

SYSTEM AND METHOD FOR OPTICAL COMMUNICATIONS, AND USE OF THE SYSTEM**TECHNICAL FIELD**

5 The present disclosure relates to a system and a method for optical communications. Said system and method may be used in free-space optical communications i.e. communications involving the transmission of optical pulses via free space e.g. via the atmosphere and/or space. Advantageously, said system and method may particularly be used for achieving the generation of a train of pulses, i.e. a series of pulses, comprising pulses of low and high
10 amplitudes corresponding to "0" and "1" bits, respectively, and for suppressing the "0" bit pulses relatively to the "1" bit pulses such that an extinction ratio is increased. The system may be or be called "apparatus" or "module".

STATE OF THE ART

15 There are known systems and methods for generating optical pulses for optical communications i.e. optical telecommunications. Typically, optical telecommunications are based on the generation, transmission and detection of optical signals which comprise successive pulses of different amplitudes. A lot of such systems are binary systems, wherein
20 the pulses have low or high amplitudes, with the low-amplitude pulses corresponding to "0" information bits, and the high-amplitude pulses corresponding to "1" information bits, such that the information being communicated is encoded in a series of successive "0" and "1" pulses.

Typically, said pulses, after being generated, are being transmitted over large distances via
25 optical fibers and/or via free-space. Then, in conventional telecommunication systems, the transmitted pulses are detected by a receiver-detector which can distinguish whether each pulse is a high-amplitude "1" bit pulse or a low-amplitude "0" bit pulse. For facilitating the distinction between the "1" and the "0" pulses by the receiver, and for reducing the probability of erroneously confusing a "0" pulse as a "1" or vice versa, it is desirable that the relative
30 difference of the amplitudes between the "0" and the "1" pulses is consistently large. When the difference is large, then the ratio between the amplitude, e.g. the power level, of the "1" bit pulse and the amplitude, e.g. the power level, of the "0" bit pulse will be large. Said ratio is commonly known as the extinction ratio, and it is used as a figure of merit of the quality of the optical signal. It is broadly considered that the higher the extinction ratio is, the better the optical

- signal's quality will be. However, this is not always achieved in many conventional systems in which the extinction ratio may consistently or temporarily be low, because during the generation of the "0" and "1" pulses environmental fluctuations or malfunctions may result to erroneously generating high amplitude "0" pulses which at the receiver may be mistakenly measured as being "1" pulses. This problem may become more pronounced in free-space telecommunications where during the transmission of the optical signal via free space, the attenuation of the transmitted "1" pulses may impose additional difficulties in correctly distinguishing between the "0" and the "1" pulses.
- It can be understood that the above not only apply in telecommunication systems which are based on the transmission of binary ("0" and "1") signals but may also apply in any optical telecommunication system which involves the generation, transmission, detection and optical pulses of different amplitudes. Hence, there is a need for systems and methods for optical communications which can address the problem of how to consistently provide pulses of different amplitudes in an optimized way for facilitating the correct detection and distinction between the pulses at a receiver's end, especially for optical communications via free space.

DESCRIPTION OF THE INVENTION

- The present invention overcomes the above problems, because it may consistently provide pulses of different amplitudes for optical communications in an optimized way for facilitating the correct detection of the pulses and their distinction. The present invention is particularly suitable for optical communications via free space. Advantageously, the invention of the present disclosure overcomes the above problems in a simple, cost-effective and easy to implement way, and may be applied for improving existing systems and infrastructure for optical telecommunications.

- The invention in a first aspect concerns a system for optical communications, wherein the system comprises a pulse generator, a modulator and a saturable noise suppressor. The pulse generator is configured to generate a train of pulses of electromagnetic radiation. Said train of pulses may also be referred to as "a series of pulses". The modulator is optically connected to the pulse generator and is configured to modulate the train via modulating an amplitude of at least some of the pulses of the train such that the modulated train comprises a first set of pulses and a second set of pulses, wherein the amplitude of the pulses of the first set is smaller than the amplitude of the pulses of the second set. The saturable noise suppressor is optically

connected to the modulator and comprises a saturable absorber. Also, the saturable noise suppressor is configured to receive the modulated train, attenuate the amplitude of the pulses of the first set, and output the pulses of the second set and the attenuated pulses of the first set.

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The saturable absorber advantageously enables the attenuation of the amplitude of the pulses of the first set by the saturable noise suppressor. In some embodiments the saturable absorber may be configured to operate in a transmission mode wherein the pulses are transmitted via the saturable absorber which thereby may attenuate the amplitude of the pulses. In some
10 other embodiments the saturable noise suppressor may be configured to operate in a reflection mode wherein the pulses are reflected by the saturable absorber which thereby may attenuate the amplitude of the pulses. Hence, the saturable absorber may be a saturable absorber mirror or reflector or may be a saturable absorber used in transmission. In a very preferred embodiment, the saturable absorber is a saturable absorber mirror, and the saturable noise
15 suppressor further comprises a circulator optically connected to the saturable absorber mirror.

Advantageously the latter configuration based on the circulator and the saturable absorber mirror promotes the simplicity, manufacturability, robustness and good operation of the system. In a very preferred embodiment of invention, the saturable absorber is a saturable
20 absorber mirror; the saturable noise suppressor further comprises a circulator which is optically connected to the saturable absorber mirror; and the saturable noise suppressor is configured to: receive the modulated train via (by means of) the circulator; attenuate the amplitude of the pulses of the first set via (i.e. by means of) the saturable absorber mirror; and output the pulses of the second set and the attenuated pulses of the first set via (i.e. by means of) the circulator.
25 In a preferred embodiment wherein the saturable absorber is a saturable absorber mirror, and the saturable noise suppressor further comprises a circulator which is optically connected to the saturable absorber mirror, in addition: the circulator comprises a first port connected to the modulator, a second port connected to the saturable absorber mirror, and a third port; the circulator is configured to receive the modulated train via the first port; the circulator is
30 configured to transmit, via the second port, the modulated train to the saturable absorber mirror; the saturable absorber mirror is configured to absorb the pulses of the first set or to attenuate them more strongly compared to the pulses of the second set, and to reflect the pulses of the first and the second sets; the circulator is configured to receive the reflected pulses; and the circulator is configured to output the received reflected pulses via the third port.

- The aforementioned configuration involving the circulator with the three ports, advantageously is a simple and easy to fabricate configuration which advantageously promotes and facilitates the good operation of the system. In some preferred embodiments which comprise a circulator with the three ports as describe above, the circulator is configured to receive the reflected pulses via the second port. In some other preferred embodiments which comprise a circulator with the three ports as describe above, the circulator further comprises a fourth port and is configured to receive the reflected pulses (i.e. the pulses reflected by the saturable mirror) via the fourth port.
- 10 In a preferred embodiment in which the system comprises a circulator, the circulator comprises a polarization-maintaining fiber. Using a polarization-maintaining fiber advantageously optimizes the operation of the saturable noise suppressor and the ability of the latter to improve the extinction ratio between the high-amplitude (first set) and the low-amplitude (second set) pulses. Saturable absorber mirrors can be sensitive to polarization of light. By using a
- 15 polarization maintainer configuration, advantageously it can be achieved that the pulses of the first set and the pulses of the second set may arrive at the saturable absorber mirror under the same conditions. Therefore, the attenuation of the pulses may not vary depending on the polarization of the light that enters the saturable noise suppressor.
- 20 The saturable noise suppressor, and particularly the saturable absorber, may also be able (i.e be configured) to absorb and attenuate the pulses of the second set. However, the potential attenuation of the amplitude of the pulses of the second set by the saturable noise suppressor may be much smaller or insignificant, or even challenging to measure and resolve, compared to the attenuation of the pulses of the first set. For example, in the optional case that the
- 25 saturable absorber is a saturable absorber mirror having a saturation fluence which is much smaller than the intensity or power density of a pulse of the second set received by the saturable absorber, it may be considered that the possible attenuation of that pulse of the second set by the saturable absorber is insignificant or negligible and hence, for practical purposes, can be ignored.
- 30 In a preferred embodiment, the pulse generator, the modulator and the saturable noise suppressor are optically connected via respective optical fiber sections. Using optical fibers sections, i.e. optical fibers, for connecting the pulse generator, the modulator and the saturable

noise suppressor advantageously promotes the compactness, durability and manufacturability of the system.

5 It is noted that in embodiments of the invention, one or more of the pulses of the first set may chronologically be generated and transmitted in between one or more pulses of the second set, and vice versa. Hence, one or more pulses of the first set may be preceded and/or followed by one or more pulses of the second set, and vice versa. Alternatively, albeit not very likely, all of the pulses of the first set may be preceded or followed by the pulses of the second set.

10 The pulse generator creates the train of pulses which may be visible light pulses, or they may be of a wavelength outside the visible spectrum e.g. be infrared pulses. However, preferably the wavelength(s) of the pulses is within one of the telecom windows which are typically used in optical telecommunications for minimizing the attenuation of the pulses during their transmission over large distances via optical fiber or free space. Hence, said wavelength(s) of
15 the pulses may for example be in the C-band ("erbium window") from 1530 nm to 1565 nm, particularly at about 1550 nm. It is possible to create pulses in the ultraviolet, visible or infrared using an optical source such as a laser, preferably a fiber laser. Said fiber laser may comprise a laser seed source and a preamplifier connected to the laser seed source and configured to receive and amplify seed pulses which are provided by the laser seed source. Said preamplifier
20 may comprise an erbium or an erbium/ytterbium doped fiber for amplifying pulses the wavelength of which is within the aforementioned C-band. Hence, in preferred embodiments of the invention the pulse generator is an optical source or an oscillator comprising a laser seed source and preferably an optical preamplifier connected to the laser seed source.

25 Preferably, the pulses being generated by the pulse generator have substantially similar or equal initial amplitudes for making easier the subsequent modulation of the pulses' amplitude by the modulator. Also, preferably the pulse generator generates the pulses at a substantially constant repetition rate i.e. preferably the time delay between each two consecutive pulses of the train is substantially constant. The duration of each pulse and the repetition rate are
30 preferably sufficiently short and low, respectively, for high speed (i.e. high information rate) optical communications which typically involve the generation and transmission of short pulses at high repetition rates, wherein "short pulses" means that the duration of the pulse is equal to or less than 1 ns, 100 ps, 10 ps or 1 ps, and the "high repetition rate" means a rate which is equal to larger than 10 MHz, 100 MHz, 1 GHz or 100 GHz. Hence, in preferred embodiments

of the system of the first aspect of the invention, the pulses of the train generated by the pulse generator are of a duration of ≤ 1 ns, or ≤ 100 ps, or ≤ 10 ps, or ≤ 1 ps. Also, in preferred embodiments of the system of the first aspect of the invention, the pulses of the train generated by the pulse generator are of a repetition rate of ≥ 10 MHz, or ≥ 100 MHz, or ≥ 1 GHz, or $\geq$ 100 GHz.

The modulation of the amplitude of the pulses by the modulator allows for encoding information in the train of pulses. Hence, a specific combination, i.e. a sequence, of a number of pulses of the first and/or of the second set may be associated with specific information such as a number, a letter or other type of information. Most commonly, optical communications are based on a binary encoding using bits where each bit is "0" or "1" and is represented by a low-amplitude or high-amplitude pulse, respectively. The amplitude of the "1" bit pulse, i.e. of the pulse representing a "1" bit, is of a high-amplitude, meaning that the "1" pulse has an amplitude which is measurably higher than a "0" bit pulse. Similarly, the amplitude of the "0" bit pulse, i.e. of the pulse representing a "0" bit, is of a low-amplitude, meaning that the "0" pulse has an amplitude which is measurably lower than a "0" bit pulse. It is known in the field, how to measure the amplitude of pulses of electromagnetic radiation. Therefore, in a preferred embodiment of the invention, each of the first set of pulses corresponds to a respective "0" information bit, and each of the second set of pulses corresponds to respective "1" information bit. Most preferably, the amplitude of a "1" pulse is much higher, e.g. is 10 or 100 times higher, compared to the amplitude of a "0" bit pulse so that when measuring the pulses it is easier to distinguish between the "0" and the "1" pulses for avoiding erroneously confusing a "0" pulse as a "1", and vice versa.

It should be noted that the present invention may be adapted and used for communications based on a binary encoding, but alternatively may be used and adapted for communications based on a non-binary or other type of encoding which involve the generation of pulses of three or more sets of pulses of corresponding different amplitudes. For this purpose, optionally the modulator may be configured to modulate the train such that more than two sets of pulses of different amplitudes are being output by the modulator. Considering the above, it is understood that regardless of whether the modulator of the system is configured for modulating the pulses such that more than two sets of pulses of different amplitudes are being created (by the modulator), it is preferable that the amplitude of the second set of pulses is a 10 or 100 or 1000 times higher compared to the amplitude of the pulses of the first set. Hence, in some

preferred embodiments of the invention, the modulator is configured to modulate the train such that the amplitude of the pulses of the first set is at least ten or hundred or thousand times smaller than the amplitude of the pulses of the second set.

- 5 The modulator of the system of the first aspect of the invention may be of various types. Hence, the modulator may be an electrooptic (i.e. electro-optic) modulator, or an acousto-optic modulator, or an electro-absorption modulator (e.g. a modulator based on the Franz–Keldysh effect) or a modulator based on a magneto-optic effect, or a different type of modulator. A type of a modulator which is particularly suitable for use in the present invention is the Mach-
- 10 Zehnder modulator which advantageously may allow for encoding information onto the train of pulses with low insertion loss. Hence, using a Mach-Zehnder modulator advantageously allows avoiding significant signal degradation. Moreover, an electrooptic modulator, particularly a Mach-Zehnder modulator, may advantageously offer a high extinction ratio for ensuring a clear differentiation between the pulses of the first and the second sets, and may also have a wide
- 15 bandwidth for thereby enabling high-speed data transmission. Moreover, a Mach-Zehnder modulator may advantageously exhibit a low polarization dependence, thereby promoting a possible compatibility of the system of the first aspect of the invention with various optical fiber components for optical communications and related infrastructure. Moreover, an electrooptic modulator, such as a Mach-Zehnder modulator, may be compact, thereby promoting the
- 20 compactness of the overall system of the first aspect of the invention. Considering the above, in a preferred embodiment of the invention, the modulator is an electrooptic modulator, preferably a Mach-Zehnder modulator.

- As mentioned further above, a figure of merit which is often used for characterizing (describing)
- 25 the difference between high-amplitude pulses and low-amplitude pulses of a series (train) of pulses, is the extinction ratio, and the same figure of merit is also often used for describing (characterizing) the modulator's capacity to modulate the amplitude of the pulses. Preferably, the extinction ratio of the modulator is at least 10, meaning that the amplitude of the pulses of the second set is 10 times larger than the amplitude of the pulses of the first set. In preferred
- 30 embodiments, said amplitude refers to the intensity or power of the electromagnetic radiation pulses. The extinction ratio can be understood as being the ratio I_B/I_A , where I_A is the amplitude of a pulse of the first set, and I_B is the amplitude of a pulse of the second set. Said amplitudes I_A and I_B may be the respective power levels of a digital signal generated when detecting (e.g. using a photodiode) the pulses of the first and second sets, respectively. Alternatively, the

amplitudes I_A and I_B may be the respective optical energies or peak powers or intensities of the pulse of the first set and of the pulse of the second set, respectively.

Modulators may not always function optimally, and often in conventional optical communication systems, variations of environmental conditions or suboptimal conditions in the operation of a modulator which produces different types of pulses e.g. "0" bit and "1" bit pulses, may cause an undesirably small and suboptimal difference between the amplitudes of the different types of pulses. Hence, in a conventional optical communications system which employs a modulator which produces "0" bit and "1" bit pulses, the extinction ratio may be small and suboptimal due to variations of environmental conditions or suboptimal operational parameters of the modulator. This may for example occur when the modulator is an electrooptic modulator operated at a suboptimal bias voltage or under a varying environmental temperature.

However, in the present invention, the saturable noise suppressor by attenuating the pulses of the first set, can advantageously reduce the amplitude of the pulses of the first set, and therefore, may allow increasing the difference or ratio between the amplitudes of the second and first sets of pulses. Therefore, the saturable noise suppressor of the system according to the present invention, may advantageously improve the difference or ratio, e.g. the extinction ratio, between the amplitudes of the pulses of the second and first set, and thereby, compensate for potential undesired instabilities or suboptimal operation of the modulator. Said potential undesired instabilities or suboptimal operation of the modulator may manifest as noise in an optical output of the modulator, and the saturable noise suppressor can advantageously suppress, diminish, or even completely extinguish said noise.

In a preferred embodiment of the system of the first aspect of the invention, the amplitude of the pulses is an intensity of the pulses; the intensity of the pulses of the first set is smaller than a saturation intensity of the saturable absorber; and the intensity of the pulses of the second set is larger than said saturation intensity. In the latter case, advantageously a pulse of the first set, in contrast to a pulse of the second set, may completely or nearly completely be absorbed by the saturable absorber, and this may further promote increasing the difference or extinction ratio between the amplitudes of the second and first set of pulses.

In a preferred embodiment of the system of the first aspect of the invention, the saturable absorber is a resonant saturable absorber mirror (RSAM), particularly a RSAM which is

resonant to a wavelength of the pulses. Such a RSAM, when compared to a non-resonant saturable absorber mirror (SAM) may advantageously exhibit a larger saturable absorption, a smaller bandwidth and a lower saturation fluence, so that advantageously the using the RSAM in the saturable noise suppressor can allow increasing the extinction ratio between the pulses
5 of the second type and the pulses of the first type, even when the amplitude, intensity of fluence of the of the pulses of the first type is substantially small or very small (e.g. 10 times smaller or more) compared to the amplitude, intensity of fluence, respectively, of the pulses of the second type.

10 In a preferred embodiment according to the first aspect of the invention, the system further comprises an optical amplifier which is optically connected to the saturable noise suppressor and is configured to receive and amplify the pulses being outputted by the saturable noise suppressor. The amplification of the pulses by said amplifier which is an optional but preferable component of the system, may advantageously compensate for the possible attenuation of the
15 pulses in a possible subsequent transmission of the pulses, especially if said pulses are to be transmitted over long distances via optical fibers, air and/or another medium. In particular, a free space optical communication system may involve a substantial attenuation of the pulses being communicated over long distances and said attenuation may render difficult a correct detection and measurement of the transmitted pulses. Hence, the optical amplifier of the
20 aforementioned preferred embodiment, may advantageously promote the suitability of the system for use in free-space and/or long-distance optical communications.

In a preferred embodiment which comprises the aforementioned optical amplifier, said amplifier is further configured to amplify the received pulses with an optical power gain of at
25 least 10 dB. Said gain can further enable a possible transmission of the pulses over long distances and/or via free space, and a correct possible subsequent detection and measurement of the transmitted pulses. Said gain may be the ratio of output power and input power i.e. the ratio of the power of an amplified pulse being output by the amplifier over the power the pulses being input in the amplifier before it is amplified.

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In a preferred embodiment which comprises an amplifier as described above, said amplifier is further configured to compress the received pulses to a duration of ≤ 1 ns, preferably of ≤ 100 fs. Said compression of the pulses by the amplifier is an optional feature which may

advantageously promote the suitability and use of the system for high speed (i.e. high information rate) optical communications.

5 In a preferred embodiment which comprises an amplifier as described above, said amplifier comprises an erbium or erbium/ytterbium doped fiber. This type of amplifier advantageously has good manufacturability and durability, can be easily integrated with the rest of the system, and may enable amplifying the pulses with a good gain, e.g. with a gain of at least 10 dB, and simultaneously compressing the pulses, e.g. compressing them to a duration of less than 1ns or less than 100 fs.

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The invention in a second aspect concerns a method for optical communications, comprising: generating a train of pulses of electromagnetic radiation; modulating the train via modulating an amplitude of at least some of the pulses of the train such that the modulated train comprises a first set of pulses and a second set of pulses, wherein the amplitude of the pulses of the first
15 set is smaller than the amplitude of the pulses of the second set; by means of a saturable noise suppressor which comprises a saturable absorber, receiving the modulated train, attenuating the amplitude of the pulses of the first set, and outputting the pulses of the first and second sets.

20 The invention in a third aspect concerns a use of a system which is according to the first aspect of the invention, in a free-space telecommunication system.

Additional advantages and features of the invention will become apparent from the detailed description that follows and will be particularly pointed out in the appended claims.

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BRIEF DESCRIPTION OF THE DRAWINGS

To complete the description and in order to provide for a better understanding of the invention, a set of drawings is provided. Said drawings form an integral part of the description and
30 illustrate embodiments of the invention, which should not be interpreted as restricting the scope of the invention, but just as examples of how the invention can be carried out. The drawings comprise the following figures:

Fig. 1 schematically illustrates a preferred embodiment of a system according to the first aspect of the invention.

Fig. 2 schematically illustrates a preferred embodiment of a system according to the first aspect of the invention.

5 Fig. 3 schematically illustrates a flow diagram of a preferred embodiment of a method according to the second aspect of the invention.

Fig. 4 illustrates a detected pulsed signal resulting for the use of a system which does not comprise a saturable noise suppressor.

10 Fig. 5 illustrates a detected pulsed signal resulting for the use of a system according to the first aspect of the invention.

DESCRIPTION OF A WAY OF CARRYING OUT THE INVENTION

15 The following description is not to be taken in a limiting sense but is given solely for the purpose of describing the broad principles of the invention. Next embodiments of the invention will be described by way of example, with reference to the above-mentioned drawings, showing apparatuses, methods and results according to the invention.

A preferred embodiment of a system according to the invention, is shown in Fig. 1. The system
20 shown in Fig. 1 comprises a pulse generator 1 configured to generate a train of pulses of electromagnetic radiation; a modulator 2 optically connected to the pulse generator 1 and configured to modulate the train via modulating an amplitude of at least some of the pulses of the train such that the modulated train comprises a first set of pulses and a second set of pulses, wherein the amplitude of the pulses of the first set is smaller than the amplitude of the
25 pulses of the second set; a saturable noise suppressor 3 which is optically connected to the modulator 2, comprises a saturable absorber 4, and is configured to receive the modulated train, attenuate the amplitude of the pulses of the first set, and output the pulses of the second set and the attenuated pulses of the first set. The train of pulses generated by the pulse generator 1 is also illustrated by the graph I which is included in Fig. 1. Moreover, graph II in
30 Fig. 1 illustrates the modulated amplitudes of the pulses of the train that is being output by the modulator. The pulses shown in graph II of Fig. 1 comprise a first set of pulses A, and a second set of pulses B, wherein the amplitude of pulses A is notably smaller than the pulses B.

Moreover, graph III in Fig. 1 illustrates the amplitudes of the pulses of the train that is being output by the saturable noise suppressor 3. As can be readily observed and derived by said in graph III, the attenuation of the pulses A by the saturable noise suppressor 3 results to suppression and near-extinction of the said pulses A, and consequently, to an increase of the extinction ratio of the signal, said extinction ratio being equal to I_B/I_A , wherein I_A is the amplitude of a pulse A, and I_B is the amplitude of a pulse B. It is noted that the term "amplitude" may refer or be the intensity, peak power, or energy of the pulse, or may refer to the power level of a digital signal generated when detecting (e.g. using a photodiode) the pulse.

10 In an embodiment which is similar to the embodiment of Fig. 1, the saturable absorber 4 is used in a transmission mode. In another embodiment which is also similar to the embodiment of Fig. 1, the saturable absorber 4 is a saturable absorber which is used in a reflection mode.

A very preferred embodiment of a system according to the invention, is shown in Fig. 2. The embodiment shown in Fig. 2 is similar to the embodiment of Fig. 1, but also comprises the following additional features. The pulse generator 1 is an oscillator comprising a laser seed source 11 and an optical preamplifier 12 connected to the laser seed source 11. The saturable absorber is a saturable absorber mirror 41, and the saturable noise suppressor 3 further comprises a circulator 5 optically connected to the saturable absorber mirror 41. Said circulator 5 comprises a first port 51 connected to the modulator, a second port 52 connected to the saturable absorber mirror 41, and a third port 53. The circulator 5 is configured to receive the modulated train via the first port 51. Also, the circulator 5 is configured to transmit, via the second port 52, the modulated train to the saturable absorber mirror 41. Also, the saturable absorber mirror 41 is configured to absorb the pulses of the first set or to attenuate them more strongly compared to the pulses of the second set, and to reflect the pulses of the first and the second sets. Moreover, the circulator 5 is configured to receive the reflected pulses, and to output the received reflected pulses via the third port 53. Also, the embodiment of Fig. 2 comprises an optical amplifier 6 optically connected to the saturable noise suppressor 3 and configured to receive and amplify the pulses being outputted by the saturable noise suppressor 3. In addition, in the embodiment of Fig. 2, the pulse generator 1, the modulator 2, the saturable noise suppressor 3, and the amplifier 6 are optically connected via respective optical fiber sections 7 (i.e. optical fibers).

The embodiment of the method illustrated in Fig. 3 comprises the following steps:

In step 101, generating a train of pulses of electromagnetic radiation.

In step 102 modulating the train via modulating an amplitude of at least some of the pulses of
5 the train such that the modulated train comprises a first set of pulses and a second set of
pulses, wherein the amplitude of the pulses of the first set is smaller than the amplitude of the
pulses of the second set.

In step 103, receiving the modulated train.

In step 104, attenuating the amplitude of the pulses of the first set of the received modulated
10 train.

In step 105, outputting the pulses of the second set and the attenuated pulses of the first set.

The method of Fig. 3 may be preferably implemented with a system of the first aspect of the
invention, and for example with the embodiments of Fig. 1 or Fig. 2. Hence, step 101 may be
15 done using the pulse generator 1, step 102 may be done using the modulator 2, and each of
steps 104-15 can be done using (i.e. by means of) the saturable suppression absorber.

The use of embodiments of the system and method according to the present invention can
advantageously increase the extinction ratio of an amplitude modulated pulsed signal. In an
20 exemplary embodiment of the invention, the invention is used in an optical communications
system based on ultrashort pulse lasers, for offering a free space optics communication link
that is tolerant to variations of the atmospheric conditions. This exemplary embodiment is
further described below.

25 In said exemplary embodiment, first there are generated ultrashort pulses of < 2 ps duration
and repetition rate in the gigahertz range. These pulses are modulated in amplitude with a
Mach-Zehnder electrooptic modulator (MZM). After modulation each laser pulse corresponds
to an information bit: the pulses that suffer higher extinction (ideally total extinction) are "0"s,
the pulses that suffer lower extinction (ideally no extinction at all) are "1"s. Then, the optical
30 signal encoded with the information passes through a saturable noise suppressor (SNS) which
comprises a circulator and a resonant saturable absorber mirror. The pulses are passed to an
optical amplifier, where the pulses are compressed to a duration of < 100 fs and amplified with
a gain of > 10 dB. It was observed that the SNS of said exemplary embodiment increases the
extinction ratio of the amplitude modulated signal (amplitude difference between "1"s and "0"s

after amplification) by at least 10 dB. Consequently, the "1" and "0" bits are easier to differentiate in the receivers. Moreover, it was observed that when the modulator's BIAS voltage is not at the optimum point or varies due to environmental conditions, the extinction ratio of the modulated signal decreases. In addition, it was observed that the SNS damps the imbalance caused by non-desired variations in the BIAS voltage.

In said exemplary embodiment, the SNS is located after the MZM and consists of a polarization-maintaining (PM) fiber circulator and a semiconductor saturable absorber mirror (SESAM). The SESAM absorbs the weak signals with a higher ratio and is saturated with strong signals. This means the SESAM absorbs the bits that have been attenuated by the modulator and correspond to a "0" and reflects the bits that have passed through the modulator without substantial attenuation and correspond to a "1". Some experimental results that were obtained by experiments done with said exemplary embodiment are described below.

Experimental results

The typical extinction ratio of the used electrooptic Mach-Zehnder modulator (MZM) is of around 20 dB, so to appreciate the effect of the SNS, a detector with a wide dynamic range was needed. Therefore, for the tests carried out, an avalanche photodetector was used. For distinguishing the level of the "0s", there was used a power regime in which the "1s" were saturated in the avalanche photo-detector (APD) used for measuring the optical signal.

The effect of the SNS was measured with the APD placed after the MZM (where the train of pulses of a 1.3 GHz fundamental repetition rate was modulated with a non-return-to-zero pseudo-random bit sequence (NRZ PRBS) signal. The photodetected signal was evaluated with a digital phosphor oscilloscope. Fig. 4 and Fig. 5 illustrates measurements taken with the oscilloscope, where the modulated signal in the APD is shown. In both Fig. 4 and Fig. 5, a top trace and a bottom trace can be observed. The top trace was used as a trigger and is obtained directly from the laser oscillator of 1.3 GHz repetition rate. The bottom trace was the photodetected signal at the APD after the MZM that modulates the pulse train with a NRZ PRBS signal. The optical power at the APD has been controlled to be -15.0 dBm in both cases (Fig. 4 and Fig. 5), to work in a regime where the "1s" are saturated and the "0s" can be observed in the oscilloscope. Both measures have been carried out using a persistence mode of the oscillator, as it is necessary to observe a PRBS signal. Fig. 4 shows the measured PRBS

modulated pulse train without implementing the SNS. It is easy to observe that there is a “dot cloud” in the middle of the pulses that correspond to the “0s” being detected by the APD. The “dot cloud” level is as high as the saturated ones. For the measurement of Fig. 5, the SNS has been implemented, and as a result the “dot cloud” is almost at the baseline which means that the “0s” are being absorbed by the SESAM, enhancing the signal quality and improving the modulated signal extinction ratio by approximately 10 dB.

A second test was done to observe the improvement that the SNS may achieve in an APD non-saturation regime. For the second test, the power of the signals was set to -35.0 dBm in the APD. However, at this non-saturation level of the “1s”, the APD was unable to detect the “0s” when the BIAS voltage in the MZM is optimized. Therefore, to observe the “0s” the MZM BIAS voltage was changed to a suboptimal point. The measurements showed that when the bias voltage is not optimized, there can be observed (measured) “0s” that have not been completely suppressed. When the SNS system was implemented while the BIAS voltage was kept not optimized, the “0s” were absorbed by the SESAM and could not be observed. That confirmed the signal quality enhancement by the SNS of the system of the invention and indicates that small deviations or instabilities in the BIAS voltage are corrected by the SNS system.

In the context of the present disclosure, the term “approximately” and terms of its family (such as “approximate”, etc.) should be understood as indicating values very near to those which accompany the aforementioned term. That is to say, a deviation within reasonable limits from an exact value should be accepted, because a skilled person in the art will understand that such a deviation from the values indicated is inevitable due to measurement inaccuracies, etc. The same applies to the terms “about”, “around” and “substantially”.

The invention is obviously not limited to the specific embodiment(s) described herein, but also encompasses any variations that may be considered by any person skilled in the art (for example, as regards the choice of components, configuration, etc.), within the general scope of the invention as defined in the claims.

CLAIMS

1. A system for optical communications, comprising:
a pulse generator (1) configured to generate a train of pulses of electromagnetic radiation, the
5 pulses being of a duration of ≤ 1 ns and/or of a repetition rate of ≥ 10 MHz;
a modulator (2) optically connected to the pulse generator (1) and configured to modulate the
train via modulating an amplitude of at least some of the pulses of the train such that the
modulated train comprises a first set of pulses and a second set of pulses, wherein the
amplitude of the pulses of the first set is smaller than the amplitude of the pulses of the second
10 set;
a saturable noise suppressor (3) which is optically connected to the modulator (2), comprises
a saturable absorber (4), and is configured to receive the modulated train, attenuate the
amplitude of the pulses of the first set, and output the pulses of the second set and the
attenuated pulses of the first set.
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2. A system according to claim 1, wherein the saturable absorber (4) is a saturable
absorber mirror (41), and the saturable noise suppressor (3) further comprises a circulator (5)
optically connected to the saturable absorber mirror (41), preferably the saturable absorber
mirror (41) being a resonant saturable absorber mirror.
20
3. A system according to claim 2, wherein the circulator (5) comprises a first port (51)
connected to the modulator (2), a second port (52) connected to the saturable absorber mirror
(41), and a third port (53);
the circulator (5) is configured to receive the modulated train via the first port;
25 the circulator (5) is configured to transmit, via the second port (52), the modulated train to the
saturable absorber mirror (41);
the saturable absorber mirror (41) is configured to absorb the pulses of the first set or to
attenuate them more strongly compared to the pulses of the second set, and to reflect the
pulses of the first and the second sets;
30 the circulator (5) is configured to receive the reflected pulses; and
the circulator (5) is configured to output the received reflected pulses via the third port (53).
4. A system according to claim 2 or 3, wherein the circulator (5) comprises a polarization-
maintaining fiber.

5. A system according to any of the previous claims, wherein the modulator (2) is an electrooptic modulator, preferably a Mach-Zehnder modulator.
- 5 6. A system according to any of the previous claims, wherein the modulator (2) is configured to modulate the train such that the amplitude of the pulses of the first set is at least ten times smaller than the amplitude of the pulses of the second set.
7. A system according to any of the previous claims, wherein saturable noise suppressor (3)
- 10 is configured to attenuate the amplitude of the pulses of the first set such that the latter's attenuated amplitude is at least 100 smaller, preferably at least 1000 smaller, than the amplitude of the pulses of the second set being outputted by the saturable noise suppressor (3) .
- 15 8. A system according to any of the previous claims, wherein the pulse generator (1), the modulator (2) and the saturable noise suppressor (3) are optically connected via respective optical fiber sections (7).
- 20 9. A system according to any of the previous claims, further comprising an optical amplifier (6) optically connected to the saturable noise suppressor (3) and configured to receive and amplify the pulses being outputted by the saturable noise suppressor (3), preferably the optical amplifier (6) being configured to amplify the received pulses with an optical power gain of at least 10 dB
- 25 10. A system according to claim 9, wherein the optical amplifier (6) is further configured to compress the received pulses to a duration of <1 ns, preferably of ≤ 100 fs.
11. A system according to any of the previous claims, wherein the amplitude of the pulses
- 30 is an intensity of the pulses; the intensity of the pulses of the first set is smaller than a saturation intensity of the saturable absorber (4); and the intensity of the pulses of the second set is larger than said saturation intensity.

12. A system according to any of the previous claims, wherein each of the first set of pulses corresponds to a respective "0" information bit, and each of the second set of pulses corresponds to respective "1" information bit.
- 5 13. Use of a system which is according to any of the previous claims, in a free-space telecommunication system.
14. A method for optical communications, comprising:
generating a train of pulses of electromagnetic radiation;
- 10 modulating the train via modulating an amplitude of at least some of the pulses of the train such that the modulated train comprises a first set of pulses and a second set of pulses, wherein the amplitude of the pulses of the first set is smaller than the amplitude of the pulses of the second set;
- by means of a saturable noise suppressor (3) which comprises a saturable absorber
- 15 (4), receiving the modulated train, attenuating the amplitude of the pulses of the first set, and outputting the pulses of the second set and the attenuated pulses of the first set.