(54) Title: OPTICAL NETWORK ELEMENT

Fig.9
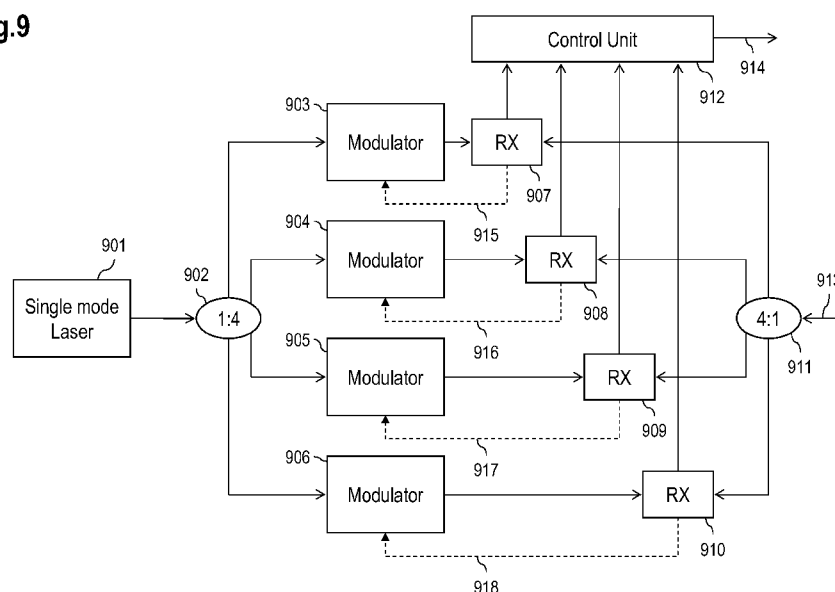
(57) Abstract: The invention relates to an optical network element comprising a light source providing an optical signal that is fed to at least two modulators; wherein each modulator provides an optical carrier signal that is conveyed to a receiving unit; wherein the receiving unit is arranged to determine a deviation signal between the optical carrier signal and a carrier conveyed via an incoming signal and to feed the deviation signal to the modulator for adjusting the frequency and/or the phase of the optical carrier signal. Also, a corresponding method for processing data and a communication system comprising at least one optical network are suggested.

Description

<u>Optical network element</u>

5   The invention relates to an optical network element and to a
     method for processing data. Also, a communication system
     comprising at least one optical network is suggested.

     A passive optical network (PON) is a promising approach re-
10   garding fiber-to-the-home (FTTH), fiber-to-the-business
     (FTTB) and fiber-to-the-curb (FTTC) scenarios, in particular
     as it overcomes the economic limitations of traditional
     point-to-point solutions.

15   Several PON types have been standardized and are currently
     being deployed by network service providers worldwide. Con-
     ventional PONs distribute downstream traffic from the optical
     line terminal (OLT) to optical network units (ONUs) in a
     broadcast manner while the ONUs send upstream data packets
20   multiplexed in time to the OLT. Hence, communication among
     the ONUs needs to be conveyed through the OLT involving
     electronic processing such as buffering and/or scheduling,
     which results in latency and degrades the throughput of the
     network.
25
     A Costas loop is a phase-locked loop used for carrier phase
     recovery from suppressed-carrier modulation signals, such as
     from double-sideband suppressed carrier signals. It is known
     in the art to use a Costas loop to determine a deviation bet-
30   ween two optical carrier signals. Further details about the
     Costas loop could be found, e.g., at
             - http://de.wikipedia.org/wiki/Costas_Loop or
             - http://michaelgellis.tripod.com/mixerscom.html.

35   In fiber-optic communications, wavelength-division multiple-
     xing (WDM) is a technology which multiplexes multiple optical
     carrier signals on a single optical fiber by using different
     wavelengths (colors) of laser light to carry different sig-

nals. This allows for a multiplication in capacity, in addition to enabling bidirectional communications over one strand of fiber.

5   WDM systems are divided into different wavelength patterns, conventional or coarse and dense WDM. WDM systems provide, e.g., up to 16 channels in the 3rd transmission window (C-band) of silica fibers of around 1550 nm. Dense WDM uses the same transmission window but with denser channel spacing.
10 Channel plans vary, but a typical system may use 40 channels at 100 GHz spacing or 80 channels with 50 GHz spacing. Some technologies are capable of 25 GHz spacing. Amplification options enable the extension of the usable wavelengths to the L-band, more or less doubling these numbers.
15
    Optical access networks, e.g., coherent Ultra-Dense Wavelength Division Multiplex (UDWDM) networks, are deemed to be a promising approach for future data access.

20 Data transmission of spectrally densely spaced wavelengths is utilized by applications as Next Generation Optical Access (NGOA) systems allowing high data rates of, e.g., 100 Gbit/s.

    In these optical scenarios, a multitude of optical wave-
25 lengths is required in order to be individually modulated. Such optical wavelengths may have a spectral distance of a few gigahertz and can be used either for a ultra dense wavelength grid optical access system like NGOA where each user may be assigned a wavelength of his own or for a transmission
30 of high data rates such as 100 Gbit/s where a multitude of wavelengths are bundled and transmitted over a small spectral range.

    Supplying such individual wavelengths by several discrete la-
35 sers leads to a huge amount of laser sources that require a significant amount of precision and thus involve high costs. As an alternative, modulating a multitude of single sidebands on an optical carrier also leads to significant costs because

of the electronics involved needing to cope with high frequencies required.

The **problem** to be solved is to overcome the disadvantages
stated above and in particular to suggest an efficient solution for providing a multitude of optical wavelengths at a
spectral distance of, e.g., a few GHz and at the same time
allow for a precise adjustment of the optical wavelengths.

This problem is solved according to the features of the independent claims. Further embodiments result from the depending
claims.

In order to overcome this problem, an optical network element
is provided
- comprising a light source providing an optical signal
that is fed to at least two modulators;
- wherein each modulator provides an optical carrier
signal that is conveyed to a receiving unit;
- wherein the receiving unit is arranged
- to determine a deviation signal between the optical
carrier signal and a carrier conveyed via an incoming signal; and
- to feed the deviation signal to the modulator for
adjusting the frequency and/or the phase of the optical carrier signal.

It is noted that the optical network element may be a component comprising optical and electrical signal processing capabilities. The light source may be a laser or any laser
source. The optical network element may comprise more than
two modulators, wherein each modulator is connected to only
one receiving unit. Hence, each modulator may provide the optical carrier signal, e.g., a local oscillator signal, for
its receiving unit.

Advantageously, a single light source, e.g., laser, could be
used to provide an optical signal for several receivers (also

referred to as receiving units) of the optical network ele-
ment. Each modulator can derive an optical carrier signal
from the optical signal of the light source; each optical
carrier signal (e.g., optical local oscillator signal) may

5   have a different frequency offset from the frequency of the
single mode laser's optical signal. This frequency and/or
phase of the optical carrier signal can be adjusted by the
deviation signal, which allows using an imprecise light sour-
ce element.

10

The optical network element may be a centralized component of
an optical network, in particular an optical line terminal
(OLT) deployed, e.g., in a central office or cabinet.

15   The carrier conveyed via an incoming signal may comprise a
carrier signal within an incoming UDWDM signal that is split
towards the at least two modulators, wherein each receiver
determines a deviation signal based on the actual difference
between the optical carrier signal provided by the modulator

20   that is associated with the particular receiver and one par-
ticular carrier signal of the UDWDM signal.

The deviation signal may be an electrical signal that is con-
veyed to the modulator to adjust the phase and/or frequency

25   of the optical carrier signal.

In an embodiment, the modulator is an electrically operable
optical modulator.

30   The modulator may comprise an electrically adjustable optical
modulator, e.g., phase and/or frequency of such modulator may
be adjusted in particular based on at least one electrical
signal. The electrical signal may be used to adjust a fre-
quency and/or phase shift and in particular to at least par-

35   tially compensate any deviation conveyed by the deviation
signal. In addition, the electrical signal can be used to set
the frequency of the optical carrier signal relative to an
offset of the frequency of the optical signal of the light

source. Hence, the modulator can be set to various carrier
frequencies to be used as local oscillator frequencies.

In another embodiment, the optical carrier signal has an off-
5   set relative to the optical signal of the light source.

Hence, the offset may be relative to the frequency of the op-
tical signal provided by the light source.

10   In a further embodiment, the optical carrier signal of each
of the at least two modulators provides a different offset.

In particular each modulator may provide a different offset
relative to the optical signal of the light source thereby
15   providing several local oscillator signals that are supplied
to the several receivers for demodulating the incoming sig-
nal, e.g., the UDWDM signal.

In a next embodiment, the offset is adjustable by a control
20   unit.

For example, the offset of each modulator may be adjusted by
such control unit. This allows for optical carrier signals of
different frequencies based on the single light source.
25

It is also an embodiment that the deviation signal is deter-
mined or generated via a Costas loop.

It is noted that instead of the Costas Loop a phase-locked
30   loop (PLL) could be used. Also, any solution that allows for
demodulation via periodically triggering a pulse (e.g., of
constant duration) by a zero crossing of an ac voltage could
be applied. This may lead to pulse width modulation, which
preferably is processed by a low pass to reduce portions of
35   high frequency (smoothing) in order to obtain an analog demo-
dulation signal. In addition, mechanisms of phase discrimina-
tion or demodulation utilizing feedback loops could be ap-
plied. Also frequency modulation techniques could be utili-

zed, wherein some aspects of frequency modulation could be applied to phase modulation techniques as a frequency modulation differentiated with respect to time can be regarded as phase modulation.

Pursuant to another embodiment, the modulator comprises a frequency shifter that is arranged to process the deviation signal from the receiving unit.

The frequency shifter may be realized as or comprise a voltage controlled oscillator (VCO) that can be used for integrating the deviation signal, i.e. adjusting the frequency according to an integrating portion of a control mechanism. Hence, mid-term or long-term changes of the frequency can be compensated by this frequency shifter.

The frequency shifter is arranged to adjust the frequency of the optical carrier signal.

According to an embodiment, the modulator comprises a phase modulator that is arranged to process the deviation signal from the receiving unit.

The phase modulator is arranged to adjust the frequency and/or phase of the optical carrier signal. A change of phase over time corresponds to a change of frequency. The phase modulator can be used to compensate short-term frequency deviations, hence adjusting the frequency according to a proportional portion of a control mechanism.

According to another embodiment, the phase modulator comprises at least one of the following:
   - a semiconductor optical amplifier;
   - an element comprising indium phosphide;
   - an element comprising lithium niobate.

7

The problem stated above is further solved by a communication system comprising at least one optical network element as described herein.

5   The problem mentioned above is also solved by a method for processing data,
        – wherein an optical signal provided by a light source is fed to at least two modulators;
        – wherein each modulator provides an optical carrier
10   signal that is conveyed to a receiving unit;
        – wherein the receiving unit determines a deviation signal between the optical carrier signal and a carrier conveyed via an incoming signal; and
        – wherein the deviation signal is conveyed to the modu-
15   lator for adjusting the frequency and/or the phase of the optical carrier signal.

It is noted that the features described with regard to the device above are applicable for the method in an analog man-
20   ner.

According to an embodiment, each the optical carrier signals of each modulator has a different offset relative to the frequency of the optical signal of the light source.
25
According to a further embodiment, the offset is adjusted for at least one of the modulators by a control unit.

In yet another embodiment, the modulator comprises a frequen-
30   cy shifter that adjusts the optical carrier signal based on the deviation signal obtained from the receiving unit.

According to a next embodiment, the modulator comprises a phase modulator that adjusts the optical carrier signal based
35   on the deviation signal obtained from the receiving unit.

Embodiments of the invention are shown and illustrated in the following figures:

Fig.1   shows an optical modulator that supplies optical car-
         riers relative to a frequency of a light source input
         to the optical modulator;

5

Fig.2   shows a schematic block diagram comprising an exem-
         plary optical multi-channel generator;

Fig.3   shows a schematic diagram, wherein the structure of
10   Fig.2 is extended to provide polarization multiplex
         (PolMux);

Fig.4   shows an alternative block structure of an optical
         multi-channel generator providing six carriers;

15

Fig.5   shows another schematic block structure of an optical
         multi-channel generator providing 14 carriers;

Fig.6   shows a further schematic block structure of an opti-
20   cal multi-channel generator with a parallel structure
         providing 8 carriers;

Fig.7   shows a schematic diagram comprising a four channel
         transceiver to be used in an OLT, wherein the trans-
25   ceiver comprises the optical multi-channel generator
         as shown in Fig.2;

Fig.8   shows a more generalized structure as Fig.1, wherein
         instead of the MZM different modulator schemes may
30   apply as indicated by two modulator branches;

Fig.9   shows a multi-channel receiver that can be utilized,
         e.g., in case electrical and/or optical frequency
         splitting is not identical for transmitter and re-
35   ceiver and in case separate frequency and/or phase
         control of the optical local oscillator is required;

Fig.10 shows a more detailed schematic comprising the modu-
        lator and the receiver in combination with the con-
        trol unit of Fig.9.

5   **Fig.9** shows a multi-channel receiver that can be utilized,
     e.g., in case electrical and/or optical frequency splitting
     is not identical for transmitter and receiver and in case se-
     parate frequency and/or phase control of the optical local
     oscillator is required.
10
     In Fig.9, a single mode laser 901 conveys a light signal via
     a 1:4-splitter 902 to modulators 903 to 906. Each modulator
     903 to 906 may comprise an electrically controlled optical
     modulator, e.g., a single sideband modulator to provide a lo-
15   cal oscillator signal at a predetermined frequency towards a
     connected receiver 907 to 910. Hence, each receiver 907 to
     910 can be supplied with an optical local oscillator signal
     at a different (e.g., preset) frequency.

20   The modulator 903 to 906 may be any optical modulator that
     can be adjusted by at least one electrical signal.

     An example as how to generate several such optical local os-
     cillator signals from a single light source, e.g., the single
25   mode laser 901, will be shown and described below.

     On the other hand, each receiver 907 to 910 is connected to a
     splitter 911, to which an optical signal 913 is fed. This op-
     tical signal 913 may comprise several carrier frequencies,
30   each being modulated with user data; the optical signal 913
     may thus be a UDWDM signal with adjacent optical carriers,
     each conveying user data, e.g., from an optical network unit
     (ONU) or any subscriber. The user data modulated on each op-
     tical carrier of the optical signal 913 may be a portion of a
35   data stream that can be combined via the several receivers
     907 to 910.

It is noted that the component schematically depicted in
Fig.9 may be an optical line terminal (OLT) or any combining
unit deployed, e.g. at a cabinet or central office.

5   Each receiver 907 to 910 is able to determine a deviation of
the local oscillator signal provided by its associated modu-
lator 903 to 906 and a carrier frequency obtained from the
optical signal 913. Thus, the receiver 907 to 910 may convey
information regarding such deviation via a respective signal
10   915 to 918 to the modulator 903 to 906. Based on this signal
915 to 918 the modulator 903 to 906 adjusts the local oscil-
lator signal fed to the receiver 907 to 910 to reduce or at
least partially compensate such deviation.

15   The signal 915 to 918 indicating the deviation can be deter-
mined at the receiver 907 to 910 by utilizing a Costas loop.

The arrangement shown in Fig.9 thus allows for homodyne re-
ception.
20
The receivers 907 to 910 process the incoming optical signal
913 using different local oscillator signals and convey a de-
modulated electrical signal towards a control unit 912, which
may, e.g., combine the several electrical signals from the
25   receivers 907 to 910 into a combined electrical signal 914
(e.g., a combined data stream).

As an alternative, the control unit 912 may also process the
signals provided by the receivers 907 to 910 separately.
30
Advantageously, the approach provided allows improving the
spectral accuracy of the local oscillator signal even in case
the single mode laser 901 merely provides an optical signal
with an imprecise linewidth or in case the single mode laser
35   901 is fluctuating, e.g., changing its frequency over time
and/or due to temperature changes. The modulator 903 to 906
not only provides a stable frequency of the local oscillator
signal, but also a sharp spectral linewidth.

Fig.10 shows a more detailed schematic comprising the modulator 903 and the receiver 907 in combination with the control unit 912 of Fig.9. It is noted, however, that this applies
5   for the remaining modulators 904 to 906 and receivers 908 to 910 accordingly.

As indicated above, the modulator 903 is supplied by the single mode laser with the light signal that is modulated (or
10 converted) into a local oscillator signal to be fed to the receiver 907. The receiver 907 provides the signal 915 to the modulator 903, which can be used to adjust phase and/or frequency of the local oscillator signal. It is noted that the signal 915 may be an electrical signal.
15
The signal 915 is fed to a frequency shifter 1001, in particular comprising a voltage controlled oscillator, of the modulator 903, which compensates slow frequency variations. In addition, the signal 915 is fed to a phase modulator 1002,
20 which compensates fast frequency variation. In particular the combination of the frequency shifter 1001 and the phase modulator 1002 allows for a stable optical local oscillator signal. It is noted that compensating also refers to at least partially reducing or in particular fully reducing any (unde-
25 sired) variation.

The frequency shifter 1001 corresponds to an integrating portion of a control and the phase modulator 1002 corresponds to a proportional portion of a control.
30
The phase modulator 1002 could be an element comprising an optical length, which may be modified by applying a voltage to this element. The phase modulator could be realized as or comprise a semiconductor optical amplifier (SOA). The phase
35 modulator may also comprise indium phosphide or lithium niobate.

It is noted that instead of the frequency shifter 1001 any control element that allows adjusting the frequency of the modulator 903 could be utilized. Due to the slow control compared to the fast control provided by the phase modulator

5   1002, the frequency shifter 1001 (or any similar control element) may ensure that the phase modulator 1002 operates in a suitable range, e.g., by shifting the frequency such that the correction capability of the phase modulator 1002 could be efficiently employed.

10

In addition, the control unit 912 may be used to convey a control signal 1003 to the modulator 903 adjusting the frequency of the local oscillator (not shown in Fig.9). This may apply for all modulators 903 to 906 shown in Fig.9 accor-

15   dingly (with different control signals, not shown).

The control signal 1003 adjusts the frequency offset of the optical carrier relative to a frequency of the single mode laser 901. Hence, the control unit 912 by supplying such

20   control signals to the various modulators 903 to 906 (see Fig.9) allows flexibly adjusting the frequency offset and hence the frequency of the optical local oscillator signal provided by each modulator 903 to 906.

25   Hereinafter, it will be shown in more detail as how to obtain several optical local oscillator signals from a light signal of a single mode laser (or any suitable light source), wherein each optical local oscillator signal may have, e.g., a different frequency offset from the frequency of the single

30   mode laser's light signal. In addition to merely providing such several carrier signals that could be used as local oscillator signal, e.g., in an OLT, these several carrier signals are also frequency and/or phase controlled as shown above. This allows efficiently operating the optical network

35   element, e.g., OLT, using a rather imprecise light source as, e.g., the single mode laser.

Generating Local Oscillator Signals

It is in particular suggested to use both outputs of a single
sideband modulator (SSBM), wherein several such modulators

5   could be connected in series or in parallel such that based
on an input from a single light source (i.e. a single car-
rier) several carriers (frequencies) could be generated that
are spaced apart from each other by, e.g., only a few giga-
hertz. These frequencies (or wavelengths) could be individu-

10   ally modulated and thus utilized for NGOA systems or UDWDM
networks.

The SSBM could be realized as a two-beam interferometer,
e.g., a Michelson interferometer, in particular by a Mach-

15   Zehnder Modulator (MZM).

Fig.1 shows a modulator structure comprising a coupler 104
(also referred to as splitter) to which an input signal
(light) 101 is fed. The coupler 104 is further connected to a

20   coupler 105 and to a coupler 106, thereby conveying the input
signal 101.

The coupler 105 conveys the incoming light via a phase ad-
justment 110 and a phase modulator 111 to a coupler 107 and

25   also directly via a phase modulator 112 to said coupler 107.

Accordingly, the coupler 106 conveys the incoming light via a
phase adjustment 113 and a phase modulator 114 to a coupler
108 and also directly via a phase modulator 115 to said

30   coupler 108.

The output of the coupler 107 is fed via a terminal 119 to a
monitor diode 117 and via a phase adjustment 116 to a coupler
109. The output of the coupler 108 is fed via a terminal 120

35   to a monitor diode 118 and to the coupler 109.

The coupler 109 provides two output signals 102 and 103. The
modulator unit with its input and output ports 101, 102, 103,

14

119 and 120 is also depicted as a block 121, which will be used as such in the figures below.

The output signal 103 contains the same modulated data as does the output signal 102, but on the opposite spectral side of the carrier signal 101.

The modulator 121 is driven at a frequency ω, e.g., 5 GHz. The light of the output signal 102 is offset by +5 GHz and the light of the output signal 103 is offset by -5 GHZ from the carrier frequency.

As the driving signals are single frequencies, both the driving circuit and the electrode structure can be tailored to the respective frequency (e.g., by using resonant circuits), thus easing the requirements for the electronics.

The modulator 121 can be adjusted such that the carrier is in principle completely eliminated. In practice, without additional measures, the degree of carrier elimination is limited by the symmetry of the interferometer arms visible in a finite extinction ratio if the modulator is used as an amplitude modulator. A counter measurement against poor carrier suppression caused by poor symmetry of the modulator can be a slight misadjustment of the phase bias in the modulator arm with better extinction ratio.

The carrier is directed to the outputs which contain the monitor diodes 117, 118, which can be used for adequate adjustment of the bias phases. The carrier can, in some cases, also be used for further processing purposes.

To avoid strong distortions by harmonics, the best compromise between SSB generation efficiency and low harmonics seems to be a modulation depth of about 90° to 110° resulting in an efficiency of about 30%.

Fig.8 shows a more generalized structure as Fig.1. Instead of the MZM mentioned, different modulator schemes may apply as indicated by blocks 801 and 802.

5   A first branch 801 provides an amplitude modulation with a first signal, said first signal being substantially sinusoidal. In addition, the first branch provides a phase shift, i.e., a 180-degree phase shift at the zero-crossing of the optical signal. A second branch 802 provides an amplitude mo-

10   dulation with a second signal, wherein the second signal is substantially 90 degree phase shifted compared to the first signal. For example, the first signal may be a sinus with a predefined frequency and the second signal may be a cosine with the same frequency. Due to the phase adjustment 116, the

15   signals that are fed to the coupler 109 have an optical phase difference of (substantially) 90 degrees.

It is noted that hereinafter the modulator 121 may be realized as shown and explained in Fig.1 or Fig.8.

20

Fig.2 shows a schematic block diagram comprising an exemplary optical multi-channel generator.

A single mode laser 201 feeds an optical signal via a split-

25   ter 202 to a modulator 203 and to a modulator 204. Each of the modulators 203 and 204 corresponds to the modulator 121 as shown in Fig.1. The modulator 203 operates at a frequency of 5 GHz and the modulator 204 operates at a frequency of 2 GHz.

30

The output signal of the modulator 203 provides a frequency with an offset of 5 GHz, which is fed via an optical ampli- fier 205 to a modulator 209 where it is modulated with a data signal D1. The output of the modulator 209 is conveyed to a

35   combiner 213. Accordingly, another output signal of the modu- lator 203 provides a frequency with an offset of -5 GHz, which is fed via an optical amplifier 206 to a modulator 210

where it is modulated with a data signal D2. The output of
the modulator 210 is conveyed to the combiner 213.

Also the output signal of the modulator 204 provides a fre-
5   quency with an offset of 2 GHz, which is fed via an optical
amplifier 207 to a modulator 211 where it is modulated with a
data signal D3. The output of the modulator 211 is conveyed
to the combiner 213. Accordingly, another output signal of
the modulator 203 provides a frequency with an offset of
10   -2 GHz, which is fed via an optical amplifier 208 to a modu-
lator 212 where it is modulated with a data signal D4. The
output of the modulator 212 is conveyed to the combiner 213.

The output of the combiner 213 is fed to an optical amplifier
15   214.

Hence, the modulator 203 generates two wavelengths with an
offset of 5 GHz and -5 GHz from the carrier, i.e. the fre-
quency of the single mode laser 201. The modulator 204 gene-
20   rates two wavelengths with an offset of 2 GHz and -2 GHz from
the carrier. Each of the four outputs from the modulators 203
and 204 is then individually modulated with a data signal D1
to D4 at the data baseband and the four modulated signals are
combined for transmission purposes.
25
The optical amplifiers 205 to 208 and 214 can be included in
the structure; their dimensioning may in particular depend on
the optical power budget.

30   **Fig.3** shows a schematic diagram, wherein the structure of
Fig.2 is extended to provide polarization multiplex (PolMux).

An optical signal 301 is fed to a splitter 302 and further to
a modulator 303 and to a modulator 304. Each of the modula-
35   tors 303 and 304 corresponds to the modulator 121 as shown in
Fig.1.

The output signals of the modulator 303 are fed via splitters 305, 306 to modulators 309 to 312 where they are modulated with data signals D_k (k=1…4). Each output of the modulators 309, 311 is conveyed via a $\lambda/4$ polarization converter 318,

5   319 to a combiner 317 and each output of the modulators 310, 312 is directly conveyed to the combiner 317.

Accordingly, output signals of the modulator 304 are fed via splitters 307, 308 to modulators 313 to 316 where they are

10   modulated with data signals D_k (k=5…8). Each output of the modulators 313, 315 is conveyed via a $\lambda/4$ polarization converter 320, 321 to the combiner 317 and each output of the modulators 314, 316 is directly conveyed to the combiner 317.

15   **Fig.4** shows an alternative block structure of an optical multi-channel generator providing six carriers.

An optical signal 401 is fed to a modulator 402 and further to a modulator 403 and to a modulator 404. Each of the modu-

20   lators 402 to 404 corresponds to the modulator 121 as shown in Fig.1. The modulator 402 operates at a frequency of 5 GHz and the modulators 403, 404 each operates at a frequency of 3 GHz.

25   The output of the modulators 403 and 404 provides the carrier frequencies as shown on the right hand side, i.e. amounting to 5 GHz, 8 GHz, 2 GHz, -2 GHz, -8 GHz and -5 GHz relative to the frequency f_0 of the carrier frequency provided by the optical signal 401.

30
Each output signal of the modulators 403 and 404 is modulated with data signals (not shown in Fig.4) via modulators 404 to 409.

35   Both the parallel and the cascaded solution can be combined for a higher number of carrier frequencies to be provided. Also polarization multiplex could be combined if required.

Fig.5 shows another schematic block structure of an optical
multi-channel generator providing 14 carriers.

An optical signal 501 is fed to a modulator 502, next to a
5   modulator 503 and to a modulator 504 and further to modula-
tors 505 to 508. Each of the modulators 502 to 508 cor-
responds to the modulator 121 as shown in Fig.1. The modula-
tor 502 operates at a frequency of 11 GHz, the modulators
503, 504 each operates at a frequency of 6 GHz and the modu-
10   lators 505 to 508 each operates at a frequency of 3 GHz.

The output of the modulators provides carrier frequencies
amounting to 11 GHz, 17 GHz, 20 GHz, 14 GHz, 8 GHz, 2 GHz,
5 GHz and -11 GHz, -17 GHz, -20 GHz, -14 GHz, -8 GHz, -2 GHz,
15   -5 GHz relative to the frequency f_0 of the carrier frequency
provided by the optical signal 501.

The output signals of the modulators are modulated with data
signals (not shown in Fig.5) via modulators 509 to 522.
20
Fig.6 shows a further schematic block structure of an optical
multi-channel generator with a parallel structure providing 8
carriers.

25   An optical signal 601 is fed to a 1:4 splitter 602 and
further to a modulator 603 with an operating frequency of
11 GHz, to a modulator 604 with an operating frequency of
7 GHz, to a modulator 605 with an operating frequency of
5 GHz and to a modulator 606 with an operating frequency of
30   2 GHz. Each of the modulators 603 to 606 corresponds to the
modulator 121 as shown in Fig.1.

The output signals of the modulators 603 to 606 are modulated
with data signals (not shown in Fig.6) via modulators 607 to
35   614.

It is noted that the combining of the data signal-modulated
wavelengths is not shown in Fig.4 to Fig.6 for legibility

reasons. However, as a final stage (according to Fig.2 and Fig.3), a combiner can be provided that conveys all wavelengths onto a single fiber.

5   It is further noted that as an option, optical amplifiers may be supplied for power regeneration purposes. Such optical amplifiers may be provides as SOAs (semiconductor optical amplifiers) allowing integrating of all structures in InP.

10   It is also an option that the modulation signal which is modulated onto the generated wavelengths comprises several n sub-carriers itself, thus multiplying the number of wavelengths generated by the whole transmitter by n.

15   This can be achieved using the MZM (or a Michelson interferometer based, in general a two-way interferometer based IQ modulator) by applying electrical signals D_k as depicted in Fig.2 or in Fig.3 with two or more signals in a baseband and additional electrical carriers. Preferably, a total phase mo-
20   dulation index may not exceed a value leading to a high harmonic generation, in case of a simple design without electronic pre-distortion the total modulation index may be below 110°.

25   A numeric example for generating eight wavelengths with frequency offsets compared to a carrier laser source according to Fig.2 is as follows: Driving the modulator 203 with a frequency amounting to 0,5 GHz and the modulator 204 with a frequency amounting to 6,5 GHz delivers frequency offsets of
30   ± 0,5 GHz and ± 6,5 GHz at the outputs of the modulators 203, 204. Using carriers at the data modulation portion amounting to 1,5 GHz and 4,5 GHz an output of optical carriers may amount to ± 2 GHz, ± 5 GHz, ± 8 GHz and ± 11 GHz.

Schematic of a Transceiver

Fig.7 shows a schematic diagram comprising a four channel
transceiver to be used in an OLT. The transceiver comprises

5   the optical multi-channel generator as shown in Fig.2.

In addition to Fig.2, the output of the optical amplifier is
fed to a circulator 701, which is also connected to a fiber
712. Further, the circulator 702 is connected via an optical

10   amplifier 702 to a 1:4 splitter 703 conveying incoming sig-
nals towards receivers 704 to 707.

Each of the receivers 704 to 707 receives an optical local
oscillator signal 708 to 711, which is supplied by the opti-

15   cal multi-channel generator. Hence, the optical multi-channel
generator is used for modulating the outgoing data signals D1
to D4 and for demodulating incoming signals conveyed to the
receivers 704 to 707.

20   This approach also reduces electrical requirements at the co-
herent receiver by using a multi-wavelength optical local os-
cillator with multiple optical outputs each carrying one wa-
velength. A single local oscillator wavelength 704 to 707 is
used for selection and demodulation of one optical channel or

25   a subset of optical channels.

Further Advantages:

The solution provided could be applied to, e.g., 100 G sys-

30   tems. The combination of four wavelengths, polarization mul-
tiplex and DQPSK results in 4 x 2 x 6,25 GSymbols/s which
corresponds to 100 Gbit/s. In this arrangement the data pro-
cessing speed, respectively the bandwidth of electrical cir-
cuitry, analog-to-digital converters and digital-to analog-

35   converters may cope with a processing speed of 6,25 Gbit/s,
which is a significant reduction for a 100 G solution.

Hence, the solution requires less bandwidth for electrical circuitry, in particular with regard to analog-to-digital converters and digital-to-analog converters in case of digital processing.

5

The concept suggested is highly scalable to flexibly provide an appropriate number of wavelengths.

The costs of the overall system could be reduced by optimi-

10   zing the number of optical components required (i.e. the chip-size) in view of electrical bandwidth requirements.

List of Abbreviations:

	DQPSK	Differential QPSK
	HF	High Frequency
5	MZM	Mach-Zehnder Modulator
	NGOA	Next Generation Optical Access
	OLT	Optical Line Terminal
	PolMux	Polarization Multiplex
	PSK	Phase Shift Keying
10	QPSK	Quadrature PSK
	SSB	Single Sideband
	SSBM	SSB Modulator
	ONU	Optical Network Unit
	PLL	Phase-Locked Loop
15	PON	Passive Optical Network
	FTTH	Fiber-to-the-Home
	FTTB	Fiber-to-the-Business
	FTTC	Fiber-to-the-Curb
	WDM	Wavelength Division Multiplexing
20	UDWDM	Ultra Dense WDM

Claims:

1.   An optical network element
     – comprising a light source providing an optical signal
       that is fed to at least two modulators;
5   – wherein each modulator provides an optical carrier
       signal that is conveyed to a receiving unit;
     – wherein the receiving unit is arranged
       – to determine a deviation signal between the optical
         carrier signal and a carrier conveyed via an incom-
10   ing signal; and
       – to feed the deviation signal to the modulator for
         adjusting the frequency and/or the phase of the op-
         tical carrier signal.

2.   The optical network element according to claim 1,
15   wherein the modulator is an electrically operable opti-
     cal modulator.

3.   The optical network element according to any of the pre-
     ceding claims, wherein the optical carrier signal has an
     offset relative to the optical signal of the light
20   source.

4.   The optical network element according to claim 3,
     wherein the optical carrier signal of each of the at
     least two modulators provides a different offset.

5.   The optical network element according to any of claims 3
25   or 4, wherein the offset is adjustable by a control
     unit.

6.   The optical network element according to any of the pre-
     ceding claims, wherein the deviation signal is deter-
     mined or generated via a Costas loop.

30 7.   The optical network element according to any of the pre-
     ceding claims, wherein the modulator comprises a fre-
     quency shifter that is arranged to process the deviation
     signal from the receiving unit.

8.   The optical network element according to any of the pre-
     ceding claims, wherein the modulator comprises a phase
     modulator that is arranged to process the deviation sig-
     nal from the receiving unit.

9.   The optical network element according to claim 8,
     wherein the phase modulator comprises at least one of
     the following:
     – a semiconductor optical amplifier;
     – an element comprising indium phosphide;
     – an element comprising lithium niobate.

10. A communication system comprising at least one optical
     network element according to any of claims 1 to 9.

11. A method for processing data,
     – wherein an optical signal provided by a light source
       is fed to at least two modulators;
     – wherein each modulator provides an optical carrier
       signal that is conveyed to a receiving unit;
     – wherein the receiving unit determines a deviation
       signal between the optical carrier signal and a car-
       rier conveyed via an incoming signal; and
     – wherein the deviation signal is conveyed to the modu-
       lator for adjusting the frequency and/or the phase of
       the optical carrier signal.

12. The method according to claim 11, wherein each the opti-
     cal carrier signal of each modulator has a different
     offset relative to the frequency of the optical signal
     of the light source.

13. The method according to claim 12, wherein the offset is
     adjusted for at least one of the modulators by a control
     unit.

14. The method according to any of claims 11 to 13, wherein
     the modulator comprises a frequency shifter that adjusts
     the optical carrier signal based on the deviation signal
     obtained from the receiving unit.

15. The method according to any of claims 11 to 14, wherein
     the modulator comprises a phase modulator that adjusts
     the optical carrier signal based on the deviation signal
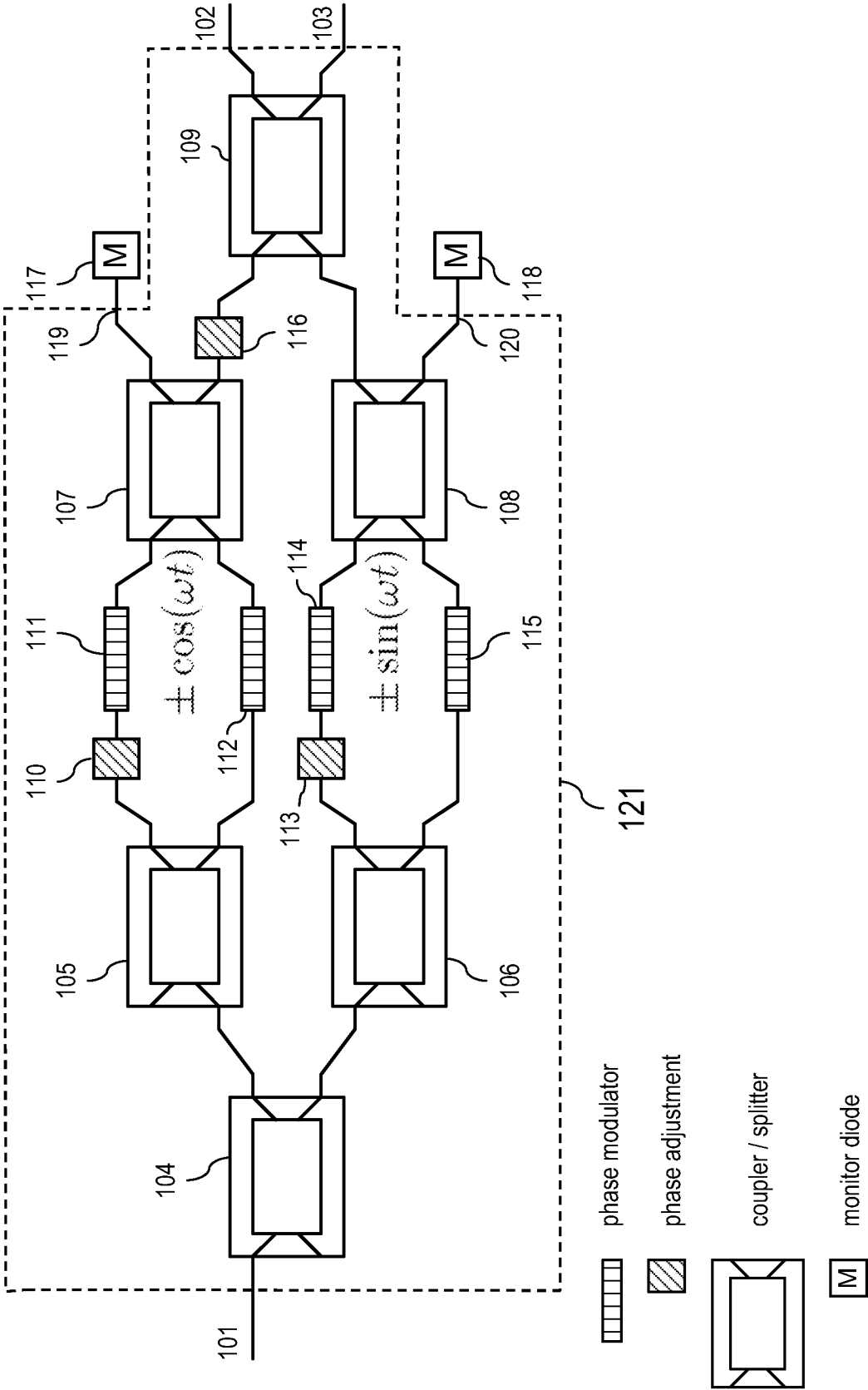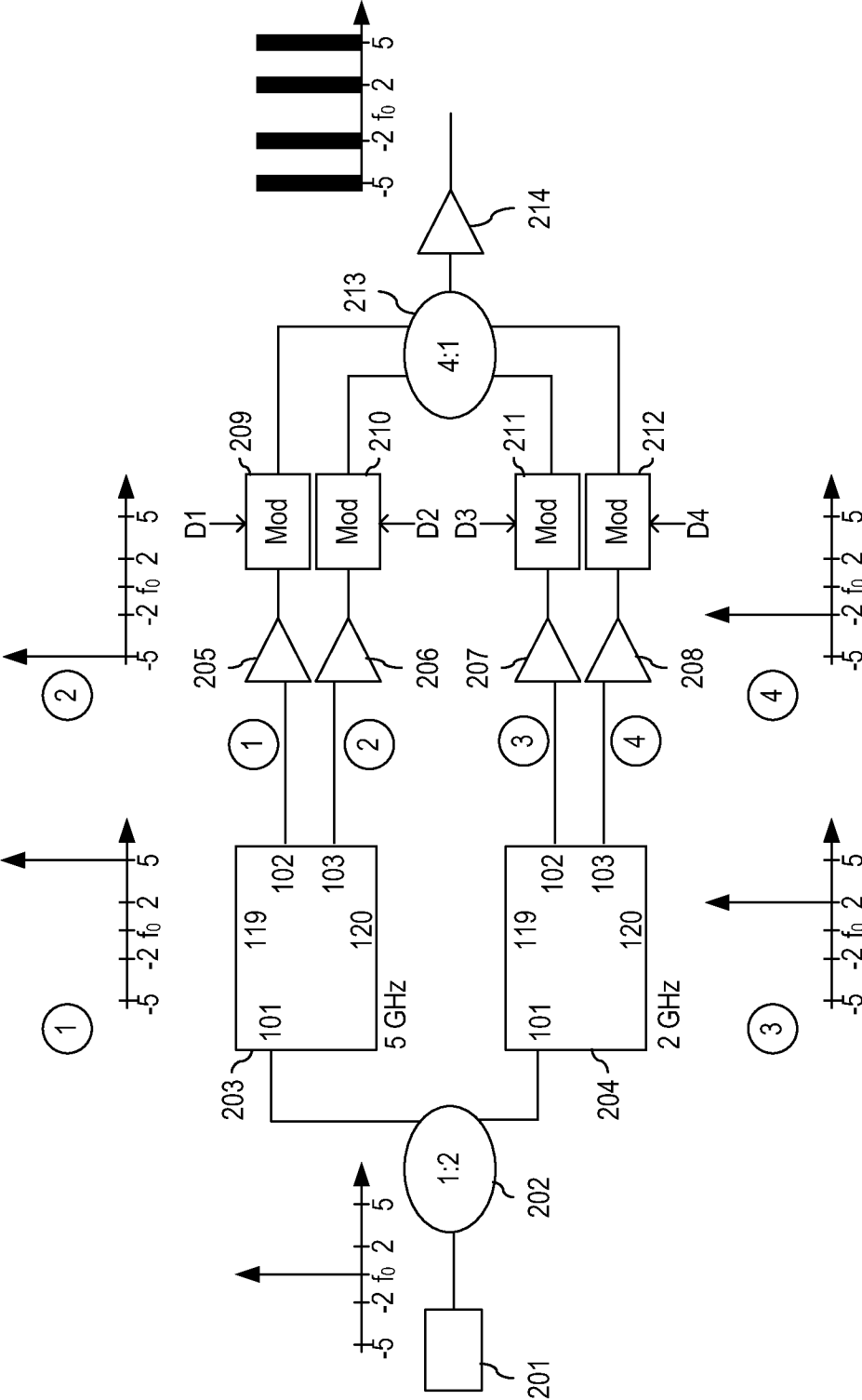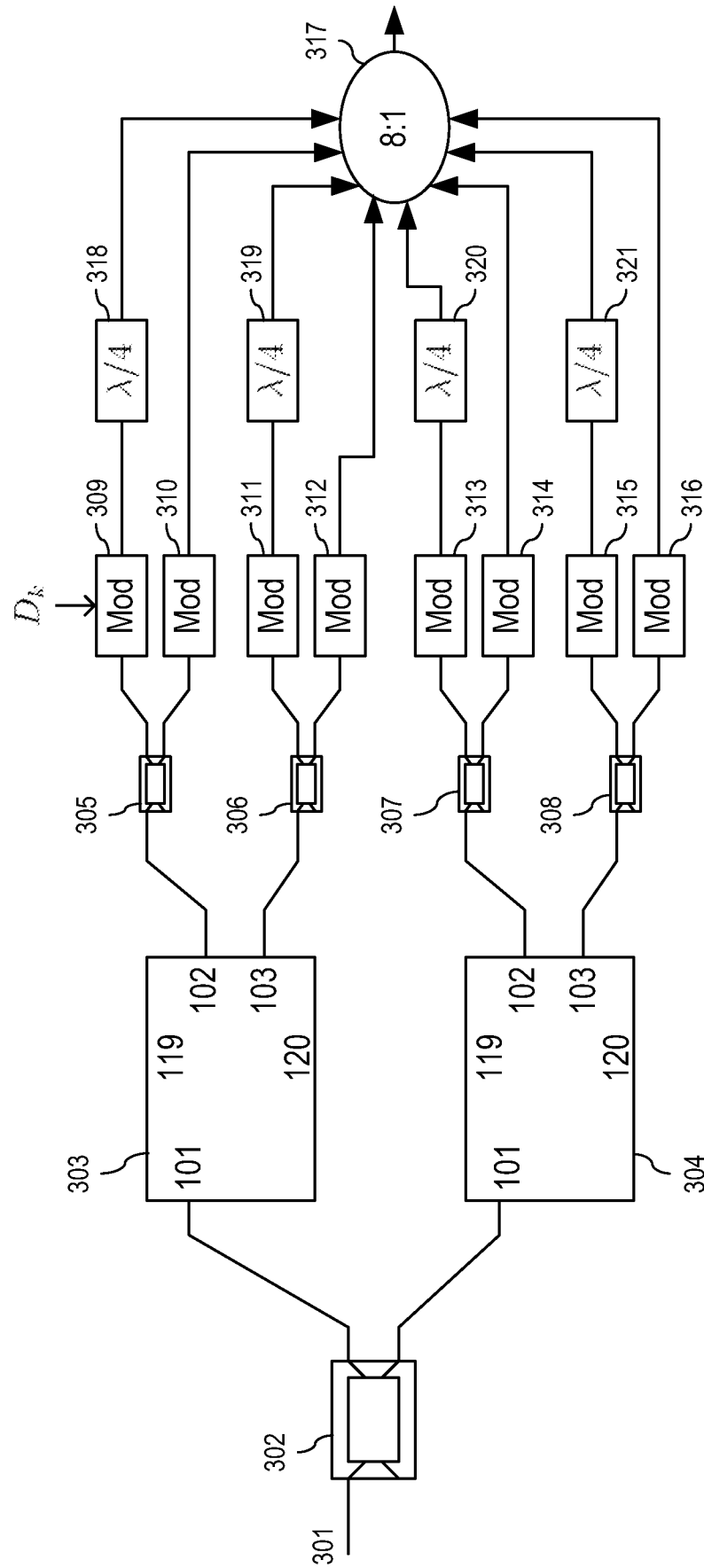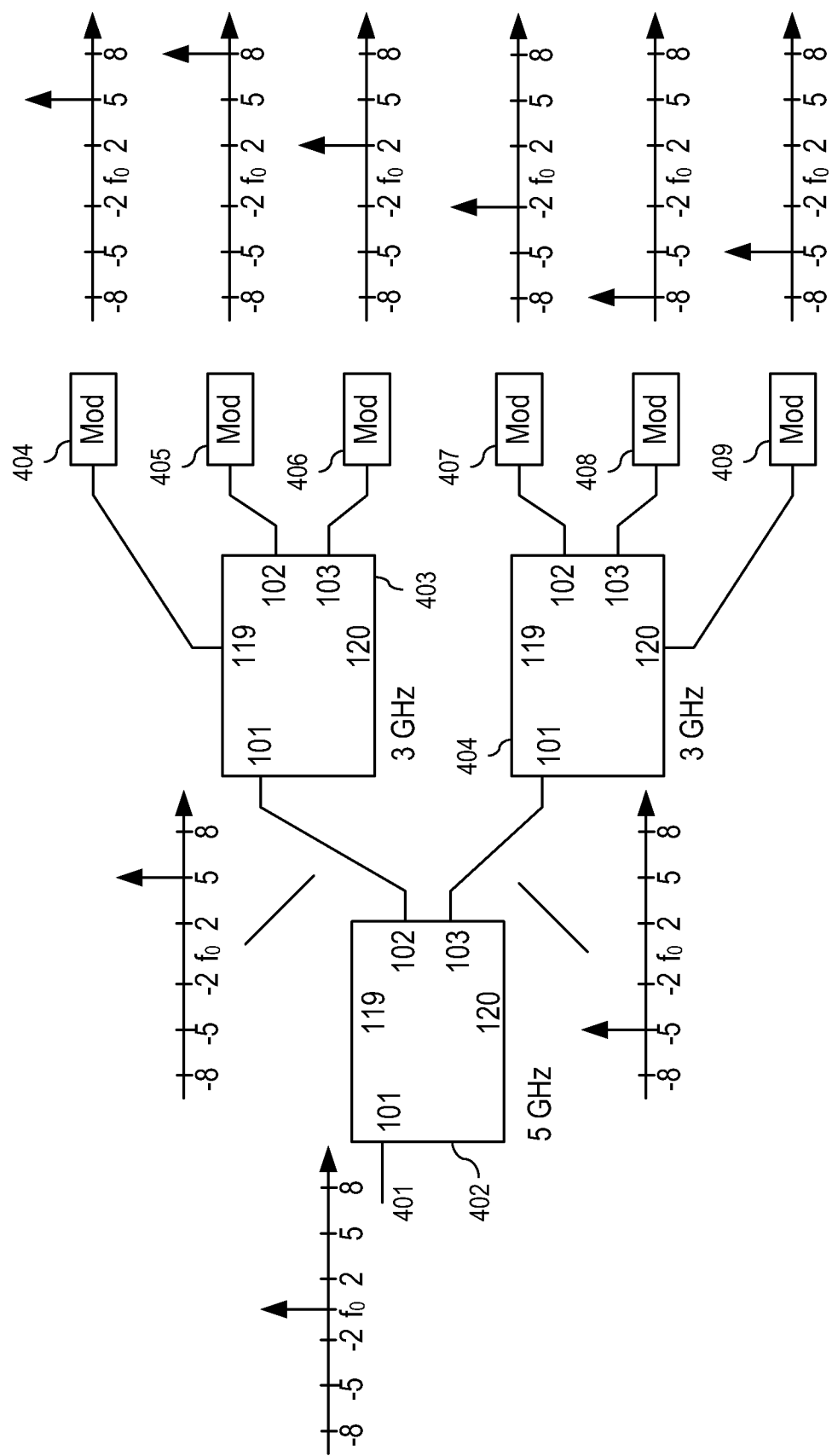   obtained from the receiving unit.

5

Fig.1

phase modulator

phase adjustment

coupler / splitter

M   monitor diode

Fig.2

Fig.3

Fig.4

Fig.5
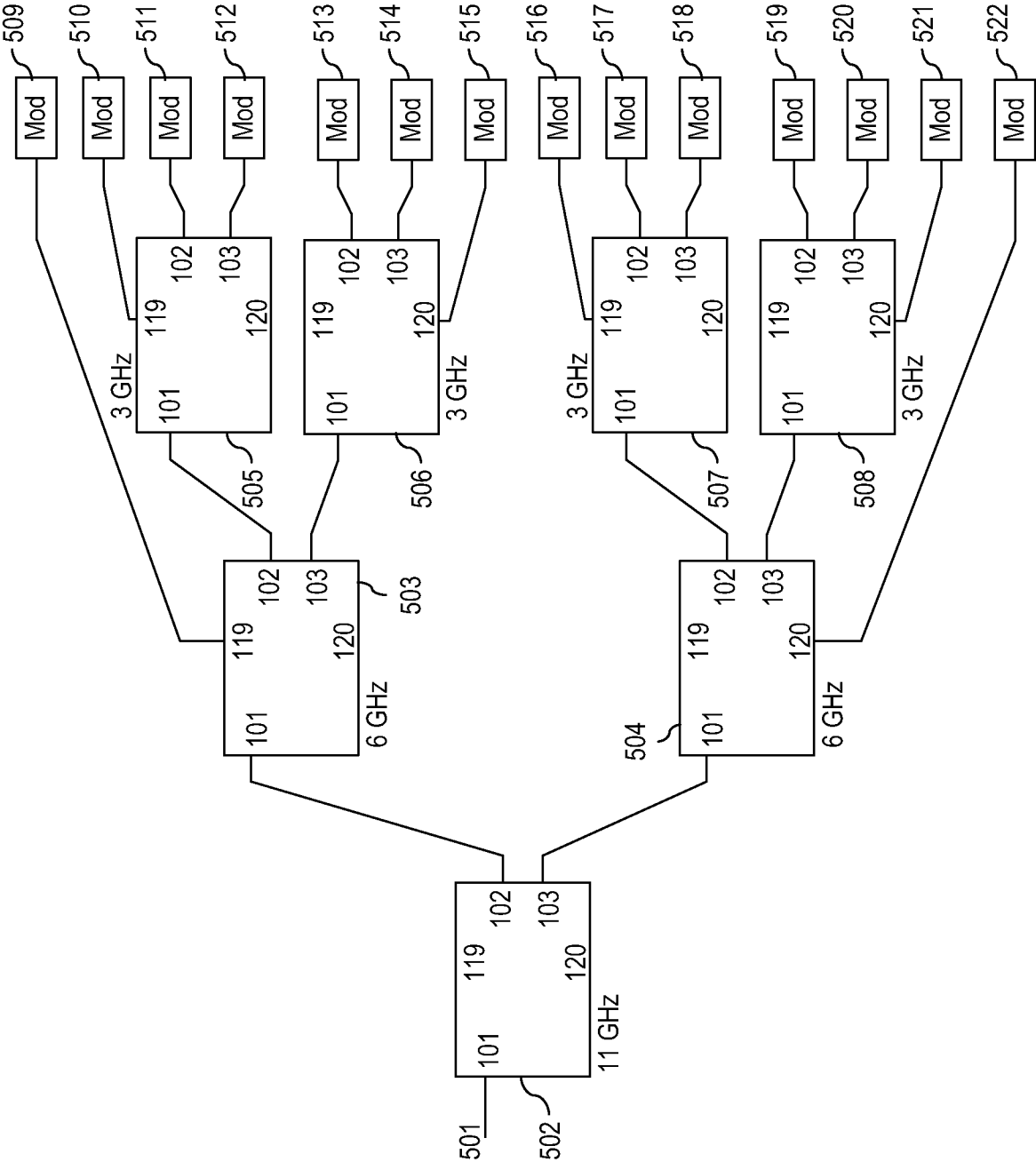
Fig.6
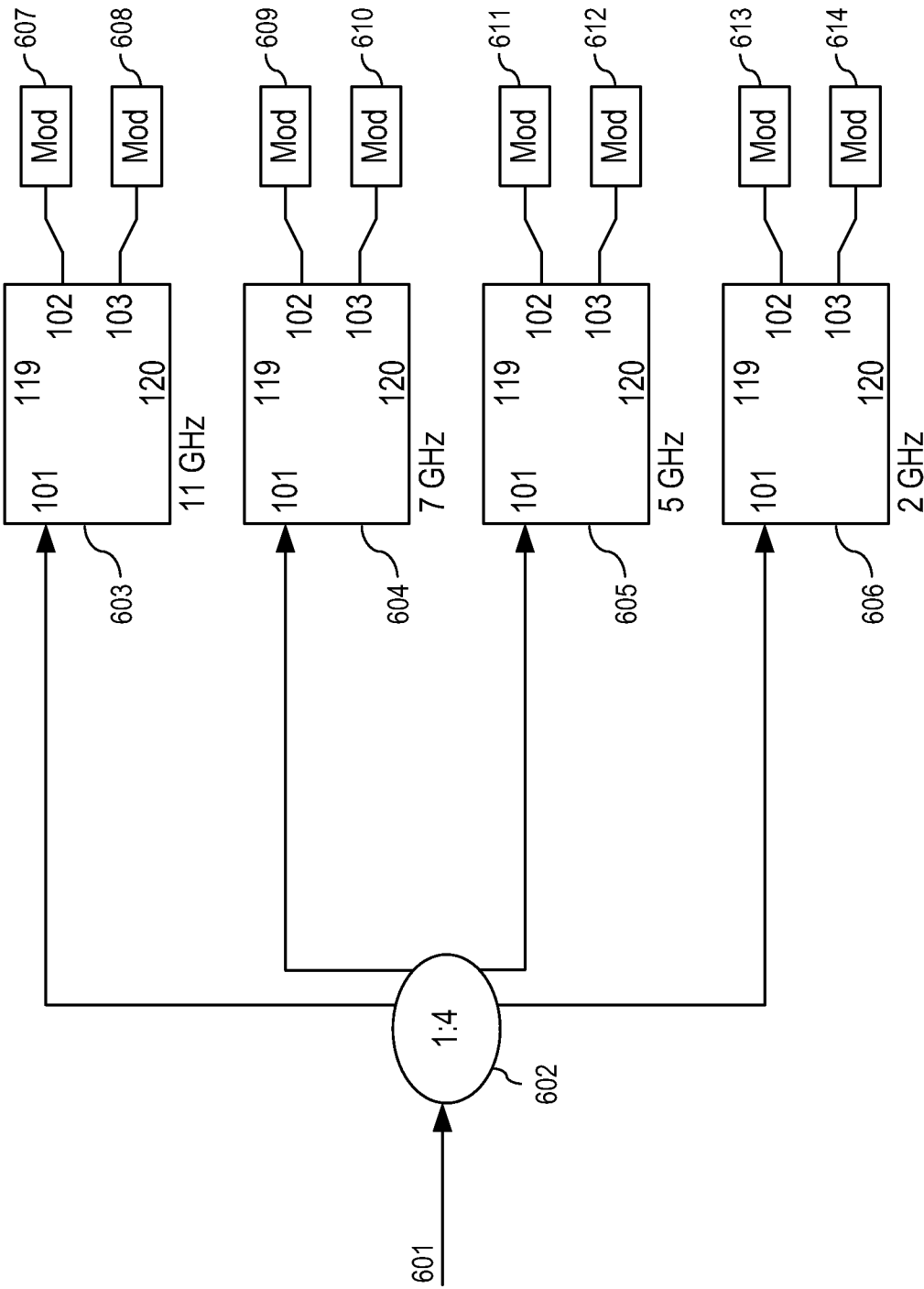
Fig.7
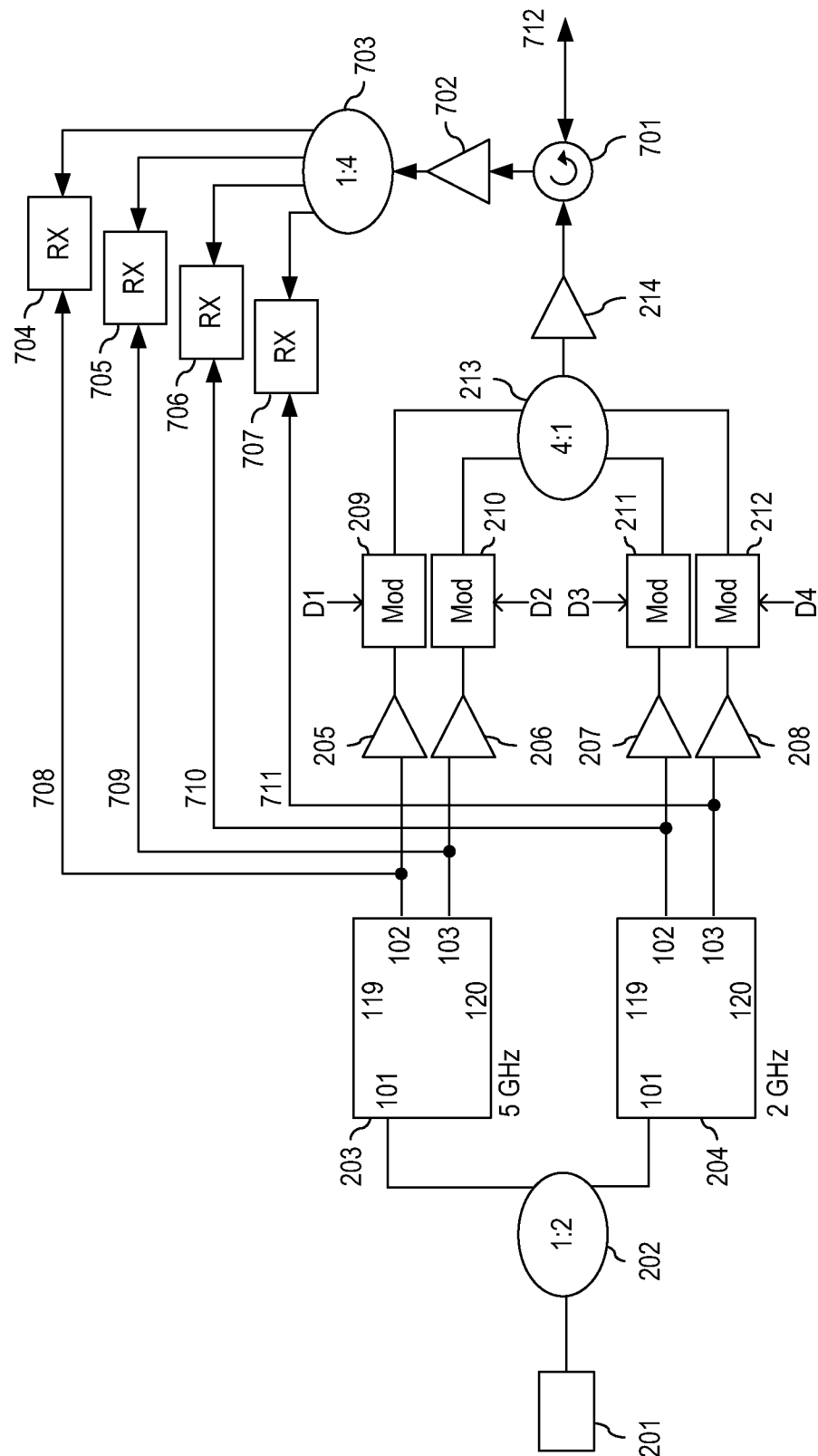
Fig.8
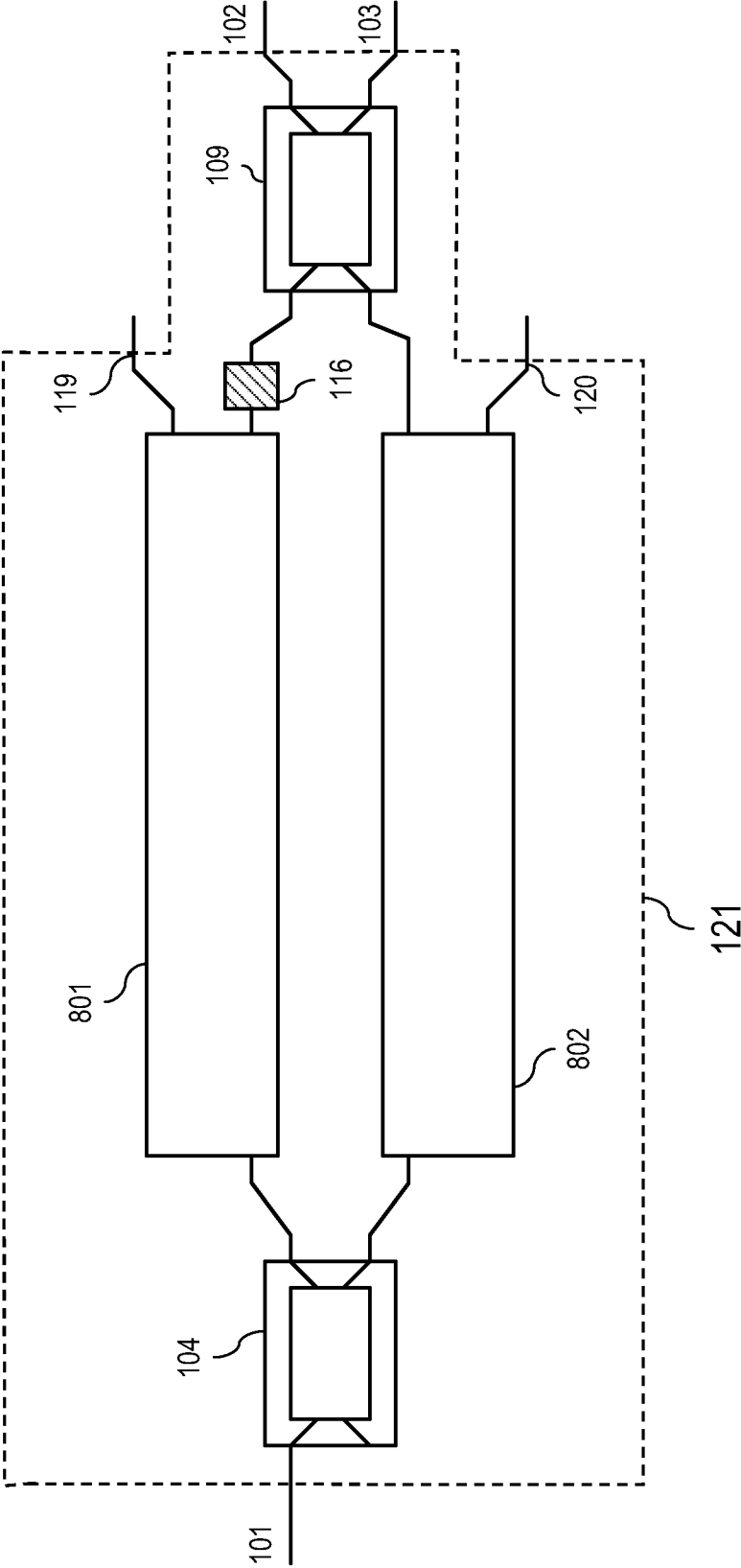
Fig.9
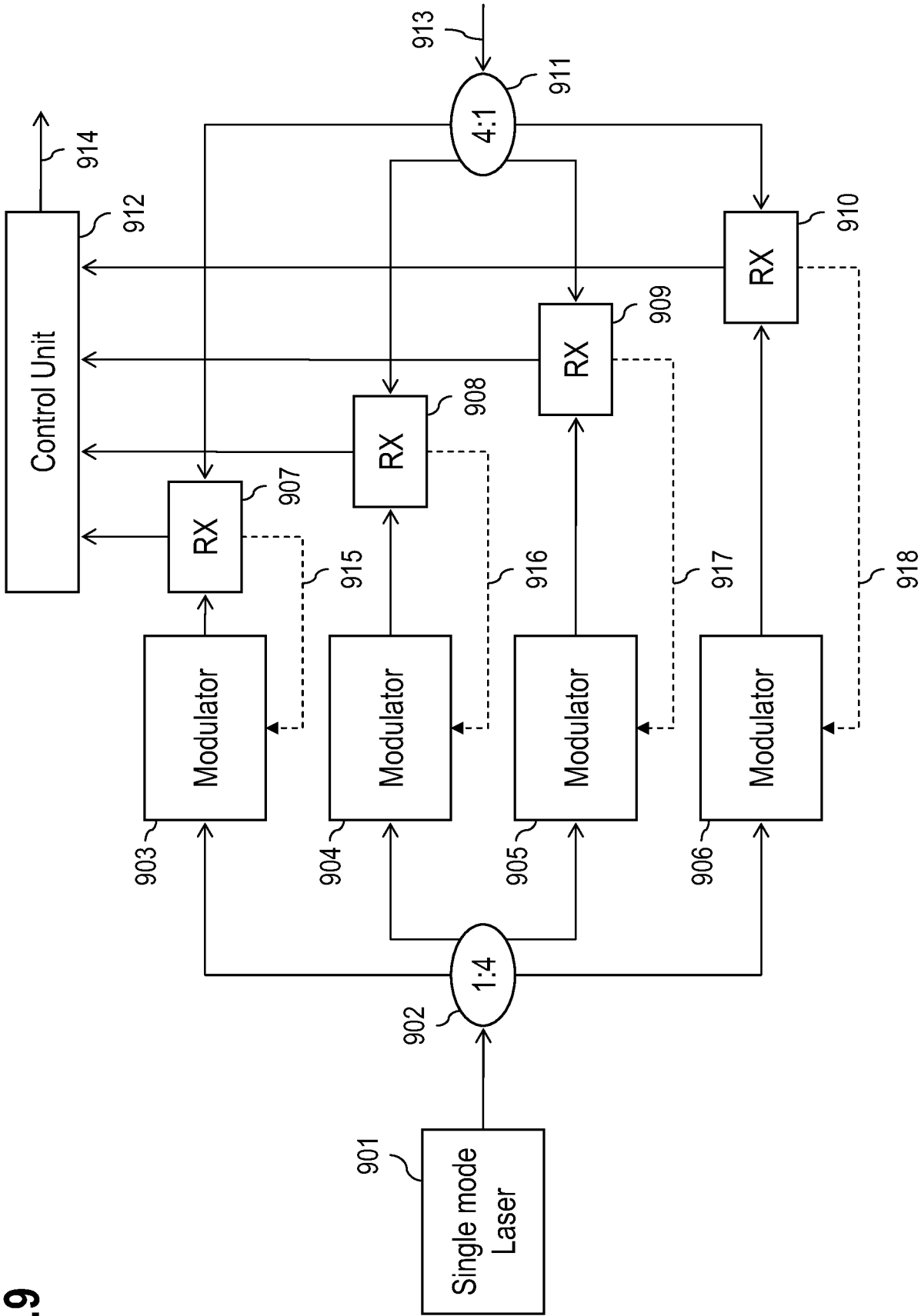
Fig.10
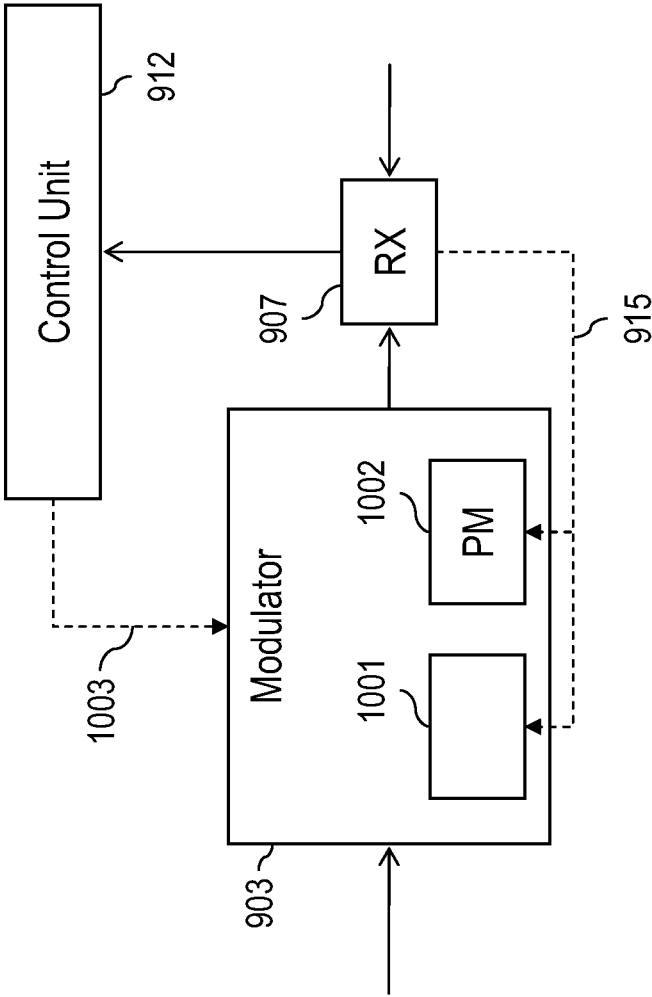
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04B10/155
ADD.

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)

H04B H01S G02F G01F

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	US 2002/041422 A1 (MAHLAB URI [IL]) 11 April 2002 (2002-04-11) figures 1,2 paragraphs [0010] - [0014] -----	1-6,9-13
Y	EP 0 494 831 A2 (FUJITSU LTD [JP] FUJITSU LTD [DE]) 15 July 1992 (1992-07-15) column 1, line 29 - column 2, line 5 figure 1 ----- -/--	1-15

☒ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
8 March 2011	15/03/2011

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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