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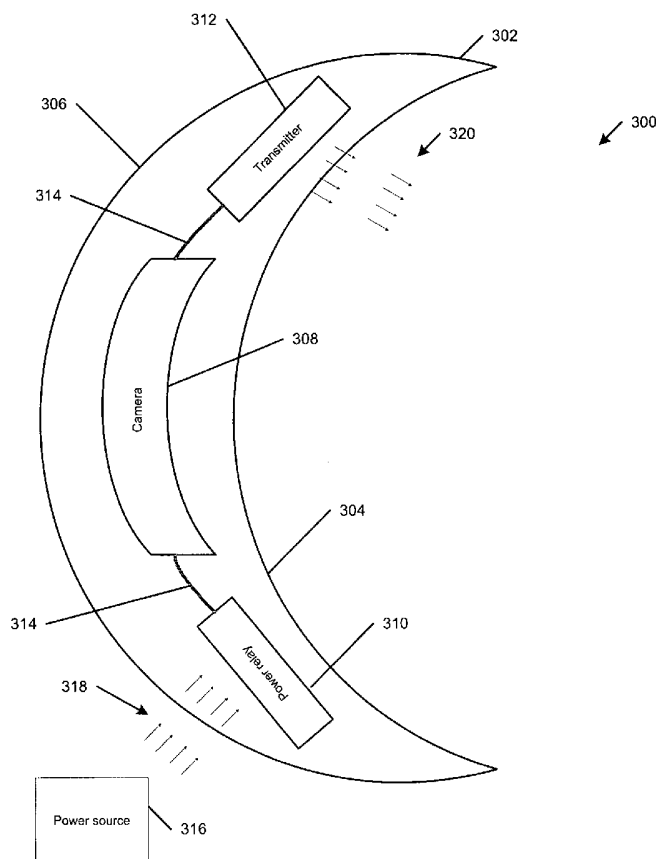
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(54) Title: INTRAOCULAR VIDEO SYSTEM



(57) Abstract: According to one aspect of the present invention, an intraocular video system (100, 200) includes a contact lens (116, 302), a camera (104, 204, 308), and a display (106, 220). The contact lens (116, 302) is adapted to be carried on a surface of a user's eye. The camera (104, 204, 308) is coupled to the contact lens (116, 302), and is adapted to generate a signal indicative of an image received by the camera (104, 204, 308). The display (106, 220) is positioned within the user's eye and it provides a display image to the retina in the user's eye. The display image is at least in part based upon the signal.

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INTRAOCULAR VIDEO SYSTEM

Background

Field

[0001] This invention relates generally to a device for restoring or enhancing vision and, in particular, to an intraocular display for providing images to the retina.

Description of the Related Art

[0002] Corneal opacity, the clouding of the cornea due to scar tissue, an injury, or infection, is a common cause of blindness affecting millions worldwide. The cornea, the clear surface that covers the front of the eye, must remain transparent in order to refract light properly and allow vision. The tiniest scar tissue or opacification can interfere with this process, blocking out the outside world like a boarded up window, while the rest of the eye remains unaffected. Corneal opacity affects all ages and can be caused by physical or chemical trauma, viral, bacterial or fungal infection, or hereditary disease.

[0003] Corneal transplant surgery (or laser surgery in mild cases) is currently the only available treatment for corneal opacity, with about 40,000 procedures performed each year in the United States alone. There are several reasons to identify an alternative to this surgery, the greatest of which are that some patients are not good candidates for the surgery and approximately 20 percent of corneal transplant patients – between 6,000 – 8,000 a year in the United States – reject their donor corneas. Other difficulties in corneal transplantation include: reliance on donor tissue supply, which currently cannot meet demand; requirements for careful follow-up to ensure immunosuppression; and substantial risk of infection or other disease processes within grafts, which results in graft rejection. Without a successful transplant, patients suffering from corneal opacity become permanently blind.

[0004] There are currently no other options for patients for whom corneal transplantation does not work to regain sight. In the United States, approximately 1,000 – 2,000 new patients face blindness each year without possible alternatives to corneal transplantation.

[0005] In related vision fields, scientists have been creating and adapting biomedical materials and electronics for years. For example, intraocular lenses (IOLs), which are implanted in cataract surgery to replace the human lens, may be one of the most important ophthalmic developments in the past 30 years. Another example is the retina chip, which has recently

demonstrated that intraocular electronics can now be implanted into the human eye with promising results. The retina chip, consisting of a miniature circuit board placed inside the eye in contact with the retina, is designed to simulate the retinal ganglion cells in patients who lack photo-receptors. The chip's circuit board is an array of stimulating electrodes that are activated by images from a camera located outside the eye. While the retinal chip faces some challenges because it is in contact with the retina and involves the neurological process of vision, it provides an example of how far the science has progressed. Although technological options are promising, there is still no alternative treatment for those suffering from corneal opacity for whom corneal transplantation is not possible.

Summary

[0006] According to one aspect of the present invention, a system for restoring vision in a patient with corneal opacity is provided. The system includes a contact lens and an intraocular lens. The contact lens includes at least one induction coil for receiving power from an external power source, at least one camera for receiving an image, and at least one video transmitter for transmitting the image. The intraocular lens includes at least one induction coil for receiving power from an external power source, at least one video receiver for receiving the transmitted image, and a display for displaying the transmitted image.

[0007] Some embodiments include a biomedical system for restoring vision in a patient with corneal opacity, the system including a contact lens having at least one induction coil for receiving power from an external power source; at least one camera for receiving an image; at least one video transmitter coupled to the camera for transmitting the image; an intraocular lens having at least one induction coil for receiving power from an external power source, at least one video receiver for receiving the transmitted image, and a display coupled to the video receiver for displaying the transmitted image.

[0008] In some embodiments, the intraocular lens further comprises an optical element for focusing the displayed image generally onto a patient's macula.

[0009] In one embodiment, an intraocular video system includes: a contact lens adapted to be carried on a surface of a user's eye; a camera coupled to the contact lens, wherein the camera is adapted to generate a signal indicative of an image received by the camera; and a display, wherein the display is positioned within the user's eye, wherein the display provides a display

image to a retina in the user's eye, and wherein the display image is at least in part based upon the signal.

[0010] The intraocular video system can also include a power source, wherein the power source is adapted to provide electrical power to the camera and the display. The power source can include an inductor or an inductive coil. The intraocular video system can also include eyeglasses, wherein the power source is mounted on the eyeglasses. The camera can be integrated within or mounted on the contact lens.

[0011] In one embodiment, the contact lens includes a concave surface and a convex surface and the camera is located between the concave surface and the convex surface. In another embodiment, the contact lens includes a concave surface and a convex surface and the camera includes circuitry, and the circuitry is located between the concave surface and the convex surface. In another embodiment, the intraocular video system also includes a transmitter coupled to the camera. In another embodiment, the contact lens includes a concave surface and a convex surface and the transmitter is located between the concave surface and the convex surface. The transmitter can emit a signal having at least one of radiofrequency energy, infrared energy, acoustic energy, or optical energy. In one embodiment, the contact lens is flexible, and in another embodiment, the contact lens is soft.

[0012] In one embodiment of the present invention, a wearable camera assembly includes: a contact lens adapted to be carried on the surface of a user's eye, the contact lens having a concave surface and a convex surface; and a camera located in or on the contact lens. In one embodiment, the camera is mounted to at least a portion of the convex surface. In another embodiment, the the position of the camera with respect to the user's head is adjusted based at least in part upon movement of the user's eye.

[0013] One embodiment of a method of receiving a video image includes: receiving an image of a target object with a camera located in or on a contact lens carried by a user's eye; generating a signal indicative of the image; and transmitting the signal to a receiver, said receiver coupled to a display that displays a display image based at least in part upon the signal.

[0014] One embodiment of a method of receiving a video image includes: receiving a signal indicative of an image of a target object, wherein the signal is generated by a camera located in or on a contact lens carried by a user's eye; generating a display image based at least in part on the signal; and providing the display image to the retina of the user's eye.

[0015] One embodiment of a method of video transmission includes: generating an electrical signal within about 10 mm of a surface of a user's cornea.; and transmitting the electrical signal into the user's eye. The electrical signal can include a digital signal. The method can also include receiving the signal within the user's eye and displaying an image based upon the signal. The generating step can include generating an electrical signal within about 8 mm, about 6 mm, about 4 mm or about 2 mm of the surface of a user's cornea.

[0016] In one embodiment of the present invention, a contact lens includes an electrically conductive material.

[0017] In another embodiment of the present invention, a contact lens includes a camera. In another embodiment, the camera includes a video camera.

[0018] In yet another embodiment of the present invention, an intraocular video system includes: means for receiving an image of a target object, said means for receiving located in or on a contact lens carried by a user's eye; means for generating a signal indicative of the image; and means for transmitting the signal to a receiver, said receiver coupled to a display that displays an image based at least in part upon the signal.

[0019] In another embodiment of the present invention, an intraocular video receiver includes: means for receiving a signal indicative of an image of a target object, wherein the signal is generated by a camera located in or on a contact lens carried by a user's eye; means for generating a display image based at least in part on the signal; and means for providing the display image to the retina of the user's eye.

[0020] In one embodiment, an intraocular video transmitter includes: means for generating an electrical signal within 10 mm of a surface of a user's cornea; and means for transmitting the electrical signal into the user's eye. The means for generating an electrical signal can include means for generating an electrical signal within about 8 mm, about 6 mm, about 4 mm or about 2 mm of the surface of a user's cornea.

Brief Description of the Drawings

[0021] Embodiments depicting various aspects of invention are shown in the accompanying drawings, which are for illustrative purposes only. The drawings include the following Figures, with like numerals indicating like parts.

[0022] Figure 1 shows a plan view of a biomedical system for restoring vision according to one embodiment of the present invention.

[0023] Figure 2 shows a block diagram of biomedical system for restoring vision according to another embodiment of the present invention.

[0024] Figure 3 shows a plan view of a wearable camera assembly that can be used with the biomedical systems of Figures 1 or 2.

[0025] Figure 4 is a flow chart of one method of receiving a video image in accordance with one embodiment of the present invention.

[0026] Figure 5 is a flow chart of another method of receiving a video image in accordance with another embodiment of the present invention.

[0027] Figure 6 is a flow chart of a method of video transmission in accordance with another embodiment of the present invention.

Detailed Description

[0028] A biomedical system, such as an intraocular video system, is a timely and appropriate approach for providing visual function to those suffering from corneal opacity. In fact, because the vision damage in these individuals is generally limited to a distinct external tissue and does not affect any capabilities inside the eye, corneal opacity is perhaps the blinding disease most amenable to restoring vision through such a system. Unlike retinal diseases like macular degeneration, patients suffering from corneal opacity generally have full retina function and the intact neurological processes of vision. In corneal opacity, only the cornea is damaged. With a bionic alternative to a transparent cornea, vision can be restored for patients not able to be helped by transplant surgery. For example, by using a camera and a display, an imaging system can be designed to bypass the blocked corneal window.

[0029] Figure 1 illustrates one embodiment of a biomedical system 100 implanted within an eye 102 for restoring vision to a patient having corneal opacity. In other embodiments, the patient may have his or her vision affected in some other way, or may simply wish to enhance his or her vision with digital technologies. The biomedical system 100 includes a camera 104 for receiving an image and a display 106 for displaying the received image such that the retina 108 receives the displayed image. Typically, the system 100 is provided in both eyes 102. However, in some patients, only one eye 102 is affected, and the system 100 is only inserted on or in one eye 102.

[0030] An eye 102 is generally illustrated in Figure 1. However, much of the eye's anatomy has been left out to facilitate discussion of the biomedical system 100. As illustrated, the cornea 110 is facing to the left in Figure 1, and the macula 112 and optic nerve 114 face to the right.

[0031] The camera 104 of the biomedical system 100 receives the image that is provided to the retina 108. The camera 104 can be any of a number of cameras, including a CMOS camera, a CCD camera, a conventional video camera, or others, as is well known to those of skill in the art. The camera 104 can focus upon different objects in some embodiments, and can have a large depth of field in other embodiments. Of course, such variations are well known to those of skill in the art.

[0032] In one embodiment, the camera 104 is mounted within or on a contact lens 116 that can be worn by the patient. The contact lens 116 can have dimensions similar to those contact lenses typically used by patients to correct vision. The contact lens 116 can also have other dimensions and can be wider or larger in order to accommodate electronic components, such as digital equipment described herein. Since the camera 104 is located on or within the contact lens 116, the image received by the camera 104 can change with the eye movements made by the patient. As a person would normally move their eye 102 in order to focus on different objects, a patient may similarly move his or her eye 102 in order to point the camera 104 in different directions.

[0033] In other embodiments, the camera 104 is mounted or carried in other ways. In one embodiment, for example, the camera 104 is mounted on a pair of glasses (not shown) worn by the patient. In such embodiments, the patient moves his or her head in order to obtain different images. In another embodiment, the camera 104 is carried by the user, and different images are received as the user directs the camera 104 in different directions.

[0034] The term "carried by" is a broad term intended to have its ordinary meaning. In addition, the term "carried by" is intended to mean any or all of "in proximity to," "in contact with," "adhering to," or "adjacent to."

[0035] In a preferred embodiment, the camera 104 is mounted within a contact lens 116 along with a power source 118 and a video transmitter 120. The power source 118 is used to generate the electricity necessary to power the camera 104 and video transmitter 120. The power source 118 can, in some embodiments, store or create electrical energy and/or power. However, in one embodiment, the power source 118 transforms energy from an externally located energy source

(not shown). For example, the power source 118 can include an induction coil that generates an electric current from a changing magnetic field running through it. The magnetic field is, in turn, created by an external source, such as an eyeglass frame capable of creating such a field. Of course, other devices and methods for creating power and disseminating power to the contact lens 116 are well known to those of skill in the art. In one embodiment, for example, a wire or wires run to the contact lens 116 in order to power the camera 104 and video transmitter 120.

[0036] The video transmitter 120 transmits the images received by the camera 104 to the display 106 on which the images will be displayed. In one embodiment, the video transmitter 120 transmits images at a fast enough rate to achieve relatively smooth video at the display. For example, in one embodiment, the video transmitter 120 transmits the images at a rate of 30 images or frames per second.

[0037] The video transmitter 120 can transmit the information at radio or infrared frequencies. In one embodiment, the video transmitter 120 includes a photodiode. In another embodiment, the video transmitter 120 includes a wire connection running from the contact lens 116, such as from the back, center, side, or front of the contact lens 116, to the display 106.

[0038] The display 106 can be located in a number of places in order to provide the images received by the camera 104 to the retina 108. In one embodiment, an intraocular lens 122 is inserted into the patient's eye 102, within or upon which the display 106 is mounted. In other embodiments, the display 106 is mounted at other locations within the eye 102. For example, the display 106 can be mounted in front of the iris, between the iris and the patient's lens, behind the patient's lens with its own focusing element, and at other locations well known to those of skill in the art. The lens 122 can provide optical focusing of the image from the display 106 to the retina 108, or the lens 122 can serve as a mere carrier of the display 106 and its associated optics. In such cases, an additional focusing element can be provided, such as a focusing lens or window mounted to or placed adjacent or near the display 106.

[0039] As is well known to those of skill in the art, a liquid crystal display can be used as the display 106 of the biomedical system 100 because it consumes relatively little power and can be made quite thin. However, in other embodiments, different displays 106 can be used in place of an LCD display.

[0040] In one embodiment, the LCD display 106 communicates with an associated LCD circuit board 124, which can also be located within the intraocular lens 122, as shown in Figure 1.

The intraocular lens 122 can also act as a heat sink for the LCD circuit board 124 and display 106, preventing heat from these electronic components from escaping into and/or damaging the sensitive tissues of the eye 102.

[0041] In order to power the LCD circuitry of the LCD circuit board 124, and in order to receive images from the video transmitter 120, the intraocular lens 122 can also contain a power source 126 and a video receiver 128. The power source 126 can be similar in function and/or structure to the power source 118 discussed above. The video receiver 128 communicates with the video transmitter 120 discussed above and is generally configured to receive the images sent by the video transmitter 120. In one embodiment, the power source 126 and video receiver 128 are inserted into or are attached to the intraocular lens 122. In a preferred embodiment, however, the power source 126 and video receiver 128 can be integral with haptics (not shown) attached to the body of the intraocular lens 122, thus avoiding overcrowding of the intraocular lens 122 itself.

[0042] In one embodiment, the intraocular lens 122 also includes an optical element 130 configured or adapted to cover the LCD display 106. The optical element 130 can focus the image displayed on the LCD display 106 onto the macula 112, thus mimicking the functionality normally provided by a healthy patient's lens. In some embodiments, the optical element 130 is designed or selected to have a focal length calibrated to the actual distance to a particular patient's macula 112. In another embodiment, the optical element 130 is configured for an average distance. More precise focusing can be performed with conventional eyeglasses, for example, which can be used to modify the image received by the camera 104 and the image projected by the LCD display 106. In still further embodiments, the optical element 130 dynamically focuses after the surgery is completed.

[0043] In another embodiment of the present invention, the biomedical system 100 includes a light source (not shown) at the rear of the contact lens 116 in order to illuminate the LCD display 106. This illumination would thereby improve the quality of the image displayed to the retina 108.

[0044] In still further embodiments, the display 106 transmits other information to the patient, including digital information processed by surgically inserted or otherwise implanted chips. Similarly, the display can display images representing infrared data received by the camera 104. There are many examples of systems by which sight is not merely restored, but also enhanced.

[0045] Another embodiment of a biomedical system for restoring vision to a patient having corneal opacity is illustrated in Figure 2. The biomedical system 200 includes external components 201 and internal components 212 that together generating an image of a target object 205 and provide the image to the retina 108 of a patient's eye. The external components 201 of the biomedical system 200 are generally located or positioned on a device to be worn by the patient. For example, the external components 201 may be mounted on or in a contact lens that a patient can wear on his eye. The internal components 212 are generally positioned or located on a device implanted within the patient's eye. For example, the internal components 212 may be placed on or within an implantable intraocular lens as described above.

[0046] The external components 201 of the biomedical system 200 include a power source 202, a camera 204, a power coupling transmitter 206, and a video modulator and radio frequency link transmitter 210. Many of these components, in some embodiments, are the same as the components described in greater detail above. For example, the camera 204 can be the same as the camera 104 described above with respect to Figure 1. Similarly, the power source 202 can be the power source 118.

[0047] The power source 202 can be a battery or an induction link that supplies power to the camera 204, the illumination light 208, as well as to the internal components 212. The power supplied by the power source 202 can be delivered through a radio frequency (RF) or induction coupling, or by any other method known to those of skill in the art. The power source 202 can be mounted on eyeglasses and link by induction or RF to the contact lens holding the external components 201. In addition, the power source 202 can directly power the components of the biomedical system 100.

[0048] In one embodiment, the camera 204 of the biomedical system 200 is a miniature pinhole-type camera. The camera 204 can be made from CMOS technology and can be fabricated on a CMOS chip. The CMOS chip can also contain the circuitry used to produce a composite or other standard serial video signal. The camera 204 can be a color video camera or black and white. In some embodiments, the camera 204 can use a non-visible wavelength, such as infrared light, to generate an image. Such cameras are used in night-vision applications, and are well known to those of skill in the art.

[0049] The camera 204 can have a variety of ranges for receiving an image, such as up to about 100 feet, up to about 250 feet or up to about 1,000 feet. The camera 204 generally requires

little power to operate. For example, in one embodiment, the camera 204 requires only about 200 mW of power.

[0050] The camera 204 can produce a signal that corresponds to an image detected by the camera 204, and can transmit that signal at a desired frequency to a receiver. In one embodiment, the camera 204 transmits a video signal at 1.2 GHz. Alternatively, the camera can transmit its signal at 2.4 GHz. In other embodiments the camera transmits the signal at a frequency less than about 1.2 GHz, between about 1.2 GHz and about 2.4 GHz, or greater than about 2.4 GHz. In one embodiment, the camera 204 can operate for up to 8 hours on a 9V charge.

[0051] The camera 204 can have a resolution of about 380 lines, and also can have automatic exposure, iris, and/or focus adjustments. The video signal generated by the camera 204 can be NTSC, PAL, or other standard compliant. The camera 204 can have any of a variety of viewing angles, such as less than about 40°, between about 40° and about 60°, or greater than about 55°. In one embodiment, the camera 204 has a viewing angle of about 52°.

[0052] The viewing distance of the camera 204 can be any viewing distance such as, for example, 50 mm to infinity. The minimum illumination of the camera 204 can be about 3 lux. The camera 204 can operate from a low Voltage such as less than about 1 V, about 1 V to about 3 V, about 3 V to about 6 V, or about 6 V to about 9 V. The camera 204 can weigh very little, such as less than about 5 g, less than about 10 g, or less than about 20 g. The camera 204 can be sized to have a width and length of less than about 0.2", less than about 0.4", or less than about 0.6". In one embodiment, the camera 204 has a non-standard scan rate.

[0053] The power coupling transmitter 206 of the biomedical system 200 can be a component included within the power source 202 or may be a separate component, such as a discrete component. In one embodiment, the power coupling transmitter 206 includes a radio frequency signal generator to provide power from the external components 201 to the power coupling receiver 214 of the internal components 212. The power coupling transmitter 206 can non-invasively transfer power across the boundary or surface of the eye and can be radio frequency (RF) or inductive-type coupling.

[0054] The illumination light 208 provides illumination for the display 220 of the internal components 212. Illumination may be desired when the display 220 includes a transmission-type liquid crystal display. Any of a variety of displays of illumination sources may

be used as the illumination light 208. In addition, the illumination light 208 can include a driver chip (not shown).

[0055] In one embodiment, the illumination light 208 includes a high efficiency white LED driver such as the MP1521 chip manufactured by monolithic power systems. The driver of the illumination light 208 can include a constant current boost regulator and can have individual current sensing feedback for driving multiple strings of series connected light-emitting diodes. The driver can detect loose or open LED connections as well.

[0056] In one embodiment, the driver of the illumination light 208 uses a peak current, constant minimum off-time architecture. Feedback pins on the driver can measure Voltage across sense resistors in series with LED strings. The driver can supply a bias current of about 20 mA and can minimize power loss by having a low Voltage drop across a sense resistor, such as only 0.4 V. LED brightness can be controlled by either a DC Voltage or a pulse-width modulated (PWM) signal at a driver input. The driver of the illumination light 208 can also include an onboard power MOSFET switch protected by current limit open load shutdown, thermal shutdown, and/or under Voltage lockout. In one embodiment, the driver of the illumination light 208 can drive nine white LEDs from a 2.7 V input, and/or drive 15 white LEDs from a 5 V input. The driver can be up to 90% efficient and have over an 80 mA output current capacity and open load shutdown. The driver can also have a low current sensing feedback Voltage and multiple string current sensing feedbacks as well. The driver can be packaged in any package suitable for implantation in or on an eye, including a compact MSOP10 or 3 mm x 3 mm QFN16 package.

[0057] One light source suitable as the illumination light 208 of the biomedical system 200 is a side view-type chip LED, such as the LNJ010X6FRA LED, manufactured by Kagoshima Matsushita Electronics Co. Ltd. (Panasonic). The illumination light 208 can include a white light emitting diode such as a diode made from gallium nitride (GaN). In one embodiment, the illumination light 208 has an absolute maximum power rating of 120 mW, a forward DC current rating of 30 mA, a forward peak current rating of 80 mA, and a reverse DC current rating of 100 mA. In one embodiment, the illumination light 208 operates in the range of about 2.8 V to about 3.9 V, and in another embodiment, it operates at about 3.4 V. The illumination light 208 can have a reverse leakage current of less than about 2.5 μ A and a luminous intensity in the range of about 180 mcd to about 337 mcd. In one embodiment, the illumination light 208 has a luminous intensity of about 260 mcd. In one embodiment, the x-chromatic coordinate of the illumination

light 208 is generally in the range of about 0.261 to about 0.357 and the y-chromatic coordinate is in the range of about 0.242 to about 0.375.

[0058] In one embodiment, the illumination light 208 has a width about 2.4 mm, a height of about 0.7 mm, and a depth of about 1.2 mm. In another embodiment, the illumination light 208 has a width of about 2 mm, a height of about 0.5 mm, and a depth of about 1 mm.

[0059] The video modulator and RF link transmitter 210 can be included in the packaging of the camera 204. The video modulator and RF link transmitter 210 provide modulation to the composite video signal generated by the camera 204. The modulated signal can be passed or transmitted to the internal components 212 of the biomedical system 200 by any wired or wireless link. For example, in some embodiments, the video modulator and RF link transmitter 210 transmits a signal with radio frequency or capacitive coupling transmission.

[0060] One video modulator suitable for use as the video modulator of the biomedical system 200 is the MC44BC375UA VHF audio/video modulator manufactured by Freescale Semiconductor, Inc.. The video modulator and RF link transmitter 210 can include a phase locked loop (PLL) tuned, very high frequency (VHF) audio/video, high integration modulator, integrated circuit. In one embodiment, a 4 MHz crystal oscillator provides the PLL reference signal. The video modulator and RF link transmitter 210 can include a power save function that turns off internal components of the video modulator and RF link transmitter 210 and switches on logic output. In one embodiment, the video modulator and RF link transmitter 210 has an 80 dBuV RF output level, channel selection capability, integrated on-chip oscillator, adjustable video modulation depth, peak white clip, a modulator standby mode, a transient output inhibit during PLL lockup at power on, a logic output port, and/or ESD protection, such as minimum 4 kV, typically 6 kV. The adjustable video modulation depth can be about 85%.

[0061] The power coupling receiver 214 of the biomedical system 200 can rectify and filter received radio frequency or induction AC power signals received from the power coupling transmitter 206. In one embodiment, the power coupling receiver 214 is a wire loop antenna, similar to those used in radio-frequency identification (RFID) devices. One such antenna suitable for use as the power coupling receiver 214 is the TAG-IT® HF-I Transponder Inlay manufactured by Texas Instruments, Inc. The power coupling receiver 214 can have any of a variety of shapes and sizes. For example, in one embodiment, the power coupling receiver 214 has a circular shape and a diameter of about 24 mm. Of course, the power coupling receiver 214 can have any shape

suitable for use in a component implanted within the eye, such as oval, elliptical, hexagonal, etc. In other embodiments, the power coupling receiver 214 has a diameter of less than about 10 mm, less than about 25 mm, or less than about 50 mm. In some embodiments, multiple power coupling receivers 214 are utilized.

[0062] The power coupling receiver 214 can operate at any of a variety of operating frequencies. In one embodiment, the power coupling receiver 214 operates at about 13 MHz. The power coupling receiver 214 can include foil that is coiled into multiple concentric circles where the foil has a foil width of about 48 mm and a foil pitch of about 50 mm. The power coupling receiver 214 can be made from PET (polyethyleneterephthalate), and the antenna can be made from aluminum, although any of a variety of material may be used.

[0063] The RF video link receiver and demodulator 218 receives a modulated composite video signal from the video modulator and RF link transmitter 210. In one embodiment, the RF video link receiver and demodulator 218 demodulates the signal received from the video modulator and RF link transmitter 210 into composite video that can be provided to the circuitry of the display 220.

[0064] One RF receiver suitable for use as the RF video link receiver and demodulator 218 is the ATS7000 CMOS semiconductor chip manufactured by Athena Semiconductors, Inc. The RF video link receiver and demodulator 218 can include a noise figure of about 4 dB. The RF video link receiver and demodulator 218 can have less than 0.4° integrated phase noise a signal-to-noise ratio of greater than about 30 dB. The RF video link receiver and demodulator 218 can require less than about 25 mW in time slicing mode and less than about 10 mW in power-down mode, and can be provided in a very small package, such as a 40-pin MLF, or a package having dimension of about 6 mm x about 6 mm.

[0065] The rectifier and filter 216 of the biomedical system 200 generally processes the power received from the power source 202 via the power coupling receiver 214 to generate DC power used by the internal components 212 of the biomedical system 200. For example, the rectifier and filter 216 can provide power to the display 220 and its associated circuitry. In one embodiment, the rectifier and filter 216 includes a full wave Schottky diode bridge, capacitive passive filter and optionally, a capacitive energy storage element.

[0066] One such rectifier and filter is the MBRS130LT3 manufactured by Semiconductor Components Industries, LLC, sometimes referred to as ONSEMICONDUCTOR®.

The rectifier and filter 216 can have a low forward drop Voltage of about 0.395 V max at 1.0 A at 25°C. The rectifier and filter 216 can have a small surface mountable package with J-bend leads and highly stable oxide passivated junctions. The rectifier and filter 216 can have a peak repetitive reverse Voltage of about 30 V and an average rectified forward current of about 1 A at 120°C. The rectifier and filter 216 can have a peak repetitive reverse Voltage of about 30 V and an average rectified forward current of about 1 A at 120 °C and about 2 A at about 110 °C. The rectifier and filter 216 can also have a non-repetitive peak surge current of about 40 A and an operating junction temperature in the range of about -65 °C to about 125 °C.

[0067] The maximum instantaneous forward Voltage of the rectifier and filter 216 can be about 0.395 V at a 1 A forward current and about 0.445 V at a 2 A forward current. The maximum instantaneous reverse current of the rectifier and filter 215 can be about 1 A at about 25 °C and about 1 mA at about 25 °C and about 10 mA at about 100 °C at the rated DC Voltage.

[0068] The rectifier and filter 216 can be sized or selected to have a width in the range of about 0.16" to about 0.18" (about 4.0 mm to about 4.6 mm), or about 0.20" to about 0.22" (about 5.2 mm to about 5.6 mm). The depth of the rectifier and filter 216 can be in the range of about 0.077" to about 0.083" (about 1.96 mm to about 2.11 mm) or in the range of about 0.13" to about 0.15" (about 3.3 mm to about 3.8 mm). In addition, the height of the rectifier and filter 216 can be in the range of about 0.075" to about 0.095" (about 1.90 mm to about 2.41 mm).

[0069] The display 220 of the biomedical system 200 can include a transmission LCD that converts a composite video signal into xy-plane component signals and use them to reconstruct the image taken by the camera 204 onto the surface of the display 220. In one embodiment, the display 220 includes an XGA1 miniature LCD manufactured by CRL Opto. The display 220 can have a diagonal dimension of about 1.8" or 46 mm, and a resolution of about 1024 by 768 pixels. The display 220 can be a miniature transmission TFT LCD with a fast response twisted nematic liquid crystal structure and high contrast. Such displays are generally lightweight and portable and require minimal space.

[0070] The display 220 can be made or selected to have a variety of sizes and shapes. For example, in one embodiment, the display 220 has a square or rectangular shape, and has a diagonal dimension of about 1.3" (33 mm), about 0.9" (23 mm), or about 0.7" (18 mm). The display 220 can have a pixel pitch of about 36 μ m x about 36 μ m, and a pixel dimension of about

33 μm x about 25 μm . The pixels can be rectangular in shape or any other shape, such as circular, elliptical, oval, etc. The display 220 can have an active area of about 37 mm x about 27 mm and can transmit about 21% at 600 nm. In addition, the display 220 can have a contrast ratio of greater than 100:1. The display 220 can operate at any of a variety of frame rates, including about 60 Hz, greater than about 50 Hz, and less than about 80 Hz.

[0071] The display 220 can operate at a Voltage of about 5 V and consume about 4.3 W without backlight or about 6 W with a backlight. The line frequency of the display 220 can be about 48.4 kHz, the pixel frequency can be about 65 Hz, and the refresh rate can be about 60 Hz, non-interlaced.

[0072] Another display that is suitable for use as the display 220 of the biomedical system 200 is the LIGHTVIEW™, 311K digital display module manufactured by Display Tech, Inc. (Model LDM-0311-D1). The display 220 can have a resolution of about 432 by 240 full-color pixels, or 311,000 effective dots. The display 220 can include fast switching ferroelectric liquid crystal material (FLC) which can eliminate motion smearing. The display 220 can utilize less than 175 mW, including LED illumination and display driver power. The display 220 can have a 360 Hz RGB field rate and adjustable brightness and gamma settings. In one embodiment, the display 220 has an 8-bit RGB serial data interface. In other embodiments, the display 220 has a CCIR 601 and/or a CCIR 656 interface. The diagonal of the display 220 can be about 0.26" and can have a pixel pitch of about 12 μm x about 16.2 μm and a fill factor of about 93%. The color depth of the display 220 can be about 24 bits (8-bit RGB) and can have a color field rate of about 360 Hz for 60 Hz NTSC video input or about 300 Hz for 50 Hz PAL video input.

[0073] The display 220 can have a brightness of about 350 cd/m^2 , adjustable to $1/64^{\text{th}}$ full scale, and a contrast ratio of 100:1. The display 220 can operate from any suitable power supply Voltage, including a power supply Voltage of about 2.5 V, about 3.3 V, or about 5.0. The dimensions of the display 220 can be about 20 mm long, about 19.2 mm wide, and about 11.4 mm high.

[0074] In addition, the biomedical system 200 can include a processor or controller to control operation of the various components described above. However, in some embodiments, a processor or controller is not required as the camera 204 and display 220 may include their own controllers or processors that control their operations. Digital logic can be employed to control these as well as the other components in addition to, or instead of a processor. In addition, although

in some embodiments composite video is used, other serial video modulation methods may be used, as known by those of skill in the art.

[0075] In operation, the external components 201 of the biomedical system 200 are attached to the convex surface of a contact lens and worn on a user's eye. The internal components 212 of the biomedical system 200 are implanted inside of an artificial intraocular lens and are inserted inside of the patient's eye. By moving the eyeball, the patient can aim and direct and focus the camera 204 upon a target object 205 that the wearer desires to view.

[0076] The camera 204 generates a signal corresponding to an image received from the target object 204 and provides it to the video modulator and RF link transmitter 210. The power source 202 provides power to the camera 204, power coupling transmitter 206, illumination light 208, and video modulator and RF link transmitter 210. The video signal received by the video modulator and RF link transmitter 210 from the camera 204 is modulated and transmitted to the RF video link receiver and demodulator 218 of the internal components 212 of the biomedical system 200.

[0077] Power is received from the power coupling transmitter 206 by the power coupling receiver 214. As described above, the power coupling transmitter can transmit the power as a low frequency RF signal. The video modulator and RF link transmitter 210 transmits a video signal to the RF video link receiver and demodulator 218 with high frequency RF. The power signal received by the power coupling receiver 214 is generally an AC signal that is rectified and filtered by the rectifier and filter 216. The DC power generated by the rectified and filter 216 is provided to the RF video link receiver and demodulator 218, as well as to the display 220 of the biomedical system 200.

[0078] The display also receives a composite video signal from the RF video link receiver and demodulator 218. An image corresponding to the composite video signal is displayed on the display 220 and that image is provided to the retina 108 of the wearer's eye. In the manner described above, the user of the biomedical system 200 is able to view a target object 205 even though he or she suffers from corneal opacity.

[0079] Figure 3 shows a wearable camera assembly in accordance with another embodiment of the present invention. The camera assembly 300 generally includes a contact lens 302 that has a concave surface 304 and a convex surface 306. The curvature of the concave surface 304 is selected to conform with the cornea of a user's eye. The camera assembly 300 also includes

a camera 308, a power relay 310, and a transmitter 312. The camera 308, power relay 310, and transmitter 312 can be any of the cameras, power sources and video transmitters or video modulator and RF link transmitters described in greater detail above with respect to Figures 1 and 2.

[0080] At least one conductor 314 provides electrical connectivity between the camera 308, power relay 310 and transmitter 312. In one embodiment, the camera 308, power relay 310 and transmitter are separate components, such as shown in Figure 3. However, in other embodiments, at least two of the camera 308, power relay 310 and transmitter 312 are fabricated on the same semiconductor.

[0081] The camera 308 can be made from a flexible material to conform to the shape of the user's eye. In other embodiments, the camera 308 is pre-shaped to have an arching curvature to conform to the shape of the user's eye. The power relay 310 and transmitter 312 can also be flexible or pre-shaped to conform to the shape of a user's eye.

[0082] Power can be received by the camera assembly 300 from a power source 316. The power source 316 can be a battery, capacitor, or any other power source known to those of skill in the art that can wirelessly provide energy or power 318 to the power relay 310 of the camera assembly 300. For example, the power source 316 can be a battery and transmitter mounted to a pair of eyeglasses worn by the user, and the power relay 310 can be an inductor that receives power 318 from the power source 316.

[0083] The transmitter 312 can generate a video signal 320 based upon an image received by the camera 308. The video signal 320 can be wirelessly transmitted from the transmitter 312 to the receiver of an intraocular display system (not shown), such as describe in greater detail above with respect to Figures 1 and 2.

[0084] Figure 4 shows one method of receiving a video image in accordance with one embodiment of the present invention. At step 402 of the method 400 receives an image of a target object with a camera located in or on a contact lens carried by a user's eye. At step 404, the method 400 generates a signal indicative of the image. At step 406, the method 400 transmits the signal to a receiver coupled to a display that displays a display image based at least in part on the signal.

[0085] Figure 5 shows another method of receiving a video image in accordance with another embodiment of the present invention. At step 502, the method 500 receives an image of a target object with a camera located in or on a contact lens carried by a user's eye. At step 504, the

method 500 generates a display image based at least in part on the signal. At step 506, the method 500 provides the display image to the retina of the user's eye.

[0086] Figure 6 shows a method of video transmission in accordance with another embodiment of the present invention. At step 602, the method 600 generates an electrical signal within 10 mm of a surface of a user's cornea. At step 604, the method 600 transmits the electrical signal into the user's eye. The method 600 can also include step 606. At step 606, the method 600 receives the signal within the user's eye and displays an image based upon the signal.

[0087] Although this invention has been disclosed in the context of certain embodiments, it will be understood by those skilled in the art that the present invention extends beyond the specifically disclosed embodiment to other alternative embodiments and/or uses of the invention and obvious modifications and equivalents thereof. In particular, while the present biomedical system and methods have been described in the context of one particular embodiment, the skilled artisan will appreciate, in view of the present disclosure, that certain advantages, features and aspects of the information communication system, device, and method may be realized in a variety of other applications and systems.

[0088] Additionally, it is contemplated that various aspects and features of the invention described can be practiced separately, combined together, or substituted for one another, and that a variety of combination and subcombinations of the features and aspects can be made and still fall within the scope of the invention. Thus, it is intended that the scope of the present invention herein disclosed should not be limited by the particular disclosed embodiment described above, but should be determined only by a fair reading of the claims that follow.

WHAT IS CLAIMED IS:

1. An intraocular video system, comprising:
a contact lens adapted to be carried on a surface of a user's eye;
a camera coupled to the contact lens, wherein the camera is adapted to generate a signal indicative of an image received by the camera; and
a display, wherein the display is positioned within the user's eye, wherein the display provides a display image to a retina in the user's eye, and wherein the display image is at least in part based upon the signal.
2. The intraocular video system of Claim 1, further comprising a power source, wherein the power source is adapted to provide electrical power to the camera and the display.
3. The intraocular video system of Claim 1, wherein the power source comprises an inductor.
4. The intraocular video system of Claim 1, wherein the power source comprises an inductive coil.
5. The intraocular video system of Claim 2, further comprising eyeglasses, wherein the power source is mounted on the eyeglasses.
6. The intraocular video system of Claim 1, wherein the camera is integrated within the contact lens.
7. The intraocular video system of Claim 1, wherein the camera is mounted on the contact lens.
8. The intraocular video system of Claim 1, wherein the contact lens comprises a concave surface and a convex surface and the camera is located between the concave surface and the convex surface.
9. The intraocular video system of Claim 1, wherein the contact lens comprises a concave surface and a convex surface and the camera comprises circuitry, and the circuitry is located between the concave surface and the convex surface.
10. The intraocular video system of Claim 1, further comprising a transmitter coupled to the camera.
11. The intraocular video system of Claim 10, wherein the contact lens comprises a concave surface and a convex surface and the transmitter is located between the concave surface and the convex surface.

12. The intraocular video system of Claim 10, wherein the transmitter emits a signal having at least one of radiofrequency energy, infrared energy, acoustic energy, or optical energy.
13. The intraocular video system of Claim 1, wherein the contact lens is flexible.
14. The intraocular video system of Claim 1, wherein the contact lens is soft.
15. A wearable camera assembly, comprising:
 - a contact lens adapted to be carried on the surface of a user's eye, the contact lens having a concave surface and a convex surface; and
 - a camera located in or on the contact lens.
16. The wearable camera assembly of Claim 15, wherein the camera is mounted to at least a portion of the convex surface.
17. The wearable camera assembly of Claim 15, wherein the position of the camera with respect to the user's head is adjusted based at least in part upon movement of the user's eye.
18. A method of receiving a video image, comprising:
 - receiving an image of a target object with a camera located in or on a contact lens carried by a user's eye;
 - generating a signal indicative of the image; and
 - transmitting the signal to a receiver, said receiver coupled to a display that displays a display image based at least in part upon the signal.
19. A method of receiving a video image, comprising:
 - receiving a signal indicative of an image of a target object, wherein the signal is generated by a camera located in or on a contact lens carried by a user's eye;
 - generating a display image based at least in part on the signal; and
 - providing the display image to the retina of the user's eye.
20. A method of video transmission, comprising:
 - generating an electrical signal within about 10 mm of a surface of a user's cornea; and
 - transmitting the electrical signal into the user's eye.
21. The method of Claim 20, wherein the electrical signal comprises a digital signal.
22. The method of Claim 20, further comprising receiving the signal within the user's eye and displaying an image based upon the signal.
23. A contact lens comprising an electrically conductive material.

24. A contact lens comprising a camera.
25. The contact lens of Claim 24, wherein the camera comprises a video camera.
26. An intraocular video system, comprising:
 - means for receiving an image of a target object, said means for receiving located in or on a contact lens carried by a user's eye;
 - means for generating a signal indicative of the image; and
 - means for transmitting the signal to a receiver, said receiver coupled to a display that displays an image based at least in part upon the signal.
27. An intraocular video receiver, comprising:
 - means for receiving a signal indicative of an image of a target object, wherein the signal is generated by a camera located in or on a contact lens carried by a user's eye;
 - means for generating a display image based at least in part on the signal; and
 - means for providing the display image to the retina of the user's eye.
28. An intraocular video transmitter, comprising:
 - means for generating an electrical signal within about 10 mm of a surface of a user's cornea; and
 - means for transmitting the electrical signal into the user's eye.

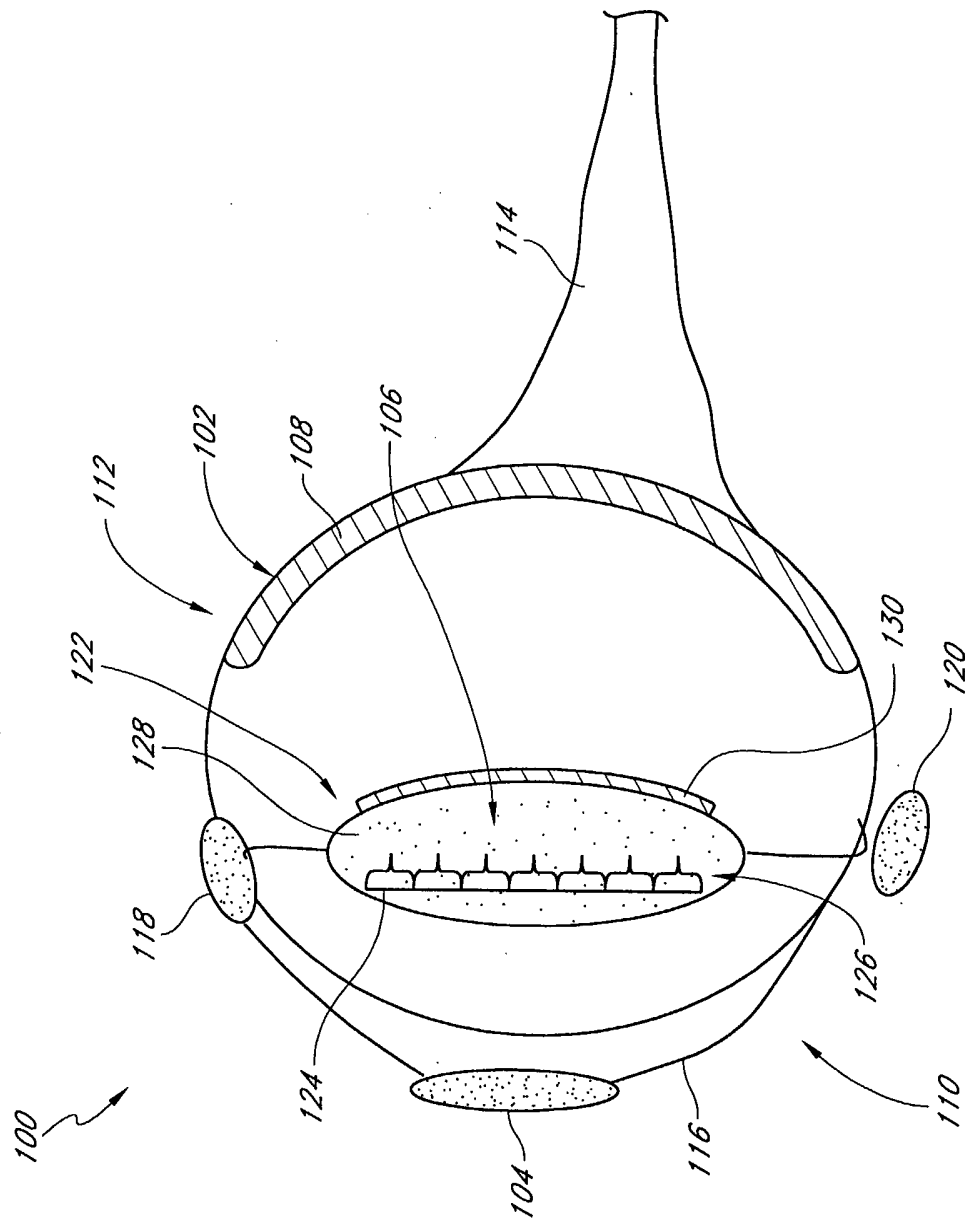


FIG. 1

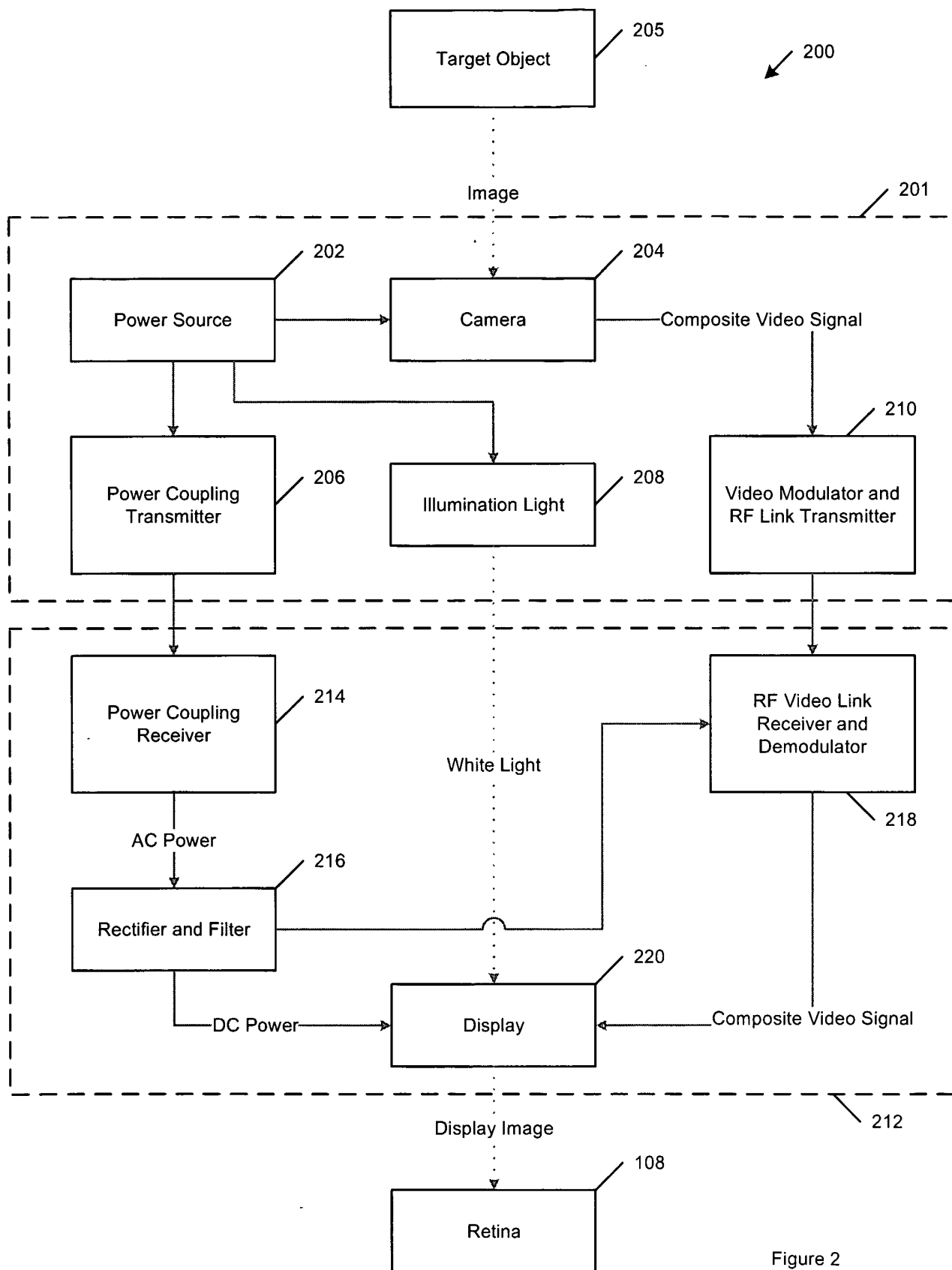


Figure 2

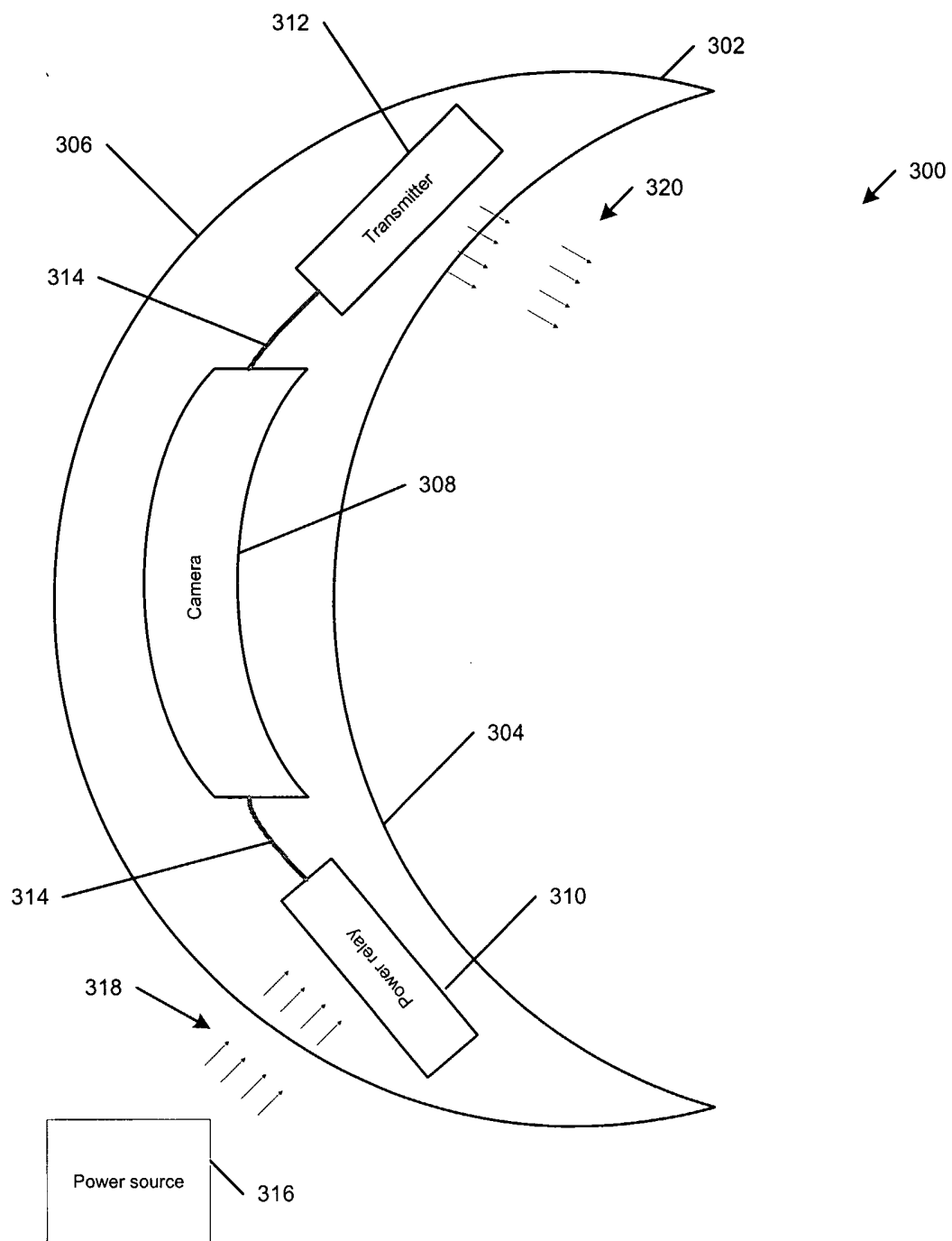


Figure 3

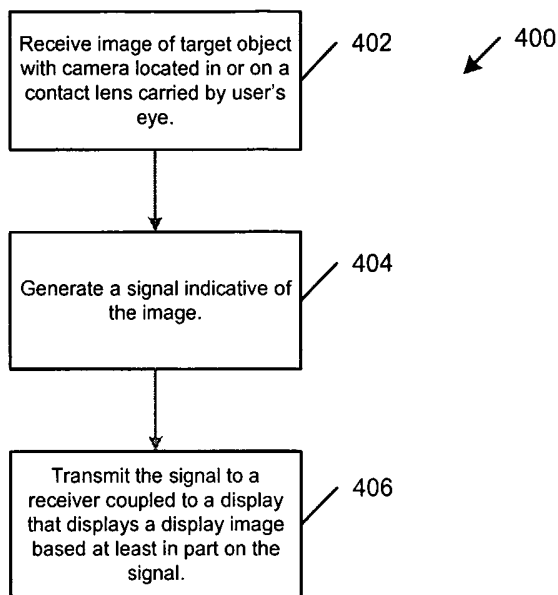


Figure 4

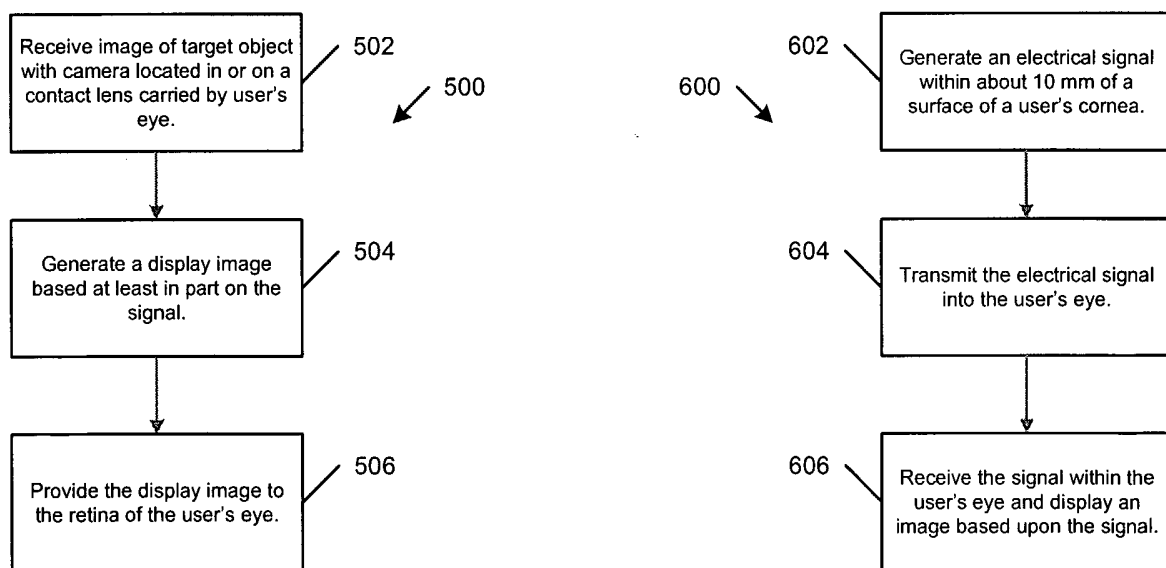


Figure 5

Figure 6