Title: METHOD AND MODULE FOR OPTICAL SUBCARRIER LABELLING

Abstract: The present invention relates to optical labelling in WDM networks, in that it provides a method and a module to be used in subcarrier label generation and switching in network edge nodes and core switch nodes. The methods and modules are typically employed in Optical Subcarrier Multiplexing (OSCM) transmitters. The payload and the label are encoded independently on optical carrier and subcarrier signals respectively, using electro-optical modulators. The invention applies single or double sideband carrier-suppressed modulation to generate subcarrier signals for encoding of the label. Thereby the payload encoded carrier signal and the label encoded subcarrier signal can be coupled directly without prior filtering.
before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
METHOD AND MODULE FOR OPTICAL SUBCARRIER LABELLING

FIELD OF THE INVENTION

The present invention relates to optical labelling in WDM networks. More particularly, the invention provides a method and a module to be used in subcarrier label generation and switching in network edge nodes and core switch nodes.

BACKGROUND OF THE INVENTION

Today’s optical transmission systems based on WDM technology have provided us enormous bandwidth, and great achievements have been made in increasing the bit-rate of single channels and enlarging the span of available wavelength channels. Presently, a bottleneck in the switching layer prevents current networks from operating with higher performance.

The concept of generalised multi-protocol label switching (GMPLS) plays an important role in present optical networks. The GMPLS layer adds the label to the IP packet so that the layers below it, including the optical layer, need only process the labels to perform the routing. In this way, the packet can be transparently transported through the network, without regard to the IP packet format. The GMPLS scheme is extensive and can be applied into both electrical and optical domains. The present invention relates to the optical domain, where GMPLS is implemented by optical label transmission modules at network edge nodes and network core switch nodes. The optical label transmission modules generate labels on new packets or replace old labels with new labels on switched packets.

Until now, several optical labelling methods have been proposed. Currently, some WDM networks employ the wavelength as the optical label, using wavelength routers to perform the routing in the optical network, this is known as lambda or wavelength switching.

Optical Subcarrier Multiplexing (OSCM) for insertion of label information has been shown to be an efficient approach and have the advantage of carrying in-band information and can be detected in asynchronous way. It puts stringent requirements on the optical filter in the label-swapping node, but the development of narrow-bandwidth filter technology such as fibre interleaver, fibre-Bragg-grating provides efficient solutions.

A number of references relate to OSCM:

US 6,111,673 and US 2001/0017723 describe networks using optical subcarrier label switching modules performing header generation, detection and reinsertion. In the header
generation, the header and the payloads are first combined electrically and then optically impressed together (e.g. Figure 7 and section [0086] in US 2001/0017723). In header reinsertion, the header is impressed directly on the payload data signal in MZM 1270 (Figure 12 and sections [0099] and [0100] in US 2001/0017723).

In US 5,956,165, OSCM is used for insertion of network management information in sidebands to the high data rate optical signal. As described in column 11, lines 21-38, the updated electrical subcarrier modulation signal 446 (and signal 438 cancelling the old subcarrier modulation) are modulated directly onto the optical signal 411 carrying the high data rate signal.

Blumenthal et al. (IEEE Phot. Tech. Lett., 9, 1397 (1997) and Journ. Lightw. Tech., 18, 2058 (2000)) describe two types of OSCM transmitters. In the first type, a single, external dual-electrode Mach-Zehnder modulator simultaneously impresses both payload and header onto the optical signal. In the second type, the optical carrier signal is split before the header and payload are impressed independently using standard modulation techniques. To perform double sideband modulation of the header part of the optical signal, the header signal is multiplexed with a RF clock signal in a RF mixer.

US 6,271,946 and US 6,160,651 (Chang et al.) disclose systems for optical label switching in WDM networks, including header detection and insertion of new headers. Figures 16 through 19 show circuitry used to detect, delete and reinsert headers in the optical signal. The optical switch and add/drop multiplexer 1607 impresses the new headers in the optical signal containing the payload. Circuit 1607 frequency shifts the new header above the data payload as well as above all other existing headers in the incoming signal.


It is a disadvantage of the disclosed techniques for subcarrier multiplexing and label insertion that a label transmitter is usually configured using analogue RF circuits. In most subcarrier labelling methods of the prior art, the label and the payload are combined electrically by an electrical combiner or opto-electrically by a MZM. In this way, it is very hard to generate a crosstalk-free signal. There will be crosstalk between the payload and the label when they are modulated on the same optical carrier signal.

The transmitter module on Figure 15 in Journ. Lightw. Tech., 18, 2058 combines the label and the payload optically, and uses a birefringent loop mirror filter shown in Figure 16.
This filter removes the carrier from the subcarrier signal to avoid coherent interference with the carrier signal.

It is a disadvantage of the OSCM transmitter disclosed in Journ. Lightw. Tech, 18, 2058 that it needs an optical notch filter making the transmitter more complex.

As GMPLS are often combined with wavelength switching in optical networks, it is desirable to be able to tune the wavelength of the carrier and subcarrier signals for OSCM transmitters. Fast tunable lasers are commercially available making it possible to tune the wavelength of the original optical signal to be modulated. However, no fast tunable filters are presently available. When an OSCM transmitter with an optical notch filter is employed by the network nodes, the network nodes will lose the capability of fast wavelength tuning and thereby hinder wavelength switching.

It is another disadvantage of the OSCM transmitter disclosed in Journ. Lightw. Tech, 18, 2058 that it can not be employed in wavelength switching networks until sufficiently fast tunable filters have been developed.

**SUMMARY OF THE INVENTION**

The present invention provides a method and a module for optical subcarrier labelling to be used in label generation, switching and multiplexing in network edge nodes and core switch nodes. The invention can be used to upgrade existing wavelength switched WDM networks as well as in the construction of packet switched WDM networks.

It is an advantage of the optical subcarrier labelling modules of the invention that no complex RF processing circuits are needed.

It is another advantage of the optical subcarrier labelling modules of the invention that the payload and the label are optically encoded independently on separate optical signals to avoid crosstalk.

It is another advantage of the optical subcarrier labelling modules of the invention that no optical notch filter is needed, which simplifies the design and construction of the modules.

It is a further advantage of the subcarrier labelling modules of the invention that the sidebands are generated from same signal as the payload carrier, giving a well-defined frequency relation between the payload carrier and the subcarrier label.
It is a still further advantage of the subcarrier labelling modules of the invention that they allow for fast wavelength tuning of the carrier and subcarrier signals. This is possible since fast wavelength tunable lasers are commercially available and since no optical notch filter is needed. Thereby, the modules of the invention can be employed in fast wavelength switching networks.

The above objects and advantages are met by the following aspects of the present invention.

In a first aspect, the present invention provides a method for performing optical subcarrier labelling of an optical signal, comprising the steps of

- receiving a first optical signal having a carrier frequency \( \nu_c \),
- splitting the first optical signal in a label part and a payload part,
- generating one or more optical sideband signals having frequencies \( \nu_c \pm \nu_{sf} \) on the label part of the first optical signal by performing single/double sideband carrier-suppressed modulation of at least part of the label part of the first optical signal,
- providing label data,
- optically encoding the label data on at least one of said one or more optical sideband signals,
- coupling the encoded optical sideband signal(s) with the payload part of the first optical signal.

Thus, according to the present invention, the label data is impressed on an optical signal which is physically separated from the carrier signal with the payload data. The two signals are then coupled afterwards. This approach provides the advantages stated above and renders the invention inventive over the OSCM techniques of the prior art.

In a preferred embodiment, the method refers to labelling in a network edge node in that it further comprises the steps of

- providing payload data, and
- optically encoding the payload data on the payload part of the first optical signal.

In another preferred embodiment, the method refers to labelling in a network core switch node in that it further comprises the steps of

- receiving a second optical signal having a carrier frequency \( \nu_{c2} \) and being encoded with payload data, and
- optically encoding said payload data on the payload part of the first optical signal.

Typically, the received second optical signal also comprises subcarrier label data to be decoded.
In another preferred embodiment, the method refers to labelling in a network core switch node in that the step of receiving the first optical signal comprises the step of receiving an optical signal having a carrier frequency $\nu_c$ and being encoded with payload data, said optical signal being the first optical signal. Typically, the received signal also comprises a subcarrier label to be extracted and decoded. Part of the remaining carrier part of the received signal is then used for the carrier-suppressed modulation. As the carrier part of the received signal holds payload information, some crosstalk may arise.

Preferably, the optical encoding of both the label and the payload data are performed by electro-optically intensity modulating the relevant optical signal.

Both single and double sideband carrier-suppressed modulation may be performed. However the double sideband carrier-suppressed modulation is presently the most matured technique and may therefore be preferred.

In a second aspect, the present invention provides an optical subcarrier labelling module for generating and inserting labels in optical data signals, the module comprising
- a continuous wave laser source for generating a first optical signal having carrier frequency $\nu_c$,
- a first splitter for receiving the first optical signal from the laser source, and for splitting the first optical signal in a label part and a payload part,
- a first electro-optical modulator for receiving the label part from the first splitter, and for generating one or more optical sideband signals having frequencies $\nu_c \pm \nu_{RF}$ on the label part of the first optical signal by performing single/double sideband carrier-suppressed modulation of the label part of the first optical signal,
- a second electro-optical modulator for receiving the optical sideband signal(s) from the first electro-optical modulator and label data, and being adapted to optically encode the label data on the optical sideband signal(s), and
- a coupler for receiving the encoded optical sideband signal(s) from the second electro-optical modulator and said payload part from the splitter, and for coupling the encoded optical sideband signal(s) with the payload part.

The module can thereby generate sidebands for label encoding directly from the same optical signal that will be used for payload encoding. This gives a well-defined frequency relation between the payload carrier and the subcarrier label.

In order to optically encode the payload, the module preferably further comprises an electro-optical modulator adapted to receive the payload part of the first optical signal and
electron payload data, and to optically encode the received electronic payload data on
the received payload part of the first optical signal.

In a preferred embodiment according to the second aspect, the module is employed in a
network core switch node and further comprises a wavelength converter adapted to
receive a second optical signal holding payload data and the payload part of the first
optical signal, and to optically encode the payload data of the second optical signal on to
the payload part of the first optical signal.

In a third aspect, the invention provides an optical subcarrier labelling module for
detection and reinsertion of labels in optical data signals to be employed in a network core
switch node, the module comprising
- an optical notch filter for splitting an incoming data signal in a sideband part and a
carrier part,
- a label processor for receiving the sideband part of the incoming signal from the notch
filter, and for reading label data from the sideband part and generating new label data,
- a splitter for receiving the carrier part of the incoming signal from the notch filter and
for splitting the carrier part in a label part and a payload part,
- a first electro-optical modulator for receiving said label part from the splitter and for
generating one or more optical sideband signals having frequencies $\nu_c \pm \nu_{rf}$ on the label
part of the first optical signal by performing single/double sideband carrier-suppressed
modulation on the label part,
- a second electro-optical modulator adapted to receive the optical sideband signal(s)
from the first electro-optical modulator and the new label data from the label
processor, and to optically encode the received label data on the received optical
sideband signal(s), and
- a coupler for receiving the encoded optical sideband signal(s) from the second electro-
optical modulator and said payload part from the splitter, and for coupling the encoded
optical sideband signal(s) with the payload part.

The module can thereby generate sidebands for label encoding directly from the same
optical signal that holds the payload. This gives a well-defined frequency relation between
the payload carrier and the subcarrier label.

Preferably, the first electro-optical modulator according to the second and third aspect is a
Mach-Zehnder modulator (MZM) comprising an input for receiving the label part of the first
optical signal, a splitter for dividing the received signal, first and second arms for receiving
separate parts of the divided signal, one or more electrodes for adjusting an
electromagnetic field in the first and/or second arm, respectively, and a coupler for
coupling or superposing the parts of the divided signal transmitted by the first and second arms. The module preferably further comprises an RF clock generator providing one or more RF clock signal(s) having frequency \( \nu_{RF} \) to the MZM to generate sidebands to the optical signal.

The phase difference \( \Delta \phi \) between the first and second arms of the modulator are preferably centred around \( \pi \) and \( \pi/2 \) for double and single sideband generation respectively. This is typically controlled by adjusting a DC bias difference between the arms of the MZM to full or half of the switching voltage \( V_s \) of the modulator. The switching voltage \( V_s \) denotes the voltage required to change output light intensity from its maximum value to minimum value. However, depending on the specific parameters chosen for optical performance, \( \Delta \phi \) and the DC bias of the MZM may be set to different values.

In a preferred embodiment, the MZM is a dual-electrode Mach-Zehnder modulator (DE-MZM). The module is adapted to perform double sideband carrier-suppressed modulation by supplying first and second RF clock signals having frequencies \( \nu_{RF} \) and \( \pi \) phase difference from the RF clock generator to the first and the second electrode respectively, and by DC biasing the first and second electrodes to provide a phase difference \( \Delta \phi \) between the arms, the DC bias difference being adjusted to give a mean value of the phase difference \( \Delta \phi \) in the interval \( 3\pi/4 < \Delta \phi_{mean} < 5\pi/4 \).

In another preferred embodiment the MZM is also a DE-MZM, but here the module is adapted to perform single sideband modulation by supplying first and second RF clock signals having frequencies \( \nu_{RF} \) and \( \pi \) phase difference from the RF clock generator to the first and the second electrode respectively, and by DC biasing the first and second electrodes to provide a phase difference \( \Delta \phi \) between the arms, the DC bias difference being adjusted to give a mean value of the phase difference \( \Delta \phi \) in the interval \( \pi/4 < \Delta \phi_{mean} < 3\pi/4 \) so as for the DE-MZM to perform single sideband modulation, the module further comprising an interferometer for receiving a second part of the label part of the first optical signal and the coupled signal from the coupler of the DE-MZM to suppress a carrier frequency part in the coupled signal from the coupler of the DE-MZM. The DE-MZM and the interferometer thereby being adapted to perform single sideband carrier-suppressed modulation on the label part of the first optical signal.

The words label and header will be used interchangeably to means a portion of a data packet that contains information that will guide the package to the correct destination.

Binary data can be encoded optically on to an optical signal. Optical signals have an inherent carrier frequency, namely the frequency \( \nu_c \) of the electromagnetic wave:
\[ E = A_e(t) \exp[i \nu_e(t)t + \phi_e(t)]. \] (1)

When optically encoding an electromagnetic wave, different modulation schemes are possible:
- intensity modulating where the amplitude \( A_e(t) \) is modulated in time,
- frequency modulating where the frequency \( \nu_e(t) \) is modulated in time,
- phase modulating where the phase \( \phi_e(t) \) is modulated in time.

Optical fibres and components degrade optical signals in different ways, which may deteriorate the signals and increase the bit error ratio. It may therefore be profitable to choose signal characteristics with respect to the type of deterioration to conserve the signal in the best manner. Hence, in embodiments according to different aspects of the invention, the optical encoding of the label data and the payload date may be performed in the same modulation scheme. Thereby, the modulation scheme which conserves the signal the best can be chosen for both the label and the payload. As label and payload are encoded on sidebands and carrier respectively, the separation can be carried using an optical notch filter.

The label and the payload may also be encoded in orthogonal modulation schemes. In this case, the label and the payload may be decoded by direct detection, that is, without prior separation of the carrier and sideband signals.

In the subcarrier labelling methods of the prior art, the label information is modulated on the electric RF carrier (RF mixer) which generates the subcarrier signal. In the present invention, the payload and the label are encoded independently on optical carrier and subcarrier signals respectively, using electro-optical modulators. The invention applies single or double sideband carrier-suppressed modulation to generate subcarrier signals for encoding of the label. Firstly, an optical signal is split in a label part and a payload part. Secondly, the label part of the optical signal is modulated with a RF subcarrier signal in a specially configured optical modulator to generate the optical subcarrier (sideband) while suppressing the carrier part. Thirdly, the label information is optically modulated onto the optical subcarrier in a second optical modulator. At the same time, payload information is optically modulated onto the optical carrier in a second optical modulator. Fourthly, the optical subcarrier label is optically combined with the optical carrier payload. Thus, the payload encoded carrier signal and the label encoded subcarrier signal can be coupled directly without prior filtering. This is the basic idea of the invention. It is this principle which renders the mentioned advantages possible. It permits an arbitrary label to payload power ratio with no inter-modulation distortion between them.
BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the invention in a network edge node according to a preferred embodiment.

Figure 2 shows the invention in a core switch node according to a preferred embodiment.

Figure 3 shows the invention in a core switch node according to another preferred embodiment.

Figure 4A and 4B show a set-up and a diagram used to explain double sideband carrier-suppressed modulation.

Figure 5 shows a diagram of an experimental set-up used to demonstrate the invention in a network edge node according to the embodiment shown in Figure 1.

Figure 6A-D show spectra of label and payload before and after transmission from the experimental set-up of Figure 5.

Figure 7A-D show eye-diagrams of label and payload before and after transmission from the experimental set-up of Figure 5.

Figure 8 shows bit error ratios of label and payload from the experimental set-up of Figure 5 before and after transmission.

Figure 9 shows a diagram of an experimental set-up used to demonstrate the invention in a core switch node according to the embodiment shown in Figure 3.

Figure 10 shows an optical spectrum of a carrier suppressed modulated payload from the experiment of Figure 9.

Figure 11 shows bit error ratios of label and payload from the experimental set-up of Figure 9 before and after transmission. The insert shows reflection spectra of OADMs and spectrum of label and payload from the experimental set-up of Figure 9.

Figure 12 shows a diagram used to demonstrate optical single-sideband labelling process according to another preferred embodiment of the present invention.

Figure 13 shows a diagram of an experimental set-up used to demonstrate the optical single-sideband label generation with the aid of an optical filter.
Figure 14 shows bit error ratios of label and payload from the experiment of Figure 13.

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

In the following sections, a more detailed description of preferred embodiments of the invention will be given. First, embodiments for use in network edge nodes and core switch nodes will be presented. Then, the principle of double sideband carrier-suppressed modulation will be explained in more detail. Thereafter, experiments verifying the working principle of the embodiments are reported. Finally, an embodiment utilising single sideband carrier-suppressed modulation is presented, and an experiment verifying the working principle of this embodiment is reported.

Figure 1 shows an optical label transmitter according to a preferred embodiment to be used in a network edge node 100. The light source is a continuous-wave laser node 101, the output of which is split into a label arm 104 and a payload arm 105 by an optical splitter 102. Thereby, an optical carrier signal 103 from laser 101 is split into a label part 118 and a payload part 112. The payload information is directly impressed upon the payload part using an external electro-optical intensity modulator 113. For the label arm 104, the light is firstly modulated by a Dual Electrode Mach-Zehnder Modulator (DE-MZM) 106 driven by a RF clock generator 107. This modulator is specially configured to perform carrier suppression modulation. Thereby, input optical carrier 103 is suppressed so that the output 108 mainly consists of two sidebands. The label information is impressed upon the two optical sidebands using a usual electro-optical intensity modulator 109. As the generated label 111 does not have optical carrier component in its spectrum, it can be directly multiplexed with the optical payload 115 through a usual coupler 116. This produces an optical signal with both the payload and the sub-carrier label. The combined label and payload spectrum is shown in 117.

Figure 2 shows an optical label transmitter according to another preferred embodiment to be used in a network core switch 200. In this embodiment, an optical signal with the payload information 201 is received, and the transmitter generates a new optical signal with another wavelength, carrying the received payload information and a new label. A continuous-wave laser 101, having a different wavelength than the received signal 201, is split into a label arm 104 and a payload arm 105 by an optical coupler 102. The two optical carrier signals are used for the label generation and payload wavelength conversion respectively. The payload to be switched can be extracted from the incoming labelled packet 201 by a notch filter 202. The received payload signal is injected into a wavelength converter 203 in the payload arm 105, together with the new optical carrier signal. After wavelength conversion the payload information is replicated onto the wavelength of the
laser 101. The generation of the new label and coupling of the label and the payload signals is similar to the process described in relation to Figure 1.

Figure 3 shows an optical label transmitter according to another preferred embodiment to be used in a network core switch 300. In this embodiment, an optical signal 201 is received, and the transmitter generates a new optical signal having the same wavelength as the received packet carrying the same payload information and a new header. Here, the label swapping function is carried out without using a continuous-wave laser as in the embodiments of Figures 1 and 2. The incoming label 301 is separated from the payload 303 by an optical filter 202 and is injected into a label-processing module 302. Label-processing module reads the label data and generates new label data, which may be equivalent to the read data. The incoming payload 303 is amplified in amplifier 304 and split into a label arm 104 and a payload arm 105 by optical coupler 102. In the label arm 104, the payload carrier signal fed to a Mach-Zehnder modulator 106 performing double sideband carrier-suppressed modulation so that two sidebands are generated 108. This process is similar to the one described in relation to Figures 1 and 2. The new label from label processing module 302 is then electro-optically modulated onto the sidebands by another modulator 109. In future applications, the label-processing module may be a purely optical device, in which case the new label data will be optical with corresponding modulation onto the sidebands. The received payload signal 115 in the payload arm 105 can now be combined with the new label by coupler 116 to form the new packet 117. It is an important feature that the new label is generated from the received payload signal, by subcarrier labelling on sidebands generated by suppressed-carrier modulation of the payload. This ensures that there is a well-defined wavelength relation between the payload and the labels.

The basic principle of double-sideband carrier-suppressed modulation will be described in relation to Figure 4A and B. A more detailed explanation of double-sideband carrier-suppressed modulation may be found in IEEE Photonics Tech. Lett. 7, 434 (1995) and references therein. Figure 4A shows a set-up wherein a carrier signal 103 from a continuous-wave laser 101 is modulated by a dual driven Mach-Zehnder modulator 106. The RF clock 107 signal is applied to a hybrid coupler 401, whose outputs 402 and 403 have a π phase shift in relation to each other. Combined with different DC bias 404 and 405 respectively, the RF clock signals drive the modulator 106 in the push-pull style. The respective phase change in each arm is induced by the applied voltage acting on that arm, thus the output of the electrical field E can be expressed as,

$$E = A_e \cos(\frac{\Delta \phi}{2}) \exp(-j \frac{\theta_0}{2}) \cdot \exp(iv \cdot t)$$  (2)
In the expression, $\Delta \phi$ denotes the difference of the phases of the two arms while $\phi_0$ denotes the sum of them. $\nu_c$ denotes the optical carrier frequency. Thus the field envelope $E_A$ of the optical signal is expressed as

$$E_A = A_c \cos\left(\frac{\Delta \phi}{2}\right) \exp\left(-j \frac{\phi_0}{2}\right)$$  \hspace{1cm} (3)

The magnitude of the carrier, namely the spectral intensity at the carrier frequency, is determined by the average of $E_A$ over time.

Due to the push-pull operation of the RF clocks, the sum of the phases $\phi_0$ will keep as a constant over time and thus sees no modulation. For the carrier-suppressed modulation, the DC bias difference of the two arms is also preferably set equal to the switching voltage $V_s$, so that the phase difference between the arms swings around $\pi$. When the phase difference $413$ between the arms swings around $\pi$, we are working at "null point" which theoretically should give a total suppression of the carrier. However, several parameters affect the result of the carrier-suppression, and often small departures from null point operation is experienced when adjusting the voltages to obtain the desired suppression. Thus, the DC bias difference of the two arms may be adjusted so that the phase difference $413$ swings around, or has a mean value $\Delta \phi_{\text{mean}}$, close to $\pi$, preferably in the interval $3\pi/4 < \Delta \phi_{\text{mean}} < 5\pi/4$. Naturally, as the curve $408$ is periodical, $\Delta \phi_{\text{mean}}$ may be in an interval centred around $p\pi$, where $p$ is an integer.

Overlooking the constant phase item, the relation between the output envelope and the input electrical signal can be further derived,

$$E_A = A_c \cos\left(\frac{\pi}{2} + m(t)\right)$$ \hspace{1cm} (4)

$m(t)$ is determined by the input electrical waveform.

Figure 4B shows the working principle of the optical carrier-suppressed modulation. The optical continuous-wave signal $406$ is modulated by the DE-MZM, whose modulation characteristics are shown in curve $408$ according to expression (4). Axis $407$ denotes the modulation on the field envelope while axis $409$ denotes the phase difference between the two arms. When the phase difference $413$ between the arms swings around $\pi$, the field envelope of the optical output $410$ will switch between negative and positive. In this way, the average of the envelope over time will be identical to zero as can also be seen from curve $408$. In other words, the spectral component at the carrier frequency, namely the optical carrier, is greatly suppressed.

In standard intensity modulation according to the prior art, the MZM modulator is single-arm-driven or dual-arm-driven. Moreover, the DC bias difference between the arms is
equal to half of the switching voltage $V_s$, so that the DE-MZM operates in the linear intensity modulation region and outputs the optical intensity waveform identical to the input electrical one. In the dual-arm-driven case, the field envelope of the optical output is expressed as

$$E_d = A_c \exp(i \nu_c t) \cos\left(\frac{\pi}{4} + m(t)\right)$$

(5)

As shown in Figure 4B, when the phase difference between the arms 412 swings around $\pi/2$, there would present a continuous-wave (CW) component at the envelope of optical output 414, thus the carrier cannot be suppressed.

In conclusion, push-pull operation of the RF clock and appropriate DC bias on the arms of DE-MZM enable the carrier-suppressed modulation of the optical signal.

Other modulators than MZMs may be applied to perform the carrier-suppressed sideband generation as well as the encoding. Another applicable type of MZM is the X-cut Mach-Zehnder LiNbO3 modulator. Here, the RF clock generator providing only a single RF clock signal to an active electrode which induce a phase shift in both arms. The phase shifts on both arms always have the same absolute value, but opposite signs, hence the push-pull operation of the two arms is achieved with a single-electrode-drive. To obtain carrier-suppressed modulation, the DC bias between the arms must be adjusted to obtain the proper phase difference $\Delta \phi$. The operation principle for this modulator can also be explained by equation (1) - (5).

Experimental demonstration

In the following sections, experiments verifying the working principle of the embodiments of Figures 1 and 3 are reported.

Figure 5 shows a diagram of an experimental set-up 500 used to demonstrate the switching node according to the embodiment described in relation to Figure 1. A CW laser 501 provides an optical signal at 1550 nm, which is split in a 3dB splitter 502 into a label part in arm 503 and a payload part in arm 504. In the label arm 503, a dual-arm LiNbO3 MZ modulator 505, which has a 3dB modulation bandwidth of 15GHz and 3.5dB insertion loss, was configured to perform the carrier-suppressed modulation. The DC bias difference for the two arms is exactly equal to the switching voltage $V_s$. A RF clock 506 at 15GHz was applied to a hybrid coupler 507 whose two outputs have $\pi$ phase shift with respect to each other. These two outputs then drove the modulator 505 to perform the carrier-suppressed modulation. Another MZ modulator 508 functioned as intensity modulator to impress the 156Mb/s label information. In the payload arm 504, MZ modulator 511 functioned as
intensity modulator to impress the 10Gb/s payload. An optical attenuator was inserted in
the payload arm to adjust the relative power ratio. The label arm 503 and payload arm
504 where coupled in coupler 510 and then transmitted over 50km SMF and a matching
length of dispersion compensating fibre. To optimise both the payload and label receivers’
performance, the input power to the fibre was set to 10dBm. At the end of transmission
link, two fibre-Bragg-grating (FBG) based Optical-add/drop-multiplexers (OADM) 513 and
514 were used for the extraction of the payload and label from the transmitted signals.
The edge of the first OADM 513 transfer function was selected to be located between the
wavelengths of one sideband and the carrier. In such a way, this sideband with label
information was dropped and input to the optical receiver 516 for bit error ratio testing,
the other sideband and the carrier was located between the second OADM 514, whose
transmission edge situated between them. In this way, the carrier with the payload
information was dropped by the second OADM 514 and then input to another error
detector 515 for performance evaluation.

Figures 6A-D shows the spectrum of (Figure 6A) the generated label with the suppressed
carrier (Figure 6B) the generated signal consisting of payload and label (Figure 6C) the
extracted label after first OADM (Figure 6D) the payload with the residual label after
second OADM. As can be seen from Figure 6A, the carrier component in the optical label
spectrum is greatly suppressed. The power ratio of carrier to sideband is measured to be
below –32dB, which ensured that no modulation distortion was added to payload. In the
transmitter, the label (one-sideband) to payload power ratio could be adjusted by the
attenuator, and was set as 5dB for the purpose of transmission system optimisation, as
shown in Figure 6B. At the receiver node, an OADM 513 extracted one sideband label, the
payload was extracted with some residual label due to the not-so-steep edge of the second
OADM 514, as shown in Figure 6C.

The comparison of the eye-diagrams of the label and payload before multiplexing and after
transmission and extraction are given in Figure 7A-D showing Eye-diagrams of (7A)
original label before multiplexing (7B) extracted label (7C) original payload before
multiplexing (7D) extracted payload. The BER curves in Figure 8 shows that the penalties
induced by the labelling and transmission are about 0.3dB for both label and payload;
curve 801 shows label back-to-back, curve 802 shows label after 50km SMF, curve 803
shows payload back to back, curve 804 shows payload after 50km SMF.

Figure 9 shows a diagram of an experimental set-up 500 used to demonstrate the working
principle of a switching node according to the embodiment described in relation to Figure
3. A wavelength tunable external cavity laser (ECL) 501 working at 1555.2 nm provides
the optical signal on which payload data is optically encoded by amplitude modulation
using a MZM 502 receiving a binary 10Gbit/s signal from generator 503. The modulated signal is amplified in Erbium-doped fibre amplifier (EDFA) 504 and split into a label part in arm 512 and a payload part in arm 513. RF synthesiser 506 provides a sinusoidal clock signal at 15 GHz to hybrid coupler 507 whose two outputs have π phase shift with respect to each other. The phase shifted RF signals drive a push-pull type MZM 508 in which carrier-suppression occurs. Figure 6 shows a spectrum of the carrier suppressed payload intensity modulated at 10 Gbit/s. A suppression ratio of up to 30 dB can be achieved by controlling the input RF voltage and the polarisation state of the polarisation controller 505 before the push-pull MZM 508. Two sidebands with 30 GHz spacing are generated and amplified in EDFA 504. Generator 509 provides a 1.25 Gbit/s label to MZM 510, which is optically encoded onto the sidebands by amplitude modulation. The payload is then combined with the subcarrier label via a 3 dB coupler, thus making the optically labelled packet ready for transmission. The transmission span consists of 50 km standard fibre followed by 8.6 km dispersion compensating fibre. A variable attenuator 514 is inserted before the transmission fibre link to get optimum span input power.

At the receiver, two fibre Bragg grating based OADMs 515 and 516 with carefully selected rising edges are deployed to extract the subcarrier label and the payload, respectively. The optical spectra of the payload with subcarrier label and the reflection of OADMs 515 and 516 are detected by error detectors 517 and 518. The insert in Figure 7 shows the reflection spectra 702 of OADM 515, the reflection spectra 703 of OADM 516, and the received spectrum 704 of the label and payload. Because of the sharp edges of the OADMs, the extracted label and payload have a signal to noise ratio about 20dB. Larger signal to noise ratio may be obtained if a narrow notch filter is used for the payload and label separation.

The measured bit-error ratio (BER) performance of the payload and label for back-to-back and after 50 km transmission are shown in Figure 7. Points 705 shows back-to-back label BER, points 706 shows back-to-back payload BER, points 707 shows label BER after 50 km transmission, and points 708 shows payload BER after 50 km transmission. Error-free transmission of both payload and label can be achieved simultaneously. After transmission, the label and payload show a small power penalty below 1 dB.

In the following sections, we describe an embodiment employing single sideband carrier-suppressed modulation used to perform the optical single-sideband labelling. Figure 12 shows the configuration of a module 1200. Most of the configuration is similar to the one shown in Figure 1, except that the DE-MZM 106 is integrated with a Sagnac interferometer 1201 to perform the optical single-sideband carrier-suppressed modulation. The Sagnac
interferometer 1201 is further composed of a coupler 1202 and a loop 1203, with the DE-MZM 106 situating in the loop 1203. The label part of the optical signal injected into the loop 1203 is first split into a forward propagating wave and a reverse propagating wave. With the RF generator 107 providing two RF clock signals with a phase difference around \( \pi/2 \), the DE-MZM performs the single sideband modulation of the forward propagating wave, while having little modulation effect on the reverse propagating wave. To get high performance of single sideband modulation, the DC bias of the modulator 106 is also preferred to be equal to half of the switching voltage \( V_x \). When the forward propagating wave is finally combined with the reverse propagating wave at the coupler, the carrier will be suppressed and only the single sideband is present in the output 1204 of Sagnac interferometer 1201. To efficiently suppress the carrier, the coupler 1202 is preferred to be asymmetric and the amplitudes of the clock signals should be finely adjusted. The second electro-optical modulator 109 was adapted to receive the generated optical single-sideband signal 1204 and electronic label data 110, and to generate the encoded label part 1205. A coupler 116 couples the encoded label part 1205 with the payload part of the optical signal 115 and outputs the single sideband-labelled signal 1206.

Figure 13 shows a diagram of an experimental set-up used to demonstrate the optical single-sideband label generation scheme described in relation to Figure 12. Instead of single-sideband modulation, double sideband carrier-suppressed modulation is carried out, where after one of the sidebands is removed using an optical filter. Thus, compared with the set-up of Figure 12, a FBG based filter 1301 is inserted into the label arm and no Sagnac interferometer is used. The rising edge of the FBG 1301 is deployed to extract only one single sideband of the output of the MZM 1208.

The experimental set-up of Figure 13 is otherwise similar to the set-up of Figure 5. The optical single-sideband labelled signal consisting of 10 Gb/s payload and 155 Mb/s label is transmitted through 94 km standard fibre followed by 13 km dispersion compensating fibre. At the receiver, only one fibre Bragg grating based OADM 513 with carefully selected rising edge is deployed to extract the single-sideband subcarrier label and the payload. The extracted label is detected at the reflection port of OADM 513 by error detector 516, while the extracted payload is detected at the transmission port of OADM 513 by error detector 515.

The measured bit-error ratio (BER) performance of the payload and label for back-to-back and after transmission are shown in Figure 14. Points 1401 shows back-to-back payload BER, points 1402 shows back-to-back label BER, points 1403 shows label BER after transmission, and points 1404 shows payload BER after transmission. Error-free transmission of both payload and label can be achieved simultaneously.
CLAIMS

1. A method for performing optical subcarrier labelling of an optical signal, comprising the steps of
   - receiving a first optical signal having a carrier frequency $\nu_c$,
   - splitting the first optical signal in a label part and a payload part,
   - generating one or more optical sideband signals having frequencies $\nu_c \pm \nu_{RF}$ on the label part of the first optical signal by performing single or double sideband carrier-suppressed modulation of at least part of the label part of the first optical signal,
   - providing label data,
   - optically encoding the label data on at least one of said one or more optical sideband signals,
   - coupling the encoded optical sideband signal(s) with the payload part of the first optical signal.

2. The method according to claim 1, further comprising the steps of
   - providing payload data, and
   - optically encoding the payload data on at least part of the payload part of the first optical signal.

3. The method according to claim 1, further comprising the steps of
   - receiving a second optical signal having a carrier frequency $\nu_{c2}$ and being encoded with payload data, and
   - optically encoding said payload data on at least part of the payload part of the first optical signal.

4. The method according to claim 1, wherein the step of receiving the first optical signal comprises the step of receiving an optical signal having a carrier frequency $\nu_c$ and being encoded with payload data, said optical signal being the first optical signal.

5. The method according to claim 1, wherein the step of optically encoding the label data comprises the step of electro-optically intensity modulating the at least one sideband signal.

6. The method according to claim 2 or 3, wherein the step of optically encoding the payload data comprises the step of electro-optically intensity modulating the payload part of the first optical signal.
7. The method according to claim 1, wherein the step of performing sideband carrier-suppressed modulation comprises the step of performing double sideband carrier-suppressed modulation.

8. An optical subcarrier labelling module (100, 200, 1200) for generating and inserting labels in optical data signals, the module comprising
   - a continuous wave laser source (101) for generating a first optical signal (103) having carrier frequency $v_c$,
   - a first splitter (102) for receiving the first optical signal from the laser source, and for splitting the first optical signal in a label part (118) and a payload part (112),
   - a first electro-optical modulator (106) for receiving the label part from the first splitter, and for generating one or more optical sideband signals (108) having frequencies $v_c \pm v_{\text{rf}}$ on the label part of the first optical signal by performing single/double sideband carrier-suppressed modulation of the label part of the first optical signal,
   - a second electro-optical modulator (109) for receiving the optical sideband signal(s) from the first electro-optical modulator and label data, and being adapted to optically encode the label data on the optical sideband signal(s), and
   - a coupler (116) for receiving the encoded optical sideband signal(s) (111) from the second electro-optical modulator and the payload part (112, 115), and for coupling the encoded optical sideband signal(s) with the payload part.

9. The module according to claim 8, wherein the first electro-optical modulator is a Mach-Zehnder modulator (MZM), the module further comprising an RF clock generator (107) for providing one or more RF clock signal(s) with frequency $v_{\text{rf}}$ to the MZM to generate sidebands to the label part of the first optical signal, the MZM being adjusted to provide a phase difference $\Delta \phi$ between a first and second arm of the MZM, a mean value of the phase difference $\Delta \phi$ being in the interval $3\pi/4 < \Delta \phi_{\text{mean}} < 5\pi/4$ or in the interval $\pi/4 < \Delta \phi_{\text{mean}} < 3\pi/4$.

10. The module according to claim 8, wherein the first electro-optical modulator is an X-cut LiNbO$_3$ Mach-Zehnder modulator comprising an input for receiving the label part of the first optical signal, a second splitter for dividing the received signal, first and second arms for receiving separate parts of the divided signal, at least one electrode for adjusting an electromagnetic field in the first and/or second arm, and a coupler for coupling the parts of the divided signal transmitted by the first and second arms, the module further comprising an RF clock generator (107), the module being adapted to perform carrier-suppressed modulation by supplying an RF clock signal with frequency $v_{\text{rf}}$ to the at least one electrode from the RF clock generator and by DC biasing the first and second arms to provide a
phase difference $\Delta \phi$, the DC bias difference being adjusted to give a mean value of the phase difference $\Delta \phi$ in the interval $3\pi/4 < \Delta \phi_{\text{mean}} < 5\pi/4$.

11. The module according to claim 8, wherein the first electro-optical modulator is a dual-electrode Mach-Zehnder modulator (DE-MZM) comprising an input for receiving the label part of the first optical signal, a second splitter for dividing the received signal, first and second arms for receiving separate parts of the divided signal, first and second electrodes for adjusting an electromagnetic field in the first and second arm, respectively, and a coupler for coupling the parts of the divided signal transmitted by the first and second arms, the module further comprising an RF clock generator (107), the module being adapted to perform double sideband carrier-suppressed modulation by supplying first and second RF clock signals having frequencies $\nu_{\text{RF}}$ and $\pi$ phase difference from the RF clock generator to the first and the second electrode respectively, and by DC biasing the first and second electrodes to provide a phase difference $\Delta \phi$ between the arms, the DC bias difference being adjusted to give a mean value of the phase difference $\Delta \phi$ in the interval $3\pi/4 < \Delta \phi_{\text{mean}} < 5\pi/4$.

12. The module according to claim 8, wherein the first electro-optical modulator is a dual-electrode Mach-Zehnder modulator (DE-MZM) comprising an input for receiving a first part of the label part, a second splitter for dividing the received signal, first and second arms for receiving separate parts of the divided signal, first and second electrodes for adjusting an electromagnetic field in the first and second arm, respectively, a coupler for coupling the parts of the divided signal transmitted by the first and second arms, and an output for transmitting the coupled signal, the module further comprising an RF clock generator (107), the module being adapted to perform single sideband modulation by supplying first and second RF clock signals having frequencies $\nu_{\text{RF}}$ and $\pi$ phase difference from the RF clock generator to the first and the second electrode respectively, and by DC biasing the first and second electrodes to provide a phase difference $\Delta \phi$ between the arms, the DC bias difference being adjusted to give a mean value of the phase difference $\Delta \phi$ in the interval $\pi/4 < \Delta \phi_{\text{mean}} < 3\pi/4$, the module further comprising an interferometer (1201) for receiving a second part of the label part of the first optical signal and the coupled signal from the coupler of the DE-MZM to suppress a carrier frequency part in the coupled signal.

13. The module according to claim 8, further comprising a third electro-optical modulator (113) adapted to receive the payload part (112) of the first optical signal from the first splitter and payload data, and to optically encode the payload data on the payload part of the first optical signal.
14. The module according to claim 8, further comprising a wavelength converter (203) adapted to receive a second optical signal holding payload data and the payload part (112) of the first optical signal, and to optically encode the payload data of the second optical signal on to the payload part of the first optical signal.

15. An optical subcarrier labelling module (300) for detection and reinsertion of labels in optical data signals, the module comprising
- an optical notch filter (202) for splitting an incoming data signal (201) in a sideband part (301) and a carrier part (303),
- a label processor (302) for receiving the sideband part of the incoming signal from the notch filter, and for reading label data from the sideband part and generating new label data,
- a splitter (102) for receiving the carrier part of the incoming signal from the notch filter and for splitting the carrier part in a label part (118) and a payload part (115),
- a first electro-optical modulator (106) for receiving said label part from the splitter and for generating one or more optical sideband signals (108) having frequencies $v_c \pm v_{RF}$ on the label part of the first optical signal by performing single/double sideband carrier-suppressed modulation on the label part,
- a second electro-optical modulator (109) adapted to receive the optical sideband signal(s) from the first electro-optical modulator and the new label data from the label processor, and to optically encode the received label data on the received optical sideband signal(s), and
- a coupler (116) for receiving the encoded optical sideband signal(s) (11) from the second electro-optical modulator and said payload part from the splitter, and for coupling the encoded optical sideband signal(s) with the payload part.
Fig. 10

Fig. 11
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC 7 H04Q11/00

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04Q H04J

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

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

EPO-Internal, INSPEC, WPI Data, PAJ

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>WO 01 35185 A (TELCORDIA TECH INC) 17 May 2001 (2001-05-17) page 13 -page 14 page 42, line 21 -page 43, line 22; figure 12</td>
<td>1-15</td>
</tr>
<tr>
<td>X</td>
<td>WO 02 23772 A (OPVISTA INC ;WAY WINSTON (US)) 21 March 2002 (2002-03-21) page 6, line 8 - line 25 figures 5,6</td>
<td>1-15</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of box C. Patent family members are listed in annex.

---

*Special categories of cited documents:

* "A" document defining the general state of the art which is not considered to be of particular relevance
* "E" earlier document but published on or after the international filing date
* "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
* "C" document referring to an oral disclosure, use, exhibition or other means
* "P" document published prior to the international filing date but later than the priority date claimed

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

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

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

* "S" document member of the same patent family

Date of the actual completion of the international search: 22 March 2004

Date of mailing of the international search report: 07.04.2004

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax. (+31-70) 340-2018

Authorized officer

STURE Elnäs/MN
<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>BLUMENTHAL D J ET AL: &quot;All-optical label swapping networks and technologies&quot;</td>
<td>1,8,15</td>
</tr>
<tr>
<td></td>
<td>JOURNAL OF LIGHTWAVE TECHNOLOGY, DEC. 2000, IEEE, USA,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>vol. 18, no. 12, pages 2058-2075,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XP00274421</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISSN: 0733-8724</td>
<td></td>
</tr>
<tr>
<td></td>
<td>figure 22</td>
<td></td>
</tr>
<tr>
<td>P,X</td>
<td>CHI N ET AL: &quot;All-optical subcarrier labeling based on the carrier suppression</td>
<td>1-15</td>
</tr>
<tr>
<td></td>
<td>of the payload&quot;                     IEEE PHOTONICS TECHNOLOGY LETTERS, MAY</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2003, IEEE, USA,                    vol. 15, no. 5, pages 781-783,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XP00274422</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISSN: 1041-1135</td>
<td></td>
</tr>
<tr>
<td></td>
<td>see entire document</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>RONGQING HUI ET AL: &quot;Subcarrier multiplexing for high-speed optical transmission&quot;</td>
<td>1-15</td>
</tr>
<tr>
<td></td>
<td>JOURNAL OF LIGHTWAVE TECHNOLOGY, MARCH 2002, IEEE, USA,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>vol. 20, no. 3, pages 417-427,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XP00274423</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISSN: 0733-8724</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cited in the application abstract</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>LIN Y M ET AL: &quot;A novel optical label swapping technique using erasable optical</td>
<td>1-15</td>
</tr>
<tr>
<td></td>
<td>single-sideband subcarrier label&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEEE PHOTONICS TECHNOLOGY LETTERS, AUG. 2000, IEEE, USA,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>vol. 12, no. 8, pages 1088-1090,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XP00274424</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISSN: 1041-1135</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cited in the application abstract</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-----</td>
<td></td>
</tr>
</tbody>
</table>
# INTERNATIONAL SEARCH REPORT

Information on patent family members

<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AU 8017500 A</td>
<td>06-06-2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TW 502510 B</td>
<td>11-09-2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 0135185 A2</td>
<td>17-05-2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 2001017723 A1</td>
<td>30-08-2001</td>
</tr>
<tr>
<td>WO 0223772 A</td>
<td>21-03-2002</td>
<td>AU 9265601 A</td>
<td>26-03-2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 0223772 A2</td>
<td>21-03-2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 2002135838 A1</td>
<td>26-09-2002</td>
</tr>
</tbody>
</table>