Polarization Diversity Image-Reject Homodyne Receiver for Directional Radial Velocity Measurements in Light Detection and Ranging (LIDAR) Instruments

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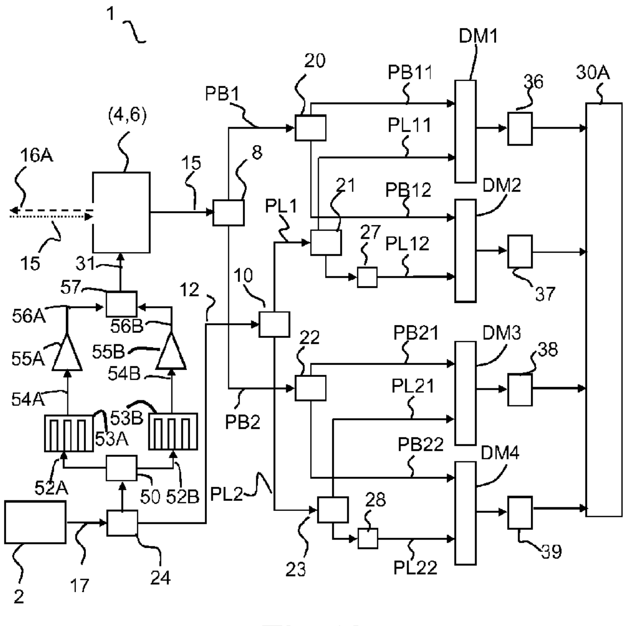

Fig. 10

(57) Abstract: The present invention relates to an improved method and a LIDAR system comprising an emitter for emission of a coherent electromagnetic EM signal and a transmitting optical arrangement configured to transmit the electromagnetic signal towards a measurement area. By the method and system, detection of both the polarized and depolarized backscattered EM signal is obtained, whereby an improved signal-to-noise ratio is obtained.

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Polarization diversity image-reject homodyne receiver for directional radial velocity measurements in light detection and ranging (LIDAR) instruments

The present invention relates to an improved method and a LIDAR system comprising an emitter for emission of a coherent electromagnetic (em) signal and a transmitting optical arrangement configured to transmit the electromagnetic signal towards a measurement area. By the method and system, detection and discrimination of both the polarized and depolarized backscattered EM signal is obtained: As a result, the invention improves the signal to noise ratio (SNR) in both continuous wave (CW) and pulsed lidars while providing the possibility to detect atmospheric depolarization whereby detecting the nature of reflecting particles in the atmosphere.

Background of the invention

There are generally two approaches to extract the direction of a radial velocity associated with a target in coherent LIDAR (light detection and ranging) instruments. The two approaches mainly differ in the employed optical/radio frequency (RF) front-end architectures. In heterodyne architectures, the received signal (back scatter) which may have experienced frequency shifting due to Doppler is down-converted to an intermediate frequency (IF) band. This approach has certain drawbacks such as costly and sometimes noisy components for frequency shifting as well as wideband photo detectors.

An alternative approach is to employ a homodyne receiver where I/Q (in-phase/quadrature) demodulation of the received signal allows for discrimination of the radial velocity direction. Homodyne with quadrature demodulation (also known as image-reject homodyne) makes it feasible to employ single-ended or balanced photo detectors eliminating the costly frequency shifting components (exhibiting spurious effects) employed in the heterodyne receivers such as optic modulators, also known as Brag cells or acoustic optic modulators. This technique is well established in optical communications.

An electro-optical homodyne receiving circuit used for coherent detection of optical signals in optical communication and remote sensing, such as LIDAR has been disclosed previously. Furthermore, polarization separation of received signal (back scatter) into two orthogonal polarization states and a local oscillator signal, has also been shown. Additionally, mixing of a phase shifted receiving signal and a local oscillator signal and a mixing of a phase shifted local oscillator signal and a receiving signal, has also been disclosed previously.

The drawback of the above mentioned approach, however, is that these techniques are not able to detect depolarized backscattered electromagnetic (em) signals, and thereby, is not able to detect, e.g. clouds or non-spherical particles. Furthermore, the above mentioned approach, however, is not employed with a smart signal processing technique and passive components, and thereby, avoiding the need for costly active components, such as acoustic optic modulators and optical amplifiers for backscatter signal regeneration.

An object of this invention is to discriminate the light polarization resulting in either an improved SNR due to polarization diversity as well as detection of atmospheric features such as presence of clouds through detection of depolarized backscattered EM signals. Besides, by employing passive components while employing smart signal processing techniques the need for costly active components such as acoustic optic modulators for sign detection and optical amplifiers for backscatter signal regeneration is circumvented.

Summary

It is an object of the present invention to provide a LiDAR system for detection of polarized (PB) and de-polarized backscattered (DPB) electromagnetic (em) signals. The LIDAR system comprises an emitter for emission of a coherent electromagnetic (em) signal and a transmitting optical arrangement configured to transmit an electromagnetic signal towards a measurement area.

Additionally, the LIDAR system comprises a receiving optical arrangement for receiving a backscattered EM signal from the measurement area, and at least a first and a second polarizing beam splitter. The first polarizing beam splitter is configured to receive the backscattered EM signal and to split the backscattered EM signal into a first polarized backscattered EM signal and a second polarized backscattered EM signal. The second polarizing beam splitter is configured to receive a local oscillator signal, the local oscillator signal being extracted from the coherent electromagnetic signal, and to split the local oscillator signal into a first polarized local oscillator signal and a second polarized local oscillator signal.

Furthermore, the LIDAR system comprises a first detector and mixer and a third detector and mixer for receiving a first primary polarized backscattered EM signal and a first secondary polarized backscattered EM signal, respectively, and a first primary polarized local oscillator signal and a first secondary local oscillator signal, respectively. The first detector and mixer and the third detector and mixer are configured to output a first mixed signal and a third mixed signal.

The LIDAR system also comprises a second detector and mixer and a fourth detector and mixer for receiving a second primary polarized backscattered EM signal and a second secondary polarized backscattered EM signal, respectively, and a second primary polarized local oscillator signal and a second secondary local oscillator signal. The second primary local oscillator signal and the second secondary local oscillator signal are phase shifted with respect to the first primary and the first secondary local oscillator signals. The second detector and mixer and the fourth detector and mixer are configured to output a second mixed signal and a fourth mixed signal, respectively.

Furthermore, the LIDAR system comprises a processor configured to receive at least the first, second, third and fourth mixed signals, and to perform a cross correlation of the first (MS1)/second (MS2) mixed signal and the third (MS3)/fourth (MS4) mixed signal to provide an output comprising information from polarized (PB) and depolarized backscattered (DPB) EM signal.

According to another aspect of the present invention, a LIDAR system for detection of polarized (PB) and de-polarized backscattered (DPB) electromagnetic (em) signals is provided. The LIDAR system comprises an emitter for emission of a coherent electromagnetic (EM) signal and a transmitting optical arrangement configured to transmit an electromagnetic signal towards a measurement area.

Additionally, the LIDAR system comprises a receiving optical arrangement for receiving a backscattered EM signal from the measurement area, and at least a first and a second polarizing beam splitter. The first polarizing beam splitter is configured to receive the backscattered EM signal and to split the backscattered EM signal into a first polarized backscattered EM signal and a second polarized backscattered EM signal. The second polarizing beam splitter is configured to receive a local oscillator signal, the local oscillator signal being extracted from the coherent electromagnetic signal, and to split the local oscillator signal into a first polarized local oscillator signal and a second polarized local oscillator signal.

Furthermore, the LIDAR system comprises a first detector and mixer and a third detector and mixer for receiving a first primary polarized backscattered EM signal and a first secondary polarized backscattered EM signal, respectively, and a first primary polarized local oscillator signal and a first secondary local oscillator signal, respectively. The first detector and mixer and the third detector and mixer are configured to output a first mixed signal and a third mixed signal.

The LIDAR system also comprises a second detector and mixer and a fourth detector and mixer for receiving a second primary polarized backscattered EM signal and a second secondary polarized backscattered EM signal, respectively, and a second primary polarized local oscillator signal and a second secondary local oscillator signal. The second primary local oscillator signal and the second secondary local oscillator signal are phase shifted with respect to the first primary and the first secondary local oscillator signals. The second detector and mixer and the fourth detector and mixer are configured to output a second mixed signal and a fourth mixed signal, respectively.

Furthermore, the LIDAR system comprises a processor configured to receive at least the first, second, third and fourth mixed signals and to process the mixed signals to provide an output comprising information from polarized and depolarized backscattered EM signal.

According to a third aspect of the present invention, a LIDAR system for detection of polarized (PB) and de-polarized backscattered (DPB) electromagnetic (em) signals is provided. The LIDAR system comprises a front-end which is configured to transmit an optical transmitter signal to a preferred target or a measurement area, and the transmitter signal may be either a continuous-wave or a pulsed signal. The front-end is further configured to receive an optical backscattered EM signal which is generated due to a collision between the transmitted signal and airborne particles.

The backscattered EM signal may be either polarized or depolarized.Furthermore, the front-end may be configured to generate a local-oscillator signal.

The received backscattered EM signal and the generated local oscillator signal may further be transmitted to a polarization splitter being configured to split both signals into two separate polarizations, and thereby, generating multiple backscattered EM signals having different polarizations and multiple local oscillator signals having different polarizations.

The polarized-splitted backscattered EM signals and the polarized-splitted local oscillator signals may then be received by a mixer, wherein the mixer is configured to generate for each polarization an in-phase signal based on a backscattered EM signal and a local oscillator signal having the same polarization. The mixer may further be configured to generate for each polarization a quadrature-phase signal based on a backscattered EM signal and a phase shifted local oscillator signal having the same polarization.

The in-phase signal and the quadrature-phase signals, for each polarization, may be processed in a signal processing unit so as to extract information from the received backscattered EM signal being either polarized or de-polarized.

Alternatively, the signal processing unit may be configured to perform cross correlations between the in-phase signal and the quadrature-phase signal, having the same polarization, so as to extract information from the received backscattered EM signal being either polarized or de-polarized.

Thereby, a LIDAR system which is able to detect polarized and depolarized backscattered EM signals is configured to improve the signal-to-noise ratio, whereby the previously defined problems with the known technique are overcome. The effect thereof, is an increased radial velocity measurement range (i.e. detection bandwidth) for the same sampling frequency, and a more accurate radial velocity and wind direction estimations of particles, specially for low wind speeds where the spurious effects of active components such as acoustic optic modulator (AOM) in heterodyne receivers may mask the signal.

The advantage of having an increased radial velocity measurement range is an improved possibility of adjusting a plurality of parameters of a windmill, which increases the wind-to-energy conversion efficiency.

Additionally, the LIDAR system disclosed herein may be further capable of detecting the nature of the atmospheric return such as spherical and non-spherical particles which provides additional information about the atmosphere such as presence of clouds, rain, mist, etc. for various radial velocity measurement ranges, i.e., measurement areas. Furthermore, the LIDAR system disclosed herein may be further capable of providing information about particle shape and size based on the amount of depolarization and backscatter signal strength.

A further technical effect may be an increased radial velocity measurement range and a more accurate way of estimating the radial velocity, wind direction, and nature of particles, such as shape and size. This can be used for improving the safety of an airplane, since the accuracy/preciseness of the LIDAR system significantly improves the long distance detection of turbulences, plums and clouds.

An advantage of performing a cross correlation between the first and the second mixed signal and between the third and the fourth mixed signal is that an improved SNR may be obtained due to the elimination of uncorrelated shot-noise and electronic noise while eliminating the need for additional signal processing, such as spectral whitening. The LIDAR system may be a Doppler LIDAR, a Rayleigh LIDAR, a Mie LIDAR, a Raman LIDAR, a Na/Fe/K fluorescence LIDAR, a Differential Absorption LIDAR (DIAL-LIDAR) or similar. Additionally, the LIDAR system may be an incoherent LIDAR or a coherent LIDAR detection system.

The LIDAR system may be based on a homodyne technique or an image-reject homodyne technique. Compared to a LIDAR system based on a heterodyne technique, a homodyne technique or an image-reject homodyne technique is advantageous as it allows for a doubling of the radial velocity measurement range while sustaining an equal bandwidth for a detector and analog-to-digital converter (ADC) and possible minimization of the cost of the LIDAR system. Furthermore, by using an image-reject homodyne technique, radial velocity, direction, and acceleration of one or more individual airborne particle are measureable.

The image-reject homodyne technique is a combination of a homodyne receiver and I/Q modulation, where “I” represents the “in-phase signal” and “Q” represents the “quadrature signal”.

In the present invention, the first and the third mixed signals are denoted as in-phase signals, and the second and fourth mixed signals are denoted as quadrature signals. The quadrature signals may be phase shifted compared to the in-phase signals, and thereby, when combining the in-phase and the quadrature signals provides the possibility of extracting the sign of the Doppler shift. Besides, by performing a cross-correlation analysis between the in-phase and quadrature components, the uncorrelated noise arising from the two separate detection chains, ie, photo-detectors and electronic circuitry will be suppressed resulting in an improved SNR, The emitter may be a single or a multi mode laser source, such as a gas laser, a NdYAG laser, a chemical laser, a dye laser, a metal-vapor laser, a solid-state laser, a semiconductor laser, a super continuum laser, a Raman laser, a fiber laser or any other kind of a laser source. Additionally, the emitter may emit at least one incoherent or at least one coherent electromagnetic signal. Furthermore, the emitter may be a continuous wave (CW) or a pulse laser.

The emitter may comprise at least one laser source.

A transmitting optical arrangement may comprise a circulator or an optical insulator being able to transmit an optical signal of any kind.

A measurement area may comprise a plurality of airborne particles in the air or any kind of a gas species. Furthermore, the measurement area may also be in a liquid comprising a plurality of particles. Additionally, the measurement area may comprise an object of any kind, such as an airplane, a car, a person, a house etc.

The present invention is able to detect polarized or depolarized backscattered EM signals from an object, and thereby, the LIDAR system comprises an improved way of detecting size and shape of an object comprising a plurality of particles.

The receiving optical arrangement may be a circulator or an optical insulator being able to receive an optical signal of any kind.

The first and a second polarizing beam splitter may be a fiber-based polarization combiner or splitter. Furthermore, the first and the second polarizing beam splitter may be a free space polarization combiner or splitter. The first and the second polarizing beam splitter may be able to receive at least one optical signal and transmit at least two optical signals, each comprising at least a first polarization and a second polarization.

The backscattered EM signal may be a polarized or a depolarized signal, being either single mode or multi mode. Furthermore, the backscattered EM signal may also be a CW signal or a pulse signal, where the pulse signal may comprise at least one pulse. Additionally, the backscattered EM signal may comprise at least a first polarization. The LIDAR system may receive at least one backscattered EM signal.

The local oscillator signal may be a single mode or a multi mode signal. Furthermore, the local oscillator signal may also be a CW signal or a pulse signal, where the pulse signal may comprise at least one pulse. Additionally, the local oscillator signal may comprise at least a first polarization. The LIDAR system may generate at least one local oscillator signal.

The detector and mixer may be a balanced detector and mixer able to mix at least two optical signals and transmitting at least one mixed signal. The LIDAR system may comprise plurality of detector and mixer.

The processor may be a part of a computing device including, for example, a server computer, a personal computer, workstation, web server, and/or other suitable computing devices. The processor may perform a cross correlation between the first and the second mixed signals and also between the third and the fourth mixed signals.

Between the measurement area and the transmitting optical arrangement a telescope or a focus lens may be placed to focus and/or parallelize the transmitted electromagnetic signal towards the measurement area.

Disclosed herein is also a method for detecting a polarized and a depolarized backscattered EM signals in a LIDAR system. The method comprises the steps of emitting a coherent electromagnetic signal, and transmitting the electromagnetic signal towards a measurement area via a transmitting optical arrangement. The method further comprises the steps of receiving a backscattered EM signal from the measurement area by a first polarizing beam splitter, and splitting the backscattered EM signal into a first polarized backscattered EM signal and a second polarized backscattered EM signal, and extracting a local oscillator signal from the emitted coherent electromagnetic signal.

The method also discloses the step of receiving the local oscillator signal by a second polarizing beam splitter, and splitting the local oscillator signal into a first polarized local oscillator signal and a second polarized local oscillator signal.

The method also discloses the step of dividing the first and the second polarized backscattered EM signals into a first and a second primary polarized backscattered EM signal and a first and a second secondary polarized backscattered EM signal, respectively, and the step of dividing the first and the second polarized local oscillator signals into a first and a second primary polarized local oscillator signal and a first and a second secondary polarized local oscillator signal, respectively,

Disclosed in the method is also detecting and mixing the first primary polarized backscattered EM signal and the first primary polarized local oscillator signal, and the first secondary polarized backscattered EM signal and the first secondary local oscillator signal to provide a first and a third mixed signal, respectively.

The method also discloses the step of detecting and mixing the second primary polarized backscattered EM signal and the second primary polarized local oscillator signal, and the second secondary polarized backscattered EM signal and the second secondary local oscillator signal to provide a second and a fourth mixed signals, respectively, the second primary local oscillator signal and the second secondary local oscillator signal being phase shifted with respect to the first primary and first secondary local oscillator signals.

The method also discloses the steps of receiving at least the first, second, third and fourth mixed signals in a processor, and processing the mixed signals to provide an output comprising information from polarized (PB) and depolarized backscattered EM signal (DPB).

It is an advantage of detecting and processing the polarized and the depolarized backscattered EM signals since the SNR increases, and furthermore, the amount and the quality of received information improve.

In one or more embodiments, the LIDAR system comprises a pulse shaper configured to receive the coherent electromagnetic signal and transmit a pulsed coherent electromagnetic signal.

The pulse shaper may be configured to generate at least one pulse having a pulse width (FW) between 4 ns to 30 ns, or between 10 ns to 60 ns, or between 20 ns to 100 ns, or between 30 ns to 150 ns, or between 50 ns to 300 ns, or between 5 ns to 300 ns. The advantage of the pulse shaper is the possibility of adjusting a range resolution of the present invention by adjusting the pulse width (FW). By increasing the pulse width, the range resolution increases. The pulse width (FW) may be defined as being the width of a pulse at half its maximum intensity.

The pulsed coherent electromagnetic signal may comprise plurality of pulses, and each pulse may have at least a first polarization.

The advantage of having a pulsed based LIDAR system is an improved measurement range, insensitive to a measurement area being out of focus, and a limited average power. The effect thereof is an improved signal-to-noise ratio which leads to an improved quality/reliability of the information being detected by the LIDAR system. A further effect thereof, is an improved stability of the LIDAR system

The measurement range may depend on the power of the emitted electromagnetic signal and with any power of the emitted electromagnetic signal, the measurement range of the present invention may be improved with a factor of between 1.1 to 4,or between 1.5 to 3.5, or between 2 to 3, or between 4 to 6 or between 6 to 10.

With any non-scientific laser applications and a regular transmitting optical arrangement, the measurement range of the present invention may be between 500 m to 15000 m, or between 200 m to 10000 m, or between 500 m to 5000 m, or between 600 m to 1000 m, or between 5 m to 3000, or between 1 m to 1000 m.

In one or more embodiments, the LIDAR system comprises a polarization rotator configured to receive the pulsed coherent electromagnetic signal and transmit a polarized pulsed coherent electromagnetic signal having at least a first polarization.

The polarization rotator may transmit at least a pulse comprising at least a first and a second polarization, and the effect thereof is an increased observation time due to an increased pulse repetition rate (PRR). The advantage of increasing the observation time is an improved signal-to-noise ratio for the same measurement range or an increased measurement range for the same SNR.

The LIDAR system is able to switch between a single polarization and a multi polarization mode by controlling the pulse shaper as well as the polarization rotator electronically. In the single polarization mode the LIDAR system is emitting a pulse electromagnetic signal comprising a single polarization, and in the multi polarization mode, the LIDAR system is emitting pulse electromagnetic signals comprising at least two polarizations.

The advantage of having the pulse shaper and the polarization rotator is that the LIDAR system is able to switch between the single polarization mode and the multi polarization mode. For example, if the LIDAR system is in the multi polarization mode emitting pulsed electromagnetic signals, cross-talks would occur if detecting depolarized backscattered EM signals. Then switching the LIDAR system to the single polarization mode no cross-talks would occur due to the depolarized backscattered EM signals.

In one or more embodiments, the LIDAR system comprising a first slow axis of the first polarizing beam splitter aligning 0° with the slow axis of a first input optical fiber, and a second slow axis of the second polarizing beam splitter aligning 45° with a second input optical fiber.

In one or more embodiments, the LIDAR system comprising a first slow axis of the first polarizing beam splitter aligning 0° with the slow axis of a first input polarization maintaining optical fiber, and a second slow axis of the second polarizing beam splitter aligning 45° with a second input optical fiber.

In one or more embodiments, the LIDAR system comprises a first coupler and a third coupler configured to divide the first and second polarized backscattered EM signals into first primary and first secondary polarized backscattered EM signal and into second primary and second secondary polarized backscattered EM signals, respectively.

In one or more embodiments, the LIDAR system comprises at least a second and a fourth coupler configured to divide the first and second polarized local oscillator signals into first primary and first secondary polarized local oscillator signal and into second primary and second secondary polarized local oscillator signals, respectively.

The LIDAR system may comprise at least a first coupler being able to split at least a first polarized backscattered EM signal into at least a first primary and a first secondary polarized backscattered EM signal.

In one or more embodiments, the transmitting optical arrangement and the receiving optical arrangement may be combined in a circulator or an optical insulator configuring to receive the coherent electromagnetic signal and to transmit the electromagnetic signal towards a measurement area, and to receive the backscattered EM signal from the measurement area and transmit the backscattered EM signal to the first polarizing beam splitter.

In one or more embodiments, the first, the second, the third and the fourth detector and mixer may be a first, a second, a third and a fourth balanced detector and mixer, respectively.

The detectors may be single ended detectors or balanced detectors.

In one or more embodiments, the emitter may comprise a laser, such as a gas laser, such as a NdYAG laser, a chemical laser, a dye laser, a metal-vapor laser, a solid-state laser, a semiconductor laser, a super continuum laser, a Raman laser, or a fiber laser.

The LIDAR system may comprise at least one emitter.

In one or more embodiments, the LIDAR system comprises polarization maintaining fibers and polarization maintaining components.

The LIDAR system may comprise a digital signal processing unit configured to perform a cross correlation of the first/second mixed signal and the third/fourth mixed signal.

The cross correlation may be a convolution between two functions/signals, a normalized cross correlation, phase cross correlation, single channel cross correlation or a multi channel cross correlation.

The advantage of performing a cross correlation between the first and the second mixed signal and between the third and the fourth mixed signal is an improved SNR due to the elimination of uncorrelated shot-noise and electronic noise while eliminating the need for additional signal processing such as spectral whitening. Besides, due to the SNR improvement, and a further technical effect is the elimination of complicated optical amplifiers resulting in a more cost efficient LIDAR system.

In one or more embodiments, the method for detecting the polarized and the depolarized backscattered EM signals in a LIDAR may comprise the step of pulse shaping the coherent electromagnetic signal and transmitting a pulsed coherent electromagnetic signal.

In one or more embodiments, the method may comprise the step of rotating the polarization of the pulsed electromagnetic signal to provide a polarization diversity pulsed coherent electromagnetic signal.

The advantage of providing the polarization rotation is the possibility for polarization diversity measurement, and furthermore, it is an advantage of having at least a 90° polarization difference between at least a first polarization and a second polarization of at least one pulse to provide independent measurement of at least the first polarization and the second polarization.

In one or more embodiments, the method may comprise a digital signal processing unit performing a cross correlation of at least the first/second mixed signals and at least the third/fourth mixed signals.

In one or more embodiments, the LIDAR system comprises a third polarization beam splitter configured to receive the coherent electromagnetic signal, and to transmit a first polarized transmitter signal and a second polarized transmitter signal.

Furthermore, the LIDAR system may comprise a first pulse shaper and a second pulse shaper for receiving the first polarized transmitter signal and the second polarized transmitter signal, respectively. The first polarized transmitter signal may be polarized orthogonal relative to the second polarized transmitter signal. The first pulse shaper is configured for transmitting a first polarized pulsed transmitter signal and the second pulse shaper is configured to transmit a second polarized pulsed transmitter signal, respectively.

Additionally, the LIDAR may comprise a first optical amplifier and a second optical amplifier configured to receive the first polarized pulsed transmitter signal and the second polarized pulsed transmitter signal, respectively, and to transmit a first and a second amplified polarized pulsed transmitter signal, respectively.

Furthermore, the LIDAR may comprise a first polarization beam combiner configured to receive at least the first amplified polarized pulsed transmitter signal, and to transmit a polarized pulsed coherent electromagnetic signal having at least a first polarization.

Alternatively, the LIDAR may comprise a first polarization beam combiner configured to receive the first amplified polarized pulsed transmitter signal and the second amplified polarized pulsed transmitter signal, and to transmit a polarized pulsed coherent electromagnetic signal having a first polarization and a second polarization.

Thus, the LIDAR may be configured to transmit the polarized pulsed coherent electromagnetic signal via the transmitting optical arrangement towards a measurement area.

By dividing or discriminating the polarization state of the transmitted polarized pulsed coherent electromagnetic signals, which means alternating the orthogonal polarization states, it may be possible to double the maximum optical output power by integrating at least two optical amplifiers, one for each polarization state of the polarized pulsed coherent electromagnetic signal. This is specially important in all-fiber coherent Doppler lidars (CDL) where the fiber-based optical amplifiers may have a limited average output power

Dividing or discriminating the polarization of the coherent electromagnetic signal and the possibility of amplifying the divided polarization states, i.e. the at least first polarization and/or the at least second polarization, may give the system the possibility to either operate in a multi-polarization mode, wherein the LIDAR system emits a polarized pulsed coherent electromagnetic signal comprising plurality of optical pulses which every second pulse has a second polarization being orthogonal to a first polarization of a previous pulse, or in a single-polarization mode, wherein the LIDAR system emits a polarized pulsed coherent electromagnetic signal comprising plurality of optical pulses having a first polarization.

The LIDAR system may be able to switch between the single-polarization mode and the multi-polarization mode by switching between operating with one or two optical amplifiers, respectively. Additionally, the LIDAR system may be able to increase the pulse-repetition-rate (PRR), such as to double the pulse-repetition-rate (PRR), by switching from single-polarization mode to multi-polarization mode.

In an ordinary or prior-art pulsed coherent LIDAR system the pulse-repetition rate may be the limiting factor rather than the available optical power. It is a disadvantage of such ordinary or prior-art pulsed coherent LIDAR system that when transmitting multiple pulses, the system has to wait for one pulse to die out before it can transmit the next pulse., If in such ordinary or prior-art pulsed coherent LIDAR system, a wait is not provided, the two pulses may interfere to thereby create cross-talking or cross-talking noise. The waiting time between the pulses thus creates a limitation to the pulse-repetition rate.

However, the present LIDAR system may be configured to transmit a series of optical pulses, wherein every second pulse of the series of optical pulses has a second polarization being orthogonal to a first polarization of a previous pulse of the series of optical pulses. Thereby, cross-talking is reduced as no or limited cross-talking occurs between the optical pulses having different polarizations.

Thereby, the waiting time between the transmitted optical pulses of the plurality of optical pulses may be reduced to thereby obtain an improved pulse-repetition-rate.

This is specifically useful when the LIDAR system operates in clear air atmosphere. In clear air atmosphere, the concentration of airborne particles is low and mainly spherical airborne particles are present in clear air. Due to the low concentrations, collisions between the spherical airborne particles and transmitted pulses are reduced, and as a consequence of the reduced number of collisions, the SNR of the LIDAR system is typically reduced.

It is therefore an advantage of the LIDAR system of the present disclosure that an increase in the pulse-repetition-rate may improve the SNR of the LIDAR system, due to an increased number of observations because of the increased number of optical pulses being transmitted into the clear air.

The optical amplifier implemented into the LIDAR system may be a fibre amplifier, a doped fibre amplifier, or an Erbium doped fibre amplifier (EDFA),

The polarization beam combiner may be an open space polarization beam splitter cube which acts both as a polarization splitter and a combiner.

In one or more embodiments, the method may comprise the step of dividing the coherent electromagnetic signal into a first polarized transmitter signal and a second polarized transmitter signal, and pulse shaping the first polarized transmitter signal and the second polarized transmitter signal into a first polarized pulse transmitter signal and a second polarized pulse transmitter signal, respectively.

The method may also comprise the step of amplifying at least the first polarized pulse transmitter signal into at least a first amplified polarized pulsed transmitter signal, and receiving at least the first amplified polarized pulsed transmitter signal into a first polarized beam combiner. Furthermore, the method may comprise the step of transmitting a polarized pulsed coherent electromagnetic signal having at least a first polarization.

Alternatively, the method may comprise the step of amplifying at least the first polarized pulse transmitter signal and the second polarized pulse transmitter signal into at least a first amplified polarized pulsed transmitter signal and a first amplified polarized pulsed transmitter signal, respectively, and receiving at least the first amplified polarized pulsed transmitter signal and the second amplified polarized pulsed transmitter signal into a polarized beam combiner. Furthermore, the method may comprise the step of transmitting a polarized pulsed coherent electromagnetic signal having at least a first polarization and a second polarization.

Brief Description of Drawings

Embodiments of the invention will be described in the figures, whereon:

Fig. 1A illustrates an example of a LIDAR system transmitting an electromagnetic signal towards a measurement area comprising plurality of airborne particles,

Fig. 1B illustrates an example of a LIDAR system comprising a DIAL-LIDAR configured to emit multi wavelength electromagnetic signal towards a measurement area comprising plurality of airborne particles,

Fig. 2A schematically illustrates an example of an electromagnetic signal emitted from a LIDAR system and reflected from a measurement area generating a polarized backscattered EM signal,

Fig. 2B schematically illustrates an example of an electromagnetic signal emitted from a LIDAR system and reflected from a measurement area generating a depolarized backscattered EM signal,

Fig. 3 schematically illustrates an exemplary LIDAR system according to the invention emitting an electromagnetic signal being a continuous wave signal,

Fig. 4 schematically illustrates an exemplary LIDAR system according to the invention emitting an electromagnetic signal being a continuous wave signal, wherein the LIDAR system comprises a digital processing unit.

Fig. 5 schematically illustrates an exemplary LIDAR system according to the invention emitting a pulse electromagnetic signal being a pulse signal, wherein the LIDAR system comprises a digital processing unit.

Fig. 6A illustrates a schematically exemplary of a LIDAR system emitting an electromagnetic signal, being a single mode continuous wave signal, towards a measurement area comprising a low concentration of airborne particles and the weather condition is clear sky and no wind,

Fig. 6B illustrates a schematically exemplary of a LIDAR system emitting an electromagnetic signal, being a single mode continuous wave signal, towards a measurement area comprising a high concentration of airborne particles and the weather condition is harsh,

Fig. 7A illustrates a schematically exemplary of a LIDAR system emitting a pulsed electromagnetic signal, being a single mode continuous wave signal, towards a measurement area comprising a low concentration of airborne particles being a mix of spherical and non-spherical particles, with a significant presence of non-spherical particles,

Fig. 7B illustrates a schematically exemplary of a LIDAR system emitting a pulse electromagnetic signal, being a single mode continuous wave signal, towards a measurement area comprising a high concentration of airborne particles being a mix of spherical and non-spherical particles, with a significant presence of non-spherical particles,

Fig. 8A illustrates a schematically exemplary of a LIDAR system emitting a pulse electromagnetic signal towards a measurement area and receiving pulsed backscattered EM signal comprising plurality of dispersed pulses and depolarization,

Fig. 8B illustrates a schematically exemplary of a LIDAR system emitting a pulse electromagnetic signal towards a measurement area and receiving pulsed backscattered EM signal comprising plurality of dispersed pulses and no cross-talking,

Fig. 9 illustrates a method for detecting at least a polarized and at least a depolarized backscattered EM signals,

Fig. 10 schematically illustrates an exemplary LIDAR system according to the invention emitting a polarized pulsed coherent electromagnetic signal being a pulse signal, wherein the LIDAR system comprises a digital processing unit,

Fig. 11 illustrates a method for transmitting a polarized pulsed coherent electromagnetic signal being a pulse signal.

Detailed Description of the Invention

Fig. 1A and 1B schematically illustrates an exemplary LIDAR system 1 according to the invention, emitting an electromagnetic signal, being either a CW signal or a Pulse signal, towards a measurement area. Based on different the nature of the backscatter, the LIDAR system 1 may be a Doppler LIDAR, a Rayleigh LIDAR, Mie LIDAR, Raman LIDAR, Na/Fe/K fluorescence LIDAR or a Differential Absorption LIDAR (DIAL-LIDAR) etc. Additionally, the LIDAR system 1 may be an incoherent LIDAR or a coherent LIDAR detection system.

The LIDAR system 1 may be a continuous wave (CW) or a pulse LIDAR system emitting an electromagnetic signal being either a CW signal or a pulse signal and single mode or multi mode. The LIDAR system 1 then receives a backscattered EM signal 14 being either a CW signal or a pulse signal and comprising at least one wavelength and at least a first polarization 34. Fig. 1A illustrates an example of a LIDAR system 1 transmitting an electromagnetic signal 16 towards a measurement area 18 comprising plurality of airborne particles 44, wherein the electromagnetic signal 16 comprises a single mode CW signal having a first polarization 34. The LIDAR system 1 detects a backscattered signal 14 comprising at least one polarized backscattered EM signal PB and at least one depolarized backscattered EM signal DPB both being a single mode CW signal. The polarized backscattered EM signal PB comprises a first polarization 34 and the depolarized backscattered EM signal comprises a first and/or a second polarization 35.

Fig. 1B illustrates an example of a LIDAR system 1 including a DIAL-LIDAR configured to emit multi wavelength electromagnetic signal 16B towards a measurement area 18 comprising a plurality of airborne particles 44 and receiving at least a first wavelength backscattered EM signal 14A and at least a second wavelength backscattered EM signal 14B from the measurement area 18. The at least first wavelength backscattered EM signal 14A and the at least second wavelength backscattered EM signal 14B may both comprise at least a polarized backscattered EM signal PB and/or at least a depolarized backscattered EM signal DPB.

Fig. 2A and 2B schematically illustrate an example of an electromagnetic signal 16 emitted from a LIDAR system 1 and reflected from a measurement area 18 comprising an airborne particle 44 generating a polarized backscattered EM signal PB or a depolarized backscattered EM signal DPB, respectively. Fig. 2A the electromagnetic signal 16, having a first polarization 34, is reflected from the measurement area 18, comprising an airborne particle 44 being a spherical particle, creating a polarized backscattered signal PB having a first polarization 34 parallel to the first 34 polarization of the electromagnetic signal 16. Fig. 2B the electromagnetic signal 16, having a first polarization 34, is reflected from the measurement area 18, comprising an airborne particle 44 being a non-spherical particle, creating a depolarized backscattered signal DPB comprising a first 34 and a second polarization 35 not parallel to the polarization of the electromagnetic signal 16.

Fig.3 schematically illustrates an exemplary LIDAR system 1 according to the invention, comprising an emitter 2 being a single or a multi mode laser source, such as a gas laser, a NdYAG laser, a chemical laser, a dye laser, a metal-vapor laser, a solid-state laser, a semiconductor laser, a super continuum laser, a Raman laser, a fiber laser or any other kind of a light source. The emitter 2 may emit an incoherent or a coherent electromagnetic signal, and in this particular example the emitter emits a coherent electromagnetic signal 17 being a CW signal and single mode. The coherent electromagnetic signal 17 is divided by an emitter splitter 24 into an electromagnetic signal 16 and a local oscillator signal 12. The electromagnetic signal 16 is amplified by an optical amplifier 32.

A transmitting optical arrangement 4 is configured to receive the electromagnetic signal 16 and to transmit the electromagnetic signal 16 towards a measurement area 18. A receiving optical arrangement 6 is configured to receive a backscattered EM signal 14 from the measurement area 18 and to forwarding the backscattered EM signal 14 towards at least a first polarization beam splitter 8. At least a second polarization beam splitter 10 receives the local oscillator signal 12.

The transmitting optical arrangement 4 and the receiving optical arrangement 6 are combined in a circulator 47 or an optical insulator 48. The circulator 47 and the optical insulator 48 are not shown Fig. 3.

The first polarization beam splitter 8 and the second polarization beam splitter 10 may be a polarization fiber splitter, a polarization beam splitter or a 50/50 splitter combined with a phase retarder. The first polarization beam splitter 8 and the second polarization beam splitter 10 may be configured to split at least one incoming signal into at least two signals.

A first slow axis of the first polarization beam splitter 8 is aligned 0° with the respective slow axis of a first input optical fiber 45 going in to the first polarization beam splitter 8. The first polarizing beam splitter 8 is configured to receive the backscattered EM signal 14 and to split the backscattered EM signal 14 into a first polarized backscattered EM signal PB1 and a second polarized backscattered EM signal PB2. In this particular example, the first polarized backscattered EM signal PB1 comprises at least a first polarization 34 and the second polarized backscattered EM signal PB2 comprises at least a second polarization 35.

A second slow axis of a second polarization beam splitter 10 is aligned 45° with a second input optical fiber 46. The second polarization beam splitter 10 is configured to receive the local oscillator signal 12 and to split the local oscillator signal 12 into a first polarized local oscillator signal PL1 and a second polarized local oscillator signal PL2. In this particular example, the first polarized local oscillator signal PL1 comprises at least a first polarization 34 and the second polarized local oscillator signal PL2 comprises at least a second polarization 35.

A first 20 and a third 22 splitter receive the first polarized backscattered EM signal PB1 and the second polarized backscattered EM signal PB2, respectively. The first splitter 20 is configured to split the first polarized backscattered EM signal PB1 into a first primary polarized backscattered EM signal PB11 and a second primary polarized backscattered EM signal PB12. The third splitter 22 is configured to split the second polarized backscattered EM signal PB2 into a first secondary polarized backscattered EM signal PB21 and a second secondary polarized backscattered EM signal PB22.

A second 21 and a fourth 23 splitter receive the first polarized local oscillator signal PL1 and the second polarized local oscillator signal PL2, respectively. The second splitter 21 is configured to split the first polarized local oscillator signal PL1 into at least a first primary polarized local oscillator signal PL11 and a second primary polarized local oscillator signal PL12 being phase shifted by a first phase shifter 27. The fourth splitter 23 is configured to split the second polarized local oscillator signal PL2 into a first secondary polarized local oscillator signal PL21 and a second secondary polarized local oscillator signal PL22 being phase shifted by a second phase shifter 28.

The first 20, second 21, third 22 and fourth 23 splitter may be configured to receive at least one incoming signal and transmitting at least two signals having a power ratio of 50/50, 40/60, 30/70, 20/80 or 10/90. Furthermore, the first 20, second 21, third 22 and fourth splitter 23 may be a first coupler 20A, a second coupler 21A, a third coupler 22A and a fourth coupler 23A, respectively. The couplers are not shown in Fig. 3.

The first detector and mixer DM1 receives the first primary polarized backscattered EM signal PB11 and the first primary polarized local oscillator signal PL11, and the first detector and mixer DM1 is configured to output a first mixed signal MS1 having a first polarization 34. The second detector and mixer DM2 receives the second primary polarized backscattered EM signal PB12 and the phase shifted second primary polarized local oscillator signal PL12, and the second detector and mixer DM2 is configured to output a second mixed signal MS2 having a first polarization 34. The third detector and mixer DM3 receives the first secondary polarized backscattered EM signal PB21 and the first secondary polarized local oscillator signal PL21, the third detector and mixer DM3 is configured to output a third mixed signal MS3 having a second polarization 35. The fourth detector and mixer DM4 receives the second secondary polarized backscattered EM signal PB22 and the phase shifted second secondary polarized local oscillator signal PL22, the fourth detector and mixer DM4 is configured to output a fourth mixed signal MS4 having a second polarization 35.

The first DM1, the second DM2, the third DM3 and the fourth DM4 detector and mixer, respectively, may be a first BDM1, a second BDM2, a third BDM3 and a fourth BDM4 balanced detector and mixer. The plurality of balanced detectors and mixers are not shown in Fig. 3.

A processor 30 is configured to receive at least the first mixed signal MS1, the second mixed signal MS2, the third mixed signal MS3 and the fourth MS4 mixed signal and to perform a cross correlation between the first MS1 and the second mixed signals MS2 and between the third MS3 and the fourth MS4 mixed signals in order to extract information from the polarized backscattered EM signal PB and the depolarized backscattered EM signal DPB. The information may comprise a measurement of particle shape, size, radial velocity and direction, detection of gas species, detection of plumes and/or clouds. Furthermore, the LIDAR system 1 is also able of predicting turbulences by extracting the turbulence intensity from the radial velocity. Since the LIDAR system 1 is able to detect both the polarized PB and the depolarized backscattered EM signals DPB, the LIDAR system 1 is ideal for short and, specially, long range detection because of an improved signal-to-noise ratio (SNR).

Fig. 4 schematically illustrates an exemplary LIDAR system 1 according to the invention, wherein the LIDAR system 1 comprises at least a first 36, a second 37, a third 38 and a fourth 39 analog-to-digital processing components each comprising a low-pass filter, an RF amplifier and an analog-to-digital converter. The analog-to-digital processing component is configured for filtering, amplifying and converting an analog signal into a digital signal. The first 36 and the second 37 analog-to-digital processing components are configured for receiving and processing the first MS1 and the second MS2 mixed signals, respectively. The processed mixed signals (MS1 and MS2), having the same polarization, is added together by a first adder 40 generating a first I/Q signal. The first I/Q signal is feed into a digital signal processing unit 30A. The third 38 and the fourth 39 analog-to-digital processing components are configured for receiving and processing the third MS3 and the fourth MS4 mixed signals into a digital signal, respectively. The processed mixed signals (MS3 and MS4), having the same polarization, are added together by a second adder 41 generating a second I/Q signal. The second I/Q signal is fed into the digital signal processing unit 30A.

The digital signal processing unit 30A is configured to perform a cross correlation between the first MS1 and the second MS2 mixed signals and between the third MS3 and the fourth MS4 mixed signals in order to extract information from the polarized backscattered EM signal PB and the depolarized backscattered EM signal DPB, respectively. The information may comprise measuring of particle shape, size, radial velocity and direction, EDR, detection of gas species, detection of plumes and/or clouds.

Fig 5 schematically illustrates an exemplary LIDAR system 1 according to the invention, wherein the LIDAR system 1 is configured to emit a pulse electromagnetic signal 16A and to receive a pulsed backscattered EM signal 15 comprising at least a polarized backscattered EM signal PB and/or at least a depolarized backscattered EM signal DPB. The LIDAR system 1 comprises an emitter 2 generating a coherent electromagnetic signal 17 which is divided by an emitter splitter 24 into an electromagnetic signal 16 and a local oscillator signal 12. The electromagnetic signal 16 is fed into a pulse shaper 33 configured to generate a pulsed coherent electromagnetic signal 19. The local oscillator signal 12 is fed into a second polarization beam splitter 10.

In another embodiment the emitted coherent electromagnetic signal 17 is fed into the pulse shaper 33 generating a pulsed coherent electromagnetic signal 19 which is divided by an emitter splitter 24 into a pulsed coherent electromagnetic signal 19 and a pulsed local oscillator signal 13. The pulsed local oscillator signal 13 is fed into a second polarization beam splitter 10.

The pulsed coherent electromagnetic signal 19 is then amplified by an optical amplifier 32, and the amplified pulsed coherent electromagnetic signal 19 is then fed into a polarization rotator 29. The polarization rotator 29 is configured to emit a polarized pulsed coherent electromagnetic signal 31 to the transmitting optical arrangement 4 having at least a first polarization.

The combination of the pulse shaper 33 and the polarization rotator 29 makes it possible for the LIDAR system to operate in a single polarization mode and/or a multi polarization mode.

Then if the LIDAR system is switched to a single polarization mode, the transmitting optical arrangement 4 may be configured to transmit the pulsed electromagnetic signal 16A towards a measurement area 18, wherein the pulsed electromagnetic signal 16A comprises plurality of pulses 25 each having a first polarization 34. The LIDAR system 1 comprises a receiving optical arrangement 6 for receiving a pulsed backscattered signal 15 and to forward the pulsed backscattered signal 15 to a first polarization beam splitter 8.

Then if the LIDAR system is switched into a multi polarization mode, the transmitting optical arrangement 4 may be configured to transmit the pulsed electromagnetic signal 16A towards a measurement area, wherein the pulsed electromagnetic signal 16A comprises plurality of pulses 25 each having at least a first polarization 34 and/or at least a second polarization 35.

Fig. 5 the LIDAR system 1 comprising a processing of the local oscillator signal 12 or the pulsed local oscillator signal 13 and the pulsed backscattered EM signal 15 which is identical to the processing of the local oscillator signal 12 and the backscattered signal 14, shown in Fig. 3 and Fig. 4.

The signals in the LIDAR system 1 may be guided by air or optical fibers, such as a single mode fiber, multi mode fiber being either polarization maintainable or none-polarization maintainable. The components being optical or non-optical in the LIDAR system 1 may be polarization maintainable or none-polarization maintainable. In this particular example the signals in the LIDAR system 1 are guided by polarization maintainable optical fibers between polarization maintainable components, such as an emitter 2, an optical emitter 32, a pulse shaper 33, a polarization rotator 29, a transmitting optical arrangement 4, a receiving optical arrangement 6, a first/second polarization beam spliter 8/10, splitters 20, 21, 22, 23, phase shifters 27, 28 and/or detector and mixers DM1, DM2, DM3, DM4.

Fig. 6A and 6B illustrate a schematically exemplary of a LIDAR system 1 emitting an electromagnetic signal 16 towards a measurement area 18 being a single mode continuous wave signal. Furthermore, the electromagnetic signal 16 comprises a first polarization 34. In Fig. 6A the weather condition of the measurement area 18 is clear sky and no wind, and thereby, the measurement area 18 obtains a low concentration of airborne particles 44 which are spherical. The LIDAR system 1 receives at least one backscattered EM signal 14 generated due to the reflection of the emitted electromagnetic signal 16 from the airborne particles 44. The backscattered EM signal 14 comprises polarized backscattered EM signals PB and no depolarized backscattered EM signals DPB. The backscattered EM signal 14 comprises a first polarization 34. In Fig. 6B the weather condition of the measurement area 18 has changed and the wind speed has increased. The concentration of airborne particles 44 within the measurement area 18 has increased so has the shape and nature of particles, and the backscattered EM signal 14 may comprise a plurality of polarized backscattered EM signals PB and a plurality of depolarized backscattered EM signals DPB. Then the backscattered EM signal 14 comprises at least a first 34and a second 35 polarization.

Since the LIDAR system 1 in present invention discriminates the polarization of the backscattered 14 the LIDAR system 1 is able to detect polarized PB and depolarized backscattered EM signals DPB, which also leads to an improved SNR. The possibility to perform a cross correlation (or cross spectral analysis) between the mixed signals MS1, MS2, MS3, and MS4 also contributes to the improvement of the SNR.

Fig 7A and 7B illustrate a schematically exemplary of a LIDAR system 1 emitting a pulsed electromagnetic signal 16A comprising plurality of pulses 25. In Fig. 7A the weather condition of the measurement area 18 is harsh, and the measurement area 18 comprises a high concentration of airborne particles 44 being a mix of spherical and non-spherical particles. The pulsed electromagnetic signal 16A comprises multiple pulses 25 having a first polarization 34 colliding with the airborne particles 44 which then generates a pulsed backscattered EM signal 15 having plurality of dispersed pulses 25A being either a polarized backscattered EM signal PB or a depolarized backscattered EM signal DPB. The pulsed backscattered EM signal 15 comprises plurality of dispersed pulses 25A having at least a first polarized 34 or at least a second polarized 35.

Again, since the LIDAR system 1 in present invention splits the polarization of a pulsed backscattered EM signal 15 and a local oscillator signal 12 or a pulsed local oscillator signal 13 and/or performing a cross correlation between the mixed signals MS1, MS 2. MS3, MS4, the LIDAR system 1 is able to detect polarized PB and depolarized backscattered EM signals DPB, which also leads to an improved signal-to-noise ratio (SNR) and an improved radial velocity measurement range which is denoted as being the distance from the LIDAR system 1 to the radial velocity measurement area 18. The radial velocity measurement range may depend on the power of the emitted electromagnetic signal and with any power of the emitted electromagnetic signal, the radial velocity measurement range of the present invention may be improved with a factor of between 1.1 to 3,or between 1.1 to 2.5 or between 2 to 3.

With any non-scientific laser applications and a regular transmitting optical arrangement, the radial velocity measurement range of the present invention may be between 500 m to 10000 m, or between 200 m to 5000 m, or between 500 m to 2500 m, or between 600 m to 1000 m, or between 5 m to 2000, or between 1 m to 500 m.

Fig 7B illustrates a schematically exemplary of a LIDAR system 1 emitting a pulsed electromagnetic signal 16A comprising plurality of pulses 25 each having at least a first polarization 34 and a second polarization 35 generated by a polarization rotator 29. The polarization rotator may rotate a first or a second polarization of a pulse 25 between 0° and 180°, or between 45° and 90°, or between 0° to 45° or between 90° to 180°. Thereby, by generating at least two pulses 25 separated by polarization the pulse repetition rate (PRR) would increase.

By increasing the PRR the number of measurements for a specific range does also increase, and which leads to an increased signal-to-noise (SNR). By increasing the SNR the LIDAR system 1 is able to perform long distance detection, wherein with any non-scientific laser applications and a regular transmitting optical arrangement, the radial velocity measurement range of the present invention may be between 500 m to 15000 m, or between 200 m to 10000 m, or between 500 m to 2500 m, or between 600 m to 5000 m, or between 5 m to 2000, or between 1 m to 500 m.

The pulsed electromagnetic signal 16A may comprise at least one wavelength, and at least one pulse 25 having at least one first polarization 34.

In this particular example the pulsed electromagnetic signal 16A comprises a single wavelength, plurality of pulses 25 each having a first 34 and a second polarization 35. The weather condition of the measurement area 18 is clear sky and no wind, and thereby, the measurement area 18 obtains a low concentration of airborne particles 44. The LIDAR system 1 transmits the pulsed electromagnetic signal 16A towards the measurement area 18 and receives a pulsed backscattered EM signal 15 comprising plurality of dispersed pulses 25A each having a first 34 and a second 35 polarization. Due to the weather condition the pulsed backscattered EM signal 15 comprises plurality of dispersed pulses 25 being polarized backscattered EM signals PB.

Fig 8A and 8B schematically illustrate an exemplary of a LIDAR system 1 emitting a pulsed electromagnetic signal 16A towards a measurement area 18. Fig 8a the LIDAR system is operating in a multi polarization mode, wherein a pulsed electromagnetic signal 16A comprising plurality of pulses 25 each having at least a first polarization 34 and at least a second polarization 35. This particular example is an illustration of a situation where the weather condition is harsh, and thereby, the measurement area 18 has a high concentration of airborne particles 44 being a mix of spherical and non-spherical particles. The LIDAR system 1 receives a pulsed backscattered EM signal 15 comprising plurality of dispersed pulses 25A being either a polarized backscattered EM signal PB or a depolarized backscattered EM signal DPB. Because of the non-spherical particles depolarization of the pulses occurs creating several cross-talks between the polarized backscattered EM signals and the depolarized backscattered EM signals.

Fig 8B schematically illustrates an exemplary of a LIDAR system 1 in a similar situation as in Fig. 8A, but this time the LIDAR system is operating in a single polarization mode. A pulsed electromagnetic signal 16A comprising pulses each having a first polarization emitted towards a measurement area 18. The measurement area 18 comprises airborne particles 44 being a mix of spherical and non-spherical particles, with a significant presence of non-spherical particles. A pulsed backscattered EM signal 15 is received comprising no cross talking between the dispersed pulses 25A, although, the pulsed backscattered EM signal 15 comprises polarized PB and depolarized DPB backscattered EM signals.

Thus, when the LIDAR system operates in the multi polarization mode and detecting cross-talk between the pulses in the pulsed backscattered EM signal 15, the LIDAR system may be switched to the single polarization mode to prevent cross-talking.

Fig. 9 illustrates a method for detecting at least a polarized PB and at least a depolarized DPB backscattered EM signals, comprising the steps of: emitting a coherent electromagnetic signal 17 or a pulsed coherent electromagnetic signal 19 (step S1); forming an electromagnetic signal 16 or a pulsed electromagnetic signal 16A, and transmitting the electromagnetic signal 16 or the pulsed electromagnetic signal 16A towards a measurement area 18 (step S2). If (49) emitting a pulsed coherent electromagnetic signal (17) at least one pulse 25 may be rotated to provide a polarized pulsed coherent electromagnetic signal 31, as illustrated in step S3.

The method further comprises a step of extracting the local oscillator signal 12 or pulsed local oscillator signal 13 (step S4), while a backscattered EM signal 14 or a pulsed backscattered EM signal 15 is received (step S5).

Further step include dividing/splitting the local oscillator signal 12 or the pulsed local oscillator signal 13 by a second polarization beam splitter 10 (step S6), and dividing the backscattered EM signal or the pulsed backscattered EM signal 15 by a first polarization beam splitter 8 (step S7).

The method also comprises the steps of dividing/splitting the first PL1 and the second PL2 polarized local oscillator signals, respectively, into first PL11 and second PL12 primary polarized local oscillator signals and first PL21 and second PL22 secondary polarized local oscillator signal (steps S8 and S9).

Afterwards, the method comprises dividing/splitting the first PB1 and the second PB2 polarized backscattered EM signals, respectively, into first PB11 and second

PB12 primary polarized backscattered EM signals and first PB21 and second PB22 secondary polarized backscattered EM signal (steps S10 and S11).

The method also comprises the steps of detecting and mixing the first primary polarized backscattered EM signal PB11 and the first primary polarized local oscillator signal PL11, the first secondary polarized backscattered EM signal PB21 and the first secondary local oscillator signal PL21 to provide a first MS1 and a third MS3 mixed signal MS3, respectively (steps S12 and S13)

After steps 12 and 13, the method comprises the steps of detecting and mixing the second primary polarized backscattered EM signal PB12 and the second primary polarized local oscillator signal PL12, and the second secondary polarized backscattered EM signal PB22 and the second secondary local oscillator signal PL22, the second primary local oscillator signal PL12 and the second secondary local oscillator signal PL22 being phase shifted 26 with respect to the first primary PL11 and first secondary local oscillator signals PL21, to provide a second MS2 and a fourth MS4 mixed signals, respectively (steps S14 and S15).

The methods may further comprise the steps of performing a cross correlation of at least the first (MS1) /second (MS2) mixed signals and at least the third (MS3) /fourth (MS4) mixed signals by a digital signal processing unit (30A) (step S16), and processing the mixed signals (MS1 - MS4) to provide an output comprising information from polarized (PB) and depolarized backscattered EM signal (DPB) (step S17).

Fig 10 schematically illustrates an exemplary LIDAR system 1 according to the invention, wherein the LIDAR system 1 is configured to emit a pulsed electromagnetic signal 16A and to receive a pulsed backscattered EM signal 15 comprising at least a polarized backscattered EM signal PB and/or at least a depolarized backscattered EM signal DPB. The LIDAR system 1 comprises an emitter 2 generating a coherent electromagnetic signal 17 which is divided by an emitter splitter 24 extracting a local oscillator signal 12.

The LIDAR system 1 comprises a third polarization beam splitter 50 configured to receive the coherent electromagnetic signal 17 and to divide the coherent electromagnetic signal 17 into a first polarized transmitter signal 52A and a second polarized transmitter signal 52B. The first polarized transmitter signal 52A comprises an optical continuous wave having a first polarization 34 being perpendicular to a second polarization 35 of an optical continuous wave of the second polarized transmitter signal 52B.

A first pulse shaper 53A and a second pulse shaper 53B receive the first polarized transmitter signal 52A and the second polarized transmitter signal 52B, respectively. Both pulse shapers (53A, 53B) convert the optical continuous waves of the first and the second polarized transmitter signal 52B into multiple pulses. Thereby, the first pulse shaper 53A is configured for transmitting a first polarized pulsed transmitter signal 54A and the second pulse shaper 53B is configured to transmit a second polarized pulsed transmitter signal 54B, respectively.

The first polarized pulsed transmitter signal 54A comprises multiple pulses with first polarization 34 and the second polarized pulsed transmitter signal 54B comprises multiple pulses with second polarization 35.

The first polarized pulsed transmitter signal 54A and the second polarized pulsed transmitter signal 54B are transmitted into a first optical amplifier 55A and a second optical amplifier 55B, respectively. The first and the second optical amplifier (55A, 55B) are configured to amplify and transmit the first and the second polarized pulsed transmitter signal (54A, 54B), respectively, into a first polarization beam combiner 57. The time delay between the two polarized pulses are fine tuned by the pulse shaper such that the pulses at the output of the polarization beam slitter are interleaved where the state of polarization alternates from pulse to pulse.

The first polarization beam combiner is configured to receive at least the first amplified polarized pulsed transmitter signal, and to transmit a polarized pulsed coherent electromagnetic signal 31 having at least a first polarization 34.

Alternatively, the first polarization beam combiner 57 is configured to receive the first amplified polarized pulsed transmitter signal 56A and the second amplified polarized pulsed transmitter signal 56B, and to transmit a polarized pulsed coherent electromagnetic signal 31 having a first polarization 34 and a second polarization 35.

In one or more embodiments, the first polarization beam combiner 57 is configured to receive the first amplified polarized pulsed transmitter signal 56A and/or the second amplified polarized pulsed transmitter signal 56B, and to transmit a polarized pulsed coherent electromagnetic signal 31 having a first polarization 34 and/or a second polarization 35.

A transmitting optical arrangement 4 receives the polarized pulsed coherent electromagnetic signal 31 and transmit a pulsed electromagnetic signal 16A comprising the polarized pulsed coherent electromagnetic signal 31.

A receiving optical arrangement 6 receives a pulsed backscattered signal 15 generated by the collision between airborne particles and the multiple pulses from the pulsed electromagnetic signal 16A. The receiving optical arrangement 6 is configured to forward the pulsed backscattered signal 15 to a first polarization beam splitter 8.

Fig. 10 the LIDAR system 1 comprising a processing of the local oscillator signal 12 and the pulsed backscattered EM signal 15 which is identical to the processing of the local oscillator signal 12 and pulsed backscattered signal 14, shown in Fig. 3.

Alternatively, the LIDAR system 1 comprising a processing of the local oscillator signal 12 and the pulsed backscattered EM signal 15 which is identical to the processing of the local oscillator signal 12 and pulsed backscattered signal 14, shown in Fig. 4 and Fig. 5.

Fig. 11 illustrates a method for detecting at least a polarized PB and at least a depolarized DPB backscattered EM signals, comprising the steps of: dividing S1A the coherent electromagnetic signal 17 into a first polarized transmitter signal 52A and a second polarized transmitter signal 52B, and pulse shaping (S1B, S1B') the first polarized transmitter signal 52A and the second polarized transmitter signal 52B into a first polarized pulse transmitter signal 54A and a second polarized pulse transmitter signal 54B, respectively.

Furthermore, the method comprises the step of amplifying S1C at least the first polarized pulse transmitter signal 54A into at least a first amplified polarized pulsed transmitter signal 56A, and receiving S1D at least the first amplified polarized pulsed transmitter signal 56A into a first polarized beam combiner 57. Furthermore, the method may comprise the step of transmitting S1E a polarized pulsed coherent electromagnetic 31 signal having at least a first polarization 34.

Alternatively, the method may comprise the step of amplifying S1C’ at least the second polarized pulse transmitter signal 54B into at least a second amplified polarized pulsed transmitter signal 56B, respectively, and receiving S1D’ at least the second amplified polarized pulsed transmitter signal 56B into a first polarized beam combiner 57. Furthermore, the method may comprise the step of transmitting S1E’ a polarized pulsed coherent electromagnetic signal 31 having at least a first polarization 34 and a second polarization 35.

Items

1	LIDAR system
2	Emitter
4	Transmitting optical arrangement
6	Receiving optical arrangement
8	First polarization beam splitter
10	Second polarization beam splitter
12	Local oscillator signal
13	Pulsed local oscillator signal
14	Backscattered EM signal
14A	First wavelength backscattered EM signal
14B	Second wavelength backscattered EM signal
15	Pulsed backscattered EM signal
16	Electromagnetic signal
16A	pulsed electromagnetic signal
16B	multi wavelengths electromagnetic signal
17	Coherent electromagnetic signal
18	Measurement area
19	Pulsed coherent electromagnetic signal
20	First splitter

20A	First coupler
21	second splitter
21A	Second coupler
22	third splitter
22A	Third coupler
23	Fourth splitter
23A	Fourth coupler
24	Emitter splitter
25	Pulse
25A	Dispersed pulse
26	Phase shifter
27	First phase shifter
28	Second phase shifter
29	Polarization rotator
30	Processor
30A	Digital signal processing unit
31	Polarized pulsed coherent electromagnetic signal
32	Optical amplifier
33	Pulse shaper
34	First polarization
35	Second polarization
36	First analog-to-digital processing component
37	Second analog-to-digital processing component
38	Third analog-to-digital processing component
39	Fourth analog-to-digital processing component
40	First adder
41	Second adder
43	Pulse period
44	Airborne particles
45	First input optical fiber
46	Second input optical fiber
47	Circulator
48	Optical insulator

49	If transmitting a pulsed coherent elec. signal 16A
50	Third polarization beam splitter
52A	First polarized transmitter signal
52B	Second polarized transmitter signal
53A	First pulse shaper
53B	Second pulse shaper
54A	First polarized pulsed transmitter signal
54B	Second polarized pulsed transmitter signal
55A	First optical amplifier
55B	Second optical amplifier
56A	First amplified polarized pulsed transmitter signal
56B	Second amplified polarized pulsed transmitter signal
57	First polarization beam combiner
S1A	Dividing the coherent electromagnetic
S1B	Pulse shaping the first polarized transmitter signal.
S1C	Amplifying at least the first polarized pulse transmitter signal into at least a first amplified polarized pulsed transmitter signal, respectively
S1D	Receiving at least the first amplified polarized pulsed transmitter signal
S1E	Transmitting a polarized pulsed coherent electromagnetic signal having at least a first polarization
S1B’	Pulse shaping the second polarized transmitter signal
S1C’	Amplifying at least the second polarized pulse transmitter signal into at least a second amplified polarized pulsed transmitter signal, respectively
S1D’	Receiving at least the second amplified polarized pulsed transmitter signal
S1E’	Transmitting a polarized pulsed coherent electromagnetic signal having at least a first polarization and at least a second polarization
FW	Pulse width
DPB	Depolarized backscattered EM signal
PB	Polarized backscattered EM signal
PB1	First polarized backscattered EM signal
PB2	Second polarized backscattered EM signal
PB11	First primary polarized backscattered EM signal

PB12	Second primary polarized backscattered EM signal
PB21	First secondary polarized backscattered EM signal
PB22	Second secondary polarized backscattered EM signal
PL	Polarized local oscillator signal
PL1	First polarized local oscillator signal
PL2	Second polarized local oscillator signal
PL11	First primary polarized local oscillator signal
PL12	Second primary polarized local oscillator signal
PL21	First secondary polarized local oscillator signal
PL22	Second secondary polarized local oscillator signal
DM1	First detector and mixer
DM2	Second detector and mixer
DM3	Third detector and mixer
DM4	Fourth detector and mixer
BDM1	First balanced detector and mixer
BDM2	Second balanced detector and mixer
BDM3	Third balanced detector and mixer
BDM4	Fourth balanced detector and mixer
MS1	First mixed signal
MS2	Second mixed signal
MS3	Third mixed signal
MS4	Fourth mixed signal

CLAIMS

1. A LIDAR system (1) for detection of polarized (PB) and de-polarized backscattered (DPB) electromagnetic (EM) signals, the LIDAR system (1) comprising:

an emitter (2) for emission of a coherent EM signal (17);

a transmitting optical arrangement (4) configured to transmit an EM signal (16) towards a measurement area (18);

a receiving optical arrangement (6) for receiving a backscattered EM signal (14) from the measurement area (18), and

at least a first (8) and a second (10) polarizing beam splitter,

the first polarizing beam splitter (8) being configured to receive the backscattered EM signal (14) and to split the backscattered EM signal (14) into a first polarized backscattered EM signal (PB1), and a second polarized backscattered EM signal (PB2),

the second polarizing beam splitter (10) being configured to receive a local oscillator signal (12), the local oscillator signal (12) being extracted from the coherent electromagnetic signal 17, and to split the local oscillator signal (12) into a first polarized local oscillator signal (PL1) and a second polarized local oscillator signal(PL2),

the LIDAR system further comprising:

a first detector and mixer (DM1) and a third detector and mixer (DM3) for receiving a first primary polarized backscattered EM signal (PB11) and a first secondary polarized backscattered EM signal (PB21), respectively, and a first primary polarized local oscillator signal (PL11) and a first secondary local oscillator signal (PL21), respectively, the first detector and mixer (DM1) and the third detector and mixer (DM3) being configured to output a first mixed signal (MS1) and the third mixed signal (MS3), respectively, a second detector and mixer (DM2) and a fourth detector and mixer (DM4) for receiving a second primary polarized backscattered EM signal (PB12) and a second secondary polarized backscattered EM signal (PB22), respectively, and a second primary polarized local oscillator signal (PL12) and a second secondary local oscillator signal (PL22), the second primary local oscillator signal (PL12) and the second secondary local oscillator signal (PL22) being phase shifted with respect to the first primary and first secondary local oscillator signals (PL11 and PL21), the second detector and mixer (DM2) and the fourth detector and mixer (DM4) being configured to output a second (MS2) mixed signal and a fourth mixed (MS4) signal, respectively,

a processor (30) configured to receive at least the first (MS1), second (MS2), third (MS3) and fourth (MS4) mixed signal, and to perform a cross correlation of the first (MS1)/second (MS2) mixed signal and the third (MS3)/fourth (MS4) mixed signal to provide an output comprising information from polarized (PB) and depolarized backscattered (DPB) EM signal.

2. The LIDAR system (1) according to claim 1, wherein the LIDAR system (1) comprises a pulse shaper (33) configured to receive the coherent electromagnetic signal (17) and transmit a pulsed coherent electromagnetic signal (19).

3. The LIDAR system (1) according to claim 2, wherein the LIDAR system (1) comprises a polarization rotator (29) configured to receive the pulsed coherent electromagnetic signal (19) and transmit a polarized pulsed coherent electromagnetic signal (31) having at least a first polarization (34).

4. The LIDAR system (1) according to claim 1, wherein the LIDAR system (1) comprises:

a third polarization beam splitter configured to receive the coherent electromagnetic signal (17), and to transmit a first polarized transmitter signal (52A) and a second polarized transmitter signal (52B), a first pulse shaper (53A) and a second pulse shaper (53B) for receiving the first polarized transmitter signal (52A) and the second polarized transmitter signal (52B), respectively, and for transmitting a first polarized pulsed transmitter signal (54A) and a second polarized pulsed transmitter signal (54B), respectively,

a first optical amplifier (55A) and a second optical amplifier (55B) configured to receive the first polarized pulsed transmitter signal (54A) and the second polarized pulsed transmitter signal (54B), respectively, and to transmit of a first (56A) and a second amplified polarized pulsed transmitter signal (56B), respectively,

a first polarization beam combiner (57) configured to receive at least the first amplified polarized pulsed transmitter signal (56A), and to transmit a polarized pulsed coherent electromagnetic signal (31) having at least a first polarization (34).

5. The LIDAR system (1) according to any of the preceding claims, wherein a first slow axis of the first polarizing beam splitter (8) is aligned 0° with the slow axis of a first input optical fiber (45), and a second slow axis of the second polarizing beam splitter (10) is aligned 45° with a second input optical fiber (46).

6. The LIDAR system (1) according to any of the preceding claims, wherein the LIDAR system (1) comprises a first coupler (20A) and a third coupler (22A) configured to divide the first (PB1) and second (PB2) polarized backscattered EM signals into first primary (PB11) and first secondary (PB21) polarized backscattered EM signal and into second primary (PB12) and second secondary (PB22) polarized backscattered EM signals, respectively.

7. The LIDAR system (1) according to any of the preceding claims, wherein the LIDAR system (1) comprises at least a second (21A) and a fourth coupler (23A) configured to divide the first (PL1) and second (PL2) polarized local oscillator signals into first primary (PL11) and first secondary (PL21) polarized local oscillator signal and into second primary (PL12) and second secondary (PL22) polarized local oscillator signals, respectively.

8. The LIDAR system (1) according to any of the preceding claims, wherein the transmitting optical arrangement (4) and the receiving optical arrangement (6) are combined in a circulator (47) or an optical insulator (48) configuring to receive the

coherent electromagnetic signal (17) and to transmit the electromagnetic signal (16) towards a measurement area (18), and to receive the backscattered EM signal (14) from the measurement area (18) and transmit the backscattered EM signal (14) to the first polarizing beam splitter (8).

9. The LIDAR system (1) according to any of the preceding claims, wherein the first (DM1), the second (DM2), the third (DM3) and the fourth detector and mixer (DM4), respectively, may be a first (BDM1), a second (BDM2), a third (BDM3) and a fourth (BDM4) balanced detector and mixer.

10. The LIDAR system (1) according to any of the preceding claims, wherein the emitter (2) comprises a laser, such as a gas laser, a NdYAG laser, a chemical laser, a dye laser, a metal-vapor laser, a solid-state laser, a semiconductor laser, a super continuum laser, a Raman laser, or a fiber laser.

11. The LIDAR system (1) according to any of the preceding claims, wherein the LIDAR system (1) comprises polarization maintaining fibers and polarization maintaining components.

12. A method for detecting polarized (PB) and depolarized DPB backscattered EM signals in a LIDAR system (1), the method comprising:

emitting (S1) a coherent electromagnetic signal (17),

transmitting (S2) the electromagnetic signal (16) towards a measurement area (18) via a transmitting optical arrangement (4),

receiving (S5) a backscattered EM signal (14) from the measurement area (18) by a first polarizing beam splitter (8), and splitting (S7) the backscattered EM signal (14) into a first polarized backscattered EM signal (PB1) and a second polarized backscattered EM signal (PB2),

extracting (S4)a local oscillator signal (12) from the emitted coherent electromagnetic signal (17), receiving the local oscillator signal (12) by a second polarizing beam splitter (10), and splitting (S6) the local oscillator signal (12) into a first polarized local oscillator signal (PL1) and a second polarized local oscillator signal (PL2),

dividing (S10, S11) the first (PB1) and the second (PB2) polarized backscattered EM signals into a first (PB11) and a second primary (PB12) polarized backscattered EM signal and a first (PB21) and a second secondary (PB22) polarized backscattered EM signal, respectively,

dividing (S8, S9) the first (PL1) and the second (PL2) polarized local oscillator signals into a first (PL11) and a second (PL12) primary polarized local oscillator signal and a first (PL21) and a second (PL22) secondary polarized local oscillator signal, respectively,

detecting and mixing (S12,S13) the first primary polarized backscattered EM signal (PB11) and the first primary polarized local oscillator signal (PL11), and the first secondary polarized backscattered EM signal (PB21) and the first secondary local oscillator signal (PL21) to provide a first (MS1) and a third mixed signal (MS3), respectively,

detecting and mixing (S14, S15) the second primary polarized backscattered EM signal (PB12) and the second primary polarized local oscillator signal (PL12), and the second secondary polarized backscattered EM signal (PB22) and the second secondary local oscillator signal (PL22) to provide a second (MS2) and a fourth (MS4) mixed signals, respectively, the second primary local oscillator signal (PL12) and the second secondary local oscillator signal (PL22) being phase shifted with respect to the first primary (PL11) and first secondary local oscillator signals (PL21),

receiving at least the first (MS1), second (MS2), third (MS3) and fourth (MS4) mixed signals in a processor (30), and

performing a cross correlation (S16) of at least the first (MS1) /second (MS2) mixed signals and at least the third (MS3) /fourth (MS4) mixed signals to provide an output comprising information from polarized (PB) and depolarized backscattered EM signal (DPB).

13. The method according to claim 12, further comprising the step of pulse shaping (S2) the coherent electromagnetic signal (17) and transmitting a pulsed coherent electromagnetic signal (19) by a pulse shaper (33).

14. The method according to any of claims 12 to 13, further comprising the step of rotating the polarization (S3) of the pulsed electromagnetic signal (16A) to provide a polarized pulsed coherent electromagnetic signal (31) by a polarization rotator (29).

15. The method according to claim 12, further comprising the step of:

dividing the coherent electromagnetic signal into a first polarized transmitter signal (52A, S1A) and a second polarized transmitter signal (52B, S1A),

pulse shaping the first polarized transmitter signal (52A, S1B) and the second polarized transmitter signal (52B, S1B’) into a first polarized pulse transmitter signal (54A, S1B) and a second polarized pulse transmitter signal (54B, S1B’), respectively,

amplifying at least the first polarized pulse transmitter signal (54A, S1C) into at least a first amplified polarized pulsed transmitter signal (56A, S1C), respectively,

receiving at least the first amplified polarized pulsed transmitter signal (56A, S1D) into a first polarized beam combiner (57, S1D), and

transmitting a polarized pulsed coherent electromagnetic signal (31, S1E) having at least a first polarization (34).

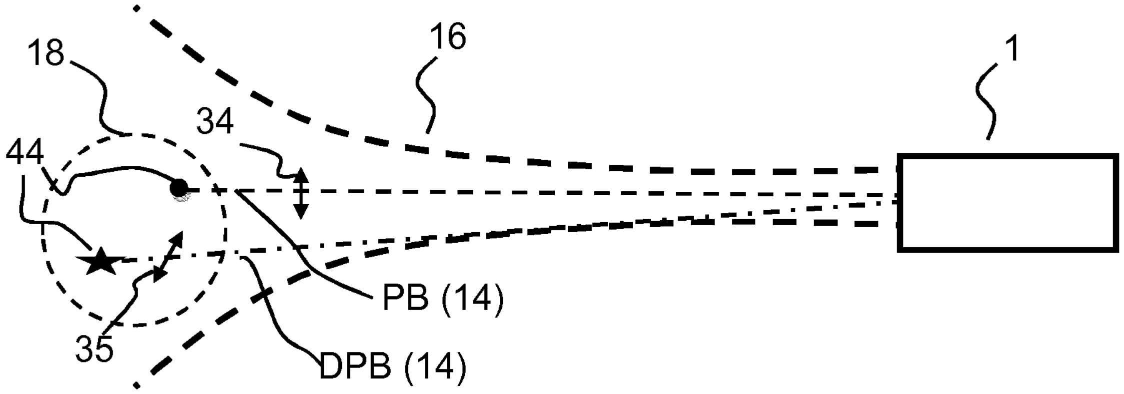


Fig. 1A

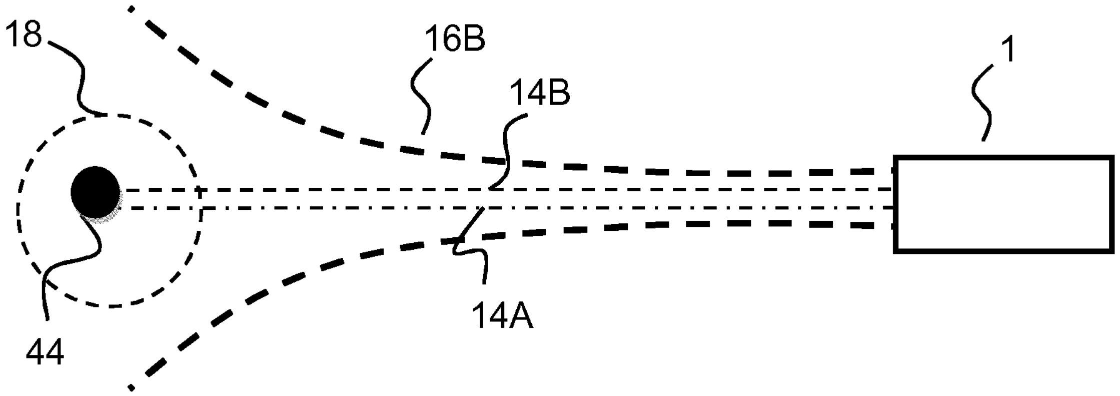


Fig. 1B

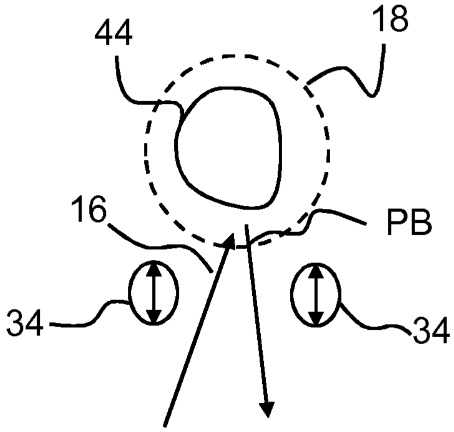


Fig 2A

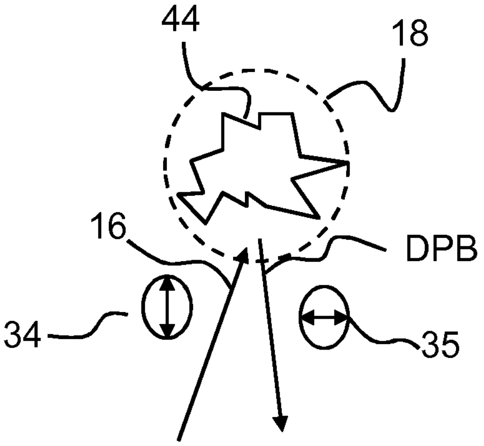


Fig. 2B

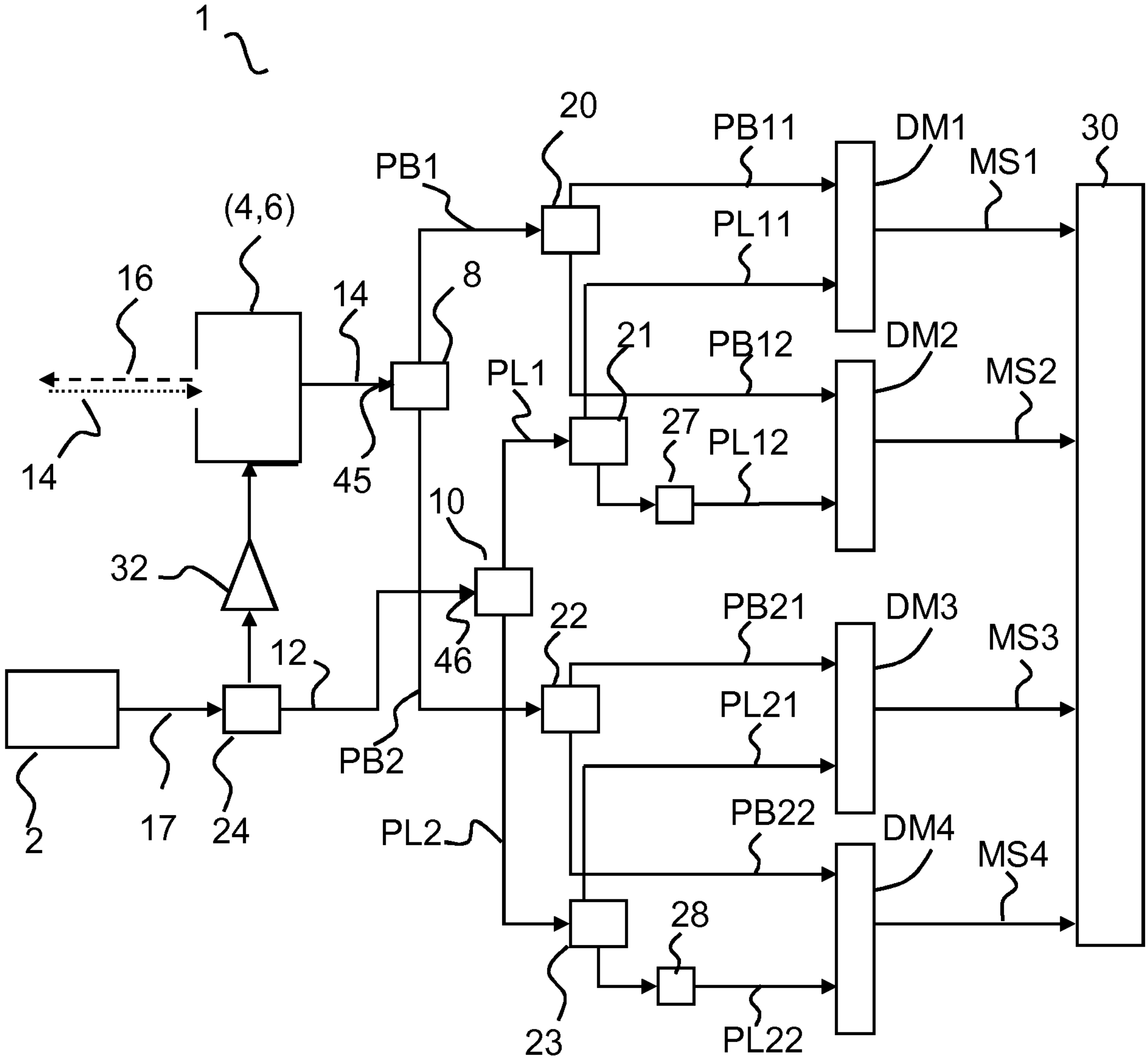
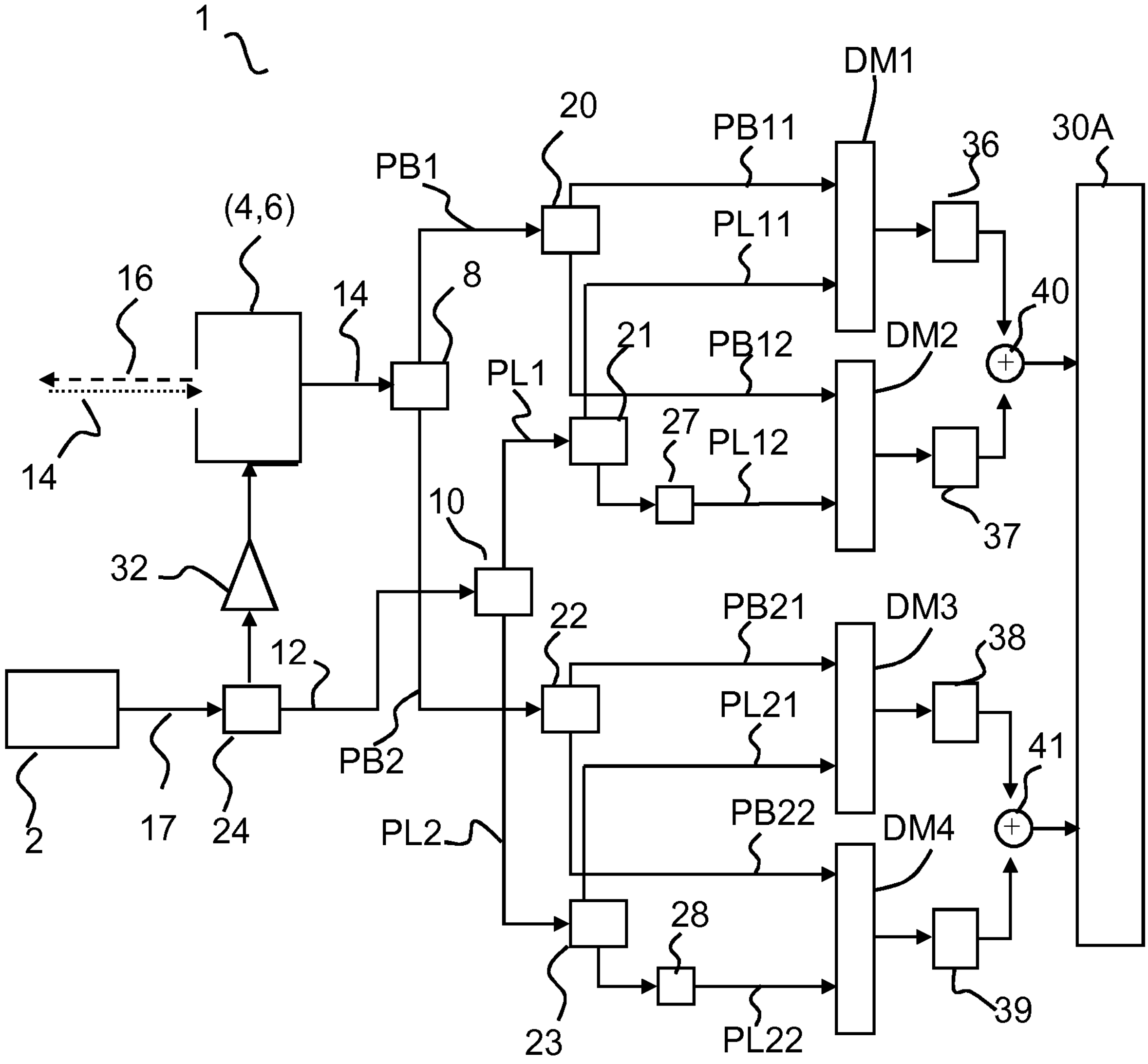

1
20
PB11
DM1
30
PB1
MS1
(4,6)
PL11
16
14
8
21
PB12
DM2
MS2
PL1
27
PL12
14
45
10
32
22
PB21
DM3
12
MS3
46
PL21
PB2
2
17
24
PL2
PB22
DM4
MS4
28
23
PL22

Fig. 3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16
14
14
8
PB1
20
PB11
DM1
36
30A
PL11
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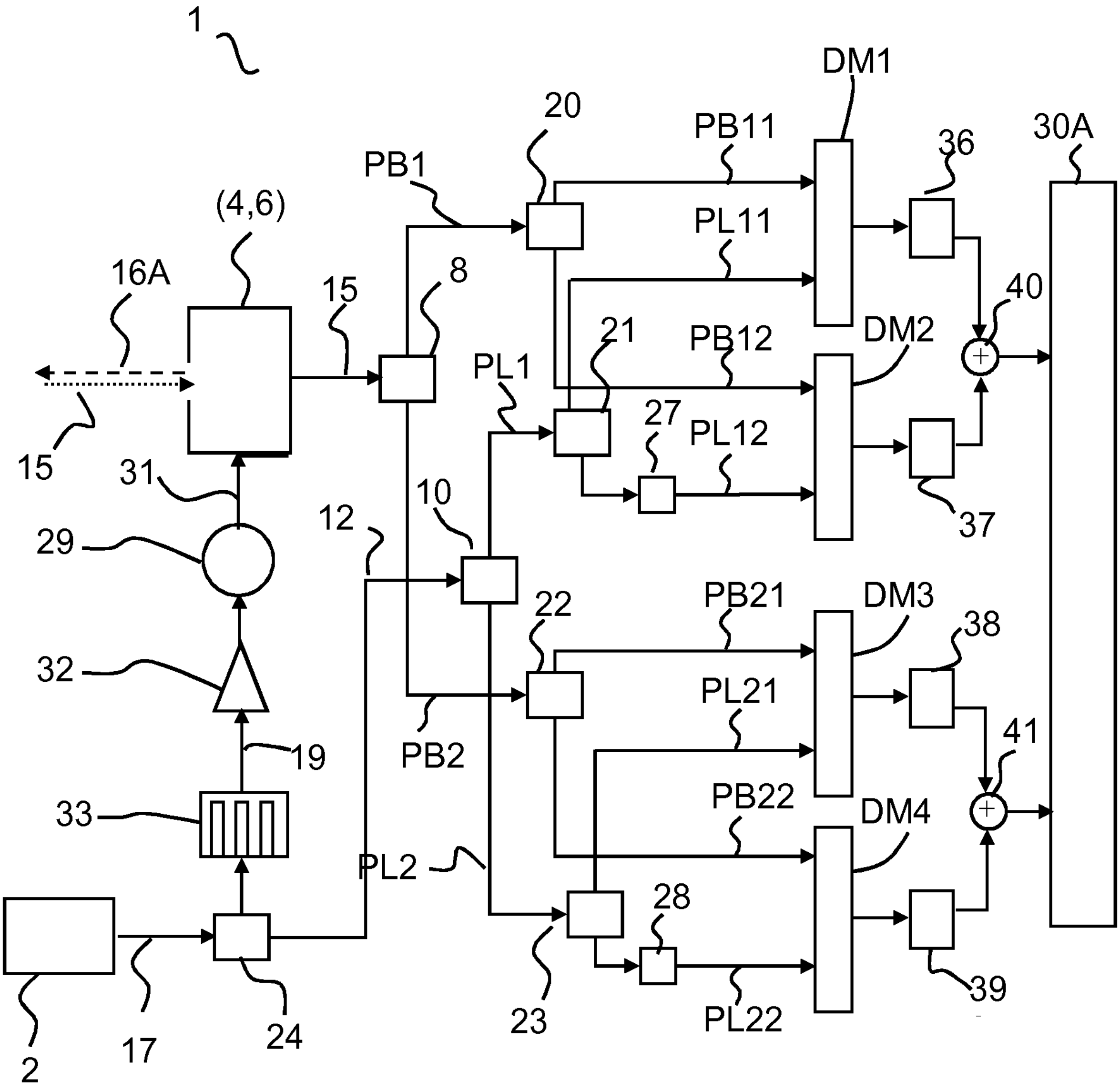
PB12
DM2
PL1
27
PL12
37
10
32
22
PB21
DM3
38
12
PL21
41
2
17
24
PB2
PL2
PB22
DM4
28
23
PL22
39

Fig. 4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16A
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19
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PB11
DM1
36
30A
PL11
40
21
PB12
DM2
PL1
27
PL12
10
37
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PB21
DM3
38
PB2
PL21
41
PB22
DM4
PL2
28
23
PL22
39

Fig. 5

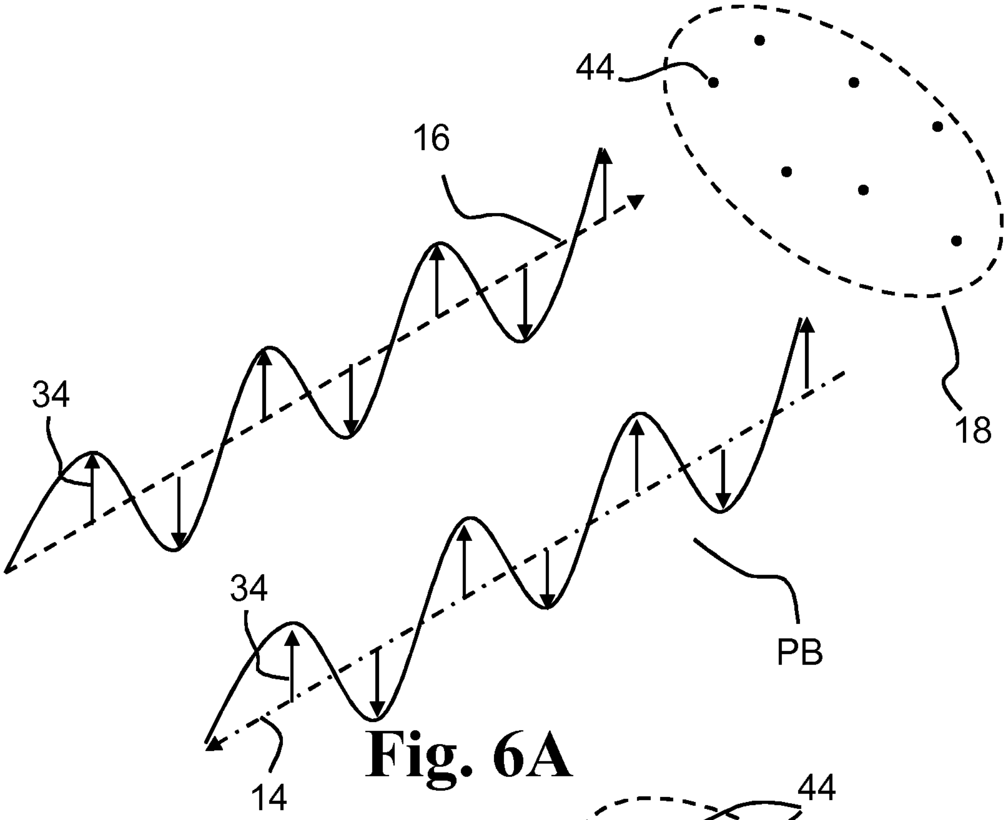


Fig. 6A

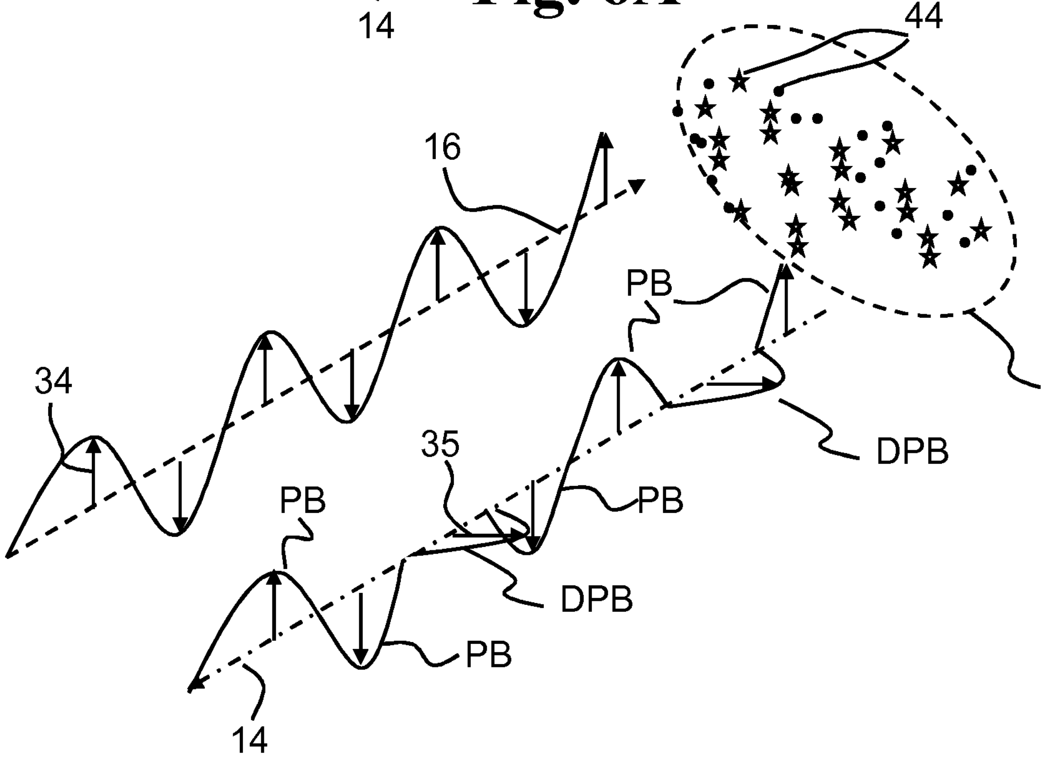


Fig. 6B

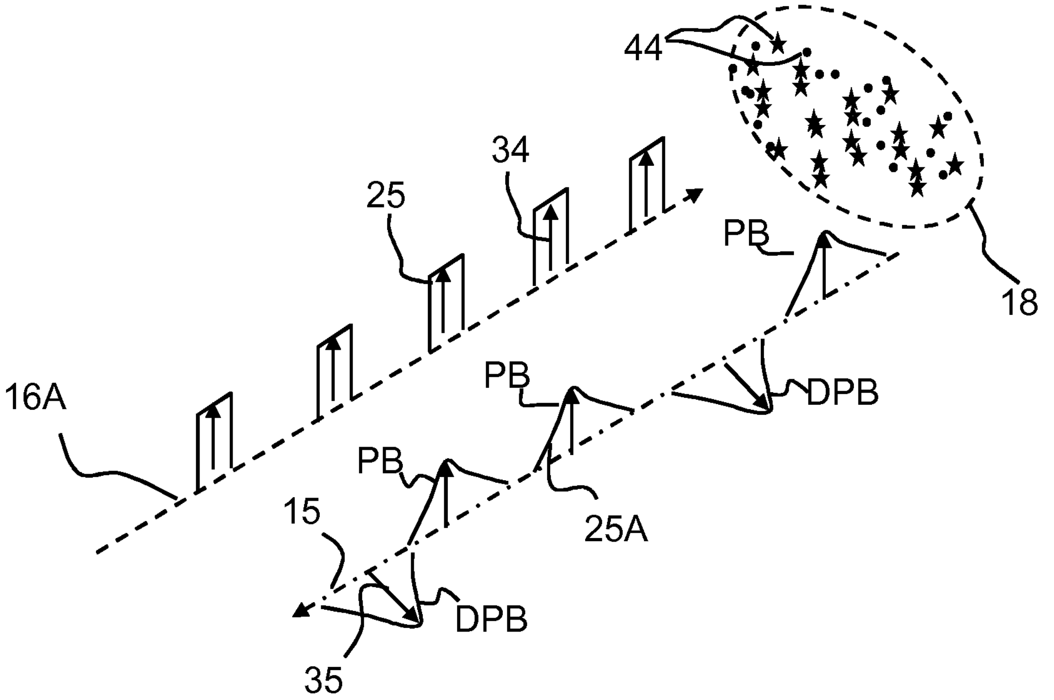
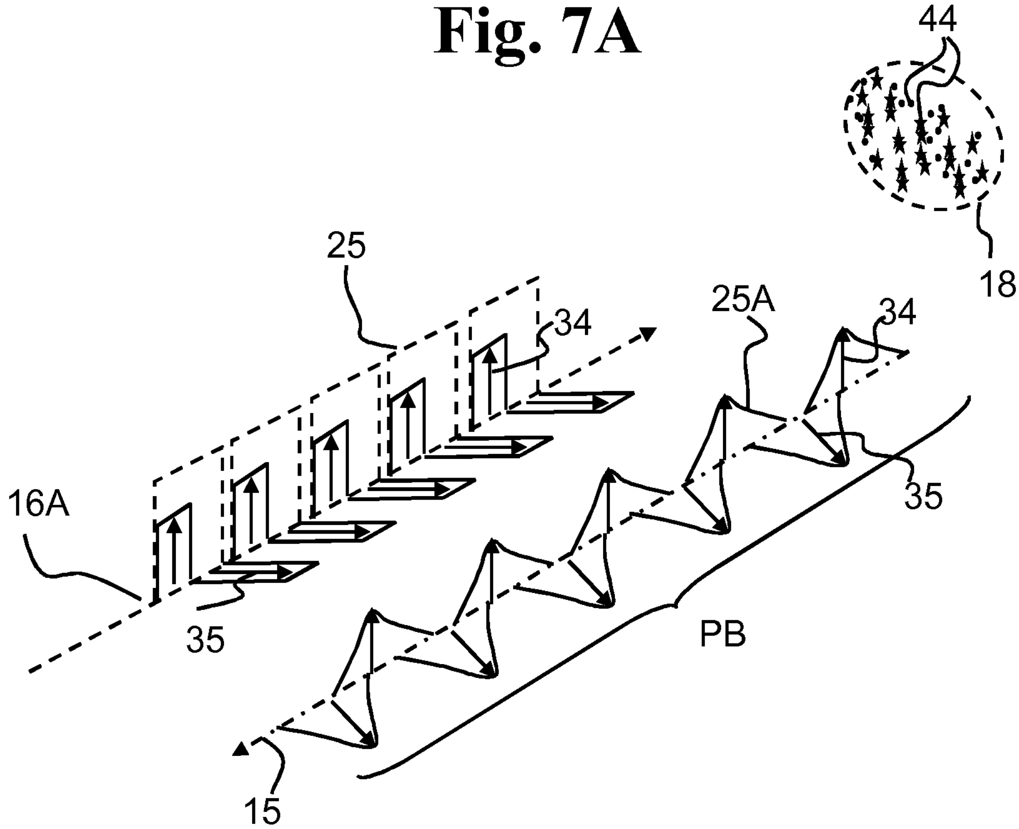

44
34
25
PB
18
16A
PB
DPB
PB
25A
15
DPB
35

Fig. 7A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25
34
25A
34
18
16A
35
35
PB
15

Fig. 7B

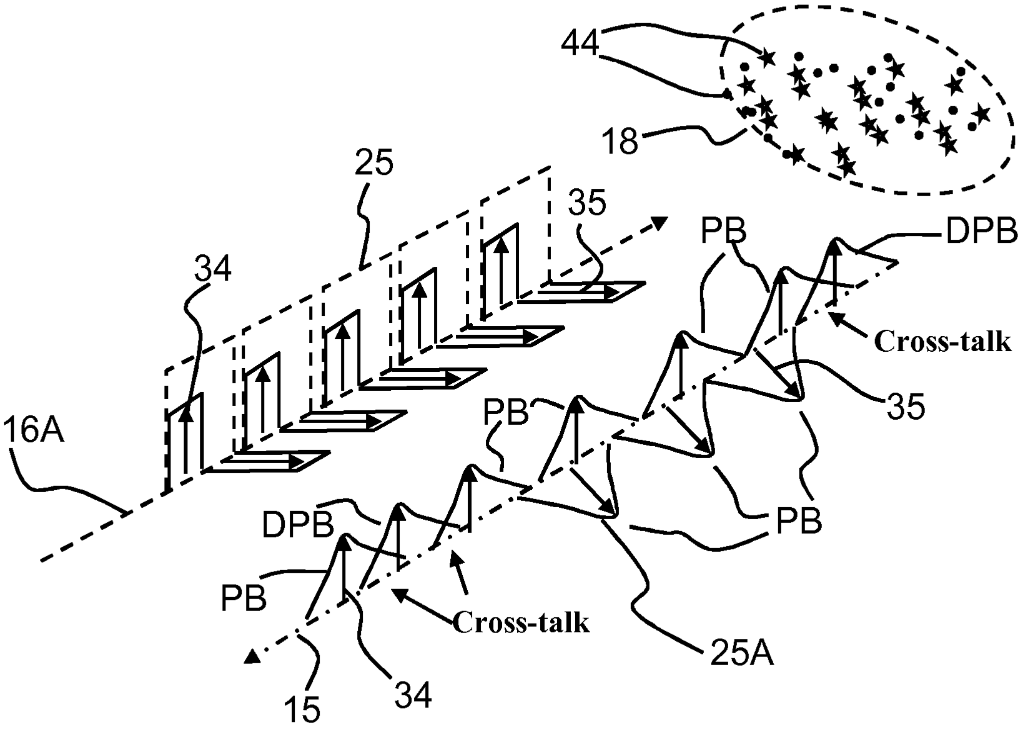
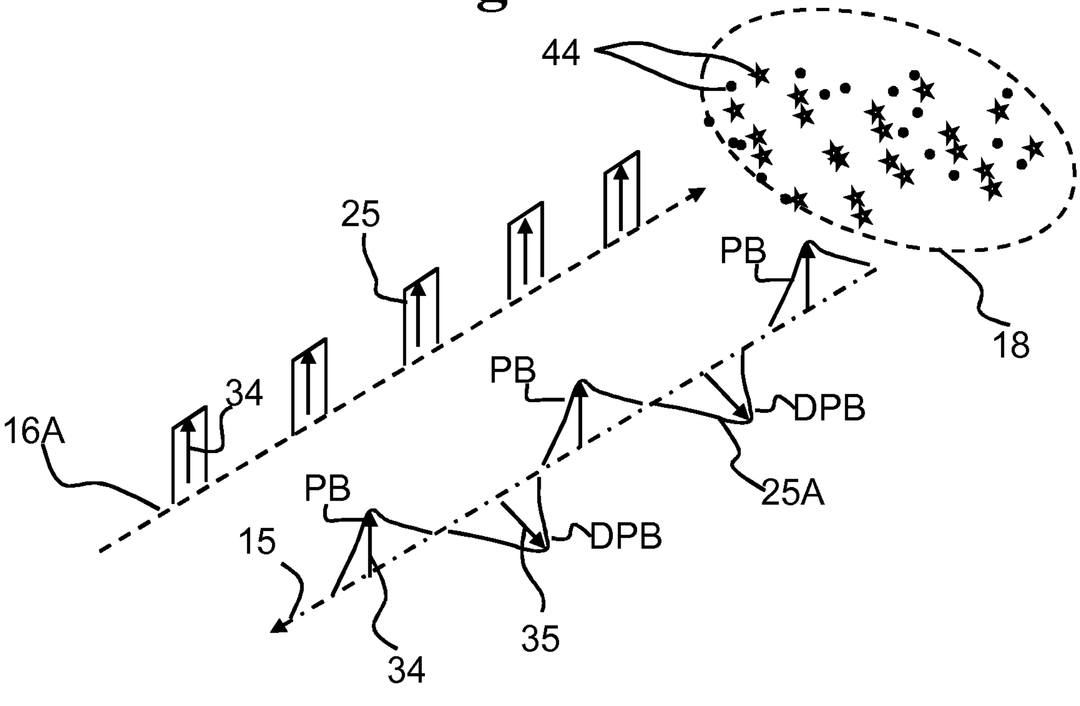

44
18
25
35
34
PB
DPB
Cross-talk
16A
PB
35
PB
DPB
PB
PB
Cross-talk
25A
15
34

Fig. 8A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25
PB
18
34
16A
PB
DPB
25A
PB
DPB
15
35
34

Fig. 8B

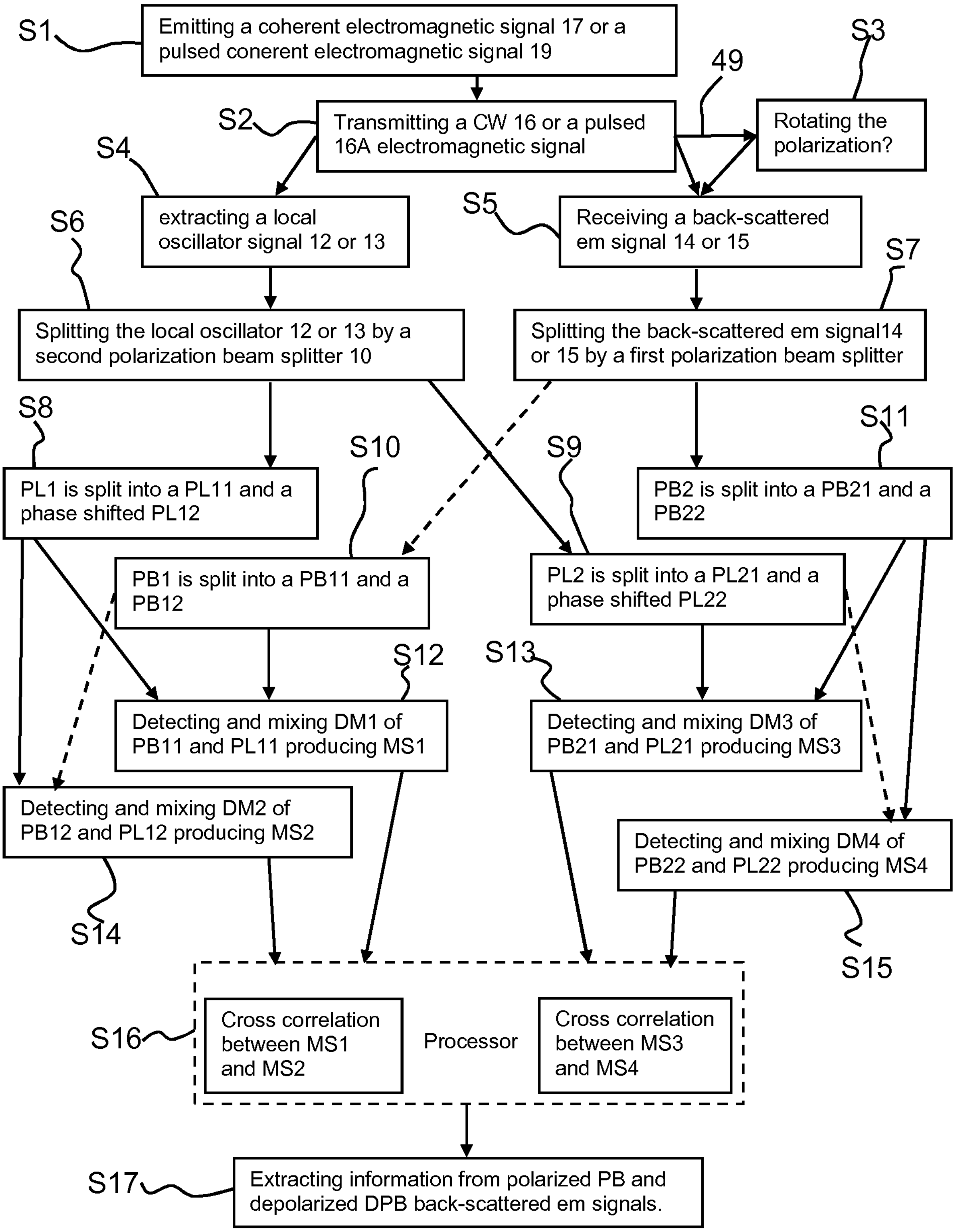
S1
Emitting a coherent electromagnetic signal 17 or a pulsed conerent electromagnetic signal 19
S2
Transmitting a CW 16 or a pulsed 16A electromagnetic signal
49
S3
Rotating the polarization?
S4
extracting a local oscillator signal 12 or 13
S5
Receiving a back-scattered em signal 14 or 15
S6
Splitting the local oscillator 12 or 13 by a second polarization beam splitter 10
S7
Splitting the back-scattered em signal14 or 15 by a first polarization beam splitter
S8
PL1 is split into a PL11 and a phase shifted PL12
S10
S9
S11
PB2 is split into a PB21 and a PB22
PB1 is split into a PB11 and a PB12
PL2 is split into a PL21 and a phase shifted PL22
S12
S13
Detecting and mixing DM1 of PB11 and PL11 producing MS1
Detecting and mixing DM3 of PB21 and PL21 producing MS3
Detecting and mixing DM2 of PB12 and PL12 producing MS2
Detecting and mixing DM4 of PB22 and PL22 producing MS4
S14
S15
S16
Cross correlation between MS1 and MS2
Processor
Cross correlation between MS3 and MS4
S17
Extracting information from polarized PB and depolarized DPB back-scattered em signals.

Fig. 9

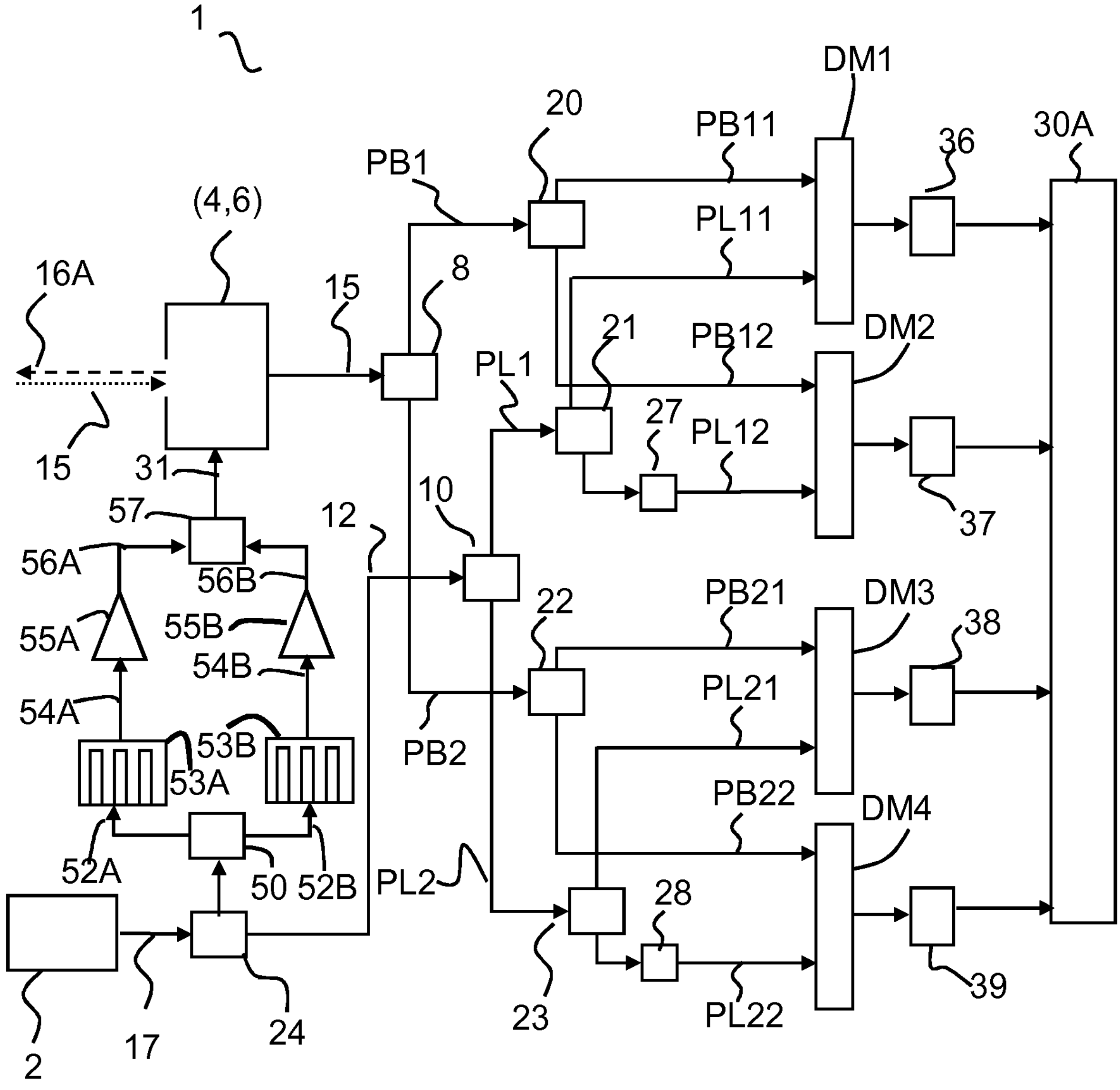
1
(4,6)
16A
15
15
31
8
PB1
20
PB11
DM1
36
30A
PL11
21
PB12
DM2
PL1
27
PL12
37
10
12
57
56A
56B
55A
55B
54B
54A
53B
53A
52A
50
52B
PL2
2
17
24
22
PB21
DM3
38
PL21
PB2
PB22
DM4
23
28
PL22
39

Fig. 10

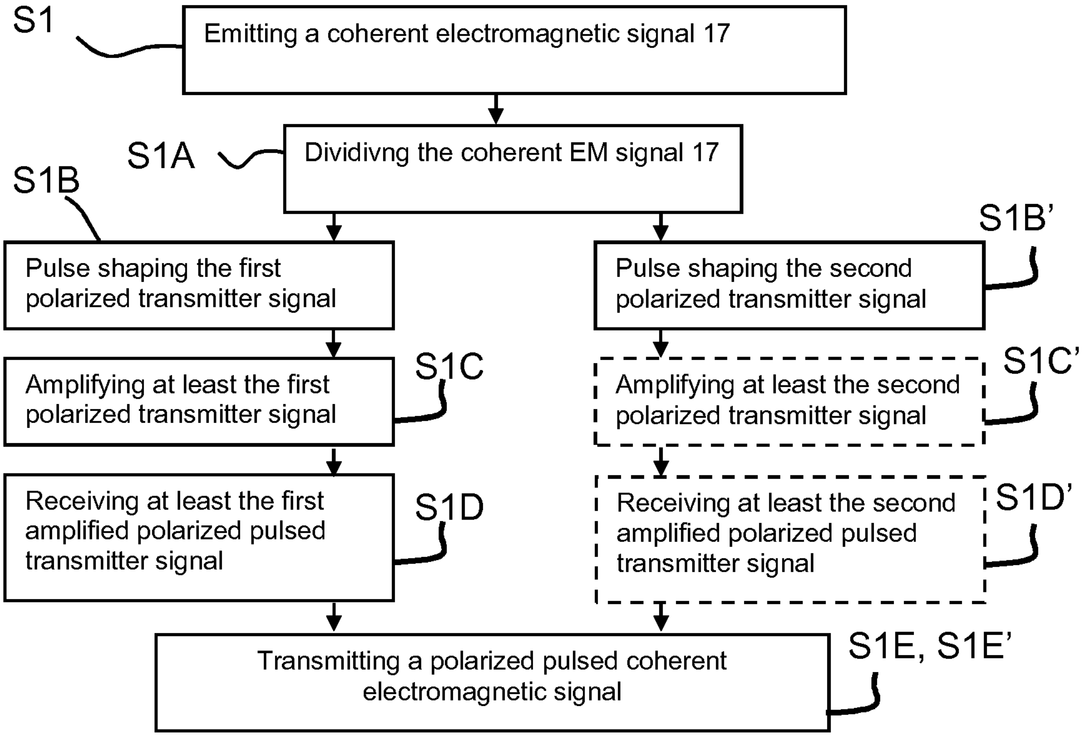
S1
Emitting a coherent electromagnetic signal 17
S1A
Dividivng the coherent EM signal 17
S1B
Pulse shaping the first polarized transmitter signal
S1B’
Pulse shaping the second polarized transmitter signal
S1C
Amplifying at least the first polarized transmitter signal
S1C’
Amplifying at least the second polarized transmitter signal
S1D
Receiving at least the first amplified polarized pulsed transmitter signal
S1D’
Receiving at least the second amplified polarized pulsed transmitter signal
S1E, S1E’
Transmitting a polarized pulsed coherent electromagnetic signal

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/070651

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S17/88 G01S7/499 G01S7/48 G01S7/491 G01S17/58
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)
G01S

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005/083513 A1 (ROGERS PHILIP L [US]) 21 April 2005 (2005-04-21) paragraphs [0013] - [0031]; figures 1,2 -----	1-15
Y	MATTHEW MCGILL ET AL: "Cloud Physics Lidar: Instrument Description and Initial Measurement Results", APPLIED OPTICS, vol. 41, no. 18, 20 June 2002 (2002-06-20), page 3725, XP055031173, ISSN: 0003-6935, DOI: 10.1364/AO.41.003725 page 3726; figure 1 ----- -/--	1-15

☒ 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 15 January 2015	Date of mailing of the international search report 26/01/2015
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Damp, Stephan

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SATOSHI TSUKAMOTO ET AL: "Optical Homodyne Receiver Comprising Phase and Polarization Diversities with Digital Signal Processing", PROCEEDINGS / ECOC 2006, 32ND EUROPEAN CONFERENCE ON OPTICAL COMMUNICATION : 24 - 28 SEPTEMBER 2006, CANNES, FRANCE, SEE, PARIS, FRANCE, 24 September 2006 (2006-09-24), pages 1-2, XP031437001, ISBN: 978-2-912328-39-7 page 1; figure 1 -----	1-15
Y	CHUNHUI WANG ET AL: "<title>Investigation of balanced detection and receiver for coherent lidar</title>", PROCEEDINGS OF SPIE, vol. 7382, 3 July 2009 (2009-07-03), pages 73820I-73820I-8, XP055105874, ISSN: 0277-786X, DOI: 10.1117/12.829459 pages 1-3; figure 3 -----	1-15
Y	JOHN E YORKS ET AL: "Statistics of depolarization ratio from an airborne backscatter lidar", GEOSCIENCE AND REMOTE SENSING SYMPOSIUM (IGARSS), 2010 IEEE INTERNATIONAL, IEEE, PISCATAWAY, NJ, USA, 25 July 2010 (2010-07-25), pages 2579-2582, XP031815212, ISBN: 978-1-4244-9565-8 page 1 -----	1-15
Y	YONGHANG SHEN ET AL: "PPMgLN-Based High-Power Optical Parametric Oscillator Pumped by Yb-Doped Fiber Amplifier Incorporates Active Pulse Shaping", IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 15, no. 2, 1 March 2009 (2009-03-01), pages 385-392, XP011254851, ISSN: 1077-260X the whole document -----	1-15
Y	US 7 580 127 B1 (MAYOR SHANE [US] ET AL) 25 August 2009 (2009-08-25) columns 11,12,21 ----- -/--	1-15

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	LIN F-Y ET AL: "Chaotic Lidar", IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 10, no. 5, 1 September 2004 (2004-09-01), pages 991-997, XP011123126, ISSN: 1077-260X, DOI: 10.1109/JSTQE.2004.835296 the whole document -----	1-15

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/070651

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005083513 A1	21-04-2005	US 2005083513 A1 US 2008024756 A1	21-04-2005 31-01-2008
US 7580127 B1	25-08-2009	NONE	