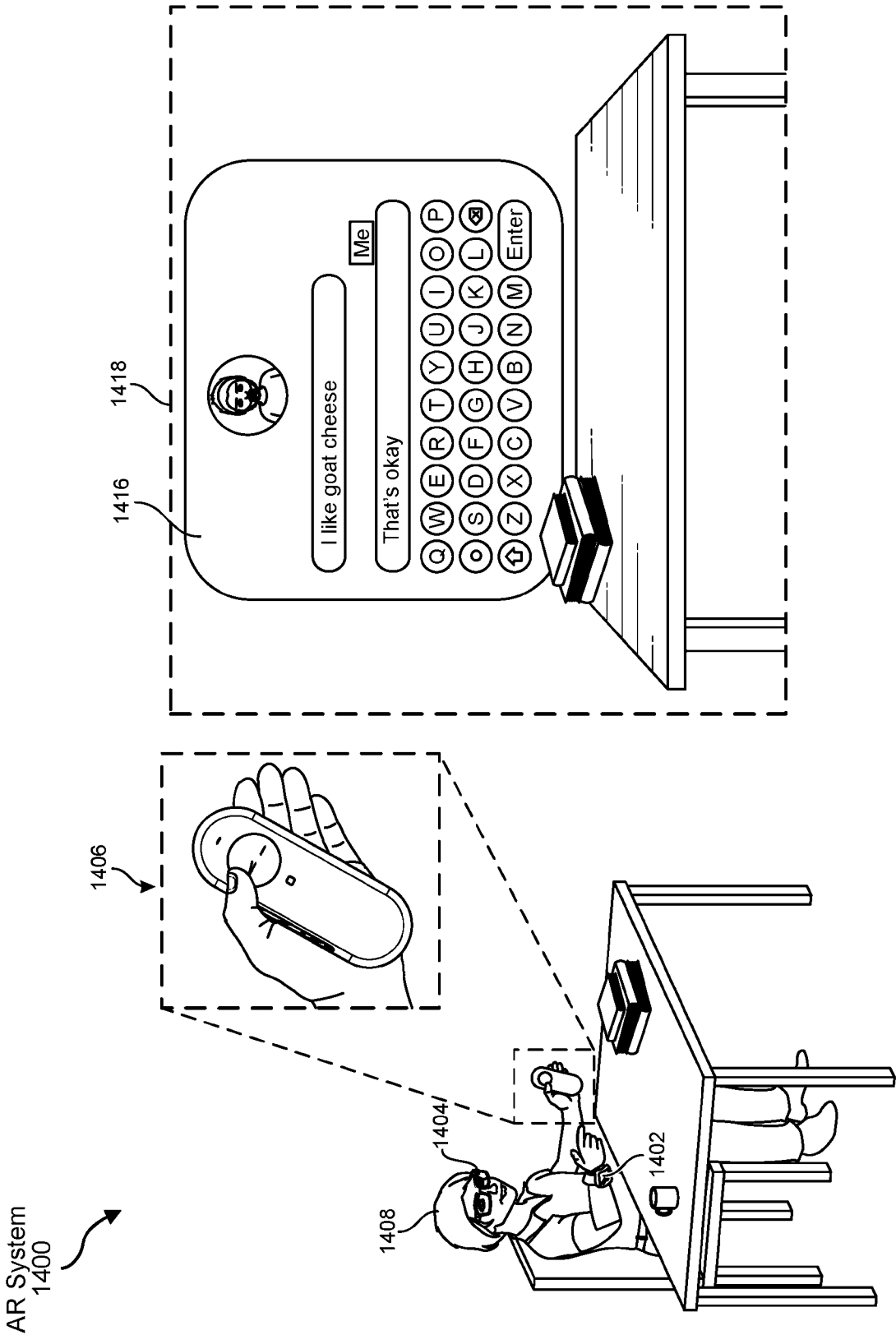


FIG. 14

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AR System
1500

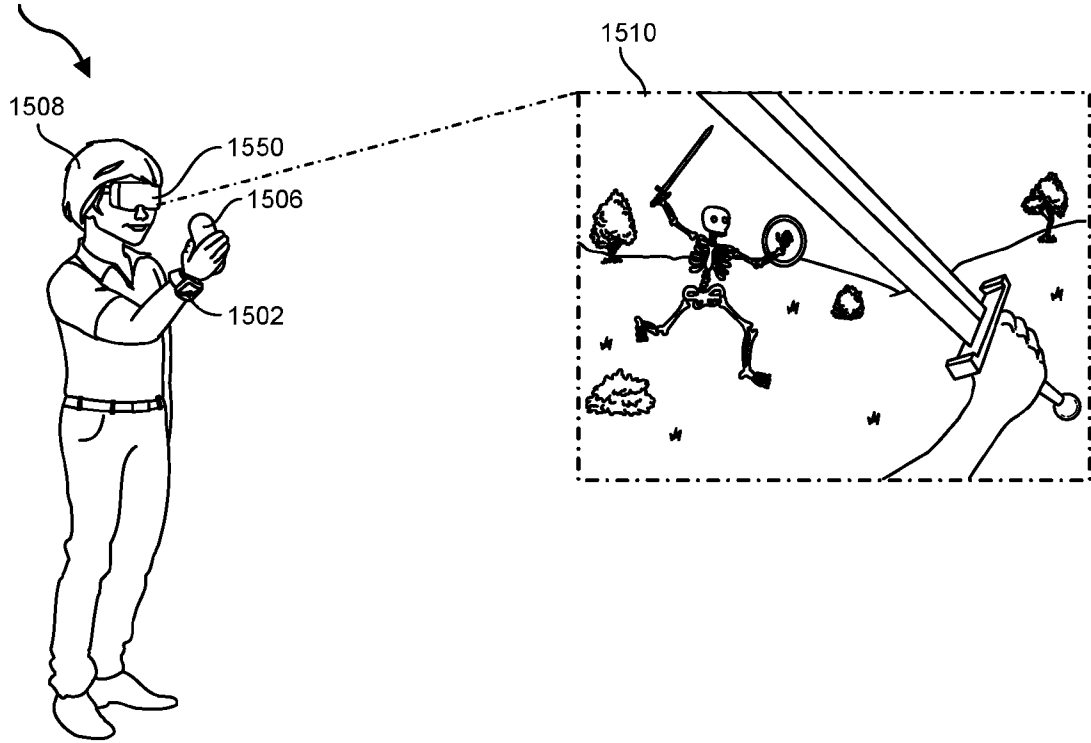


FIG. 15A

AR System
1500

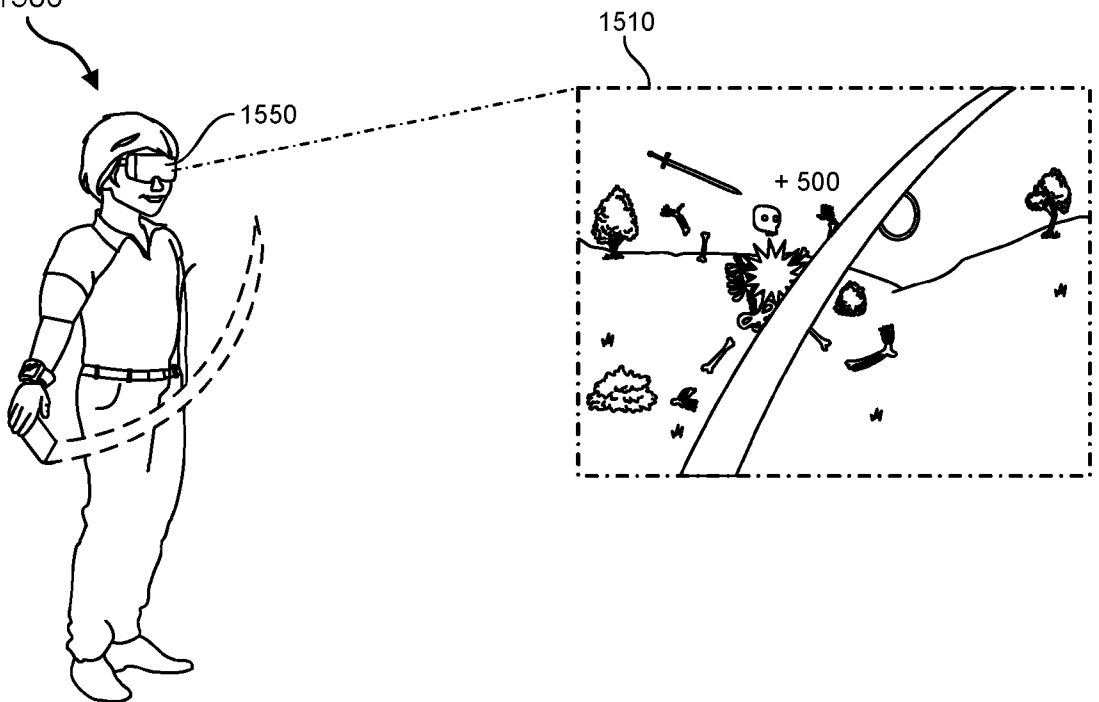


FIG. 15B

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AR System
1600

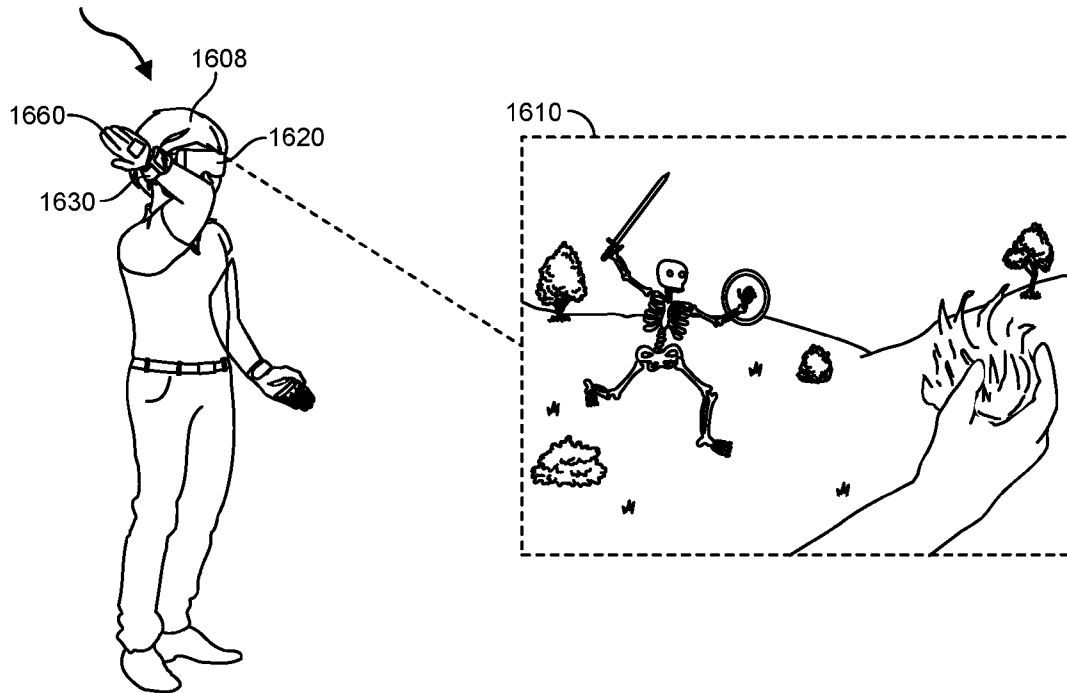


FIG. 16A

AR System
1600

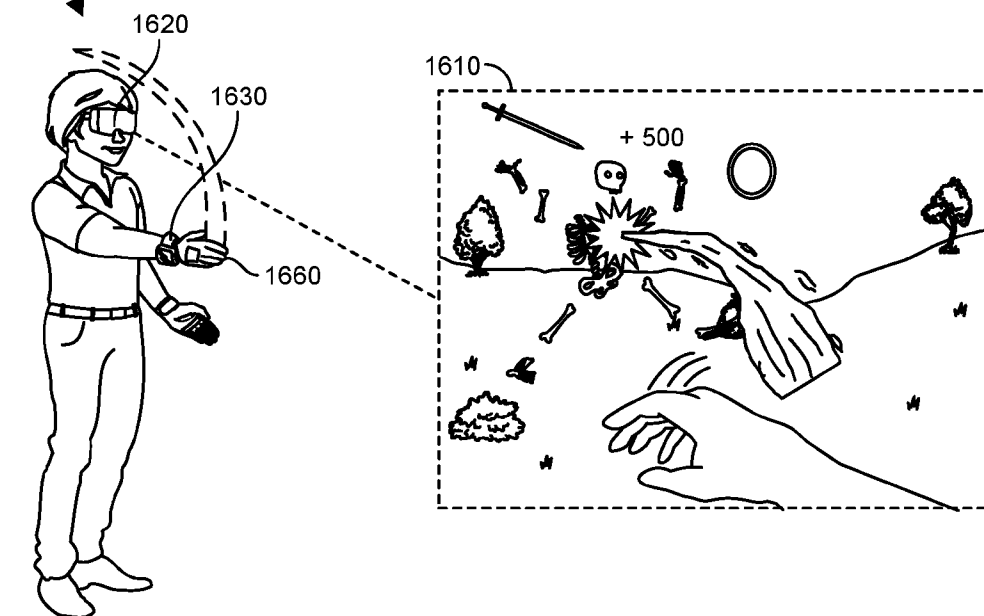


FIG. 16B

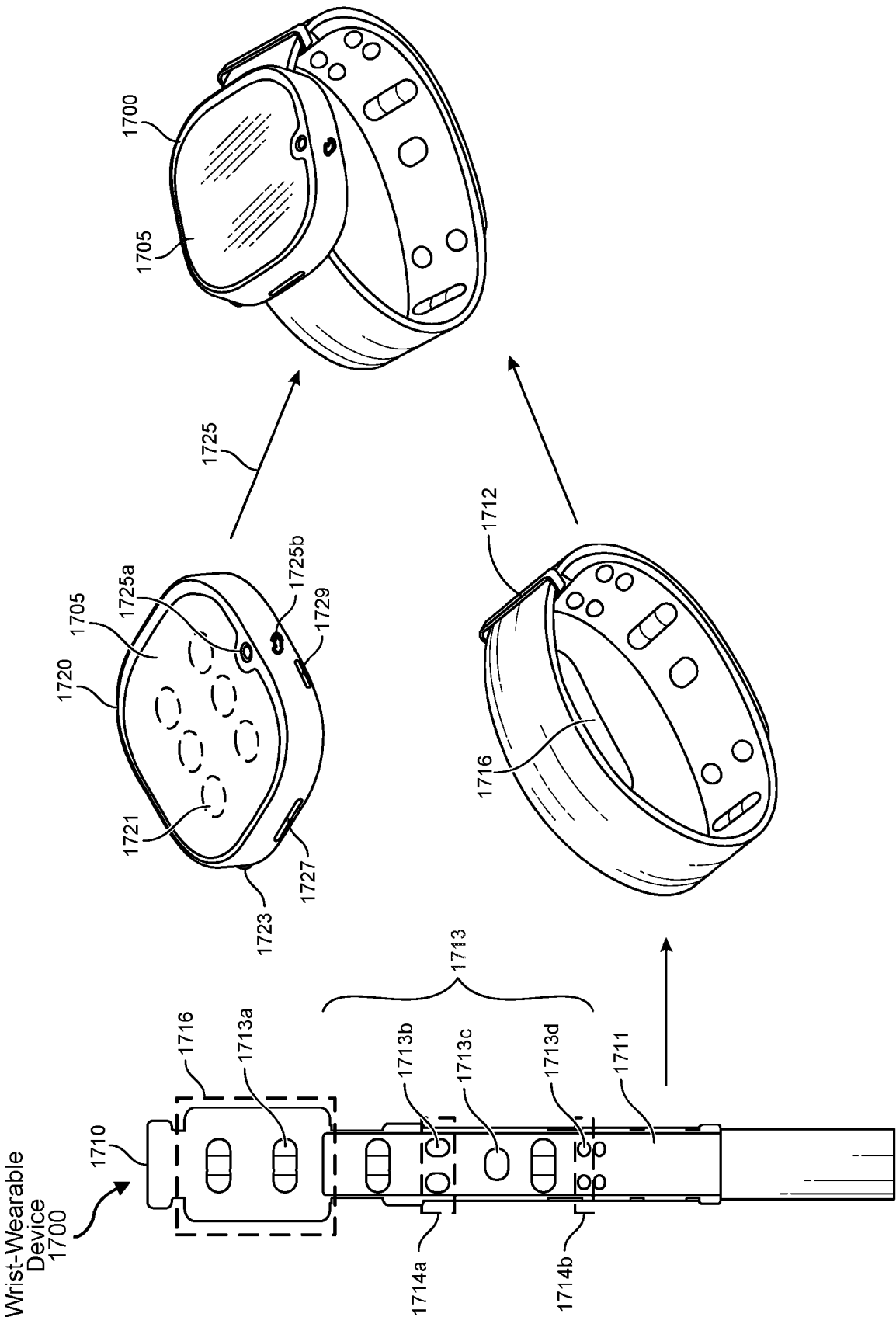


FIG. 17

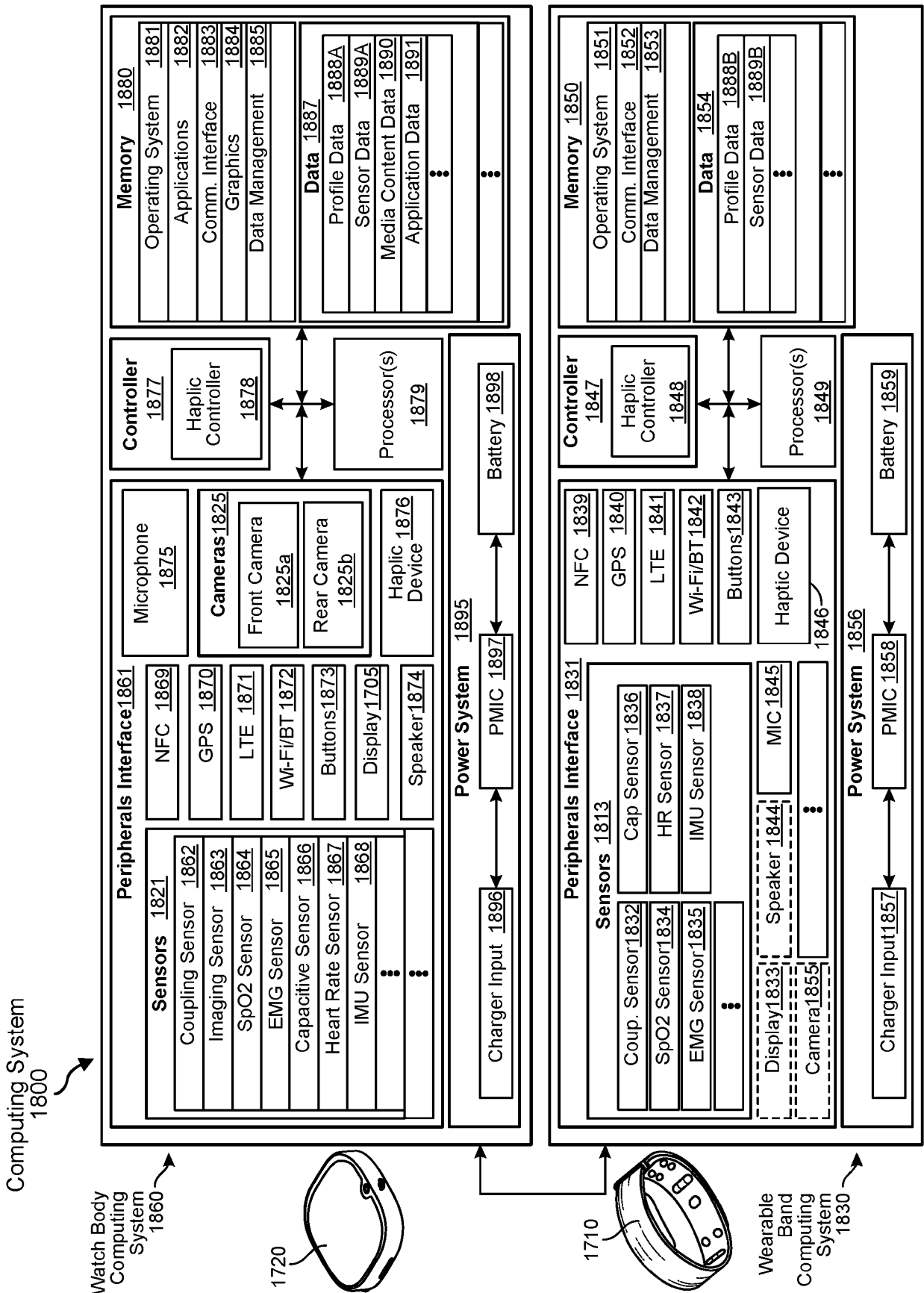


FIG. 18

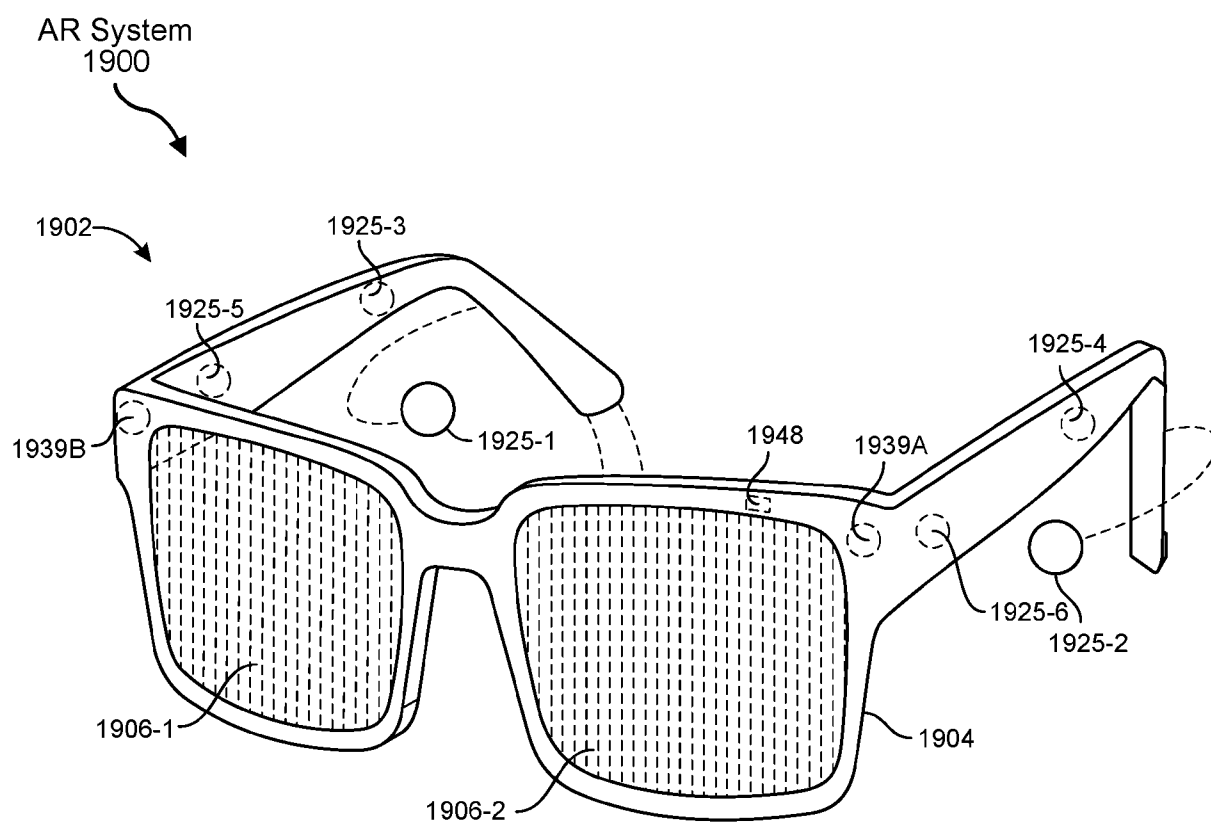


FIG. 19

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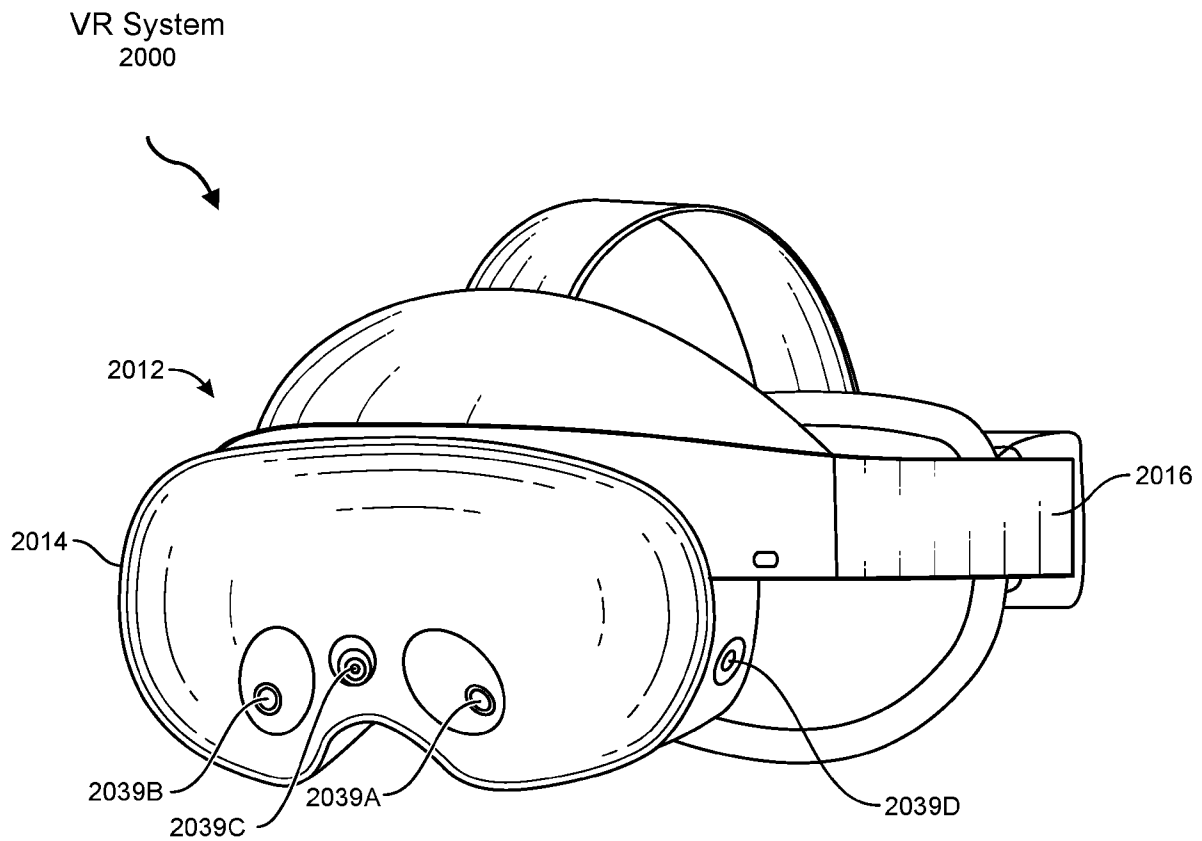


FIG. 20A

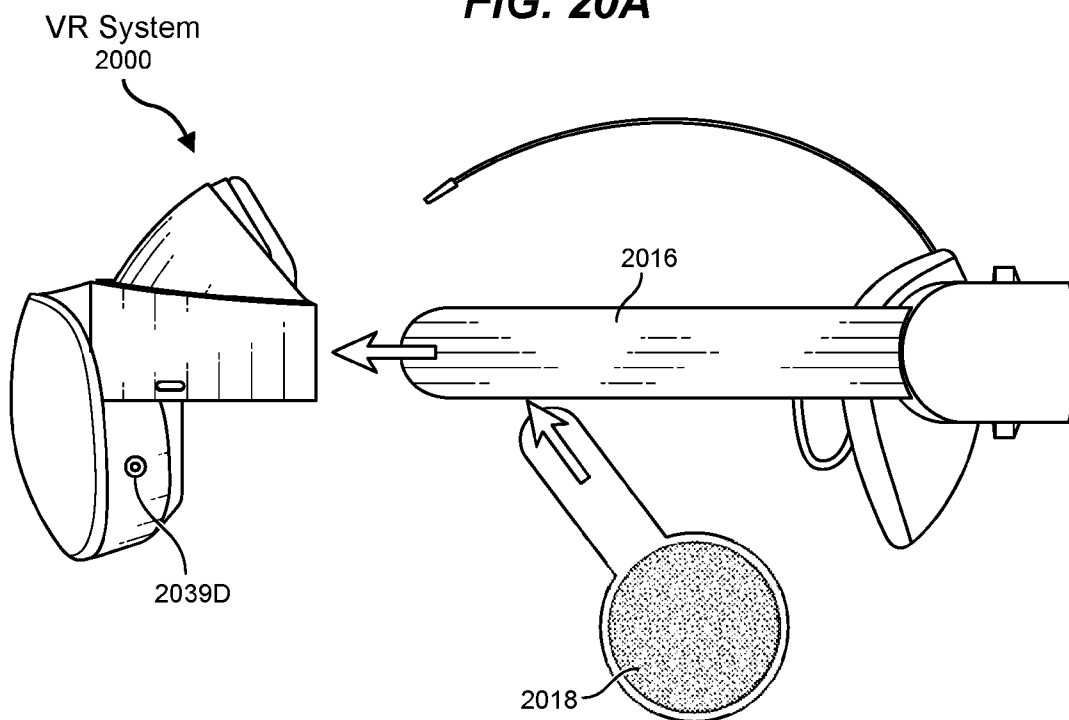


FIG. 20B

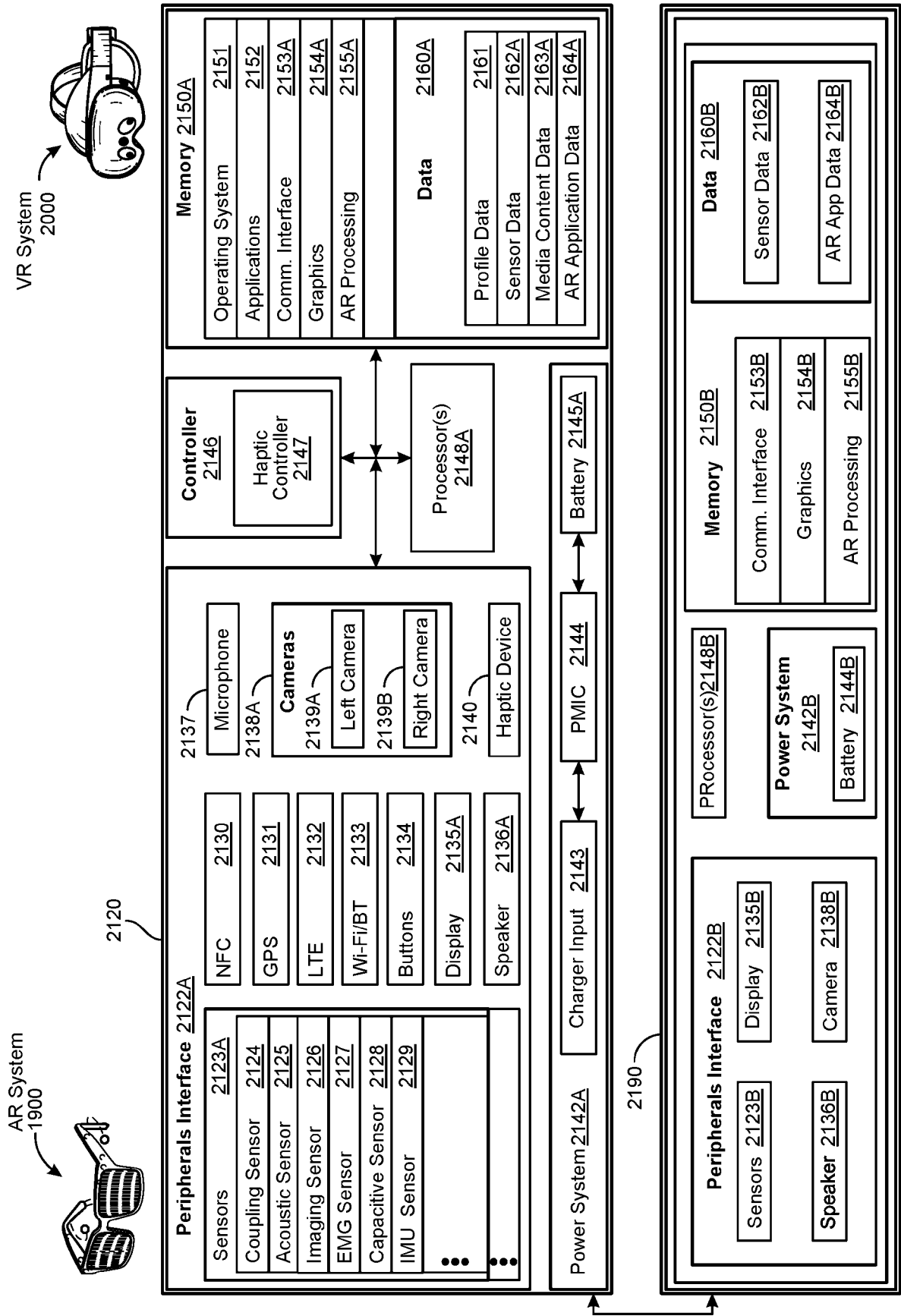


FIG. 21

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/056197

A. CLASSIFICATION OF SUBJECT MATTER INV. G02B27/01 F21V8/00 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) G02B G02F Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Chinnock Chris: "Laser backlights have advantages for liquid-crystal displays", Laser Focus World, 10 December 2020 (2020-12-10), pages 1-20, XP093238826, Retrieved from the Internet: URL:https://www.laserfocusworld.com/detectors-imaging/article/14186970/laser-backlights-have-advantages-for-liquid-crystal-displays [retrieved on 2025-01-13]	1-7, 9-12,14
Y	figure 2	8,13,15
Y	WO 2023/288092 A1 (META PLATFORMS TECH LLC [US]) 19 January 2023 (2023-01-19) paragraph [0065]; figure 6	8,13,15
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 13 January 2025		Date of mailing of the international search report 03/02/2025
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Jones, Julian

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2024/056197

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2023288092 A1	19 - 01 - 2023	EP 4370828 A1	22 - 05 - 2024
		TW 202305427 A	01 - 02 - 2023
		WO 2023288092 A1	19 - 01 - 2023
