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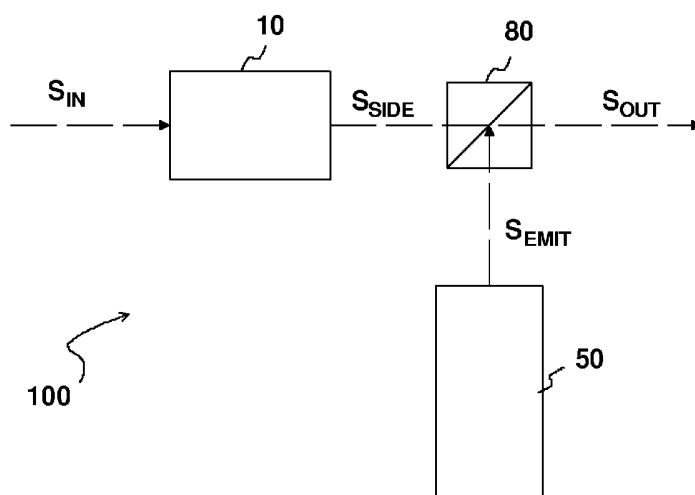
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(54) Title: OPTICAL SIGNAL PROCESSING DEVICE



(57) Abstract: The signal processing device (100) comprises a light source (50) to emit light (S_{EMIT}) at a wavelength which is substantially equal to the carrier wavelength (λ_0) of an optical input signal (S_{IN}), an optical resonator (10) to provide a filtered signal (S_{SIDE}) by optical filtering of said optical input signal (S_{IN}), said optical resonator (10) being non-matched with the carrier wavelength (λ_0) of said optical input signal (S_{IN}), and an optical combiner (80) to combine said filtered signal (S_{SIDE}) with said emitted light (S_{EMIT}) to form an optical output signal (S_{OUT}). The signal processing device (100) may be adapted to recover the clock frequency of a modulated input signal (S_{IN}). The intensity of said output signal (S_{OUT}) exhibits periodic variations at the clock frequency when the resonator (10) is adjusted at least approximately to the predetermined sideband of the modulated input signal (S_{IN}).

WO 2006/120281 A1

OPTICAL SIGNAL PROCESSING DEVICE

FIELD OF THE INVENTION

5 The present invention relates to optical signal processing.

BACKGROUND OF THE INVENTION

10 Signals have been traditionally processed in the electrical domain. However, conversion of optical signals to electrical signals is non-trivial at high modulation frequencies. Optical processing of optical signals provides an efficient and cost-effective approach at high modulation frequencies, e.g. when the modulation frequency is in the order of 40 GHz or higher.

15 Optical signal processing may be used e.g. for the recovery of clock frequency from an optical data signal.

20 US Patent publication 2001/0038481A1 discloses an apparatus for extraction of optical clock signal from an optical data signal. The apparatus comprises a non-linear optical element coupled to receive an optical data signal, said non-linear element generating a chirped signal based on the optical data signal, and an optical frequency discriminator coupled to receive said chirped signal from the non-linear
25 element, the discriminator generating an optical clock signal based on chirped frequency components of the chirped signal.

30 An article "Optical Tank Circuits Used for All-Optical Timing Recovery" by M.Jinno, T.Matsumoto, IEEE Journal of Quantum Electronics, Vol. 28, No. 4 April 1992 pp. 895-900, discloses a timing recovery scheme based on an optical resonator. When processing an optical signal which is modulated according to the return-to-zero format, one of the resonance peaks of the optical resonator is adjusted to the center frequency of the incoming optical data stream, and the separation
35 between the pass bands of the optical resonator is selected to be equal to the clock frequency. The spectral components which correspond to the center frequency of the signal and to the sideband frequencies

corresponding to the modulation of the signal are transmitted, which results in the recovery of the optical clock signal.

5 SUMMARY OF THE INVENTION

It is an object of the present invention to provide a device for processing of optical signals. It is also an object of the present invention to provide a method for processing of optical signals. It is a
10 further object of the present invention to provide a device and a method for spectral analysis of optical signals.

According to a first aspect of the invention, there is a device for processing of an optical input signal, which optical input signal has one
15 or more carrier wavelengths, said device comprising at least:
- an optical resonator to provide a filtered signal by optical filtering of said optical input signal, said optical resonator being non-matched with a predetermined carrier wavelength of said optical input signal,
- one or more light sources to emit light at one or more wavelengths
20 such that at least one wavelength of the emitted light is substantially equal to said predetermined carrier wavelength of said optical input signal, and
- an optical combiner to combine said filtered signal with said emitted light to form an optical output signal.

25 According to a second aspect of the present invention, there is a method for processing of an optical input signal, which optical input signal has one or more carrier wavelengths, wherein said method comprises at least:
30 - optical filtering of said optical input signal to provide a filtered signal by using an optical resonator, said resonator being non-matched with a predetermined carrier wavelength of said optical input signal,
- providing emitted light by using a light source at a wavelength which is substantially equal to said predetermined carrier wavelength of said
35 optical input signal,
- optically combining said filtered signal with said emitted light to form an optical output signal.

According to a third aspect of the present invention, there is a device for analyzing wavelength components an optical input signal, said device comprising at least:

- 5 - a tunable optical resonator to provide a filtered signal by optical filtering of said optical input signal,
- a light source to emit light a wavelength in the vicinity of a wavelength range of said optical input signal to be analyzed,
- a combiner to optically combine said filtered signal with said emitted
- 10 light to form an optical output signal, and
- at least one detector to monitor the amplitude of beating of said optical output signal.

15 According to a fourth aspect of the present invention, there is a method for analyzing wavelength components an optical input signal, said method comprising at least:

- optical filtering of said optical input signal to provide a filtered signal by using a tunable optical resonator,
- providing emitted light having a wavelength in the vicinity of a
- 20 wavelength range of said optical input signal to be analyzed,
- optically combining said filtered signal with said emitted light to form an optical output signal, and
- monitoring the amplitude of beating of said optical output signal.

25 An optical resonator is a device which has a capability to wavelength-selectively store optical energy carried at one or more wavelengths. The term non-matched means that the optical resonator is adapted to provide one or more optical pass bands such that the predetermined carrier wavelength does not coincide with the pass bands, i.e. the

30 carrier wavelength is outside the wavelength range of each pass band of the resonator.

The optical input signal may be modulated. Consequently, it may comprise a sideband at a wavelength which is different from the carrier

35 wavelength of said input signal. The optical resonator may be matched with the wavelength of the sideband, which means that at least one pass band of the optical resonator coincides at least approximately with

4

the wavelength of the sideband such that the optical resonator is adapted to store optical energy carried at the wavelength of the sideband. The output signal is formed by the combination of the sideband signal and the emitted light, and consequently it exhibits a beat at a frequency which is proportional to the difference between the sideband wavelength and the wavelength of the emitted light.

In an embodiment, the signal processing device and the method according to the present invention may be used to process simultaneously, i.e. parallel in time domain, a plurality of optical signals having different carrier wavelengths and/or data rates and/or different formats of modulation.

Because the optical resonator has the capability to store optical energy, it may provide a filtered signal also during periods when the optical input signal does not change its state.

In an embodiment, the signal processing device may be used as a clock signal recovery device to recover at least one clock signal associated with the optical input signal.

In an embodiment, the signal processing device may be applied to simultaneously recover a plurality of different clock signals associated with data transmitted at different optical channels, i.e. at different carrier wavelengths.

In the above-mentioned method by Jinno et al. the separation between the adjacent optical channels has to correspond to an integer multiple of the clock frequency. When compared with the method by Jinno et al., the method according to the present invention may also be adapted to process signals in which the separation between the adjacent optical channels does not correspond to an integer multiple of the clock frequency.

The recovered clock signal decays when the optical input signal does not change its state. Assuming that the optical resonators used in the method by Jinno et al. and in the method according to the present

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invention have equal time constants, the clock signal recovered using the method according to the present invention decays at a slower rate than the clock signal recovered by the method by Jinno et al.

- 5 The implementation of the devices and the methods according to the present invention requires a relatively small number of optical components, providing thus simplicity and savings in cost.

10 The embodiments of the invention and their benefits will become more apparent to a person skilled in the art through the description and examples given herein below, and also through the appended claims.

15 BRIEF DESCRIPTION OF THE FIGURES

In the following examples, the embodiments of the invention will be described in more detail with reference to the appended drawings, in which

- 20 Fig. 1 shows a block diagram of a signal processing device,
- Fig. 2 shows schematically an optical resonator based on a cavity between reflectors,
- 25 Fig. 3a shows by way of example a return-to-zero modulated data signal consisting of a sequence of rectangular pulses, and a clock signal associated with said data signal,
- Fig. 3b shows the frequency decomposition of the data signal according to Fig. 3a,
- 30 Fig. 3c shows an optical input signal modulated by the data signal according to Fig. 3a,
- 35 Fig. 4 shows schematically filtering and combination of optical signals in the wavelength domain,

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- Fig. 5a shows by way of example a return-to-zero modulated optical input signal, the temporal evolution of a sideband signal and the temporal evolution of an output signal corresponding to said input signal,
- Fig. 5b shows by way of example an output signal which is stabilized with respect to the beat amplitude,
- Fig. 6 shows a block diagram of a signal processing device comprising a wavelength feedback loop,
- Fig. 7 shows a block diagram of a signal processing device comprising a light source which is coupled to a second resonator,
- Fig. 8 shows schematically an optical resonator based on a fiber optic Bragg grating,
- Fig. 9 shows schematically an optical resonator based on two Bragg gratings,
- Fig. 10a shows schematically an optical resonator based on a micro ring,
- Fig. 10b shows schematically an optical resonator based on a plurality of optically coupled micro rings,
- Fig. 11 shows schematically an optical resonator based on a photonic microstructure,
- Fig. 12 shows a block diagram of a signal processing device, said device comprising a polarization controller to control the polarization of the optical input signal,
- Fig. 13 shows a block diagram of a signal processing device, said device comprising an arrangement to provide insensitivity

with regard to the polarization of a primary optical input signal,

- 5 Fig. 14 shows a block diagram of a signal processing device, said device comprising pre-processing means to generate further frequency components based on a primary signal, which does not have significant spectral components corresponding to clock frequencies,
- 10 Fig. 15 shows a block diagram of a signal processing device, said device comprising a delay unit and an optical combiner to generate further frequency components based on a primary signal, which does not have significant spectral components corresponding to clock frequencies,
- 15 Fig. 16 shows a block diagram of a signal processing device, said device comprising means to stabilize a fluctuating amplitude of the optical output signal and to reshape its waveform,
- 20 Fig. 17 shows schematically filtering and combination of an optical input signal, the separation between adjacent pass bands of the resonator being smaller than the separation between the carrier wavelength and the sideband wavelength,
- 25 Fig. 18 shows schematically filtering of an optical input signal consisting of data transmitted at three different optical channels,
- 30 Fig. 19 shows a block diagram of a signal processing device, which device comprises at least two light sources, each light source being adapted to emit light at one or more wavelengths,
- 35 Fig. 20 shows a block diagram of the signal processing device adapted for spectral analysis of the optical input signal, and

Fig. 21 shows schematically spectral analysis of the optical input signal, said analysis being based on recording the beat amplitude as a function of the beat frequency.

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DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a block diagram of the signal processing device 100. An input signal S_{IN} is filtered by a first resonator 10 to provide a filtered signal S_{SIDE} . The signal filtered using the first resonator 10 is herein called as the sideband signal. The sideband signal S_{SIDE} is subsequently combined with emitted light S_{EMIT} in an optical combiner 80 to provide an output signal of the signal processing device 100. The emitted light S_{EMIT} is provided by a light source 50. The light source 50 is advantageously adapted to emit continuous wave light. Advantageously, the emitted light S_{EMIT} is at least partially coherent. The light source 50 may be a laser.

Referring to Fig. 2, an optical resonator 10 may be implemented using an optical cavity 7 defined between two reflectors 5, 6. The optical length of the cavity 7 is L . The optical length L is equal to the distance between the reflectors 5, 6 multiplied by the refractive index of the cavity medium. The resonator 10 acts as a band pass filter having a plurality of pass bands (see the second curve from the top in Fig 4). The reflectors 5, 6 may be e.g. planar or spherical reflective surfaces. In case of planar reflective surfaces, adjacent pass bands in the vicinity of a wavelength λ are separated by a separation range $\Delta\lambda_{SR}$ given by

$$\Delta\lambda_{SR} = \frac{\lambda^2}{2L}. \quad (1)$$

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The separation range $\Delta\nu_{SR}$ may also be expressed in the frequency domain:

$$\Delta\nu_{SR} = \frac{c}{2L}, \quad (2)$$

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where c is the speed of light in vacuum.

The separation range $\Delta\nu_{SR}$ may be substantially constant over a predetermined wavelength range. In order to implement a constant separation range, the cavity 7 may be non-dispersive. Alternatively, the resonator 10 may comprise further elements to compensate dispersion. On the other hand, the resonator 10 may also be dispersive to provide a varying separation range $\Delta\nu_{SR}$. Such a resonator may be used e.g. in applications where the pass bands should coincide with several optical channels which have non-equal separations in the frequency domain.

Referring to the upper curve of Fig. 3a, a data signal DATA may consist of a sequence of rectangular pulses. The data signal DATA shown in Fig. 3a is modulated in the return-to-zero (RZ) format. t denotes time and A denotes amplitude. At this stage the data signal DATA may be an optical signal or it may be an electrical signal. The data signal assumes values 0 or 1. In a remote optical transmitter (not shown), the timing of the data pulses is controlled by a real or hypothetical sequence of clock pulses CLK, which are shown by the lower curve of Fig. 3a. The time period between two consecutive clock pulses is T_{CLK} . The frequency ν_{CLK} of the clock is equal to $1/T_{CLK}$, respectively.

Fig. 3b shows the frequency decomposition of the data signal DATA according to Fig. 3a. ν denotes frequency. The ordinate and the abscissa values are shown in logarithmic scale. The frequency decomposition exhibits several distinctive spectral peaks $\nu_A, \nu_B, \nu_C, \dots$. In this case the spectral position of the peak ν_A is equal to the clock frequency ν_{CLK} associated with the data sequence according to Fig. 3a.

Fig. 3c shows schematically an optical input signal S_{IN} having a carrier wavelength λ_0 . I denotes intensity. The optical input signal S_{IN} may be formed in the remote optical transmitter (not shown) by multiplying a continuous optical signal having wavelength λ_0 with the data signal DATA. The electric field of the optical input signal S_{IN} is modulated according to the data signal DATA, but it comprises also the optical frequency $(=c/n\lambda_0)$ corresponding to the wavelength λ_0 , which

wavelength is herein called as the carrier wavelength. Said optical frequency is herein called as the carrier frequency. n is the index of refraction.

- 5 The uppermost curve of Fig. 4 shows the spectral composition of the optical input signal S_{IN} in the wavelength domain. In this example the optical input signal S_{IN} consists of data transmitted at one optical channel only. The spectrum of the optical input signal S_{IN} exhibits a central peak at the carrier wavelength λ_0 . Due to the modulation of the
- 10 signal there are typically at least two side peaks at the wavelengths λ_{-1} and λ_1 . The peak at λ_{-1} is blue-shifted (having a shorter wavelength) and the peak at λ_1 is red-shifted (having a longer wavelength) with respect to the carrier wavelength λ_0 . The spectrum may comprise further spectral peaks, but they have been omitted for the sake of
- 15 clarity of Fig. 4.

- The difference $\lambda_1 - \lambda_0$, and the difference $\lambda_0 - \lambda_{-1}$ depend on the clock frequency ν_{CLK} . There may be more spectral peaks than those at λ_{-1} and λ_1 . Based on the known format of modulation and the known form
- 20 of the data, the person skilled in the art is able to select which one(s) of the side peaks corresponds to the desired filtered frequency, e.g. to the clock frequency.

- Referring to the second curve F10 from the top in Fig. 4, the spectral
- 25 transmittance of the first resonator 10 (Figs. 1 and 2) may have several adjacent pass bands PB. The separation of the pass bands PB is equal to the separation range $\Delta\lambda_{SR}$. At least one of the pass bands PB is tuned at least approximately to the wavelength λ_1 such that the carrier wavelength λ_0 is substantially not transmitted, i.e. the spectral
- 30 component at the carrier wavelength λ_0 is substantially rejected by the first resonator 10. TR denotes the transmittance, i.e. the ratio of the transmitted intensity to the input intensity. Alternatively, at least one of the pass bands PB may be tuned at least approximately to the wavelength λ_{-1} . Yet, the pass bands PB may be tuned simultaneously
- 35 to the both sideband wavelengths λ_{-1} and λ_1 , provided that the separation range $\Delta\lambda_{SR}$ of the first resonator 10 or its integer multiple

matches with the separation between the sideband wavelengths λ_{-1} and λ_1 .

Referring to the third curve S_{SIDE} from the top in Fig. 4, only the sideband of the original input signal S_{IN} is transmitted through the first resonator 10, to provide the sideband signal S_{SIDE} .

Referring to the fourth curve from the top in Fig. 4, the light source 50 (Fig. 1) is adapted to provide emitted light S_{EMIT} at the wavelength λ_0 . Advantageously, the intensity of the emitted light S_{EMIT} is substantially constant.

Referring to the lowermost curve in Fig. 4, the emitted light S_{EMIT} is combined with the sideband signal S_{SIDE} by the combiner 80 (Fig 1) to provide the output signal S_{OUT} . The output signal S_{OUT} has a spectrum consisting of two peaks at the wavelengths λ_0 and λ_1 . The output signal S_{OUT} may have further spectral peaks and/or components.

The carrier wavelength λ_0 corresponds to a carrier frequency ν_0 which is equal to $c/n\lambda_0$. λ_0 refers to the wavelength in vacuum and n is the index of refraction. The sideband wavelength λ_1 corresponds to a sideband frequency ν_1 which is equal to $c/n\lambda_1$. The intensity of the output signal S_{OUT} exhibits now periodic variations, i.e. beat in a frequency which is equal to the difference between the sideband frequency ν_1 and the carrier frequency ν_0 . Said difference is equal to the clock frequency ν_{CLK} . The output signal S_{OUT} may be used as an optical clock signal.

The electric field E_{OUT} of the optical output signal S_{OUT} is a superposition

$$E_{\text{OUT}}(t) = E_1 \exp(j2\pi\nu_1 t) + E_0 \exp(j2\pi\nu_0 t), \quad (3)$$

where E_1 is the amplitude of the field of the sideband signal S_{SIDE} after the combiner 80 and E_0 is the amplitude of the electric field of the emitted light S_{EMIT} after the combiner 80. The intensity I_{OUT} of the output signal is given by

$$I_{OUT}(t) = E_{OUT}(t) E_{OUT}^*(t) \quad (4)$$

$$I_{OUT}(t) = E_1^2 + E_0^2 + 2E_1E_0 \cos[2\pi(\nu_1 - \nu_0)t] \quad (5)$$

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$$I_{OUT}(t) = E_1^2 + E_0^2 + 2E_1E_0 \cos(2\pi\nu_{CLK}t) \quad (6)$$

10 The output intensity exhibits a substantially sinusoidal beat at the frequency $\nu_1 - \nu_0$, i.e. at the frequency ν_{CLK} of the clock. The last term in the equation (5) is herein called as the beating term.

15 The combiner 80 may be a semitransparent reflector, a beam splitter or a beam coupler based on fiber optics, an integrated optical Y-coupler, a directional coupler, a filter, a grating-based coupler, a polarizer or a spatial multiplexer. The combiner 80 may also be a combination of these and/or related optical elements. The output signal S_{OUT} is a vector sum of the sideband signal S_{SIDE} and the emitted light S_{EMIT} . When the sideband signal S_{SIDE} and the emitted light S_{EMIT} are combined by the beam combiner 80, the polarization (i.e. the orientation of polarization) of the sideband signal S_{SIDE} may be at any angle with respect to the polarization of the emitted light S_{EMIT} . Parallel polarization provides maximum beating amplitude.

25 Distinctive beating may be observed when the polarization of the emitted light S_{EMIT} may be adjusted to be parallel to the polarization of the sideband signal S_{SIDE} . The intensity of the sideband signal S_{SIDE} is typically low, but the beating term in the equation (5) may be amplified by increasing the amplitude E_0 of the electric field of the emitted light S_{EMIT} , i.e. by increasing intensity of the emitted light S_{EMIT} .

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On the other hand, the relative contribution of the beating term may be maximized by setting the intensity of the emitted light S_{EMIT} to be approximately equal to the average intensity of the sideband signal S_{SIDE} , i.e. by setting $E_1 \approx E_0$.

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The relative intensities of the emitted light S_{EMIT} and the sideband signal S_{SIDE} may be adjusted e.g. by adjusting the power or current of a laser, or by adjusting the angular orientation of a polarizer positioned in the optical path.

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The optical resonator has a capability to store optical energy. This phenomenon is now discussed with reference to the resonator according to Fig. 2. However, the discussion is relevant also regarding other types of optical resonators. Photons coupled into the resonator according to Fig. 2 pass, in average, several times back and forth between the reflectors 5, 6 before escaping from the cavity 7. Thus, the resonator 10 can sustain its state for some time regardless of perturbations of the optical input signal S_{IN} . The time constant τ of the resonator 10 is given by the equation

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$$\tau = \frac{L}{-c \ln(r)}, \quad (7)$$

where L is the optical length of the cavity 7 (physical distance multiplied by the refractive index) between the reflectors 5, 6, c is the speed of light in vacuum and r is the reflectance of the reflectors 5, 6. For example, by selecting the parameters $r = 0,99$ and $L = 1$ mm, the time constant τ of the resonator is 332 picoseconds.

Advantageously, the time constant τ is selected to be greater than or equal to the average time period during which the optical input signal S_{IN} does not change its state. In case of return-to-zero (RZ) signals, the time constant τ is advantageously selected to be greater than or equal to the average time period during which the optical input signal S_{IN} remains at zero.

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Fig. 5a shows the temporal behavior of the sideband signal S_{SIDE} and the output signal S_{OUT} corresponding to a return-to-zero-modulated input signal S_{IN} . The uppermost curve shows the input signal S_{IN} . The second curve from the top shows the temporal behavior of the sideband signal S_{SIDE} . The intensity of the sideband signal S_{SIDE} decreases when no optical energy is delivered to the first resonator 10,

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i.e. the first resonator 10 is discharged. The intensity of the sideband signal S_{SIDE} increases when optical energy is delivered to the first resonator 10, i.e. the first resonator 10 is charged. The lowermost curve shows the temporal behavior of the output signal S_{OUT} . The output signal S_{OUT} exhibits a beat at the recovered clock frequency ν_{CLK} . The envelope ENV of the output signal S_{OUT} fluctuates according to the fluctuating sideband signal S_{SIDE} . It is emphasized that although the envelope ENV of the output signal intensity fluctuates, the amplitude of the beating of the output signal S_{OUT} approaches zero only if the input signal S_{IN} is at zero for a long time. Thus, the beating output signal S_{OUT} can be used as an uninterrupted clock signal.

It is emphasized that because the intensity of the emitted light S_{EMIT} remains substantially constant, the beat term in the equation (5) decreases only at the same rate as the amplitude of the sideband signal S_{SIDE} . Thus, the decay of the beat signal takes place at a slower rate than, for example, in the above-mentioned method by Jinno et al.

The signal processing device 100 may further comprise an output stabilization unit to provide an output signal which is stabilized with respect to the beat amplitude, and reshaped (See Fig. 16 and the related discussion). Fig. 5b shows, by way of example an output signal S_{OUT} which is stabilized with respect to the beat amplitude.

The recovered clock signal is accurate only when the wavelength of the emitted light S_{EMIT} is equal to the carrier wavelength λ_0 of the input signal S_{IN} . The light source 50, e.g. a laser may comprise a wavelength reference for locking the wavelength to a predetermined carrier wavelength λ_0 . The wavelength reference may be an internal wavelength reference. However, the approach of using the wavelength standard is applicable only when the carrier wavelength of the input signal S_{IN} is stable.

The signal processing device 100 may comprise means to set the wavelength of the emitted light S_{EMIT} to be equal to the carrier wavelength of the input signal S_{IN} .

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Referring to Fig. 6, the wavelength of the emitted light S_{EMIT} may be set to the carrier wavelength λ_0 using a wavelength feedback loop. A part of the input signal S_{IN} is separated using a beam splitter 60 and coupled through a second resonator 20 to recover the carrier wavelength λ_0 . The second resonator 20 is tuned at least approximately to the carrier wavelength λ_0 . Only those components of the input signal S_{IN} which are at the carrier wavelength λ_0 or in the vicinity of said carrier wavelength λ_0 are passed through the second resonator 20 to provide a reference signal S_{REF} . A part of the emitted light S_{EMIT} may be separated by a second beam splitter 70. The wavelength of the reference signal S_{REF} is compared with the wavelength of the emitted light S_{EMIT} in a wavelength comparator 52. The wavelength comparator provides a control signal to a wavelength tuner 51. The wavelength tuner 51 adjusts the wavelength of the light source 50, e.g. a laser, such that the wavelength of the emitted light S_{EMIT} becomes equal to the wavelength of reference signal S_{REF} . Mirrors M may be used to direct light. The second resonator 20 may be implemented in the same way as the first resonator 10.

The second resonator 20 may also be replaced with a wavelength-selecting component such as a wavelength selective filter, grating based device, monochromator, an arrayed waveguide grating, a periodic microstructure, a stack of thin films, a wavelength-selective absorbing filter, a filter based on non-linear optical phenomena, or a combination thereof.

The wavelength comparator 52 may be implemented e.g. by combining the reference signal S_{REF} and the emitted light S_{EMIT} and monitoring the beat frequency of the combined signal.

Referring to Fig. 7, the light source 50 may also be an optical amplifier or an arrangement comprising several optical amplifiers. The optical amplifier 50 may be e.g. an injection seeded laser, a semiconductor optical amplifier, or an erbium-doped fiber amplifier, or another light-amplifying device known by the person skilled in the art. The wavelength of the emitted light S_{EMIT} may be set to the carrier wavelength λ_0 using an optical amplifier 50. A part of the input signal

S_{IN} is separated by a beam splitter 60 and coupled through a second resonator 20 to recover the carrier wavelength λ_0 . The second resonator 20 is tuned at least approximately to the carrier wavelength λ_0 . Only those components of the input signal S_{IN} which are at the carrier wavelength λ_0 or in the vicinity of said carrier wavelength λ_0 are passed through the second resonator 20 to provide a reference signal S_{REF} . The reference signal S_{REF} is coupled to the light source 50, which subsequently provides emitted light S_{EMIT} at the wavelength λ_0 . Mirrors M may be used to direct light. The second resonator 20 may be implemented in the same way as the first resonator 10.

The first resonator 10 and/or the second resonator 20 may be implemented using optical resonators known by the person skilled in the art. Suitable optical resonators are disclosed e.g. in an article "Optical Tank Circuits Used for All-Optical Timing Recovery" by M.Jinno, T.Matsumoto, IEEE Journal of Quantum Electronics, Vol. 28, No. 4 April 1992 pp. 895-900, herein incorporated by reference.

Referring to the resonator shown in Fig. 2, the first resonator 10 and/or the second resonator 20 may be tuned by adjusting the distance between the reflectors 5, 6. The wavelength tuning of the pass bands PB may be performed by methods known by the person skilled in the art. The methods comprise e.g. controlling temperature, pressure, electric field, voltage, current or mechanical deformation.

Referring to Fig. 8, the first resonator 10 and/or the second resonator 20 may be implemented using a fiber optic Bragg grating. The fiber optic Bragg grating comprises a portion of optical waveguide 8 comprising periodic features 9.

Referring to Fig. 9, the first resonator 10 and/or the second resonator 20 may be implemented using structure which comprises two Bragg gratings, said gratings defining a cavity between them.

Referring to Fig. 10a, the first resonator 10 and/or the second resonator 20 may be implemented using a micro ring resonator. Waveguides 11, 12 may be arranged to couple light in and out from a

17

micro ring 13, said micro ring 13 forming an optical resonator. Light may be coupled to and from the waveguides and other optical components, such as the ring resonators 13, by evanescent coupling.

- 5 Referring to Fig. 10b, the first resonator 10 and/or the second resonator 20 may be implemented using a plurality of optically coupled micro ring resonators.

- 10 Referring to Fig. 11, the first resonator 10 and/or the second resonator 20 may be implemented using light-scattering periodic microstructures 14. Also optical splitters or combiners may be implemented by the microstructures.

- 15 The first resonator 10 and/or the second resonator 20 may also be implemented using a resonator formed based on a fiber loop or a portion of a fiber defined between two reflectors (not shown).

- 20 The first resonator 10 and the second resonator 20 may be implemented using a birefringent structure, e.g. a cavity 7 comprising birefringent medium. Thus, two different optical lengths may be implemented simultaneously using a single physical unit. The input signal S_{IN} may be divided into two parts having e.g. vertical and horizontal polarizations inside the birefringent resonator. The optical length of the cavity 7 corresponding to the vertical polarization may be adjusted to provide a pass band at the carrier wavelength λ_0 . The optical length of the cavity 7 corresponding to the horizontal polarization may be adjusted to provide a pass band at the sideband wavelength λ_1 . The reference signal S_{REF} (Figs.6 and 7) is separated from the sideband signal S_{SIDE} after the resonator by use of a polarizing beam splitter, or a combination comprising one or more polarizers.
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The first resonator 10 and/or the second resonator 20 may be used in the transmissive mode or in the reflective mode.

- 35 Referring to Fig. 12, the signal processing device 100 may comprise a polarization controlling element 95. The polarization controlling element 95 may be adapted to select a portion of input signal S_{IN} having a

18

predetermined polarization, i.e. orientation of polarization. The polarization controlling element 95 is advantageously used when the input signal S_{IN} is unstable or unknown. The polarization controlling element 95 may also be adapted to change the polarization of the input signal S_{IN} . One or more polarization controlling elements 95 may be positioned before the first resonator 10, between the first resonator 10 and the combiner 80, or after the combiner 80. One or more polarization controlling elements 95 may also be positioned between the light source 50 and the combiner 80. One or more polarization controlling elements 95 may also be positioned between the first resonator 10 and the second resonator 20 (not shown). One or more polarization controlling elements 95 may also be positioned after the second resonator 20 (not shown). Also the combiner 80 may be a polarizing combiner.

The polarization controlling element 95 may be any type of polarizer or polarization controller known by the person skilled in the art. The polarization controlling element 95 may be a fiber-based polarization controller, a set of waveplates, a polarizing crystal, or a polarizing foil. The polarization controlling element 95 may comprise a combination of optical components.

Referring to Fig. 13, the signal processing device 100 may be adapted to provide insensitivity with regard to the polarization of an optical primary signal S_{IN1} . An optical primary signal S_{IN1} is first divided into two parts using beam splitters 60, 61. The parts have substantially perpendicular polarization. One part constitutes an optical signal S_{INA} , which is coupled to a resonator 10a. The polarization of the other part is rotated substantially 90 degrees by a polarization controlling element 95 to form an optical signal S_{INB} which is coupled to a resonator 10b. The resonators 10a, 10b are tuned substantially to the same wavelength. Two sideband signals $S_{SIDE,A}$, $S_{SIDE,B}$ are provided, which are combined using a combiner 81 to provide a sideband signal S_{SIDE} . The polarization of the sideband signal S_{SIDE} is substantially insensitive with regard to the polarization of the optical primary signal (S_{IN1}). The sideband signal S_{SIDE} is combined with the emitted light S_{EMIT} to provide the optical output signal S_{OUT} . The signal processing device 100 may

comprise a resonator 20 to select a wavelength which is coupled to the light emitting unit 50 to stabilize the wavelength.

5 A primary optical input signal S_{IN1} may be amplitude-modulated, phase-modulated, quadrature-modulated or modulated according to a further format known by the person skilled in the art. The primary optical input signal S_{IN1} may comprise data transmitted at several optical channels such that data transmitted at the different optical channels are modulated in different ways. The data rates associated with the
10 different channels may be different.

The primary optical input signal S_{IN1} may be modulated in such a way that it does not originally comprise spectral components corresponding to the clock. The primary optical input signal S_{IN1} may be modulated
15 e.g. according to the non-return-to-zero (NRZ) format. Referring to Fig. 14, the signal processing device 100 may comprise a pre-processing unit 110 to provide an optical input signal S_{IN} which comprises spectral components associated with the clock frequency of the primary optical input signal S_{IN1} .

20 Referring to Fig. 15, the pre-processing unit 110 may comprise a delay line 62 and an optical combiner 82. The primary optical input signal S_{IN1} may be delayed and combined with the original undelayed primary optical input signal S_{IN1} to perform an exclusive-OR-operation of the
25 delayed and undelayed signals. Consequently, an optical input signal S_{IN} may be provided which comprises frequency components associated with the clock frequency. Such an arrangement is disclosed e.g. in an article "All-Optical Clock Recovery from NRZ Data of 10 Gb/s", by H.K.Lee, J.T.Ahn, M.-Y.Jeon, K.H.Kim, D.S.Lim, C.-H.Lee,
30 IEEE Photonics Technology Letters, Vol. 11 No.6 June 1999 pp. 730-732, herein incorporated by reference.

The pre-processing unit 110 may also be implemented by non-linear devices such as disclosed e.g. in US Patent 5339185.

35 Referring to Figs. 16 and 5b, the signal processing device 100 may further comprise an output stabilization unit 85 to provide an output

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signal $S_{OUT,STAB}$ which is stabilized and reshaped with respect with respect to the beat amplitude. The stabilization unit 85 may be based on an optical resonator exhibiting optical bistability. The stabilization unit 85 may be based on an optically saturable element. The stabilization unit 85 may be based on the use of one or more semiconductor optical amplifiers.

Referring to Fig. 17, the first resonator 10 may have several pass bands with a separation which is smaller than the separation between the carrier wavelength λ_0 and the wavelength λ_1 of the sideband.

The signal processing device 100 may be used in combination with optical data receivers, repeaters, transponders or other type of devices used in fiber optic networks. The signal processing device 100 may be used in combination with optical data receivers, repeaters, transponders or other type of devices used in optical communications systems operating in free air or in space.

The optical input signal S_{IN} may comprise data sent at several optical channels, i.e. associated with different carrier wavelengths. Carrier wavelengths for optical channels in fiber optic networks have been standardized e.g. by the International Telecommunication Union within the United Nations System. The separation between at least two carrier wavelengths ($\lambda_{0,A}$, $\lambda_{0,B}$) may be e.g. 100 GHz in the frequency domain.

Referring to Fig. 18, the signal processing device 100 may be used to recover clock frequencies associated with several optical channels CHA, CHB, CHC. The uppermost curve of Fig. 18 shows the spectral components of an optical input signal S_{IN} , which comprises data sent at three optical channels CHA, CHB and CHC. There are three carrier wavelengths $\lambda_{0,A}$, $\lambda_{0,B}$ and $\lambda_{0,C}$ and six sideband wavelengths $\lambda_{-1,A}$, $\lambda_{1,A}$, $\lambda_{-1,B}$, $\lambda_{1,B}$, $\lambda_{-1,C}$, $\lambda_{1,C}$ corresponding to the modulation at three different clock frequencies.

The second curve F10 of Fig. 18 shows the pass bands PB of the first resonator 10. One of the pass bands is set at least approximately to the sideband wavelength $\lambda_{1,A}$, one of the pass bands is set at least

approximately to the sideband wavelength $\lambda_{-1,B}$ and one of the pass bands is set at least approximately to the sideband wavelength $\lambda_{1,C}$.

Referring to the lowermost curve of Fig. 18, the emitted light S_{EMIT} is adapted to comprise spectral components at least at the three carrier wavelengths $\lambda_{0,A}$, $\lambda_{0,B}$ and $\lambda_{0,C}$.

Combination of the transmitted sideband signal S_{SIDE} and the emitted light S_{EMIT} provides an output signal S_{OUT} which exhibits three beat terms. A first term exhibits beat at the clock frequency associated with the first optical channel CHA, a second beat term exhibits beat at the clock frequency associated with the second optical channel CHB, and a third term exhibits beat at the clock frequency associated with the third optical channel CHC. The output signal S_{OUT} may be further coupled to a wavelength demultiplexer to provide three separate optical signals, beating at the respective clock frequencies.

The pass bands PB of the first optical resonator 10 may be simultaneously adapted to correspond to a set of frequencies ν_q given by:

$$\nu_q = \nu_{0,A} + q\Delta\nu_{SR} + \nu_{CLK,A}, \quad (8)$$

or, alternatively, simultaneously given by:

$$\nu_q = \nu_{0,A} + q\Delta\nu_{SR} - \nu_{CLK,A}, \quad (9)$$

where q is an integer (...-2, -1, 0, 1, 2, 3,...), $\nu_{0,A}$ is the optical frequency ($=c/n\lambda_0$) corresponding to the carrier wavelength λ_0 of a predetermined optical channel A, $\Delta\nu_{SR}$ is the separation between the pass bands of the first resonator 10 in the frequency domain and $\nu_{CLK,A}$ is the lowest clock frequency associated with said optical channel.

For example, the separation between the carrier wavelengths may be 100 GHz, the separation range $\Delta\nu_{SR}$ may be 50 GHz and the lowest clock frequency $\nu_{CLK,A}$ may be 10 GHz. In that case the first resonator

22

10 may be adapted to simultaneously filter frequencies $\nu_{0,A} - 140$ GHz, $\nu_{0,A} - 90$ GHz, $\nu_{0,A} - 40$ GHz, $\nu_{0,A} + 10$ GHz, $\nu_{0,A} + 60$ GHz, $\nu_{0,A} + 110$ GHz, $\nu_{0,A} + 160$ GHz, $\nu_{0,A} + 210$ GHz... .Consequently, several clock frequencies associated with different optical channels, i.e. associated with several carrier wavelengths may be recovered simultaneously, providing that the respective sidebands coincide with the pass bands of the first resonator 10. An example of a possible combination of carrier frequencies and clock frequencies is presented in Table 1.

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Table 1. A possible combination of carrier frequencies, clock frequencies and pass band positions, by way of example.

Optical Channel No.	Carrier frequency	Clock frequency	Positions of 1st resonator passbands	Positions of emitted light S_{EMIT}
1	$\nu_{0,A}-200$ GHz	10 GHz	$\nu_{0,A}- 190$ GHz	$\nu_{0,A}-200$ GHz
2	$\nu_{0,A}$	40 GHz	$\nu_{0,A} - 40$ GHz	$\nu_{0,A}$
3	$\nu_{0,A}+200$ GHz	10 GHz	$\nu_{0,A}+210$ GHz	$\nu_{0,A}+200$ GHz
4	$\nu_{0,A}+1000$ GHz	160 GHz	$\nu_{0,A}+1160$ GHz	$\nu_{0,A}+1000$ GHz

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The light source 50 is adapted to emit light S_{EMIT} at the respective carrier frequencies.

20 The separation range $\Delta\lambda_{\text{SR}}$ of the first resonator 10 may be selected to be substantially equal to the minimum separation between adjacent carrier wavelengths $\lambda_{0,A}$, $\lambda_{0,B}$ multiplied by an integer number.

25 A second resonator 20 may be used to stabilize the wavelengths of the light sources 50 (Figs 6 and 7). The separation range $\Delta\lambda_{\text{SR}}$ of the second resonator 20 may be selected to be substantially equal to the minimum separation between adjacent carrier wavelengths $\lambda_{0,A}$, $\lambda_{0,B}$ multiplied by an integer number.

It is emphasized that the channel separation need not be an integer multiple of the clock frequency. For comparison, in the above-mentioned approach by Jinno & al., the channel separation has to be an integer multiple of the clock frequency.

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Referring to Fig. 19, the signal processing device may comprise two or more light sources 50A, 50B. Each light source 50A, 50B may emit light at one or more wavelengths, corresponding to the carrier wavelengths of a plurality of respective optical data transmission channels. The light emitted S_{EMIT} by the light sources 50A, 50B are combined with the sideband signal S_{SIDE} by the combiners 80 to provide the output signal S_{OUT} . The signal processing device 100 may further comprise a wavelength demultiplexer (not shown) to separate recovered optical clock signals associated with the different optical channels.

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Referring to Fig. 20, The signal processing device 101 may be used for signal frequency component analysis of the optical input signal S_{IN} . In this embodiment the optical input signal S_{IN} need not be a data signal. E.g. the optical input signal S_{IN} may have a continuous spectrum and/or it may be a continuous wave signal. The signal processing device 101 further comprises an optical sensor 201 and a data acquisition unit 200. The optical sensor may be e.g. a photodiode with a suitable amplifier. The signal 202 may be transferred to the data acquisition unit 200 electronically or as a data signal. The data acquisition unit may be a computer equipped with data acquisition capabilities. The data acquisition unit 200 may send a tuning signal 203 to the resonator to set the wavelength position of the resonator 10 to a predetermined wavelength position or to scan the wavelength position of the resonator 10 over a predetermined wavelength range.

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Referring to the upper curve in Fig. 21, the wavelength of the emitted light S_{EMIT} is preferably selected to be in the vicinity of said predetermined wavelength range, which includes the spectral peaks PA, PB of the optical input signal S_{IN} . The separations between the wavelength of the emitted light S_{EMIT} and the wavelengths of the spectral peaks PA, PB are $\Delta\lambda_0$ and $\Delta\lambda_1$. The wavelength separation is

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selected small enough such that a resulting beat amplitude can be monitored by devices and methods known by the person skilled in the art. The wavelength separation may be e.g. smaller than or equal to 20 GHz. The bandwidth of the input signal S_{IN} is advantageously smaller than the separation range $\Delta\lambda_{SR}$ of the first resonator 10.

Combination of the filtered signal S_{SIDE} and the emitted light S_{EMIT} result as an output signal S_{OUT} which comprises a beating term. The amplitude and the frequency of the beating varies as the resonator is tuned over the predetermined wavelength range.

The amplitude and the frequency of the beat signal detected by the optical sensor are recorded by the data recording unit 200 during the scanning. The second curve in Fig. 21 shows schematically the recorded beat signal, an oscillogram, corresponding to the spectral peaks PA, PB. The envelope ENV of the oscillogram is also shown. The frequency of the beating corresponds to the difference between the resonator wavelength and the wavelength of the emitted light S_{EMIT} . The amplitude of the beating is proportional to amplitude of the respective spectral component of the optical input signal S_{IN} . The amplitude of beating is marked by A_0 and A_1 . T_0 and T_1 denote the cycle times.

The lowermost curve in Fig. 21 shows a plot of the modulation amplitude versus frequency corresponding to the spectral peaks PA, PB of the input signal S_{IN} . The plot gives directly the spectral analysis of the input signal S_{IN} .

The amplitude of the beat signal may also be plotted as a function of the wavelength position of the resonator 10, or as a function of the tuning signal 203, to provide spectral analysis of the input signal S_{IN} .

The signal processing device 100 may be implemented using fiber optic components.

The signal processing device 100 may be implemented using separate free-space optical components. The resonators 10, 20 may e.g.

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comprise a pair of dielectric-coated mirrors separated by a gas air, such as air, or vacuum.

5 The signal processing device 100 may be implemented with methods of integrated optics on a solid-state substrate using miniaturized components.

10 The cavity 7 of the first resonator 10 and/or the second resonator 20 may comprise transparent dielectric liquid and/or solid material.

The signal processing device 100 is understood to comprise optical paths between the optical components, said paths being implemented by free-space optical links, liquid or solid-state optical waveguides, and/or optical fibers.

15 The signal processing device 100 may further comprise light-amplifying means to amplify the input signal S_{IN} , the output signal S_{OUT} , the sideband signal S_{SIDE} and/or the reference signal S_{REF} . The light amplifying means may be implemented by e.g. rare-earth doped materials or waveguides. The light amplifying means may be a semiconductor optical amplifier.

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25 For the person skilled in the art, it will be clear that modifications and variations of the signal processing devices and methods according to the present invention are perceivable. The particular embodiments described above with reference to the accompanying drawings and table are illustrative only and not meant to limit the scope of the invention, which is defined by the appended claims.

CLAIMS

1. A device (100) for processing of an optical input signal (S_{IN}), which optical input signal (S_{IN}) has one or more carrier wavelengths (λ_0), said device (100) comprising at least:
- an optical resonator (10) to provide a filtered signal (S_{SIDE}) by optical filtering of said optical input signal (S_{IN}), said optical resonator (10) being non-matched with a predetermined carrier wavelength (λ_0) of said optical input signal (S_{IN}),
 - one or more light sources (50) to emit light (S_{EMIT}) at one or more wavelengths such that at least one wavelength of the emitted light (S_{EMIT}) is substantially equal to said predetermined carrier wavelength (λ_0) of said optical input signal (S_{IN}), and
 - an optical combiner (80) to combine said filtered signal (S_{SIDE}) with said emitted light (S_{EMIT}) to form an optical output signal (S_{OUT}).
2. The device (100) according to the claim 1, wherein said device (100) is adapted to recover at least one clock frequency ($v_{CLK,A}$) associated with said optical input signal (S_{IN}), one pass band (PB) of said optical resonator 10 being substantially matched with a first spectral component ($\lambda_{1,A}$) of said optical input signal (S_{IN}), said first spectral component ($\lambda_{1,A}$) being associated with a first clock frequency ($v_{CLK,A}$) of a signal sent at a first carrier wavelength ($\lambda_{0,A}$).
3. The device (100) according to the claim 2, wherein said device (100) is adapted to recover a second clock frequency ($v_{CLK,B}$) associated with said optical input signal (S_{IN}), a further pass band (PB) of said optical resonator 10 being substantially matched with a second spectral component ($\lambda_{-1,B}$) of said optical input signal (S_{IN}), said second spectral component ($\lambda_{-1,B}$) being associated with a second clock frequency ($v_{CLK,B}$) of a signal sent at a second carrier wavelength ($\lambda_{0,B}$).
4. The device (100) according to any of the foregoing claims 1 to 3, wherein the time constant (τ) of said optical resonator (10) is greater than or equal to an average time period during which said optical input signal (S_{IN}) does not change its state.

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5. The device (100) according to any of the foregoing claims 1 to 4, wherein at least one of said light sources (50) is adapted to emit substantially coherent light (S_{EMIT}) at said predetermined carrier wavelength (λ_0).

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6. The device (100) according any of the foregoing claims 1 to 5, wherein at least one light source (50) is a laser which is adapted to emit light at one or more wavelengths.

10 7. The device (100) according to any of the foregoing claims 1 to 6, wherein said device (100) further comprises means to tune said optical resonator (10) to optimize the intensity of said filtered signal (S_{SIDE}).

15 8. The device (100) according to any of the foregoing claims 1 to 7, wherein the wavelength position of at least one pass band (PB) of the resonator (10) is adjustable such that it may be adjusted to coincide with at least one sideband (λ_1) of said optical input signal (S_{IN}).

20 9. The device (100) according to any of the foregoing claims 1 to 8, wherein at least one wavelength of said emitted light S_{EMIT} is adjustable.

25 10. The device (100) according to any of the foregoing claims 1 to 9, wherein said device (100) further comprises adjustment means to set the wavelength of the light source (50) at least approximately to the carrier wavelength (λ_0) of said optical input signal (S_{IN}).

30 11. The device (100) according to any of the foregoing claims 1 to 10, wherein the separations between adjacent pass bands (PB) of the resonator (10) are substantially equal in the frequency domain.

35 12. The device (100) according to any of the foregoing claims 1 to 11, wherein the separation range ($\Delta\lambda_{\text{SR}}$) of the resonator (10) is adapted to be substantially equal to an integer number times the minimum separation between two adjacent carrier wavelengths ($\lambda_{0,A}$, $\lambda_{0,B}$) of said optical input signal (S_{IN}).

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13. The device (100) according to any of the foregoing claims 1 to 12, wherein the resonator (10) comprises an optical cavity (7) defined by at least two reflectors (5, 6).

5 14. The device (100) according to any of the foregoing claims 1 to 13, wherein the resonator (10) is selected from the group of a micro ring resonator, a sphere resonator and a toroid resonator.

10 15. The device (100) according to any of the foregoing claims 1 to 14, wherein the resonator (10) comprises several optical resonators which are coupled together, preferably a series of micro ring resonators.

15 16. The device (100) according to any of the foregoing claims 1 to 15, wherein the resonator (10) comprises at least one Bragg grating.

17. The device (100) according to any of the foregoing claims 1 to 16, wherein the cavity (7) of the resonator (10) comprises gas or vacuum.

20 18. The device (100) according to any of the foregoing claims 1 to 17, wherein the cavity (7) of the resonator (10) comprises transparent material in solid or liquid state.

25 19. The device (100) according to any of the foregoing claims 1 to 18, wherein the resonator (10) comprises a closed optical loop to which light is coupled by evanescent coupling.

30 20. The device (100) according to any of the foregoing claims 1 to 19, wherein the resonator (10) and/or further optical components and/or optical paths are implemented using free-space optical components, integrated optics and/or fiber optical components.

35 21. The device (100) according to any of the foregoing claims 1 to 20, wherein at least one of said light sources (50) comprises a wavelength reference.

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22. The device (100) according to any of the foregoing claims 1 to 21, wherein at least one light source (50) is an injection seeded laser which is coupled to a second resonator (20).
- 5 23. The device (100) according to any of the foregoing claims 1 to 22, wherein at least one light source (50) comprises an optical amplifier adapted to amplify light filtered by a second resonator (20) or by a further filter.
- 10 24. The device (100) according to any of the foregoing claims 1 to 23, wherein at least one light source (50) comprises a semiconductor optical amplifier.
- 15 25. The device (100) according to any of the foregoing claims 1 to 24, wherein at least one light source (50) comprises a rare earth doped optical amplifier, preferably an erbium doped optical amplifier.
- 20 26. The device (100) according to any of the foregoing claims 1 to 25, wherein said device (100) comprises means to control the relative contribution of the optical input signal (S_{IN}) and/or the relative contribution of the emitted light (S_{EMIT}) to the optical output signal (S_{OUT}).
- 25 27. The device (100) according to any of the foregoing claims 1 to 26, wherein said device (100) comprises means to control the polarization of the optical input signal (S_{IN}) and/or the polarization of the emitted light (S_{EMIT}).
- 30 28. The device (100) according to any of the foregoing claims 1 to 27, wherein the polarization of the sideband signal (S_{SIDE}) is adapted to be substantially parallel to the polarization of the emitted light (S_{EMIT}) in the combiner (80).
- 35 29. The device (100) according to any of the foregoing claims 1 to 28, wherein the combiner (80) is selected from the group of a semitransparent reflector, a bifurcated optical fiber element, an Y-

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coupler, a directional coupler, a filter, a grating based coupler, a polarizer or a spatial multiplexer.

5 30. The device (100) according to any of the foregoing claims 1 to 29, wherein the optical division ratio of the combiner (80) is substantially 50%/50%.

10 31. The device (100) according to any of the foregoing claims 1 to 30, wherein said device (100) further comprises an output stabilization unit 85 to provide an output signal $S_{OUT,STAB}$ which is stabilized and/or reshaped with respect to a beat amplitude.

15 32. The device (100) according to the claim 31, wherein said intensity stabilizing unit (85) comprises an optical resonator exhibiting optical bistability.

33. The device (100) according to the claim 31, wherein said intensity stabilizing unit (85) comprises an optically saturable element.

20 34. The device (100) according to the claim 31, wherein said intensity stabilizing unit (85) comprises a semiconductor optical amplifier.

25 35. The device (100) according to any of the foregoing claims 1 to 34, wherein said device (100) further comprises a polarization controlling element (95) to control the polarization of the optical input signal (S_{IN}), said polarization controlling element (95) being a component or a combination of components selected from the group of fiber-based polarization controller, set of waveplates, Wollaston prism, Glan-Focault polarizer, Nicol prism, Rochon prism, polarizer comprising dielectric coating, wire grid polarizer, polymer-based film polarizer, fiber transmitting single polarization mode only, and photonic crystal polarization separator.

35 36. The device (100) according to any of the foregoing claims 1 to 35, wherein said device (100) further comprises a pre-processing unit (110) to generate further spectral components from a modulated primary optical input signal (S_{IN1}).

37. The device (100) according to the claim 36, wherein said primary optical input signal (S_{IN1}) is modulated according to the non-return-to-zero (NRZ) format.

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38. The device (100) according to the claim 36 or 37, wherein said pre-processing unit (110) comprises a beam splitter 60 to divide said primary optical input signal (S_{IN1}) into at least two parts, a delay line (62) to delay said primary optical input signal (S_{IN1}), and an optical combiner (82), said primary optical input signal (S_{IN1}) and the delayed primary optical input signal (S_{DELAY}) being coupled to the inputs of said combiner (82) such that said pre-processing unit (110) performs an exclusive-OR operation (XOR) of said primary optical input signal (S_{IN1}) and said delayed primary optical input signal (S_{DELAY}).

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39. The device (100) according to any of the foregoing claims 1 to 38, wherein said device (100) comprises two optical resonators (10a, 10b) to filter two substantially perpendicular polarizations of an optical primary signal (S_{IN1}) to provide insensitivity with regard to the polarization of said optical primary signal (S_{IN1}), said two optical resonators (10a, 10b) being tuned substantially to the same wavelength.

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40. A method for processing of an optical input signal (S_{IN}), which optical input signal (S_{IN}) has one or more carrier wavelengths (λ_0), wherein said method comprises at least:

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- optical filtering of said optical input signal (S_{IN}) to provide a filtered signal (S_{SIDE}) by using an optical resonator (10), said resonator (10) being non-matched with a predetermined carrier wavelength (λ_0) of said optical input signal (S_{IN}),
- 30 - providing emitted light (S_{EMIT}) by using a light source (50) at a wavelength which is substantially equal to said predetermined carrier wavelength (λ_0) of said optical input signal (S_{IN}),
- optically combining said filtered signal (S_{SIDE}) with said emitted light (S_{EMIT}) to form an optical output signal (S_{OUT}).

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41. The method according to the claim 40, wherein said method is applied to recover at least one clock frequency ($v_{CLK,A}$) associated with

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said optical input signal (S_{IN}), one pass band (PB) of said optical resonator 10 being substantially matched with a first spectral component ($\lambda_{1,A}$) of said optical input signal (S_{IN}), said first spectral component ($\lambda_{1,A}$) being associated with a first clock frequency ($\nu_{CLK,A}$) of a signal sent at a first carrier wavelength ($\lambda_{0,A}$).

42. The method according to the claim 41, wherein said method is applied to recover a second clock frequency ($\nu_{CLK,B}$) associated with said optical input signal (S_{IN}), a further pass band (PB) of said optical resonator 10 being substantially matched with a second spectral component ($\lambda_{1,B}$) of said optical input signal (S_{IN}), said second spectral component ($\lambda_{1,B}$) being associated with a second clock frequency ($\nu_{CLK,B}$) of a signal sent at a second carrier wavelength ($\lambda_{0,B}$).

43. The method according to any of the foregoing claims 40 to 42, wherein the time constant (τ) of the resonator (10) is selected to be greater than or equal to the average time period during with the state of said optical input signal (S_{IN}) remains unchanged.

44. The method according to any of the claims 40 to 43, wherein at least one pass band (PB) of the resonator (10) substantially coincides with at least one sideband (λ_1) of said optical input signal (S_{IN}).

45. The method according to any of the claims 40 to 44, wherein the wavelength of said emitted light (S_{EMIT}) is tuned to be at least approximately equal to the carrier wavelength (λ_0) of said optical input signal (S_{IN}).

46. The method according to any of the claims 40 to 45, wherein said optical input signal (S_{IN}) comprises at least one component which is amplitude modulated.

47. The method according to any of the claims 40 to 46, wherein said optical input signal (S_{IN}) comprises at least one component which is phase-modulated.

48. The method according to any of the claims 40 to 47, wherein said optical input signal (S_{IN}) comprises at least one component modulated according to the return-to-zero (RZ) format.

5 49. The method according to any of the claims 40 to 48, wherein said method comprises pre-processing of an optical primary signal (S_{IN1}) to form said optical input signal (S_{IN}) such that said optical input signal (S_{IN}) comprises at least one optical frequency component dependent on the clock frequency (ν_{CLK}), said optical primary signal being
10 modulated according to the non-return-to-zero (NRZ) format.

50. The method according to the claim 49, wherein said pre-processing comprises delaying said optical primary signal (S_{IN1}) to form a delayed signal (S_{DELAY}), and combining the delayed signal (S_{DELAY}) and the
15 optical primary signal (S_{IN1}) such that an exclusive-OR operation (XOR) of said optical primary signal (S_{IN1}) and said delayed signal (S_{DELAY}) is performed.

51. The method according to any of the claims 40 to 50, wherein the
20 separation range ($\Delta\lambda_{SR}$) of the resonator (10) is substantially equal to the minimum separation between adjacent carrier wavelengths ($\lambda_{0,A}$, $\lambda_{0,B}$) multiplied by an integer number.

52. The method according to any of the claims 40 to 51, wherein the
25 separation between at least two carrier wavelengths ($\lambda_{0,A}$, $\lambda_{0,B}$) is selected according to a standard set for optical telecommunications channels in fiber optic networks by the International Telecommunication Union within the United Nations System.

53. The method according to any of the claims 39 to 52, wherein the
30 separation between at least two carrier wavelengths ($\lambda_{0,A}$, $\lambda_{0,B}$) is substantially an integer multiple of the frequency 100 GHz in the frequency domain.

54. The method according to any of the claims 40 to 53, wherein the
35 signal components of said optical input signal (S_{IN}) associated with at

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least two different carrier wavelengths ($\lambda_{0,A}$, $\lambda_{0,B}$) are modulated according to a different format.

5 55. The method according to any of the claims 40 to 54, wherein at least two optical channels of said optical input signal (S_{IN}) have different clock frequencies (v_{CLK}).

10 56. The method according to any of the claims 40 to 55, wherein said optical input signal (S_{IN}) consists of substantially one wavelength only.

57. The method according to any of the claims 40 to 56, wherein said method is applied to recover at least one clock frequency (v_{CLK}) associated with said optical input signal (S_{IN}).

15 58. The method according to any of the claims 40 to 57, wherein said method is applied to analyze the frequency components of said optical input signal (S_{IN}).

20 59. A device (101) for analyzing wavelength components an optical input signal (S_{IN}), said device (101) comprising at least:
- a tunable optical resonator (10) to provide a filtered signal (S_{SIDE}) by optical filtering of said optical input signal (S_{IN}),
- a light source (50) to emit light (S_{EMIT}) a wavelength (λ_0) in the vicinity of a wavelength range of said optical input signal (S_{IN}) to be analyzed,
25 - a combiner (80) to optically combine said filtered signal (S_{SIDE}) with said emitted light (S_{EMIT}) to form an optical output signal (S_{OUT}), and
- at least one detector (201) to monitor the amplitude of beating of said optical output signal (S_{OUT}).

30 60. The device (101) according to the claim 59, wherein said device (101) further comprises data acquisition means (200) to monitor the amplitude of beating of said optical output signal (S_{OUT}) as a function of the beat frequency of said optical output signal (S_{OUT}).

35 61. The device (101) according to the claim 59, wherein said device (101) further comprises data acquisition means (200) to monitor the

35

amplitude of beating of said optical output signal (S_{OUT}) as a function of the tuned wavelength position of said optical resonator (10).

- 5 62. A method for analyzing wavelength components an optical input signal (S_{IN}), said method comprising at least:
- optical filtering of said optical input signal (S_{IN}) to provide a filtered signal (S_{SIDE}) by using a tunable optical resonator (10),
 - providing emitted light (S_{EMIT}) having a wavelength (λ_0) in the vicinity of a wavelength range of said optical input signal (S_{IN}) to be analyzed,
 - 10 - optically combining said filtered signal (S_{SIDE}) with said emitted light (S_{EMIT}) to form an optical output signal (S_{OUT}), and
 - monitoring the amplitude of beating of said optical output signal (S_{OUT}).
- 15 63. The method according to the claim 62, wherein said method further comprises
- tuning said optical resonator (10) over the wavelength range of said optical input signal (S_{IN}) to be analyzed, and
 - recording the beat amplitude of said optical output signal (S_{OUT}) as a
 - 20 function of the beat frequency of said optical output signal (S_{OUT}).
64. The method according to the claim 62, wherein said method further comprises
- tuning said optical resonator (10) over the wavelength range of said
 - 25 optical input signal (S_{IN}) to be analyzed, and
 - recording the beat amplitude of said optical output signal (S_{OUT}) as a function of the tuned wavelength position of said optical resonator (10).

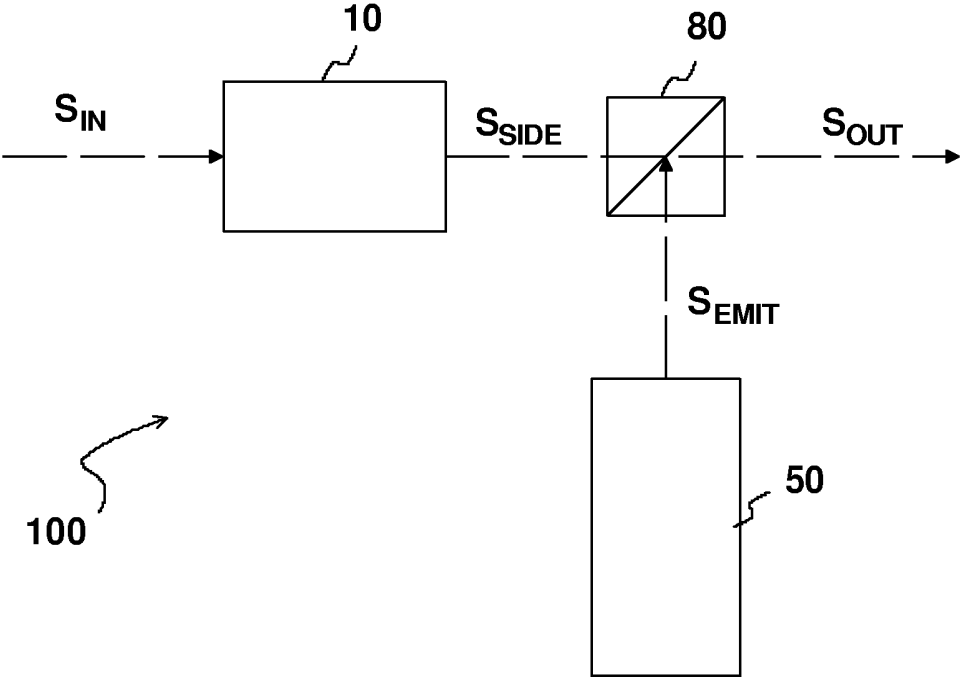


Fig 1

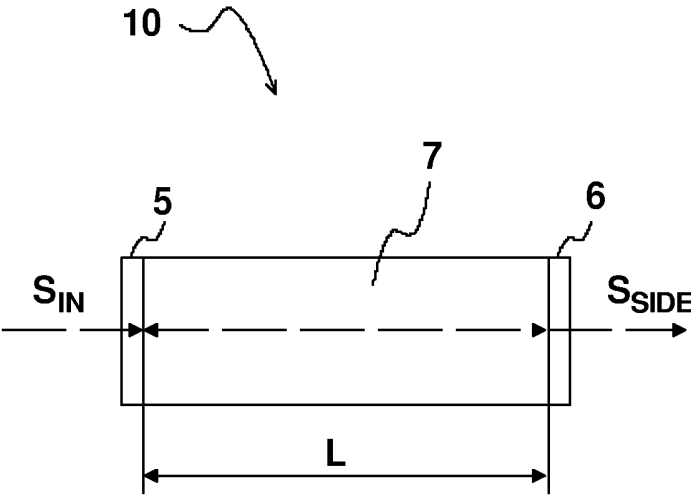


Fig 2

2/15

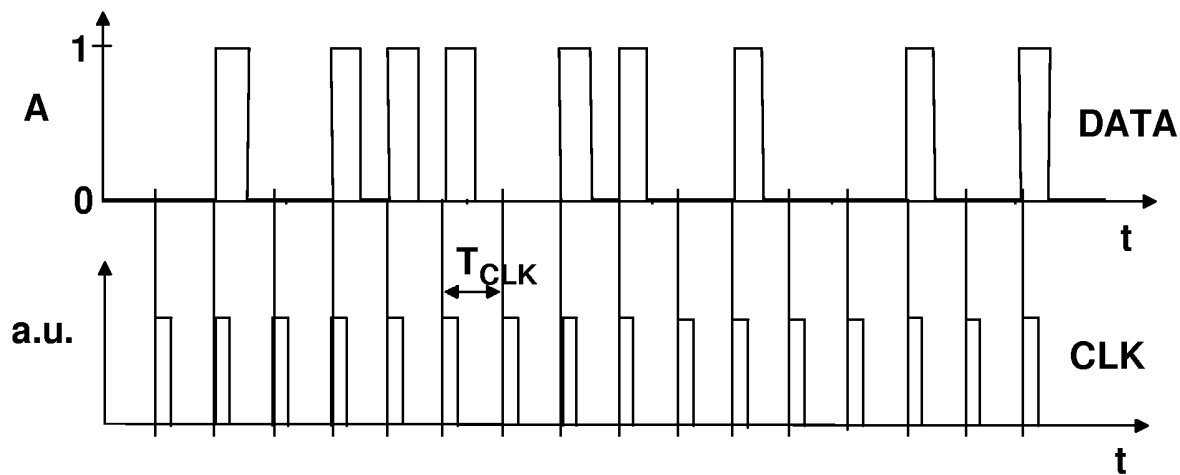


Fig 3a

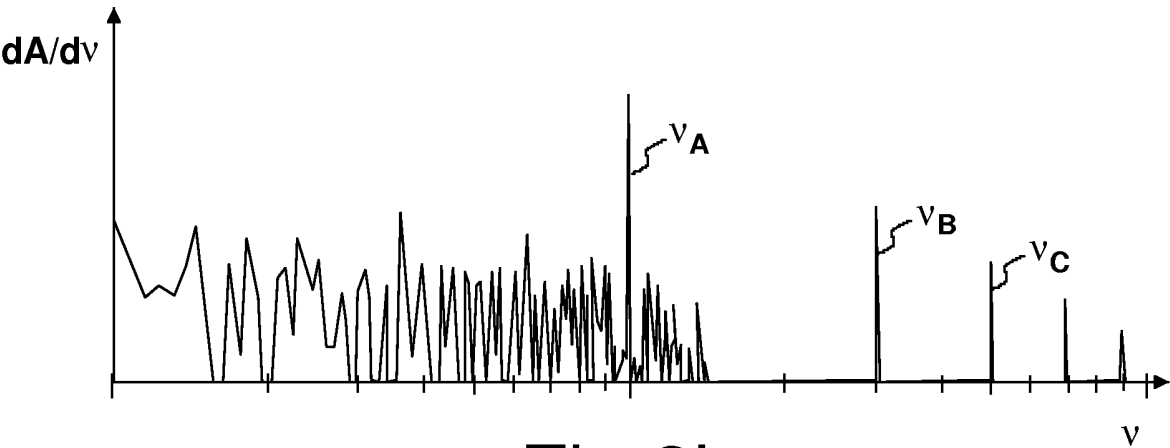


Fig 3b

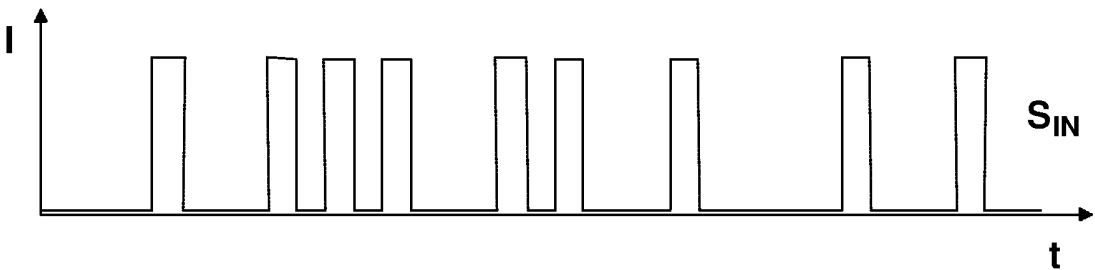


Fig 3c

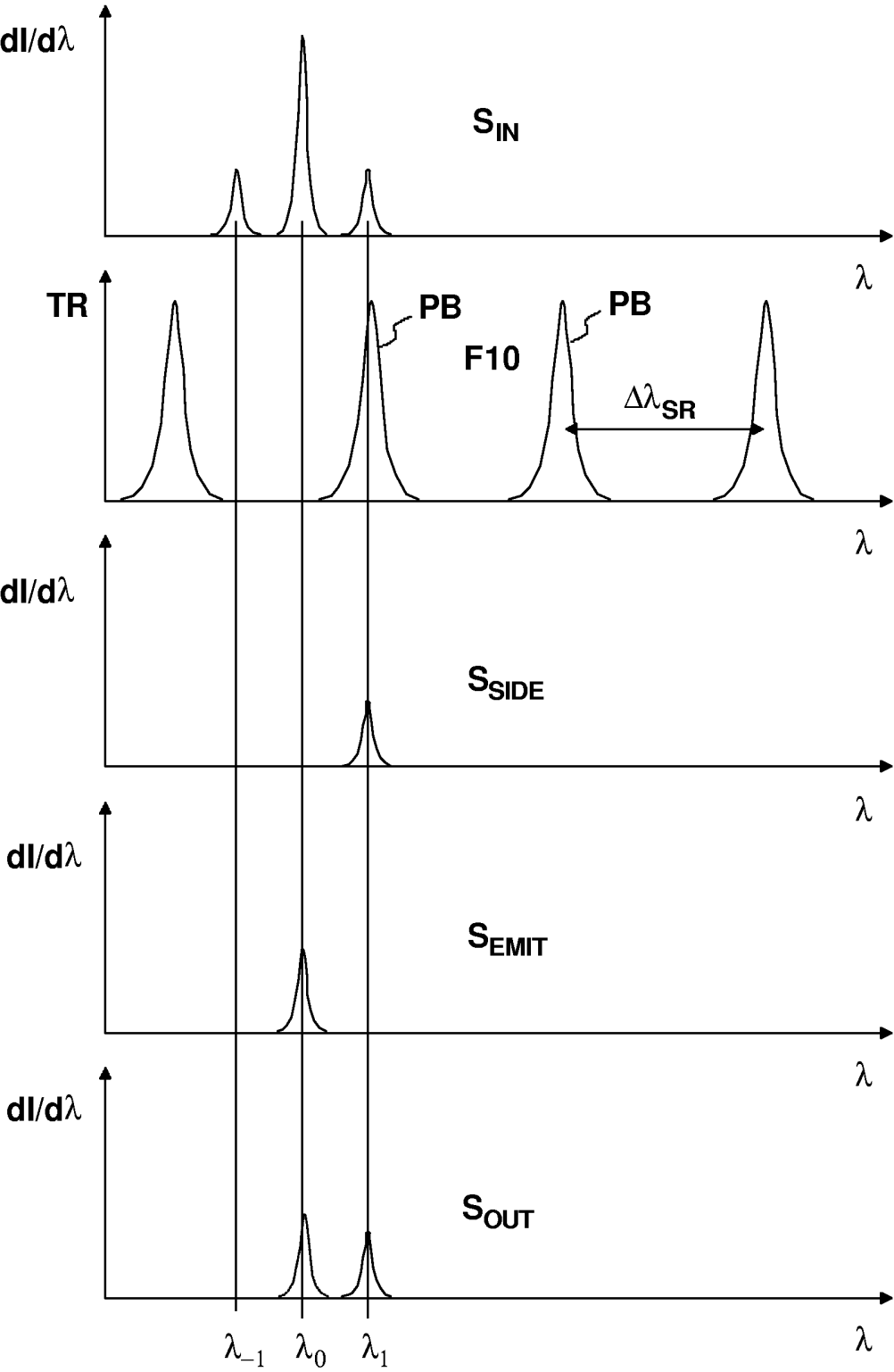


Fig 4

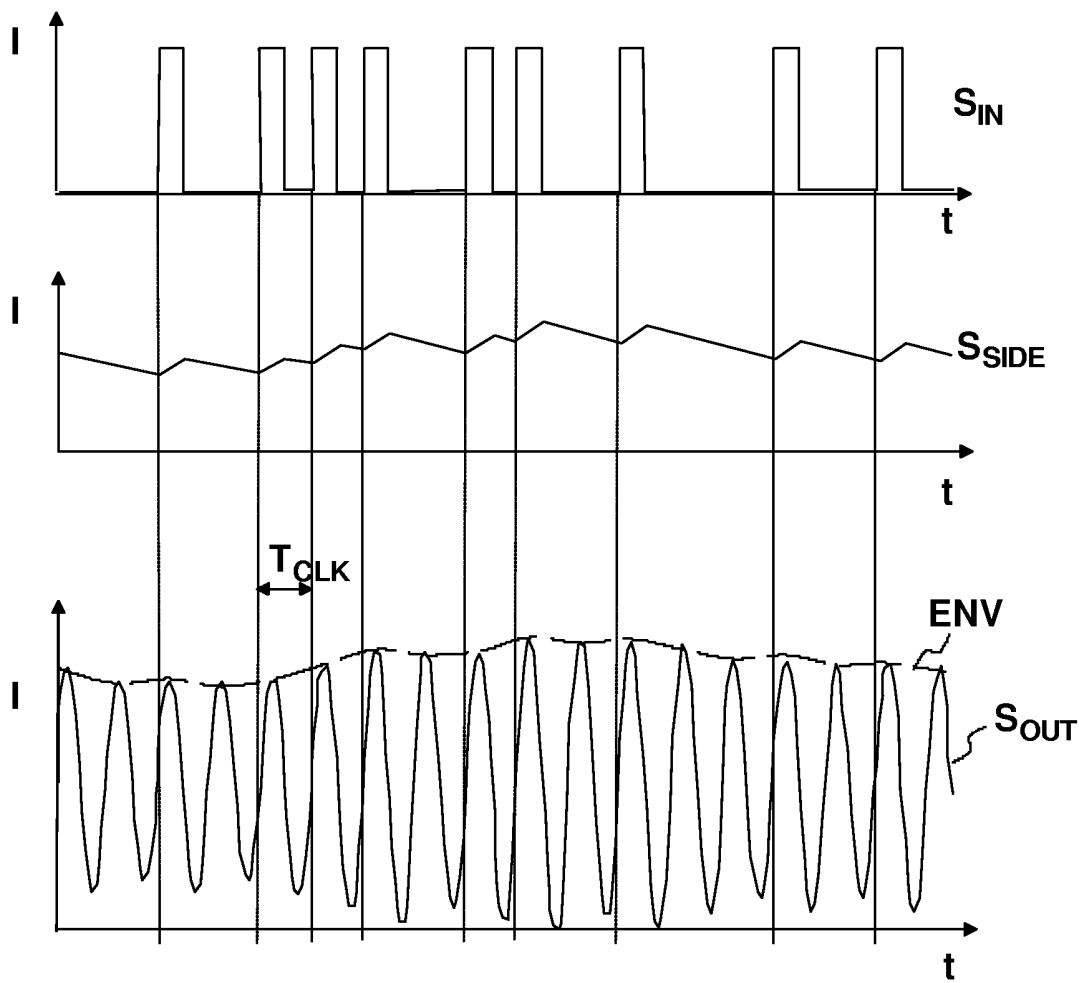


Fig 5a

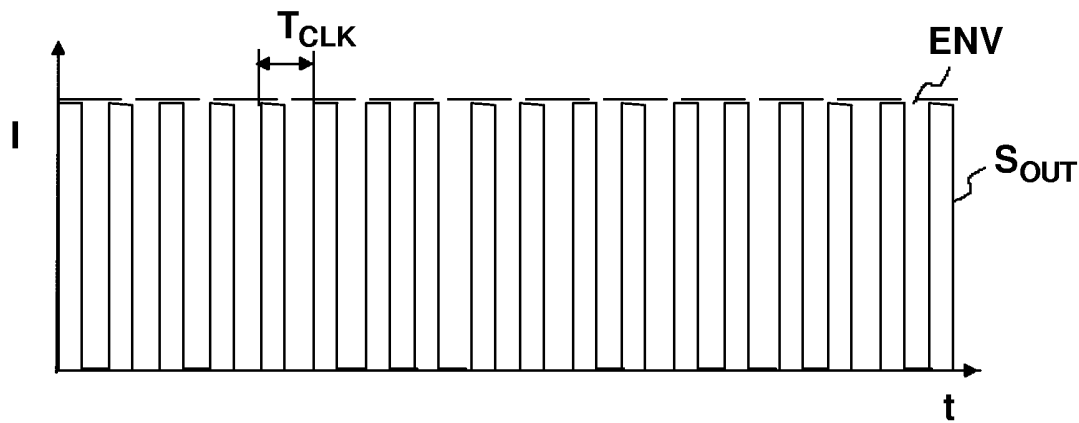


Fig 5b

5/15

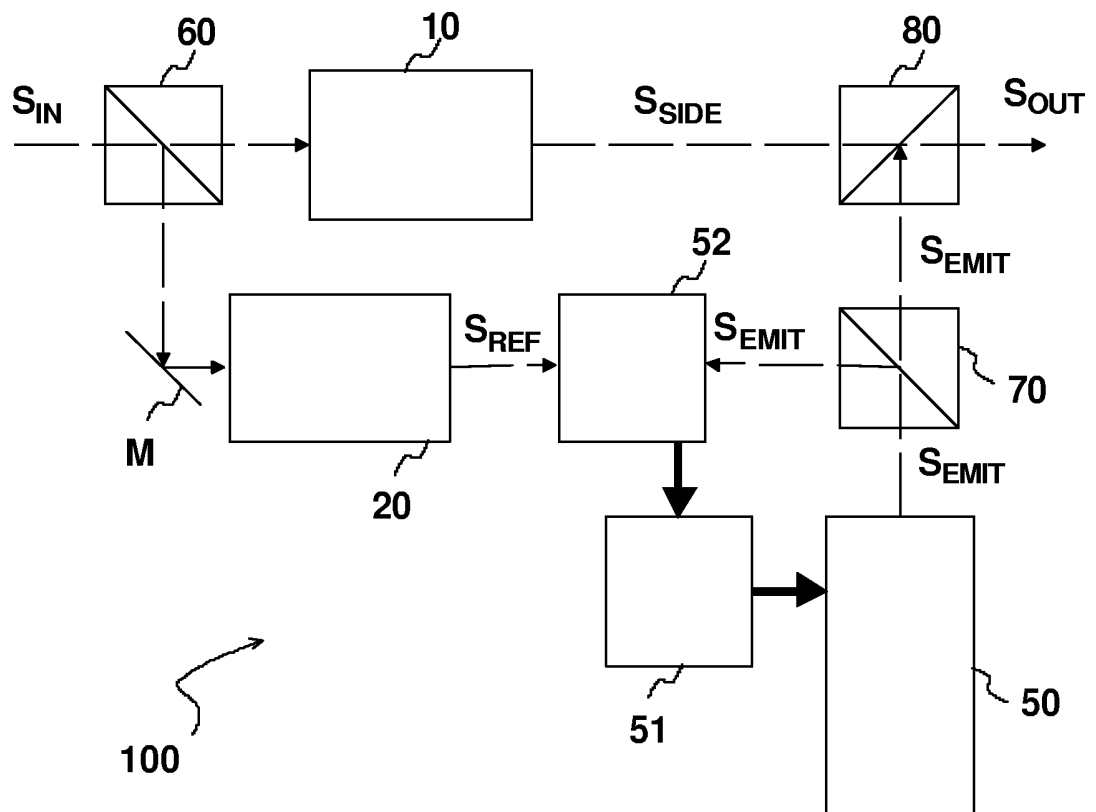


Fig 6

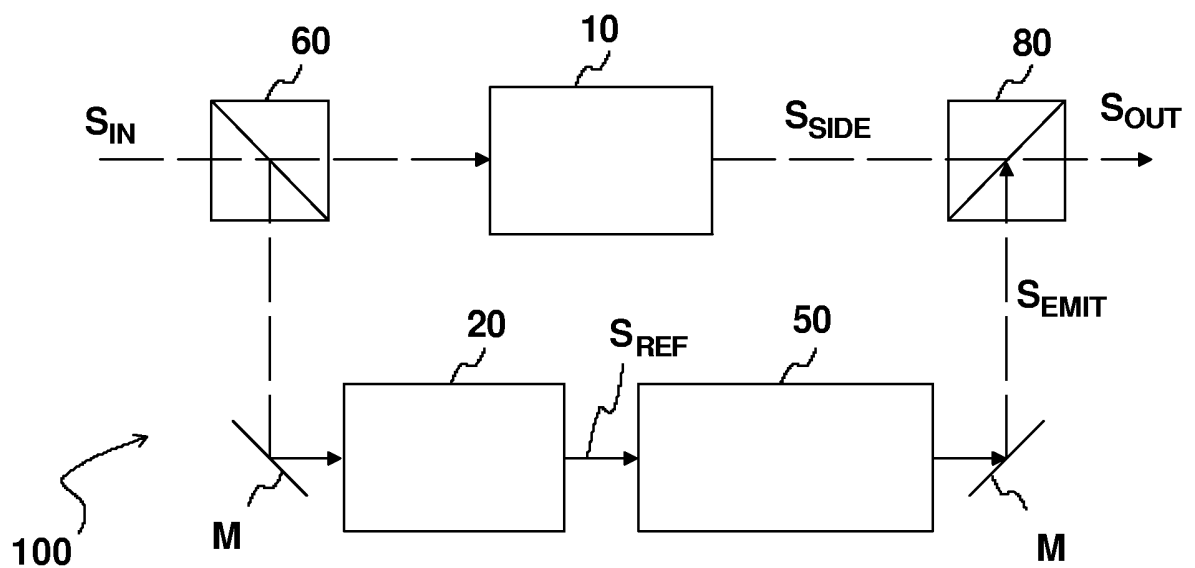


Fig 7

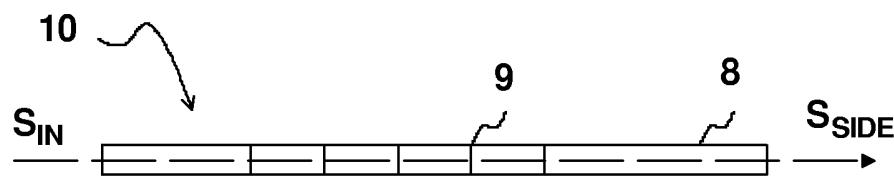


Fig 8

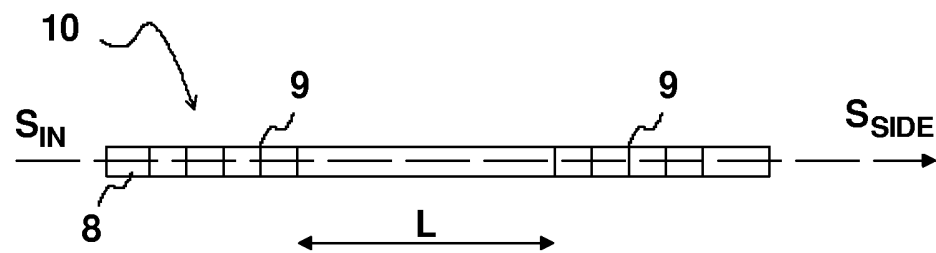


Fig 9

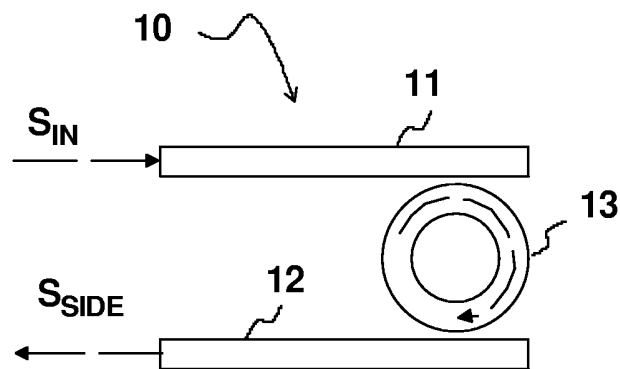


Fig 10a

7/15

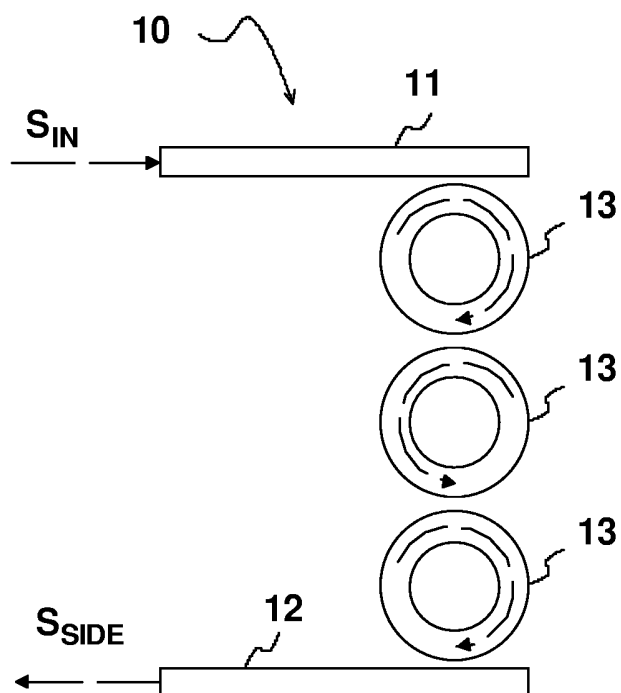


Fig 10b

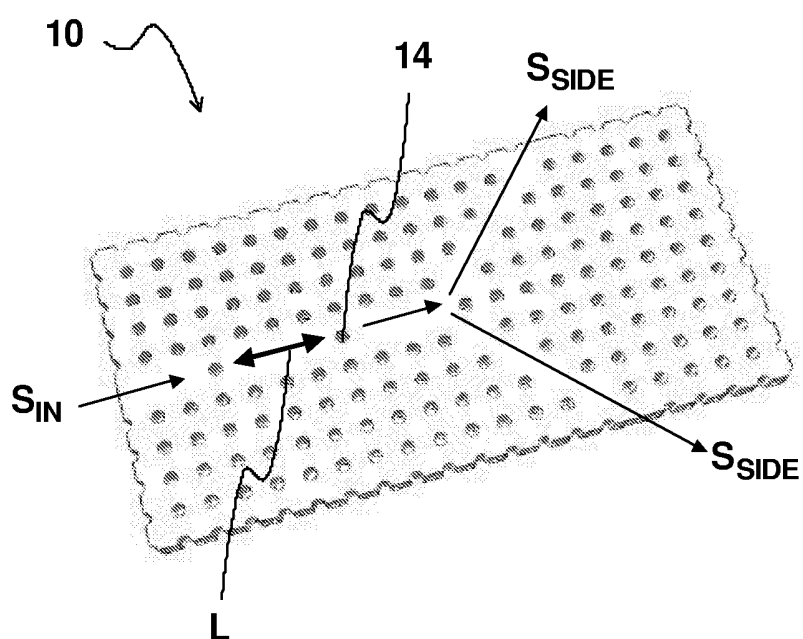


Fig 11

8/15

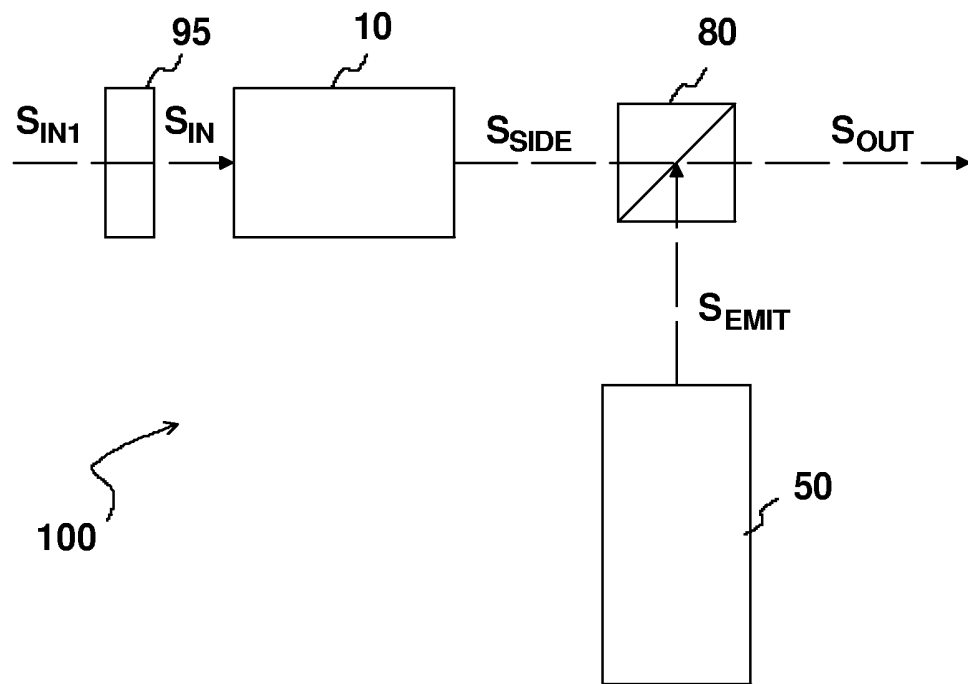


Fig 12

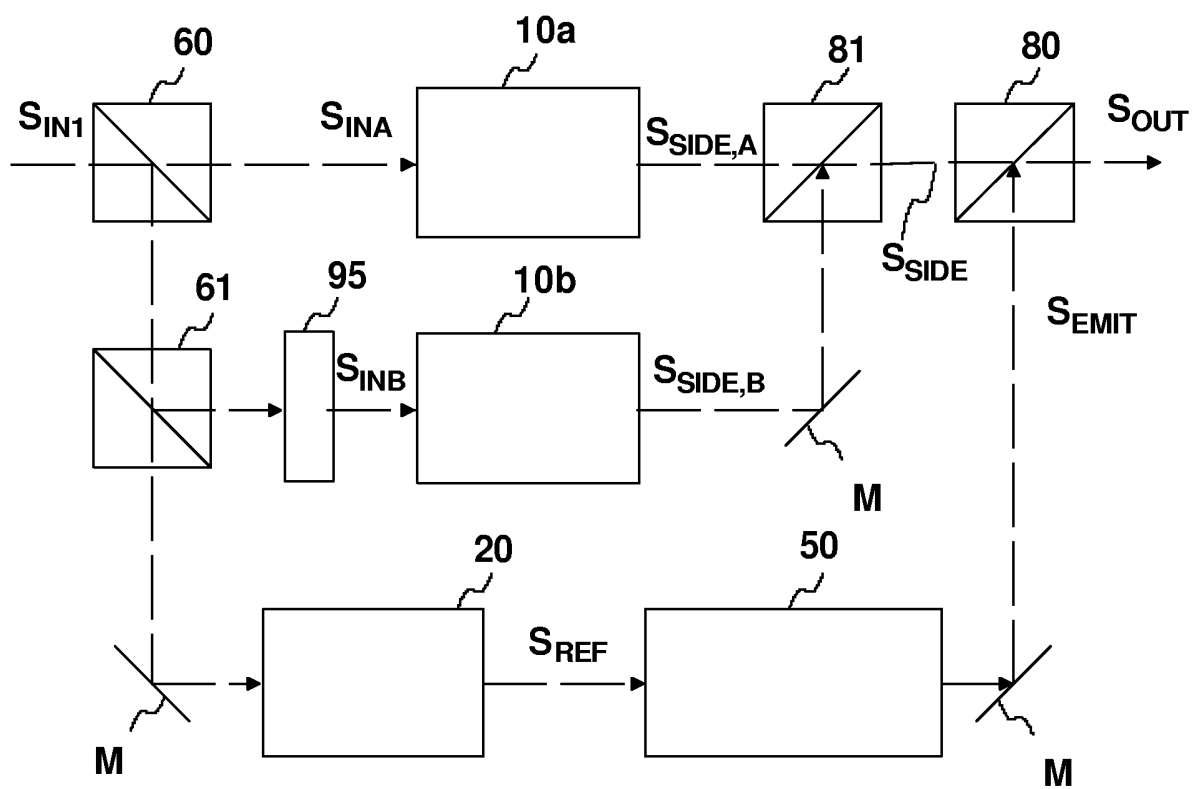


Fig 13

9/15

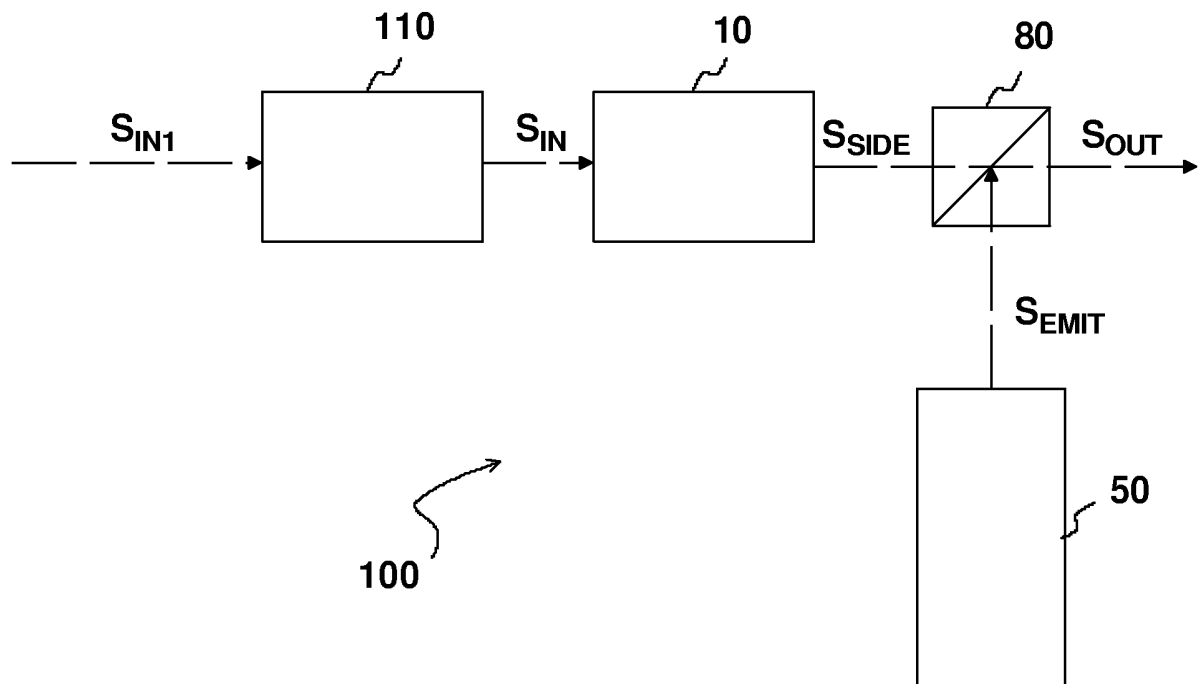


Fig 14

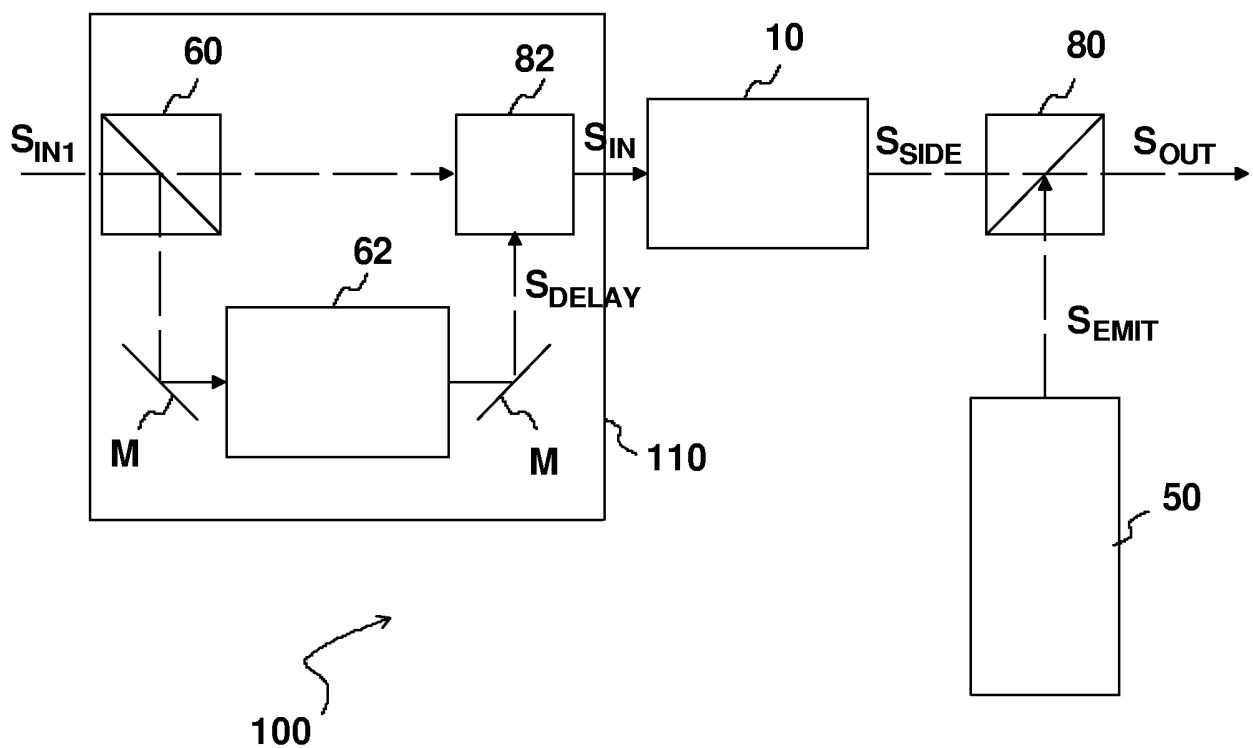


Fig 15

10/15

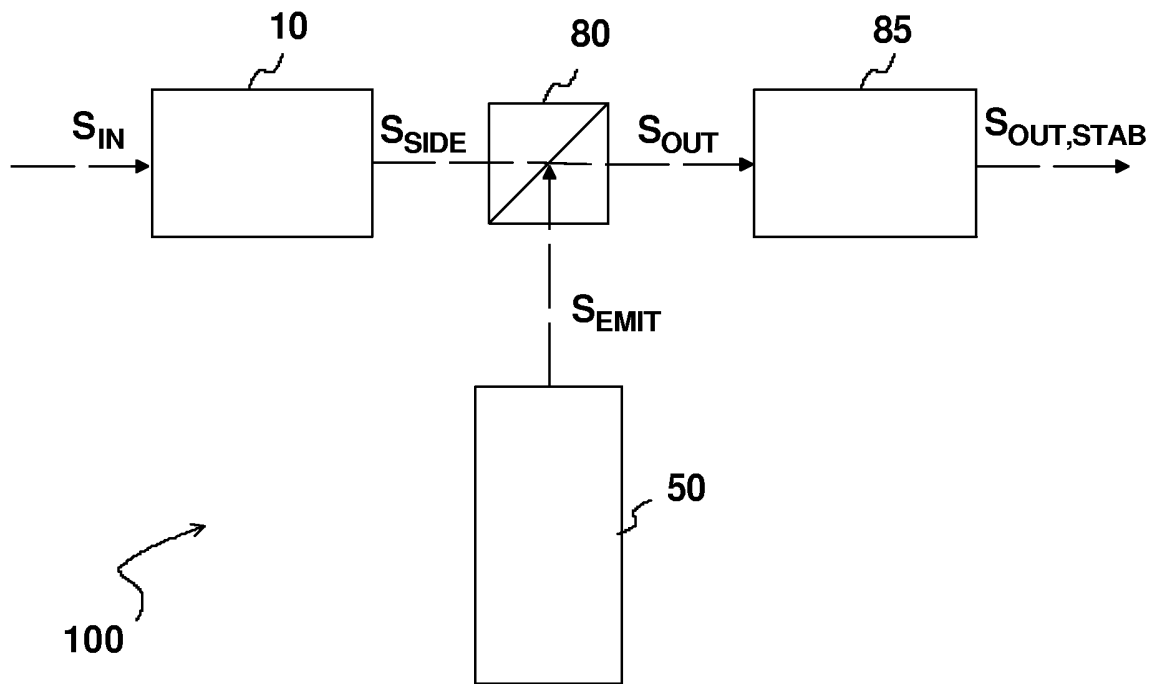


Fig 16

11/15

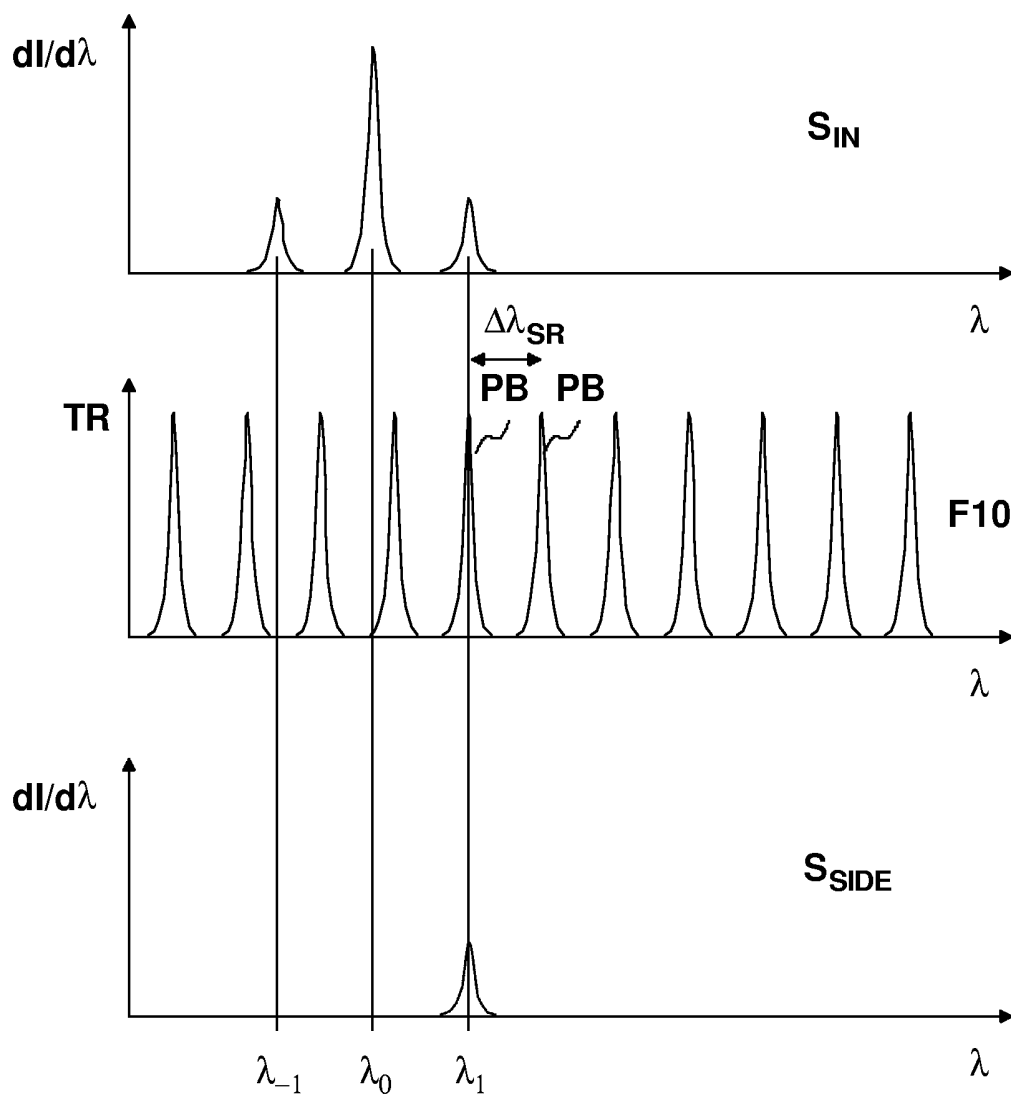


Fig 17

12/15

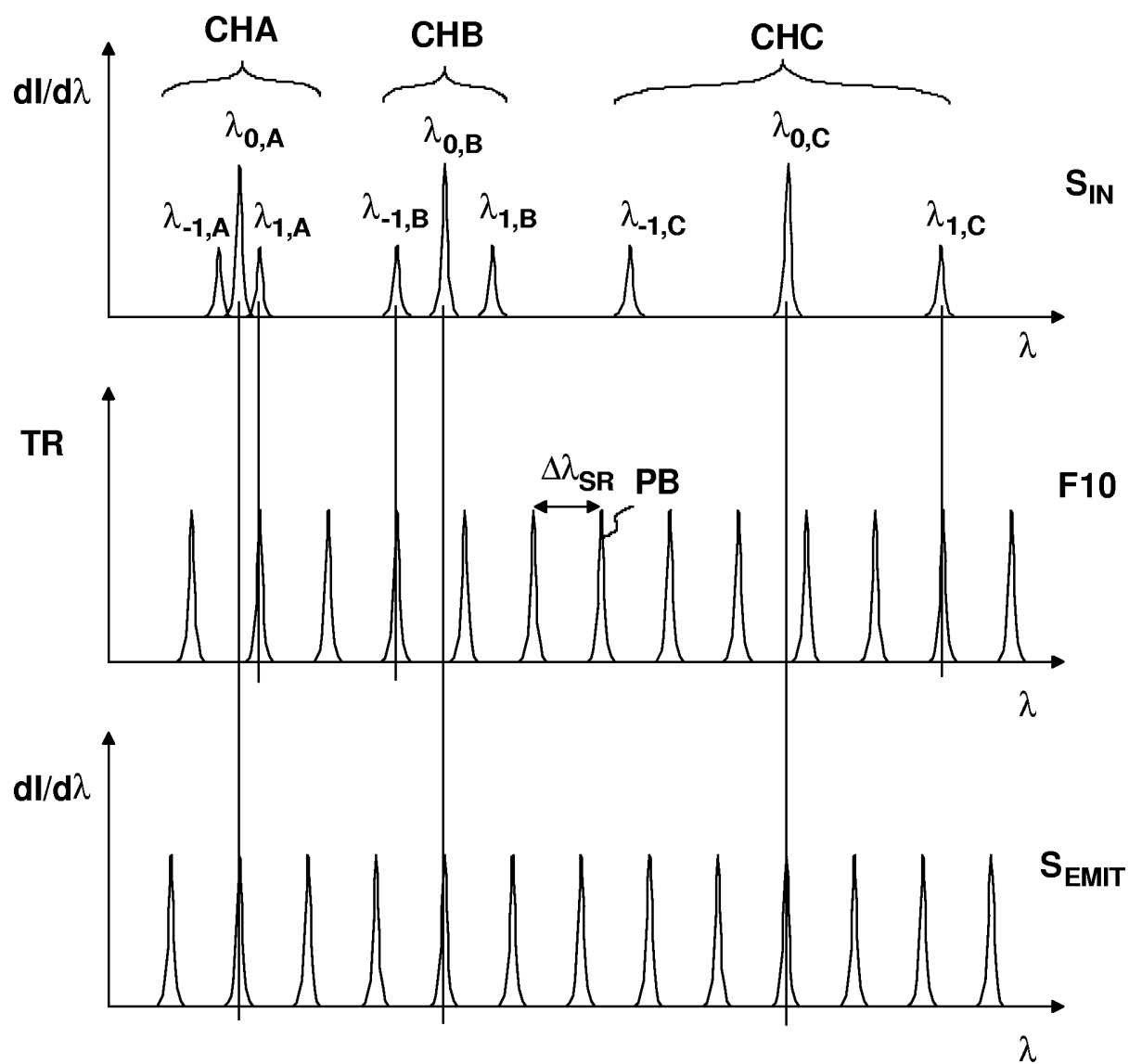


Fig 18

13/15

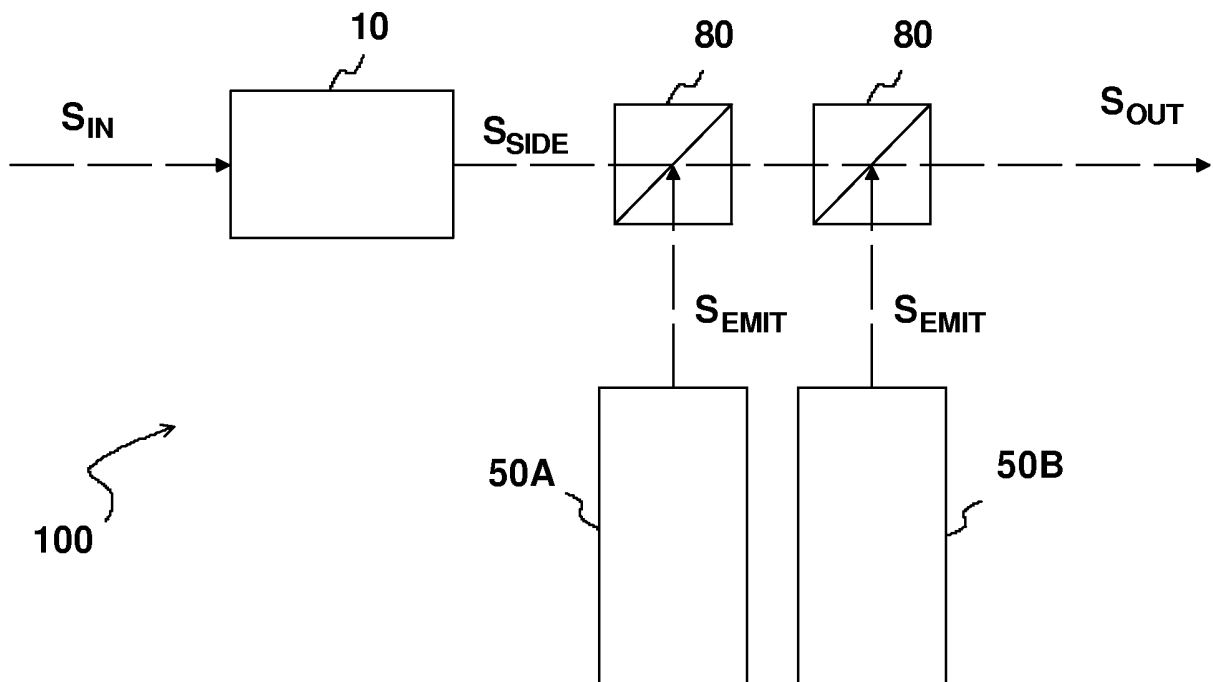


Fig 19

14/15

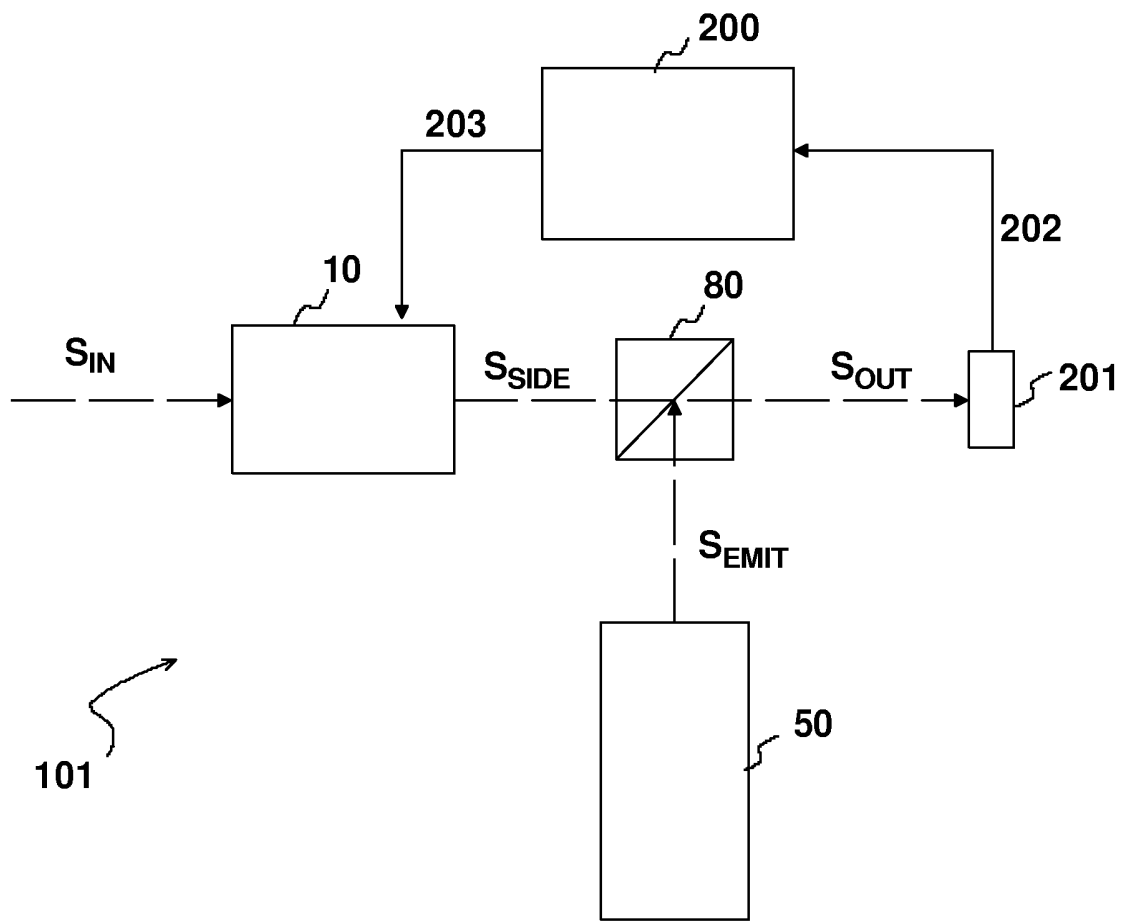


Fig 20

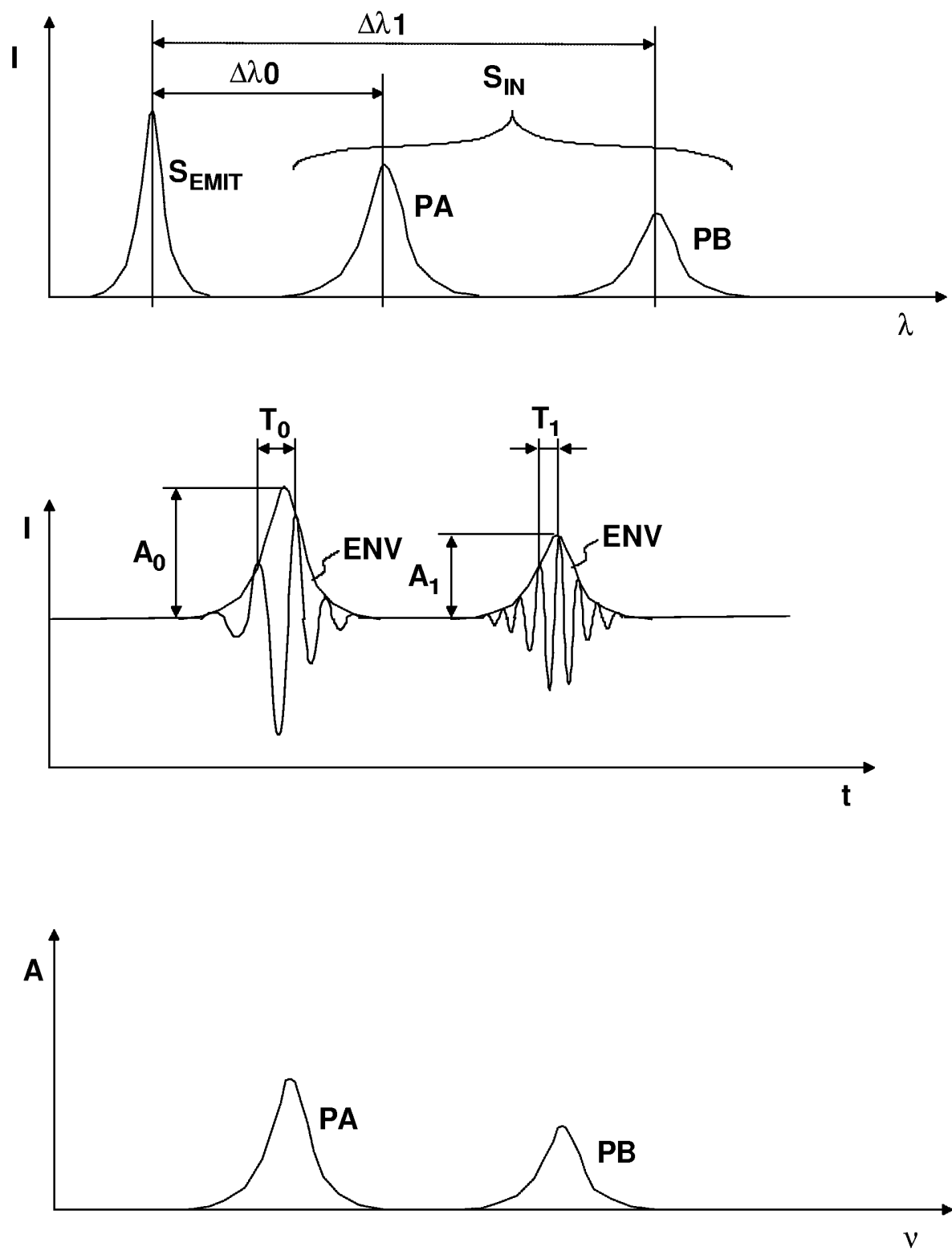


Fig 21

INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI2005/050156

A. CLASSIFICATION OF SUBJECT MATTER		
See extra sheet		
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: H04B, G02F, H04L, H04J, G02B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
DK, FI, NO, SE		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
EPO-internal, WPI, PAJ, INSPEC		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 4163532 A (NIPPON TELEGRAPH & TELEPHONE) 09 June 1992 (09.06.1992), PAJ-abstract	1-64
A	JINNO, M. et al., Optical Tank Circuits Used for All-Optical Timing Recovery, IEEE Journal of Quantum Electronics, Vol. 28, No. 4, April 1992, pages 895-900, cited in the application, whole document	1-64
A	US 2004/0067063 A1 (LEE JAE-MYOUNG et al.) 08 April 2004 (08.04.2004), paragraphs 7-10	1-64
A	JP 5257185 A (NIPPON TELEGRAPH & TELEPHONE) 08 October 1993 (08.10.1993), PAJ-abstract	1-64
☐ Further documents are listed in the continuation of Box C. ☒ See patent family 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 application or patent 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) "O" 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 "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
29 December 2005 (29.12.2005)		05 January 2006 (05.01.2006)
Name and mailing address of the ISA/FI National Board of Patents and Registration of Finland P.O. Box 1160, FI-00101 HELSINKI, Finland Facsimile No. +358 9 6939 5328		Authorized officer Jari Partanen Telephone No. +358 9 6939 500

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/FI2005/050156

Patent document cited in search report	Publication date	Patent family members(s)	Publication date
JP 4163532 A	09/06/1992	None	
US 2004/0067063 A1	08/04/2004	None	
JP 5257185 A	08/10/1993	None	

CLASSIFICATION OF SUBJECT MATTER

Int.Cl.

H04B 10/06 (2006.01)**G02F 2/00** (2006.01)**H04L 7/00** (2006.01)