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(54) Title: MODULATION AND DEMODULATION METHODS FOR POLARIZED SIGNAL TRANSMISSION PRESENTING AN IMPROVED BIT RATE

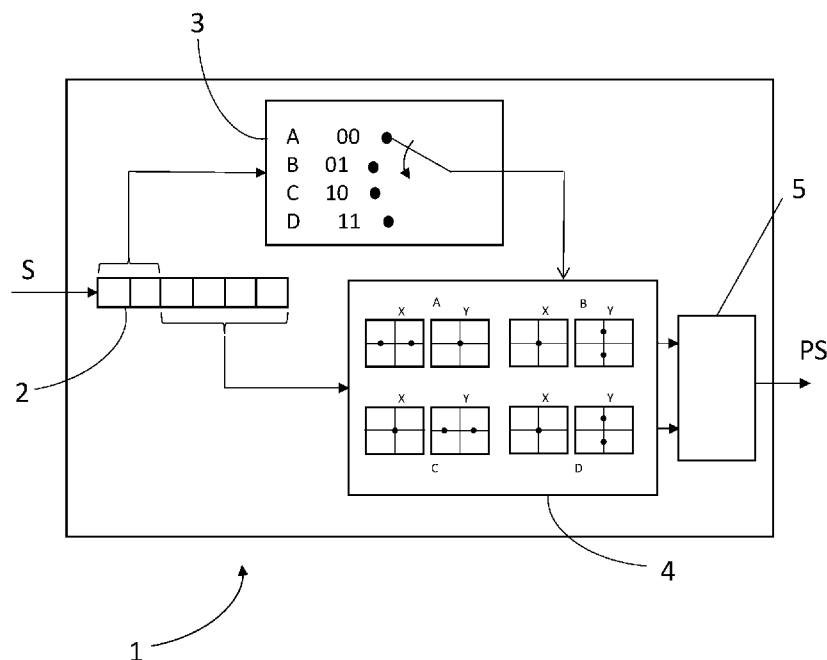


Figure 2

(57) Abstract: The invention concerns a modulation method for modulating a stream (S) of binary data into a polarized signal (PS), the method comprising : providing a segment from the stream (S) of binary data, the segment comprising at least 4 bits; extracting two bits from the segment; decoding the two bits to select a modulation scheme among four binary phase shift keying modulation scheme presenting distinct constellation diagrams; and modulating the remaining bits of the segment into the polarized signal using the selected modulation scheme. The invention also relates to the converse demodulation method.



MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
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MODULATION AND DEMODULATION METHODS FOR POLARIZED SIGNAL
TRANSMISSION PRESENTING AN IMPROVED BIT RATE.

FIELD OF THE INVENTION

The present invention relates to digital modulation and demodulation methods, for transmitting data over a communication channel.

BACKGROUND OF THE INVENTION

Phase Shift Keying (PSK) is a very well-known scheme for modulating a stream of binary data for transmission over a communication channel. In a PSK scheme, the binary information (symbols) is embedded in the phase of a generally sinusoidal carrier. The resulting signal is transmitted over a communication channel, and demodulated at the other extremity to provide the original symbol. As it is well known, a PSK scheme is defined by a constellation diagram, associating a definite number of symbols to phases represented as points lying on a circle in a complex plane.

A PSK scheme can be adapted to modulate a stream of binary data into a polarized signal, for instance by polarization multiplexing of two PSK modulated signals. With the two polarizations orthogonal, the spectral efficiency is doubled compared to a standard PSK scheme.

Figure 1 represents the constellation diagram for Binary PSK modulation. As seen on this figure, two phases separated by 180° are used to modulate a symbol consisting of one bit of information. BPSK is known to form a robust modulation scheme, since it requires much distortion to the transmitted signal for the demodulator to decode the information wrongly. Since each symbol only represent one bit, BPSK is usually not used for applications that require high transmission bit-rates.

OBJECT OF THE INVENTION

The present invention aims at improving bit rate transmission using a polarized signal, in particular for application presenting a low signal to noise ratio, and thus requiring a robust modulation scheme.

SUMMARY OF THE INVENTION

To this effect, one aspect of the invention relates to a modulation method for modulating a stream of binary data into a polarized signal, the method comprising :

- providing a segment from the stream of binary data, the segment comprising at least 4 bits;
- extracting two bits from the segment;
- decoding the two bits to select a modulation scheme among four binary phase shift keying modulation scheme presenting distinct constellation diagrams;
- modulating the remaining bits of the segment into the polarized signal using the selected modulation scheme.

Another aspect of the invention relates to a demodulation method for demodulating a polarized signal into a stream of binary data, the method comprising :

- demodulating the polarized signal concurrently using four binary phase shift keying demodulation schemes presenting distinct constellation diagrams to provide four pluralities of demodulated bits and four demodulation error estimates, each of the demodulation scheme being associated with a two bits codeword ;

- selecting the most appropriate plurality of bits among the four pluralities of demodulated bits, that corresponds to the demodulation scheme providing the lowest demodulation error estimates;
- merging the most appropriate plurality of demodulated bits with the two bits codeword that is associated with the demodulation scheme providing the lowest demodulation error estimates to form a segment of the stream of binary data.

In the modulation/demodulation method according to the invention, the information contained in the stream of binary data is encoded both in the modulated bits and in the choice of the modulation scheme. This allows to increase significantly the bit rate of the communication channel.

According to further non-limitative features of the invention, either taken alone or in any technically feasible combination:

- the modulation method further comprises repeating the providing, extracting, decoding and modulating steps on contiguous segments of the stream of binary data;
- the demodulation method further comprises repeating the demodulating, selecting and merging steps to provide contiguous segment of the stream of binary data;
- the distinct constellation diagrams are:
 - o A first constellation diagram being a BPSK diagram in a first polarization direction only ;
 - o a second constellation diagram being a BPSK diagram in the first polarization direction only, the BPSK diagram of the second constellation diagram corresponding to the rotation by 90° in the complex

- plane of the BPSK diagram of the first constellation diagram;
- o a third constellation diagram being a BPSK diagram in a second polarization direction only, perpendicular to the first polarization direction, the BPSK diagram in the second polarization direction of the third constellation diagram being identical to the BPSK diagram in the first polarization direction of the first constellation diagram ;
 - o a fourth constellation diagram being a BPSK diagram in the second polarization direction only, the BPSK diagram of the fourth constellation diagram corresponding to the rotation by 90° in the complex plane of the BPSK diagram of the third constellation diagram;
- the segment comprises at least six bits.

FIGURES

Many other features and advantages of the present invention will become apparent from reading the following detailed description, when considered in conjunction with the accompanying drawings, in which:

- Figure 1 represents the constellation diagram for Binary PSK modulation;
- Figure 2 represents schematically a modulation method and a modulator according to one embodiment of the invention;

- Figure 3 represents the constellation diagram of four BPSK modulation schemes according to a preferred embodiment of the invention;
- Figure 4 represents schematically a demodulation method and a demodulator according to an embodiment of the invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS OF THE INVENTION

Figure 2 represents schematically a modulation method and a modulator 1 according to one embodiment of the invention. The modulator 1 is transforming a stream of binary data S into a polarized signal PS. Modulator 1 can form an optical transmitter coupled to one extremity of a fiber optic communication channel. The communication channel presents a first polarization direction X, and second polarization directions Y.

The modulator 1 comprises a demultiplexer register 2, a constellation mapper 3, a bit mapper 4 and polarized signal generator 5.

The stream S of binary data enters the demultiplexer register 2. The register 2 provides a segment from the stream S of binary data, for further processing.

Two bits of the segment, forming a codeword, are extracted from register 2. Those two bits may be located at any position in the register to the extent that those positions are fixed and known, such that that the segment of binary data can reconstructed in its original form at a receiver side of the communication channel.

The codeword constituted by the extracted two bits is provided to constellation mapper 3 and decoded to select a modulation scheme, among four BPSK modulation scheme A, B, C, D. In the embodiment illustrated on figure 1, the extracted two bits "0,0", "0,1", "1,0", and "1,1" are respectively selecting a first BPSK modulation scheme A, a second BPSK modulation scheme B, a third BPSK modulation scheme C, and a BPSK fourth modulation scheme D. The four modulation schemes A, B, C, D are different from each other's, meaning that they present distinct constellation diagrams.

Since the transmission is performed on a communication channel presenting two polarization directions X, Y, the constellation diagrams are comprising two parts, each part being associated with a polarization direction.

Advantageously, to preserve the robustness of the BPSK, each modulation scheme A, B, C, D are encoding symbols formed of a single bit.

As it is apparent on figure 2, the remaining bits of the segment stored in the demultiplexer register 2 are provided to bit mapper 4. For avoidance of doubt, the expression "remaining bits" is designating the bits of the segment that are not included in the two bits codeword. Bit mapper 4 is providing the successive phase values, for each polarization direction X, Y, associated with the remaining bits of the segment, using the selected modulation scheme. The phases are provided to signal generator 5 that combines the successive phases with a carrier of appropriate polarization, and merge the generated signals to form the polarized signal PS. In other terms, the remaining bits of the segment are modulated into the polarized signal using the selected modulation scheme.

In the modulation method according to the invention, the information contained in the stream S of binary data is encoded both in the transmitted bits and in the choice of the modulation scheme. This approach allows to increase significantly the bit rate of the communication channel. For instance, when a segment is composed of 6 bits, the bit rate of the proposed modulation method is increased by 33% over a standard BPSK modulation scheme.

To allow detection at the other extremity of the communication channel, the demultiplexer register 2 is configured to store segment of at least 4 bits, such that the same modulation scheme is used for two or more transmitted bits. Preferably, the demultiplexer register 2 is configured to store a segment comprising at least 6 bits such that the bit error rate of the transmission is maintained closed to the bit error rate of a standard BPSK modulation.

It is worth noting that the proposed modulation scheme does not degrade significantly the bit error rate or impact the required signal to noise ratio as compared to a standard BPSK modulation.

According to a preferred embodiment, and as represented on figure 3, the constellation diagrams defining the 4 BPSK modulation schemes A, B, C, D are defined as follows.

The first constellation diagram A is a BPSK diagram in the first polarization direction X only. The second polarization direction is not used.

The second constellation diagram B is also a BPSK diagram in the first polarization direction X only, corresponding to the rotation by 90° in the complex plane of the BPSK diagram in the first direction of the first constellation diagram.

The third constellation diagram C comprises a BPSK diagram in the second polarization direction Y only. The third

constellation diagram is corresponding to the first constellation diagram switched into the second polarization direction Y.

The fourth constellation diagram D also comprises a BPSK diagram in the second polarization direction Y only, corresponding to the rotation by 90° in the complex plane of the BPSK diagram in the second polarization direction Y of the third constellation diagram.

Using the modulation schemes of the preferred embodiment is advantageous because it preserves the robustness of the BPSK modulation scheme without requiring more energy, since a single polarization direction is activated at a time.

Figure 4 represents schematically a demodulation method and a demodulator 6 according to an embodiment of the invention. The demodulator 6 is transforming the polarized signal PS, as modulated by the modulator 1 according to the invention, into a stream S of binary data originally transmitted over the communication channel. The demodulator 6 is paired with the modulator 1, it shares the same constellation diagram, associated codeword and length of encoded/decoded segment.

The demodulator 6 can be implemented as an optical receiver coupled to the other extremity of the fiber optic communication channel.

Demodulator 6 comprises a signal conditioner 7, a constellation demapper 8, a selector 9 and a multiplexer register 10.

The polarized signal PS enter the signal conditioner 7 for instance to split the two polarization directions and recover the encoded phase in each polarization direction X, Y. Those informations are provided to constellation demapper 8.

The polarization signal is demodulated using concurrently the four BPSK modulation scheme, presenting the distinct constellation diagram used in the modulator. The constellation demapper 8 provides four pluralities of bits and four demodulation error estimates. Demodulation error estimates corresponds for instance to the squared error, in the complex plane of a constellation diagram, of the phase decoded from the received signal versus the exact phase of the constellation diagram.

Once the expected number of bits have been received and decoded, selector 9 selects the most appropriate plurality of bits among the four decoded pluralities, i.e. the demodulated bits that corresponds to the demodulation scheme providing the lowest demodulation error estimate.

Then the selected plurality of bits is combined in the multiplexer register 10 with the codeword associated to the selected demodulation scheme to provide a segment of the stream S of binary data.

The modulation and demodulation method have been explained on a segment of the stream of binary data, and obviously, the different step of the methods can be repeated to provide a continuous transmission. More specifically, the modulation method is repeating the providing, extracting, decoding and modulating steps on contiguous segments of the stream S of binary data. Similarly, the demodulation method is repeating the demodulating, selecting and merging steps to provide contiguous segment of the stream S of binary data.

The functions performed by the modulator 1, demodulator 6 and all included elements may be implemented in various forms. They may comprise optical or electronic devices, or comprised a microprocessor configured to execute a program stored in an associated memory, or comprised programmable hardware elements such as FPGA.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In particular, the invention is not limited to the BPSK constellation represented on figure 1 and 3, and any BPSK constellation in the complex plan may be used.

CLAIMS

1. A modulation method for modulating a stream (S) of binary data into a polarized signal (PS), the method comprising :
 - Providing a segment from the stream (S) of binary data, the segment comprising at least 4 bits;
 - Extracting two bits from the segment;
 - Decoding the two bits to select a modulation scheme among four binary phase shift keying modulation scheme (A, B, C D) presenting distinct constellation diagrams;
 - Modulating the remaining bits of the segment into the polarized signal using the selected modulation scheme.
2. A modulation method according to claim 1, further comprising repeating the providing, extracting, decoding and modulating steps on contiguous segments of the stream (S) of binary data.
3. A demodulation method for demodulating a polarized signal (PS) into a stream (S) of binary data, the method comprising :
 - Demodulating the polarized signal concurrently using four binary phase shift keying demodulation schemes (A, B, C, D) presenting distinct constellation diagrams to provide four pluralities of demodulated bits and four demodulation error estimates, each of the demodulation scheme being associated with a two bits codeword ;
 - Selecting the most appropriate plurality of bits among the four pluralities of demodulated bits, that corresponds to the demodulation scheme providing the lowest demodulation error estimates;
 - Merging the most appropriate plurality of demodulated bits with the two bits codeword that is associated with

the demodulation scheme providing the lowest demodulation error estimates to form a segment of the stream (S) of binary data.

4. A demodulation method according to claim 3, further comprising repeating the demodulating, selecting and merging steps to provide contiguous segment of the stream of binary data.
5. A method as claimed in any preceding claims wherein the distinct constellation diagrams (A, B, C, D) are:
 - A first constellation diagram (A) being a BPSK diagram in a first polarization direction (X) only ;
 - a second constellation diagram (B) being a BPSK diagram in the first polarization direction (X) only, the BPSK diagram of the second constellation diagram corresponding to the rotation by 90° in the complex plane of the BPSK diagram of the first constellation diagram;
 - a third constellation diagram (C) being a BPSK diagram in a second polarization direction (Y) only, perpendicular to the first polarization direction (X), the BPSK diagram in the second polarization direction (Y) of the third constellation diagram (C) being identical to the BPSK diagram in the first polarization direction of the first constellation diagram (A) ;
 - a fourth constellation diagram (D) being a BPSK diagram in the second polarization direction (Y) only, the BPSK diagram of the fourth constellation diagram corresponding to the rotation by 90° in the complex plane of the BPSK diagram of the third constellation diagram.
6. A method as claimed in any preceding claims wherein the segment comprises at least six bits.

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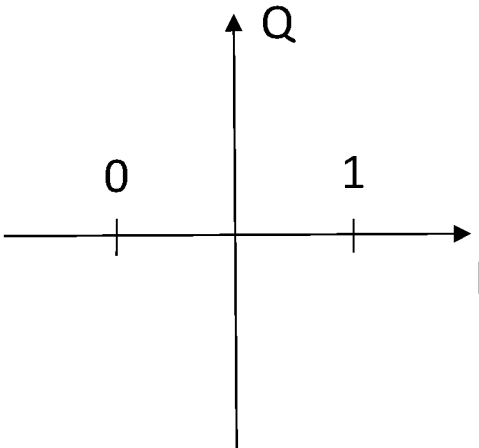


Figure 1

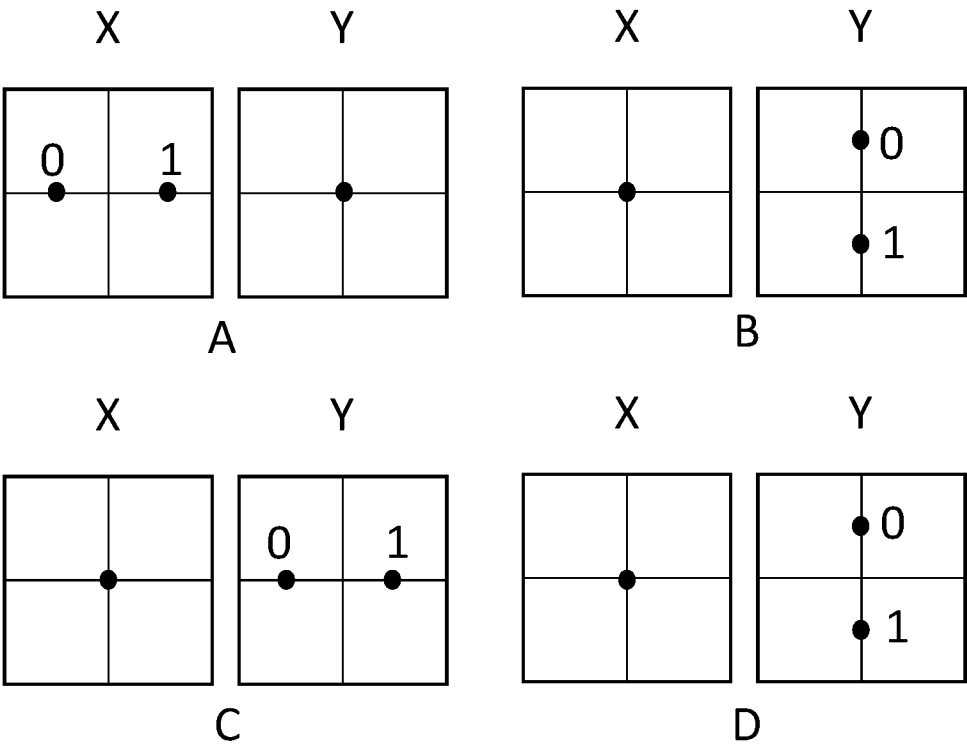


Figure 3

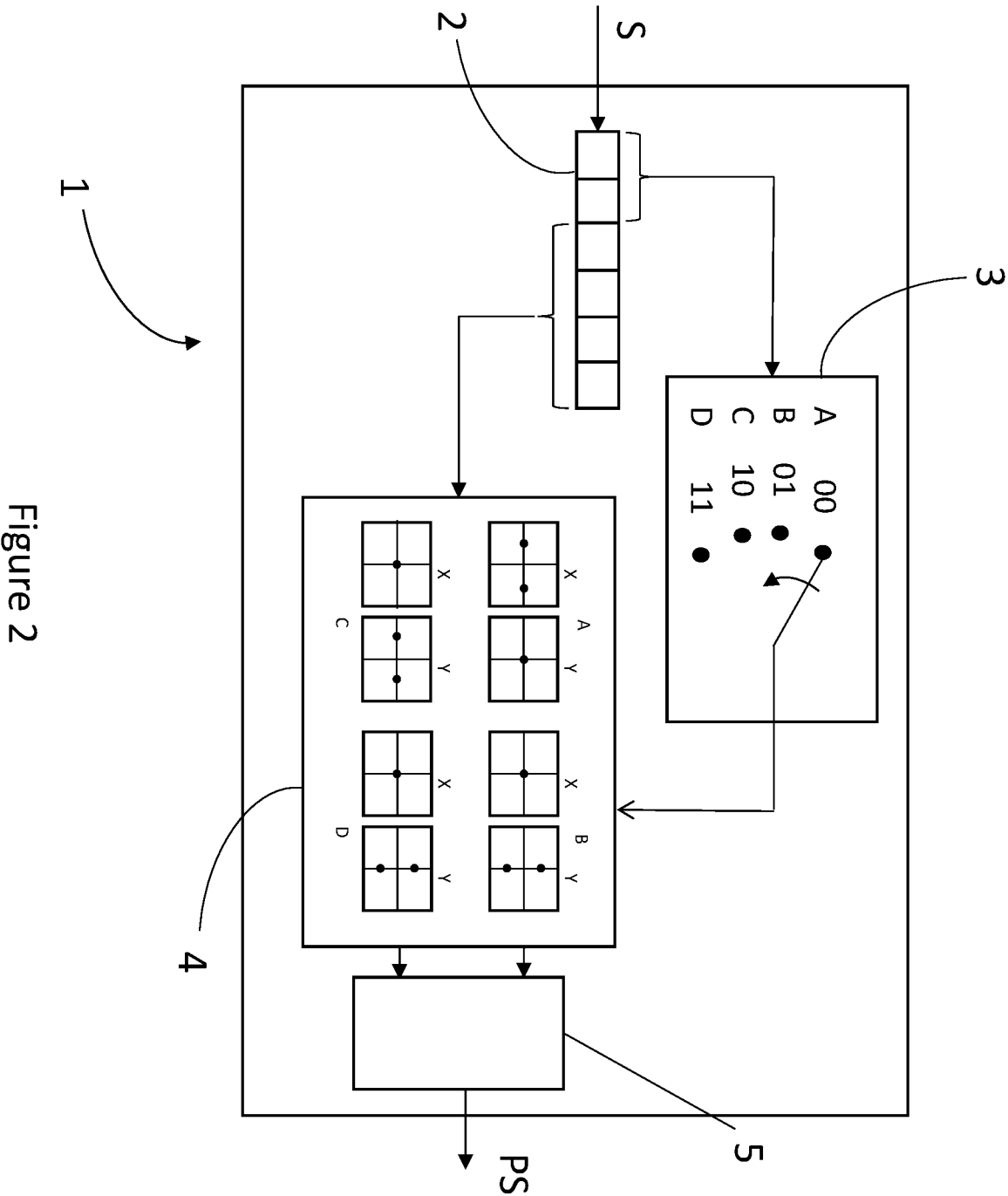
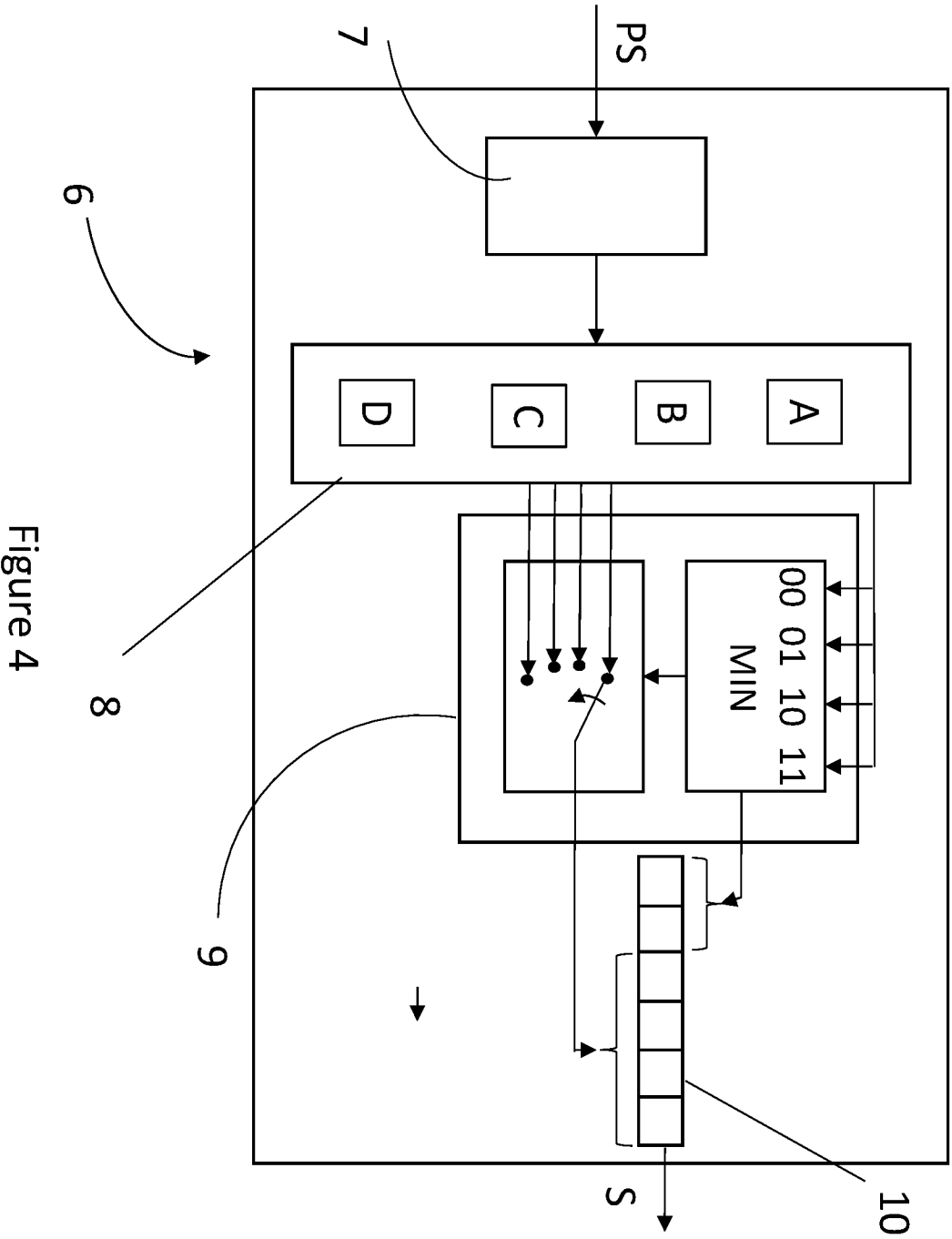


Figure 2



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B10/61 H04J14/06 H04L27/00 H04L27/18
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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)
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SOUMYA SUNDER DASH ET AL: "Receiver Algorithm for Decoding Constellation Modulation", ADVANCED PHOTONICS 2016 (IPR, NOMA, SENSORS, NETWORKS, SPPCOM, SOF), OSA TECHNICAL DIGEST (ONLINE) (OPTICAL SOCIETY OF AMERICA, 2016), PAPER SOM4F.4 PRESENTED IN THE SESSION OPTICAL FIBER DEVICES, SPECIALTY OPTICAL FIBERS 2016, VANCOUVER CANADA, 18-2, 18 July 2016 (2016-07-18), XP055484275, DOI: 10.1364/SPPCOM.2016.SpTu1F.3 ISBN: 978-1-943580-14-9 the whole document ----- -/-	1-6



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No
PCT/CH2018/050011

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WEI LU ET AL: "Transmission efficient modulation based on constellation switching in wireless communication", COMMUNICATIONS AND NETWORKING IN CHINA (CHINACOM), 2011 6TH INTERNATIONAL ICST CONFERENCE ON, IEEE, 17 August 2011 (2011-08-17), pages 98-101, XP032119879, DOI: 10.1109/CHINACOM.2011.6158127 ISBN: 978-1-4577-0100-9 the whole document	1-6
A	----- DASH SOUMYA SUNDER ET AL: "Approaching the shannon limit through constellation modulation", 2016 OPTICAL FIBER COMMUNICATIONS CONFERENCE AND EXHIBITION (OFC), OSA, 20 March 2016 (2016-03-20), pages 1-3, XP032942444, [retrieved on 2016-08-09] the whole document -----	1-6