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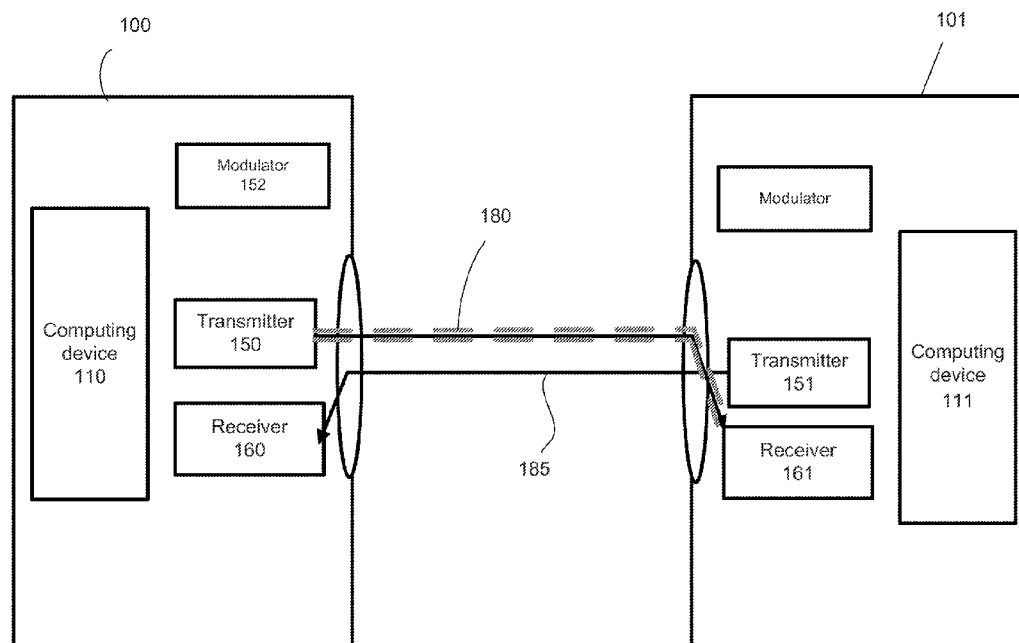


FIG. 1

(57) Abstract: A data rate at which data can be transmitted is adapted in real-time to power fluctuations. Bits of data to be sent by a transmitter are mapped to physical symbols, where a first modulation uses a first number of bits per pulse and a second modulation uses a second number of bits per pulse. Both modulations are sent, with one nested inside the other. A receiver decodes one or both bit streams, depending on a signal to noise ratio (SNR). In this regard, the data rate traces the received power, and higher data rates may be used despite periods of power fluctuations. This technique enables rapid, or even instantaneous, changes by using nested modulation. Moreover, a fast feedback mechanism is used to inform the transmitter when to change its modulation and to retransmit bits lost during an initial transmission.



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FAST ADAPTIVE NESTED MODULATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a continuation of U.S. Patent Application No. 15/633,252, filed June 26, 2017, which claims the benefit of the filing date of U.S. Provisional Patent Application No. 62/438,510 filed December 23, 2016, the disclosure of which is hereby incorporated herein by reference.

BACKGROUND

[0002] When sending data, or information, over a channel, a data rate at which the data can be transmitted increases with the received power. In many channels of interest, such as free space optical communication (FSOC) channels, the received power changes with time, for example due to atmospheric scintillation. In the presence of power fluctuations, the data rate is typically set to a level sustainable based on a lowest received power, to prevent loss of transmitted data.

BRIEF SUMMARY

[0003] According to the present disclosure, the data rate at which data can be transmitted can adapt in real-time to power fluctuations. Bits of data to be sent by a transmitter are mapped to physical symbols, where a first modulation uses a first number of bits per pulse and a second modulation uses a second number of bits per pulse. Both modulations are sent, with one nested inside the other. A receiver decodes one or both bit streams, depending on a signal to noise ratio (SNR). In this regard, the data rate traces the received power, and higher data rates may be used despite periods of power fluctuations. This technique enables rapid, or even instantaneous, changes by using nested modulation. Moreover, a fast feedback mechanism may be used to inform the transmitter when to change its modulation and to retransmit bits lost when they were first transmitted.

[0004] One aspect of the disclosure provides a communication system, including a transmitter, a receiver, and a processor in communication with the transmitter and the receiver. The processor is configured to map data to be transmitted to a first set of symbols and a second set of symbols, wherein the second set of symbols includes the first set of symbols. When the receiver receives one or more signals, a power level associated with one or more transmission channels is determined based on the received one or more signals, and the processor adjusts a transmission rate of the transmitter based on the determined power level, the adjusting including sending either the first set of symbols or the second set of symbols. The one or more transmission channels may include optical transmission channels between the transmitter and a remote optical device. The first set of symbols may be used for transmission when the power level is below a predetermined threshold, and the second set of symbols may be used for transmission when the power level is above the predetermined threshold. According to some examples, the receiver is configured to receive messages from a second communication system regarding a modulation of signals being decoded by the second communication system. The receiver may be configured to relay information to the transmitter regarding a number of bits being received from a

second communication system. The transmitter may automatically adjust its transmission rate in response to the information relayed from the receiver. In some embodiments, the transmitter is adapted to transmit the first set of symbols on a first channel and transmit the second set of symbols on a second channel. For example, each symbol includes two or more bits, and a most significant bit is transmitted on the first channel and a least significant bit is transmitted on the second channel.

[0005] Another aspect of the disclosure provides a method of fast adaptive communication, including mapping, with one or more processors, data to be transmitted by a transmitter, the mapping including mapping the data to a first set of symbols and a second set of symbols, wherein the second set of symbols includes the first set of symbols. The method further includes receiving, at a receiver in communication with the one or more processors, one or more optical signals, determining, with the one or more processors based on the received one or more signals, a power level associated with one or more transmission channels, and adjusting, with the one or more processors, a transmission rate of the transmitter based on the determined power level, the adjusting including sending either the first set of symbols or the second set of symbols. The method may further include receiving information through a feedback loop between the receiver and the transmitter, the information indicating which bits of a transmitted signal using the second set of symbols were lost, and retransmitting the lost bits using the first set of symbols.

[0006] Yet another aspect of the disclosure provides a non-transitory computer-readable medium storing instructions executable by one or more processors for performing a method, including mapping data to be transmitted to a first set of symbols and a second set of symbols, wherein the second set of symbols includes the first set of symbols, receiving one or more signals, determining, based on the received one or more signals, a power level associated with one or more transmission channels, and adjusting a transmission rate of a transmitter based on the determined power level, the adjusting including sending either the first set of symbols or the second set of symbols.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Fig. 1 is a block diagram illustrating communication between two FSOC systems according to aspects of the disclosure;

[0008] Figs. 2A-2B illustrate examples of mapping bits of data to symbols according to aspects of the disclosure;

[0009] Figs. 3A-3B illustrate examples of bitstreams corresponding to the mapped data according to aspects of the disclosure;

[0010] Fig. 4 is an example plot illustrating variations in data rate of transmitted data over time, according to aspects of the disclosure;

[0011] Fig. 5 illustrates the plot of Fig. 4, highlighting example transitions in data rate according to aspects of the disclosure;

[0012] Fig. 6 is a block diagram of an example system for fast adaptive modulation according to aspects of the disclosure;

[0013] Fig. 7 is a flow diagram illustrating a method of transmitting signals with fast adaptive modulation according to aspects of the disclosure.

DETAILED DESCRIPTION

Overview

[0014] The technology relates to a communication system, such as a free space optical communication (FSOC) system, in which a transmission rate is varied in accordance with fluctuations in power of received signals. Modulation is changed between on-off-keying (OOK) and pulse amplitude modulation 4 (PAM4). To achieve fast switching, both modulations are sent in transmissions by the FSOC system. For example, the modulation may be nested, such that two OOK points are contained within four PAM4 points. A receiving communication recognizes the modulation of a received signal, and can thus decode the signal.

[0015] The FSOC system includes a transmitter and a receiver. According to some examples, the receiver may communicate with the transmitter through an internal feedback loop. In this regard, as the receiver receives signals from a second communication system, the receiver may use those signals to determine information relevant for the transmitting. For example, a power level of the received signals may be detected, and used to determine the transmission rate at which the transmitter will send information.

[0016] According to some examples, the transmission rate may be determined without a feedback loop or information from the receiver. For example, the transmitter may be used to determine, based on a power level at which it is transmitting, how many bits are being lost by the second communication system. The transmitter may then adjust its transmission rate based on this inference.

[0017] Two or more bits are mapped to symbols being sent by the FSOC system. As opposed to typical systems, where an optical communication signal is either on (wherein a bit “1” is sent) or off (where a bit “0” is sent), according to the present technology four or more symbols may be sent in each transmission using two or more bits. Accordingly, signals may be transmitted at three or more different possible power levels (“01,” “11,” and “10”) in addition to the “off” symbol (“00”). In this regard, two OOK points (00 and 10) are contained within four PAM 4 points (00, 01, 11, 10).

[0018] The receiver of the second communication system may always attempt to decode PAM4 modulation, upon receipt of the signals. If the receiver detects that it is making errors on bits of the received signals, the receiver may notify the first FSOC system, which adapts in real-time. For example, if there is a low signal-to-noise (SNR) ratio, the receiver of the second communication system may be receiving less than all of the transmitted bits. For example, the receiver may only be detecting the most significant bit. The receiver may relay such information back to the transmitter of the first FSOC. Upon receiving such information, the first FSOC may automatically adjust (e.g., reduce) its transmission rate. Moreover, any lost bits may be retransmitted.

Example Systems

[0019] Fig. 1 provides an example of communication between a first FSOC systems 100 and a second FSOC system 101. The systems 100, 101 are shown as having the same structure, including a transmitter

150, receiver 160, modulator 152, and computing device 110. However, it should be understood that the structure of either or both FSOC systems 100,101 may differ. Moreover, while some example components are shown, it should be understood that a variety of other components may be present.

[0020] Modulator 152 may be used to modulate data to be sent by the first FSOC system 100. The modulator 152 may be adapted to use any of a variety of modulation schemes, including pulse amplitude modulation, pulse position modulation, on-off keying (OOK), etc. According to one example, the modulator 152 modulates the data to be sent using both PAM4 and OOK. For example, the modulator 152 maps the data to be sent to a plurality of symbols. For example, for each pulse, four symbol values send two bits of data. In that regard, the symbol values may be 00, 01, 10, 11. In other examples, a different number of symbol values may be used, such as eight symbol values. If more symbol values are used, more bits per pulse may also be sent. While one modulator 152 is shown in the first FSOC system 100, it should be understood that a plurality of modulators 152 may be present. For example, separate modulators may be used for PAM4 and for OOK.

[0021] The transmitter 150 is adapted to send data using nested modulation signals 180. For example, the signals 180 may include a first bitstream modulated using OOK and a second bitstream, nested within the first bitstream, using PAM4 modulation. The signals 180 are received at receiver 161 of FSOC system 101.

[0022] The receiver 161 may always try to decode PAM 4. At times when a power level of a channel over which the signal 180 is received is low, the receiver 161 may make errors on bits. Computing device 111 may determine, for example, that a bit-error rate of the signal 180 received at the receiver 161 is above a predetermined threshold. According to some examples, transmitter 151 may report information regarding the bit-error rate back to the first FSOC system 100.

[0023] The FSOC system 101 may send a second signal 185 to the first FSOC system 100 through transmitter 151. The second signal 185 may include information regarding the bit-error rate of the signal 180 received at the receiver 161. In other examples, the second signal 185 may include any other data to be sent to the first FSOC system 100. The second signal 185, similar to the signal 180, may be a PAM4 modulated bitstream nested within an OOK modulated bitstream. The second signal 185 is received at the receiver 160 of the first FSOC 100.

[0024] In some examples, the second signal is used to determine a bit rate for further signals to be transmitted from the first FSOC system 100 to the second FSOC system 101. For example, a feedback loop may exist between the receiver 160 and the transmitter 150. The feedback loop may include computing device 110. The computing device 110 may determine a power level of the received signal. The power level may be measured, for example, by a signal to noise ratio (SNR) of a channel over which the second signal 185 was received, a bit-error rate of the second signal 185, etc. Based on the determined power level, the computing device 110 may cause a bit rate at which further signals are transmitted by the transmitter 150 to change. For example, if the SNR is determined to be below a predetermined threshold, the transmitter 150 may switch to sending further signals using only OOK modulation. For example, the transmitter 150 may continue to receive two bitstreams from the

modulator 152, but selects to send only one. As additional signals are continually received at the receiver 160, information is provided through the feedback loop to the transmitter. In that regard, as soon as the power level of the channel increases above a threshold, the transmitter 150 may send subsequent information using nested PAM4 in OOK signals. In one implementation, computing device 110 infers that bits are being lost at receiver 161 by monitoring the SNR at receiver 160 and using prior knowledge that the SNRs at receiver 160 and receiver 161 are correlated.

[0025] Figs. 2A-2B illustrate examples of mapping bits of data to symbols according to aspects of the disclosure. Fig. 2A is a constellation diagram, providing an example of the mapping using OOK. The constellation diagram shows the modulation in terms of amplitude and phase. In this example the x-axis represents in-phase and the y-axis represents quadrature. As shown, two symbol values are provided: 00 and 10. The symbol value 10 corresponds to peak power (P_{pk}). According to one example, two independent data channels are used – one for a most significant bit (MSB) and one for a least significant bit (LSB). At times when a power level is low, only the MSB data channel may be used.

[0026] Fig. 2B provides an example of the mapping using PAM4. As shown, four symbols are provided: 00, 01, 11, 10. Two of these symbols (00, 10) correspond to the symbols used in the OOK mapping. The additional symbols (01, 11) are nested within the OOK symbols, and represent $1/3P_{pk}$ and $2/3P_{pk}$, respectively. At times when the power level is high, the MSB and the LSB are used.

[0027] Figs. 3A-3B illustrate examples of bitstreams corresponding to the mapped data. Fig. 3A corresponds to the OOK mapping of Fig. 2A, and Fig. 3B corresponds to the PAM4 mapping of Fig. 2B. In Fig. 3A, only outside levels are sent, while in Fig. 3B additional levels are nested within the outside levels.

[0028] Fig. 4 is an example plot illustrating variations in data rate of transmitted data over time. A vertical axis of the plot represents a power level of one or more available optical channels, shown as ranging between -10dB and above 5dB. As mentioned above, the power level may be measured based on received signals. A horizontal axis of the plot represents time, shown as ranging from 0s to 1s. It should be understood that the ranges of power level and time provided are merely examples, and that the power level may vary outside of such ranges over extended time periods.

[0029] OOK threshold 410 represents a power level of the channels above which OOK signals may be sent by a first FSOC system and accurately received by a second FSOC system. Below the OOK threshold 410, no communications are sent. As such, the data rate of transmitted data below the OOK threshold 410 is zero. The OOK threshold may be, for example, approximately 5-10 dB, or any other value.

[0030] PAM4 threshold 420 represents a power level of the channels above which PAM4 communications may be sent by the first FSOC system and accurately received by the second FSOC system. In some examples, the PAM4 threshold may be approximately 1dB, although in other examples different values may be used for the PAM4 threshold. Between the PAM4 threshold 420 and the OOK threshold 410, OOK communications are sent.

[0031] As time passes, over the course of 1s, the power level for the channels varies between -10dB and above 5dB. The transmitting FSOC system in turn adapts the data rate at which data is sent. Between 0.1s and 0.2s, the data rate fluctuates within the PAM4 range. Between 0.2s and 0.5s, the data rate fluctuates between the PAM4 range and the OOK range. Between 0.5s and 0.6s the data rate fluctuates between the OOK range and the no communications range. Between 0.6s and 1s, the data rate fluctuates between the OOK range and the PAM4 range.

[0032] Fig. 5 illustrates a portion of the plot of Fig. 4, highlighting example transitions in the power level of the channels and therefore the data rate of the transmitted data. In this example, two channels may be used, with a first channel mapped to the MSB and a second channel mapped to the LSB, described above in connection with Figs.2A-2B and 3A-3B. Each channel may have a bandwidth of, for example, approximately 10Gbps. It should be understood that in other examples, particularly examples using different types of communications or different modulations, channels of different bandwidths, such as 15Gbps, 100Mbps, 100Gbps, may be used.

[0033] At transition point 530, the power level of the first and second channels drops below the PAM4 threshold. For example, the SNR of the received signal at the first FSOC system drops below approximately 8dB. At this point, the second FSOC system receiving the signals will be able to decode the MSB, but not the LSB. Accordingly, the first FSOC system transitions from PAM4 to OOK, stops transmitting the LSB, and only transmits the MSB. The first FSOC system may also determine, via a feedback path, which LSB bits were lost and retransmit those, using only the MSB. Thus, for example, the change in data rate by the transmitting first FSOC is responsive to the detected power level of the available channels. The PAM4 threshold shown in Fig. 5 is merely an example, and it should be understood that any of a broad range of values may be used.

[0034] At transition point 540, the power level increases and therefore the transmitted data transitions from OOK to PAM4. Accordingly, the first FSOC system may begin transmitting the LSB again.

[0035] At transition point 550, the power level becomes very low. For example, the SNR may be less than the OOK threshold. Alternatively or additionally, the bit error rate may be very high. In some examples, the first FSOC system may stop transmitting, as too many bits will be lost by the second FSOC system trying to receive the data. In other examples, the first FSOC continues transmitting, allowing the second FSOC system to continuously try recovering the data and to quickly determine when data is received correctly. In yet another example, the first FSOC system sends data only sporadically during this low power interval in order to save transmit power. It may return to transmitting at full rate when it receives a signal from the second FSOC system that the data is being received correctly.

[0036] At transition point 560, the power level rises back up above the OOK threshold. Accordingly, the first FSOC system transitions from transmitting no signals to transmitting the MSB. The second FSOC system receiving the MSB may need to re-acquire a lock to the data. For example, the second FSOC system re-acquires phase and frequency lock of the receiver clock to the data.

[0037] By adapting the data rate to the fluctuations in available power level, throughput is increased. For example, rather than continuously sending at a fixed data rate, the FSOC system can take

advantage of periodic increases in power, even if such increases only last a tenth or hundredth of a second.

[0038] Fig. 6 is a block diagram illustrating an example system 600, such as an FSOC system. The system 600 includes various components, including one or more computers, such as computer 610 containing one or more processors 620, memory 630, and other components typically present in general purpose computers. The one or more computers 610 may further include, for example, a power detection unit 642 and a bit-mapping unit 644. The one or more computers 310 may be in communication with other components of a FSOC system, such as transmitter 650, receiver 660, modulator 652, light source 654, and other components that are not shown, such as fibers, amplifiers, circuitry, wiring, etc.

[0039] The memory 630 stores information accessible by processor 620, including instructions 632 and data 634 that may be executed or otherwise used by the processor 620. The memory 630 may be of any type capable of storing information accessible by the processor, including a computer-readable medium, or other medium that stores data that may be read with the aid of an electronic device, such as a hard-drive, memory card, ROM, RAM, DVD or other optical disks, as well as other write-capable and read-only memories. Systems and methods may include different combinations of the foregoing, whereby different portions of the instructions and data are stored on different types of media.

[0040] The instructions 632 may be any set of instructions to be executed directly (such as machine code) or indirectly (such as scripts) by the processor. For example, the instructions may be stored as computer code on the computer-readable medium. In that regard, the terms "instructions" and "programs" may be used interchangeably herein. The instructions may be stored in object code format for direct processing by the processor, or in any other computer language including scripts or collections of independent source code modules that are interpreted on demand or compiled in advance. Functions, methods and routines of the instructions are explained in more detail below.

[0041] The data 634 may be retrieved, stored or modified by processor 620 in accordance with the instructions 632. For instance, although the system and method is not limited by any particular data structure, the data may be stored in computer registers, in a relational database as a table having a plurality of different fields and records, XML documents or flat files. The data may also be formatted in any computer-readable format. The data may comprise any information, such as numbers, descriptive text, proprietary codes, references to data stored in other areas of the same memory or different memories (including other network locations) or information that is used by a function to calculate the relevant data.

[0042] The processor 620 may be any conventional processor, such as processors from Intel Corporation or Advanced Micro Devices. Alternatively, the processor may be a dedicated device such as an ASIC. Although Fig. 6 functionally illustrates the processor, memory, and other elements of computer 610 as being within the same block, it will be understood by those of ordinary skill in the art that the processor and memory may actually comprise multiple processors and memories that may or may not be stored within the same physical housing. For example, memory may be a hard drive or other storage

media located in a server farm of a data center. Accordingly, references to a processor or computer will be understood to include references to a collection of processors or computers or memories that may or may not operate in parallel.

[0043] Computer 610 may include all of the components normally used in connection with a computer such as a central processing unit (CPU), graphics processing unit (GPU), memory (e.g., RAM and internal hard drives) storing data 634 and instructions such as a web browser, an electronic display (e.g., a monitor having a screen, a small LCD touch-screen or any other electrical device that is operable to display information), and user input (e.g., a keyboard, touch-screen and/or microphone). While the computer system 610 is shown as being within the FSOC system 600, it should be understood that the computer system 610 may be external to the FSOC system 600 but still communicatively coupled to the components within.

[0044] Computer 610 may also include a bit-mapping unit 644. The bit-mapping unit may be used to map data to be transmitted to symbols. For example, the data may be mapped according to two different modulations. In one example, the first modulation is OOK and the second modulation is PAM 4, although it should be understood that other modulations are possible. As such, the OOK symbols may include 00 and 10, while the PAM4 symbols include 00, 01, 11, 10. Keeping with this example, two symbols/pulse may be sent using OOK modulation and four symbols/pulse may be sent with PAM4 modulation.

[0045] Computer 610 may also include power detection unit 642, which determines a power level of one or more available communication channels between the FSOC system and other communication systems. According to one example, the power detection unit receives information from signals received at receiver 660. Such information may include signal strength, bit error rate, SNR, or any of a variety of other information. For example, the signals received at the receiver 660 may include feedback from another FSOC system, based on signals previously sent by the transmitter 650 to the other FSOC system. This information may indicate which bits were received at the other FSOC system, such as whether the LSB is received or only the MSB. As another example, the power level may be inferred by other information received at the receiver 660, although such information may not include specific feedback on information sent by the transmitter 650.

[0046] The transmitter 650 and the receiver 660 may include any commercially available components, or they may have specialized hardware. For example, the specialized hardware may be adapted to increase a rate at which feedback is provided from the receiver 660 to the transmitter 650. As another example, the specialized hardware may be adapted to enhance communication with the modulator 652. While the transmitter 650 and receiver 660 are shown as separate entities, it should be understood that they may be a single transceiver unit. Moreover, while the computer system 610 is shown as being separate from by communicatively coupled with the transmitter 650 and receiver 660, it should be understood that the computer system 610 may be incorporated within either or both of the transmitter 650 and receiver 660.

[0047] The modulator 652 may be a single modulator or may be multiple modulators working in parallel. For example, the modulator 652 may encode the data to be transmitted using both OOK and PAM4, or a separate modulator may be used for each type of encoding. The modulator 652 may always encode using both OOK and PAM4 and possibly other types of modulation, or in other examples the modulator 652 may selectively perform the encoding based on the available power levels. For example, if the available power level is below the PAM4 threshold, the modulator 652 may only encode data using OOK modulation.

[0048] The light source 654 may be a laser or any other type of light source. Moreover, while the foregoing examples relate primarily to optical communications, it should be understood that such techniques may be adapted to other types of communication as well.

Example Methods

[0049] Fig. 7 illustrates a method 700 of transmitting signals with fast adaptive modulation. The method 700 may be performed by, for example, a FSOC system. While the operations associated with the method 700 are described in a particular order, it should be understood that they may be performed in a different order or simultaneously. Moreover, operations may be added or omitted.

[0050] In block 710, bits of data are mapped to a first set of symbols for a first modulation and a second set of symbols for a second modulation. For example, referring back to Figs. 2A-2B, the data may be mapped to the symbols 00, 10 for OOK modulation, and at the same time the data may be mapped to the symbols 00, 01, 11, 10 for PAM4 modulation. While these examples use two bits to represent each symbol, it should be understood that additional bits may be used, and additional symbols may be used. Moreover, other types of modulation may be used.

[0051] In block 720, a first bitstream of data is transmitted for a first bit of each symbol (MSB), while a second bitstream is transmitted for the second bit of each symbol (LSB). The second bitstream may be nested within the first bitstream. According to one example, the most significant bit for each symbol is sent on a first channel while the least significant bit for each symbol is sent on a second channel. In examples where additional bits are used to represent each symbol, third or further channels may be used for the additional bits.

[0052] In block 730, a signal is received by the FSOC system. The signal may include feedback related to the transmitted bitstreams, or it may include any other type of information not related to the bitstreams.

[0053] In block 740, a power level of available communication channels is determined based on the received signal. For example, a received signal strength is measured. In other examples, a signal-to-noise ratio or bit error rate is measured.

[0054] In block 750, it is determined whether the measured power level is below a predetermined threshold, such as the PAM4 threshold. For example, the threshold may be set to a value between approximately 7-9dB. If the power level is above the threshold, the FSOC system continues sending both bitstreams in block 760. For example, both the MSB and the LSB of each symbol are transmitted. However, if it is determined that the power level is below the threshold, then only the first bitstream is transmitted in block 770. For example, the LSB is dropped.

[0055] Unless otherwise stated, the foregoing alternative examples are not mutually exclusive, but may be implemented in various combinations to achieve unique advantages. As these and other variations and combinations of the features discussed above can be utilized without departing from the subject matter defined by the claims, the foregoing description of the embodiments should be taken by way of illustration rather than by way of limitation of the subject matter defined by the claims. In addition, the provision of the examples described herein, as well as clauses phrased as "such as," "including" and the like, should not be interpreted as limiting the subject matter of the claims to the specific examples; rather, the examples are intended to illustrate only one of many possible embodiments. Further, the same reference numbers in different drawings can identify the same or similar elements.

CLAIMS

1. A communication system, comprising:
a transmitter;
a receiver;
a processor in communication with the transmitter and the receiver, the processor configured to:
map data to be transmitted to a first set of symbols and a second set of symbols, wherein the second set of symbols includes the first set of symbols;
receive one or more signals;
determine, based on the received one or more signals, a power level associated with one or more transmission channels; and
adjust a transmission rate of the transmitter based on the determined power level, the adjusting including sending either the first set of symbols or the second set of symbols.
2. The communication system of claim 1, further comprising a feedback loop between the receiver and the transmitter.
3. The communication system of claim 2, wherein the receiver is configured to receive messages from a second communication system regarding a modulation of signals being decoded by the second communication system.
4. The communication system of claim 2, wherein the receiver is configured to relay information to the transmitter regarding a number of bits being received from a second communication system.
5. The communication system of claim 2, wherein the transmitter is configured to automatically adjust its transmission rate in response to the information relayed from the receiver.
6. The communication system of claim 1, wherein the transmitter is adapted to transmit the first set of symbols on a first channel and transmit the second set of symbols on a second channel.
7. The communication system of claim 6, wherein each symbol includes two or more bits, and a most significant bit is transmitted on the first channel and a least significant bit is transmitted on the second channel.
8. The communication system of claim 1, wherein the first set of symbols are on-off-keying (OOK) modulation symbols.

9. The communication system of claim 1, wherein the second set of symbols are pulse amplitude modulation 4 (PAM4) symbols.

10. The communication system of claim 1, wherein the one or more transmission channels include optical transmission channels between the transmitter and a remote optical device.

11. The communication system of claim 1, wherein the first set of symbols are used for transmission when the power level is below a predetermined threshold, and the second set of symbols are used for transmission when the power level is above the predetermined threshold.

12. The communication system of claim 11, wherein the one or more processors are configured to continuously measure the power level of the received signals, and adjust the transmission rate of the transmitter in response.

13. A method of fast adaptive communication, comprising:
mapping, with one or more processors, data to be transmitted by a transmitter, the mapping including mapping the data to a first set of symbols and a second set of symbols, wherein the second set of symbols includes the first set of symbols;
receiving, at a receiver in communication with the one or more processors, one or more optical signals;
determining, with the one or more processors based on the received one or more signals, a power level associated with one or more transmission channels; and
adjusting, with the one or more processors, a transmission rate of the transmitter based on the determined power level, the adjusting including sending either the first set of symbols or the second set of symbols.

14. The method of claim 13, further comprising:
receiving information through a feedback loop between the receiver and the transmitter, the information indicating which bits of a transmitted signal using the second set of symbols were lost; and
retransmitting the lost bits using the first set of symbols.

15. The method of claim 13, further comprising receiving messages from a second communication system regarding a modulation of signals being decoded by the second communication system.

16. The method of claim 15, further comprising relaying information to the transmitter regarding a number of bits being received from the second communication system.

17. The method of claim 13, further comprising transmitting the first set of symbols on a first channel and transmitting the second set of symbols on a second channel.

18. The method of claim 17, wherein each symbol includes two or more bits, and a most significant bit is transmitted on the first channel and a least significant bit is transmitted on the second channel.

19. The method of claim 18, wherein the one or more transmission channels include optical transmission channels between the transmitter and a remote optical device.

20. A non-transitory computer-readable medium storing instructions executable by one or more processors for performing a method, comprising:

mapping data to be transmitted to a first set of symbols and a second set of symbols, wherein the second set of symbols includes the first set of symbols;

receiving one or more signals;

determining, based on the received one or more signals, a power level associated with one or more transmission channels; and

adjusting a transmission rate of a transmitter based on the determined power level, the adjusting including sending either the first set of symbols or the second set of symbols.

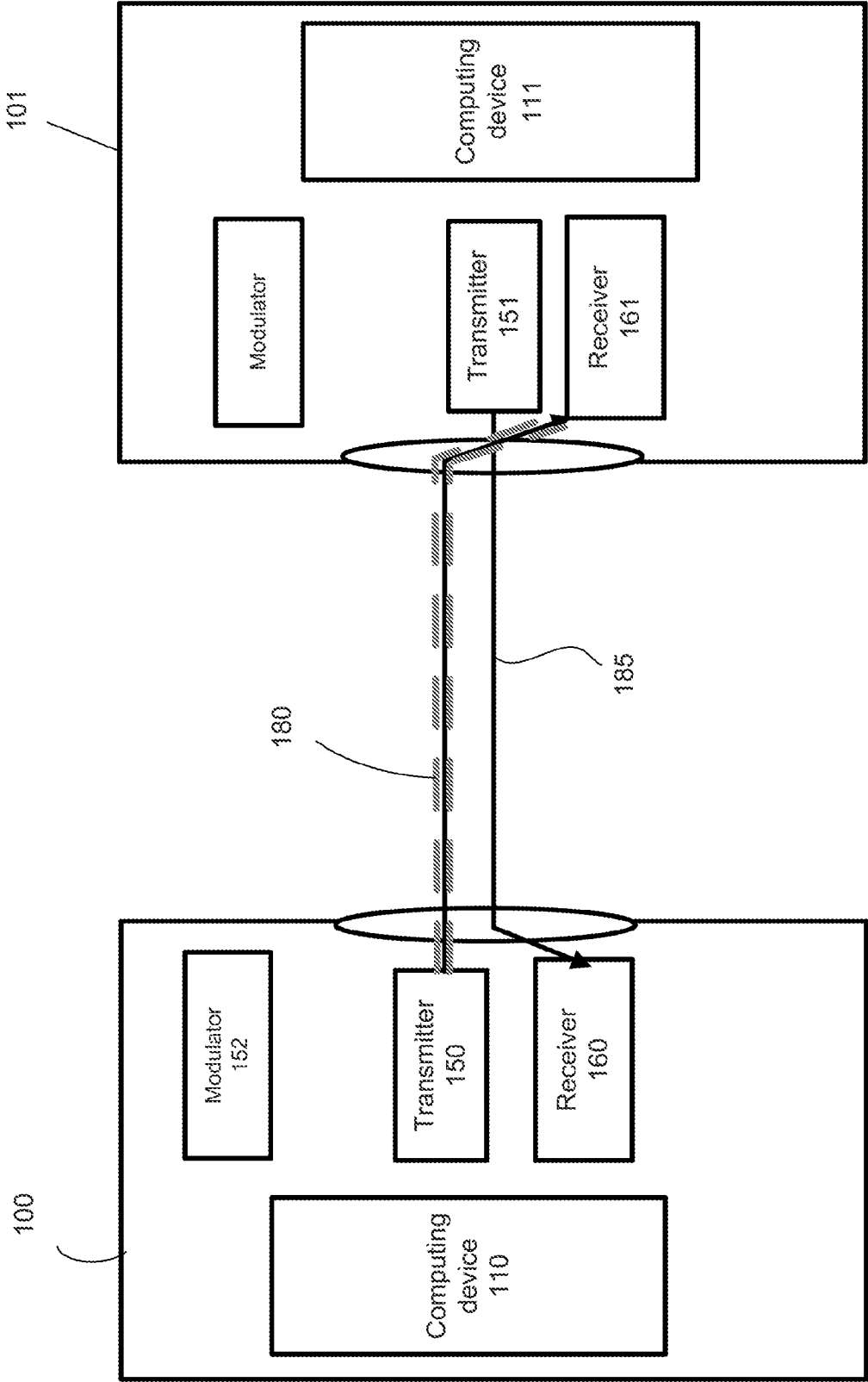


FIG. 1

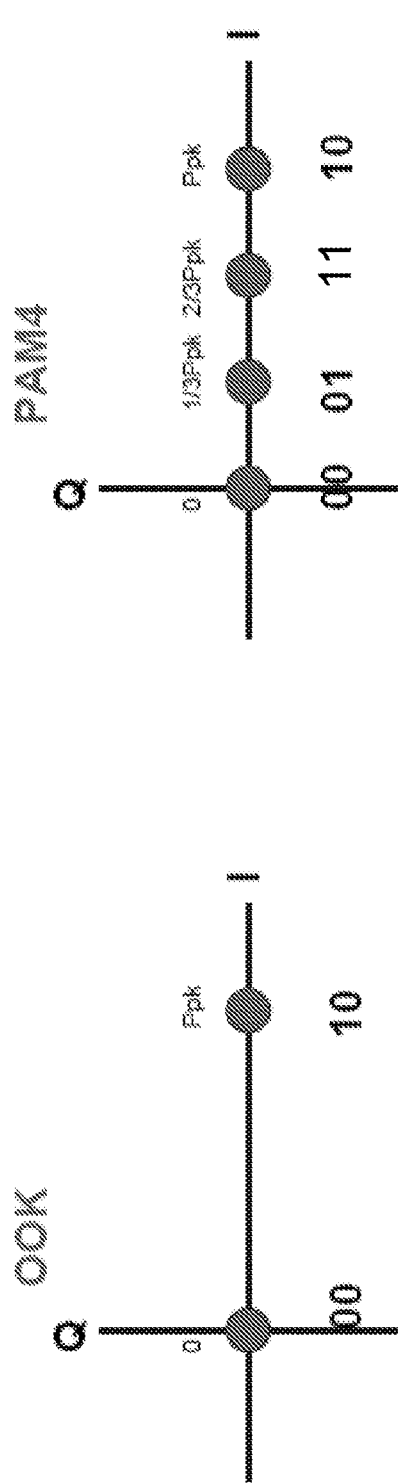


FIG. 2A

FIG. 2B

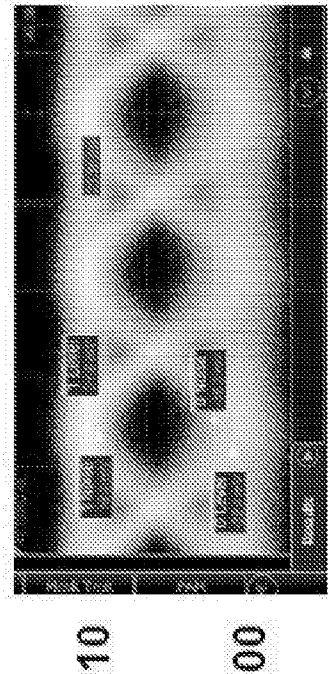


FIG. 3A

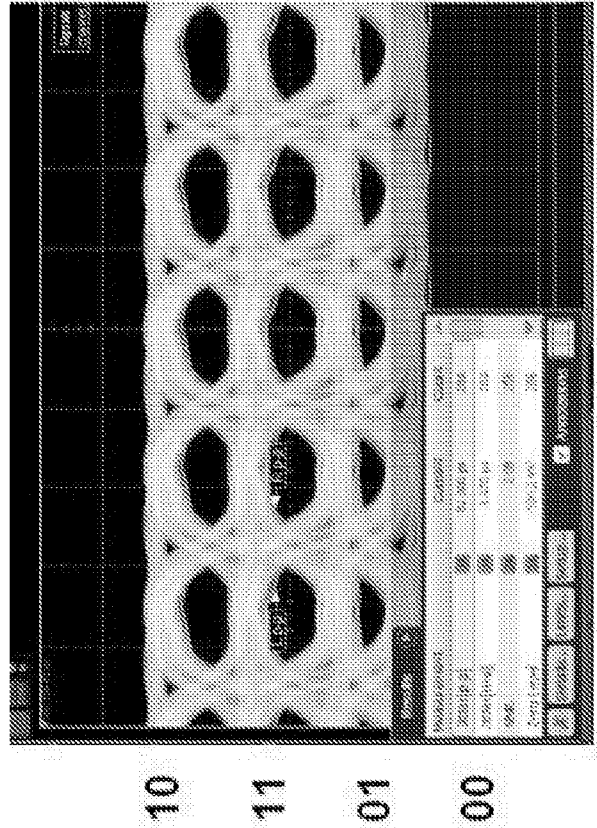
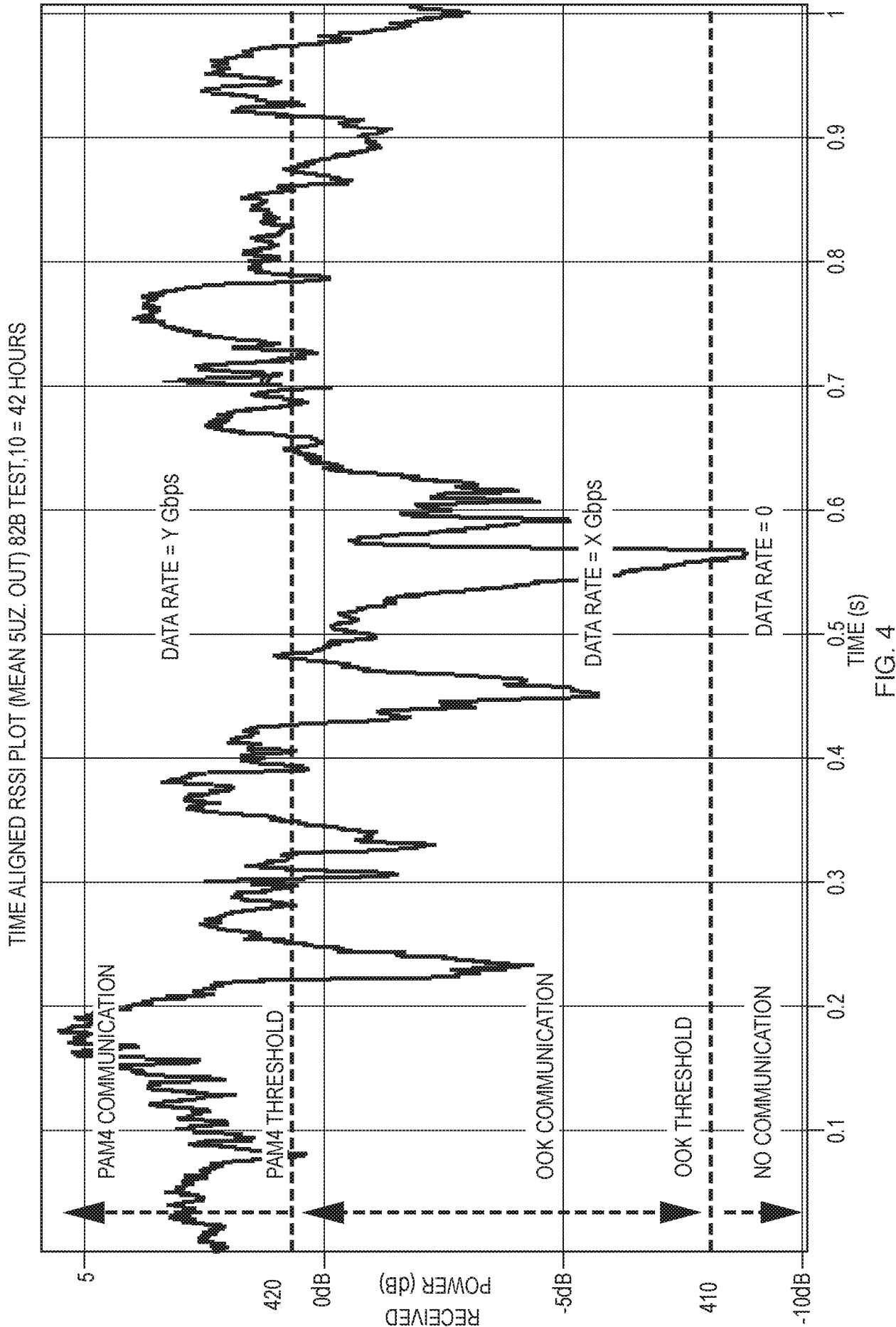


FIG. 3B



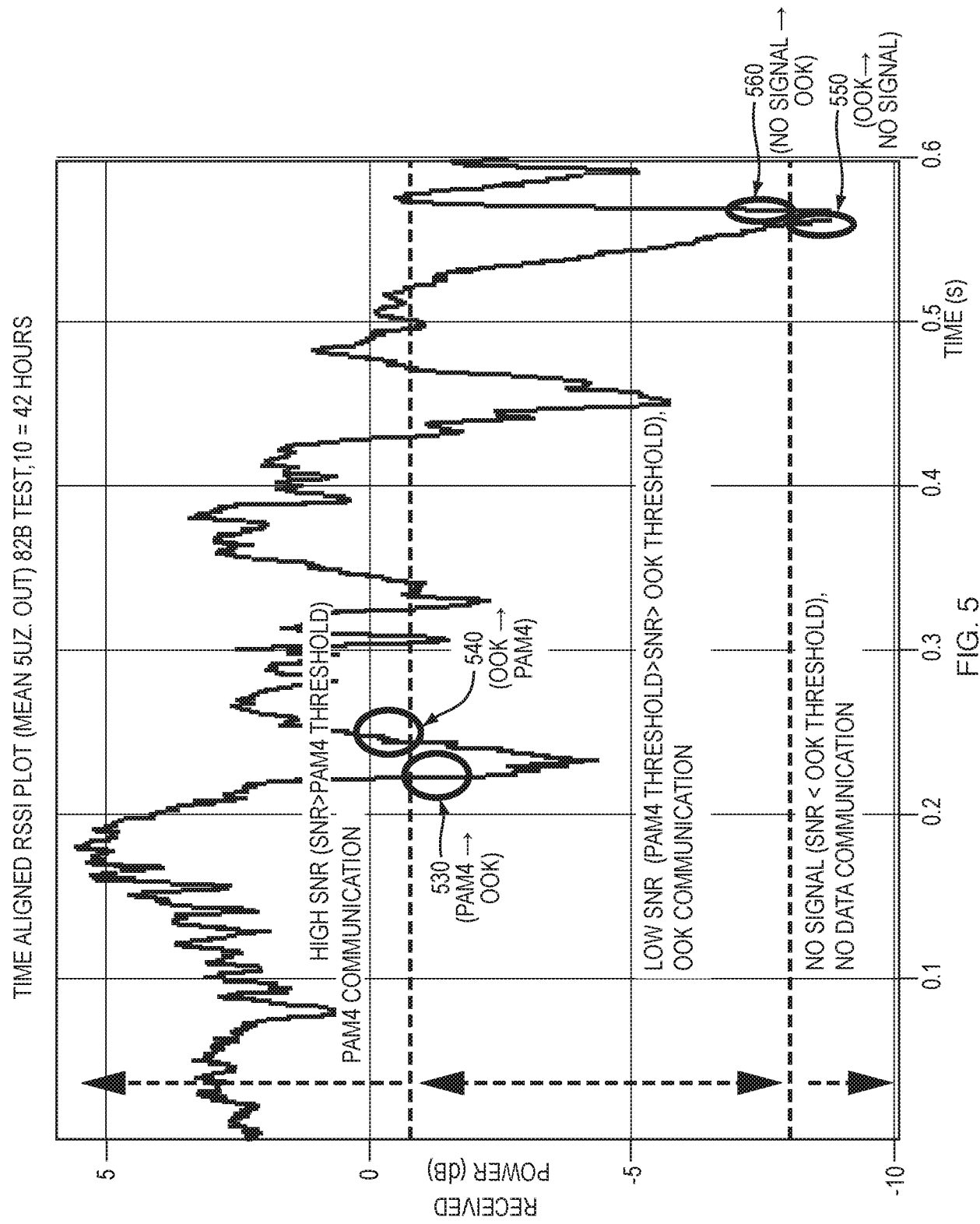


FIG. 5

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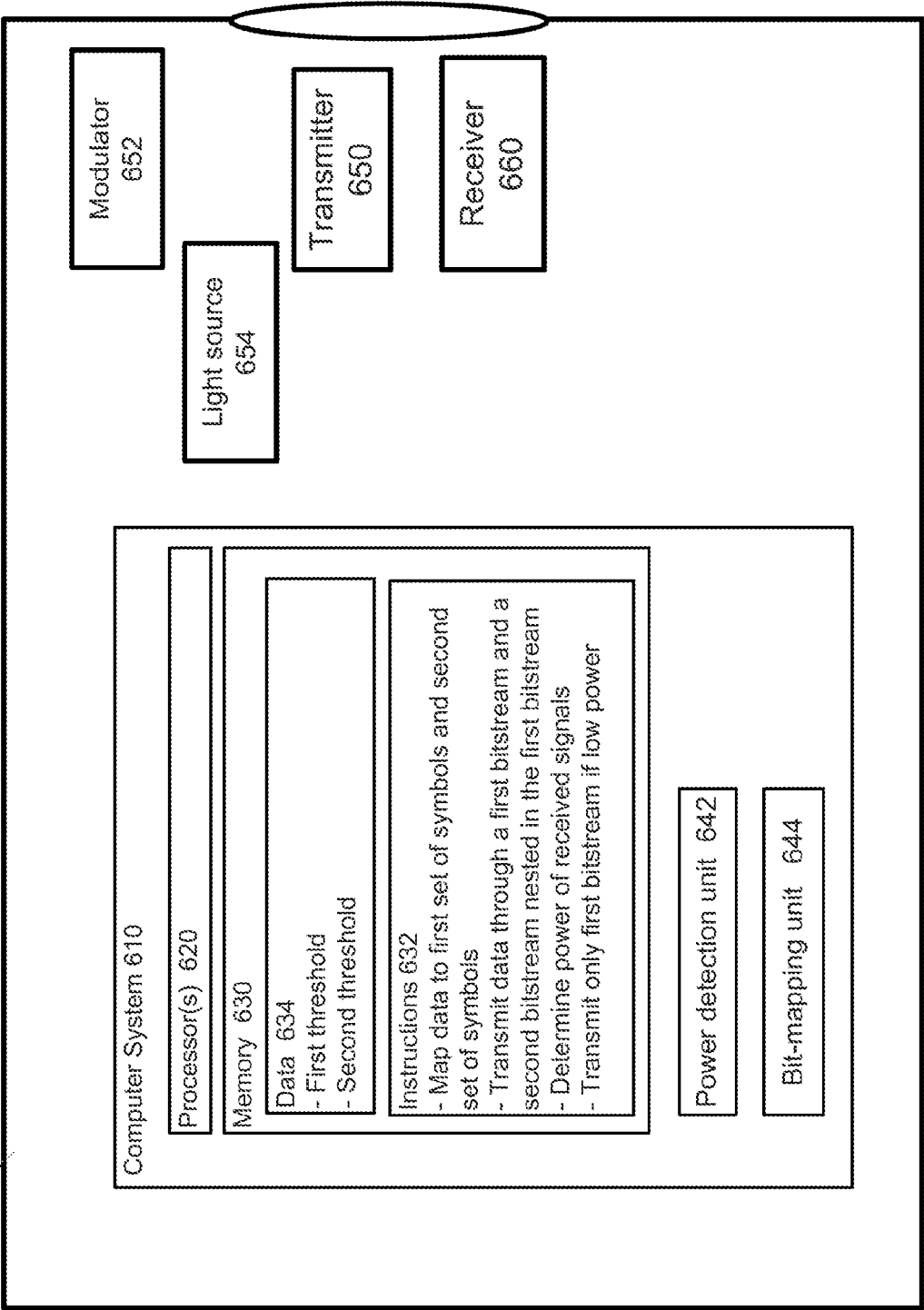


FIG. 6

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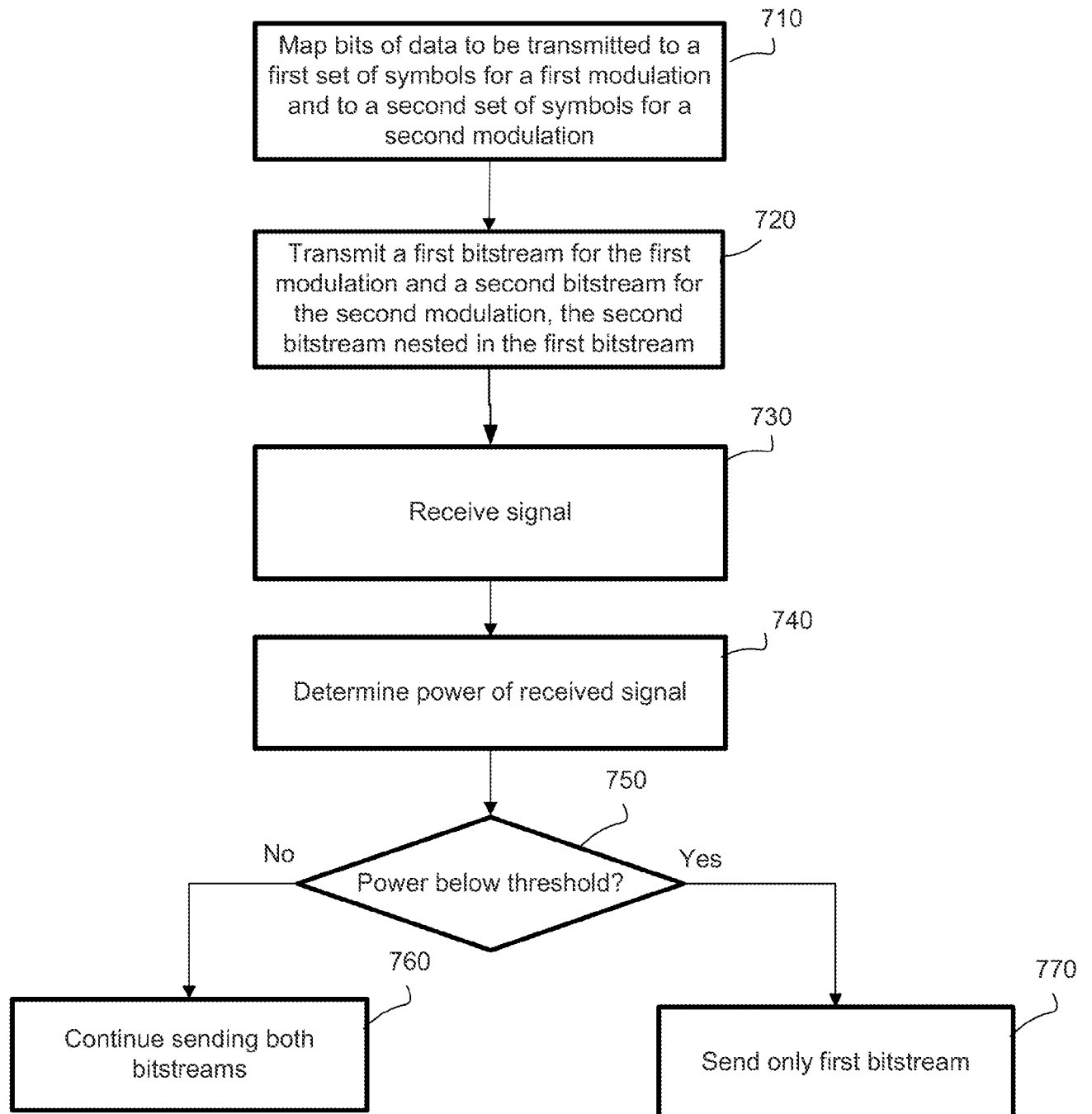
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Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/064193**A. CLASSIFICATION OF SUBJECT MATTER****H04L 27/00(2006.01)i, H04L 27/04(2006.01)i**

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)

H04L 27/00; H04L 1/00; H04B 10/2507; H04J 11/00; H04W 52/28; H04W 52/24; G02F 1/225; H04W 72/04; H04B 10/2575; H04L 27/04

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: map, adjust, transmission rate, power, OOK, PAM

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015-0282185 A1 (FUTUREWEI TECHNOLOGIES, INC.) 01 October 2015 See paragraphs [0008], [0027], [0036], [0107]; claims 1, 10, 41; and figure 1 2B.	1-7, 11-18, 20
Y		8-10, 19
Y	US 2016-0099775 A1 (FUTUREWEI TECHNOLOGIES, INC.) 07 April 2016 See paragraphs [0032], [0065]; claim 16; and figures 1, 4.	8-10, 19
A	US 2007-0291639 A1 (ERIC A. JACOBSEN et al.) 20 December 2007 See paragraphs [0012]-[0058]; and figures 1-5.	1-20
A	US 2013-0051346 A1 (JOHAN MIKAEL BERGMAN et al.) 28 February 2013 See paragraphs [0012]-[0019]; and figures 1-3.	1-20
A	US 2016-0103382 A1 (ODILE LIBOIRON-LADOUCEUR et al.) 14 April 2016 See abstract; and claim 1.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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"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

15 March 2018 (15.03.2018)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/064193

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015-0282185 A1	01/10/2015	CN 106465365 A EP 3130190 A1 EP 3130190 A4 WO 2015-144094 A1	22/02/2017 15/02/2017 19/07/2017 01/10/2015
US 2016-0099775 A1	07/04/2016	AU 2015-327566 A1 CA 2963504 A1 CN 106716878 A EP 3189604 A1 JP 2017-536011 A KR 10-2017-0062512 A SG 11201702630 PA US 09590730 B2 US 09843390 B2 US 2017-149503 A1 WO 2016-050079 A1	07/04/2016 07/04/2016 24/05/2017 12/07/2017 30/11/2017 07/06/2017 27/04/2017 07/03/2017 12/12/2017 25/05/2017 07/04/2016
US 2007-0291639 A1	20/12/2007	AT 363798 T AT 414375 T AT 429752 T AT 485647 T AT 493856 T AT 508607 T AT 511729 T AT 526753 T AT 527771 T AT 542345 T CN 100521596 C CN 101032127 A CN 101032127 B CN 101112061 A CN 101112061 B CN 101888365 A CN 101888365 B CN 101895502 A CN 101895502 B CN 101895509 A CN 101895509 B CN 101924732 A CN 101924732 B CN 102164107 A CN 102164107 B CN 102176691 A CN 102176691 B CN 102571293 A CN 102571293 B CN 103152132 A CN 103152132 B CN 103178884 A	15/06/2007 15/11/2008 15/05/2009 15/11/2010 15/01/2011 15/05/2011 15/06/2011 15/10/2011 15/10/2011 15/02/2012 29/07/2009 05/09/2007 29/10/2014 23/01/2008 28/03/2012 17/11/2010 20/06/2012 24/11/2010 06/03/2013 24/11/2010 17/07/2013 22/12/2010 05/06/2013 24/08/2011 20/11/2013 07/09/2011 22/10/2014 11/07/2012 08/07/2015 12/06/2013 07/12/2016 26/06/2013

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/064193

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		CN 103178884 B	22/06/2016
		CN 103227700 A	31/07/2013
		CN 1677915 A	05/10/2005
		CN 1849769 A	18/10/2006
		CN 1849769 B	16/06/2010
		CN 1849772 A	18/10/2006
		CN 1849772 C	18/10/2006
		CN 1849788 A	18/10/2006
		CN 1849788 C	18/10/2006
		CN 1853373 A	25/10/2006
		CN 1853373 C	25/10/2006
		CN 1853374 A	25/10/2006
		CN 1853374 C	25/10/2006
		CN 1853375 A	25/10/2006
		CN 1853375 C	25/10/2006
		CN 1856976 A	01/11/2006
		CN 1856976 B	14/12/2011
		CN 1856976 C	01/11/2006
		CN 1860714 A	08/11/2006
		CN 1860714 B	07/12/2011
		CN 1860714 C	08/11/2006
		CN 1864360 A	15/11/2006
		CN 1864360 B	03/11/2010
		CN 1864360 C	15/11/2006
		CN 1864375 A	15/11/2006
		CN 1864375 B	09/05/2012
		CN 1864375 C	15/11/2006
		CN 1864381 A	15/11/2006
		CN 1864381 B	23/03/2011
		CN 1864381 C	15/11/2006
		CN 1871807 A	29/11/2006
		CN 1871807 B	08/09/2010
		CN 1883151 A	20/12/2006
		CN 1883151 B	16/06/2010
		CN 1890907 A	03/01/2007
		CN 1890907 B	05/10/2011
		CN 1894864 A	10/01/2007
		CN 1894864 C	10/01/2007
		CN 1894917 A	10/01/2007
		CN 1894917 B	20/04/2011
		CN 1894917 C	10/01/2007
		CN 1898893 A	17/01/2007
		CN 1898893 B	05/10/2011
		CN 1902828 A	24/01/2007
		CN 1902828 B	29/02/2012
		CN 1902828 C	24/01/2007
		CN 1922841 A	28/02/2007
		CN 1922841 B	03/11/2010
		CN 1926830 A	07/03/2007
		CN 1926830 B	29/12/2010

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/064193

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		CN 1926830 C	07/03/2007
		CN 1930825 A	14/03/2007
		CN 1930825 B	18/05/2011
		CN 1930842 A	14/03/2007
		CN 1930842 B	06/07/2011
		CN 1930843 A	14/03/2007
		CN 1930843 B	08/08/2012
		CN 1965554 A	16/05/2007
		CN 1965554 B	05/10/2011
		DE 112005002295 T5	27/09/2007
		DE 602004017753 D1	24/12/2008
		DE 602004032567 D1	16/06/2011
		DE 602005001269 D1	12/07/2007
		DE 602005001269 T2	31/01/2008
		DE 602005014083 D1	04/06/2009
		DE 602005024233 D1	02/12/2010
		DE 602005025595 D1	10/02/2011
		DK 1712043 T3	29/06/2009
		DK 2056637 T3	04/07/2011
		EP 1652317 A1	03/05/2006
		EP 1652350 A1	03/05/2006
		EP 1652361 A1	03/05/2006
		EP 1652362 A2	03/05/2006
		EP 1652362 B1	18/01/2012
		EP 1656737 A1	17/05/2006
		EP 1661281 A1	31/05/2006
		EP 1661287 A1	31/05/2006
		EP 1661287 B1	05/10/2011
		EP 1661321 A1	31/05/2006
		EP 1661321 B1	28/09/2011
		EP 1661322 A1	31/05/2006
		EP 1661349 A2	31/05/2006
		EP 1661349 B1	12/11/2008
		EP 1665614 A2	07/06/2006
		EP 1665616 A2	07/06/2006
		EP 1665704 A2	07/06/2006
		EP 1665704 B1	06/11/2013
		EP 1692825 A1	23/08/2006
		EP 1692825 B1	04/05/2011
		EP 1704693 A1	27/09/2006
		EP 1709762 A1	11/10/2006
		EP 1712024 A1	18/10/2006
		EP 1712027 A1	18/10/2006
		EP 1712027 B1	27/07/2016
		EP 1712043 A1	18/10/2006
		EP 1712043 B1	22/04/2009
		EP 1712102 A1	18/10/2006
		EP 1712102 B1	29/12/2010
		EP 1714417 A1	25/10/2006
		EP 1714417 B1	20/10/2010

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/064193

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		EP 1714453 A1	25/10/2006
		EP 1714453 B1	30/05/2007
		EP 1714454 A1	25/10/2006
		EP 1733523 A1	20/12/2006
		EP 1745574 A2	24/01/2007
		EP 1916793 A2	30/04/2008
		EP 1916793 A3	01/10/2008
		EP 2056637 A2	06/05/2009
		EP 2056637 A3	15/07/2009
		EP 2056637 B1	01/06/2011
		EP 2173050 A2	07/04/2010
		EP 2173050 A3	23/06/2010
		EP 2267928 A1	29/12/2010
		EP 2273740 A2	12/01/2011
		EP 2273740 A3	04/05/2011
		EP 2273740 B1	09/07/2014
		EP 2804339 A1	19/11/2014
		ES 2326087 T3	30/09/2009
		ES 2365512 T3	06/10/2011
		ES 2366519 T3	21/10/2011
		ES 2372818 T3	26/01/2012
		ES 2373722 T3	08/02/2012
		GB 2433009 A	06/06/2007
		HK 1089307 A1	05/10/2012
		HK 1094103 A1	16/09/2011
		HK 1097367 A1	21/04/2017
		HK 1097382 A1	26/08/2011
		HK 1100471 A1	03/08/2012
		HK 1152421 A1	28/11/2014
		HK 1161942 A1	13/06/2014
		JP 04327851 B2	09/09/2009
		JP 04358859 B2	04/11/2009
		JP 2007-502071 A	01/02/2007
		JP 2007-502072 A	01/02/2007
		JP 2007-502074 A	01/02/2007
		JP 2007-502076 A	01/02/2007
		JP 2007-502077 A	01/02/2007
		JP 2007-502078 A	01/02/2007
		JP 2007-502079 A	01/02/2007
		JP 2007-506303 A	15/03/2007
		JP 2007-506304 A	15/03/2007
		JP 2007-506307 A	15/03/2007
		JP 2007-507133 A	22/03/2007
		JP 2007-520935 A	26/07/2007
		JP 2011-019231 A	27/01/2011
		JP 4396993 B2	13/01/2010
		JP 4459960 B2	28/04/2010
		JP 5065454 B2	31/10/2012
		KR 10-0751161 B1	22/08/2007
		KR 10-0791311 B1	04/01/2008

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/064193

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		KR 10-0824814 B1	23/04/2008
		KR 10-0825585 B1	25/04/2008
		KR 10-0845934 B1	11/07/2008
		KR 10-0872190 B1	09/12/2008
		KR 10-2006-0029193 A	04/04/2006
		KR 10-2006-0032649 A	17/04/2006
		KR 10-2006-0039452 A	08/05/2006
		KR 10-2006-0113751 A	02/11/2006
		MY 136499 A	31/10/2008
		MY 136642 A	28/11/2008
		MY 137109 A	31/12/2008
		MY 137452 A	30/01/2009
		MY 137504 A	27/02/2009
		MY 139177 A	28/08/2009
		MY 141800 A	30/06/2010
		MY 141977 A	16/08/2010
		MY 142160 A	15/10/2010
		MY 144161 A	15/08/2011
		MY 144415 A	15/09/2011
		MY 148413 A	30/04/2013
		MY 156404 A	26/02/2016
		TW 1276317 B	11/03/2007
		TW 1302413 B	21/10/2008
		TW 1303521 B	21/11/2008
		TW 1311010 B	11/06/2009
		TW 1316352 B	21/10/2009
		TW 200511736 A	16/03/2005
		TW 200511740 A	16/03/2005
		TW 200511753 A	16/03/2005
		TW 200513062 A	01/04/2005
		TW 200520443 A	16/06/2005
		TW 200524330 A	16/07/2005
		TW 200533088 A	01/10/2005
		TW 200533105 A	01/10/2005
		TW 200534600 A	16/10/2005
		TW 200603588 A	16/01/2006
		TW 200620863 A	16/06/2006
		TW 200627875 A	01/08/2006
		TW 250728 B	01/03/2006
		TW 264192 B	11/10/2006
		TW 264891 B	21/10/2006
		TW 272777 A	01/02/2007
		TW 272777 B	01/02/2007
		TW 272789 B	01/02/2007
		TW 285479 B	11/08/2007
		US 07039412 B2	02/05/2006
		US 07213197 B2	01/05/2007
		US 07245879 B2	17/07/2007
		US 07263651 B2	28/08/2007
		US 07286609 B2	23/10/2007

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/064193

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		US 07289585 B2	30/10/2007
		US 07315577 B2	01/01/2008
		US 07321614 B2	22/01/2008
		US 07324605 B2	29/01/2008
		US 07333556 B2	19/02/2008
		US 07345989 B2	18/03/2008
		US 07373112 B2	13/05/2008
		US 07394858 B2	01/07/2008
		US 07395495 B2	01/07/2008
		US 07408908 B2	05/08/2008
		US 07423968 B2	09/09/2008
		US 07440423 B2	21/10/2008
		US 07440510 B2	21/10/2008
		US 07460494 B2	02/12/2008
		US 07474608 B2	06/01/2009
		US 07515541 B2	07/04/2009
		US 07567612 B2	28/07/2009
		US 07570953 B2	04/08/2009
		US 07665008 B2	16/02/2010
		US 07672365 B2	02/03/2010
		US 07738579 B2	15/06/2010
		US 07769097 B2	03/08/2010
		US 07822135 B2	26/10/2010
		US 07826798 B2	02/11/2010
		US 07839836 B2	23/11/2010
		US 07885346 B2	08/02/2011
		US 07929632 B2	19/04/2011
		US 08019010 B2	13/09/2011
		US 08126077 B2	28/02/2012
		US 08315321 B2	20/11/2012
		US 08396147 B2	12/03/2013
		US 08478201 B2	02/07/2013
		US 08565253 B2	22/10/2013
		US 08699508 B2	15/04/2014
		US 08705645 B2	22/04/2014
		US 08824582 B2	02/09/2014
		US 08903003 B2	02/12/2014
		US 09001636 B2	07/04/2015
		US 09270429 B2	23/02/2016
		US 09379863 B2	28/06/2016
		US 2005-030897 A1	10/02/2005
		US 2005-031047 A1	10/02/2005
		US 2005-032478 A1	10/02/2005
		US 2005-032514 A1	10/02/2005
		US 2005-034053 A1	10/02/2005
		US 2005-041611 A1	24/02/2005
		US 2005-058212 A1	17/03/2005
		US 2005-058217 A1	17/03/2005
		US 2005-068916 A1	31/03/2005
		US 2005-128936 A1	16/06/2005

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/064193

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		US 2005-129101 A1	16/06/2005
		US 2005-135410 A1	23/06/2005
		US 2005-136910 A1	23/06/2005
		US 2005-136933 A1	23/06/2005
		US 2005-144307 A1	30/06/2005
		US 2005-147076 A1	07/07/2005
		US 2005-147115 A1	07/07/2005
		US 2005-152299 A1	14/07/2005
		US 2005-152328 A1	14/07/2005
		US 2005-152330 A1	14/07/2005
		US 2005-152357 A1	14/07/2005
		US 2005-152465 A1	14/07/2005
		US 2005-152466 A1	14/07/2005
		US 2005-152473 A1	14/07/2005
		US 2005-152484 A1	14/07/2005
		US 2005-154957 A1	14/07/2005
		US 2005-154958 A1	14/07/2005
		US 2005-157682 A1	21/07/2005
		US 2005-157695 A1	21/07/2005
		US 2005-157734 A1	21/07/2005
		US 2005-166131 A1	28/07/2005
		US 2005-174927 A1	11/08/2005
		US 2008-181162 A1	31/07/2008
		US 2008-198760 A1	21/08/2008
		US 2008-253471 A1	16/10/2008
		US 2009-147879 A1	11/06/2009
		US 2009-245405 A1	01/10/2009
		US 2009-252257 A1	08/10/2009
		US 2010-098181 A1	22/04/2010
		US 2010-195545 A1	05/08/2010
		US 2011-013524 A1	20/01/2011
		US 2011-096856 A1	28/04/2011
US 2013-0051346 A1	28/02/2013	CA 2673280 A1	26/06/2008
		CN 101563857 A	21/10/2009
		CN 101563857 B	25/12/2013
		CN 103647731 A	19/03/2014
		CN 103647731 B	26/04/2017
		EP 2095529 A2	02/09/2009
		EP 2095529 A4	03/06/2015
		NZ 577332 A	12/01/2012
		US 08369260 B2	05/02/2013
		US 09867145 B2	09/01/2018
		US 2010-0022284 A1	28/01/2010
		WO 2008-076065 A2	26/06/2008
US 2016-0103382 A1	14/04/2016	WO 2008-076065 A3	14/08/2008
		US 9470951 B2	18/10/2016