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(54) Title: LASER DOPPLER VELOCIMETER WITH EDGE FILTER DEMODULATION

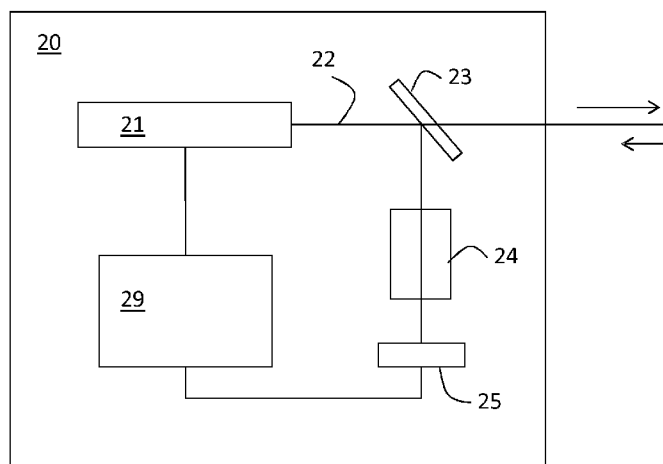


Fig. 2

(57) Abstract: The invention relates to a velocimeter and a method for determining the speed of a target. The velocimeter comprises a laser source comprising a laser cavity for producing a continuous-wave laser beam, a light detector, and means for directing a first portion of the laser beam to a moving target outside the velocimeter for producing scattered light from the target, the scattered light exhibiting a Doppler shift corresponding to the speed of the moving target. Further, the velocimeter comprises means for guiding scattered light back to the laser cavity for providing frequency-modulation of the laser beam through perturbation in the laser source, and means for guiding a second portion of the laser beam to the light detector. According to the invention, there is further provided an optical edge filter adapted to demodulate said frequency-modulated laser beam before guiding to the light detector and wherein said laser source is adapted to produce laser light at a wavelength corresponding to the wavelength of the edge of the optical edge filter. The invention improves the sensitivity of self-mixing velocimeters.

Laser Doppler Velocimeter with Edge Filter Demodulation

Field of the Invention

The invention relates to measuring the speed of a target, such as wind, or the speed of any other gas flow. In particular, the invention relates to laser Doppler velocimeters and
5 anemometers. The invention produces a new velocimeter and a new method of measuring the speed of a target from a distance using laser light.

Background of the Invention

Laser Doppler anemometers (LDA) or velocimeters (LDV) are well known. They are based on directing laser light to a moving object or moving particles such that the light is
10 reflected or scattered from the object or particles. The reflected or scattered light experiences a Doppler shift in its frequency, depending on the velocity of the object or particles. There exists many variations of the LDAs.

In one exemplary implementation of an LDA, a laser beam is produced as divided into two coherent beams, which are directed to the object or particles at different angles so as to
15 produce an interference pattern with equally spaced fringes that are parallel to the bisector of the beams. A particle flow passing the fringes, reflects or scatters light with variable amplitude with a frequency corresponding to the velocity of the particles normal to the fringes.

In another implementation of LDA, a laser beam is optically divided into a first reference
20 beam kept inside the anemometer or at least not directed to the object and a second beam directed to the object being measured. The second beam is scattered in the object and scattered light is guided to a detector, where it is measured. If the particles are moving, they produce a Doppler shift to the scattered beam, which can be measured in relation to the reference beam. The speed of motion of the particles can be calculated from the
25 magnitude of the Doppler shift.

Lading et al. disclose some further LDA detection methods in US 6,320,272 along with ways how to use wind speed information to maximize the output in connection with minimizing the wear of a wind turbine. This technique comprises directing a laser beam to the target and feeding light power collected from the second beam directly into the laser
5 itself, whereby it will perturb the power output. The technique can therefore be called a self-mixing or autodyne technique. Prior solutions that use this approach detect the Doppler shift from amplitude of the disturbed laser radiation or from the current that the laser passes through itself. Although providing some advantages, the disclosed implementations of the technique are not optimal as concern the sensitivity of the
10 anemometer.

Thus, there exists a need for improved velocimeters, and in particular anemometers.

Summary of the Invention

It is an aim of the invention to provide a velocimeter, in particular anemometer, with increased sensitivity.

15 Another aim is to provide a sensitive anemometric measurement method.

A particular aim is to provide a sensitive anemometer which can be implemented with relatively inexpensive equipment.

The invention is based on the laser Doppler shift principle utilized in an improved measurement setup including an optical edge filter combined with self-mixing at the laser
20 source so as to achieve the goal of improved sensitivity. More specifically, the initial continuous-wave laser light is scattered back from particles in the target, such as gas flow, with a Doppler shift in its radiation frequency. Scattered light is guided to the laser cavity for providing frequency modulation to the initial laser beam. A second portion of the frequency-modulated laser beam is guided to an optical edge filter providing demodulation
25 of the frequency modulation due to this self-mixing in the laser source by amplitude-modulation. The signal resulting from this frequency-modulation-to-amplitude-modulation process is detected at a detector. Provided that the wavelength of the laser source is correctly adjusted to correspond the properties of the edge filter, the resulting signal is an alternating amplitude signal, whose frequency is proportional to the Doppler shift and

therefore the speed of the target. The amplitude of the resulting signal is dependent inter alia on the properties of the edge filter.

More specifically, the invention is defined in the independent claims.

The invention provides considerable advantages. First, the frequency of the resulting signal is extremely sensitive to the magnitude of Doppler shift, whereby the speed of the target can be accurately measured. This is because the optical edge filter, provided that it is steep enough, magnifies the effect of the Doppler shift by adding demodulation of the frequency disturbance caused by the mixing of backscatter in the laser cavity. This kind of detection through demodulation is novel and beneficial in relation to known direct laser source amplitude or laser current-based detection methods, since the signal-to-noise ratio is much better.

The frequency signal is also inherently accurate, whereby neither complex calibration procedures nor signal processing are needed to obtain a reliable result.

Further, the cost of instrumentation is very low, since it may be constructed from basic optical and electronic parts with only one laser source, one beam divider/sampler, one edge filter, one detector etc. In particular, only one detector with associated preamplifier and signal processing instrumentation is needed, because laser power is not split into two portions to be measured, as in some prior art solutions. The outgoing laser wavelength is locked by the measurement channel, low-pass filtered at a frequency below the Doppler frequency. The detector can be an inexpensive photodiode, such as a PIN photodiode.

High sensitivity makes the invention suitable for measuring even relatively poorly reflecting or scattering targets, such as wind or other air/gas flows, even from a large distance.

According to one embodiment, the present laser Doppler velocimeter comprises a laser source comprising a laser cavity for producing a continuous-wave laser beam with initial (unperturbed) frequency characteristics, and a light detector. There are also provided optical means, such as a beam splitter or sampler for directing a first portion of the laser beam to a gas flow outside the velocimeter for producing scattered light from the gas flow. The scattered light has experienced a Doppler shift corresponding to the speed of the gas

flow. Light scattered back to the direction of the initial laser beam is collected and guided back to the laser cavity, where it affects the laser beam production process and results in a perturbed, more specifically frequency-modulated, laser beam output from the laser cavity. Thus, the output of the laser when there is detectable movement in the gas flow has
5 different frequency characteristics than in the unperturbed state of the laser source due to the Doppler shift. A second portion of the laser beam is guided to the light detector through an optical edge filter, which converts the frequency changes to amplitude changes. The edge width and steepness are chosen and the wavelength of the laser light is adjusted to correspond the edge of the optical edge filter such that the desired sensitivity range and
10 signal magnification are obtained. The frequency of the signal at the detector is proportional to the Doppler shift and gas flow speed.

According to one embodiment, the velocimeter comprises means for determining the magnitude of Doppler shift from the detector signal and, optionally, further the speed of the gas flow based on the Doppler shift. These functions may, however, be implemented in
15 a separate signal processing and computing device, too.

The laser source preferably comprises tunable wavelength laser source, such as a distributed feedback (DFB) laser. DFB lasers are beneficial also because they have high laser gain. However, any other laser type with a laser cavity with high laser gain and thus capable of efficiently self-mixing the collected Doppler-shifted light therein for providing
20 perturbed output can be used.

The optical edge filter may comprise an atomic absorption line filter, such as a fluid absorption line filter or a Bragg grating, for example. The fluid absorption line filter may be a gas absorption filter, such as an acetylene (C_2H_2) filter.

According to one embodiment, the optical edge filter has an edge steepness of at least 1/0.4
25 GHz.

In a preferred embodiment of the invention, the optical edge filter is adapted to demodulate the frequency disturbance caused by guiding the first portion of the scattered light back into the laser cavity. This is achieved by adjusting the edge wavelength of the filter properly with respect to the wavelength of the laser source. In practice, the center of the

edge is most preferably adapted to correspond with the wavelength of laser light emitted by the laser source.

The demodulation of the frequency disturbance at the edge filter results in an alternating signal at the light detector. The frequency of the signal depends on the magnitude of the
5 Doppler shift. In a preferred embodiment of the invention, the velocimeter comprises means for determining this frequency based on frequency analysis of the recorded signal.

The laser source may comprise e.g. a Master-Oscillator-Power-Amplifier (MOPA) semiconductor laser, but other laser types may be employed as well. Examples include gas
lasers and fiber lasers. In one embodiment, there is provided a lens arrangement for
10 focusing the laser beam to a considerable distance from the outer surface of the velocimeter. Typically, this distance is at least 10 m, preferably 50 – 500 m, in order to avoid placement of the velocimeter device at the measurement area and thereby to avoid influence of the velocimeter itself on the gas flow being measured.

The light detector is preferably a semiconductor detector, such as PIN photodiode.

15 According to one embodiment, the present method for determining speed of gas flow comprises producing a laser beam in a laser cavity at an initial frequency and directing a first portion of the laser beam to the gas flow outside the velocimeter for producing scattered light from the gas flow, the scattered light exhibiting a Doppler shift corresponding to the speed of the gas flow. Further, the method comprises guiding a
20 portion of the scattered light back to the laser cavity for causing frequency perturbation in the laser beam. The perturbed beam is detected by guiding a second portion of the laser beam to a light detector through an optical edge filter. The speed of the gas flow is determining by analyzing the signal measured at the light detector. If the laser beam has a wavelength corresponding to the wavelength of an edge of the optical edge filter, the signal
25 at the light detector has a frequency, which is proportional to the magnitude of said Doppler shift.

The present velocimeter and method are suitable for the measurement of speed of any moving objects or particles that reflect or scatter laser radiation of selected wavelength. Thus, the term velocimeter is used in broad sense, extending outside a traditional definition
30 of an anemometer as wind speed meter. Although in some cases wind or other gas flow are

used herein as the target to better illustrate the feasibility of the invention, the same principles may usually be used for detecting other targets.

Next, embodiments and advantages of the invention are described in more detail with reference to the attached drawings.

5 Brief Description of the Drawings

Fig. 1 shows an overview of a velocimeter with measurement beam focused at a distance from the velocimeter,

Fig. 2 shows as a block diagram the operating principle of the velocimeter according to one embodiment of the invention,

10 Fig. 3 shows as a block diagram a more detailed implementation of the invention according to one embodiment,

Fig. 4 shows a measurement beam focused using a lens,

Fig. 5 shows a graph of the intensity of distributed feedback (DFB) (MOPA = Master
15 Oscillator Power Amplifier) laser light transmitted through an acetylene cell vs. DFB current (laser wavelength),

Fig. 6 shows a graph of the detector preamplifier output voltage (light intensity at the detector) vs. time with a single target velocity,

Fig. 7 shows a graph of the detector preamplifier output voltage (light intensity at the detector) vs. time with three different target velocities, and

20 Fig. 8 shows a graph of signal above noise floor versus distance with three laser power levels using a measurement setup described in section "Example".

Detailed Description of Embodiments

Fig. 1 shows a general view of a velocimeter 10, a forward measurement beam 11 and a backward scattered beam 12. The focal point of the beam 10 is at point 14, which may be
25 e.g. 10-500 m away from the velocimeter, typically 20 – 100 m away.

Fig 2 shows as a block diagram an internal structure of a velocimeter 20 according to one embodiment in more detail. The velocimeter 20 comprises a continuous-wave laser source 21 controlled by a (micro)controller 29. The controller may adjust the power of the laser source 21, and, in the case of a tunable wavelength laser, also its wavelength.

- 5 The laser wavelength used is typically in the near infrared (NIR) or visible range, that is, between 380 and 2500 nm. Such wavelengths are beneficial e.g. in gas flow measurements. However, depending on the scattering or reflection properties of the target, other light wavelengths, such as UV wavelengths or longer IR wavelengths, may be employed too.

The laser beam 22 emitted by the laser source is conducted to a beam sampler 23, such as a
10 semitransparent mirror, such that a first portion, typically majority of light is exited from the velocimeter towards the object being measured and a second, typically smaller portion is kept within the velocimeter and guided to a sensor 25. Before hitting the sensor 25, the light is, however filtered in an optical steep edge filter 24.

The portion of the narrowband beam exiting the velocimeter 20 is focused to a sample
15 volume at target distance from the velocimeter, where it interacts with matter in the sample volume. As a result of this interaction, reflection or backscatter light is produced. The reflection or backscatter is shifted in wavelength by an amount proportional to the speed of movement of the object(s) in the sample volume along the direction of the laser beam, i.e. Doppler shift. For example in the case of wind measurement, moving particles in the
20 sample volume, such as aerosols carried by the wind may cause the necessary backscattering or reflection.

Focusing of the laser beam 22 at the desired distance can be achieved using a suitable lens or lens system. Fig. 4 illustrates an exemplary simple optical arrangement which can be
25 used for producing a focused beam. The focus distance d may be e.g. 10-500 m and the effective waist length l 1-50 m, for example. Such measurement parameters may be obtained naturally with other optical arrangements.

According to one embodiment, the laser source 21 comprises integral beam focusing means. The focusing means may be static or tunable so as to allow for variable distance
30 measurements.

A small amount of the backscattered or reflected laser light is guided back into the laser cavity of the laser source 21, preferably through the same lens or lens system used for beam focusing, causing a disturbance in the lasing action. The disturbance results effectively in frequency modulation, since the disturbance is dependent on the initial lasing
5 frequency and Doppler shifted frequency of the backscattered light. In other words, the light collected from the target is self-mixed with the source light to produce modulated light at the output of the laser source. The laser wavelength would oscillate at a basic frequency equal to the difference between that of the steady-state laser frequency and that of the basic frequency, Doppler shifted by the speed of movement in the laser beam. This
10 differential "beat frequency" has shown to be directly proportional to the speed of the disturbing movement.

According to a preferred embodiment, the laser source 21 is a tunable wavelength source, such as a distributed feedback laser (DFB laser), which may be e.g. diode or fiber-based.
15 For example diode-based DFB lasers comprise an active zone in connection with a laser cavity, the active zone being periodically structured as a diffraction grating. The grating provides wavelength selectivity for the device and reflects light back to the cavity. By using an adjustable grating, a tunable wavelength laser is obtained. This is advantageous in order to be able to match the laser wavelength accurately with the edge filter 24. In
20 addition, the frequency modulation effect using the backscatter light has been found to be strong in this laser type.

As mentioned above, a small amount of the resulting laser light is sampled by a beam sampler 23, the sample is lead through a very narrow edge filter 24, such as one created by
25 an atomic absorption line or a Bragg grating, and measured by detector 25, such as a photodiode detector connected to an amplifier. The edge filter 24 acts as a frequency modulation demodulator, because all changes in the frequency (and also amplitude) of the laser light will be visible in the amplitude of the signal output of the detector 25. The signal resulting from this conversion of frequency modulation to amplitude signal, and observed
30 by the detector 25, will be an alternating "beat" signal with a frequency equal to the Doppler shift caused by the movement of particles in the sample volume.

The frequency of the alternating signal can be determined by frequency analysis techniques known per se, such as (fast) Fourier transform. This part of the method may be carried out either in the velocimeter itself or with an external processing unit, such as a computer.

- 5 The “beat” signal is illustrated in Fig. 6 showing a real measurement graph of the detector preamplifier output voltage indicative of light intensity at the detector as a function of time with a single target velocity. It can be seen that an alternating signal with constant period is obtained. The real target speed in the experiment was 0.39 m/s, whereas the speed measured using rough graphical investigations of the measured curve and the basic
10 Doppler shift formula

$$v = \frac{\Delta f_{\text{doppler}} \cdot \lambda}{2}$$

yields a rotation speed of 40 m/s. $\Delta f_{\text{Doppler}}$ is the difference of frequencies of the incident and backscattered light, i.e., the period of the signal (here $1/1.92 \mu\text{s} = 521 \text{ kHz}$) and λ wavelength of light used (here $1.538 \mu\text{m}$).

- 15 Further, Fig. 7 shows a graph similar to that of Fig. 6 with two additional target velocities, corresponding to twofold and half target velocities compared with that in the case of Fig. 6. Other measurement conditions remained the same. As can be seen, the frequency of the beat signal is doubled when the velocity of the target is doubled and dropped to one half when the velocity of the target is halved. Thus, the period or frequency of the signal can be
20 used for determining the velocity of the target.

- The optical edge filter 24 may be an absorption filter formed of any material with an absorption edge at a wavelength range corresponding to the wavelength of the laser source and reflection or scattering wavelength of the target material. Absorption edge means a wavelength region with rapidly, preferably linearly, varying absorption profile, such that a
25 small change in wavelength at the input of the filter produces a high change in amplitude at the output of the filter.

Fig. 5 shows a graph the intensity of distributed feedback (DFB) (MOPA = Master Oscillator Power Amplifier) laser light transmitted through an acetylene cell vs. DFB

control current, i.e. laser wavelength swept up and down over a selected region. The DFB current range is 0.3...0.75 A. It can be seen that there are a plurality of absorption lines, the steep slopes of which may be chosen to act as the edge filter. One of these slopes was used in the measurements illustrated by Figs. 6 and 7, as well as the more detailed example
5 setups described below.

Instead of an absorption filter, the edge filter may comprise a Bragg grating or a thin film structure with suitably high slope in optical transmission at the desired wavelength range.

There is also preferably provided a feedback connection from the detector 25 to the
10 controller 29 for tuning the laser wavelength accurately onto a steep edge of the filter 24.

Averaging of the signal measured can be used for improving the signal-to-noise ratio (SNR) of the velocimeter. The averaging time must be adjusted with the nature of the target being measured in order to benefit from averaging. The velocity or direction of the
15 target must not significantly change during this period. For example in wind measurements, the averaging time may be set to 0.1-2 seconds.

Fig. 3 shows a more detailed implementation of the invention. In addition to the laser source 31, microcontroller 39, optical edge filter 34, photodiode 35 and laser beams 32, 32A, 32B, there are shown a power source 30 for powering the system and a heater
20 element 38 for maintaining a stable and dry atmosphere inside the instrument. In addition, there are shown a plurality of amplifiers 37A for providing main source energy for the laser source 31, wavelength tuning-signal for the laser source 31, for a thermoelectric element, such as a peltier element (not shown) integral with or connected to the laser
25 source 31 for controlling its temperature. There are also feedback lines for providing measured power level and temperature of the laser to the microcontroller 39 for control purposes. The photodiode 35 is connected to an amplifier 37B and A/D converter, also controlled by the microcontroller 39. The digital alternating amplitude signal is led from the A/D converter to the microcontroller 39, where it may be further processed or
30 communicated forward to an external processing unit.

The invention can be used for instance for measuring wind speed in the direction of the laser beam at a distance of tens or hundreds of meters. Potential wind measurement applications comprise all applications where a remote non-contact measurement is a benefit, such as at airport wind measurements (for example 10 m wind measurement
5 without masts or monitoring of wake and wingtip vortices above a runway), remote wind measurement at ballistic launch sites, wind condition measurements at wind power plants and parks etc.

By adding to the principle described above an optical scanner, for example, a three-
10 dimensional wind vector could be measured. Further, by adding a lens or lens system with adjustable mechanical or electrical focal length, a ranging property could be realized. This arrangement would then be comparable to a short-range wind lidar.

Claims

1. A velocimeter (20) comprising
- a laser source (21, 31) comprising a laser cavity for producing a continuous-wave laser beam,
 - 5 – a light detector (25),
 - means for directing (23) a first portion of the laser beam to a moving target outside the velocimeter for producing scattered light from the target, the scattered light exhibiting a Doppler shift corresponding to the radial speed of the moving target,
 - 10 – means for guiding (23) scattered light back to the laser cavity for providing frequency-modulation of the laser beam through perturbation in the laser source,
 - means for guiding a second portion of the laser beam to the light detector,
- characterized** by further comprising an optical edge filter adapted to demodulate said frequency-modulated laser beam before guiding to the light detector (25) and wherein said
- 15 laser source (21, 31) is adapted to produce laser light at a wavelength corresponding to the wavelength of the edge of the optical edge filter (24).
2. The velocimeter according to claim 1, **characterized** in that the demodulation comprises converting the frequency changes in output of the laser source to amplitude changes so as to produce at the detector a varying-amplitude signal, the frequency of which is
- 20 proportional to the Doppler shift.
3. The velocimeter according to claim 1 or 2, **characterized** in by comprising means for determining the period and/or frequency of the signal at the light detector and means for calculating the radial speed of the moving target based on the period and/or frequency.
4. The velocimeter according to any of the preceding claims, **characterized** in that the
- 25 laser source comprises a distributed feedback laser source.

5. The velocimeter according to any of the preceding claims, **characterized** in that the wavelength of the laser source is tunable and the velocimeter comprises means for tuning the wavelength of the laser source to the edge of the optical edge filter.
6. The velocimeter according to any of the preceding claims, **characterized** in that the
5 optical edge filter comprises an atomic absorption line filter, such as a fluid absorption line filter, such as an acetylene filter.
7. The velocimeter according to any of the preceding claims, **characterized** in that the optical edge filter comprises a Bragg grating.
8. The velocimeter according to any of the preceding claims, **characterized** in that the
10 optical edge filter has an edge steepness of at least 1/0.4 GHz.
9. The velocimeter according to any of the preceding claims, **characterized** in that the optical edge filter is adapted to demodulate the frequency disturbance caused by guiding scattered light back into the laser cavity.
10. The velocimeter according to any of the preceding claims, **characterized** by
15 comprising means for determining the frequency of signal detected at the light detector.
11. The velocimeter according to any of the preceding claims, **characterized** in that the laser source comprises a semiconductor laser, such as a Master-Oscillator-Power-Amplifier laser.
12. The velocimeter according to any of the preceding claims, **characterized** in that the
20 light detector comprises a semiconductor detector, such as PIN photodiode.
13. The velocimeter according to any of the preceding claims, **characterized** in that said means for directing the laser beam to a moving target outside the velocimeter are adapted to focus the beam to a distance of at least 10 m, preferably 50 – 500 m.
14. The velocimeter according to any of the preceding claims, **characterized** by
25 comprising a beam sampler, such as a semitransparent mirror, for separating the first portion of laser beam directed to the target and the second portion of laser beam guided to the optical edge filter and further to the light detector.

15. The velocimeter according to any of the preceding claims, **characterized** by being an anemometer.

16. A method for determining speed of moving target, comprising

- producing a laser beam (22) in a laser cavity at an initial frequency,
- 5 – directing a first portion of the laser beam (22) to the moving target outside the velocimeter for producing scattered light from the moving target, the scattered light exhibiting a Doppler shift corresponding to the speed of the moving target,
- guiding scattered light back to the laser cavity for causing frequency perturbation in the laser beam,
- 10 – guiding a second portion of the laser beam to a light detector (25),
- determining the speed of moving target using the signal measured at the light detector,

characterized by

- 15 – guiding the second portion of the laser beam to the light detector through a optical edge filter (24), and
- producing said laser beam at a wavelength corresponding to the wavelength of an edge of the optical edge filter (24) for obtaining a signal at the light detector whose frequency is proportional to the magnitude of said Doppler shift.

17. The method according to claim 16, **characterized** in that said moving target is a gas
20 flow, such as an air flow, comprising molecules or particles capable of scattering or reflecting said wavelength of the laser beam.

18. The method according to claim 16 or 17, **characterized** by using a velocimeter according to any of claims 1-15.

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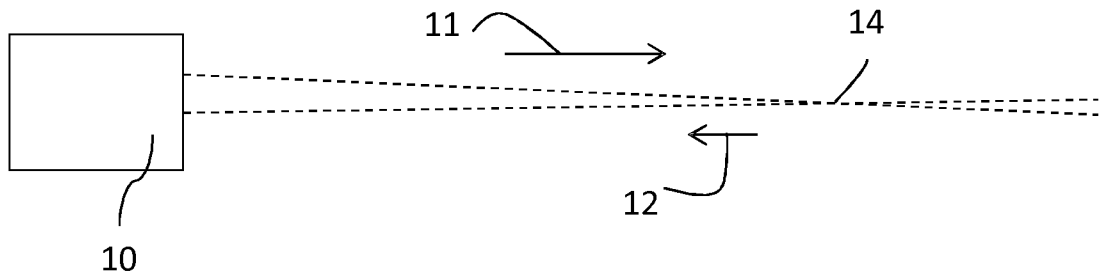


Fig. 1

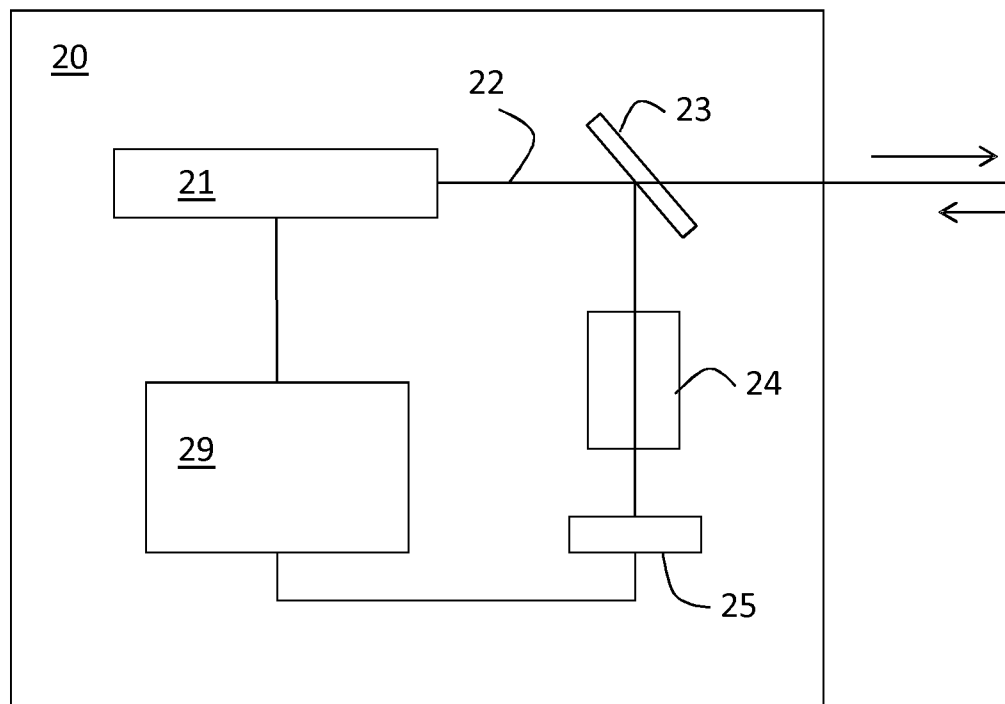


Fig. 2

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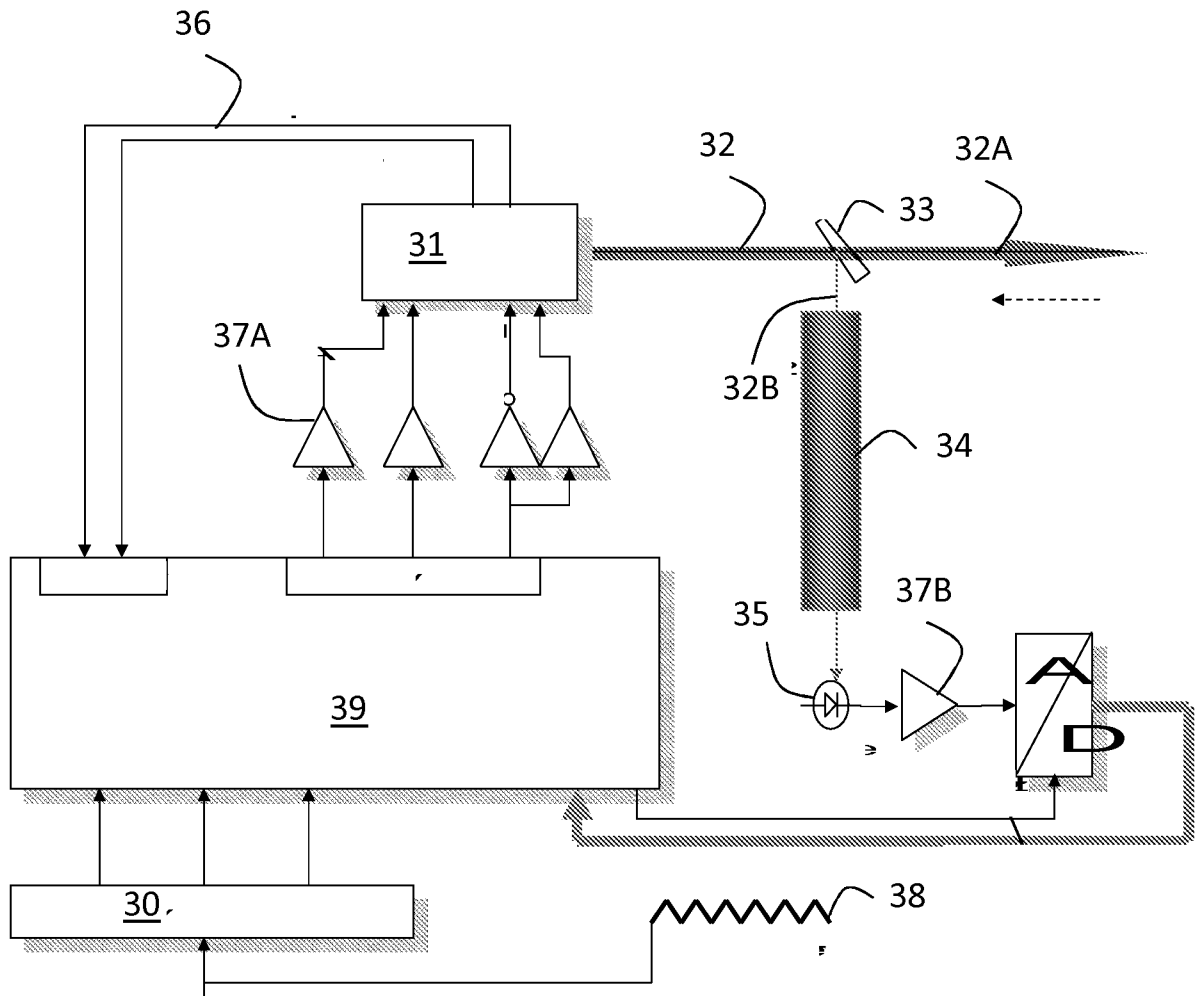


Fig. 3

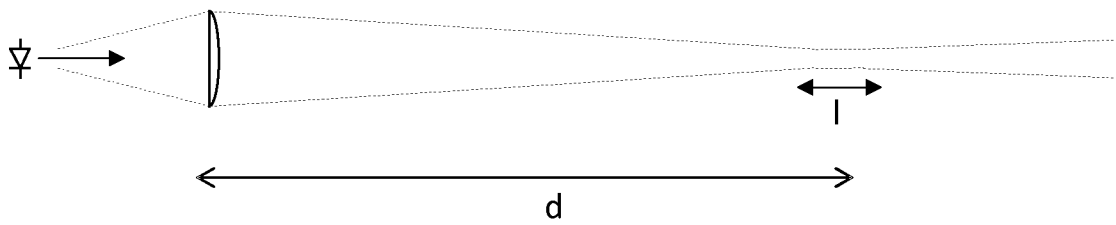


Fig. 4

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C2H2 cell with laser #111, DFB swept 0.3 ... 0.75 A; T-amp 3 A; temp 25 degC

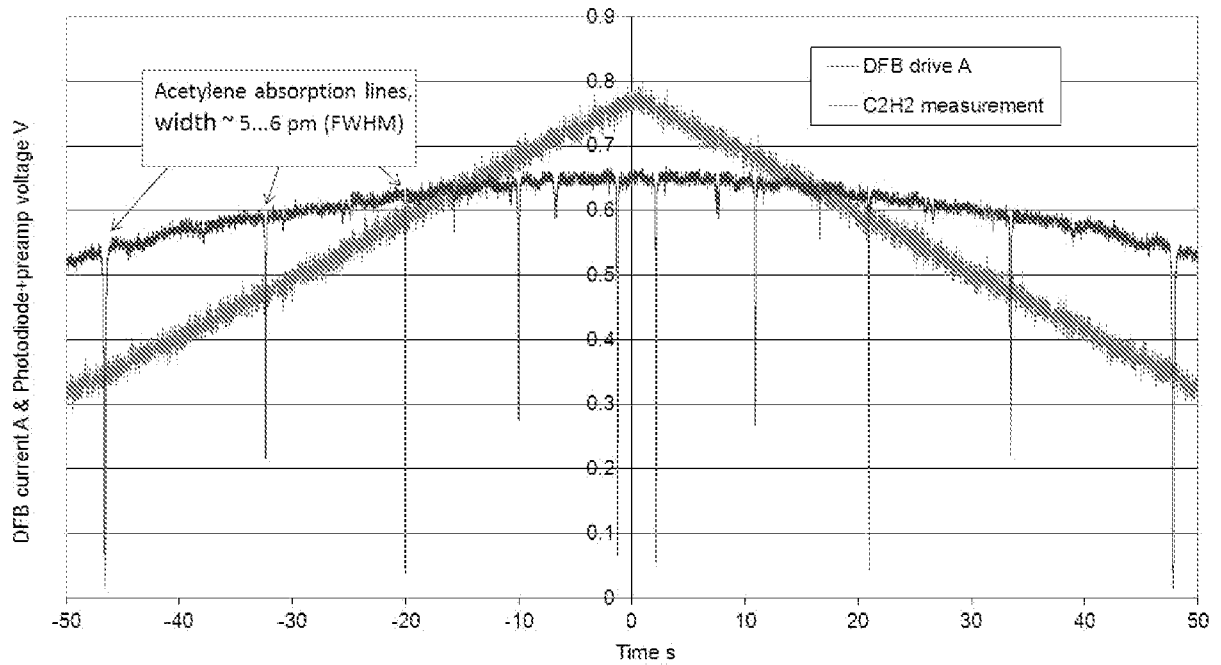


Fig. 5

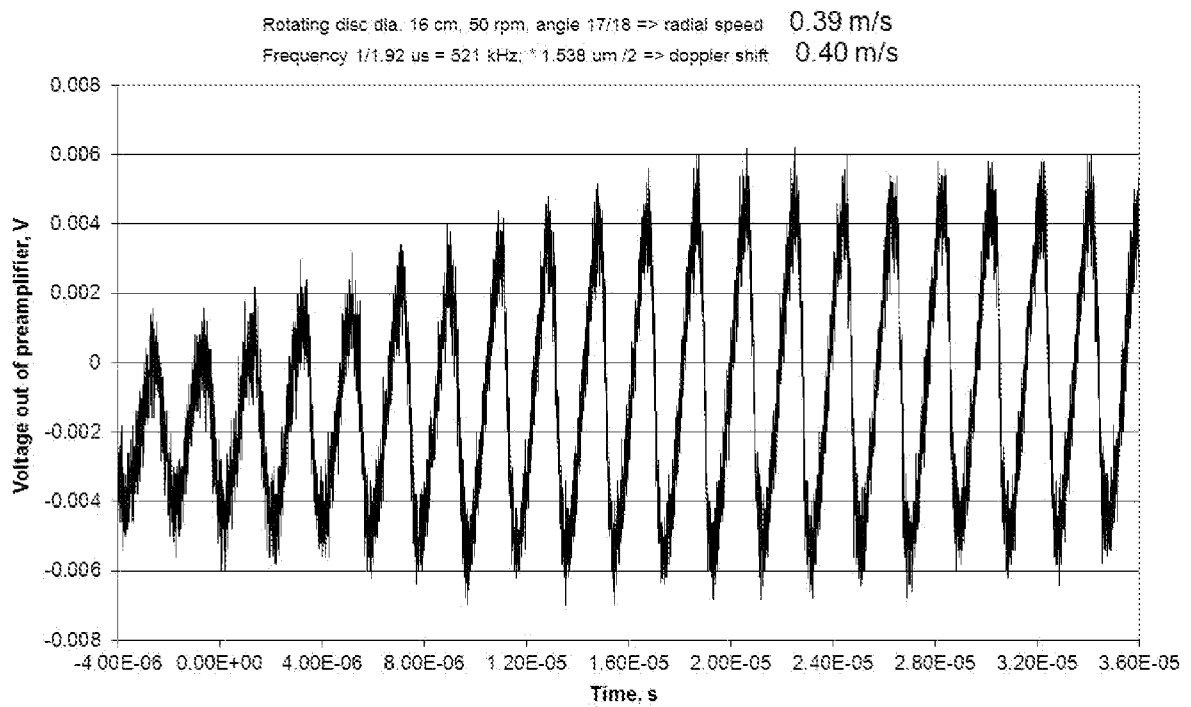


Fig. 6

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Self-mixing frequencies at various rotator motor voltages

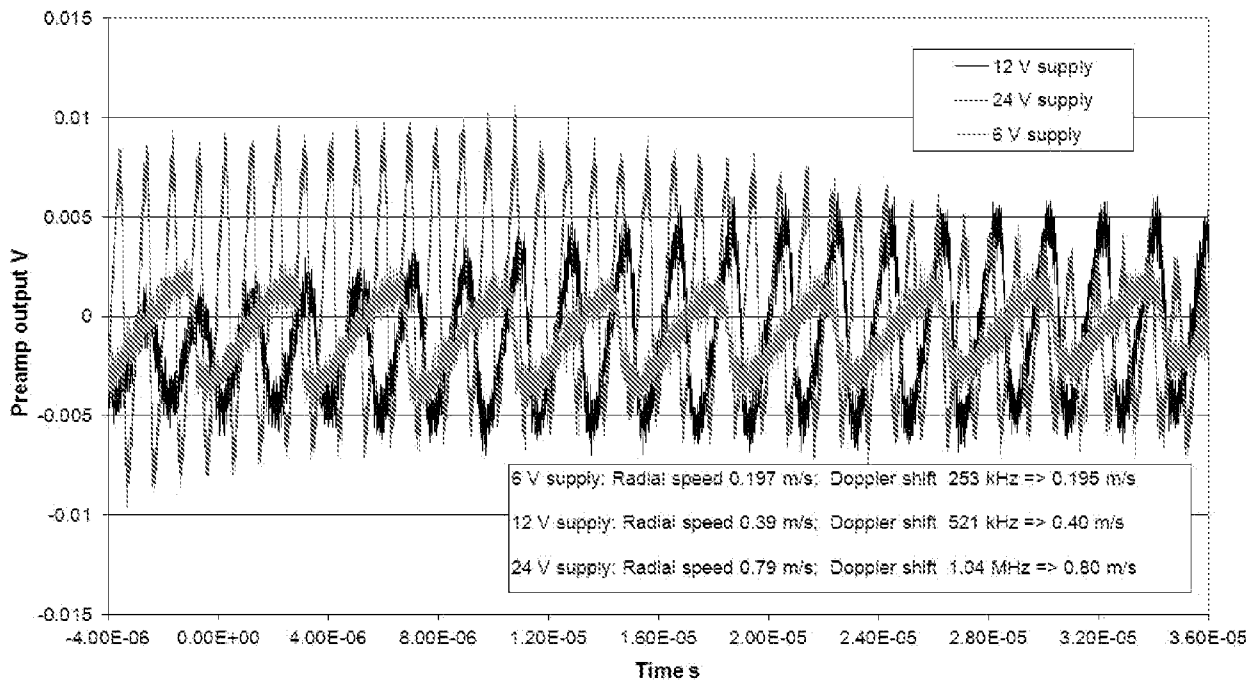


Fig. 7

Signal above noise floor, 1 & 2 & 3A laser drive, avg 10 sweeps x 0.1s = 1s

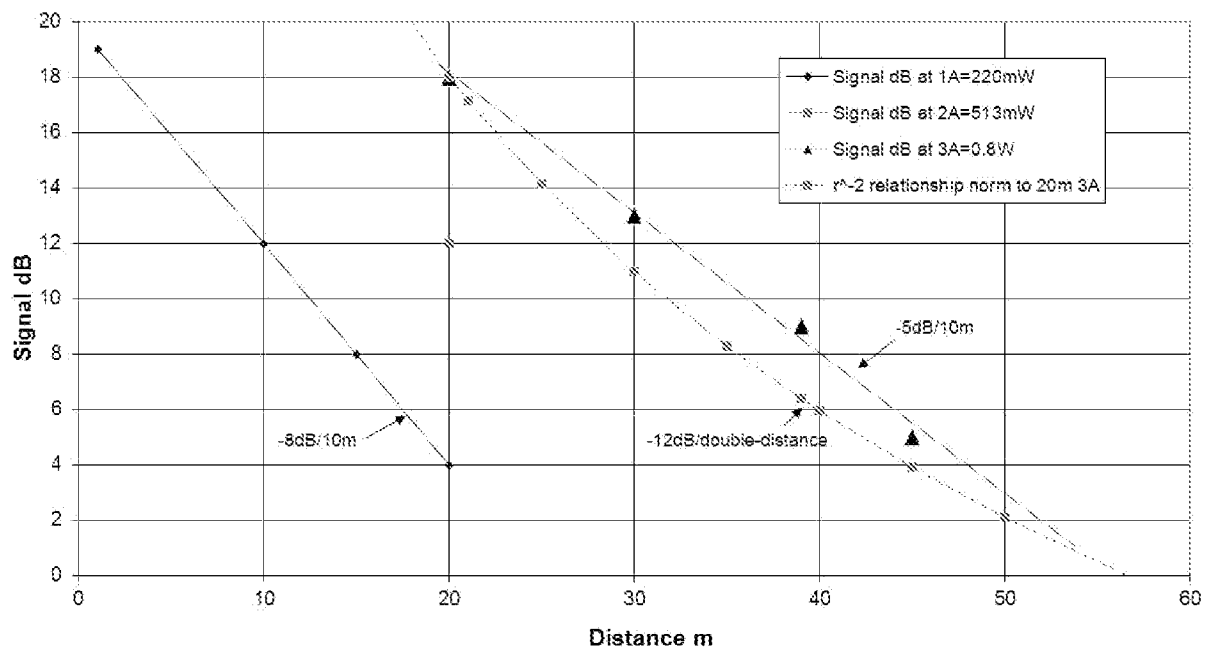


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI2014/050239

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G01P, G01S

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6233045 B1 (SUNI PAUL J M ET AL), 15 May 2001 (2001-05-15); abstract; column 1, line 31 - line 60; column 4, line 28 - line 37; column 9, line 15 - line 18; figure 9 --	1-18
A	US 20070058157 A1 (DEINES KENT L), 15 March 2007 (2007-03-15); abstract; paragraphs [0032]-[0035] --	1-18
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Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	"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
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI2014/050239

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International Patent Classification (IPC)

G01P 5/26 (2006.01)

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