

LI-FI COMMUNICATION DEVICE

Cross Reference to Related Application(s)

- 5 The present disclosure claims the benefit of Singapore Patent Application No. 10201908044S filed on 30 August 2019, which is incorporated in its entirety by reference herein.

Technical Field

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The present disclosure generally relates to a light fidelity (Li-Fi) communication device. More particularly, the present disclosure describes various embodiments of a Li-Fi communication device and a Li-Fi communication system comprising Li-Fi communication devices.

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Background

- Light fidelity or Li-Fi is an emerging wireless communication technology that utilizes light for data communications. Li-Fi has attracted great interest in recent years due to advantages like higher speed, lesser interference, and improved security, compared to radio-frequency based technologies such as Wi-Fi. Due to the wide range of unused / unlicensed spectrum, Li-Fi can support a much higher data rate than Wi-Fi and does not interfere with radio waves. Li-Fi relies upon line-of-sight for light transmission and data communications. This provides a higher level of data security since light cannot penetrate through walls. Li-Fi can complement Wi-Fi as a faster, more secure, and energy-efficient form of wireless communication and can be used in places where Wi-Fi signals are restricted or where the Wi-Fi network is congested. Using both Li-Fi and Wi-Fi as complementary data communications can facilitate development of Internet-of-Things (IoT) systems, especially in Singapore where the government has launched the Smart Nation initiative to create technology-enabled solutions.

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Summary

According to a first aspect of the present disclosure, there is a Li-Fi communication device comprising: a communication interface arranged for selectively connecting to an electronic device; and a transceiver module connected to the communication interface and arranged for selectively connecting at least one illumination element and at least one photodetector thereto. The transceiver module is configured for: converting uplink data signals received from the electronic device to uplink driving signals that control the illumination element to transmit uplink optical signals; and converting downlink detection signals received from the photodetector to downlink data signals for transmission to the electronic device, the downlink detection signals converted from downlink optical signals detected by the photodetector.

According to a second aspect of the present disclosure, there is Li-Fi communication system comprising: a communication network comprising a set of network interfaces; and a set of remote Li-Fi communication devices communicatively connected within the communication network. Each remote Li-Fi communication device comprises: a communication interface selectively connected to a respective network interface; a transceiver module connected to the communication interface; at least one illumination element selectively connected to the transceiver module; and at least one photodetector selectively connected to the transceiver module. Each transceiver module is configured for: converting downlink data signals received from the communication network to downlink driving signals that control the illumination element to transmit downlink optical signals; and converting uplink detection signals received from the photodetector to uplink data signals for transmission to the communication network, the uplink detection signals converted from uplink optical signals detected by the photodetector. The downlink optical signals are transmitted to a set of local Li-Fi communication devices and the uplink optical signals are transmitted from the local Li-Fi communication devices.

A Li-Fi communication device according to the present disclosure is thus disclosed herein. Various features, aspects, and advantages of the present disclosure will become more apparent from the following detailed description of the embodiments of the present disclosure, by way of non-limiting examples only, along with the accompanying drawings.

Brief Description of the Drawings

Figure 1A and Figure 1B are various illustrations of a Li-Fi communication device in
5 accordance with embodiments of the present disclosure.

Figure 2A is an illustration of a setup of two Li-Fi communication devices, in
accordance with embodiments of the present disclosure.

10 Figure 2B is a screenshot illustration of a diagnostic of the setup, in accordance with
embodiments of the present disclosure.

Figure 3A and Figure 3B are various schematic illustrations of a Li-Fi communication
system in accordance with embodiments of the present disclosure.

15 Figure 4 to Figure 6 are various illustrations of a transceiver circuit of the Li-Fi
communication device, in accordance with embodiments of the present disclosure.

Figure 7 is another schematic illustration of the Li-Fi communication system in
20 accordance with embodiments of the present disclosure.

Detailed Description

For purposes of brevity and clarity, descriptions of embodiments of the present
25 disclosure are directed to a Li-Fi communication device, in accordance with the
drawings. While aspects of the present disclosure will be described in conjunction with
the embodiments provided herein, it will be understood that they are not intended to
limit the present disclosure to these embodiments. On the contrary, the present
disclosure is intended to cover alternatives, modifications and equivalents to the
30 embodiments described herein, which are included within the scope of the present
disclosure as defined by the appended claims. Furthermore, in the following detailed
description, specific details are set forth in order to provide a thorough understanding
of the present disclosure. However, it will be recognised by an individual having

ordinary skill in the art, i.e. a skilled person, that the present disclosure may be practiced without specific details, and/or with multiple details arising from combinations of aspects of particular embodiments. In a number of instances, well-known systems, methods, procedures, and components have not been described in detail so as to not
5 unnecessarily obscure aspects of the embodiments of the present disclosure.

In embodiments of the present disclosure, depiction of a given element or consideration or use of a particular element number in a particular figure or a reference thereto in corresponding descriptive material can encompass the same, an equivalent,
10 or an analogous element or element number identified in another figure or descriptive material associated therewith.

References to “an embodiment / example”, “another embodiment / example”, “some embodiments / examples”, “some other embodiments / examples”, and so on, indicate
15 that the embodiment(s) / example(s) so described may include a particular feature, structure, characteristic, property, element, or limitation, but that not every embodiment / example necessarily includes that particular feature, structure, characteristic, property, element or limitation. Furthermore, repeated use of the phrase “in an embodiment / example” or “in another embodiment / example” does not
20 necessarily refer to the same embodiment / example.

The terms “comprising”, “including”, “having”, and the like do not exclude the presence of other features / elements / steps than those listed in an embodiment. Recitation of certain features / elements / steps in mutually different embodiments does not indicate
25 that a combination of these features / elements / steps cannot be used in an embodiment.

As used herein, the terms “a” and “an” are defined as one or more than one. The use of “/” in a figure or associated text is understood to mean “and/or” unless otherwise
30 indicated. The term “set” is defined as a non-empty finite organisation of elements that mathematically exhibits a cardinality of at least one (e.g. a set as defined herein can correspond to a unit, singlet, or single-element set, or a multiple-element set), in accordance with known mathematical definitions. The recitation of a particular

numerical value or value range herein is understood to include or be a recitation of an approximate numerical value or value range. The terms “first”, “second”, etc. are used merely as labels or identifiers and are not intended to impose numerical requirements on their associated terms.

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In representative or exemplary embodiments of the present disclosure, there is a light fidelity or Li-Fi communication device 100 as shown in Figure 1A and Figure 1B. The Li-Fi communication device 100 includes a communication interface 110 arranged for selectively connecting to an electronic device 150. In some embodiments, the communication interface 110 includes an Ethernet or RJ45 interface for wired data communications across an Ethernet local area network (LAN). In one embodiment, the Ethernet communication interface 110 includes a male Ethernet plug for connecting to a female Ethernet port or socket. For example, the electronic device 150 includes the female Ethernet port and the male Ethernet plug is directly connected to the female Ethernet port. In another embodiment, the Ethernet communication interface 110 includes a female Ethernet port or socket where a male Ethernet plug is connected to. For example, the electronic device 150 includes a female Ethernet port and both female Ethernet ports are connected to each other via an Ethernet cable 112, such as shown in Figure 1A. The communication interface 110 may alternatively include a USB interface.

The Li-Fi communication device 100 further includes a transceiver module 120 connected to the communication interface 110. The transceiver module 120 is arranged for selectively connecting at least one illumination element 130 and at least one photodetector 140 thereto. More specifically, the transceiver module 120 is a transceiver circuit board that includes at least one illumination element connector 122 and at least one photodetector connector 124 for connecting to the illumination element 130 and photodetector 140, respectively. The Li-Fi communication device 100 may further include a power connector 126 connected to the transceiver module 120 and for selectively connecting to a power cable or external power source that supplies power to the Li-Fi communication device 100.

The Li-Fi communication device 100 may include a plurality or an array of illumination elements 130. A larger number of illumination elements 130 generates a higher light output and this may be required for data communications over a longer range and/or across a wider coverage. Similarly, the Li-Fi communication device 100 may include
5 a plurality or an array of photodetectors 140. A larger number of photodetectors 140 expands the detection coverage can be more sensitive to lower intensities of light input.

In some embodiments, the illumination element 130 and photodetector 140 are combined into an integrated component that is configured for emitting and detecting
10 light. For example, this integrated component has a first area configured for transmitting or emitting light, and further has a second area different from the first area and configured for detecting light. The first area may or may not overlap with the second area.

15 The transceiver module 120 is configured for converting signals during uplink and downlink data communications. In the present disclosure, uplink and downlink data communications are used with respect to the electronic device 150. In other words, data is transmitted or uploaded from the electronic device 150 during uplink and data is received or downloaded by the electronic device 150 during downlink. During uplink,
20 the transceiver module 120 converts uplink data signals received from the electronic device 150 to uplink driving signals that control the illumination element 130 to transmit uplink optical signals. During downlink, the transceiver module 120 converts downlink detection signals received from the photodetector 140 to downlink data signals for transmission to the electronic device 150, wherein the downlink detection signals are
25 converted from downlink optical signals detected by the photodetector 140.

In some embodiments, the illumination element 130 and photodetector 140 are selectively connected to the transceiver module 120 such that they are directly coupled to or integrally formed with the transceiver module 120 as an integral or single body.
30 This makes the overall size of the Li-Fi communication device 100 more compact and makes it easier for the Li-Fi communication device 100 to be connected to the electronic device 150. The illumination element 130 and photodetector 140 may be permanently fixed to the transceiver module 120, but this would prevent a user of the

Li-Fi communication device 100 from customizing it with different illumination elements 130 and photodetectors 140.

In some embodiments, the illumination element 130 and photodetector 140 are
5 selectively connected to the transceiver module 120 by respective cables or wires
such that they are positioned a distance away from the transceiver module 120. This
provides greater freedom for the user in positioning the illumination element 130 and
photodetector 140 relative to another Li-Fi communication device 100 for improved
data communications between the Li-Fi communication devices 100. Additionally, an
10 array of multiple illumination elements 130 and/or photodetectors 140 can be
connected to the transceiver module 120 to expand the coverage of the optical signals.
The array of illumination elements 130 and/or photodetectors 140 can be distributed
to more directly align them with other Li-Fi communication devices, improving data
communications via the optical signals. For example, a first local illumination element
15 130 can be directed towards a remote photodetector 140 on the ceiling while a second
local illumination element 130 can be directed towards a remote photodetector 140 on
the wall.

Selective connection of the illumination element 130 and photodetector 140 allows
20 them to be easily connected to and disconnected from the transceiver module 120.
Firstly, this selective connection allows the user to easily replace the illumination
element 130 and photodetector 140 if they are damaged, instead of having to replace
or repair the entire Li-Fi communication device 100. Secondly, this selective
connection allows the user to customize or personalize the Li-Fi communication device
25 100 by using his/her preferred illumination element 130 and/or photodetector 140. For
example, the Li-Fi communication device 100 may come with an illumination element
130 that emits visible light, but the user may prefer to use an illumination element 130
that emits infrared light. In this case, the user can easily modify the Li-Fi
communication device 100 by replacing visible-light illumination element 130 with the
30 infrared-light illumination element 130. It will be appreciated the photodetector 140
may be replaced based on similar considerations. For example, the user may replace
a visible-light photodetector 140 with an infrared-light photodetector 140.

In some embodiments, the illumination element 130 is configured to emit infrared, near infrared, visible, ultraviolet, and/or near ultraviolet light or illumination. The emitted illumination carries the uplink optical signals which will be detected by the photodetector 140 of another Li-Fi communication device 100. The illumination element 130 may include a light-emitting diode (LED) or a laser diode. The illumination element 130 may include a material, such as a semiconductor material, configured to emit or transmit light of a first wavelength or a first range of wavelengths. The wavelength of near ultraviolet light may range from 350 nm to 400 nm. The wavelength of visible light may range from 400 nm to 700 nm. The wavelength of near infrared light may range from 780 nm to 930 nm. Infrared light may have longer wavelengths, such as 1330 nm and 1550 nm. It will be appreciated that the wavelengths of the emitted illumination are not limited by the examples described above.

In some embodiments, the photodetector 140 is configured to detect infrared, near infrared, visible, ultraviolet, and/or near ultraviolet light or illumination. The detected illumination carries the downlink optical signals which are emitted by the illumination element 130 of another Li-Fi communication device 100. The photodetector 140 may include a photodiode or an avalanche photodiode (APD). The photodetector 140 may include a material, such as a semiconductor material, configured to absorb light of a second wavelength or a second range of wavelengths. The first wavelength or first range of wavelengths may or may not overlap with the second predetermined or second range of wavelengths. The wavelength of visible light may range from 400 nm to 700 nm. The wavelength of infrared or near infrared light may range from 700 nm to 1550 nm. Depending on the material of the photodetector 140, the detected illumination may include ultraviolet light having a wavelength of 400 nm and below. It will be appreciated that the wavelengths of the detected illumination are not limited by the examples described above.

In the visible light spectrum, the illumination element 130 and photodetector 140 may be configured to emit and detect, respectively, one or more colours, wavelengths, or range of wavelengths of visible light. These colours may include one or more of red light, orange light, yellow light, green light, blue light, blue-green light, violet light, and white light. It will be appreciated that the illumination element 130 and photodetector

140 may be configured to suitable wavelengths or wavelength ranges based on the one or more colours.

5 The material for the illumination element 130 and photodetector 140 may include one or more inorganic semiconductor materials and/or one or more organic semiconductor materials. Some non-limiting examples of an inorganic semiconductor material include aluminium gallium arsenide (AlGaAs), aluminium gallium indium phosphide (AlGaInP), aluminium gallium phosphide (AlGaP), gallium arsenic phosphide (GaAsP), gallium arsenide (GaAs), gallium nitride (GaN), gallium phosphide (GaP), germanium (Ge),
10 indium gallium arsenide (InGaAs), indium gallium nitride (InGaN), silicon (Si), zinc selenide (ZnSe), and metal halide perovskite. Some non-limiting examples of an organic molecule or polymeric material include coumarin-based materials such as Coumarin 545T.

15 Figure 2A illustrates an exemplary setup 200 of a local Li-Fi communication device 100a for data communications with a remote Li-Fi communication device 100b. The local Li-Fi communication device 100a is selectively connected to the electronic device 150 via the communication interface 110. It will be appreciated that various aspects of the Li-Fi communication device 100 described above will apply similarly or analogously
20 to the local Li-Fi communication device 100a and remote Li-Fi communication device 100b. The electronic device 150 may be a computing device such as a computer server, desktop computer, laptop computer, or tablet computer. The electronic device 150 may also be a consumer electronic device such as a camera, mobile device, or mobile phone. In the setup 200, the electronic device 150 is a laptop computer that is
25 connected to the communication interface 110 via the Ethernet cable 112.

The remote Li-Fi communication device 100b includes at least one illumination element 130b that is configured to emit infrared, visible, and/or ultraviolet illumination. The emitted illumination carries the downlink optical signals 142 for transmitting data
30 from the remote Li-Fi communication device 100b to the local Li-Fi communication device 100a. During downlink, the photodetector 140a of the local Li-Fi communication device 100a detects the downlink optical signals 142 and converts the downlink optical signals 142 to downlink detection signals. The transceiver module 120a of the local Li-

Fi communication device 100a receives the downlink detection signals from the local photodetector 140a and converts the downlink detection signals to downlink data signals. The downlink data signals are transmitted from the local transceiver module 120a to the electronic device 150 which then processes the downlink data signals into electronic data (downloading data). It will be appreciated that uplink data communications between the illumination element 130a of the local Li-Fi communication device 100a and the photodetector of the remote Li-Fi communication device 100b will occur in a similar manner as the downlink data communications.

10 In the setup 200, the distance between the local Li-Fi communication device 100a for data communications from the remote Li-Fi communication device 100b is approximately 1.5 m and the coverage diameter is around 60 cm. A 1080p HD video was successfully communicated by the downlink optical signals 142 and streamed on the electronic device 150. The communication interface 110 of the local Li-Fi communication device 100a uses a 10BASE Ethernet connection and a diagnostic run on the electronic device 150 showed that the network speed was 10 MBps. Figure 2B illustrates a diagnostic 250 of Ethernet data packets transmitted by the local Li-Fi communication device 100a.

20 In various embodiments with reference to Figure 3A and Figure 3B, there is a Li-Fi communication system 300 including a communication network 310 having a set of one or more network interfaces. The communication network 310 may include an Ethernet LAN or wide area network (WAN) and each network interface may include an Ethernet interface. The network interfaces may alternatively include USB interfaces.

25 The Li-Fi communication system 300 further includes a set of one or more remote Li-Fi communication devices 100b communicatively connected within the communication network 310. The remote Li-Fi communication devices 100b are configured for data communications with a set of one or more local Li-Fi communication devices 100a, each local Li-Fi communication device 100a selectively connected to a respective electronic device 150. Each remote Li-Fi communication device 100b includes the communication interface 110b selectively connected to a respective network interface of the communication network 310. Each remote Li-Fi communication device 100b

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further includes the transceiver module 120b connected to the communication interface 110b. Each remote Li-Fi communication device 100b further includes at least one illumination element 130b and at least one photodetector 140b selectively connected to the transceiver module 120b.

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The communication network 310 may be established in the telecommunications infrastructure of a facility, such as a building, apartment, or an office environment. For example, the communication network 310 in an office may be connected to several remote Li-Fi communication devices 100b and the illumination elements 130b may
10 include the lighting elements such as ceiling lights of the office. People in the office use electronic devices 150, such as computers, for downlink and uplink data communications via the communication network 310.

During downlink, the electronic device 150 is downloading electronic data from the
15 communication network 310. The communication network 310 processes or converts the electronic data (downloading data) to remote downlink data signals 152. The remote downlink data signals 152 are transmitted from the communication network 310 to the remote transceiver module 120b. The remote transceiver module 120b converts the remote downlink data signals 152 received from the communication
20 network 310 to downlink driving signals 144 that control the remote illumination element 130b to transmit downlink optical signals 142. Based on the downlink driving signals 144, the remote illumination element 130b transmits the downlink optical signals 142 to communicate the downloading data from the remote Li-Fi communication device 100b to the local Li-Fi communication device 100a. The
25 downlink optical signals 142 may be in the form of a plurality of light pulses, such as rapid pulses having a frequency of at least 60 Hz so the remote illumination element 130b is perceived to be always on and the downlink optical signals 142 are constantly being transmitted. The local photodetector 140a detects the downlink optical signals 142 and converts them to downlink detection signals 146. The local transceiver
30 module 120a receives the downlink detection signals 146 from the local photodetector 140a and converts the downlink detection signals 146 to local downlink data signals 154. The local downlink data signals 154 are transmitted from the local transceiver

module 120a to the electronic device 150 which then processes the local downlink data signals 154 into downloaded data.

During uplink, the electronic device 150 is uploading electronic data to the communication network 310. The electronic device 150 processes or converts the electronic data (uploading data) to local uplink data signals 156. The local uplink data signals 156 are transmitted from the electronic device 150 to the local transceiver module 120a. The local transceiver module 120a converts the local uplink data signals 156 received from the electronic device 150 to uplink driving signals 134 that control the local illumination element 130a to transmit uplink optical signals 132. Based on the uplink driving signals 134, the local illumination element 130a transmits the uplink optical signals 132 to communicate the uploading data from the local Li-Fi communication device 100a to the communication network 310 via the remote Li-Fi communication device 100b. The uplink optical signals 132 may be in the form of a plurality of light pulses, such as rapid pulses having a frequency of at least 60 Hz so the local illumination element 130a is perceived to be always on and the uplink optical signals 132 are constantly being transmitted. The remote photodetector 140b detects the uplink optical signals 132 and converts them to uplink detection signals 136. The remote transceiver module 120b receives the uplink detection signals 136 from the remote photodetector 140b and converts the uplink detection signals 136 to remote uplink data signals 158. The remote uplink data signals 158 are transmitted from the remote transceiver module 120b to the communication network 310 which then processes the remote uplink data signals 158 into uploaded data.

In some embodiments as shown in Figure 3A and Figure 3B, the Li-Fi communication system 300 includes a remote Li-Fi communication device 100b for data communications with a local Li-Fi communication device 100a by exchange of optical signals 132 / 142 therebetween. Although the Li-Fi communication system 300 shows one local Li-Fi communication device 100a and one remote Li-Fi communication device 100b, it will be appreciated that one local Li-Fi communication device 100a can transmit uplink optical signals 132 to and receive downlink optical signals 142 from a plurality or an array of remote Li-Fi communication devices 100b. Similarly, it will be appreciated that one remote Li-Fi communication device 100b can transmit downlink

optical signals 142 to and receive uplink optical signals 132 from a plurality or an array of local Li-Fi communication devices 100a.

For example, in an office environment, there may be an array of remote Li-Fi communication devices 100b distributed in the office, such as on the ceiling where the ceiling lights function as the remote illumination elements 130b. People in the office can simply connect the local Li-Fi communication devices 100a to their respective electronic devices 150 and perform data communications through Li-Fi. This is advantageous for users who may be located near walls or corners of the office where Wi-Fi connectivity is poor. The Li-Fi connectivity provide effective data communications for such users if the local photodetectors 140a are within line-of-sight with the remote illumination elements 130b.

In some embodiments, such as in the Li-Fi communication system 300 as shown in Figure 3A, the illumination element 130 and photodetector 140 of the respective Li-Fi communication device 100 are selectively connected to the respective transceiver module 120 by respective cables or wires. Further with reference to Figure 4, the transceiver module 120 includes a transceiver circuit 400 having a transmitter circuit 420 and a receiver circuit 440. The transmitter circuit 420 connects the communication interface 110 to the illumination element 130, and the receiver circuit 440 connects the communication interface 110 to the photodetector 140.

The transmitter circuit 420 includes one or more circuit elements that process signals from the communication interface 110 to the illumination element 130. Some non-limiting examples of such circuit elements are described herein. The transmitter circuit 420 includes a bias and amplitude adjustment circuit element 422 which determines the bias and modulation amplitude applied to the illumination element 130. The transmitter circuit 420 includes a buffer circuit element 424 which is used to achieve impedance matching between the communication interface 110 and the illumination element 130. The transmitter circuit 420 includes an output circuit element 426 which generates the uplink driving signals 134 which are transmitted to the illumination element 130. The output circuit element 426 may be part of the buffer circuit element 424. The transmitter circuit 420 may include an operational amplifier circuit element

for amplifying the power of the uplink driving signals 134. The transmitter circuit 420 may include a voltage regulator circuit element for supplying stepped-up DC voltage for an array of illumination elements 130. For example, the downlink signals 146 can be received by the receiver circuit 440 requiring a lower voltage (e.g. 5 V) but the
5 voltage can be stepped-up (e.g. to 9 V) for an array of six illuminating elements 130 to transmit uplink driving signals 134.

The receiver circuit 440 includes one or more circuit elements that process signals from the photodetector 140 to the communication interface 110. Some non-limiting
10 examples of such circuit elements are described herein. The receiver circuit 440 includes a single-to-differential conversion circuit element 442 which converts the downlink detection signals 146 to differential signals. As the photodetector 140 is separated from the transceiver module 120, the downlink detection signals 146 which are in the order of millivolts may be susceptible to electrical noise pickup that could
15 corrupt the signals. The photodetector 140 may include a trans-impedance amplifier circuit element to convert the downlink detection signals 146 to differential signals and to amplify the voltage of the differential signals to a level needed for electronic signal processing. The photodetector 140 may further include a noise filtering circuit element to suppress electrical noise in the differential signals. As the length of the cables or
20 wires connecting the photodetector 140 to the transceiver module 120 affects the level of electrical noise, the trans-impedance amplifier circuit element and noise filtering circuit element should be disposed as close to the photodetector 140 as possible to optimize the signal-to-noise ratio. Preferably, the trans-impedance amplifier circuit element and noise filtering circuit element are integrated with the photodetector 140.

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The receiver circuit 440 includes a limiting amplifier circuit element 444 which amplifies the differential signals to a predefined voltage level. The receiver circuit 440 includes a differential amplifier circuit element 446 which further amplifies the amplified differential signals from the limiting amplifier circuit element 444. For example, for an
30 Ethernet communication interface 110, the amplitude of the differential signals is ± 2.5 V. The amplified differential signals from the limiting amplifier circuit element 444 is further amplified by the differential amplifier circuit element 446 to ± 2.5 V.

In some embodiments, such as in the Li-Fi communication system 300 as shown in Figure 3B, the illumination element 130 and photodetector 140 of the respective Li-Fi communication device 100 selectively connected to the respective transceiver module 120 such that they are directly coupled to or integrally formed with the respective transceiver module 120. Further with reference to Figure 5, the transceiver module 120 includes a transceiver circuit 500 having a transmitter circuit 520 and a receiver circuit 540. The transmitter circuit 520 is connected to the communication interface 110 and includes the illumination element 130 because it is integrated with the transceiver module 120. The receiver circuit 540 is connected to the communication interface 110 and includes the photodetector 140 because it is integrated with the transceiver module 120.

The transmitter circuit 520 includes one or more circuit elements that process signals from the communication interface 110 to the illumination element 130. Some non-limiting examples of such circuit elements are described herein. The transmitter circuit 520 includes a bias and amplitude adjustment circuit element 522 which determines the bias and modulation amplitude applied to the illumination element 130. The transmitter circuit 520 includes a buffer circuit element 524 which is used to achieve impedance matching between the communication interface 110 and the illumination element 130. The transmitter circuit 520 includes an output circuit element 526 which generates the uplink driving signals 134 which are transmitted to the illumination element 130. The output circuit element 526 may be part of the buffer circuit element 524. The transmitter circuit 520 may include an operational amplifier circuit element and/or a voltage regulator circuit element as mentioned above for the transmitter circuit 420.

The receiver circuit 540 includes one or more circuit elements that process signals from the photodetector 140 to the communication interface 110. Some non-limiting examples of such circuit elements are described herein. The receiver circuit 540 includes a trans-impedance amplifier circuit element 542 and a noise filtering circuit element 543. Notably, the trans-impedance amplifier circuit element 542 and noise filtering circuit element 543 of the receiver circuit 540 replace the single-to-differential conversion circuit element 442 of the receiver circuit 440. The trans-impedance

amplifier circuit element 542 is used to convert the downlink detection signals 146 from the photodetector 140 to differential signals. The noise filtering circuit element 543 is used to reduce or suppress electrical noise in the differential signals. Optionally, the noise filtering circuit element 543 includes an amplifier element which amplifies the differential signals. As the photodetector 140 is integrated with the transceiver module 120, the trans-impedance amplifier circuit element 542 and noise filtering circuit element 543 are integrated with the receiver circuit 540 so they are likewise disposed as close to the photodetector 140 as possible to optimize the signal-to-noise ratio. The receiver circuit 540 includes a limiting amplifier circuit element 544 which amplifies the differential signals to a predefined voltage level. The receiver circuit 540 includes a differential amplifier circuit element 546 which further amplifies the amplified differential signals from the limiting amplifier circuit element 544.

In one embodiment as shown in Figure 1B, the Li-Fi communication device 100 includes a power connector 126 for selectively connecting to a power cable or external power source that supplies power to the Li-Fi communication device 100. The power connector 126 may support a USB power cable as, based on the setup shown in Figure 2A, the power requirement is low at 5 V DC and 0.4 W. In another embodiment, the Li-Fi communication device 100 includes a battery power source, such as one integrated with the transceiver module 120, for powering the Li-Fi communication device 100. Due to the low power requirement, the Li-Fi communication device 100 can be integrated in a low-powered device, such as a USB device or dongle.

In some embodiments, the communication interface 110 includes an Ethernet interface that is additionally configured for a Power-over-Ethernet (PoE) connection. Instead of having a separate power connector 126 or battery power source, the Ethernet interface is configured to communicate data and to supply power to the Li-Fi communication device 100. The Ethernet interface has 8 I/O pins and a 10BASE or 100BASE Ethernet connection uses only 4 of the 8 pins. The remaining 4 pins can be used for PoE to power the Li-Fi communication device 100. In some embodiments, the communication interface 110 is configured for power-line communications (PLC). The PLC communication interface 110 is able to communicate data while simultaneously supplying power to the Li-Fi communication device 100. Thus,

configuring the communication interface 110 for PoE / PLC eliminates the power connector 126 and reduces the overall size and weight of the Li-Fi communication device 100.

- 5 With reference to Figure 6, the transceiver module 120 includes a transceiver circuit 600 having a transmitter circuit 620 and a receiver circuit 640. The transmitter circuit 620 is connected to the communication interface 110 which includes the Ethernet interface configured for PoE. The transmitter circuit 620 may follow the transmitter circuit 420 / 520 as described above. Similarly, the receiver circuit 640 may follow the receiver circuit 440 / 540 as described above. The transceiver module 120 further includes a power line 660 that is connected to the communication interface 110 and supplies power using PoE to the transmitter circuit 620 and receiver circuit 640.

- Figure 7 illustrates a schematic layout 700 of the Li-Fi communication device 100. During uplink, the communication interface 110 transmits uplink data signals 156, which are in the form of digital signals, to a transmitter circuit 720 of the transceiver module 120. The transmitter circuit 720 may follow the transmitter circuit 420 / 520 as described above. The transmitter circuit 720 converts the uplink data signals 156 to uplink driving signals 134. The uplink driving signals 134, which are in the form of analogue signals, are transmitted to the illumination element 130 to control the illumination element 130 to transmit uplink optical signals 132. During downlink, the photodetector 140 detects downlink optical signals 142 and converts them to downlink detection signals 146. The downlink detection signals 146, which are in the form of analogue signals, are transmitted to a receiver circuit 740 of the transceiver module 120. The receiver circuit 740 may follow the receiver circuit 440 / 540 as described above. The receiver circuit 740 converts the downlink detection signals 146 to downlink data signals 154. The downlink data signals 154, which are in the form of digital signals, are transmitted to the communication interface 110.

- 30 In some embodiments, the Li-Fi communication device 100 further includes at least one optical element or an array of optical elements for optical adjustment of the uplink and downlink optical signals. The optical adjustment of the uplink optical signals may include controlling beam divergence of the illumination element 130. The optical

adjustment of the downlink optical signals may include at least one of controlling collection efficiency control of the photodetector, filtering at the photodetector for wavelength division multiplexing, and polarizing at the photodetector for polarization dependence detection. The optical element may include at least one bulk optics
5 element and/or at least one flat optics element. The bulk optics element may include a flat lens, a convex lens, a collimating lens, or a Fresnel lens. The flat optics elements may include a flat lens and may include dielectric and/or metallic materials such as silicon (Si), gallium nitride (GaN), and silver (Ag). The flat optics element may include patterned structures such as pits, cones, or cylinders to improve detection of light.

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As shown in Figure 7, the illumination element 130 may include at least one optical element 710. The optical element 710 is disposed at the front of the illumination element 130 and is arranged to control the outgoing beam shape, beam range, and beam direction / divergence of the illumination element 130. For example, the optical
15 element 710 increases the range and expands the divergence of the outgoing beam from the illumination element 130 carrying the uplink optical signals 132, thus making uplink data communications more efficient.

As shown in Figure 7, the photodetector 140 may include at least one optical element
20 730. The optical element 730 is disposed at the front of the photodetector 140 and is arranged to control the incoming beam shape, beam convergence, collection efficiency, and signal-to-noise ratio of the photodetector 140. For example, the optical element 730 increases the collection efficiency and signal-to-noise ratio of the photodetector 140 receiving the downlink optical signals 142, thus making downlink
25 data communications more efficient. The photodetector 140 and/or optical element 730 may include a plurality or a pattern of structures such as pits, cones, or cylinders to improve light absorption and extraction efficiency by the photodetector 140. For example, the patterned structures may include V-shaped pits. The optical element 730 may act as a filter for wavelength division multiplexing. The optical element 730 may
30 act as a polarizer for polarization dependence detection.

In some embodiments, the communication interface 110 includes an Ethernet interface having a communication circuit. The communication circuit may be

configured for TCP/IP communication protocols, allowing the Li-Fi communication device 100 to be used with electronic devices 150 that rely on TCP/IP protocols for data communications. The communication circuit may additionally be configured to support on-off keying modulation and bidirectional communications.

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As shown in Figure 7, the communication interface 110 may be communicatively connected 114 to an adaptor module 750 so the Li-Fi communication device 100 can be used with other communication protocols. The adaptor module 750 may be configured for Wi-Fi, Bluetooth, HDMI, and/or USB, and which may be converted to an Ethernet interface for the communication interface 110. For example, if a Wi-Fi
10 adaptor module 750 is connected 114 to the communication interface 110, the Li-Fi communication device 100 can communicate data with the electronic device 150 by exchange of optical signals 132 / 142 as described above, but without having to physically connect the Li-Fi communication device 100 to the electronic device 150.

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The Li-Fi communication device 100 as described in various embodiments herein uses light or illumination for wireless and bidirectional data communications. The Li-Fi communication device 100 can be connected to an existing communication network 310, such as a home Ethernet LAN. These communication networks 310 are widely
20 available in buildings, offices, and homes, and Li-Fi communication devices 100 can be easily connected to these communication networks 310 without significantly changing the telecommunications infrastructure of the place or facility. This is an economical way of implementing Li-Fi data communications in homes and offices and the Li-Fi communication devices 100 are able to interface with the Ethernet data
25 signals of existing home Ethernet LANs with optical signals and using existing TCP/IP protocols. Additionally, the Li-Fi communication device 100 can have an array of illumination elements 130 and photodetectors 140 to support wider coverage and long-distance data communications.

30 The transceiver module 120 of the Li-Fi communication device 100 is configured with suitable circuitry as described above such that the Li-Fi data communications can be achieved without the use of microcontrollers or field-programmable gate arrays (FPGAs). As the Li-Fi communication device 100 does not require expensive

components such as microcontrollers and FGPAs, the cost of the Li-Fi communication device 100 and for implementing the Li-Fi communication system 300 can be significantly reduced.

- 5 In the foregoing detailed description, embodiments of the present disclosure in relation to a Li-Fi communication device 100 are described with reference to the provided figures. The description of the various embodiments herein is not intended to call out or be limited only to specific or particular representations of the present disclosure, but merely to illustrate non-limiting examples of the present disclosure. The present
- 10 disclosure serves to address at least one of the mentioned problems and issues associated with the prior art. Although only some embodiments of the present disclosure are disclosed herein, it will be apparent to a person having ordinary skill in the art in view of this disclosure that a variety of changes and/or modifications can be made to the disclosed embodiments without departing from the scope of the present
- 15 disclosure. Therefore, the scope of the disclosure as well as the scope of the following claims is not limited to embodiments described herein.