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Thermal architecture for smart glasses

Abstract

A method of dissipating heat generated by imaging devices and processing devices of a wearable electronic eyewear device includes providing a first heat sink thermally connecting the imaging devices to a frame of the eyewear device to sink heat to the frame and providing a second heat sink thermally connecting the processing devices to respective temples of the eyewear device to sink heat to the respective temples. The first and second heat sinks are thermally insulated from each other to direct the heat to different portions of the eyewear device. The processing devices may include a first co-processor disposed in a first temple connected to a first end of the frame and a second co-processor disposed in a second temple connected to a second end of the frame. The resulting eyewear device spreads the heat from heat generating devices over a larger area to minimize overall heating.

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References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
9423842	12/2015	Osterhout et al.	N/A	N/A
9733680	12/2016	Voth et al.	N/A	N/A
9851585	12/2016	Ashwood	N/A	N/A
10108017	12/2017	Nikkhoo et al.	N/A	N/A
10527355	12/2019	Hurbi et al.	N/A	N/A
11921289	12/2023	Travers et al.	N/A	N/A
2007/0177239	12/2006	Tanijiri et al.	N/A	N/A
2011/0221659	12/2010	King, III et al.	N/A	N/A
2016/0116745	12/2015	Osterhout et al.	N/A	N/A
2016/0212886	12/2015	Nikkhoo	N/A	N/A
2017/0097509	12/2016	Yoshida	N/A	N/A
2017/0237935	12/2016	Totani et al.	N/A	N/A
2018/0024368	12/2017	Takagi et al.	N/A	N/A
2018/0052501	12/2017	Jones, Jr.	N/A	H05K 7/20963
2020/0310118	12/2019	Kamakura	N/A	N/A
2020/0310132	12/2019	Takagi et al.	N/A	N/A
2020/0310138	12/2019	Kamakura	N/A	N/A
2020/0310139	12/2019	Takagi et al.	N/A	N/A
2020/0310140	12/2019	Kamakura	N/A	N/A
2021/0068316	12/2020	Kamakura	N/A	N/A
2021/0103146	12/2020	Travers et al.	N/A	N/A

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
110879475	12/2019	CN	N/A
110908116	12/2019	CN	N/A
111025652	12/2019	CN	N/A
112394518	12/2020	CN	N/A
1020190010345	12/2018	KR	N/A

OTHER PUBLICATIONS

International Search Report and Written Opinion for International Application No. PCT/US2022/025597, dated Aug. 10, 2022 (Oct. 8, 2022)—10 pages. cited by applicant
International Search Report and Written Opinion for International Application No. PCT/US2022/027795, dated Aug. 23, 2022 (Aug. 23, 2022)—13 pages. cited by applicant
U.S. Appl. No. 17/725,245, filed Apr. 20, 2022 to Ashwood et al. cited by applicant
Extended European Search Report for EP 22799565.1 (4335263) mailed Mar. 7, 2025 (Jul. 3, 2025), 10 pages. cited by applicant

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims priority to U.S. Provisional Application Ser. No. 63/184,879 filed on May 6, 2021, the contents of which are incorporated fully herein by reference.

TECHNICAL FIELD
(1) Examples set forth in the present disclosure relate to portable electronic devices, including wearable electronic devices such as smart glasses. More particularly, but not by way of limitation, the present disclosure describes a wearable electronic eyewear device designed to optimally manage excess heat generated by electronic components.
BACKGROUND
(2) Many electronic devices available today include wearable consumer electronic devices. Wearable consumer electronic devices may generate excess heat due to processors and other heat generating electronics. The generation of such excess heat may meaningfully constrain the power consumption of the wearable consumer electronic devices. High power displays and complex algorithms running on powerful processors are difficult to keep cool within the volume of a wearable form factor. For example, smart glasses that provide augmented reality experiences including six degrees of freedom processing may be thermally limited and necessitate throttling to ensure that safe operating temperatures are not exceeded.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) Features of the various implementations disclosed will be readily understood from the following detailed description, in which reference is made to the appending drawing figures. A reference numeral is used with each element in the description and throughout the several views of the drawing. When a plurality of similar elements is present, a single reference numeral may be assigned to like elements, with an added lower-case letter referring to a specific element.
(2) The various elements shown in the figures are not drawn to scale unless otherwise indicated. The dimensions of the various elements may be enlarged or reduced in the interest of clarity. The several figures depict one or more implementations and are presented by way of example only and should not be construed as limiting. Included in the drawing are the following figures:
(3) FIG. **1**A illustrates a side view of an example hardware configuration of a wearable electronic eyewear device showing a right optical assembly with an image display;

(4) FIG. **1**B illustrates a top cross-sectional view of a temple of the wearable electronic eyewear device of FIG. **1**A;
(5) FIG. **2**A illustrates a rear view of an example hardware configuration of a wearable electronic eyewear device in an example hardware configuration;
(6) FIG. **2**B illustrates a rear view of an example hardware configuration of another wearable electronic eyewear device in an example hardware configuration;
(7) FIG. **2**C and FIG. **2**D illustrate rear views of example hardware configurations of a wearable electronic eyewear device including two different types of image displays;
(8) FIG. **3** illustrates a rear perspective view of the eyewear device of FIG. **2**A depicting an infrared emitter, an infrared camera, a frame front, a frame back, and a circuit board;
(9) FIG. **4** illustrates a cross-sectional view taken through the infrared emitter and the frame of the eyewear device of FIG. **3**;
(10) FIG. **5** illustrates detecting eye gaze direction;
(11) FIG. **6** illustrates detecting eye position;
(12) FIG. **7** illustrates an example of visible light captured by the left visible light camera as a left raw image and visible light captured by the right visible light camera as a right raw image;
(13) FIG. **8**A illustrates a side view of a projector configured to generate a visual image;
(14) FIG. **8**B illustrates a side sectional view of a housing that encompasses the components of the system described with reference to FIG. **8**A;
(15) FIG. **8**C illustrates the portion of the system of FIG. **8**A that is an illumination section of a projector and the portion of the projector that includes a projection lens;
(16) FIG. **8**D illustrates graphs of system dimensions as a function of the curvature of the field lens;
(17) FIG. **8**E illustrates a method of generating a decentered light beam using the field lens, and displacing a display to generate a display image;
(18) FIG. **9** illustrates a block diagram of electronic components of the wearable electronic eyewear device including the projector;
(19) FIG. **10** illustrates a side view of a wearable electronic eyewear device optimized for thermal management whereby the display heat is moved forward to the frame and the heat generated by the system on chip is moved backward to the hinged arms, along with a corresponding heat map;
(20) FIG. **11**A and FIG. **11**B illustrate the two separated heat sinks enclosing a projector in a sample thermal management configuration;
(21) FIG. **12**A and FIG. **12**B illustrate the heat performance of the heat sinks of FIG. **11**A and FIG. **11**B;
(22) FIG. **13** illustrates another example of a heat sinks and the adapter;
(23) FIG. **14**A and FIG. **14**B illustrate the heat performance of the heat sink of FIG. **13**;
(24) FIG. **15** illustrates a method of operating the projector with the heat sinks of FIG. **11**A, FIG. **11**B, and FIG. **13**;
(25) FIG. **16** illustrates the power consumption of the system on chip relative to touch temperature limits without thermal management;
(26) FIG. **17** illustrates a sample configuration of the components of a vapor chamber, including top and bottom covers, top and bottom wicking structures, and copper pillars, for managing excess heat from the electronic components;
(27) FIGS. **18**A and **18**B illustrate a heat map for front and rear perspective views, respectively, of a wearable electronic eyewear device with thermal management, including a system on chip that generates 1.5 W evenly distributed across the hinged arm, with a maximum rise of 4° C. across the hinged arm;
(28) FIG. **19**A illustrates a perspective view of a thermal management device for the system on chip of the electronic eyewear device of FIG. **10** in accordance with an example;
(29) FIG. **19**B illustrates a top plan view of the thermal management device of FIG. **19**A;

(30) FIG. **20**A illustrates a perspective view of one end of the thermal management device of FIGS. **19**A and **19**B in accordance with an example;
(31) FIG. **20**B illustrates an end elevation view of FIG. **20**A;
(32) FIG. **20**C illustrates a configuration of the thermal management device of FIG. **20**A in which the heat sink and the second TIM layer are omitted such that the vapor chamber is positioned adjacent to the heat source;
(33) FIG. **21**A illustrates a perspective view of a heat sink shown in FIG. **19**A in accordance with an example;
(34) FIG. **21**B illustrates an end elevation view of the heat sink of FIG. **21**A;
(35) FIG. **22**A illustrates a perspective view of a thermal management device in accordance with another example;
(36) FIG. **22**B illustrates a top plan view of the thermal management device of FIG. **22**A;
(37) FIG. **23** illustrates a sectional view along line **23-23** of FIG. **22**A;
(38) FIG. **24** illustrates a perspective view of another configuration of the thermal management device in accordance with an example;
(39) FIG. **25** illustrates a sectional view along line **25-25** of FIG. **24**;
(40) FIG. **26**A illustrates a perspective view of another configuration of the thermal management device in accordance with an example; and
(41) FIG. **26**B illustrates a perspective view of another configuration of a thermal management device in accordance with an example.

DETAILED DESCRIPTION

(42) Wearable electronic devices available today generate excessive heat that may impair device function. A wearable electronic eyewear device that includes a thermal management device is described herein. The wearable electronic eyewear device includes a body that holds one or more optical elements. It also includes onboard electronic components and one or more heat sources that radiate heat during operation of the components. The wearable electronic eyewear device also includes a heat sink at another area of the body and a thermal coupling disposed within the eyewear body that is thermally coupled to the heat source and the heat sink to increase heat dissipation of the electronic components.

(43) A wearable electronic eyewear device designed to enable an immersive augmented reality experience may use more immersive, larger field of view displays that require significantly more projector and rendering power. It is desired to provide wearable electronic eyewear devices that may handle the heat generated during such experiences without thermal throttling. To address this challenge, the wearable electronic eyewear devices described herein are configured to decouple the heat generated by a projector designed to disperse power from light emitting diodes (LEDs) from the heat generated by processing chips that implement a vapor chamber to more evenly distribute the heat from the processing chips. The configuration includes separating the projector thermal management devices from the processing chip thermal management devices by, for example, an air gap, and guiding the heat generated by the projector(s) to the frame and the heat generated by the processing circuit(s) to the temples of the wearable electronic eyewear device. Also, the processing chips may be implemented by co-processors disposed on respective temples of the wearable electronic eyewear device to further distribute the generated heat.

(44) This disclosure is directed to a method of dissipating heat generated by imaging devices and processing devices of a wearable electronic eyewear device. The method includes providing a first heat sink thermally connecting the imaging devices to a frame of the eyewear device to sink heat to the frame and providing a second heat sink thermally connecting the processing devices to respective temples of the eyewear device to sink heat to the respective temples. The first and second heat sinks are thermally insulated from each other to direct the heat to different portions of the eyewear device. The processing devices may include a first co-processor disposed in a first temple connected to a first end of the frame and a second co-processor disposed in a second temple

connected to a second end of the frame. The resulting wearable electronic eyewear device may include a frame, at least one temple connected to the frame, at least one image display, at least one imaging device adapted to capture an image of a scene and to project the image to the at least one image display, at least one processing device, and a thermal management device. The thermal management device may include a first heat sink thermally connected to the at least one imaging device and to the frame to sink heat from the at least one imaging device to the frame, a second heat sink thermally connected to the at least one processing device and the at least one temple to sink heat from the at least one processing device to the at least one temple, and a thermally insulating gap, such as an air gap, between the first heat sink and the second heat sink. The resulting wearable electronic eyewear device spreads the heat from heat generating devices over a larger area to minimize overall heating.

(45) As used herein, the term “thermal envelope” is used to describe the amount of heat that can be dissipated in a wearable electronic eyewear device in a steady state before hitting a temperature limit. The temperature limits may generally fall into two categories: component limits and touch limits. The component limits are generally dictated by the manufacturer and are designed to ensure functionality and a desired lifetime of the electronic component. However, there are instances where the component limit may be set lower than the manufacturer's specification to ensure a minimum performance. On the other hand, touch temperature limits are dependent upon material composition and whether that material is in constant physical contact with a user. Table 1 below shows touch temperature limits set by user studies and the International Electrotechnical Commission (IEC) Guide **117** for various materials. Extended duration skin contact is set by the IEC guidelines and assumes a wear duration of greater than 10 minutes.

(46) TABLE-US-00001 TABLE 1 Touch Temperature Limits Temperature Limit for extended Temperature Limit duration skin Material (° C.) contact (° C.) Plastic 55 43 Exposed metal 43 43 Fabric 55 43

(47) The following detailed description includes systems, methods, techniques, instruction sequences, and computer program products illustrative of examples set forth in the disclosure. Numerous details and examples are included for the purpose of providing a thorough understanding of the disclosed subject matter and its relevant teachings. Those skilled in the relevant art, however, may understand how to apply the relevant teachings without such details. Aspects of the disclosed subject matter are not limited to the specific devices, systems, and methods described because the relevant teachings can be applied or practiced in a variety of ways. The terminology and nomenclature used herein is for the purpose of describing particular aspects only and is not intended to be limiting. In general, well-known instruction instances, protocols, structures, and techniques are not necessarily shown in detail.

(48) The term “connect,” “connected,” “couple,” and “coupled” as used herein refers to any logical, optical, physical, or electrical connection, including a link or the like by which the electrical or magnetic signals produced or supplied by one system element are imparted to another coupled or connected system element. Unless described otherwise, coupled, or connected elements or devices are not necessarily directly connected to one another and may be separated by intermediate components, elements, or communication media, one or more of which may modify, manipulate, or carry the electrical signals. The term “on” means directly supported by an element or indirectly supported by the element through another element integrated into or supported by the element.

(49) Additional objects, advantages and novel features of the examples will be set forth in part in the following description, and in part will become apparent to those skilled in the art upon examination of the following and the accompanying drawings or may be learned by production or operation of the examples. The objects and advantages of the present subject matter may be realized and attained by means of the methodologies, instrumentalities and combinations particularly pointed out in the appended claims.

(50) The orientations of the eyewear device, associated components and any complete devices

incorporating an eye scanner and camera such as shown in any of the drawings, are given by way of example only, for illustration and discussion purposes. In operation for a particular variable optical processing application, the eyewear device may be oriented in any other direction suitable to the particular application of the eyewear device, for example up, down, sideways, or any other orientation. Also, to the extent used herein, any directional term, such as front, rear, inwards, outwards, towards, left, right, lateral, longitudinal, up, down, upper, lower, top, bottom and side, are used by way of example only, and are not limiting as to direction or orientation of any optic or component of an optic constructed as otherwise described herein.

(51) Reference now is made in detail to the examples illustrated in the accompanying drawings and discussed below.

(52) FIG. **1**A illustrates a side view of an example hardware configuration of a wearable electronic eyewear device **100** including a right optical assembly **180**B with an image display **180**D (FIG. **2**A). Wearable electronic eyewear device **100** includes multiple visible light cameras **114**A-B (FIG. **7**) that form a stereo camera, of which the right visible light camera **114**B is located on a right temple **110**B and the left visible light camera **114**A is located on a left temple **110**A.

(53) The left and right visible light cameras **114**A-B may include an image sensor that is sensitive to the visible light range wavelength. Each of the visible light cameras **114**A-B has a different frontward facing angle of coverage, for example, visible light camera **114**B has the depicted angle of coverage **111**B. The angle of coverage is an angle range in which the image sensor of the visible light camera **114**A-B picks up electromagnetic radiation and generates images. Examples of such visible lights camera **114**A-B include a high-resolution complementary metal-oxide-semiconductor (CMOS) image sensor and a video graphic array (VGA) camera, such as 640p (e.g., 640×480 pixels for a total of 0.3 megapixels), 720p, or 1080p. Image sensor data from the visible light cameras **114**A-B may be captured along with geolocation data, digitized by an image processor, and stored in a memory.

(54) To provide stereoscopic vision, visible light cameras **114**A-B may be coupled to an image processor (element **912** of FIG. **9**) for digital processing along with a timestamp in which the image of the scene is captured. Image processor **912** may include circuitry to receive signals from the visible light camera **114**A-B and to process those signals from the visible light cameras **114**A-B into a format suitable for storage in the memory (element **934** of FIG. **9**). The timestamp may be added by the image processor **912** or other processor that controls operation of the visible light cameras **114**A-B. Visible light cameras **114**A-B allow the stereo camera to simulate human binocular vision. Stereo cameras also provide the ability to reproduce three-dimensional images (image **715** of FIG. **7**) based on two captured images (elements **758**A-B of FIG. **7**) from the visible light cameras **114**A-B, respectively, having the same timestamp. Such three-dimensional images **715** allow for an immersive life-like experience, e.g., for virtual reality or video gaming. For stereoscopic vision, the pair of images **758**A-B may be generated at a given moment in time—one image for each of the left and right visible light cameras **114**A-B. When the pair of generated images **758**A-B from the frontward facing field of view (FOV) **111**A-B of the left and right visible light cameras **114**A-B are stitched together (e.g., by the image processor **912**), depth perception is provided by the optical assembly **180**A-B.

(55) In an example, the wearable electronic eyewear device **100** includes a frame **105**, a right rim **107**B, a right temple **110**B extending from a right lateral side **170**B of the frame **105**, and a see-through image display **180**D (FIGS. **2**A-B) comprising optical assembly **180**B to present a graphical user interface to a user. The wearable electronic eyewear device **100** includes the left visible light camera **114**A connected to the frame **105** or the left temple **110**A to capture a first image of the scene. Wearable electronic eyewear device **100** further includes the right visible light camera **114**B connected to the frame **105** or the right temple **110**B to capture (e.g., simultaneously with the left visible light camera **114**A) a second image of the scene which partially overlaps the first image. Although not shown in FIGS. **1**A-B, a processor **932** (FIG. **9**) is coupled to the

wearable electronic eyewear device **100** and connected to the visible light cameras **114**A-B, and memory **934** (FIG. **9**) accessible to the processor **932**, and programming in the memory **934**, may be provided in the wearable electronic eyewear device **100** itself.

(56) Although not shown in FIG. **1**A, the wearable electronic eyewear device **100** also may include a head movement tracker (element **109** of FIG. **1**B) or an eye movement tracker (element **113** of FIG. **2**A or element **213** of FIGS. **2**B-C). Wearable electronic eyewear device **100** may further include the see-through image displays **180**C-D of optical assembly **180**A-B, respectfully, for presenting a sequence of displayed images, and an image display driver (element **942** of FIG. **9**) coupled to the see-through image displays **180**C-D of optical assembly **180**A-B to control the image displays **180**C-D of optical assembly **180**A-B to present the sequence of displayed images **715**, which are described in further detail below. Wearable electronic eyewear device **100** may further include the memory **934** and the processor **932** having access to the image display driver **942** and the memory **934**, as well as programming in the memory **934**. Execution of the programming by the processor **932** configures the wearable electronic eyewear device **100** to perform functions, including functions to present, via the see-through image displays **180**C-D, an initial displayed image of the sequence of displayed images, the initial displayed image having an initial field of view corresponding to an initial head direction or an initial eye gaze direction **230** (FIG. **5**).

(57) Execution of the programming by the processor **932** may further configure the wearable electronic eyewear device **100** to detect movement of a user of the eyewear device by: (i) tracking, via the head movement tracker (element **109** of FIG. **1**B), a head movement of a head of the user, or (ii) tracking, via an eye movement tracker (element **113** of FIG. **2**A or element **213** of FIGS. **2**B-C and FIG. **5**), an eye movement of an eye of the user of the wearable electronic eyewear device **100**. Execution of the programming by the processor **932** may further configure the wearable electronic eyewear device **100** to determine a field of view adjustment to the initial field of view of the initial displayed image based on the detected movement of the user. The field of view adjustment may include a successive field of view corresponding to a successive head direction or a successive eye direction. Execution of the programming by the processor **932** may further configure the wearable electronic eyewear device **100** to generate a successive displayed image of the sequence of displayed images based on the field of view adjustment. Execution of the programming by the processor **932** may further configure the wearable electronic eyewear device **100** to present, via the see-through image displays **180**C-D of the optical assembly **180**A-B, the successive displayed images.

(58) FIG. **1**B illustrates a top cross-sectional view of the temple of the wearable electronic eyewear device **100** of FIG. **1**A depicting the right visible light camera **114**B, a head movement tracker **109**, and a circuit board **140**. Construction and placement of the left visible light camera **114**A is substantially similar to the right visible light camera **114**B, except the connections and coupling are on the left lateral side **170**A (FIG. **2**A). As shown, the wearable electronic eyewear device **100** includes the right visible light camera **114**B and a circuit board, which may be a flexible printed circuit board (PCB) **140**. The right hinge **126**B connects the right temple **110**B to hinged arm **125**B of the wearable electronic eyewear device **100**. In some examples, components of the right visible light camera **114**B, the flexible PCB **140**, or other electrical connectors or contacts may be located on the right temple **110**B or the right hinge **126**B.

(59) As shown, wearable electronic eyewear device **100** may include a head movement tracker **109**, which includes, for example, an inertial measurement unit (IMU). An inertial measurement unit is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers. The inertial measurement unit works by detecting linear acceleration using one or more accelerometers and rotational rate using one or more gyroscopes. Typical configurations of inertial measurement units contain one accelerometer, gyro, and

magnetometer per axis for each of the three axes: horizontal axis for left-right movement (X), vertical axis (Y) for top-bottom movement, and depth or distance axis for up-down movement (Z). The accelerometer detects the gravity vector. The magnetometer defines the rotation in the magnetic field (e.g., facing south, north, etc.) like a compass that generates a heading reference. The three accelerometers detect acceleration along the horizontal, vertical, and depth axis defined above, which can be defined relative to the ground, the wearable electronic eyewear device **100**, or the user wearing the wearable electronic eyewear device **100**.

(60) Wearable electronic eyewear device **100** may detect movement of the user of the wearable electronic eyewear device **100** by tracking, via the head movement tracker **109**, the head movement of the head of the user. The head movement includes a variation of head direction on a horizontal axis, a vertical axis, or a combination thereof from the initial head direction during presentation of the initial displayed image on the image display. In one example, tracking, via the head movement tracker **109**, the head movement of the head of the user includes measuring, via the inertial measurement unit **109**, the initial head direction on the horizontal axis (e.g., X axis), the vertical axis (e.g., Y axis), or the combination thereof (e.g., transverse or diagonal movement). Tracking, via the head movement tracker **109**, the head movement of the head of the user further includes measuring, via the inertial measurement unit **109**, a successive head direction on the horizontal axis, the vertical axis, or the combination thereof during presentation of the initial displayed image.

(61) Tracking, via the head movement tracker **109**, the head movement of the head of the user may further include determining the variation of head direction based on both the initial head direction and the successive head direction. Detecting movement of the user of the wearable electronic eyewear device **100** may further include in response to tracking, via the head movement tracker **109**, the head movement of the head of the user, determining that the variation of head direction exceeds a deviation angle threshold on the horizontal axis, the vertical axis, or the combination thereof. In sample configurations, the deviation angle threshold is between about 3° to 10°. As used herein, the term “about” when referring to an angle means±10% from the stated amount.

(62) Variation along the horizontal axis slides three-dimensional objects, such as characters, Bitmojis, application icons, etc. in and out of the field of view by, for example, hiding, unhiding, or otherwise adjusting visibility of the three-dimensional object. Variation along the vertical axis, for example, when the user looks upwards, in one example, displays weather information, time of day, date, calendar appointments, etc. In another example, when the user looks downwards on the vertical axis, the wearable electronic eyewear device **100** may power down.

(63) As shown in FIG. **1**B, the right temple **110**B includes temple body **211** and a temple cap, with the temple cap omitted in the cross-section of FIG. **1**B. Disposed inside the right temple **110**B are various interconnected circuit boards, such as PCBs or flexible PCBs **140**, that include controller circuits for right visible light camera **114**B, microphone(s) **130**, speaker(s) **132**, low-power wireless circuitry (e.g., for wireless short-range network communication via BLUETOOTH®), and high-speed wireless circuitry (e.g., for wireless local area network communication via WI-FI®).

(64) The right visible light camera **114**B is coupled to or disposed on the flexible PCB **140** and covered by a visible light camera cover lens, which is aimed through opening(s) formed in the right temple **110**B. In some examples, the frame **105** connected to the right temple **110**B includes the opening(s) for the visible light camera cover lens. The frame **105** may include a front-facing side configured to face outwards away from the eye of the user. The opening for the visible light camera cover lens may be formed on and through the front-facing side. In the example, the right visible light camera **114**B has an outward facing angle of coverage **111**B with a line of sight or perspective of the right eye of the user of the wearable electronic eyewear device **100**. The visible light camera cover lens also can be adhered to an outward facing surface of the right temple **110**B in which an opening is formed with an outwards facing angle of coverage, but in a different outwards direction. The coupling can also be indirect via intervening components.

(65) Left (first) visible light camera **114**A may be connected to the left see-through image display

180C of left optical assembly **180**A to generate a first background scene of a first successive displayed image. The right (second) visible light camera **114**B may be connected to the right see-through image display **180**D of right optical assembly **180**B to generate a second background scene of a second successive displayed image. The first background scene and the second background scene may partially overlap to present a three-dimensional observable area of the successive displayed image.
(66) Flexible PCB **140** may be disposed inside the right temple **110**B and coupled to one or more other components housed in the right temple **110**B. Although shown as being formed on the circuit boards **140** of the right temple **110**B, the right visible light camera **114**B can be formed on the circuit boards **140** of the left temple **110**A, the hinged arms **125**A-B, or frame **105**.
(67) FIG. **2**A illustrates a rear view of an example hardware configuration of a wearable electronic eyewear device **100**. As shown in FIG. **2**A, the wearable electronic eyewear device **100** is in a form configured for wearing by a user, which are eyeglasses in the example of FIG. **2**A. The wearable electronic eyewear device **100** can take other forms and may incorporate other types of frameworks, for example, a headgear, a headset, or a helmet.
(68) In the eyeglasses example, wearable electronic eyewear device **100** includes the frame **105** which includes the left rim **107**A connected to the right rim **107**B via the bridge **106** adapted for a nose of the user. The left and right rims **107**A-B include respective apertures **175**A-B which hold the respective optical element **180**A-B, such as a lens and the see-through displays **180**C-D. As used herein, the term lens is meant to cover transparent or translucent pieces of glass or plastic having curved and flat surfaces that cause light to converge/diverge or that cause little or no convergence/divergence.
(69) Although shown as having two optical elements **180**A-B, the wearable electronic eyewear device **100** can include other arrangements, such as a single optical element depending on the application or intended user of the wearable electronic eyewear device **100**. As further shown, wearable electronic eyewear device **100** includes the left temple **110**A adjacent the left lateral side **170**A of the frame **105** and the right temple **110**B adjacent the right lateral side **170**B of the frame **105**. The temples **110**A-B may be integrated into the frame **105** on the respective sides **170**A-B (as illustrated) or implemented as separate components attached to the frame **105** on the respective sides **170**A-B. Alternatively, the temples **110**A-B may be integrated into hinged arms **125**A-B attached to the frame **105**.
(70) In the example of FIG. **2**A, an eye scanner **113** may be provided that includes an infrared emitter **115** and an infrared camera **120**. Visible light cameras typically include a blue light filter to block infrared light detection. In an example, the infrared camera **120** is a visible light camera, such as a low-resolution video graphic array (VGA) camera (e.g., 640×480 pixels for a total of 0.3 megapixels), with the blue filter removed. The infrared emitter **115** and the infrared camera **120** may be co-located on the frame **105**. For example, both are shown as connected to the upper portion of the left rim **107**A. The frame **105** or one or more of the left and right temples **110**A-B may include a circuit board (not shown) that includes the infrared emitter **115** and the infrared camera **120**. The infrared emitter **115** and the infrared camera **120** can be connected to the circuit board by soldering, for example.
(71) Other arrangements of the infrared emitter **115** and infrared camera **120** may be implemented, including arrangements in which the infrared emitter **115** and infrared camera **120** are both on the right rim **107**B, or in different locations on the frame **105**. For example, the infrared emitter **115** may be on the left rim **107**A and the infrared camera **120** may be on the right rim **107**B. In another example, the infrared emitter **115** may be on the frame **105** and the infrared camera **120** may be on one of the temples **110**A-B, or vice versa. The infrared emitter **115** can be connected essentially anywhere on the frame **105**, left temple **110**A, or right temple **110**B to emit a pattern of infrared light. Similarly, the infrared camera **120** can be connected essentially anywhere on the frame **105**, left temple **110**A, or right temple **110**B to capture at least one reflection variation in the emitted

pattern of infrared light.

(72) The infrared emitter **115** and infrared camera **120** may be arranged to face inwards towards an eye of the user with a partial or full field of view of the eye in order to identify the respective eye position and gaze direction. For example, the infrared emitter **115** and infrared camera **120** may be positioned directly in front of the eye, in the upper part of the frame **105** or in the temples **110**A-B at either ends of the frame **105**.

(73) FIG. **2**B illustrates a rear view of an example hardware configuration of another wearable electronic eyewear device **200**. In this example configuration, the wearable electronic eyewear device **200** is depicted as including an eye scanner **213** on a right temple **210**B. As shown, an infrared emitter **215** and an infrared camera **220** are co-located on the right temple **210**B. It should be understood that the eye scanner **213** or one or more components of the eye scanner **213** can be located on the left temple **210**A and other locations of the wearable electronic eyewear device **200**, for example, the frame **105**. The infrared emitter **215** and infrared camera **220** are like that of FIG. **2**A, but the eye scanner **213** can be varied to be sensitive to different light wavelengths as described previously in FIG. **2**A. Similar to FIG. **2**A, the wearable electronic eyewear device **200** includes a frame **105** which includes a left rim **107**A which is connected to a right rim **107**B via a bridge **106**. The left and right rims **107**A-B may include respective apertures which hold the respective optical elements **180**A-B comprising the see-through display **180**C-D.

(74) FIGS. **2**C-D illustrate rear views of example hardware configurations of the wearable electronic eyewear device **100**, including two different types of see-through image displays **180**C-D. In one example, these see-through image displays **180**C-D of optical assembly **180**A-B include an integrated image display. As shown in FIG. **2**C, the optical assemblies **180**A-B include a suitable display matrix **180**C-D of any suitable type, such as a liquid crystal display (LCD), an organic light-emitting diode (OLED) display, a waveguide display, or any other such display.

(75) The optical assembly **180**A-B also includes an optical layer or layers **176**, which can include lenses, optical coatings, prisms, mirrors, waveguides, optical strips, and other optical components in any combination. The optical layers **176**A-N can include a prism having a suitable size and configuration and including a first surface for receiving light from display matrix and a second surface for emitting light to the eye of the user. The prism of the optical layers **176**A-N may extend over all or at least a portion of the respective apertures **175**A-B formed in the left and right rims **107**A-B to permit the user to see the second surface of the prism when the eye of the user is viewing through the corresponding left and right rims **107**A-B. The first surface of the prism of the optical layers **176**A-N faces upwardly from the frame **105** and the display matrix overlies the prism so that photons and light emitted by the display matrix impinge the first surface. The prism may be sized and shaped so that the light is refracted within the prism and is directed towards the eye of the user by the second surface of the prism of the optical layers **176**A-N. In this regard, the second surface of the prism of the optical layers **176**A-N can be convex to direct the light towards the center of the eye. The prism can optionally be sized and shaped to magnify the image projected by the see-through image displays **180**C-D, and the light travels through the prism so that the image viewed from the second surface is larger in one or more dimensions than the image emitted from the see-through image displays **180**C-D.

(76) In another example, the see-through image displays **180**C-D of optical assembly **180**A-B may include a projection image display as shown in FIG. **2**D. The optical assembly **180**A-B includes a projector **150**, which may be a three-color projector using a scanning mirror, a galvanometer, a laser projector, or other types of projectors. During operation, an optical source such as a projector **150** is disposed in or on one of the temples **110**A-B of the wearable electronic eyewear device **100**. Optical assembly **180**A-B may include one or more optical strips **155**A-N spaced apart across the width of the lens of the optical assembly **180**A-B or across a depth of the lens between the front surface and the rear surface of the lens. An example of a projector **150** is shown in FIGS. **8**A-**8**E and described in more detail below.

(77) As the photons projected by the projector **150** travel across the lens of the optical assembly **180**A-B, the photons encounter the optical strips **155**A-N. When a particular photon encounters a particular optical strip, the photon is either redirected towards the user's eye, or it passes to the next optical strip. A combination of modulation of projector **150**, and modulation of optical strips, may control specific photons or beams of light. In an example, a processor controls optical strips **155**A-N by initiating mechanical, acoustic, or electromagnetic signals. Although shown as having two optical assemblies **180**A-B, the wearable electronic eyewear device **100** can include other arrangements, such as a single or three optical assemblies, or the optical assembly **180**A-B may have arranged different arrangement depending on the application or intended user of the wearable electronic eyewear device **100**.
(78) As further shown in FIGS. **2**C-D, wearable electronic eyewear device **100** includes a left temple **110**A adjacent the left lateral side **170**A of the frame **105** and a right temple **110**B adjacent the right lateral side **170**B of the frame **105**. The temples **110**A-B may be integrated into the frame **105** on the respective lateral sides **170**A-B (as illustrated) or implemented as separate components attached to the frame **105** on the respective sides **170**A-B. Alternatively, the temples **110**A-B may be integrated into the hinged arms **125**A-B attached to the frame **105**.
(79) In one example, the see-through image displays include the first see-through image display **180**C and the second see-through image display **180**D. Wearable electronic eyewear device **100** may include first and second apertures **175**A-B that hold the respective first and second optical assembly **180**A-B. The first optical assembly **180**A may include the first see-through image display **180**C (e.g., a display matrix of FIG. **2**C or optical strips **155**A-N′ and a projector **150**A). The second optical assembly **180**B may include the second see-through image display **180**D (e.g., a display matrix of FIG. **2**C or optical strips **155**A-N″ and a projector **150**B). The successive field of view of the successive displayed image may include an angle of view between about 15° to 30, and more specifically 24°, measured horizontally, vertically, or diagonally. The successive displayed image having the successive field of view represents a combined three-dimensional observable area visible through stitching together of two displayed images presented on the first and second image displays.
(80) As used herein, “an angle of view” describes the angular extent of the field of view associated with the displayed images presented on each of the left and right image displays **180**C-D of optical assembly **180**A-B. The “angle of coverage” describes the angle range that a lens of visible light cameras **114**A-B or infrared camera **220** can image. Typically, the image circle produced by a lens is large enough to cover the film or sensor completely, possibly including some vignetting (i.e., a reduction of an image's brightness or saturation toward the periphery compared to the image center). If the angle of coverage of the lens does not fill the sensor, the image circle will be visible, typically with strong vignetting toward the edge, and the effective angle of view will be limited to the angle of coverage. The “field of view” is intended to describe the field of observable area which the user of the wearable electronic eyewear device **100** can see through his or her eyes via the displayed images presented on the left and right image displays **180**C-D of the optical assembly **180**A-B. Image display **180**C of optical assembly **180**A-B can have a field of view with an angle of coverage between 15° to 30°, for example 24°, and have a resolution of 480×480 pixels.
(81) FIG. **3** illustrates a rear perspective view of the wearable electronic eyewear device **100** of FIG. **2**A. The wearable electronic eyewear device **100** includes an infrared emitter **215**, infrared camera **220**, a frame front **330**, a frame back **335**, and a circuit board **340**. It can be seen in FIG. **3** that the upper portion of the left rim of the frame of the wearable electronic eyewear device **100** may include the frame front **330** and the frame back **335**. An opening for the infrared emitter **215** is formed on the frame back **335**.
(82) As shown in the encircled cross-section **4** in the upper middle portion of the left rim of the frame, a circuit board, which may be a flexible PCB **340**, is sandwiched between the frame front **330** and the frame back **335**. Also shown in further detail is the attachment of the left temple **110**A

to the left hinged arm **325**A via the left hinge **126**A. In some examples, components of the eye movement tracker **213**, including the infrared emitter **215**, the flexible PCB **340**, or other electrical connectors or contacts may be located on the left hinged arm **325**A or the left hinge **126**A.

(83) FIG. **4** is a cross-sectional view through the infrared emitter **215** and the frame corresponding to the encircled cross-section **4** of the eyewear device of FIG. **3**. Multiple layers of the wearable electronic eyewear device **100** are illustrated in the cross-section of FIG. **4**. As shown, the frame includes the frame front **330** and the frame back **335**. The flexible PCB **340** is disposed on the frame front **330** and connected to the frame back **335**. The infrared emitter **215** is disposed on the flexible PCB **340** and covered by an infrared emitter cover lens **445**. For example, the infrared emitter **215** may be reflowed to the back of the flexible PCB **340**. Reflowing attaches the infrared emitter **215** to contact pad(s) formed on the back of the flexible PCB **340** by subjecting the flexible PCB **340** to controlled heat which melts a solder paste to connect the two components. In one example, reflowing is used to surface mount the infrared emitter **215** on the flexible PCB **340** and electrically connect the two components. However, it should be understood that through-holes can be used to connect leads from the infrared emitter **215** to the flexible PCB **340** via interconnects, for example.

(84) The frame back **335** may include an infrared emitter opening **450** for the infrared emitter cover lens **445**. The infrared emitter opening **450** is formed on a rear-facing side of the frame back **335** that is configured to face inwards towards the eye of the user. In the example, the flexible PCB **340** can be connected to the frame front **330** via the flexible PCB adhesive **460**. The infrared emitter cover lens **445** can be connected to the frame back **335** via infrared emitter cover lens adhesive **455**. The coupling also can be indirect via intervening components.

(85) In an example, the processor **932** utilizes eye tracker **213** to determine an eye gaze direction **230** of a wearer's eye **234** as shown in FIG. **5**, and an eye position **236** of the wearer's eye **234** within an eyebox as shown in FIG. **6**. The eye tracker **213** may be a scanner which uses infrared light illumination (e.g., near-infrared, short-wavelength infrared, mid-wavelength infrared, long-wavelength infrared, or far infrared) to captured image of reflection variations of infrared light from the eye **234** to determine the gaze direction **230** of a pupil **232** of the eye **234**, and also the eye position **236** with respect to the see-through display **180**D.

(86) FIG. **7** illustrates an example of capturing visible light with cameras **114**A-B. Visible light is captured by the left visible light camera **114**A with a round field of view (FOV). **111**A. A chosen rectangular left raw image **758**A is used for image processing by image processor **912** (FIG. **9**). Visible light is also captured by the right visible light camera **114**B with a round FOV **111**B. A rectangular right raw image **758**B chosen by the image processor **912** is used for image processing by processor **912**. Based on processing of the left raw image **758**A and the right raw image **758**B having an overlapping field of view **713**, a three-dimensional image **715** of a three-dimensional scene, referred to hereafter as an immersive image, is generated by processor **912** and displayed by displays **180**C and **180**D and which is viewable by the user.

(87) FIG. **8**A is a side view of a projector **150** configured to generate an image, such as shown and described as projector **150** in FIG. **2**D. Projector **150** may include a display **812** configured to modulate light beams impinging thereon from one or more colored light sources to generate the image, shown as being generated by a red/blue light-emitting diode (LED) **814** and a green LED **816**. The red/blue LED **814** selectively emits a red and blue light beam **832** that passes through respective condenser lenses **818**, reflects off a dichroic lens **820**, through a fly's eye **822**, through a powered prism **824** and a reverse total internal reflection (RTIR) light prism **826** separated from each other by a plano spacer **828**, and output at a bottom output **830** of RTIR light prism **826** to display **812** as shown. The green LED **816** selectively emits a green light beam **832** through respective condenser lenses **818** and passes through the dichroic lens **820**, fly's eye **822**, through the powered prism **824** and the RTIR light prism **826**, and output from the bottom RTIR light prism output **830** to display **812**. The LEDs **814** and **816** are time sequenced by a light controller **829** so

that only one light is on at a time, and the display **812** modulates only one colored light beam **832** at a time. The modulated light from the display **812** produces an image that is directed back into RTIR light prism **826** through bottom output **830**, reflects off plano spacer **828**, and exits through a vertical RTIR light prism output **834** to projection lens elements **836** for display on an image plane. The human eye integrates the modulated colored light beams displayed on the image plane to perceive a color image. The display **812** may be a digital micromirror device (DMD)® display manufactured by Texas Instruments of Dallas, Texas, although other displays are possible. Only this portion of the projector **150** described herein so far is a known digital light projection (DLP)® system architecture such as manufactured by Texas Instruments of Dallas, Texas.
(88) To increase a field of view (FOV) of this described DLP® projector from a diagonal 25-degree FOV to a diagonal 46-degree FOV, and maintaining resolution and display pixel pitch, this would result in a 1.9× scale of the display image diagonal. By maintaining the projection lens f-stop number (f/#) and maintaining telecentricity at the projection lens, this increase in display diagonal would typically translate into a direct 1.9× scale of the diameter of the largest element in the projection lens. Additionally, due to the need to pass the colored light beams through the RTIR prism **826**, the back focal length of the projection lens would also scale, resulting in an overall length increase as well.
(89) As shown and described with reference to FIG. **8**A-FIG. **8**E, by incorporating a positive power field lens, the projection lens telecentricity is maintained, but the ray bundle at the last element is significantly reduced, also reducing the size needed for the back focal length and overall length of the projection lens. A field lens **840** is a positive-powered lens that comes after an objective lens and before an image plane. Additional benefit is seen on the illumination side of the projector, as the size of the powered prism **24** surfaces are reduced due to the power in the field lens. In this description, the selected field lens power is reduced by 17% in each dimension (x, y, z).
(90) There is, however, a challenge that a field lens presents specifically for a DLP® display projector. A DLP® display projector requires illumination of the DMD® display **812** at a large 34-degree input angle, and a field lens centered over the DMD® display **812** poses a problem of uniform illumination on one side of the DMD® display **812**. To overcome this limitation, the projection lens may be designed to support a much larger image circle diameter, and further, the display **812** may be laterally displaced/shifted in the image plane toward a more uniform position. This display **812** displacement results in a boresight shift (i.e., the FOV of the projector is shifted from being parallel to the optical axis of rotational symmetry). This is advantageous in an augmented reality (AR) system because this enables the projector at a non-normal angle to a waveguide, such as used in eyewear optics, allowing for a better fit in the industrial design supporting a larger pantoscopic tilt.
(91) In sample configurations, a curved field lens **840** is coupled adjacent to a bottom prism face **831** forming the bottom output **830** of the RTIR light prism **826**. The curved field lens **840** is configured to decenter and angle the colored light beams **832** away from the bottom prism face **831** an angle A as shown, and evenly illuminate the display **812** that is shifted to the right in the image plane. The field lens **840** angles the light beams **832** at angle A with respect to a normal of the bottom prism face **831**, such that the light beams **832** are not output perpendicular to the normal of prism face **831**. The curved field lens **840** has an optical axis that is off center from a center of the prism face **831**.
(92) A center **846** of the display **812** is shifted to the right of a center **844** of the bottom prism face **831** by a distance D. The decentering of the colored light beams **832** generated by field lens **840**, and shifting/positioning of the display **812**, results in a favorable shifted boresight image generated by display **812** as indicated at **838** that exits the projection lens elements **836**. The curved field lens **840** enables use of smaller system components, wherein the greater the curvature of the curved field lens **840** the smaller the projector **150**, as will be discussed with reference to FIG. **8**D.
(93) FIG. **8**B illustrates a side sectional view of a housing **860** that encompasses the components of

the projector **150** described with reference to FIG. **8**A. In sample configurations, the housing **860** may comprise a material that can withstand elevated temperatures, such as generated by the light beams **832**, such as metal or synthetic materials.
(94) FIG. **8**C illustrates the portion of projector **150** that is the illumination section **870** of projector **150**, and the portion of projector **150** that is the projection lens **872**. The illumination section **870** is considered to extend from the LED **816** to the vertical output **834** formed by a vertical prism face of the RTIR light prism **826** proximate the projection lens elements **836**. The projection lens **872** is considered to extend from the left side of projection lens **840** to the right end of the projection lens elements **836**.
(95) FIG. **8**D illustrates graphs of system dimensions as a function of the curvature of the field lens **840**.
(96) Graph A depicts the width dimension of the prism face **831** of RTIR light prism **826** at output **830** as a function of the curvature of field lens **840**. As can be seen, the greater the curvature of the field lens **840**, the narrower/smaller the prism face **831** of the RTIR prism **826** and the smaller the size of system **150**.
(97) Graph B depicts the diameter of the projection lens elements **836** as a function of the field lens **840** curvature. As can be seen, the greater the curvature of the field lens **840**, the smaller the diameter of the projection lens elements **836**.
(98) Graph C depicts the length of projection lens **872** as a function of the curvature of field lens **840**. As can be seen, the greater the curvature of the field lens **840**, the shorter the length of the projection lens **872**.
(99) FIG. **8**E illustrates a method **880** of generating a decentered light beam using the field lens **840** and of generating a display image in a sample implementation.
(100) At block **882**, the light controller **829** controls the colored light sources **814** and **816** to selectively generate a red, green, and blue (RGB) colored light beam. The light sources are selectively controlled such that only one colored light beam **832** is generated at a time.
(101) At block **884**, the power prism **824** and the RTIR prism **826** route the light beams **832** therethrough. The light beams **832** are internally reflected and provided to the prism face **831** forming the output **830**.
(102) At block **886**, the curved field lens **840** decenters the light beams **832** from the prism face **831**. The curvature of the field lens **840** angles the light beams **832** at an angle A with respect to the prism face **831** such that the angle A is not normal to the prism face **831**.
(103) At block **888**, the light beams **832** are directed by the field lens **840** to the display **812** which modulates the light beams **832** to form a visual image. The center of display **812** is shifted with respect to a center of the prism face **831**, and the modulated light beams **832** uniformly illuminate the display. The light image has a downward boresight as shown at **838**.
(104) As noted above with respect to FIG. **8**D, the dimension of illumination section **870** is a function of the curvature of the curved field lens **840**, and the dimension of the projection lens **872** is a function of the curvature of the curved field lens **840**. The greater the curvature of the field lens **840**, the smaller the dimensions of components forming the projector **150** and thus the smaller the dimensions of illumination section **870** and projection lens **872**.
(105) FIG. **9** illustrates a high-level functional block diagram including example electronic components disposed in wearable electronic eyewear device **100** or **200**. The illustrated electronic components include the processor **932**, the memory **934**, and the see-through image display **180**C and **180**D.
(106) Memory **934** includes instructions for execution by processor **932** to implement the functionality of wearable electronic eyewear devices **100**/**200**, including instructions for processor **932** to control in the image **715**. Processor **932** receives power from battery **950** and executes the instructions stored in memory **934**, or integrated with the processor **932** on-chip, to perform the functionality of wearable electronic eyewear devices **100**/**200** and to communicate with external

devices via wireless connections.

(107) The wearable electronic eyewear device **100** may incorporate an eye movement tracker **213** (e.g., shown as infrared emitter **215** and infrared camera **220** in FIG. **2**B) and may provide user interface adjustments via a mobile device **990** and a server system **998** connected via various networks. Mobile device **990** may be a smartphone, tablet, laptop computer, access point, or any other such device capable of connecting with the wearable electronic eyewear device **100** using both a low-power wireless connection **925** and a high-speed wireless connection **937**. Mobile device **990** is further connected to server system **998** via a network **995**. The network **995** may include any combination of wired and wireless connections.

(108) Wearable electronic eyewear device **100** may include at least two visible light cameras **114**A-B (one associated with the left lateral side **170**A and one associated with the right lateral side **170**B). Wearable electronic eyewear device **100** further includes two see-through image displays **180**C-D of the optical assembly **180**A-B (one associated with the left lateral side **170**A and one associated with the right lateral side **170**B). Wearable electronic eyewear device **100** also includes image display driver **942**, image processor **912**, low-power circuitry **920**, and high-speed circuitry **930**. The components shown in FIG. **9** for the wearable electronic eyewear devices **100** and **200** are located on one or more circuit boards, for example, a PCB or flexible PCB **140**, in the temples. Alternatively, or additionally, the depicted components can be located in the temples, frames, hinges, hinged arms, or bridge of the wearable electronic eyewear devices **100** and **200**. Left and right visible light cameras **114**A-B can include digital camera elements such as a complementary metal-oxide-semiconductor (CMOS) image sensor, charge coupled device, a lens, or any other respective visible or light capturing elements that may be used to capture data, including images of scenes with unknown objects.

(109) Eye movement tracking programming **945** implements the user interface field of view adjustment instructions, including instructions to cause the wearable electronic eyewear device **100** to track, via the eye movement tracker **213**, the eye movement of the eye of the user of the wearable electronic eyewear devices **100** or **200**. Other implemented instructions (functions) cause the wearable electronic eyewear devices **100** and **200** to determine the FOV adjustment to the initial FOV **111**A-B based on the detected eye movement of the user corresponding to a successive eye direction. Further implemented instructions generate a successive displayed image of the sequence of displayed images based on the field of view adjustment. The successive displayed image is produced as visible output to the user via the user interface. This visible output appears on the see-through image displays **180**C-D of optical assembly **180**A-B, which is driven by image display driver **942** to present the sequence of displayed images, including the initial displayed image with the initial field of view and the successive displayed image with the successive field of view.

(110) As shown in FIG. **9**, high-speed circuitry **930** includes high-speed processor **932**, memory **934**, and high-speed wireless circuitry **936**. In the example, the image display driver **942** is coupled to the high-speed circuitry **930** and operated by the high-speed processor **932** in order to drive the left and right image displays **180**C-D of the optical assembly **180**A-B. High-speed processor **932** may be any processor capable of managing high-speed communications and operation of any general computing system needed for wearable electronic eyewear device **100**. High-speed processor **932** includes processing resources needed for managing high-speed data transfers on high-speed wireless connection **937** to a wireless local area network (WLAN) using high-speed wireless circuitry **936**. In certain examples, the high-speed processor **932** executes an operating system such as a LINUX operating system or other such operating system of the wearable electronic eyewear device **100** and the operating system is stored in memory **934** for execution. In addition to any other responsibilities, the high-speed processor **932** executing a software architecture for the wearable electronic eyewear device **100** is used to manage data transfers with high-speed wireless circuitry **936**. In certain examples, high-speed wireless circuitry **936** is

configured to implement Institute of Electrical and Electronic Engineers (IEEE) 802.11 communication standards, also referred to herein as WI-FI®. In other examples, other high-speed communications standards may be implemented by high-speed wireless circuitry **936**.
(111) Low-power wireless circuitry **924** and the high-speed wireless circuitry **936** of the wearable electronic eyewear device **100** and **200** can include short range transceivers (BLUETOOTH®) and wireless wide, local, or wide area network transceivers (e.g., cellular or WI-FI®). Mobile device **990**, including the transceivers communicating via the low-power wireless connection **925** and high-speed wireless connection **937**, may be implemented using details of the architecture of the wearable electronic eyewear device **100**, as can other elements of network **995**.
(112) Memory **934** includes any storage device capable of storing various data and applications, including, among other things, color maps, camera data generated by the left and right visible light cameras **114**A-B and the image processor **912**, as well as images generated for display by the image display driver **942** on the see-through image displays **180**C-D of the optical assembly **180**A-B. While memory **934** is shown as integrated with high-speed circuitry **930**, in other examples, memory **934** may be an independent standalone element of the wearable electronic eyewear device **100**. In certain such examples, electrical routing lines may provide a connection through a system on chip (e.g., SOC **1000** in FIG. **10**) that includes the high-speed processor **932** from the image processor **912** or low-power processor **922** to the memory **934**. In other examples, the high-speed processor **932** may manage addressing of memory **934** such that the low-power processor **922** will boot the high-speed processor **932** any time that a read or write operation involving memory **934** is needed.
(113) Server system **998** may be one or more computing devices as part of a service or network computing system, for example, that includes a processor, a memory, and network communication interface to communicate over the network **995** with the mobile device **990** and wearable electronic eyewear devices **100**/**200**. Wearable electronic eyewear devices **100** and **200** are connected with a host computer. For example, the wearable electronic eyewear device **100** is paired with the mobile device **990** via the high-speed wireless connection **937** or directly connected to the server system **998** via the network **995**.
(114) Output components of the wearable electronic eyewear device **100** include visual components, such as the left and right image displays **180**C-D of optical assembly **180**A-B as described in FIGS. **2**C-D (e.g., a display such as a liquid crystal display (LCD), a plasma display panel (PDP), a light emitting diode (LED) display, a projector, or a waveguide). The image displays **180**C-D of the optical assembly **180**A-B are driven by the image display driver **942**. The output components of the wearable electronic eyewear device **100** further include acoustic components (e.g., speakers), haptic components (e.g., a vibratory motor), other signal generators, and so forth. The input components of the wearable electronic eyewear devices **100** and **200**, the mobile device **990**, and server system **998**, may include alphanumeric input components (e.g., a keyboard, a touch screen configured to receive alphanumeric input, a photo-optical keyboard, or other alphanumeric input components), point-based input components (e.g., a mouse, a touchpad, a trackball, a joystick, a motion sensor, or other pointing instruments), tactile input components (e.g., a physical button, a touch screen that provides location and force of touches or touch gestures, or other tactile input components), audio input components (e.g., a microphone), and the like.
(115) Wearable electronic eyewear device **100** may optionally include additional peripheral device elements such as ambient light and spectral sensors, biometric sensors, heat sensor **940**, or other display elements integrated with wearable electronic eyewear device **100**. For example, the peripheral device elements may include any I/O components including output components, motion components, position components, or any other such elements described herein. The wearable electronic eyewear device **100** can take other forms and may incorporate other types of frameworks, for example, a headgear, a headset, or a helmet.
(116) For example, the biometric components of the wearable electronic eyewear device **100** may

include components to detect expressions (e.g., hand expressions, facial expressions, vocal expressions, body gestures, or eye tracking), measure biosignals (e.g., blood pressure, heart rate, body temperature, perspiration, or brain waves), identify a person (e.g., voice identification, retinal identification, facial identification, fingerprint identification, or electroencephalogram based identification), and the like. The motion components include acceleration sensor components (e.g., accelerometer), gravitation sensor components, rotation sensor components (e.g., gyroscope), and so forth. The position components include location sensor components to generate location coordinates (e.g., a Global Positioning System (GPS) receiver component), WI-FI® or BLUETOOTH® transceivers to generate positioning system coordinates, altitude sensor components (e.g., altimeters or barometers that detect air pressure from which altitude may be derived), orientation sensor components (e.g., magnetometers), and the like. Such positioning system coordinates can also be received over wireless connections **925** and **937** from the mobile device **990** via the low-power wireless circuitry **924** or high-speed wireless circuitry **936**.
(117) According to some examples, an "application" or "applications" are program(s) that execute functions defined in the programs. Various programming languages can be employed to produce one or more of the applications, structured in a variety of manners, such as object-oriented programming languages (e.g., Objective-C, Java, or C++) or procedural programming languages (e.g., C or assembly language). In a specific example, a third party application (e.g., an application developed using the ANDROID™ or IOS™ software development kit (SDK) by an entity other than the vendor of the particular platform) may be mobile software running on a mobile operating system such as IOS™, ANDROID™ WINDOWS® Phone, or another mobile operating systems. In this example, the third-party application can invoke API calls provided by the operating system to facilitate functionality described herein.
(118) In a sample configuration, the wearable electronic eyewear device **100** described herein may be designed to optimize the thermal envelope to indefinitely support at least one projector **150** of the type described above with respect to FIGS. **8**A-**8**D and processing chips (system on chip (SoC)) to implement the circuitry of FIG. **9** and to run complex algorithms such as those used to provide six degrees of freedom for augmented reality with hand tracking. In other words, the wearable electronic eyewear device **100** is designed to ensure that the electronic components are not thermally constrained for its primary feature set.
(119) By accounting for the high power consumption when rendering more pixels to the display and using projections for the power consumption of the processing chips, the power consumption for features such as six degrees of freedom with hand tracking may be estimated as shown, for example, in Table 2.
(120) TABLE-US-00002 TABLE 2 Power Consumption Model for Six Degrees of Freedom AR with Hand Tracking Six Degrees of Freedom AR with Hand Tracking State of Art State of Art Estimate for New Design Element (mW) (% of Power) New Design (5 of Power) Cameras 340 10.8% 160 4.2% System on Chip 1,463 46.5% 838 22.0% Displays 1,296 41.2% 2,762 72.5% Other 50 1.5% 50 1.3% System Total 3,149 100% 3,810 100%
It is noted that larger field of view displays increase the display subsystem power consumption substantially (e.g., from 1,296 mW for 25° displays to 2,762 mW for 46° displays). When the larger field of view displays are used, they become the largest power consumer in the wearable electronic eyewear device **100** and may account for more than 70% of the power discharged for features such as six degrees of freedom augmented reality with hand tracking.
(121) To counter the impact of the larger power consumption by the larger field of view displays, the wearable electronic eyewear device **100** may be designed to isolate the heat generated by the system on chip components from the heat generated by the display components. Rather than coupling the power of both subsystems together by "wrapping" the system on chip electronics around the projector **150**, the display subsystem power consumption may be moved forward in the temple **110**A-B to the front frame **105**, while the system on chip power consumption may be moved

backward toward the temples **110**A-B and the hinged arms **125**A-B by presenting different conduction paths, thereby maximizing heat dissipation and taking advantage of as much surface area of the wearable electronic eyewear device **100** as possible. Such a design is shown by way of example in FIG. **10**.

(122) FIG. **10** illustrates a left side view of a wearable electronic eyewear device **100** optimized for thermal management whereby the display heat is moved forward in the temple **110**A-B to the frame **105** and the heat generated by the system on chip **1000** is moved backward to the temples **110**A-B and the hinged arms **125**A-B, along with a corresponding heat map. A similar configuration may be provided on the right side of the wearable electronic eyewear device **100** and its description will be omitted to avoid redundancy.

(123) As illustrated in FIG. **10**, the temple **110**A and the hinged arm **125**A are separated by a thermally insulating gap such as an air gap **1010** at the position of the hinge **126**A (not shown). In the case where the temples **110**A-B do not include hinged arms **125**A-B (e.g., the temples **110**A-B do not fold), the air gap **1010** would be at a position between the display system **1020** and the system on chip **1000**. This architecture allows the system on chip **1000** and the display system **1020** to effectively have two different thermal envelopes separated by the air gap **1010**. Due to the air gap **1010**, the two envelopes can be assessed in thermal isolation. Also, the system on chip **1000** may be divided into co-processors, one on each hinged arm **125**A-B of the wearable electronic eyewear device **100** in order to further spread out the heat generating components to both hinged arms **125**A-B. The separated thermal locations on the respective hinged arms **125**A-B and the use of co-processors help to spread the heat dissipation over a larger area, which enables the thermal solutions to be optimized for both subsystems separately.

(124) As further illustrated in FIG. **10**, the display subsystem **1020** may include four main heat generating components: the display driver integrated circuit (DLP driver IC) **1030**, the display digital micromirror device (display DMD) **1040** that produces the image, and the light emitting diodes (LEDs) **814**, **816** used to illuminate the display, including the green LED **816** and the red/blue LED **814**. The LEDs **814**, **816** are the biggest contributor to the system power and are the most impacted by the brightness of the indoor/outdoor ambient environment on the desired display brightness. For example, it is estimated that the indoor projector LED power consumption is approximately 27% of the power required for outdoor use. Increasing the digital field of view from 25° to 46° (3.6× increase in area) may require up to 2.9× more LED power to maintain the desired brightness for outdoor use. To compensate for the additional power consumption, the heat may be more evenly distributed by using a 2 LED system including a separate red/blue (combined) LED **814** and green LED **816** instead of a single RGB LED. FIGS. **8**A-**8**D show sample configurations including a separate red/blue LED **814** and green LED **816**.

(125) Approximately 30% of the electrical power that is input into the LEDs **814**, **816** is converted to light, while the remaining 70% is dissipated as heat. To dissipate and spread the heat, each LED **814**, **816** is soldered directly into a copper heat sink **1050**, thereby reducing the LED **814**, **816** component temperature. Moving the heat forward to the front frame **105** of the wearable electronic eyewear device **100** and away from the system on chip **1000** may be accomplished by using two additional heat sinks designed to present a conduction path to the adapter as shown in FIGS. **11**A and **11**B. As noted above, the heat sinks of FIGS. **11**A and **11**B are separated from the thermal envelope for the system on chip **1000** by the air gap **1010**.

(126) During operation, both the projector **150** of the display system **1020** and the system on chip **1000** generate significant amounts of heat. This heat needs to be mitigated such that the wearable electronic eyewear device **100** can be safely and comfortably operated. In addition, the projector **150** radiates noise that falls into wireless bands, such as GPS and WI-FI®.

(127) FIG. **11**A and FIG. **11**B illustrate a pair of thermally and physically isolated heat sinks **1102** and **1104** configured to encompass projector **150**. Heat sink **1102** is physically and thermally coupled to the red/blue LED **814** on one side of the projector **150** (and potentially the light

controller **829** and power) and is configured to sink heat from the red/blue LED **814** to the frame **105**. The heat sink **1104** is physically and thermally coupled to the other side of the projector **150** and is configured to sink heat from the green LED **816** and other components to at least one of the frame **105** and the temples **110**A-B. Each of the heat sinks **1102** and **1104** is coupled at a respective proximal end to an adapter **1106**, which may or may not be thermally conductive depending on the thermal design. In one example, the heat sinks **1102** and **1104** may be comprised of copper or other highly thermally conductive material. The heat sinks **1102** and **1104** are physically and thermally separated from each other by air. A thermal interface material (TIM) **1108**, such as Fujipoly® manufactured by Fujipoly of Carteret, New Jersey, with a k=13 W/m−k gap pad may be disposed between the heat sinks **1102** and **1104** and LEDs **814** and **816** to thermally couple the heat sinks **1102** and **1104** to the respective LEDs **814** and **816**. The heat sink **1102** and the heat sink **1104** may be parallel to each other, and on opposing sides of the projector **150**, to help thermally isolate them from one another. The heat sinks **1102** and **1104** are physically and thermally separated based on their shapes and mounting locations.

(128) In sample configurations, the thermally and physically isolated heat sinks **1102** and **1104** sink heat to the frame to significantly reduce the heat generated in the wearable electronic eyewear device **100**. For instance, the heat sink **1102** coupled to the red/blue LED **814** is thermally connected to the frame **105** and sinks heat in a forward direction, while the heat sink **1104** may be coupled to the green LED **816** and to a different portion of the frame **105** to sink heat to the different portion of the frame **105**. Alternatively, the heat sink **1104** may be connected to the temple **110**A-B to sink heat in a rearward direction away from the frame **105**.

(129) FIG. **12**A and FIG. **12**B illustrate the heat sinking performance of heat sink **1102** and heat sink **1104** during operation of the projector **150**, respectively. As seen in FIG. **12**A and FIG. **12**B, heat is evenly spread throughout the heat sinks **1102** and **1104**, and heat is much lower in the adapter **1106**. The heat sinks **1102** and **1104** that encompass the projector **150** also trap the RF electromagnetic energy generated by the projector **150**, and thus prevent electromagnetic interference (EMI). The heat sinks **1102** and **1104** prevent EMI interference with other wireless systems, such as those of the wearable electronic eyewear device **100**, and external systems that operate in the vicinity.

(130) FIG. **13** illustrates another example of an adapter **1300** having a first planar surface **1310** and a web portion **1312** of the heat sink **1102** that is thermally and physically coupled to the first planar surface **1310**. The adapter **1300** also has a second planar surface **1314** that is physically and thermally isolated from the first planar surface **1310** such that the heat generated by the respective heat sinks **1102** and **1104** can be thermally directed away from each other as previously described. For example, the first planar surface **1310** may be thermally coupled to the frame **105**, and the second planar surface **1314** may be thermally coupled to another portion of the frame **105** or to the temple **110**A-B. With respect to the heat sink **1102** that is coupled to the red/blue LED **814**, the thickness “T” of the heat sink **1102** may be thicker proximate the LED **814** than at other portions of the sink **1102** for improved thermal conductivity.

(131) FIG. **14**A and FIG. **14**B illustrate the improved heat sinking performance of heat sink **1102** and heat sink **1104** during operation of the projector **150**, respectively. As in FIG. **12**A and FIG. **12**B, heat is evenly spread throughout the heat sinks **1102** and **1104**, and heat is much lower in the adapter **1300**.

(132) FIG. **15** illustrates a method **1500** of operation of the heat sinks **1102** and **1104** in a sample configuration.

(133) At block **1502**, the first heat sink **1102** is physically and thermally coupled to the red/blue LED **814** and the second heat sink **1104** is physically and thermally coupled to the green LED **816**. Each of the LEDs **814**, **816** may be coupled to the heat sinks **1102**/**1104** by thermal interface material.

(134) At block **1504**, the second heat sink **1104** is physically and thermally coupled to the other

side of the projector **150**. The projector **150** may be coupled to the sink **1104** by a thermal interface material.

(135) At block **1506**, the heat generated by the LEDs **814** and **816** is drawn into the heat sinks **1102** and **1104** and directed forwardly in the wearable electronic eyewear device **100**, such as to frame **105**. The heat generated by LEDs **814** and **816** and other electrical components of the projector **150** may be directed into another portion of the frame **105** or may be directed rearwardly in the wearable electronic eyewear device **100** to the temple **110**A-B. Each of the heat sinks **1102** and **1104** sufficiently sink heat away from the respective heat generating components such that the wearable electronic eyewear device **100** is comfortably cool to the user during operation of the projector **150**.

(136) Separating the system on chip **1000** from the projector **150** and front frame **105** results in more thermal envelope for the display system **1020** but may reduce the thermal envelope of the system on chip **1000**. This presents its own challenge as the smaller envelope for the system on chip **1000** limits the power dissipation to, for example, 500 mW to avoid excessive heating. As shown in the graph of FIG. **16**, this is meaningfully lower than the 900 mW target estimated to support six degrees of freedom and hand tracking. FIG. **16** also illustrates that the power consumption of the system on chip **1000** may exceed the touch temperature limits without taking further measures to improve the heat dissipation.

(137) To address this issue, a thermal management component including a vapor chamber **1700** may be provided to more effectively spread the heat dissipated from the system on chip **1000** over a larger surface area. In sample configurations, the vapor chamber **1700** has three parts: a vacuum sealed enclosure including top and bottom covers **1702** and **1704**, a wicking structure including top and bottom wicking components **1706** and **1708**, and a working fluid. The sealed vacuum enclosure may be a copper enclosure formed of covers **1702** and **1704** with a sintered copper wick structure including wicking components **1706** and **1708** that bond to the interior surface of the copper enclosure. De-ionized water may be used as the working fluid.

(138) FIG. **17** shows a sample configuration of the components of the vapor chamber **1700**, including the top and bottom covers **1702** and **1704**, the top and bottom wicking structures **1706** and **1708**, and copper pillars **1710** that separate the wicking structures **1706** and **1708**. A vapor chamber **1700** so constructed has an evaporator side and a condensing side. As heat is applied, some of the liquid turns to vapor (the evaporator side) and travels to an area of lower pressure (the condenser side). The condenser side allows the vapor to cool and return to a liquid. The liquid is then absorbed by the wicking structure and transported back to the evaporator side via capillary action.

(139) Ultimately, the working fluid within the vapor chamber **1700** acts to effectively distribute heat across the body of the wearable electronic eyewear device **100** so as to maintain, for example, less than a 5° C. temperature rise across the wearable electronic eyewear device **100**. As a result, the heat from the system on chip **1000** may be moved throughout the hinged arm **125** A-B and the surface area maximized from which heat can be dissipated to the ambient environment. This additional surface area may further smooth hot spots and alleviate possible touch temperature challenges that could otherwise develop.

(140) FIGS. **18**A and **18**B illustrate a heat map for front and rear perspective views, respectively, of a wearable electronic eyewear device **100** including a system on chip **1000** that generates 1.5 W evenly distributed across the hinged arm **125**A using the vapor chamber **1700**, with a maximum rise of 4° C. across the hinged arm **125**A.

(141) FIGS. **19**A and **19**B show an example thermal management device **1900** incorporating a vapor chamber **1700** for managing excess heat generated by the system on chip **1000** and other electronic components to maintain normal operation of the wearable electronic eyewear device **100** by dissipating the generated heat across the entirety of the hinged arm **125**A. It will be appreciated that another thermal management device **1900** also may be provided within the other hinged arm

125B to dissipate heat generated by a system on chip **1000** including a co-processor and other electronic components disposed within the other hinged arm **125**B. The onboard electronic components, which are substantially housed within compartment **1910** produce heat and comprise heat source **2000** (see FIGS. **20**A and **20**B), which may be, for example, a co-processor for executing instructions during a user experience. Thermal management device **1900** may include thermal coupling **1920** and heat sink **1930** that dissipate heat produced by heat source **2000**. Thermal coupling **1920** is in thermal communication with the heat source **2000** and is sized to be received within the hinged arm **125**A-B. The thermal coupling **1920** is also sized to extend through a substantial portion of the hinged arm **125**A-B to maximize the surface area for heat transfer and extends forward to a widened section of the hinged arm **125**A-B near the hinge **126**A-B (not shown) for incorporating compartment **1910** and rearward through the hinged arm **125**A-B to an angled portion **1940** corresponding to the approximate area where the hinged arm **125**A-B would contact the user's ear when worn. In some examples, the thermal coupling **1920** comprises first and second sections **1950**, **1960**. In some examples, the first and second sections **1950**, **1960** are physically separate, or are functionally separate based on coatings or other materials or other treatments or structures that alter their respective physical properties, for example, conductivity.
(142) In some examples, the thermal coupling **1920** may comprise a two-phase vapor chamber **1700** of the type described above with respect to FIG. **17**. The vapor chamber **1700** may be at least partially located within the first section **1950** of the thermal coupling **1920**. In some examples, the vapor chamber **1700** is in thermal communication with at least one thermal spreader **2200** (see FIGS. **22**A and **22**B), for example, a conductive coating or pre-manufactured layer. In some examples, a layer of thermal interface material (TIM) **2010** (FIGS. **20**A and **20**B) may be interposed between the thermal spreader **2200** and the vapor chamber **1700**. The thermal coupling **1920** further extends at least partially to heat sink **1930** and, in the illustrated example in FIGS. **19**A and **19**B, extends to heat sink **1930**.
(143) Thermal management device **1900** further includes heat sink **1930**. Heat sink **1930** can be any thermally conductive structure having lower thermal environment relative to the heat source **2000**. In some examples, the heat sink **1930** is positioned at a second portion of the body of the wearable electronic eyewear device **100**, including, for example, the ear portion **1970** of the hinged arm **125**A-B. In one example, the heat sink **1930** may include a battery shield **1980** proximate to a battery **2100** (FIG. **21**A) used for powering the onboard electrical components. The battery shield **1980** may be at any position within the hinged arm **125**A-B but, in the example shown in FIGS. **19**A and **19**B, is located in the ear portion **1970** near the end of the hinged arm **125**A-B.
(144) FIGS. **20**A and **20**B are views of the end of compartment **1910** showing the heat source **2000** in detail in relation to the thermal coupling **1920**. As shown, an electrical component **2020** (e.g., a printed circuit board) is adjacent to the heat source **2000** that draws heat from the component. In this example, the heat source **2000** is in further thermal communication with a shield can **2030** with an interspersed layer of thermal interface material (TIM) **2010** to facilitate heat transfer. A second layer of TIM (not shown) may be provided to further dissipate heat toward the thermal coupling **1920**. As noted above, in some examples the thermal coupling **1920** includes a vapor chamber **1700**. As shown in FIG. **20**C, in some examples the shield can **2030** and the second TIM layer may be omitted such that the vapor chamber **1700** of the thermal coupling **1920** is positioned adjacent to the heat source **2000**.
(145) FIGS. **21**A and **21**B illustrate an example heat sink **1930** of FIGS. **19**A-**19**B in further detail. These views show that the thermal coupling **1920** at least partially contacts heat sink **1930**. As illustrated, heat sink **1930** includes a battery shield **1980** at least partially enclosing a battery **2100**. The battery shield **1980** comprises a conductive material which receives thermal energy from thermal coupling **1920**. In some examples, the battery shield **1980** can include extended surfaces **2110** that increase the surface area contacting air. As shown, the thermal coupling **1920** may include a vapor chamber **1700** extending from the end of the hinged arm **125**A-B including

compartment **1910** to the end including the heat sink **1930**. The thermal coupling **1920** may be affixed directly to the battery shield **1980** or may include an intermediate TIM layer to facilitate heat transfer. In some examples, the thermal coupling **1920** may contact the battery **2100** directly. In other examples, thermal coupling **1920** may contact battery **2100** through a TIM layer.
(146) FIGS. **22**A and **22**B illustrate an example configuration of thermal coupling **1920** comprising first and second sections **1950**, **1960**, where the first section **1950** comprises a vapor chamber **1700** and the second section **1960** comprises a thermal spreader **2200**, and the first and second sections **1950**, **1960** are in thermal communication and, as shown, are in direct contact, but may consist of a vapor chamber **1700** with or without a thermal spreader **2200** affixed or coating the vapor chamber **1700**. Also, as shown, the thermal spreader **2200** may be attached to a carrier **2210** (FIG. **23**) that is in turn connected to the heat sink **1930**. The thermal spreader **2200** can be any suitable conductive material. In some examples, the thermal spreader **2200** is graphite or a graphite composite. In an example, the thermal spreader **2200** may be graphite on a plastic film carrier. In some examples, the carrier **2210** may be a conductive material or composite. In some examples, the carrier **2210** provides a support for the thermal spreader **2200**, while in other examples the carrier **2210** provides support for the thermal spreader **2200** but is itself a conductive material to further transfer thermal energy away from the onboard electronic components. In various examples, the carrier **2210** is a plastic or a metal or a metallic composite. In some examples, the carrier **2210** is made of aluminum.
(147) FIG. **23** illustrates a partial sectional view taken along line **23-23** of FIG. **22**A. FIG. **23** illustrates further detail of the connection of the thermal coupling **1920**, including the attachment of the carrier **2210** to the vapor chamber **1700** and to the battery shield **1980** so as to maintain the thermal communication of the vapor chamber **1700** to the heat sink **1930**. The first section **1950** is partially shown where vapor chamber **1700** is in view. Thermal spreader **2200** and its carrier **2210** are also shown. The thermal spreader **2200** is connected, adhered, or otherwise affixed to the vapor chamber **1700**. Carrier **2210** is affixed to vapor chamber **1700** to carry thermal energy from the vapor chamber **1700** to the thermal spreader **2200** to the heat sink **1930**. As illustrated, the perimeter of the thermal spreader **2200** substantially conforms to the perimeter of the battery shield **1980** along its top surface as also shown in FIG. **22**, but in some examples, the carrier **2210** may at least partially contact other surfaces of the battery shield **1980** such as battery shield end **2300**, or in some examples, the battery **2100** directly. The thermal spreader **2200** and carrier **2210** also may include a gap area **2310** that does not include the vapor chamber **1700** but may include a service loop **2320** for applications in which the hinged arms **125**A-B may bend in the gap area **2310**. In one example, the thermal spreader **2200** includes a graphite spreader with a plastic film carrier. In another example, the thermal spreader **2200** is affixed to carrier **2210**.
(148) As shown in FIGS. **24** and **25**, carrier **2210** may be composed of one or more metals (for example, aluminum) or metal composites and may include a thermal interface material layer **2500** between at least a portion of the thermal spreader **2200** and a portion of the vapor chamber **1700** or thermal spreader **2200**. As shown, the heat sink **1930** includes a metallic battery shield **1980** that allows thermal energy to dissipate from the vapor chamber **1700** and thermal spreader **2200**.
(149) FIG. **24** illustrates an example configuration where the thermal coupling **1920** extends between the heat source **2000** and heat sink **1930**. The thermal coupling **1920** comprises vapor chamber **1700**, carrier **2210**, thermal spreader **2200**, and heat sink **1930**. In one aspect, the carrier **2210** is wrapped with the thermal spreader **2200**. The vapor chamber **1700** is sized to be received in a cavity of the hinged arm **125**A-B in or near the compartment **1910** to maximize surface area for heat transfer and extends rearward through the hinged arm **125**A-B to an angled portion **1940** corresponding substantially to where the hinged arm **125**A-B is angled approximately where it would contact the user's ear when worn. At the angled portion **1940**, heat is transferred from the vapor chamber **1700** to the carrier **2210**. In some examples, the carrier **2210** is metal, metallic, or a metal alloy or composite, and in a particular example, substantially comprises aluminum. The

carrier **2210** may be at least partially enveloped by the thermal spreader **2200** (e.g., heat transfer material) by coating, wrapping, affixing, etc. In one example, the thermal spreader **2200** is graphite, which may be coated on the carrier **2210** or adhered and may include a plastic backing. The carrier **2210** contacts the heat sink **1930**, and as illustrated in FIG. **24**, may be a battery shield **1980** to dissipate the thermal energy generated by the onboard electronics. In this example, the thermal margin is increased by about 60%. In some examples, the thermal margin is increased by 55% to 65%. In other examples, the thermal margin is increased between 60% and 70%. The heat sink **1930** also may include additional sections of conductive material to facilitate heat transfer.
(150) FIG. **25** is a partial sectional view taken along line **25-25** of the thermal coupling **1920** illustrated in FIG. **24**. FIG. **25** illustrates the connection of the thermal spreader **2200** to the vapor chamber **1700** and the battery shield **1980** and in particular shows the example of a metal or metal composite carrier and a thermal interface material layer **2500** between at least a portion of the thermal spreader **2200** and a portion of the vapor chamber **1700** or thermal spreader **2200**. The heat sink **1930** includes a conductive battery shield **1980** that allows thermal energy to dissipate from the vapor chamber **1700** and thermal spreader **2200**.
(151) FIG. **26**A is a perspective view of another example of the wearable electronic eyewear device **100** showing the general spatial arrangement of the compartment **1910** including heat source **2000**, thermal coupling **1920**, and heat sink **1930**. The heat source **2000** acquires heat from nearby onboard electrical components, such as a printed circuit board including a system on chip **1000** housed within the compartments **1910** on the respective hinged arms **125**A-B. In this configuration, the thermal coupling **1920** has one or both of ends **2600** that extend towards heat sink **1930** past angled portion **1940** but does not contact heat sink end **2610**, thereby producing a gap **2620** therebetween. Heat dissipates from the thermal coupling **1920** through the internal cavity of the hinged arm **125**A-B to the heat sink **1930**. In some examples, the gap **2620** is approximately 1/20 to 1/10 the overall distance between the respective ends of thermal management device **1900**, and in one example, the gap **2620** is about 1/18 the overall distance between the respective ends of thermal management device **1900**. In this example, the thermal margin is increased by about 40%. In some examples, the thermal margin may be increased by between 35% and 45%. In other examples, the thermal margin is increased more than 45%. As shown, the thermal coupling **1920** has a substantially square area for compartment **1910** that tapers to a narrower rectangular portion **2630** that extends past angled portion **1940** before terminating at its distal end **2600**.
(152) FIG. **26**B illustrates a perspective view of another configuration of the example shown in FIG. **26**A. As illustrated, the thermal coupling **1920** extends towards heat sink **1930** but ends before reaching angled portion **1940**, thereby producing a gap **2640** between thermal coupling end **2600** and heat sink end **2610** like the configuration shown in FIG. **26**A but substantially wider. In one example, the gap **2640** is about ⅓ to ¼ the overall distance between the respective ends of thermal management device **1900**.
(153) It will be appreciated that the thermal management configuration described with respect to FIG. **10** coupled with the thermal management for the projector **150** described with respect to FIGS. **11-15**, and the thermal management for the processing circuits described with respect to FIGS. **17-26** may be combined to significantly improve the thermal performance of the wearable electronic eyewear device **100**. Further thermal improvements may be provided by separating the electronic components into the respective temples **110**A-B and hinged arms **125**A-B as described herein.
(154) It will be further appreciated that the hinged arms **125**A-B and the temples **110**A-B may be combined whereby the arms **125**A-B are not hinged but are an extended portion of the temples **110**A-B. In this case, the air gap **1010** would not be at the hinge but would be at a position within the temple **110**A-B separating the respective heat sinking assemblies for the projector **150** and the system on chip **1000** with associated electronics.
(155) Except as stated immediately above, nothing that has been stated or illustrated is intended or

should be interpreted to cause a dedication of any component, step, feature, object, benefit, advantage, or equivalent to the public, regardless of whether it is or is not recited in the claims.
(156) It will be understood that the terms and expressions used herein have the ordinary meaning as is accorded to such terms and expressions with respect to their corresponding respective areas of inquiry and study except where specific meanings have otherwise been set forth herein. Relational terms such as first and second and the like may be used solely to distinguish one entity or action from another without necessarily requiring or implying any actual such relationship or order between such entities or actions. The terms "comprises," "comprising," "includes," "including," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises or includes a list of elements or steps does not include only those elements or steps but may include other elements or steps not expressly listed or inherent to such process, method, article, or apparatus. An element preceded by "a" or "an" does not, without further constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises the element.
(157) Unless otherwise stated, any and all measurements, values, ratings, positions, magnitudes, sizes, and other specifications that are set forth in this specification, including in the claims that follow, are approximate, not exact. Such amounts are intended to have a reasonable range that is consistent with the functions to which they relate and with what is customary in the art to which they pertain. For example, unless expressly stated otherwise, a parameter value or the like may vary by as much as ±10% from the stated amount.
(158) In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in various examples for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed examples require more features than are expressly recited in each claim. Rather, as the following claims reflect, the subject matter to be protected lies in less than all features of any single disclosed example. Thus, the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separately claimed subject matter.
(159) While the foregoing has described what are considered to be the best mode and other examples, it is understood that various modifications may be made therein and that the subject matter disclosed herein may be implemented in various forms and examples, and that they may be applied in numerous applications, only some of which have been described herein. It is intended by the following claims to claim any and all modifications and variations that fall within the true scope of the present concepts.

Claims

1. A wearable electronic eyewear device, comprising: a frame; at least one temple connected to the frame; at least one image display; at least one imaging device adapted to capture an image of a scene and to project the image to the at least one image display; at least one processing device; and a thermal management device comprising a first heat sink comprising a pair of thermally and physically isolated heat sinks disposed on opposite sides of and connected to the at least one imaging device and to the frame to sink heat from the at least one imaging device to the frame, a second heat sink thermally connected to the at least one processing device and the at least one temple to sink heat from the at least one processing device to the at least one temple, and a thermally insulating gap between the first heat sink and the second heat sink.
2. The eyewear device of claim 1, wherein the thermally insulating gap comprises an air gap.
3. The eyewear device of claim 1, comprising a first temple connected to a first end of the frame and a second temple connected to a second end of the frame, wherein the at least one processing device comprises a first co-processor located in the first temple and a second co-processor located in the second temple.

4. The eyewear device of claim 1, wherein the at least one imaging device comprises at least one projector comprising a green LED and a red/blue LED.
5. The eyewear device of claim 1, wherein a first of the pair of heat sinks is connected to the frame to sink heat to the frame and a second of the pair of heat sinks is connected to the at least one temple to sink heat to the at least one temple.
6. The eyewear device of claim 1, wherein the pair of heat sinks are comprised of a highly thermally conductive material and are physically and thermally separated from each other by a thermal interface material.
7. The eyewear device of claim 1, wherein the second sink comprises a vapor chamber having an evaporator side and a condensing side.
8. The eyewear device of claim 7, wherein the vapor chamber comprises a vacuum sealed enclosure, a wicking structure, and a working fluid that is absorbed by the wicking structure and transported to the evaporator side via capillary action.
9. The eyewear device of claim 8, wherein the vacuum sealed enclosure comprises top and bottom covers, the wicking structure comprises top and bottom wicking structures, further comprising copper pillars that separate the top and bottom wicking structures.
10. The eyewear device of claim 7, wherein the second heat sink further comprises a thermal coupling that connects the vapor chamber to a heat sink so as to thermally communicate heat from the vapor chamber to the heat sink.
11. The eyewear device of claim 10, wherein the vapor chamber, thermal coupling, and heat sink are disposed within the at least one temple.
12. The eyewear device of claim 11, wherein the at least one temple comprises a hinged arm and a hinge adjacent the frame, and the at least one processing device is located in the hinged arm.
13. The eyewear device of claim 12, wherein the thermal coupling extends through a substantial portion of the hinged arm from a portion adjacent the hinge to a portion of the hinged arm that would contact a user's ear when worn.
14. The eyewear device of claim 13, wherein the heat sink is located on an end of the hinged arm behind the user's ear when worn, and the thermal coupling extends from the vapor chamber to the heat sink.
15. The eyewear device of claim 10, wherein the thermal coupling comprises a thermal spreader in thermal communication with the vapor chamber.
16. The eyewear device of claim 15, wherein the thermal coupling further comprises a layer of thermal interface material interposed between the thermal spreader and the vapor chamber.
17. The eyewear device of claim 10, wherein the heat sink includes a battery and a battery shield.
18. A method of dissipating heat generated by at least one imaging device and at least one processing device of a wearable electronic eyewear device, comprising: providing a first heat sink thermally connecting the at least one imaging device to a frame of the wearable electronic eyewear device to sink heat from the at least one imaging device to the frame; providing a second heat sink thermally connecting the at least one processing device to at least one temple of the wearable electronic eyewear device to sink heat from the at least one processing device to the at least one temple, wherein the second sink comprises a vapor chamber having an evaporator side and a condensing side; and thermally insulating the first heat sink from the second heat sink.
19. The method of claim 18, further comprising disposing a first co-processor of the at least one processing device in a first temple connected to a first end of a frame of the wearable electronic eyewear device and disposing a second co-processor of the at least one processing device in a second temple connected to a second end of the frame of the wearable electronic eyewear device.