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ALL OPTICAL INCOHERENT-TO-COHERENT WAVELENGTH CONVERSION AND OCDMA TRANSCEIVERS USING SEMICONDUCTOR OPTICAL AMPLIFIER

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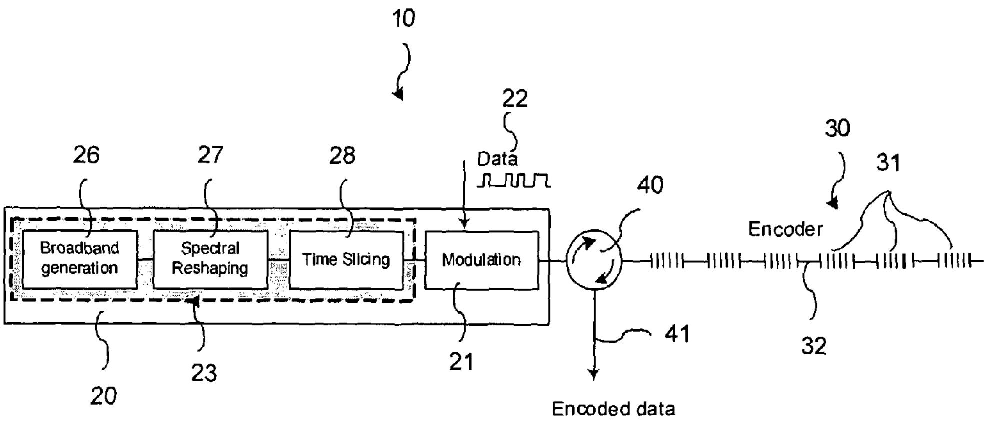

(57) Abstract: Methods for significant reduction of beat noise in incoherent optical spread spectrum communication system are disclosed. In one embodiment, we use the spectral broadening of an incoherent signal, which can be achieved with some non-linear effects as the four-waves mixing a saturated semiconductor optical amplifier. In the second embodiment, we present a new method to eliminate the bit error floor for optical systems using incoherent broadband sources based on an all-optical wavelength conversion of an incoherent optical signal to a coherent optical signal using the cross-gain modulation in semiconductor optical amplifiers. This conversion can affect positively and reduce significantly the beat noise in optical spread-spectrum communication system and can be used as an all-optical wavelength conversion process for optical signals from last miles system using spread-spectrum sources to an aggregate WDM networks. In the second field of the invention, OCDMA transmitters and receivers using Semiconductor Optical Amplifier are presented. The OCDMA transmitter includes the generation of a broadband pulse train, the encoding with the appropriate user encoder and the modulation with its proper data. In one embodiment, the modulation is done after the generation of a broadband pulse train that can be shared by several users in this case. In the other embodiment, the modulation can be done directely by monitoring the electrical bias of SOA.

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FIELD OF THE INVENTION

[0001] The present invention generally relates to the field of active components for fiber optics communication networks and more particularly concerns transmitters and receivers for Optical Code Division Multiplexing systems and methods adapted for OCDMA communications.

BACKGROUND OF THE INVENTION

[0002] Optical Code Division Multiple Access (OCDMA) communications, which is a technique presently used in wireless applications, provides a means to combine the advantages of spread spectrum multiplexing (efficient network control and switching) with the flexibility to user allocation and security against unauthorized users. It provides multiple, simultaneous, asynchronous and bursty communication. Indeed, OCDMA allows the combined use of wavelength, time and space therefore increasing the information capacity of communication systems.

[0003] Several OCDMA schemas have been proposed during the last years based in the greater part on the frequency-encoding domain of coherent and incoherent broadband sources.

[0004] For example, in "Encoding and decoding of femto-second pulse for code-division multiple access", Optics Letters, Vol. 13, pp 300,1988, A. M. Weiner et al. proposed coding mode-locked pulses in the frequency domain. In U.S. patent N° 4,866, 699, Brackett et al. disclose a coherent optical CDMA communication system where the Fourier components of radiation pulses are independently phase modulated. High-cost mode-locked lasers providing ultra-short pulse are necessary, as well as complicated receivers. Those complications push the investigations and inventors to propose other OCDM design.

[0005] In "Optical code-division-multiplexed systems based on spectral encoding of noncoherent sources", Journal of Lightwave Technology, Vol. 13, pp 534-545, March 1995, M. Kavehrad et al. discuss a Frequency-Encoded (FE) Optical CDMA where spectral, not time, coding is used. In U. S. patent N° 5,784, 506, Pfeiffer presents FE- OCDMA transmission system and optical receivers therefore, based on periodic spectrum encoding firstly proposed by L. Möller in "An Optical CDMA Method Based on Periodic Spectrum Encoding", Proceedings of the 13th Annual Conference on ECOC, 1995, pp 178-181. Each optical transmitter has a light-emitting diode (LED) and a periodic optical filter, which e.g. is a Fabry-Perot filter or a Mach-Zehnder interferometer. The received optical signals are decoded in the electric part of the optical receiver.

[0006] In a proposed network architecture described in a U. S. patent N° 6, 381,053, "Fast Frequency Hopping Spread Spectrum for Code Division Multiple Access Communications Networks, "presented by Fathallah et al., time and wavelength (spectral-temporal codes) are used to encode information in such a way that only the recipient with the proper decoder can retrieve the information, even though that information was broadcasted to all the receiving terminals in the network.

[0007] One way to generate these spectral-temporal codes is to "slice and delay" the light from a broadband optical source. In the "slice and delay' technique, an optical pulse from the broadband source is sliced in many wavelength bands and each band is delayed relative to each other in such a way that an optical code is generated.

[0008] In that context, there is still a need for a cheaper transmitter able to generate a broadband pulse that can be modulated with the appropriate data of each user and encoder with his proper encoder. In the other hand, with the aim to reduce the penalty due to the beat noise, it is essential to develop an appropriate receiver capable to enhance the quality of the received signal before the detection process.

[0009] Those two topics represent the objective of the present invention, as it will be discussed thereinafter.

[0010] PRIOR ART As an OCDMA sources, M. Kavehrad et a/. in "Optical code-division- multiplexed systems based on spectral encoding of incoherent sources", Journal of Lightwave Technology, Vol. 13, pp 534-545, March 1995, proposed a system based on a incoherent optical source such as edge-emitting LED's (EE-LED) or super- luminescent diode (SLD). In their solution, they directly modulate the SLED output power to generate a spectral coded data.

[0011] Since for EE-LED's or SLD's the transmitted power can be limited, not widely available and costly, alternative sources are proposed using erbium-doped fiber super-fluorescent sources (EDF-SFS). EDF-SFS are easily build, power salable and already fiber compatible.

[0012] In U. S. Patent N° 5,191, 586, "Narrow band incoherent optical carrier generator", Huber et a/. disclosed a double-pass super-fluorescent Erbium-doped fiber source configuration, where a multitude of fiber Bragg gratings are concatenated to form a multi-wavelength reflector. Whereas, DeMarco et a/. in U. S.

Patent N° 6, 195,200 entitled "High power multiwavelength light source "proposed a single multi-wavelength reflector.

[0013] In addition, it is important to mention that T. E. Chapuran et al. proposed in "Broadband multichannel WDM transmission with superluminescent diodes and LEDs", published in Proc. Globecom'91, Vol. 1, pp. 612-618, the use of SLD and LED in broadband multi-channel WDM

transmission which can be referred to as an Incoherent-WDM (I-WDM) system.

[0014] Those known prior art devices are not, however, optimized for Optical CDMA communication system. There is therefore a need for incoherent optical sources and transmitters with power spectral densities optimized for specific waveband that allow the generation of spectro-temporally encoded data signals. For this reason, A. Bellemare et al. in international patent application N°PCT/CA02/00524, entitled "Optical sources and transmitters for optical communications", they proposed optical sources and transmitters for OCDMA systems based on a waveband incoherent optical fiber source for fiber optics communication networks and specially for FFH- CDMA, FE-CDMA and I-WDM with enhanced power spectral density.

[0015] Up to now, the SOA in principal used as an optical amplifier at wavelengths that EDFAs couldn't operate in, such as the 820-and 1310-nm band. It can also provide the integrated functionality of internal switching and routing functions as in space switches, wavelength converters (as mentioned in"All-optical wavelength conversion by semiconductor optical amplifiers", Journal of Lightwave Technology, Vol. 14, N°6, June 1996, pp. 942-954 by T. Durhuus et al.), and wavelength selectors.

SUMMARY OF THE INVENTION It is therefore an object of the present invention to provide optical sources and transmitters based on SOA particularly adapted to OCDMA telecommunications, and that satisfy the above mentioned needs.

[0016] Accordingly, there is provided a SOA-based OCDMA transmitter for transmitting data through a network. The SOA-based OCDMA transmitter is provided with a SOA-based broadband pulse train generator for generating a broadband pulse train. The SOA-based OCDMA transmitter is also provided with amplitude modulating means operatively connected to the broadband pulse train generator for modulating the broadband pulse train according to the data, thereby providing a modulated broadband pulse train. The SOA-based OCDMA transmitter also comprises an optical circulator having a first port receiving the modulated broadband pulse train, the optical circulator also having a second and a third port. The SOA-based OCDMA transmitter is also provided with encoding means coupled to the amplitude modulating means through the second port of the optical circulator for spectro- temporally encoding the modulated broadband pulse train, thereby providing a spectro-temporally encoded optical signal forwarded to the network through the third port of the circulator for subsequent transmission.

[0017] In a preferred embodiment of the present invention, the SOA-based broadband pulse train generator comprises an optical broadband source generating a broadband optical signal. The SOA-based broadband pulse train generator also has spectral reshaping means connected to the optical broadband source for selecting a spectral part of the broadband optical signal, thereby providing a spectrally reshaped optical signal. **[0018]** The SOA-based broadband pulse train generator is also provided with time slicing means for time slicing the spectrally reshaped optical signal, thereby providing the broadband pulse train.

[0019] In another preferred embodiment of the present invention, the SOA-based broadband pulse train generator comprises a first SOA having a fixed current electrical bias for generating a broadband ASE spectrum. The SOA-based broadband pulse train generator is also provided with an optical circulator having a first port receiving the broadband ASE spectrum, the optical circulator having a second and a third port. The SOA-based broadband pulse train generator also comprises wavelength dependant reflecting means connected to the second port of the circulator, and partially reflecting the broadband ASE spectrum for forwarding a spectrally reshaped optical signal through the third port of the circulator. The SOA- based broadband pulse train generator is also provided with a second SOA operatively connected to the third port of the circulator, the second SOA having a low periodic duty cycle electrical bias for amplifying and time slicing the spectrally reshaped optical signal, thereby providing the broadband pulse train.

[0020] In another preferred embodiment of the present invention, the SOA-based broadband pulse train generator comprises a first SOA having a low periodic square duty cycle electrical bias for generating time-sliced broadband pulses. **[0021]** The SOA- based broadband pulse train generator is also provided with an optical circulator having a first port receiving the time-sliced broadband pulses, the optical circulator having a second and a third port. The SOA-based broadband pulse train generator also comprises wavelength dependant reflecting means connected to the second port of the circulator, and partially reflecting the time-sliced broadband pulses for forwarding a spectrally reshaped optical signal through the third port of the circulator.

[0022] The SOA-based broadband pulse train generator also has a second SOA operatively connected to the third port of the circulator, the second SOA having a fixed current electrical bias for amplifying the spectrally reshaped optical signal, thereby providing the broadband pulse train.

[0021] According to another preferred embodiment of the present invention, there is also provided another SOA-based OCDMA transmitter for transmitting data through a network. The SOA-based OCDMA transmitter is provided with a SOA-based modulator generating a modulated broadband optical signal modulated according to the data. The SOA-based OCDMA transmitter is also provided

with an optical circulator having a first port receiving the modulated broadband optical signal, the optical circulator having a second and a third port. The SOA-based OCDMA transmitter is also provided with encoding means coupled to the SOA-based modulator through the second port of the optical circulator for spectro-temporally encoding the modulated broadband optical signal, thereby outputting a spectro- temporally encoded optical signal through the third port of the circulator. The SOA- based OCDMA transmitter also comprises amplifying means connected to the third port for amplifying the spectro-temporally encoded optical signal, thereby providing an amplified spectro-temporally encoded optical signal forwarded to the network for subsequent transmission.

[0022] It is another object of the present invention to provide a method for transmitting data through a network. The method comprises the steps of: a) generating a broadband pulse train with a SOA-based means; b) modulating the broadband pulse train according to data for providing a modulated broadband pulse train; c) encoding the modulated broadband pulse train for providing a spectro-temporally encoded optical signal ; and d) forwarding the spectro-temporally encoded optical signal to the network for subsequent transmission.

[0023] In accordance with another aspect of the present invention, so as to reduce the penalty due to the beat noise, there is provided a receiver able to enhance the quality of the received signal before the detection process.

[0024] Accordingly, there is provided a SOA-based OCDMA receiver for receiving data from a network. The receiver comprises an optical circulator having a first port receiving a spectro-temporally encoded signal, the circulator having a second and a third port. The SOA-based OCDMA receiver is also provided with decoding means connected to the second port for receiving and decoding the spectro-temporally encoded signal, thereby providing a decoded signal forwarded through the third port.

[0025] The SOA-based OCDMA receiver also comprises SOA-based spectral broadening means connected to the third port for spectrally spreading the decoded signal, thereby providing a modulated decoded wideband spectrum. The SOA-based OCDMA receiver has detecting means receiving the modulated decoded wideband spectrum for recovering the data.

[0026] There is also provided a method for receiving data from a network. The method comprises the steps of: a) providing a spectro-temporally encoded signal ; b) decoding the spectro-temporally encoded signal, thereby providing a decoded signal ; c) spectrally spreading the decoded signal with SOA-based spectral broadening means for providing a modulated decoded wideband signal ; and d) detecting the modulated decoded wideband signal for recovering data.

[0027] In accordance with another aspect of the present invention, there is also provided a SOA-based OCDMA receiver for receiving data from a network. The receiver comprises a first optical circulator having a first port receiving a spectro-temporally encoded signal, the circulator having a second and a third port. The SOA- based OCDMA receiver is also provided with decoding means connected to the second port for receiving and decoding the spectro-temporally encoded signal, thereby providing a modulated decoded signal forwarded through the third port of the first circulator. The SOA-based OCDMA receiver is also provided with a second optical circulator having a first port receiving the modulated decoded signal, the circulator having a second and a third port. The SOA-based OCDMA receiver comprises a SOA operated with a constant electrical bias in a saturated mode, the SOA having a first port connected to the second port of the second circulator for receiving the modulated decoded signal. The SOA-based OCDMA receiver is also provided with a distributed feedback laser operated in a continuous wave regime injected in a second port of the SOA in a counter-propagating scheme. The SOA- based OCDMA receiver preferably has an isolator operatively connected between the SOA and the laser. In this particular embodiment, the modulated decoded signal modulates a gain of the SOA, thereby modulating the laser for providing a coherent modulated decoded signal through a third port of the second circulator.

[0028] In accordance with another aspect of the present invention, there is also provided a method for converting an incoherent signal into a coherent signal. The method comprises the steps of: a) providing the incoherent signal from a first port of an optical circulator having a second and a third port; b) injecting the incoherent signal into a first port of a SOA operated with a constant electrical bias in a saturated mode, the SOA being connected to the second port of the optical circulator ; and c) injecting in a counter-propagating scheme a distributed feedback laser operated in a continuous wave regime into a second port of the SOA, thereby modulating the laser for providing a coherent modulated decoded signal through the third port of the circulator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] These and other objects and advantages of the present invention will become apparent upon reading the detailed description of preferred embodiments and upon referring to the drawings in which:

[0030]

FIGURE 1 is a diagram illustrating the three majors steps generating the broadband pulse train of an OCDMA transmitter of the present invention.

FIGURE 2 shows the optical spectrum of a broadband pulse at the end of the three majors steps illustrated in FIG. 1.

FIGURE 3 is a general diagram of an OCDMA transmitter at the central office level according to a first preferred embodiment of the present invention.

FIGURE 4 is a general diagram of another OCDMA transmitter at the central office level according to a second preferred embodiment of the present invention.

FIGURE 5 is a general diagram of another OCDMA transmitter at the end user level according to a third preferred embodiment of the present invention.

FIGURE 6 is a general diagram illustrating the broadening process allowing the reduction of the beat noise effect during the detection process according to another preferred embodiment of the present invention.

FIGURE 7 is a general diagram illustrating a first implementation of the broadening process using the four wave-mixing (FWM) effect.

FIGURE 8 is a general diagram illustrating a second implementation of the broadening process using the cross-gain modulation (XGM) effect.

[0031] While the invention will be described in conjunction with example embodiments, it will be understood that it is not intended to limit the scope of the invention to such embodiments. On the contrary, it is intended to cover all alternatives, modifications and equivalents as may be included as defined by the appended claims.

DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0032] In the following description, similar features in the drawings have been given similar reference numerals and in order to weight down the figures, some elements are not referred to in some figures if they were already identified in a precedent figure.

[0033] The present invention concerns transmitters and receivers based on SOA particularly adapted to OCDMA telecommunications. Accordingly, the present invention first provides a SOA-based transmitter able to generate a broadband pulse that can be modulated with the appropriate data of each user and encoded with its own encoder. More particularly, in several preferred embodiments which will be detailed thereinafter, the SOA is used to fulfil different useful functions. For example, it can be used as a broadband pulse train generator where the duration of pulses is related to a predetermined duty cycle. The SOA may also be used as a fast modulated broadband source where user data plays the role of electrical-current pumping. The SOA may also be useful to broaden the decoded message in order to reduce the beat noise effect, as well as to convert the incoherent signal to a coherent signal.

With reference to FIGURE 1, there is shown a preferred embodiment of an integrated SOA-based OCDMA transmitter 10 for transmitting data through a network according to the present invention. The transmitter 10 has a SOA-based broadband pulse train generator for generating a broadband pulse train 23. That broadband pulse train 23 is then modulated with amplitude modulating means 21 by the proper data 22 of the user. The combination of the broadband pulse train module 23 and the amplitude modulating means 21 prompt a modulated broadband pulse train 20, which will then be encoded by encoding means, which are advantageously the user encoder 30. The generation of those broadband pulse trains 23 is the result of three major steps which are broadband generation 26, spectral reshaping 27, and time slicing 28. The two final steps 27 and 28 may be interchanged without harming the quality of the transmitter 10.

[0034] Referring now to FIGURES 3 to 5, the broadband pulse trains 23 may be generated with an optical broadband source providing a broadband optical signal.

[0035] Preferably, that broadband optical signal is obtained through feeding an SOA electrical bias by a static electrical signal. So, amplified spontaneous emission (ASE), which represents an ideal non-coherent source in the present OCDMA transmitter 10, are obtained. The generation of the ASE is preferably made over a large bandwidth, which is preferably about 45 nm. It should however be noted that any suitable value could be used for a particular application. In order to perform the spectral reshaping 27, the transmitter 10 is provided with spectral reshaping means for selecting a spectral part of the broadband optical signal, thereby providing a spectrally reshaped optical signal. The spectral reshaping means may advantageously be a waveband reflector (4-5 nm) or sampled reflectors reflecting the entire system wavelengths.

[0036] Then, to perform the step of the time slicing 28, the transmitter 10 is provided with time slicing means for time slicing the spectrally reshaped optical signal, thereby providing the broadband pulse train 23. For example, one can modulate the spectrum just by injecting it into another SOA where its electrical bias is a periodic electrical square signal that represents a low duty cycle pulse. The pulse width of the electrical input pump signal and that of the broadband output signal both correspond to the chip duration.

[0037] FIGURE 2 illustrates the succession of these three steps in the spectral dimension, where a

selection of a part of the whole spectrum and its amplification can introduce an enhancement of source quality. With respect to the level of the output power of a SOA, there is at least 26 dB gain for the waveband reflector case and 30 dB gain for the sampled reflector case.

[0038] In what follows, some transmitter architectures for Optical Code Division Multiplexing will be described in more details.

[0039] FIGURE 3 illustrates the architecture of a first preferred embodiment of an OCDMA transmitter 10 according to the present invention. **[0040]** In this system, the broadband pulse train generator 23 is provided with a first SOA 26 for generating a broadband ASE spectrum. The SOA electrical bias of the first SOA 26 is a fixed current 25. The ASE generated spectrum by the first SOA 26 is directed towards the wavelength dependant reflecting means 15, preferably waveband or sampled reflectors, through a three port optical circulator 16. The reflector mirror 15 reflects a part of the generated spectrum and sends it back toward the circulator to forward a spectral reshaped optical signal to a second SOA 28. This second SOA 28 operates as an amplifier and a time slicing. The time slicing is generated after fixing the SOA electrical bias 29 with a low periodic duty cycle, thereby providing said broadband pulse train 23. This broadband pulse train 23 can be shared by N users through a power splitter 32 (1XN), where each user can modulate the broadband pulses with an amplitude modulating means 21. Indeed, the transmitter 10 may further comprise a power splitter 32 operatively connected between the broadband pulse train generator 23 and the modulating means 21. The power splitter 32 advantageously has a plurality of outputs for providing each of a plurality of users with the broadband pulse train 23 through one of the outputs for subsequent modulation by each of the users. In this preferred embodiment, the amplitude modulating means are preferably a SOA 21. As mentioned above, the modulation of the broadband pulse train 23 is accomplished by the user-data operating as an electrical-current pumping 22. The encoding means 30, which are coupled to the amplitude modulator 21 through a three port optical circulator 40, receives the broadband pulse trains 23, separates it into its intrinsic wavebands and time spreads these wavebands according to a pre-determined code, thereby resulting in a spectro-temporally encoded optical signal.

[0041] Preferably, the encoding means 30 are embodied by series of fiber Bragg grating 31, each reflecting one of the wavebands, positioned in a length of optical fiber 32 and distanced from each other in order to generate the delay between the wavebands required by the selected code. The encoded signal 41 is then forwarded to the network 50 through the third port of the circulator 40.

[0042] Referring now to FIGURE 4, there is shown a second preferred embodiment of an optical CDMA transmitter 10 wherein the SOA-based broadband pulse train generator is provided with the same SOA 26 which is used to generate the time sliced broadband pulse. In fact, the electrical bias 24 of the SOA 26 is fed with a periodical electrical square signal having a fixed duty cycle. Once that time sliced broadband pulse has been generated, a part of the generated spectrum is selected through wavelength dependant reflecting means 15, which are preferably waveband reflector or sampled reflectors, for forwarding a spectrally reshaped optical signal through the third port of the circulator. The reflected spectrum is then amplified through a second SOA 28 in a view of subsequent splitting and modulation by the Nth data-users. A fixed SOA electrical bias 25 is supplied to the SOA 28. After being modulated via the amplitude modulating means (a SOA 21 in the illustrated case) by the user data 22, the signal is encoded using the proper user encoding means 30, then combined by a power combiner 33 and finally broadcasted to all the receiving terminals.

[0045] In the two previous illustrated architectures, a broadband pulse train 23 that can be shared by N users is generated. These two architectures are appropriate for the Central Office (CO) configuration with many users and encoders. A second SOA 28 is thereby used for amplifying the broadband signal in order to ease subsequent effect of splitting. Reflecting means 15 are used as well between the two SOAs for limiting the input spectrum to the needed region, for preventing gain saturation in the second SOA and for enhancing the power spectral density of the incoherent source.

[0046] When the OCDMA transmitters are geographically distant, it is not required to share the broadband pulse trains for many encoders. The SOA 26 can then be advantageously used as an external modulator. Indeed, as illustrated in FIGURE 5, in a third preferred embodiment, the transmitter 10 is provided with a SOA-based modulator generating a modulated broadband optical signal modulated according to the user data. Preferably, the SOA-based modulator is the SOA 26 having an electrical bias operated according to user data. The obtained optical spectrum is encoded via the encoding means 30, thereby providing a spectro-temporally encoded optical signal, which is then amplified by amplifying means for providing an amplified spectro-temporally encoded optical signal forwarded to the network for subsequent transmission. In this preferred embodiment, the amplifying means are preferably a second SOA 46 with a fixed SOA electrical bias 45. Then, the signal may advantageously be combined through a power combiner 33 with other encoded messages. In this third preferred embodiment, the spectral reshaping operation is directly made through the use of the proper user encoding means

30 which selects only the needed waveband to be amplified by the second SOA 46. As in the two previous embodiments, the encoding means 30 may advantageously be embodied by series of fiber Bragg grating 31, each reflecting one of the wavebands, positioned in a length of optical fiber 32 and distanced from each other in order to generate the delay between the wavebands required by the selected code.

[0047] It should be specified that an Erbium Doped Fiber Amplifier (EDFA) and an amplitude modulator (such as a Mach-Zehnder interferometer or an Electro- Absorption Modulator for example) can perform the amplification and the modulation functions, respectively. Of course, numerous modifications could be made to the above-described embodiments without departing from the scope of the invention.

[0048] According to another aspect of the present invention, there is also provided a method for transmitting data through a network. The method comprises the steps of: a) generating a broadband pulse train with a SOA-based means; b) modulating the broadband pulse train according to data for providing a modulated broadband pulse train; c) encoding the modulated broadband pulse train for providing a spectro- temporally encoded optical signal ; and d) forwarding the spectro-temporally encoded optical signal to the network for subsequent transmission.

[0049] Referring now to FIGURE 6, as a second field of the invention, the spectral broadening of an incoherent signal can affect positively and reduce significantly the beat noise in optical spread spectrum communication systems. The spectral broadening can be achieved with a nonlinear effect such as the four waves-mixing (FWM) or the cross-gain modulation (XGM) for example. Indeed, the spectral width of an incoherent signal at the photo-detector level influences the intensity level of the beat noise. For the same level of power, the beat noise of distributed power over a Bo frequency band would be 4 times more important than in the case where the power is distributed on a frequency band twice broader. The generation of the FWM can be carried out following the propagation along a non-linear element such a SOA, a dispersion compensating fiber (DCF), or a nonlinear optical loop mirror (NOLM) as presented by J. H. Lee et al. in"A grating-based OCDMA coding-decoding system incorporating a nonlinear loop mirror for improved code recognition and noise reduction", Journal of Lightwave technology, Vol. 20, N°1, January 2002, or any other suitable devices. The XGM phenomena, as for it, takes place in a saturated SOA. Therefore, the present invention also provides a method for receiving data from a network. The method comprises the steps of: a) providing a spectro-temporally encoded signal ; b) decoding the spectro-temporally encoded signal, thereby providing a decoded signal ; c) spectral spreading the decoded signal with SOA-based spectral broadening means for providing a modulated decoded wideband signal ; and d) detecting the modulated decoded wideband signal for recovering data.

[0050] In what follows, some receiver architectures for Optical Code Division Multiplexing using SOA are proposed in order to reduce the beat noise effect.

[0051] Referring again to FIGURE 6, a SOA-based OCDMA receiver 60 for receiving data from a network is shown. The receiver 60 has an optical circulator 80 having a first port receiving a spectro-temporally encoded signal 61, the circulator 80 having a second and a third port. The receiver 60 is also provided with decoding means 70 connected to the second port for receiving and decoding the spectro-temporally encoded signal 60, thereby providing a decoded signal 62 forwarded through the third port of the circulator 80. The receiver 60 is also provided with SOA-based spectral broadening means 90 connected to the third port for spectrally spreading the decoded signal 62, thereby providing a modulated decoded wideband spectrum. The receiver 60 is also provided with detecting means 100 receiving the modulated decoded wideband spectrum for recovering the user data.

[0052] FIGURE 7 shows another architecture of an OCDMA receiver 60 wherein the encoded broadcast information 61 reaches the decoding means 70 through a circulator 80 in order to select and recombine the optical message. Once the decoding means 70 recovers the embedding data, the obtained spectrum 62 is redirected to a saturated SOA 91 with a constant electrical bias 92, which guarantees its spectral spreading. Advantageously, to reduce the beat noise to a maximum, the obtained spectrum has to be propagated through an optical transmission filter 93 in order to eliminate the reflected slices from the decoding means 70 where we have the higher power spectral density over the entire spectrum. The obtained signal is a modulated wideband spectrum 95 with an extinction ratio depending on the power level of the decoded message and on the SOA saturation level. It is significant to note that an isolator 63 may be inserted between the circulator 80 and the SOA 91 for reducing to the maximum all damaging effects of possible reflection. In the two previous receivers, the encoding means 70 may advantageously be embodied by series of fiber Bragg grating 72, each reflecting one of the wavebands, positioned in a length of optical fiber 71 and distanced from each other in order to generate the delay between the wavebands required by the selected code.

[0053] In accordance with another aspect of the present invention, a method for converting an incoherent signal into a coherent signal is also provided. The method comprises the steps of: a) providing the incoherent signal from a first port of an optical circulator having a second and a third port; b)

injecting the incoherent signal into a first port of a SOA operated with a constant electrical bias in a saturated mode, the SOA being connected to the second port of the optical circulator ; and c) injecting in a counter-propagating scheme a distributed feedback laser operated in a continuous wave regime into a second port of the SOA, thereby modulating the laser for providing a coherent modulated decoded signal through the third port of the circulator.

[0054] Referring now to FIGURE 8, another receiver 60 according to the above- mentioned method is shown. Indeed, the decoded spectrum 62 is injected through a circulator 85 from the first port of a SOA 91. From the second port of the SOA 91, a distributed feedback (DFB) laser 94 in a continuous wave (CW) regime is also injected in a counter-propagating scheme. The modulated intensity of the decoded signal then modulates the gain in the SOA 91 due to the gain saturation effect. The CW laser is then also modulated by the gain variation, so it transmits the same information as the modulated intensity at the input. The modulated laser then reaches the third port of the circulator. At this level, we have obtained a coherent signal 95 instead of an incoherent signal 62. With this optical conversion from one incoherent source 62 to a coherent source 95, the beat noise problem in the sliced transmission system is avoided.

[0055] It should be noted that this approach differs from that of Yamatoya et. al. in "Optical preamplifier using inverted signal of amplified spontaneous emission in saturated semiconductor optical amplifier", Electronics Letters, vol. 37, pp. 1547-154, where the SOA is used to expand the optical bandwidth of the incoherent signal, essentially improving by reducing the intensity noise but not bypassing the principal source of impairment (beat noise).

[0056] Although preferred embodiments of the present invention have been described in detail herein and illustrated in the accompanying drawings, it is to be understood that the invention is not limited to these precise embodiments and that various changes and modifications may be effected therein without departing from the scope or spirit of the present invention.

WHAT IS CLAIMED IS :

1. A SOA-based OCDMA transmitter for transmitting data through a network, said SOA-based OCDMA transmitter comprising: a SOA-based broadband pulse train generator for generating a broadband pulse train; amplitude modulating means operatively connected to said broadband pulse train generator for modulating said broadband pulse train according to said data, thereby providing a modulated broadband pulse train; an optical circulator having a first port receiving said modulated broadband pulse train, said optical circulator having a second and a third port; and encoding means coupled to said amplitude modulating means through said second port of said optical circulator for spectro-temporally encoding said modulated broadband pulse train, thereby providing a spectro-temporally encoded optical signal forwarded to said network through said third port of said circulator for subsequent transmission.

2. The SOA-based OCDMA transmitter according to claim 1, wherein said SOA- based broadband pulse train generator comprises: an optical broadband source generating a broadband optical signal ; spectral reshaping means connected to said optical broadband source for selecting a spectral part of said broadband optical signal, thereby providing a spectrally reshaped optical signal ; and time slicing means for time slicing said spectral reshaped optical signal, thereby providing said broadband pulse train.

3. The SOA-based OCDMA transmitter according to claim 2, wherein said spectral reshaping means comprise a waveband reflector.

4. The SOA-based OCDMA transmitter according to claim 2, wherein said spectral reshaping means comprise a plurality of sampled reflectors.

5. The SOA-based OCDMA transmitter according to claim 2, wherein said optical broadband source comprises a SOA.

6. The SOA-based OCDMA transmitter according to claim 2, wherein said time slicing means comprise a SOA.

7. The SOA-based OCDMA transmitter according to claim 1, wherein said SOA- based broadband pulse train generator comprises: a first SOA having a fixed current electrical bias for generating a broadband ASE spectrum; an optical circulator having a first port receiving said broadband ASE spectrum, said optical circulator having a second and a third port; wavelength dependant reflecting means connected to said second port of said circulator, and partially reflecting said broadband ASE spectrum for forwarding a spectrally reshaped optical signal through said third port of said circulator ; and a second SOA operatively connected to said third port of said circulator,

said second SOA having a low periodic duty cycle electrical bias for amplifying and time slicing said spectral reshaped optical signal, thereby providing said broadband pulse train.

8. The SOA-based OCDMA transmitter according to claim 1, wherein said SOA- based broadband pulse train generator comprises: a first SOA having a low periodic square duty cycle electrical bias for generating time-sliced broadband pulses ; an optical circulator having a first port receiving said time-sliced broadband pulses, said optical circulator having a second and a third port; wavelength dependant reflecting means connected to said second port of said circulator, and partially reflecting said time-sliced broadband pulses for forwarding a spectrally reshaped optical signal through said third port of said circulator; and a second SOA operatively connected to said third port of said circulator, said second SOA having a fixed current electrical bias for amplifying said spectrally reshaped optical signal, thereby providing said broadband pulse train.

9. The SOA-based OCDMA transmitter according to anyone of claims 7 or 8, wherein said wavelength dependant reflecting means comprise a waveband reflector.

10. The SOA-based OCDMA transmitter according to anyone of claims 7 or 8, wherein said wavelength dependant reflecting means comprise a plurality of sampled reflectors.

11. The SOA-based OCDMA transmitter according to claim 1, further comprising a power splitter operatively connected between said broadband pulse train generator and said modulating means, said splitter having a plurality of outputs for providing each of a plurality of users with said broadband pulse train through one of said outputs for subsequent modulation.

12. The SOA-based OCDMA transmitter according to claim 11, further comprising a power combiner.

13. The SOA-based OCDMA transmitter according to claim 1, wherein said modulating means comprise a SOA having an electrical bias operated by said data for modulating said broadband pulse train. 14. The SOA-based OCDMA transmitter according to claim 1, wherein said encoding means comprise a series of fiber Bragg gratings spatially arranged in an optical fiber.

15. The SOA-based OCDMA transmitter according to claim 1, wherein said broadband pulse train generator and said modulating means are embedded in a single SOA having an electrical bias operated by said data.

16. A SOA-based OCDMA transmitter for transmitting data through a network, said SOA-based OCDMA transmitter comprising: a SOA-based modulator generating a modulated broadband optical signal modulated according to said data; an optical circulator having a first port receiving said modulated broadband optical signal, said optical circulator having a second and a third port; encoding means coupled to said SOA-based modulator through said second port of said optical circulator for spectro-temporally encoding said modulated broadband optical signal, thereby outputting a spectro-temporally encoded optical signal through said third port of said circulator ; and amplifying means connected to said third port for amplifying said spectro- temporally encoded optical signal, thereby providing an amplified spectro- temporally encoded optical signal forwarded to said network for subsequent transmission.

17. The SOA-based OCDMA transmitter according to claim 16, wherein said SOA- based modulator comprises a SOA having an electrical bias operated by said data.

18. The SOA-based OCDMA transmitter according to claim 16, wherein said encoding means comprise a series of fiber Bragg gratings spatially arranged in an optical fiber.

19. The SOA-based OCDMA transmitter according to claim 16, wherein said amplifying means comprise a SOA having a fixed current electrical bias.

20. The SOA-based OCDMA transmitter according to claim 16, wherein said amplifying means comprise an erbium doped fiber amplifier.

21. The SOA-based OCDMA transmitter according to claim 16, wherein wherein said SOA-based modulator comprise a SOA having an electrical bias operated by said data, said encoding means comprise a series of fiber Bragg gratings spatially arranged in an optical fiber, and said amplifying means comprise a SOA having a fixed current electrical bias.

22. The SOA-based OCDMA transmitter according to claim 16, further comprising a power combiner.

23. A method for transmitting data through a network, said method comprising the steps of: a) generating a broadband pulse train with a SOA-based means; b) modulating said broadband pulse train according to data for providing a modulated broadband pulse train; c) encoding said modulated broadband pulse train for providing a spectro- temporally encoded optical signal ; and d) forwarding said spectro-temporally encoded optical signal to said network for subsequent transmission.

24. The method for transmitting data through a network according to claim 23, wherein said step a) comprises the sub-steps of: i) generating a broadband optical signal ; ii) spectrally reshaping said broadband optical signal for selecting a spectral part thereof, thereby providing a spectral reshaped optical signal ; and iii) time slicing said spectrally reshaped optical signal, thereby providing said broadband pulse train.

25. The method for transmitting data through a network according to claim 24, wherein said step a) further comprises the sub-steps of: amplifying said spectral reshaped optical signal.

26. The method for transmitting data through a network according to claim 23, wherein said step a) comprises the sub-steps of: i) generating a broadband optical signal ; ii) time slicing said broadband optical signal for providing a time-sliced optical signal ; and iii) spectrally reshaping said time-sliced optical signal for selecting a spectral part thereof, thereby providing said broadband pulse train.

27. The method for transmitting data through a network according to claim 23, wherein said step a) comprises the sub-steps of: i) generating a broadband ASE spectrum with a SOA-based means; ii) selecting a spectral part of said broadband ASE spectrum, thereby providing a spectrally reshaped optical signal ; and iii) time slicing said spectrally reshaped optical signal, thereby providing said broadband pulse train.

28. The method for transmitting data through a network according to claim 23, wherein said step a) comprises the sub-steps of: i) generating time-sliced broadband pulses ; ii) selecting a spectral part of said time-sliced broadband pulses, thereby providing a spectrally reshaped optical signal ; and iii) amplifying said spectral reshaped optical signal, thereby providing said broadband pulse train.

29. The method for transmitting data through a network according to claim 23, said method further comprising, after step a), the step of splitting said broadband pulse train for providing each of a plurality of users with said broadband pulse train for subsequent modulation.

30. The method for transmitting data through a network according to claim 23, wherein said step a) and b) are simultaneously performed with a single SOA.

31. The method for transmitting data through a network according to claim 23, further comprising, before step d), the step of amplifying said spectro-temporally encoded optical signal.

32. A SOA-based OCDMA receiver for receiving data from a network, said receiver comprising : an optical circulator having a first port receiving a spectro-temporally encoded signal, said circulator having a second and a third port; decoding means connected to said second port for receiving and decoding said spectro-temporally encoded signal, thereby providing a decoded signal forwarded through said third port; SOA-based spectral broadening means connected to said third port for spectral spreading said decoded signal, thereby providing a modulated decoded wideband spectrum; and detecting means receiving said modulated decoded wideband spectrum for recovering said data.

33. The SOA-based OCDMA receiver according to claim 32, wherein said SOA- based spectral broadening means comprise a four waves-mixing device.

34. The SOA-based OCDMA receiver according to claim 32, wherein said SOA- based spectral broadening means comprise a cross-gain modulation device.

35. The SOA-based OCDMA receiver according to claim 32, wherein said SOA- based spectral broadening means comprise a saturated SOA operated with a constant electrical bias.

36. The SOA-based OCDMA receiver according to claim 32, further comprising an optical

transmission filter connected between said SOA-based spectral broadening means and said detecting means.

37. The SOA-based OCDMA receiver according to claim 32, further comprising an isolator inserted between said circulator and said SOA-based spectral broadening means.

38. The SOA-based OCDMA receiver according to claim 32, wherein said decoding means comprise a series of fiber Bragg gratings spatially arranged in an optical fiber.

39. A method for receiving data from a network, said method comprising the steps of: a) providing a spectro-temporally encoded signal ; b) decoding said spectro-temporally encoded signal, thereby providing a decoded signal ; c) spectral spreading said decoded signal with SOA-based spectral broadening means for providing a modulated decoded wideband signal ; and d) detecting said modulated decoded wideband signal for recovering data. 40. The method for receiving data from a network according to claim 39, wherein said spectrally spreading comprises a four-waves mixing in a saturated SOA.

41. The method for receiving data from a network according to claim 39, wherein said spectral spreading comprises a cross-gain modulation.

42. The method for receiving data from a network according to claim 39, wherein said method further comprises, before step d), the step of filtering said modulated decoded wideband signal.

43. The method for receiving data from a network according to claim 39, wherein said method further comprises, before step c), the step of isolating said SOA-based spectral broadening means.

44. A SOA-based OCDMA receiver for receiving data from a network, said receiver comprising : a first optical circulator having a first port receiving a spectro-temporally encoded signal, said circulator having a second and a third port; decoding means connected to said second port for receiving and decoding said spectro-temporally encoded signal, thereby providing a modulated decoded signal forwarded through said third port of said first circulator; a second optical circulator having a first port receiving said modulated decoded signal, said circulator having a second and a third port; a SOA operated with a constant electrical bias in a saturated mode, said SOA having a first port connected to said second port of said second circulator for receiving said modulated decoded signal ; and a distributed feedback laser operated in a continuous wave regime injected in a second port of said SOA in a counter-propagating scheme; wherein said modulated decoded signal modulates a gain of said SOA, thereby modulating said laser for providing a coherent modulated decoded signal through a third port of said second circulator.

45. The SOA-based OCDMA receiver for receiving data from a network according to claim 44, further comprising an isolator operatively connected between said SOA and said laser.

46. A method for converting an incoherent signal into a coherent signal, said method comprising the steps of: a) providing said incoherent signal from a first port of an optical circulator having a second and a third port; b) injecting said incoherent signal into a first port of a SOA operated with a constant electrical bias in a saturated mode, said SOA being connected to said second port of said optical circulator; and c) injecting in a counter-propagating scheme a distributed feedback laser operated in a continuous wave regime into a second port of said SOA, thereby modulating said laser for providing a coherent modulated decoded signal through said third port of said circulator.

47. The method for converting an incoherent signal into a coherent signal according to claim 46, said method further comprises the step of isolating said laser.

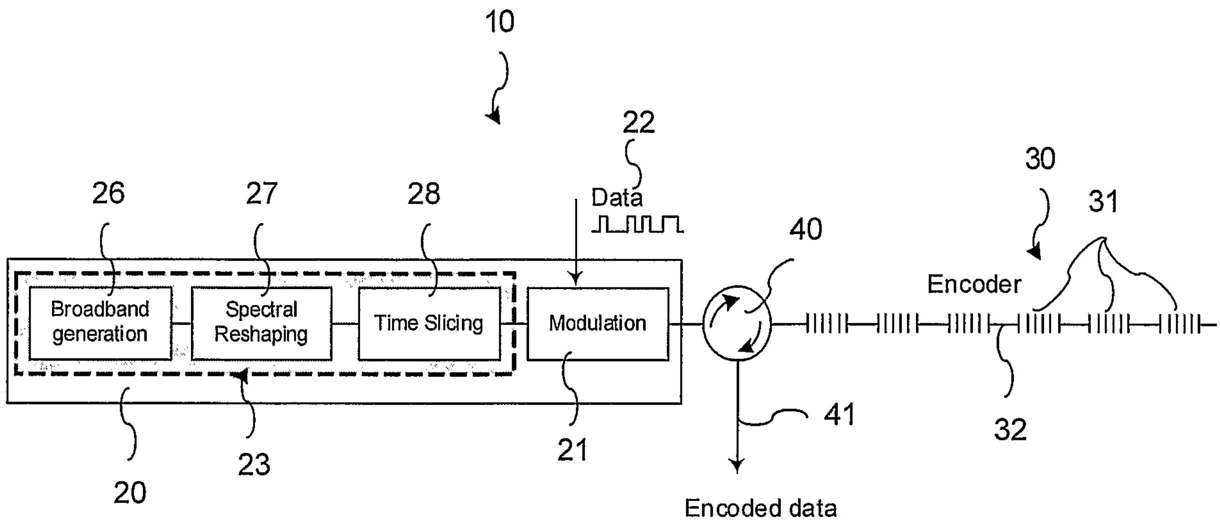

Figure 1

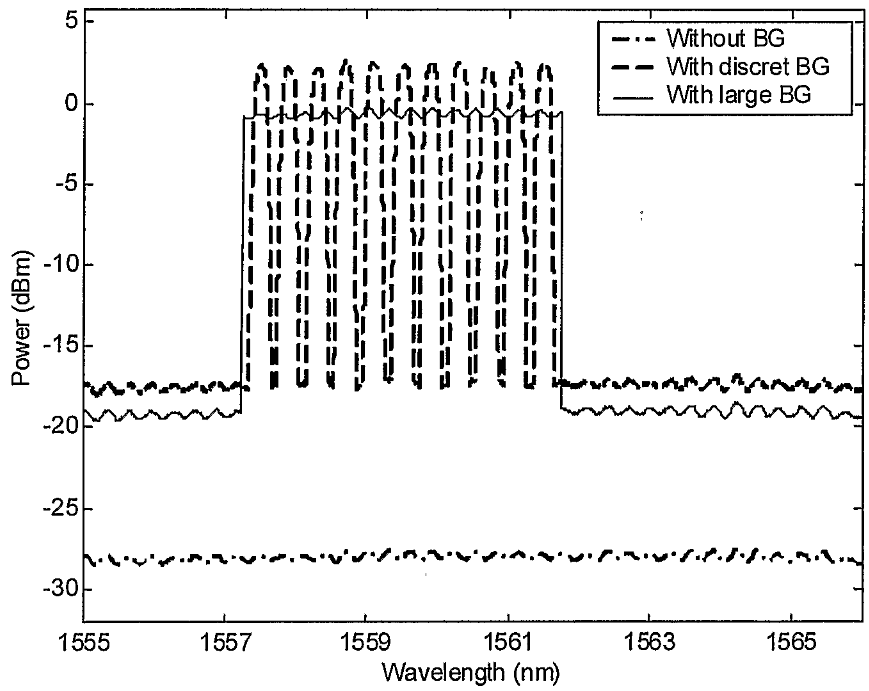

Figure 2

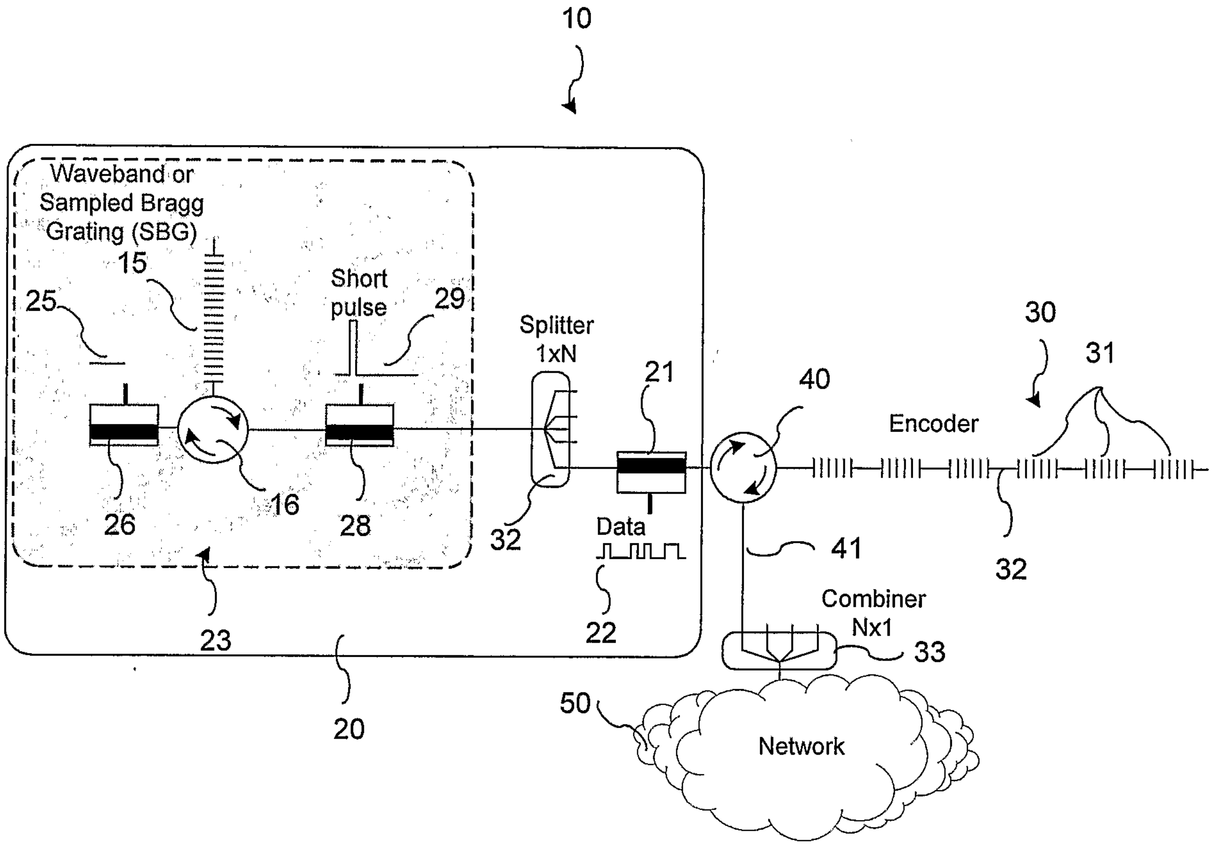
10
Waveband or
Sampled Bragg
Grating (SBG)
15
25
Short
pulse
29
Splitter
1xN
21
40
30
31
Encoder
26
16
28
32
Data
41
32
22
23
Combiner
Nx1
33
20
50
Network

Figure 3

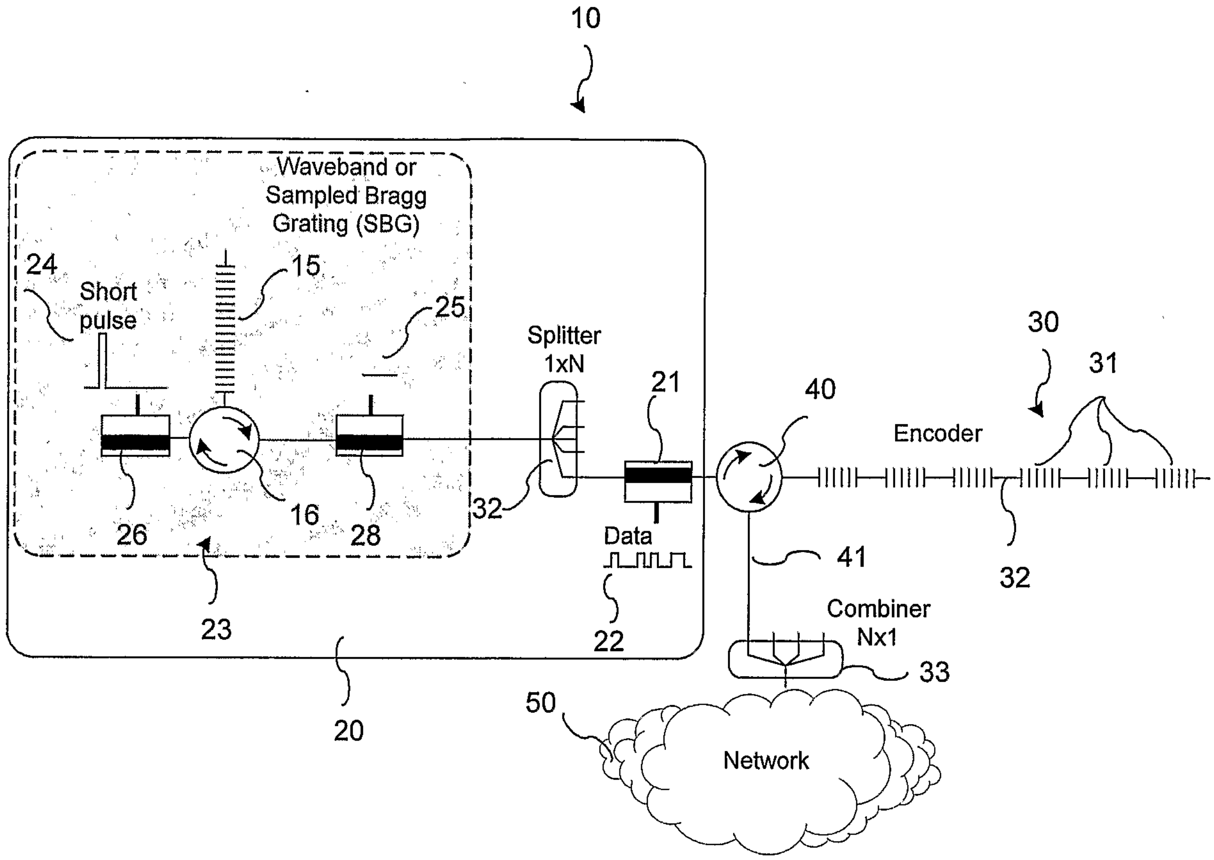
10
Waveband or
Sampled Bragg
Grating (SBG)
24
Short
pulse
15
25
Splitter
1xN
21
40
30
31
Encoder
26
16
28
32
23
Data
22
41
32
Combiner
Nx1
33
20
50
Network

Figure 4

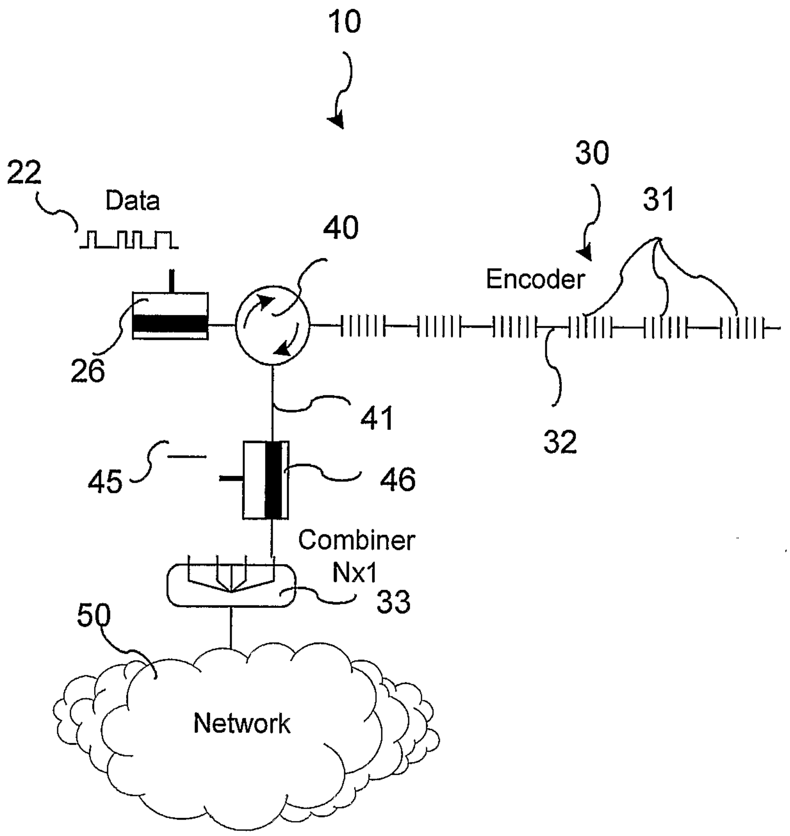
10
22
Data
40
30
31
Encoder
26
41
32
45
46
Combiner
Nx1
33
50
Network

Figure 5

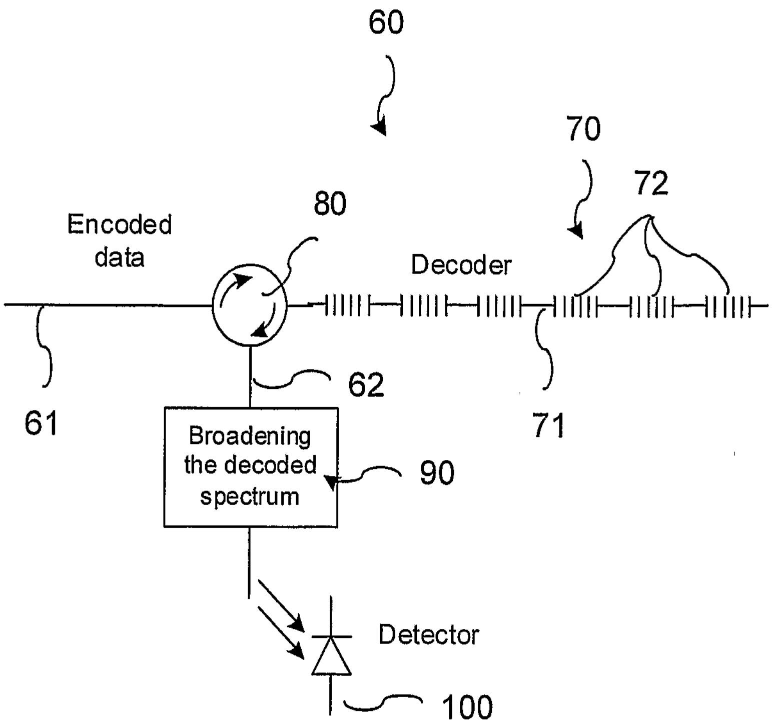
60
70
72
80
Encoded data
Decoder
61
62
71
Broadening the decoded spectrum
90
Detector
100

Figure 6

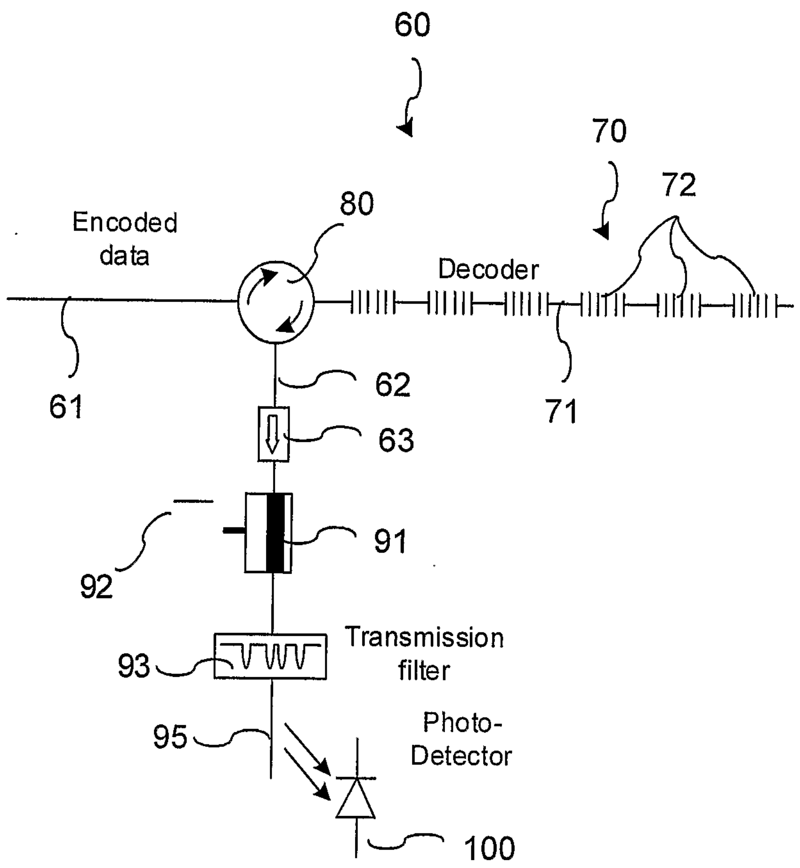

Figure 7

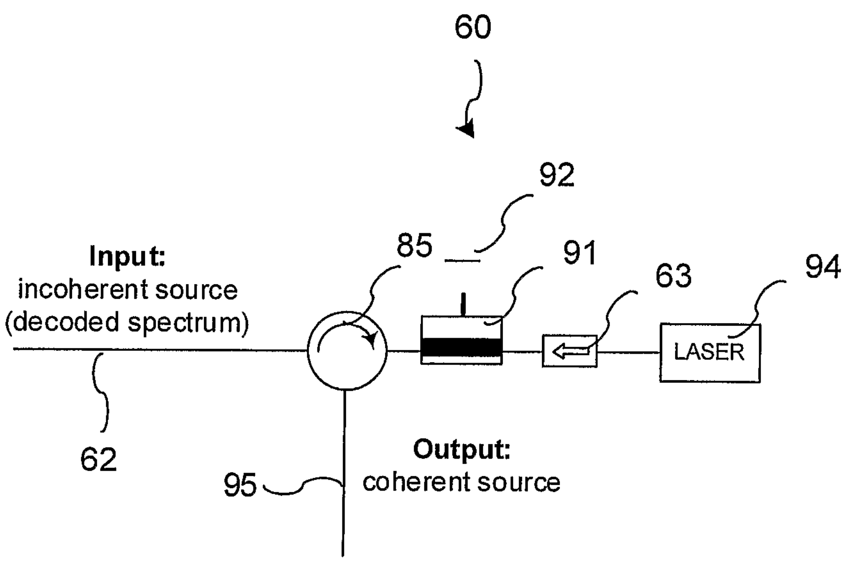

Figure 8