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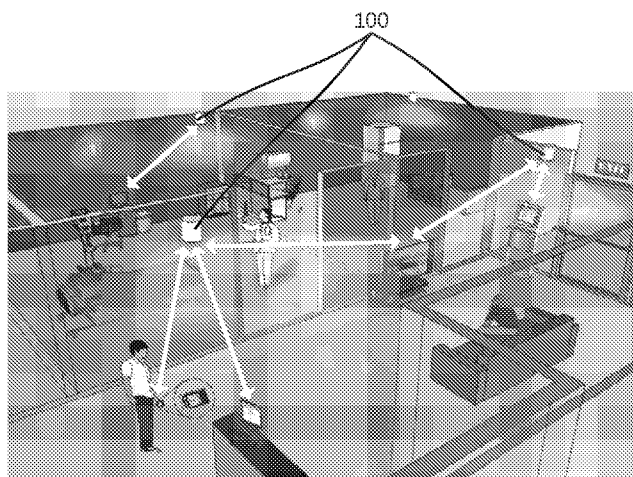


FIG. 1

(57) Abstract: This disclosure relates to mobile devices and imager sensors for visible light communication. A mobile device may include an LED configured as a VLC transmitter and one or more processors configured to encode a VLC signal. The LED may be operated to emit visible light in accordance with the VLC signal. A mobile device may include an imager sensor comprising a plurality of pixels and one or more processors. One or more pixels of the plurality of pixels may be configured as photodetector(s) to receive visible light encoded with a VLC signal. The processor(s) of the mobile device may be configured to decode the VLC signal.



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VISIBLE LIGHT COMMUNICATION FOR MOBILE DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This disclosure claims the benefit of the filing dates of United States Provisional Patent Application No. 62/401,818, filed on September 29, 2016, United States Provisional Patent
10 Application No. 62/401,837, filed on September 29, 2016, United States Provisional Patent Application No. 62/401,811, filed on September 29, 2016, United States Provisional Patent Application No. 62/417,127, filed on November 3, 2016, the entire contents of all of which are hereby expressly incorporated by reference.

TECHNICAL FIELD

15 [0002] This disclosure relates generally to visible light communication, and more specifically to visible light communication for mobile devices.

BACKGROUND

[0003] Visible light communication provide an alternative communication method to radio frequency(RF) based wireless technologies. Extending the use of visible light communication to
20 mobile devices is desirable.

SUMMARY

[0004] This disclosure relates to mobile devices and imager sensors for visible light communication (VLC). In one aspect of the disclosure, a mobile device may include an LED configured as a VLC transmitter, one or more processors coupled to the LED, and/or other components. The processor(s)
25 may be configured to encode a VLC signal. The processor(s) may be configured to operate the LED to emit visible light in accordance with the VLC signal and/or other information.

[0005] In some implementations, the mobile device may further comprise a serializer for serializing the VLC signal. In some implementations, the VLC signal may be encoded by a VLC encoder. The VLC encoder may comprise a Manchester encoder.

30 [0006] In some implementations, the VLC encoder may be implemented by a VLC encoding circuitry configured to encode the VLC signal. The VLC encoding circuitry may comprise an integrated circuit

5 (IC). The VLC encoding circuitry and the LED may be integrated into a System-on-a-Chip (SoC) system. The VLC encoding circuitry and the LED may be integrated into a System-in-a-Package (SiP) system.

[0007] In some implementations, the VLC encoder may be implemented by the processor(s) executing computer-executable instructions stored in computer-readable medium to encode the VLC
10 signal.

[0008] In some implementations, the mobile device may further comprise an overshoot/undershoot circuit coupled to the LED. The overshoot/undershoot circuit may be featured in a pre-equalizer. The overshoot/undershoot circuit may be configured to accelerate charge and discharging of the LED, hence to enhance its modulation bandwidth.

15 [0009] In some implementations, the mobile device may further comprise an imager coupled to the processor(s). The imager may be configured as a digital camera to capture an image. The imager may be further configured as a photodetector (PD) to receive visible light encoded with a second VLC signal.

[0010] In some implementations, the mobile device may further comprise a photodetector coupled to
20 the processor(s). The photodetector may be configured to receive visible light encoded with a second VLC signal. The mobile device may further comprise a micro-lens integrated on top of the photodetector.

[0011] In one aspect of the disclosure, a mobile device may include an imager sensor, one or more processors coupled to the imager sensor, and/or other components. The imager sensor may
25 comprise a plurality of pixels. A first pixel of the plurality of pixels may be configured as a first photodetector to receive visible light encoded with a VLC signal. The first pixel may generate an electrical signal based on reception of the visible light encoded with the VLC signal. The processor(s) may be configured to decode the VLC signal.

[0012] In some implementations, the mobile device may further comprise a preamplifier coupled to
30 the first pixel. The preamplifier may be configured to amplify the electrical signal generated by the first pixel.

[0013] In some implementations, a second pixel of the plurality of pixels may be configured as a second photodetector to receive the visible light encoded with the VLC signal. The second pixel may

5 be located at a different location from the first pixel. The mobile device may further comprise a programming circuit coupled to the plurality of pixels. The programming circuit may be configured to select the first photodetector or the second photodetector to receive the visible light encoded with the VLC signal. The programming functions may be realized via row and column metal interconnects to select a given photodetector.

10 [0014] In some implementations, the mobile device may further comprise an angle-diversity receiver. The angle-diversity receiver may be configured to focus the visible light onto the first pixel.

[0015] In some implementations, the VLC signal may be decoded by a VLC decoder. The VLC decoder may comprise an active feedback based ambient light cancellation circuit comprising a low pass filter, an error amplifier, and an NMOSFET.

15 [0016] In some implementations, the mobile device may further comprise an LED coupled to the processor(s). The LED may be configured as a VLC transmitter. The processor(s) may be configured to encode a second VLC signal and operate the LED to emit visible light in accordance with the second VLC signal. The second VLC signal may be encoded by a VLC encoder. In some implementations, the VLC encoder and the LED may be integrated into a SoC system or a SiP
20 system.

[0017] In one aspect of the disclosure, an imager sensor may comprise a plurality of pixels including a first pixel, a VLC decoder coupled to at least the first pixel, and/or other components. A first pixel of the plurality of pixels may be configured as a first photodetector to receive visible light encoded with a VLC signal. The first pixel may generate an electrical signal based on reception of the visible light
25 encoded with the VLC signal. The VLC decoder may be configured to decode the VLC signal.

[0018] In some implementations, the imager sensor may further comprise a preamplifier coupled to the first pixel. The preamplifier may be configured to amplify the electrical signal generated by the first pixel.

[0019] In some implementations, a second pixel of the plurality of pixels may be configured as a
30 second photodetector to receive the visible light encoded with the VLC signal. The second pixel may be located at a different location from the first pixel. The imager sensor may further comprise a programming circuit coupled to the plurality of pixels. The programming circuit may be configured to select the first photodetector or the second photodetector to receive the visible light encoded with the

5 VLC signal. The programming functions may be realized via row and column metal interconnects to select a given photodetector.

[0020] In some implementations, the imager sensor may further comprise an angle-diversity receiver. The angle-diversity receiver may be configured to focus the visible light onto the first pixel.

[0021] In some implementations, the VLC decoder may comprise an active feedback based ambient
10 light cancellation circuit comprising a low pass filter, an error amplifier, and an NMOSFET.

[0022] In some implementations, the imager sensor may further comprise an LED coupled to a VLC encoder. The LED may be configured as a VLC transmitter. The VLC encoder may be configured to encode a second VLC signal. The LED may emit visible light in accordance with the second VLC signal. In some implementations, the VLC encoder and the LED may be integrated into a SoC system
15 or a SiP system.

[0023] These and other objects, features, and characteristics of the system and/or method disclosed herein, as well as the methods of operation and functions of the related elements of structure and the combination of parts and economies of manufacture, will become more apparent upon consideration of the following description and the appended claims with reference to the accompanying drawings, all
20 of which form a part of this specification, wherein like reference numerals designate corresponding parts in the various figures. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the invention.

BRIEF DESCRIPTION OF DRAWINGS

25 [0024] FIGS. 1-2 illustrate example VLC/VLP scenarios in accordance with some implementations of the disclosure.

[0025] FIGS. 3A-3E illustrate example VLC system architectures in accordance with some implementations of the disclosure.

[0026] FIGS. 4A-4B illustrate example mobile VLC systems.

30 [0027] FIG. 4C illustrates an example visible/non-visible hybrid VLC system.

[0028] FIG. 5 illustrates an example SoC or SiP VLC functional diagram.

5 [0029] FIG. 6 illustrates imager containing PD devices as light receivers in accordance with some implementations of the disclosure.

[0030] FIGS. 7A-7B illustrate example LED modulation mechanisms in accordance with some implementations of the disclosure.

[0031] FIG. 8 illustrates an example block diagram for a transceiver SoC in accordance with some
10 implementations of the disclosure.

[0032] FIG. 9 illustrates an example Manchester encoder circuit in accordance with some implementations of the disclosure.

[0033] FIG. 10 illustrates an example Manchester decoder circuit in accordance with some implementations of the disclosure.

15 [0034] FIG. 11 illustrates example signal waveforms for Manchester encoders and/or decoders in accordance with some implementations of the disclosure.

[0035] FIGS. 12A-12B illustrate example schematics for LED driver circuit in accordance with some implementations of the disclosure.

[0036] FIG. 13 illustrates an example pre-equalizer waveform featuring an overshoot and an
20 undershoot in accordance with some implementations of the disclosure.

[0037] FIG. 14 illustrates an example schematic for a Feed-Forward Equalizer circuit in accordance with some implementations of the disclosure.

[0038] FIGS. 15A-15C illustrate example configurations for optical receiver in accordance with some implementations of the disclosure.

25 [0039] FIG. 15D illustrates an example VLC receiver with a micro-lens integrated directly on top of the PD in accordance with some implementations of the disclosure.

[0040] FIG. 16 illustrates an example active feedback trans-impedance amplifier (TIA) ambient light cancellation circuitry in accordance with some implementations of the disclosure.

[0041] FIG. 17 illustrates example amplification block in accordance with some implementations of
30 the disclosure.

5 [0042] FIGS. 18A-18C illustrate example amplifier circuit topologies for a pre-amplifier in accordance with some implementations of the disclosure.

DETAILED DESCRIPTION

[0043] Energy-efficient solid-state white LED illuminating devices are making inroads in the lighting market, and their ability to switch ON/OFF at high speed (e.g., tens of MHz) without flickering enables
10 wireless visible light communication at very high data rates. VLC communications have many unique advantages over traditional RF-based wireless technologies: First, the unlicensed and unrestricted optical spectrum offers a bandwidth up to 300THz, orders of magnitude wider than the RF spectrum. This makes wireless streaming at multiple giga-bits per second (Gbps) possible. Second, visible light is largely radiation harmless. This allows more emission power to boost data rates without risking
15 human health. Third, VLC does not penetrate through walls and provides security by localizing the area within which data transmitted via VLC may be received/sent. Fourth, VLC can co-exist with and complement existing RF technology. Fifth, VLC devices may be built with lower costs than multi-GHz RF devices.

[0044] A VLC system consists of modulated LEDs (e.g., lamps) for broadcasting and user terminals
20 (e.g., smartphones with built-in LED and PD) as optical receivers to realize full-duplex optical wireless streaming. Essentially, the VLC may be built upon existing LED lighting infrastructure, enabling many new applications. For example, a person may turn on a “light” at home and receive VLC-based wireless streaming of data. A VLC system may be used for visible light positioning (VLP), where positions of persons/objects are determined based on communications via the VLC system.

25 [0045] Wireless transfer of big data is a big challenge today. While there are existing technologies, such as Wi-Fi, which can transfer data at a speed of several hundreds of megabits per second (Mbps), it is general too slow and impractical to transfer very large data files in seconds. There is a huge demand for novel wireless technologies that is capable to wireless stream very large data files, such as a full Blue-ray movie of several GB or large image files at the similar volume, in seconds.

30 [0046] LED is a new lighting source. LED devices can be modulated at very high frequency, hence, provide visible light wireless communications. Because of the ultra-broad bandwidth of light, VLC is capable to wireless stream large data at extremely high data rate up to tens of Gbps. This will make it practical to wireless stream a large data file of several GB in seconds.

5 [0047] Fig. 1 illustrates an example VLC scenario in a hospital where RF devices may be prohibited. In this scenario, persons within the hospital (e.g., doctors, nurses, staff, patients, visitors) may send/receive data via VLC devices 100. Persons may send/receive data via VLC devices 100 when they (the devices carried by the persons) are within visible sight of VLC receivers/transmitters (e.g., VLC devices 100). Fig. 2 illustrates one VLC/VLP scenario for smart traffics. In FIG. 2, VLC systems
 10 may be used for car-to-car communication, smart traffic control, car-to-car collision avoidance (e.g., using VLC to determine distance between cars), and signage data broadcasting.

[0048] FIGS. 3A-3E show an example VLC system architecture for both host-to-slave broadcasting (e.g., LED to smartphone) and peer-to-peer full-duplex transceiving (e.g., smartphone to tablet) application modes. In a host-to-slave broadcasting mode, computer 300 uses an LED array 302 to
 15 broadcast data to smartphone 330 or tablet 360 (via a PD Array/Imager 334 or PD Array/Imager 362). In a peer-to-peer full-duplex transceiving mode, smartphone 330 or tablet 360 may communicate with another smartphone 330 or tablet 360 (via LED array 332 and PD array 334/Imager 362). Different types of optical sensors may be used. For example, a single PD, a large PD array and a CMOS/CCD imager may be used to achieve high data rate.

20 [0049] FIG. 3B shows a typical VLC transmitter circuit architecture for broadcasting light signals, which may include LED array 302, an electronic terminal as a signal source 305 (e.g., computer 300, or a part of computer 300), USB 306, TX MAC 307, buffer 308, coding 309, OFDM modulation 310, DAC 311, pre-equalizer 312, 1:N DEMUX 313, LED driver 314, LED biasing 315, and/or other components. FIG. 3C shows a typical VLC receiver circuit architecture for receiving light signals,
 25 which may include a PD array/imager 334, PD biasing 346, pre-amp 347, M:1 MUX 348, filter 349, amp 350, ADC 351, de-coding 352, DeMod 353, post equalizer 354, RX MAC 355, clock 356, an electronic terminal 365 as a display device (e.g., smartphone 330 or tablet 360) or a signal source, and/or other components. FIG. 3D is a typical transceiver circuit architecture, consisting of a transmitter and a receiver, which includes an electronic terminal 365 (e.g., computer 300, smartphone
 30 330 or tablet 360), a PD array/imager 362, LED array 364, USB 366, RX MAC 367, post equalizer 368, DeMod 369, de-coding 370, ADC 371, amp 372, filter 373, pre-amp 374, TX MAC 375, buffer 376, coding 377, OFDM modulation 378, DAC 379, pre-equalizer 380, 1:N DEMUX 381, LED driver 382, CDR 383, clock 384, LED and PD biasing 385, and/or other components. FIG. 3E shows an example circuit block diagram for a VLC transmitter circuit.

5 [0050] Buffers, coding and decoding, OFDM modulation and demodulation provide signal processing functions. Pre-equalizer may provide for wider LED modulation bandwidth. Driver may provide for LED driving current, DC biasing may provide DC biasing for LED, PD and imager, and integrated analog-to-digital convertor (ADC) and digital-to-analog convertor (DAC) provide signal conversion between analog and digital signals, CDR (clock and data recovery) circuit is used to recover the data
10 and clocks from the received signals, and clock circuit provide global clock synchronization. Pre-amplifier, main amplifier and high/low pass filters provide signal amplification and filtering for the signals received. A MUX circuit may be used to handle the received parallel signals. MAC blocks may be used for access control for multi-users. LVDS (low voltage differential signaling) may serve to remove background noises and USB interface may be used by the electronic terminals.

15 [0051] Facilitating the use of visible light communication between mobile devices may enable streaming of large data file for mobile application. Although the disclosure is described with respect with visible light communication, one or more aspects of the disclosure may be applied to non-visible light (e.g., infrared, UV) communication. In some aspects of the disclosure, a system may include components for both visible light communication and non-visible light communication. In some
20 aspects of the disclosure, different spectrum of light (e.g., light corresponding to different colors) may be used.

[0052] FIG. 4A illustrates an example system 400 of mobile devices (e.g., smartphone, tablet, laptop) for visible light communication. System 400 may include mobile devices 410, 420. Mobile device 410
25 may include LED 412, imager 414, and/or other components. Mobile device 420 may include LED 422, imager 424, and/or other components. Mobile devices 410, 420 may communicate using VLC (e.g., optical communication 416, optical communication 426) via the respective imagers 414, 424 and LEDs 412, 422. For example, LED 412 and LED 422 may be configured as VLC transmitters. Imager 414 and imager 424 may be configured as digital cameras to capture one or more images. Imager
30 414 and imager 424 may be configured as photodetectors to receive visible light encoded with VLC signal. In some implementations, imager 414 and/or imager 424 may include/be a photodetector. The photodetector may be configured to receive visible light encoded with a VLC signal. Mobile devices 410, 420 may further comprise a micro-lens integrated on top of imagers 414, 424 (e.g., on top of photodetector(s)).

5 [0053] As shown in FIG. 4A, LEDs 412, 422 and imagers 414, 424 (e.g., imager sensor, PDs) may be integrated into the host devices (mobile devices 410, 420). For example, embedded flashlight LED of a mobile device may be modified to serve as the VLC transmitter and the imager sensors (e.g., CMOS, CCD) of the mobile device may serve as PDs. Custom designs of such LEDs and PDs in a host device may improve VLC performance.

10 [0054] Mobile devices 410, 420 may include one or more processors coupled to LED 412, 422. The processor(s) may be configured to encode one or more VLC signal. The VLC signal(s) may be encoded to carry information to be transmitted from the processor(s)/mobile device 410, 420. For example, the VLC signal(s) may be encoded to carry command information to other devices (e.g., allowing mobile device 410, 420 to control other devices via VLC), file information (e.g., allowing
15 mobile device 410, 420 to send file(s) to other devices via VLC), and/or other information. The processor(s) may include/be coupled to a VLC encoder and the VLC signal(s) may be encoded by the VLC encoder. In some implementations, the VLC encoder may comprise a Manchester encoder and/or other encoders. In some implementations, the VLC encoder may be implemented by the processor(s) executing computer-executable instructions stored in computer-readable medium to
20 encode the VLC signal. For example, the VLC encoder may be part of a program/application installed on mobile device 410, 420 to facilitate VLC. In some implementations, the VLC encoder may be implemented by a VLC encoding circuitry configured to encode the VLC signal. The VLC encoding circuitry may comprise an integrated circuit. In some implementations, the VLC encoding circuitry and the LED may be integrated into a System-on-a-Chip (SoC) system. In some implementations, the
25 VLC encoding circuitry and the LED may be integrated into a System-in-a-Package (SiP) system. The processor(s) may be configured to operate LED 412, 424 to emit visible light in accordance with the VLC signal and/or other information.

[0055] Imager sensors (e.g., imagers 414, 424) may be coupled to the processor(s) of mobile devices 410, 420. An imager sensor may comprise a plurality of pixels. One or more pixels may be
30 configured as photodetectors to receive visible light encoded with a VLC signal. The pixel(s) configured as photodetectors may generate electrical signal(s) based on reception of the visible light encoded with the VLC signal. The processor(s) may be configured to decode the VLC signal. The VLC signals may be decoded based on the electrical signal(s) generated by the pixel(s). In some

5 implementations, an imager sensor may include/be part of/be integrated with other components discussed herein (e.g., preamplifier, angle-diversity receiver, LED, etc.).

[0056] The processor(s) may include/be coupled to a VLC decoder and the VLC signal(s) may be decoded by the VLC decoder. In some implementations, the VLC decoder may be implemented by the processor(s) executing computer-executable instructions stored in computer-readable medium to
10 decode the VLC signal. For example, the VLC decoder may be part of a program/application installed on mobile device 410, 420 to facilitate VLC. In some implementations, the VLC decoder may be implemented by a VLC decoding circuitry configured to decode the VLC signal. The VLC decoding circuitry may comprise an integrated circuit. The pixel(s) configured as photodetectors may be coupled to one or more VLC decoders. In some implementations, the VLC decoding circuitry and the
15 imager sensor may be integrated into a System-on-a-Chip (SoC) system. In some implementations, the VLC decoding circuitry and the imager sensor may be integrated into a System-in-a-Package (SiP) system. In some implementations, the VLC decoder may comprise an active feedback based ambient light cancellation circuit comprising a low pass filter, an error amplifier, and an NMOSFET.

[0057] The pixel(s) configured as photodetectors may be coupled to one or more preamplifiers. The
20 preamplifier(s) may be configured to amplify the electrical signal(s) generated by the pixel(s). In some implementations, at least two pixels (first pixel, second pixel) of the imager sensor may be configured as photodetectors. The two pixels may be located at different positions in the imager sensor. A programming circuit may be coupled to the pixels to enable selection of one or both pixels to receive visible light encoded with VLC signal. The programming functions may be realized via row and
25 column metal interconnects to select a given photodetector/pixel. In some implementations, mobile device 410, 420 may include one or more angle-diversity receivers. The angle-diversity receiver(s) may be configured to focus the visible light onto one or more pixels of the imager sensors.

[0058] Mobile devices 410, 420 may include other circuitry/components to process the VLC signal(s). In some implementations, mobile devices 410, 420 may include a serializer for serializing the VLC
30 signal. In some implementations, mobile devices 410, 420 may include an overshoot/undershoot circuit coupled to LEDs 412, 422. The overshoot/undershoot circuit may be featured in a pre-equalizer. The overshoot/undershoot circuit may be configured to accelerate charge and discharging of LEDs 412, 422 in order to enhance the LED bandwidth.

5 [0059] FIG. 4B illustrates an example system 430 of mobile devices (e.g., smartphone, tablet, laptop) using dangles for visible light communication. System 430 may include mobile devices 432, 434. Mobile device 432 may be coupled to dongle 436 and mobile device 434 may be coupled to dongle 438. Individual dongles 436, 438 may include a light transmitter (LED) and a light receiver (PD). A pair of dongles 436, 438 may form a closed-loop light based communication channel to stream data via VLC. The dongles 436, 438 may be hot-plugged into any host device (e.g., mobile devices, TV, storage bank, etc.) via existing interfaces, such as Ethernet, Thunderbolt, HDMI, DVI, USB, MINI and/or other interfaces. The light transmitter may use a single LED device or a LED array device to boost bandwidth and data rates. The light receiver may use a single PD or a PD array to improve reception performance.

15 [0060] FIG. 4C illustrates an example visible/non-visible hybrid VLC system 450. As shown in FIG. 4C, light sources of different visible and/or non-visible light may be used. This may include light of different colors, infrared (IR), UV light, and/or other light. The corresponding light emitter (e.g., LED) and light sensor (e.g., PD or imager) may be designed to optimize the system performance.

[0061] In some implementations, one or more components to facilitate VLC may be integrated into an integrated circuit. Such integration of components may deliver a SOC system and/or a SiP system. Such integration of components may result in a single-chip SOC system for light based streaming of data. SOC system may improve data rates and reliability while reducing system footprint and costs. FIG. 5 illustrates an example SoC VLC functional diagram. Chip 500 may include pre-amp 506, LED driver 508, signal processor 510, and interface circuit 512. Imager 502 may be coupled to pre-amp 506, and LED 504 may be coupled to LED driver 508. Pre-amp 506 and LED driver 508 may be coupled to signal processor 510. Signal processor 510 may be coupled to interface circuit 512, which allows chip 500 to communicate with other devices (e.g., via USB, Ethernet, and/or other connections). Chip 550 may include pre-amp 556, LED driver 558, signal processor 560, and interface circuit 562. Imager 552 may be coupled to pre-amp 556, and LED 554 may be coupled to LED driver 558. Pre-amp 556 and LED driver 558 may be coupled to signal processor 560. Signal processor 560 may be coupled to interface circuit 562, which allows chip 550 to communicate with other devices (e.g., via USB, Ethernet, and/or other connections). LED 504 may enable chip 500 to transmit VLC data via optical communication 512 (e.g., to imager 552 of chip 550). LED 554 may enable chip 550 to transmit VLC data via optical communication 562 (e.g., to imager

5 502 of chip 500). In some implementations, imager 502 and/or imager 552 may include/be a photodetector.

[0062] For mobile device based VLC system, the imager device (e.g., CMOS, CCD) for a mobile device (e.g., the camera of the mobile device) may be modified to contain one or more PD devices. As shown in Fig. 6, one or more pixels 620 of the imager 610 (built on a substrate 600) may be
10 optimized for PD functions. This allows mobile devices to use VLC without installing additional PDs. The substrate 600 may include integrated circuits for the VLC system. In some implementations, the pixels 620 of the imager 610 may be reconfigurable photodetectors. This may allow the use of different PDs at different locations to adapt to background light noise by field programming.

[0063] An imager may be an active-pixel sensor including an array of pixels. Individual pixel units
15 may comprise a photodiode type photodetector and a support circuitry comprising a reset gate, a selection gate and source-follower readout transistor, made in a silicon substrate. In some implementations, individual pixels may be selected based on identification of a row line and a column line corresponding to the pixels. Individual pixels may include a photodetector to receive light. Thin microlens on top of imager 610 may assist in collecting the light for the PD.

20 [0064] To enable one or more PD devices in imager 610 to serve as VLC PD devices, the support circuitry for an imager may include components to facilitate VLC. For example, the support circuitry may include a pre-amp circuit (e.g., shown in FIGS. 17, 18A-18C). VLC PD devices may be optimized for VLC performance (e.g., a smaller PD size for minimized parasitic capacitance to increase the response time of the PD, or, higher speed; wider dynamic range, i.e., to enable detection
25 of weaker light for high sensitivity, and handle stronger light (flashlight) without saturation by using an automatic gain control circuit, i.e., a varying gain amplifier, Fig. 16, etc.). Ambient light noise cancellation circuit may be added to further improve performance.

[0065] In some implementations, an imager (e.g., CMOS imager sensor array) may be reconfigurable to allow selection of one or more PD pixel units to function as the VLC PD devices as
30 needed. The programmability (or, reconfigurability) may be implemented using row and column selections of the pixels via metal interconnects. A selection circuit may be programmed/designed to select the desired VLC PD pixels in the imager.

5 [0066] For example, a flashlight LED of a mobile device may be configured for dual roles: (1) an LED illuminator (flashlight LED) to emit high-power light (at high light emission efficiency); and (2) a visible light transmitter device (VLC LED) to transmit the modulated visible light signals carrying information. A flashlight LED is typically optimized as a powerful light illuminator with high light emission efficiency and high light output power. Such may result in a larger LED device that has higher parasitic
10 capacitance, resulting in very slow on/off switching speed.

[0067] VLC LED devices may be optimized for VLC with very fast ON/OFF switching speed and wide LED modulation bandwidth to allow high data rate VLC communications. VLC LED optimization goal may be to minimize LED parasitic capacitance and improve LED modulation bandwidth. Instead of using one large LED device, a VLC LED array consisting of many small LED devices may be used. A
15 flashlight LED configured for dual roles may provide a balanced performance between flash light LED and VLC LED.

[0068] In some implementations, a flash light LED array may be configured such that one or more LED devices in the flash light LED array functions as VLC LED devices solely optimized to emit the modulated visible light signals for the VLC transmitter (e.g., embedding VLC LED in flashlight LED).
20 For the integrated flashlight/VLC LED array, a field-programmable LED array may be used. The programmability (or, reconfigurability) of the LED array in flashlight or LED function may be realized using row and column selections via metal interconnects to select particular pixels/devices in the LED array.

[0069] In some implementations, a pair of one flashlight LED device and one VLC LED device may
25 be used to replace the common mobile phone flashlight LED. The flashlight LED device may be configured for better flashlight performance (high lighting efficiency and high light output power) and the VLC LED device may be configured by better VLC LED performance (low capacitance, high ON/OFF switching speed, wide modulation bandwidth, etc.). In the integrated flashlight LED and VLC LED pair/array designs, individual VLC LED unit (i.e., a pixel in an array) may have its own support
30 circuit unit for VLC LED function. This may include LED driver, pre-equalizer circuit to enhance LED modulation bandwidth, etc. (Fig. 13).

[0070] For LED based VLC and VLP system, in theory, an LED may be rapidly switched ON/OFF in a specific pattern encoded by a specific information (LED modulation). LED modulation embeds the

intended information (i.e., the data) into the modulated light beam as visible light signals. In practical LED VLC systems, the LED is biased to emit light, and the emitted light may be modulated by the embedded electronic signals (i.e., information or data). FIGS. 7A-7B illustrate example LED modulation mechanisms. Typically, an LED illuminating device may be biased with a certain current. When the bias current reaches a certain level, the LED is turned on to emit a light. In digital modulation format (FIG. 7A), the driving current may be a current pulse with a specifically defined waveform, where a logic "0" means a "zero" modulation current (i.e., a low data current) and a logic "1" represents a "high" current (i.e., a stronger data current). This 0/1 logic bit train may be formed via modulation by the intended "data" to modulate the visible light signals emitted by an LED device.

[0071] Similarly, analog modulation (FIG. 7B) is controlled by an analog current waveform (signal).

When the current strength of a biasing analog current is changed by the intended analog "data" waveform, it modulates the light beam emitted by the LED to send out the modulated visible light signals.

[0072] Fig. 8 shows an example block diagram for a transceiver of VLC systems. The transceiver may include transmitter and receiver integrated circuits. Manchester coding may be used to avoid the flickering effect, synchronize the data with the clock, and prevent low-frequency signals. A pre-equalization circuit may be used to enlarge the modulation bandwidth of LEDs. In a transmitter channel, a Manchester coding method may be used for LED modulation (i.e., use a specific data information to modulate an LED). This may be accomplished by using a Manchester encoder circuit. An example Manchester encoder circuit is shown in FIG. 9. In a receiver channel, a reverse function may be performed to demodulate the received visible light signals to recover the specific Clock and Data signals embedded in the modulated light from an LED. A Manchester decoding method may be used for clock and data recovery (CDR) to extract the "information" carried on the light. This may be accomplished by using a Manchester decoder circuit. An example Manchester decoder circuit is shown in FIG. 10.

[0073] Fig. 11 shows example signal waveforms for Manchester encoder and decoder. The example waveforms include reference clock signals (CLK), data signals (Data)—intended data information to be carried on an emitted LED light, LED signal modulated by Manchester coding (Manc Data), a clock signal recovered by Manchester decoding (CLK_R), and data signals recovered by Manchester decoding (Data_R).

[0074] In some implementations, one or more circuits (e.g., integrated circuit) for processing VLC signals may further comprise a serializer to serialize the VLC signals. In some implementations, the circuit may further comprise a pre-equalizer using an overshoot/undershoot circuit configured to accelerate charging and discharging of the LED to enhance its modulation bandwidth. In some implementations, the circuit may further comprise an active feedback based ambient light cancellation circuit. The active feedback based ambient light cancellation circuit may comprise a low pass filter, an error amplifier, and an NMOSFET. The active feedback based ambient light cancellation circuit may comprise an active feedback transimpedance amplifier (TIA) ambient light cancellation circuit.

[0075] A pre-equalization circuit may be used to enlarge the modulation bandwidth of LEDs. Since the LED modulation bandwidth is determined by the rise/fall time of the driving current, an overshoot/undershoot technique may be used to accelerate the turn-on (charging) and then turn-off (discharging) of an LED for a wider bandwidth. Fig. 13 shows an example equalizer waveform featuring an overshoot at the rising time and an undershoot at the falling time. The overshoot and the undershoot speed up the charging and discharging procedures of an LED and make the LED modulation bandwidth wider.

[0076] FIGS. 12A-12B show example schematics for LED driver circuit. FIG. 12A may include a cherry hooper amplifier. FIG. 12B may include a CML output stage for TAP/MAIN buffers. Other designs for LED driver circuit are contemplated.

[0077] Fig. 14 shows an example schematic for a Feed-Forward Equalizer circuit inside a VLC transmitter integrated circuit. The Tap Buffer and Main Buffer in Fig. 14 may use a common-mode logic (CML) circuit shown in Fig. 12B. The main LED driver amplifier in Fig. 14 may use a circuit schematic shown in Fig. 12A. Fig. 14 may include an integrated driver and equalizer circuit for an LED. In FIG. 14, a trimmable delay line may program the timing of the Tap Buffer. The output waveforms from the Tap Buffer and the Main Buffer may be combined to produce the Equalized Output waveform with overshoot and undershoot features (e.g., shown in Fig. 13) to speed up the electronic carrier charging and discharging of an LED device, resulting in a wider LED modulation bandwidth.

[0078] FIGS. 15A-15C show three example configurations for an optical receiver. FIG. 15A shows an example single-element receiver. A single-element receiver, consisting of a light concentrator, optical filter and PD, receives light from a wide field of view (FOV) without differentiating the desired light

5 signal and ambient light noises. The single-element receiver suffers from multipath distortion due to reflected light from different surfaces.

[0079] FIG. 15B shows an example angle-diversity receiver. An angle-diversity receiver can overcome the problems of the single-element receiver because it utilizes multiple receiving elements with narrower field of view pointing to different directions. This may greatly reduce ambient light,
10 interferences and multipath distortion. Narrower field of view also allows smaller PDs (lower capacitance), and provide for a wider receiver bandwidth and lower thermal noise of the preamplifier. However, the angle-diversity receiver may increase receiver size and costs due to using multiple optical concentrators.

[0080] FIG. 15C shows an imaging angle-diversity receiver. An imaging angle-diversity receiver that
15 utilizes only one optical concentrator can resolve the problems of the angle-diversity receiver. An imaging angle-diversity receiver may be readily implemented in low-cost CMOS.

[0081] At the receiver end, unavoidable ambient light (i.e., noise) may easily saturate the input to a preamplifier of a PD. These ambient background light noises may be at DC or low frequency. A traditional solution to this ambient light problem is to add a passive resistance-capacitance (RC) high-
20 pass filter to block the DC and low-frequency background light noises in a mainly discrete receiver system. However, its drawbacks are clear. For example, the large resistance and capacitance values reduce the frequency bandwidth of the PD channel, and large resistor and capacitor components are not suitable for integrated circuits.

[0082] FIG. 16 shows an example active feedback trans-impedance amplifier (TIA) ambient light
25 cancellation circuitry. An active feedback trans-impedance amplifier (TIA) ambient light cancellation circuitry may be used to remove background light noises. The active feedback based ambient light cancellation circuit includes a low pass filter, an error amplifier and a NMOSFET (M0). The NMOSFET acts as voltage controlled current source. A strong DC ambient noise (e.g., from sunlight, fluorescent or incandescent lights) may be sensed by an error amplifier, which can turn on the NMOSFET to sink
30 the large ambient light current. This may provide ambient light noise cancellation.

[0083] A VLC receiver may include an optical filter, a PD, a pre-amplifier with automatic gain control feature, a Manchester decoder, and/or other components. A VLC receiver may include an integrated micro lens filter on top of a PD to enlarge the PD bandwidth. The narrow bandwidth of a PD may be

5 limited by the slow response of the yellow phosphor used in an LED emitter device (e.g., PD in a receiver). One solution may be to use an optical bandpass filter (discrete) in front of a PD in the receiver channel to receive the blue light only. This enhances the frequency bandwidth of a PD. A micro-lens type optical filter may be integrated directly on top of the PD. The micro-lens type optical filter may function as an optical bandpass filter on top of the PD. The micro-lens type optical filter may be fabricated with IC fabrication method (e.g., using transparent thin film or organic transparent lens), which may be integrated with the PD using standard IC fabrication process. FIG. 15D shows an example VLC receiver with an micro-lens integrated directly on top of a PD. As shown in FIG. 15D, a PD 1510 may be fabricated in/integrated with a Si IC 1500. Micro-lens 1520 may be integrated on top of the PD 1510. The integrated micro-lens filter (e.g., 1520) and small-size PD pixel(s) may provide high performance with low costs.

[0084] FIG. 17 shows an example amplification block after a PD. A pre-amplifier circuit with automatic gain control feature may follow the PD. FIGS. 18A-18C show example types of amplifier circuit topologies for the pre-amplifier. FIG. 18A shows an example high-impedance amplifier. FIG. 18B shows an example low-impedance amplifier. FIG. 18C shows an example trans-impedance amplifier. The automatic gain control function may be realized using a feedback trans-impedance amplifier (TIA) to achieve ambient noise light cancellation as shown in FIG. 16.

[0085] Spatially relative terms such as "under," "below," "lower," "over," "upper," "left," "right," and the like, are used for ease of description to explain the positioning of one element relative to a second element. These terms are intended to encompass different orientations of the device in addition to different orientations than those depicted in the figures. Further, terms such as "first," "second," and the like, are also used to describe various elements, regions, sections, etc. and are also not intended to be limiting. Like terms refer to like elements throughout the description.

[0086] As used herein, the terms "having," "containing," "including," "comprising," and the like are open ended terms that indicate the presence of stated elements or features, but do not preclude additional elements or features. The articles "a," "an" and "the" are intended to include the plural as well as the singular, unless the context clearly indicates otherwise.

[0087] Although this invention has been disclosed in the context of certain implementations and examples, it will be understood by those skilled in the art that the present invention extends beyond

5 the specifically disclosed implementations to other alternative implementations and/or uses of the invention and obvious modifications and equivalents thereof. Thus, it is intended that the scope of the present invention herein disclosed should not be limited by the particular disclosed implementations described above.

[0088] Furthermore, the skilled artisan will recognize the interchangeability of various features from
10 different implementations. In addition to the variations described herein, other known equivalents for each feature can be mixed and matched by one of ordinary skill in this art to construct analogous systems and techniques in accordance with principles of the present invention.

[0089] It is to be understood that not necessarily all objects or advantages may be achieved in accordance with any particular implementation of the invention. Thus, for example, those skilled in the
15 art will recognize that the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

5 What is claimed is:

1. A mobile device for visible light communication, comprising:
an LED configured as a VLC transmitter; and
one or more processors coupled to the LED, the one or more processors configured to:
encode a VLC signal; and
10 operate the LED to emit visible light in accordance with the VLC signal.

2. The mobile device of claim 1, further comprising a serializer for serializing the VLC signal.

3. The mobile device of claim 1, wherein the VLC signal is encoded by a VLC encoder, the VLC encoder
15 comprising a Manchester encoder.

4. The mobile device of claim 3, wherein the VLC encoder is implemented by a VLC encoding circuitry
configured to encode the VLC signal.

- 20 5. The mobile device of claim 4, wherein the VLC encoding circuitry comprises an integrated circuit.

6. The mobile device of claim 4, wherein the VLC encoding circuitry and the LED are integrated into a
System-on-a Chip (SoC) system.

- 25 7. The mobile device of claim 4, wherein the VLC encoding circuitry and the LED are integrated into a
System-in-a-Package (SiP) system.

8. The mobile device of claim 3, wherein the VLC encoder is implemented by the one or more processors
executing computer-executable instructions stored in computer-readable medium to encode the VLC signal.

30

9. The mobile device of claim 1, further comprising an overshoot/undershoot circuit coupled to the LED,
the overshoot/undershoot circuit configured to accelerate charging and discharging of the LED.

5

10. The mobile device of claim 1, further comprising an imager coupled to the one or more processors, the imager configured as a digital camera to capture an image, wherein the imager is further configured as a photodetector to receive visible light encoded with a second VLC signal.

10

11. The mobile device of claim 1, further comprising a photodetector coupled to the one or more processors, the photodetector configured to receive visible light encoded with a second VLC signal.

12. The mobile device of claim 11, further comprising a micro-lens integrated on top of the photodetector.

15

13. A mobile device for visible light communication, comprising:

an imager sensor comprising a plurality of pixels, wherein a first pixel of the plurality of pixels is configured as a first photodetector to receive visible light encoded with a VLC signal, the first pixel generating an electrical signal based on reception of the visible light encoded with the VLC signal; and

one or more processors coupled to the imager sensor, the one or more processors configured to
20 decode the VLC signal.

14. The mobile device of claim 13, further comprising a preamplifier coupled to the first pixel, the preamplifier configured to amplify the electrical signal generated by the first pixel.

25

15. The mobile device of claim 13, where a second pixel of the plurality of pixels is configured as a second photodetector to receive the visible light encoded with the VLC signal, the second pixel located at a different location from the first pixel.

30

16. The mobile device of claim 15, further comprising a programming circuit coupled to the plurality of pixels, the programming circuit configured to select the first photodetector or the second photodetector to receive the visible light encoded with the VLC signal.

5 17. The mobile device of claim 13, further comprising an angel-diversity receiver configured to focus the visible light onto the first pixel.

18. The mobile device of claim 13, wherein VLC signal is decoded by a VLC decoder, the VLC decoder comprising an active feedback based ambient light cancellation circuit comprising a low pass filter, an error
10 amplifier, and an NMOSFET.

19. The mobile device of claim 13, further comprising:
an LED coupled to the one or more processors, the LED configured as a VLC transmitter;
wherein the one or more processors are configured to encode a second VLC signal and operate the
15 LED to emit visible light in accordance with the second VLC signal.

20. The mobile device of claim 19, wherein the second VLC signal is encoded by a VLC encoder, the VLC encoder and the LED integrated into a System-on-a Chip (SoC) system.

20 21. The mobile device of claim 19, wherein the second VLC signal is encoded by a VLC encoder, the VLC encoder and the LED integrated into a System-in-a-Package (SiP) system.

22. An imager sensor, comprising:
a plurality of pixels, wherein a first pixel of the plurality of pixels is configured as a first photodetector to
25 receive visible light encoded with a VLC signal, the first pixel generating an electrical signal based on reception of the visible light encoded with the VLC signal; and
a VLC decoder coupled to at least the first pixel, the VLC decoder configured to decode the VLC signal.

30 23. The imager sensor of claim 22, further comprising a preamplifier coupled to the first pixel, the preamplifier configured to amplify the electrical signal generated by the first pixel.

5 24. The imager sensor of claim 22, where a second pixel of the plurality of pixels is configured as a second photodetector to receive the visible light encoded with the VLC signal, the second pixel located at a different location from the first pixel.

25. The imager sensor of claim 24, further comprising a programming circuit coupled to the plurality of
10 pixels, the programming circuit configured to select the first photodetector or the second photodetector to receive the visible light encoded with the VLC signal.

26. The imager sensor of claim 22, further comprising an angel-diversity receiver configured to focus the visible light onto the first pixel.

15

27. The imager sensor of claim 22, wherein the VLC decoder comprises an active feedback based ambient light cancellation circuit comprising a low pass filter, an error amplifier, and an NMOSFET.

28. The imager sensor of claim 22, further comprising:
20 an LED configured as a VLC transmitter to emit visible light in accordance with a second VLC signal;
and
a VLC encoder coupled to the LED, the VLC encoder configured to encode the second VLC signal.

29. The imager sensor of claim 28, wherein the VLC encoder and the LED are integrated into a System-
25 on-a Chip (SoC) system.

30. The imager sensor of claim 26, wherein the VLC encoder and the LED are integrated into a System-in-a-Package (SiP) system.

30

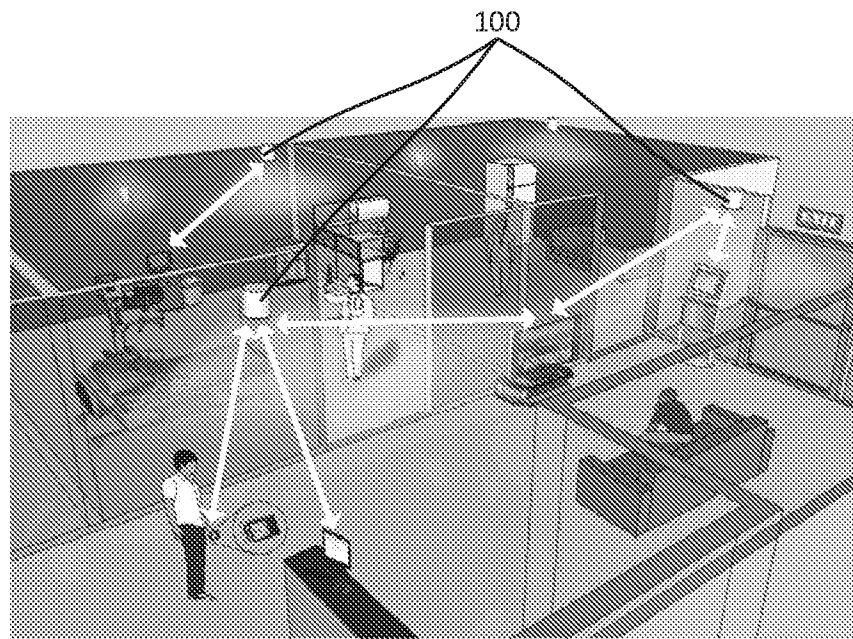


FIG. 1

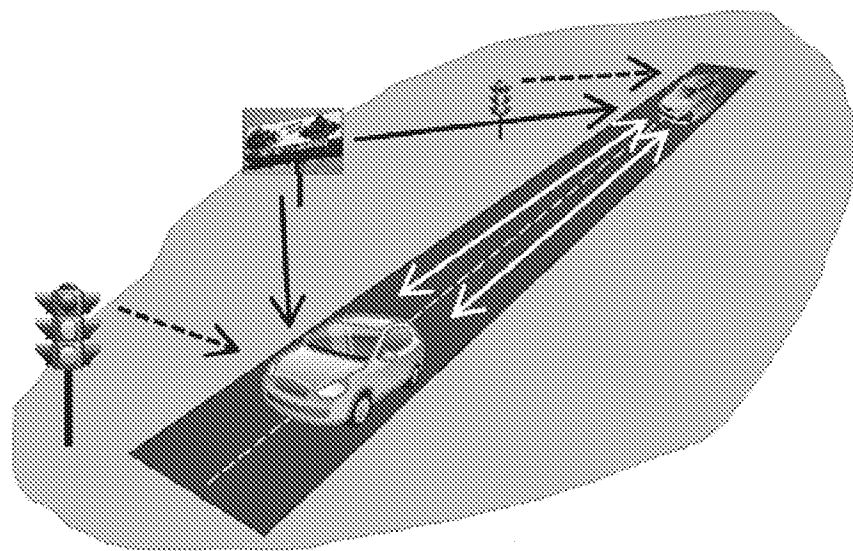
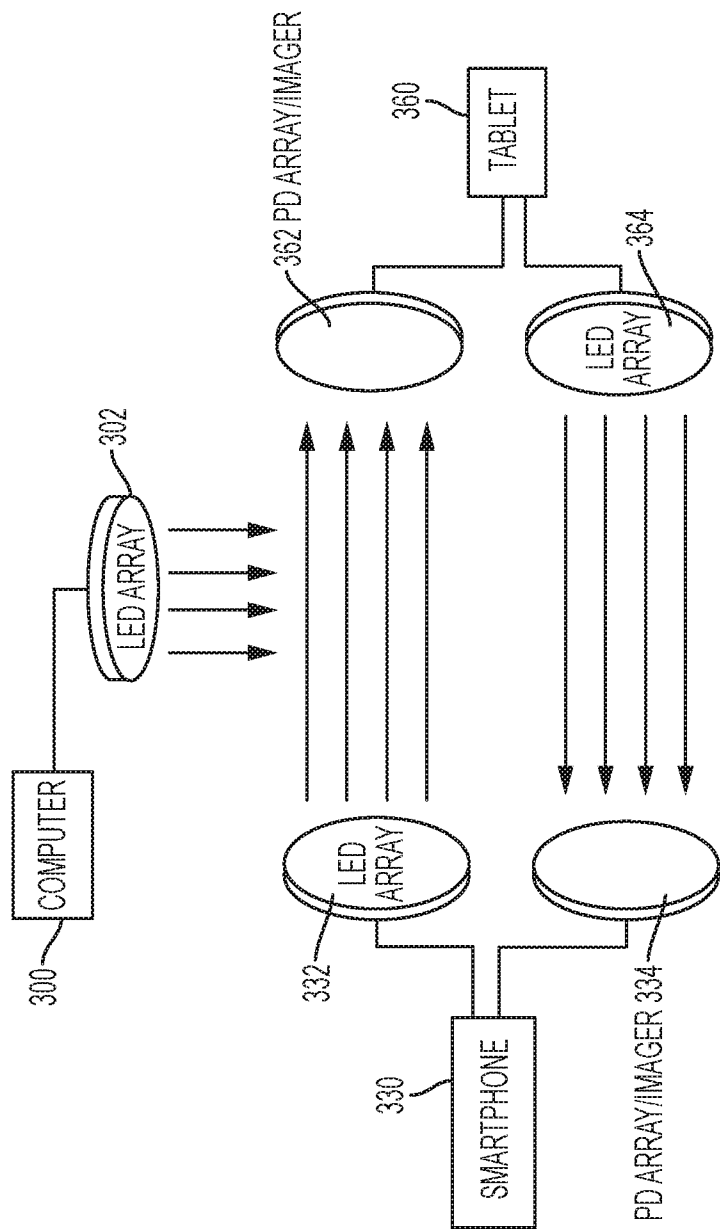
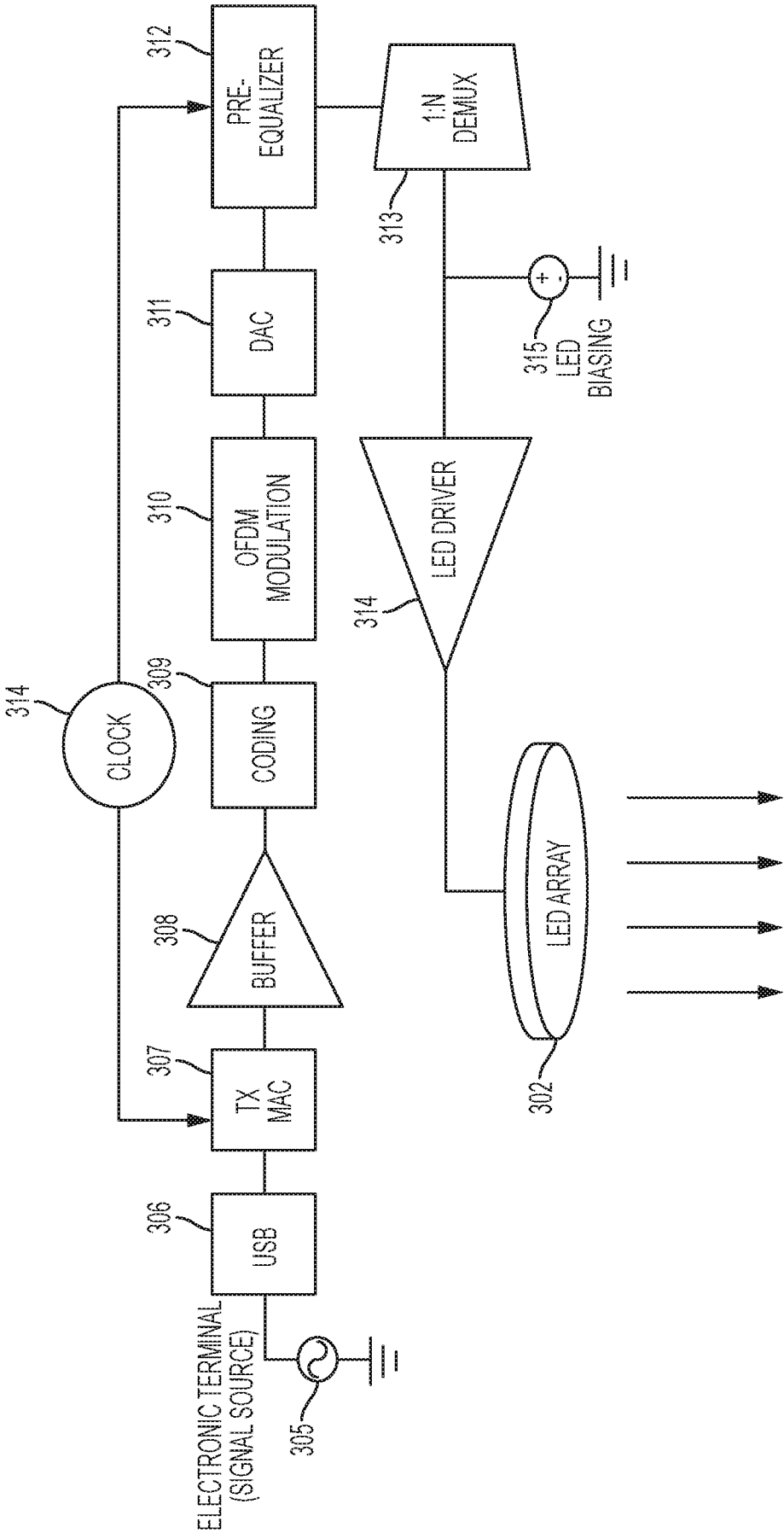


FIG. 2



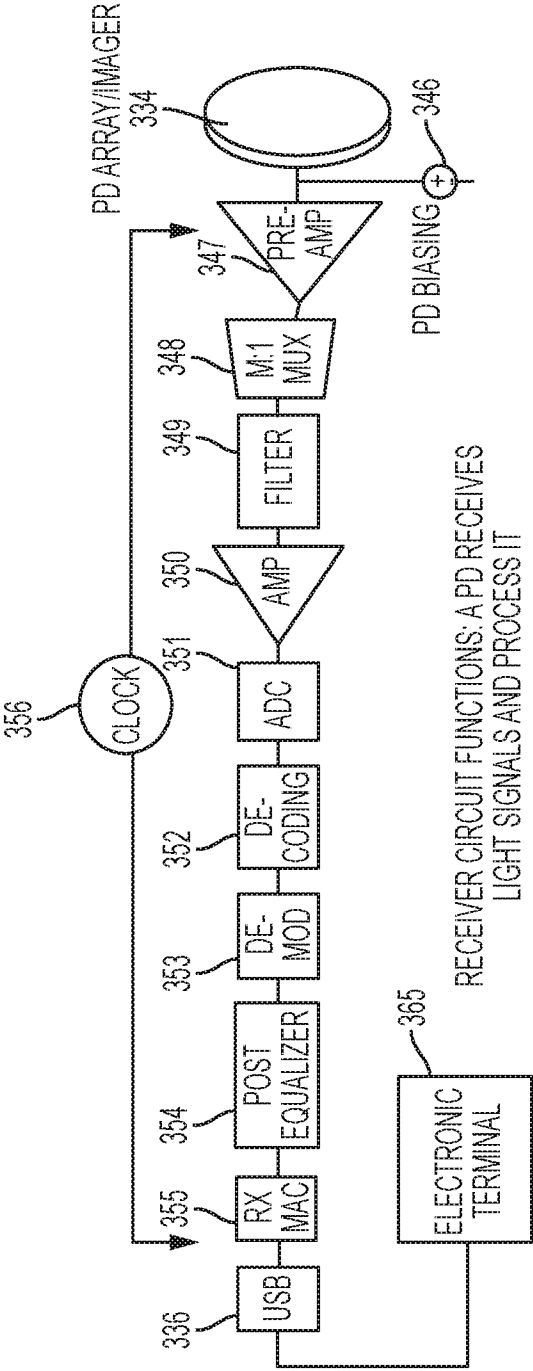
HOST/SLAVE MODE: HOST=300+302; SLAVE = 330 OR 360 (THROUGH 334 OR 362)
PEER-TO-PEER MODE: PEER-1 = 330, PEER-2 = 360

FIG. 3A



TRANSMITTER CIRCUIT FUNCTIONS: LED SENDS OUT LIGHT SIGNALS

FIG. 3B



RECEIVER CIRCUIT FUNCTIONS: A PD RECEIVES LIGHT SIGNALS AND PROCESS IT

FIG. 3C

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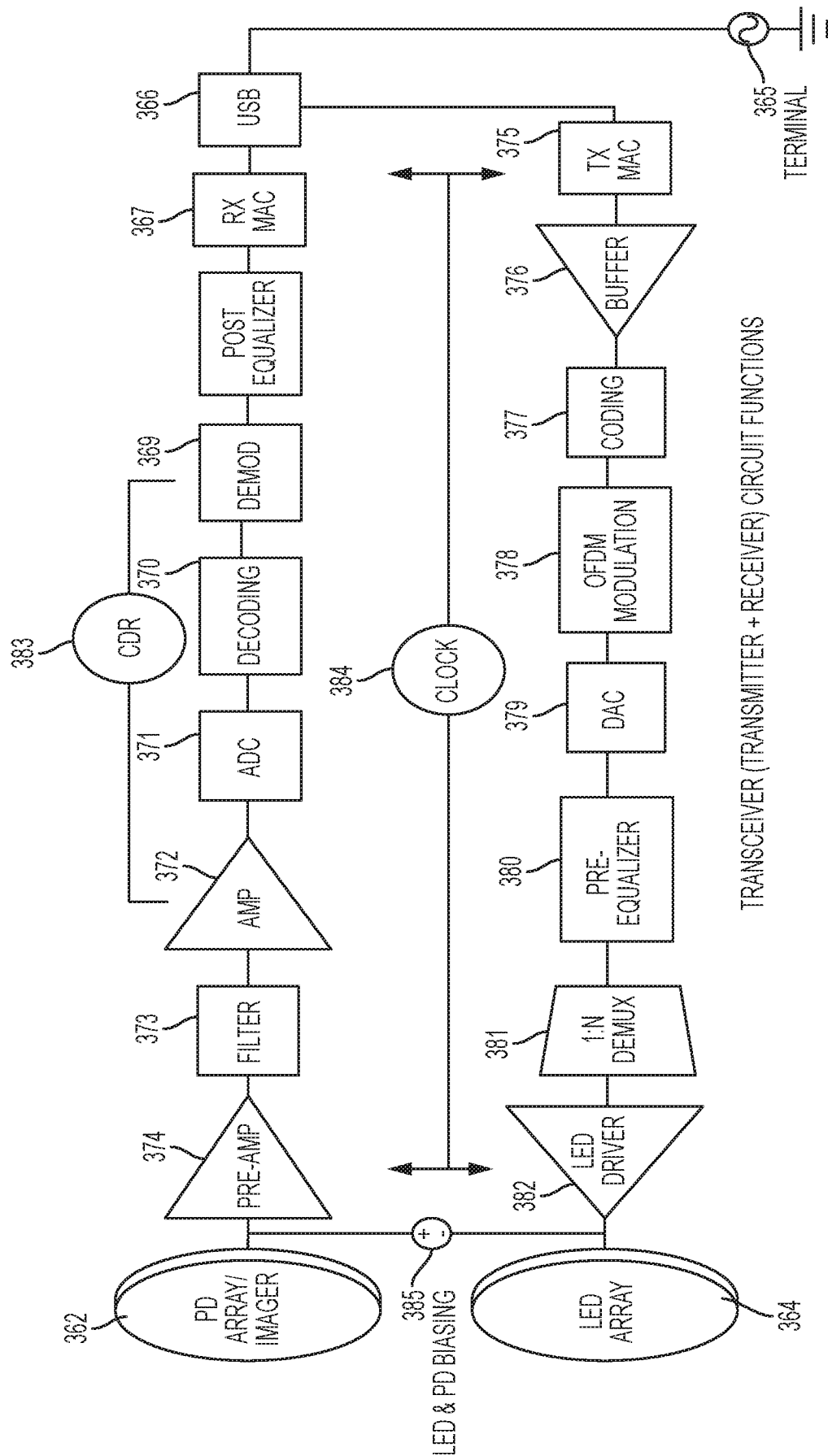


FIG. 3D

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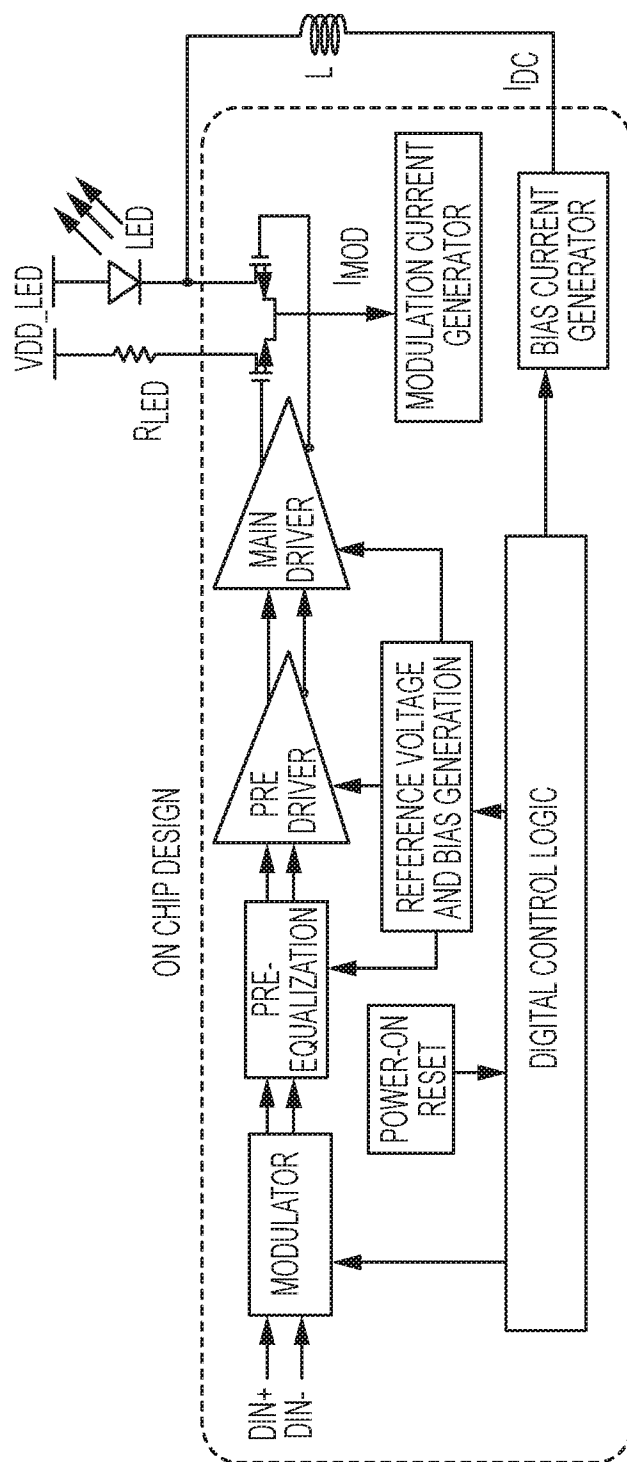


FIG. 3E

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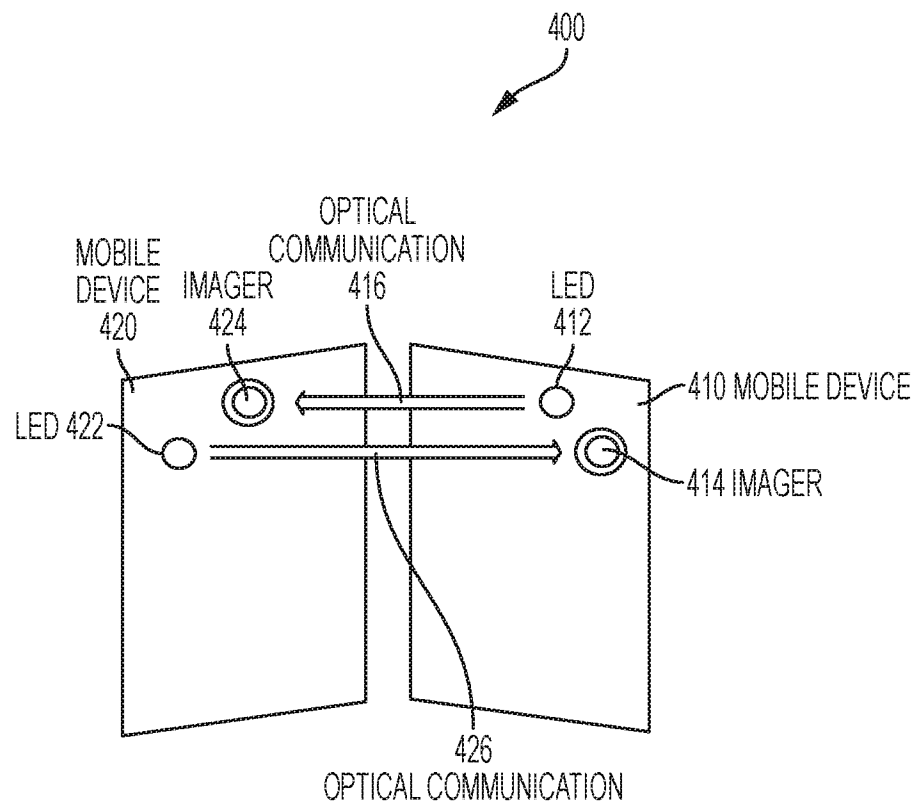


FIG. 4A

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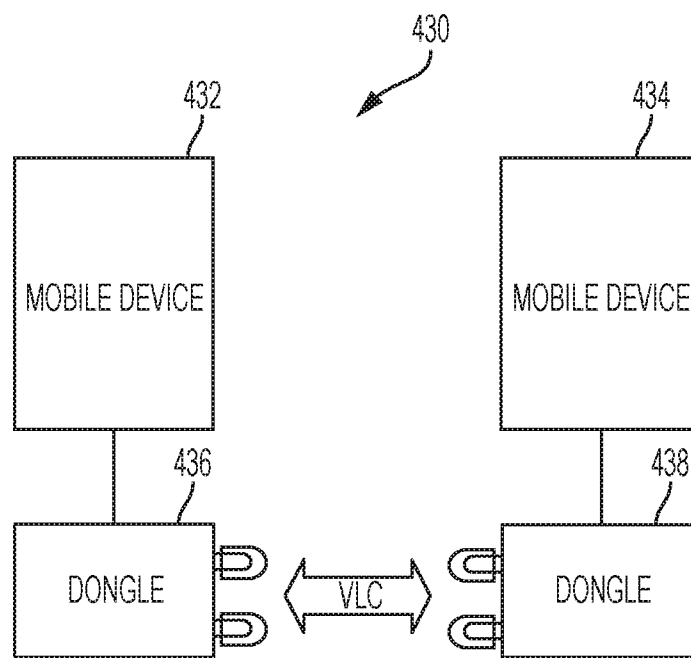


FIG. 4B

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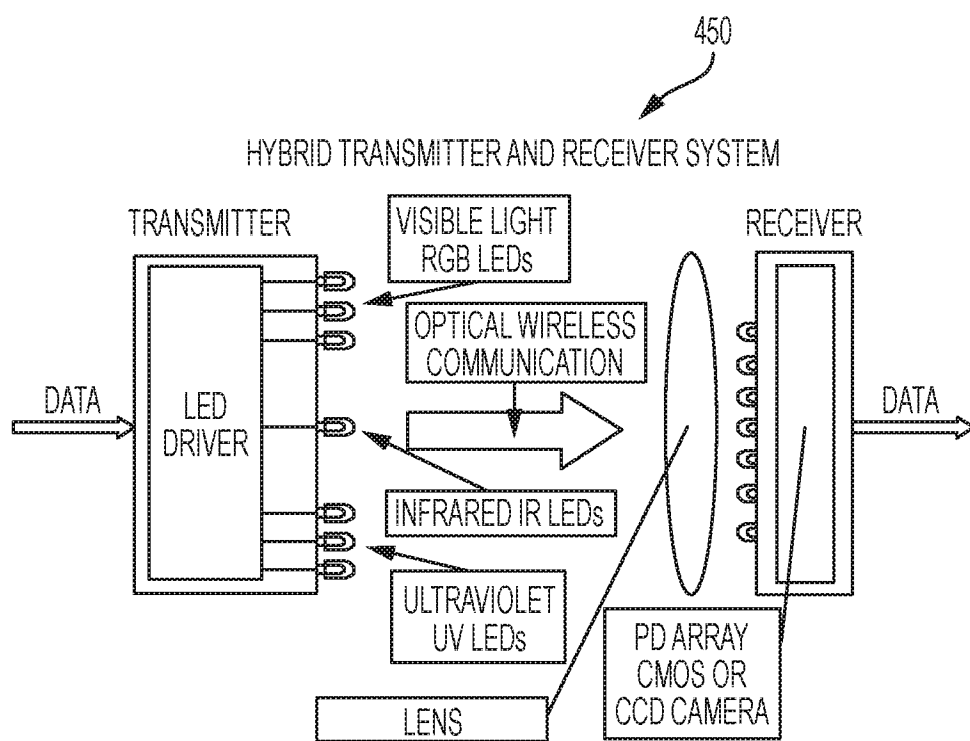


FIG. 4C

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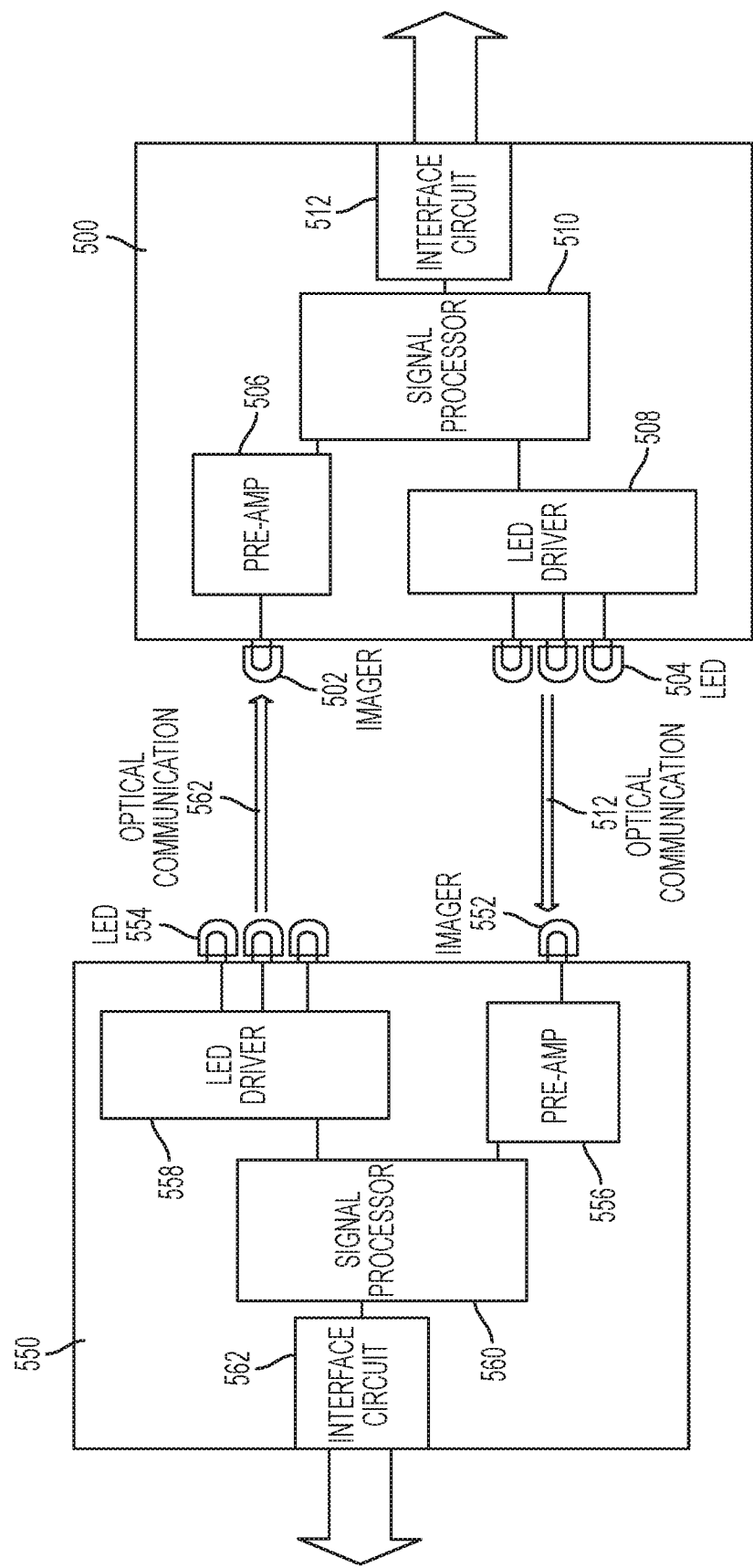


FIG. 5

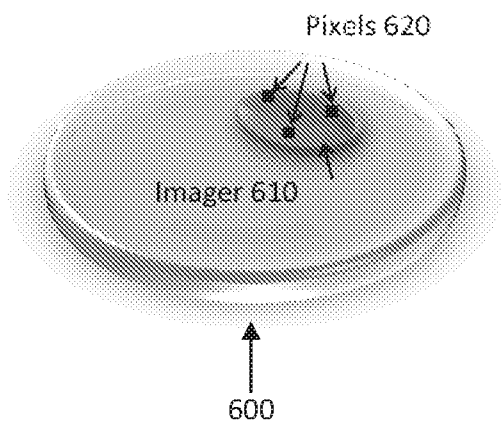


FIG. 6

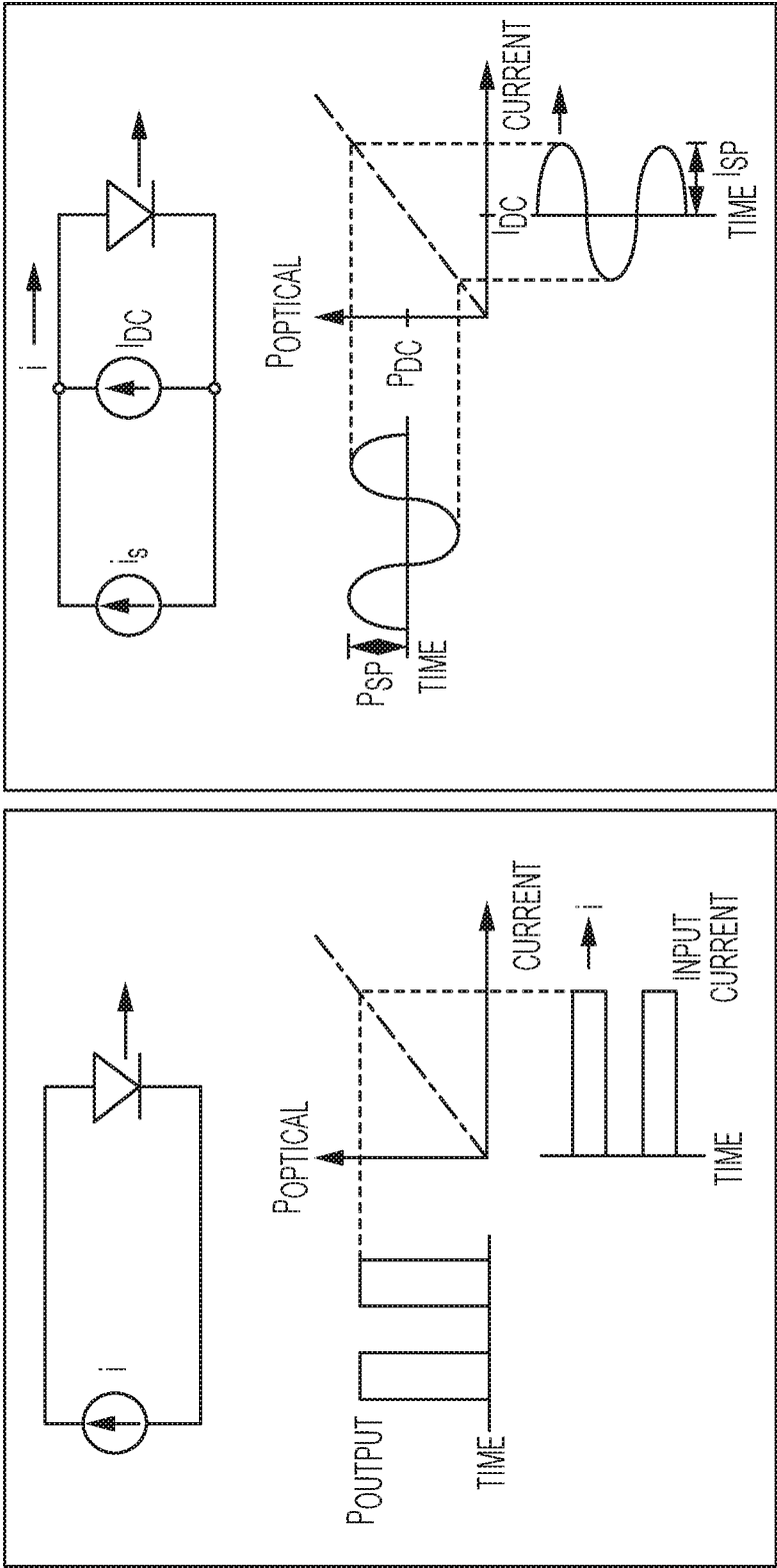


FIG. 7B

FIG. 7A

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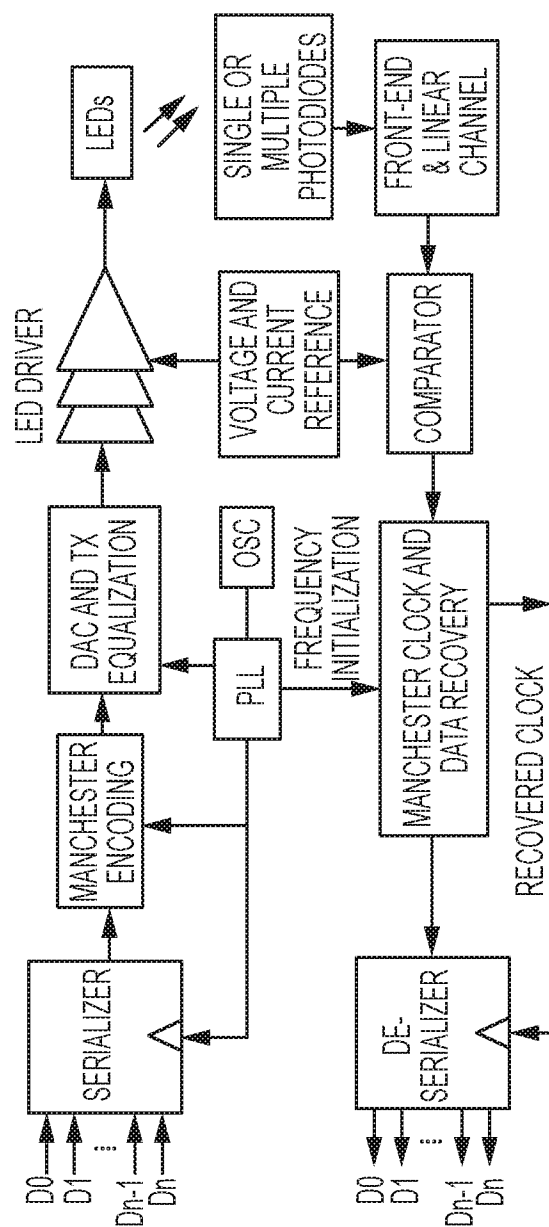


FIG. 8

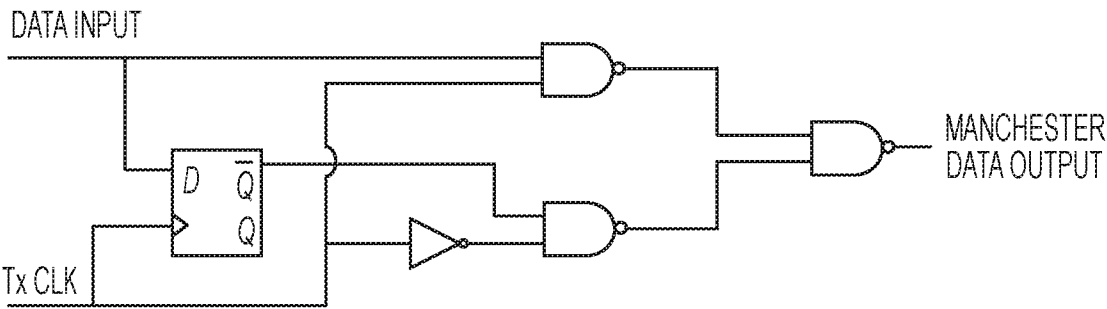
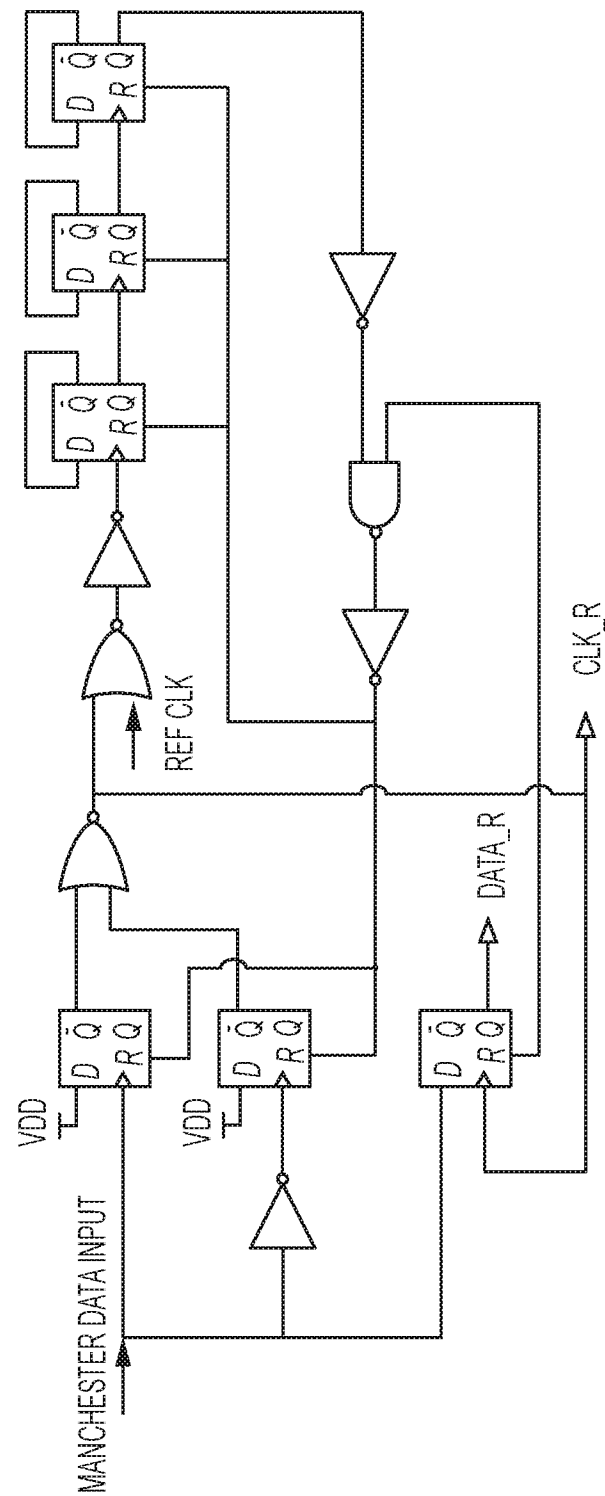


FIG. 9



0
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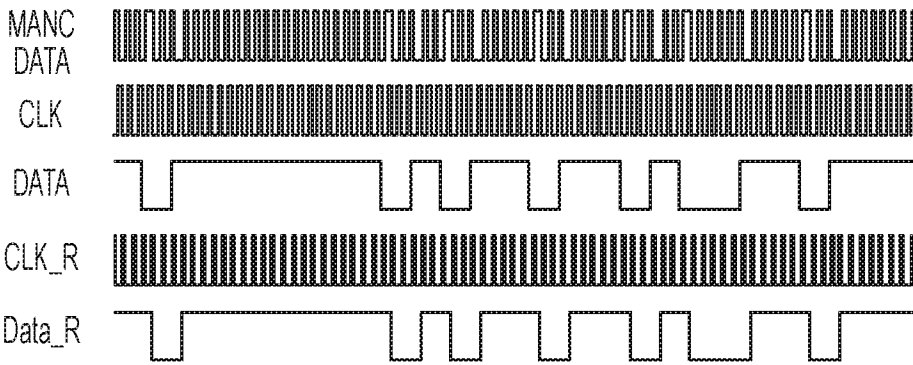


FIG. 11

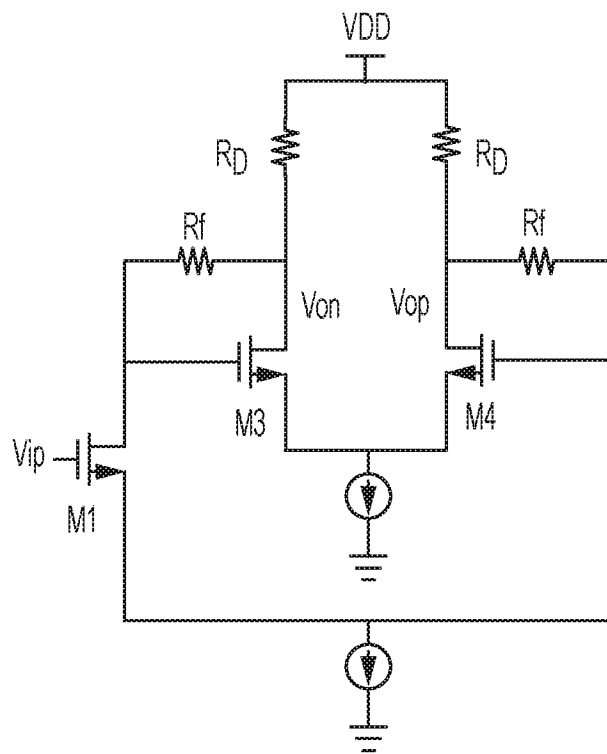


FIG. 12A

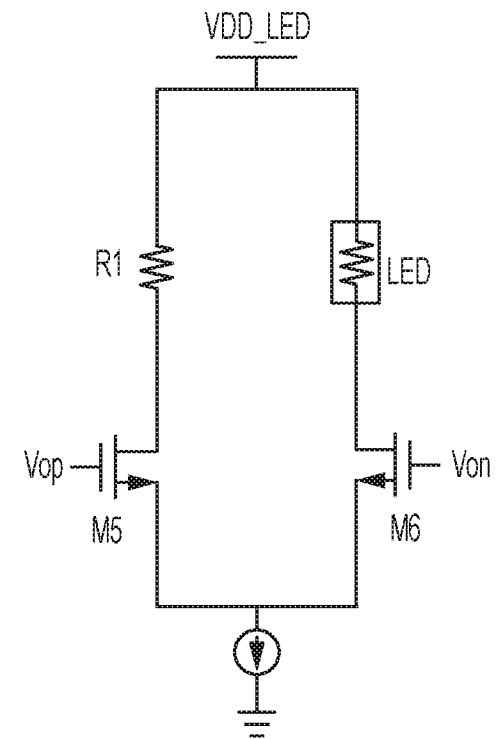


FIG. 12B

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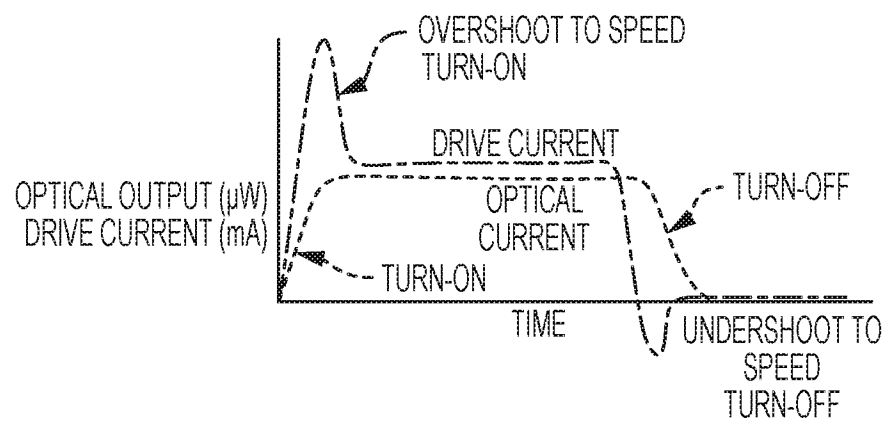


FIG. 13

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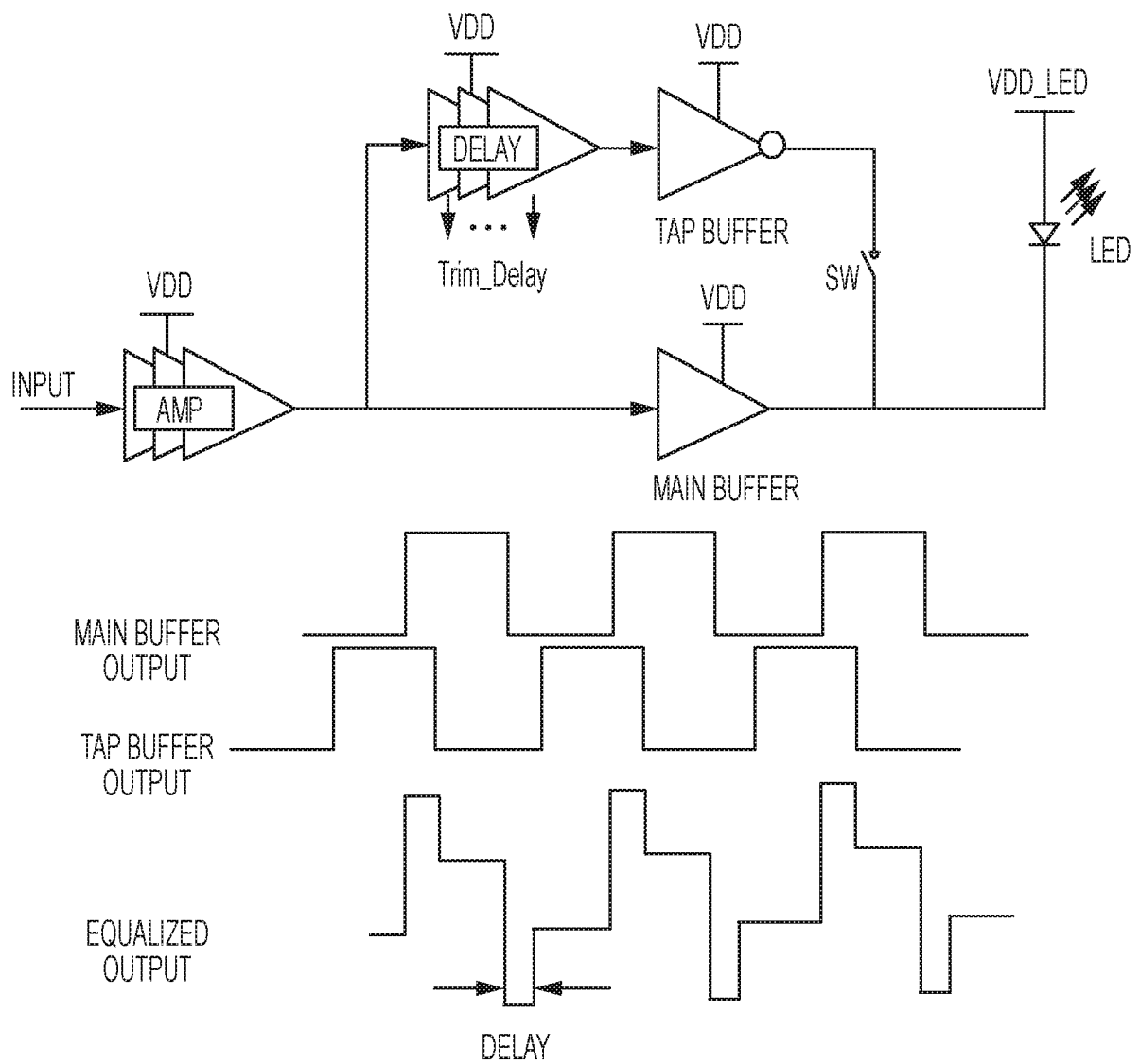
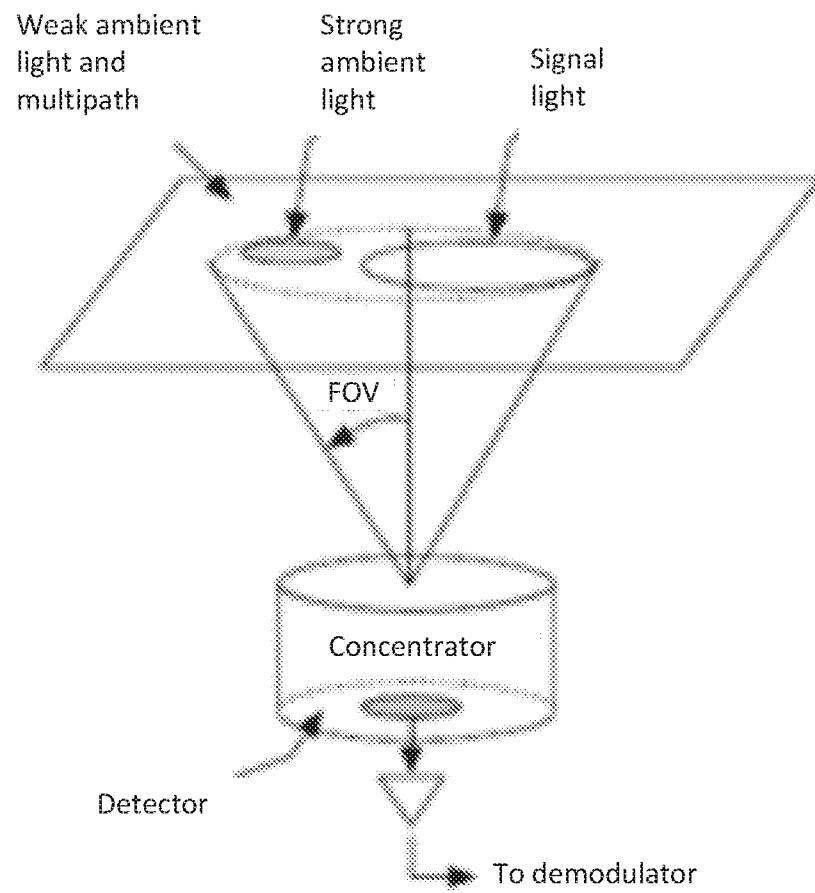


FIG. 14

**FIG. 15A**

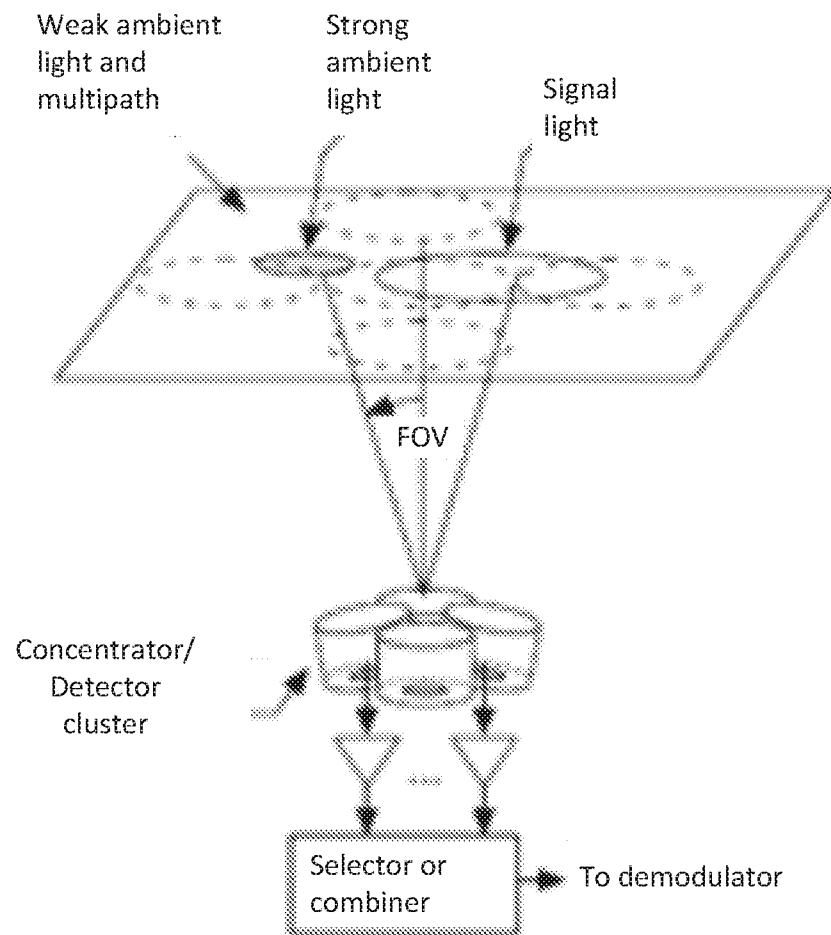
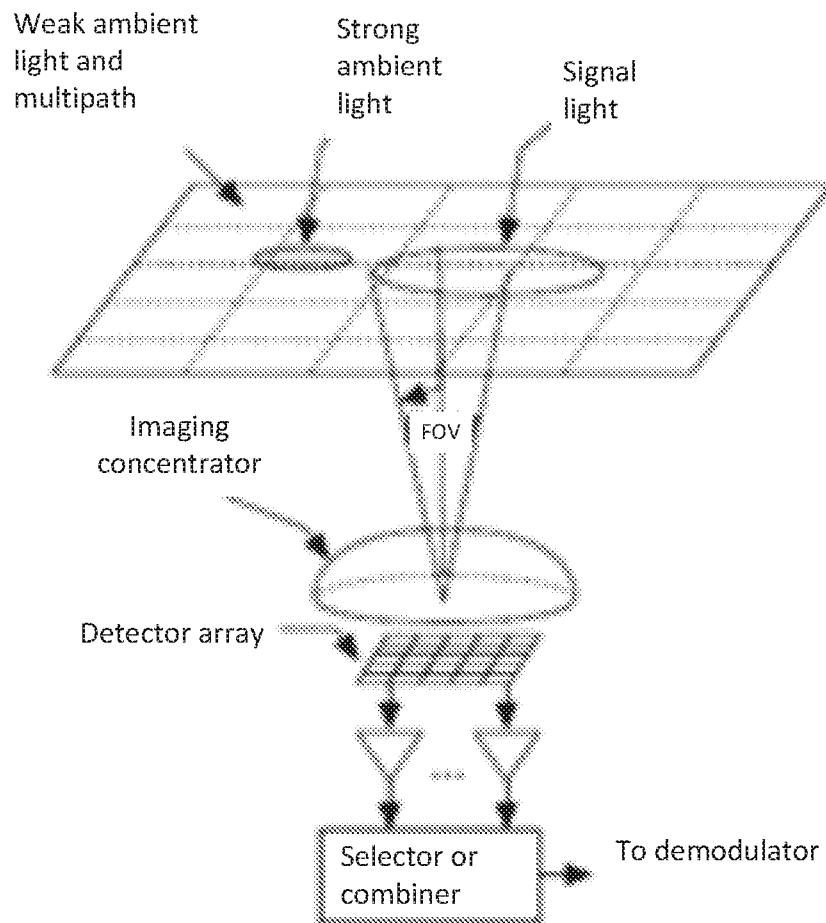


FIG. 15B

**FIG. 15C**

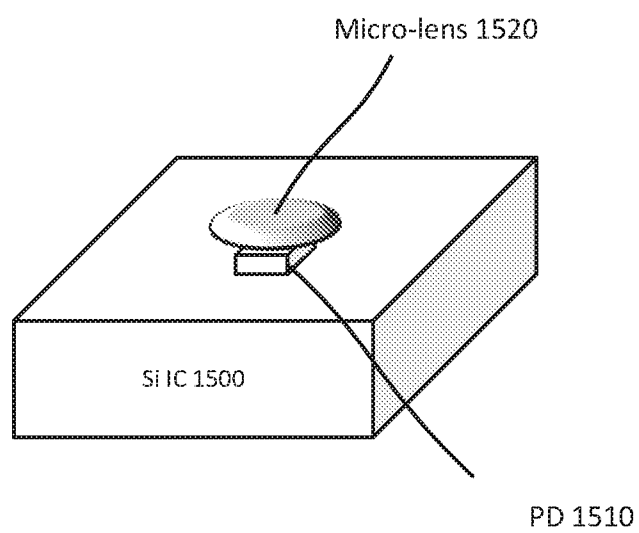


FIG. 15D

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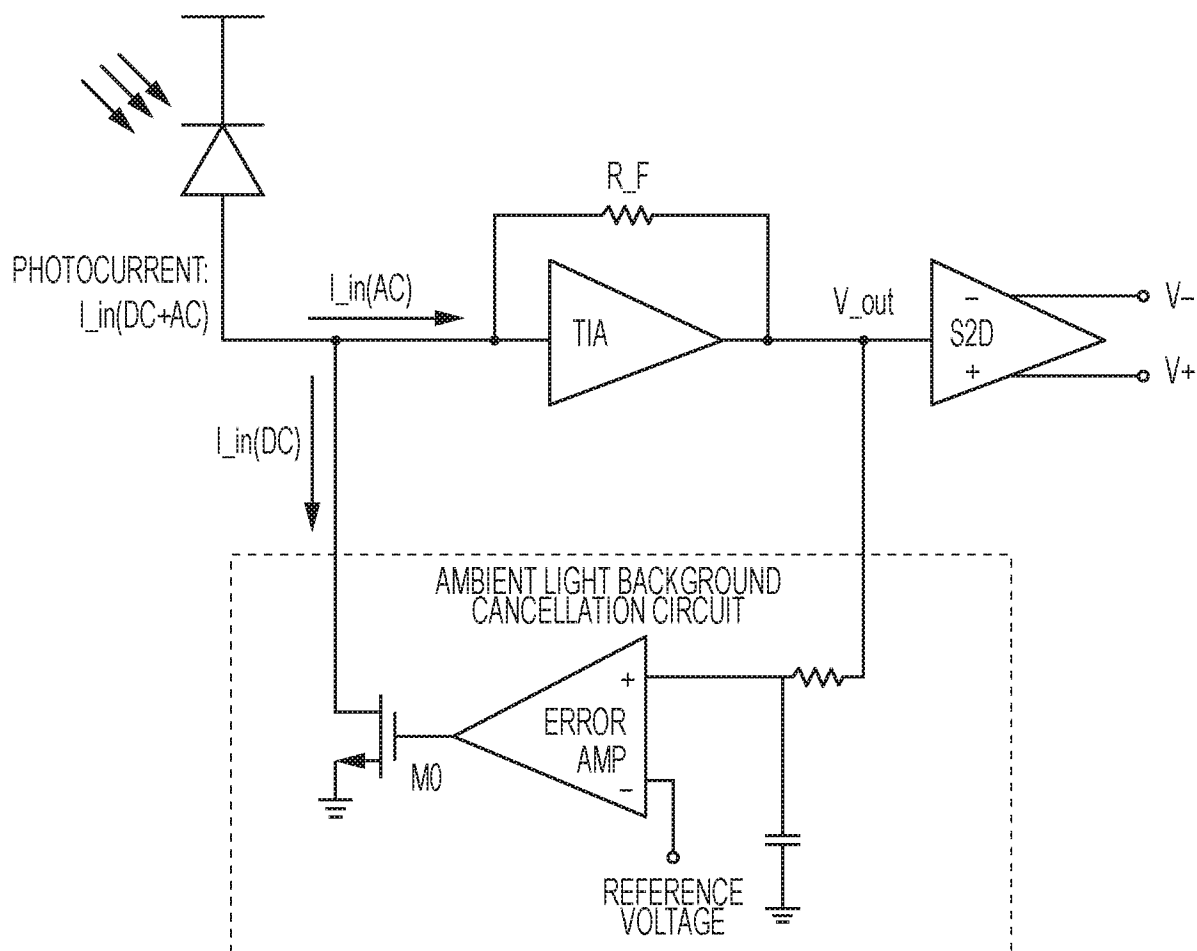


FIG. 16

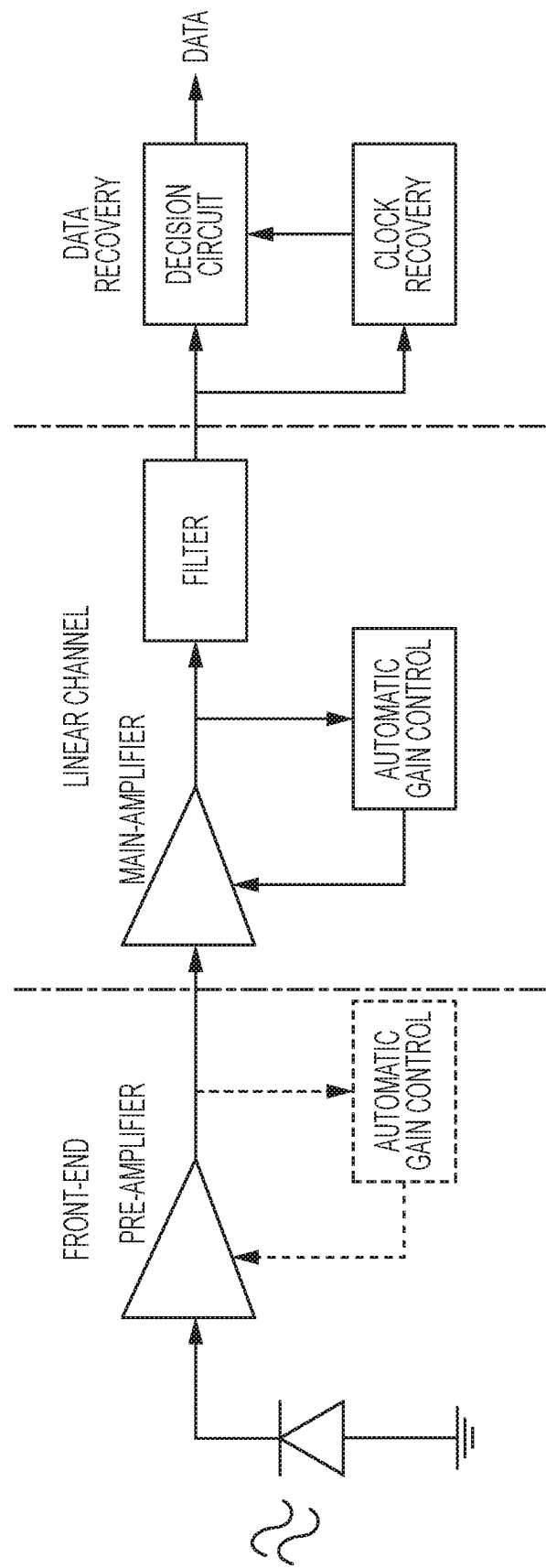


FIG. 17

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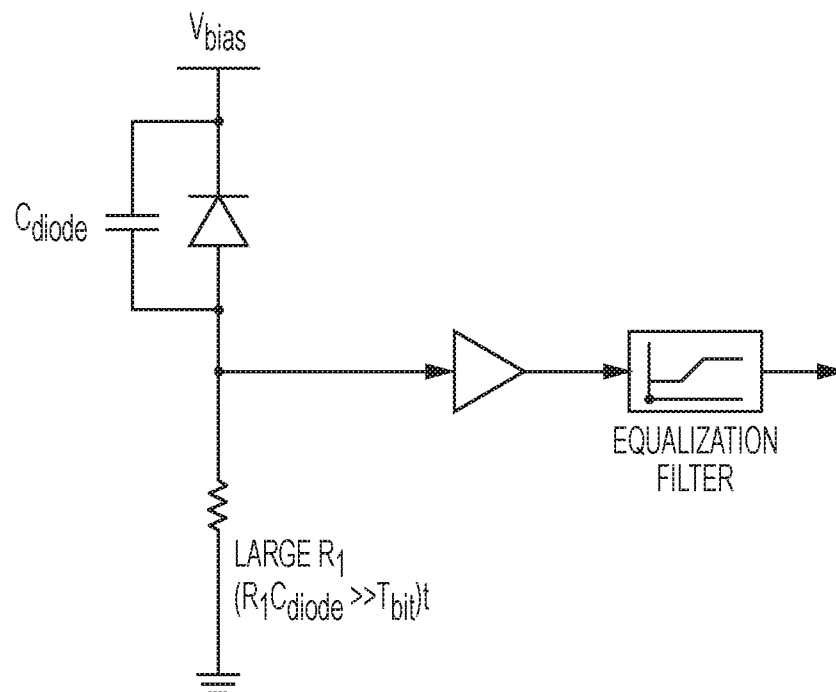


FIG. 18A

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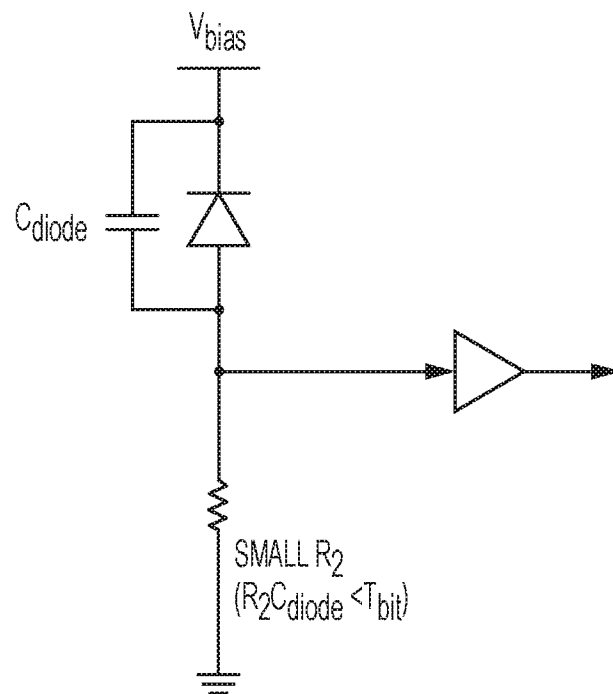


FIG. 18B

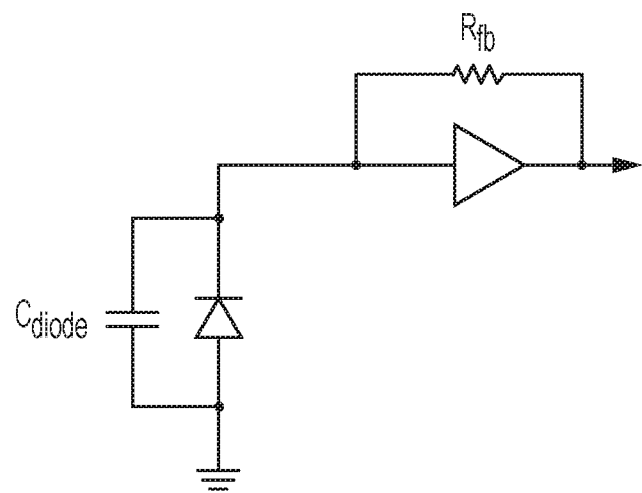


FIG. 18C

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US17/33384

A. CLASSIFICATION OF SUBJECT MATTER

IPC - H04B 10/07, 10/11, 10/50, 10/60; G05F 1/10 (2017.01)

CPC - H04B 10/07, 10/11, 10/50, 10/60; G05F 1/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y ----- A	US 2013/0287403 A1 (ROBERTS, R) 31 October 2013; paragraphs [0015]-[0018]	1-8, 10, 11 ----- 12 ----- 9
Y	US 2007/0012948 A1 (DRIES, J et al.) 18 January 2007; paragraph [0008]	12
A	US 7,595,622 B1 (TOMIYOSHI, K et al.) 29 September 2009; entire document	1-12

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

21 July 2017 (21.07.2017)

Date of mailing of the international search report

28 SEP 2017

Name and mailing address of the ISA/

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-8300

Authorized officer

Shane Thomas

PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US17/33384

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Group I: Claims 1-12; Group II: Claims 13-30

-Continued within extra sheet-

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-12

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

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---Continued from Box No. III - Observations where unity of invention is lacking---

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fee must be paid.

Group I: Claims 1-12 are directed towards a mobile device for visible light communication comprising an LED transmitter.

Group II: Claims 13-30 are directed towards a mobile device for visible light communication comprising an imager sensor.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I include at least an LED configured as a VLC transmitter, which are not present in Group II.

The special technical features of Group II include at least an imager sensor comprising a plurality of pixels, wherein a first pixel of the plurality of pixels is configured as a first photodetector to receive visible light encoded with a VLC signal, the first pixel generating an electrical signal based on reception of the visible light encoded with the VLC signal; and a VLC decoder to decode the VLC signal, which are not present in Group I.

The common technical features shared by Groups I-II are a mobile device for visible light communication; an encoded VLC signal; and emitting visible light.

However, these common features are previously disclosed by US 2016/0028477A1 to QUALCOMM INCORPORATED (hereinafter "Qualcomm"). Qualcomm discloses a mobile device for visible light communication (mobile device 115 used for visible light communication; Abstract; Fig. 2); an encoded VLC signal (an identifier encoded in a VLC signal; Abstract); and emitting visible light (light sources 145 provide ambient illumination; Fig. 2; para [0037]).

Since the common technical features are previously disclosed by the Qualcomm reference, these common features are not special and so Groups I-II lack unity.