

# A new optical technique for the generation of LDA-quadrature signals

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## ABSTRACT

A novel LDA technique which uses two single frequency lasers, one for each LDA beam is presented. In contrast to previously presented techniques using the optical frequency difference of the lasers for directional discrimination, the technique described here generates a quadrature signal pair by an *optical* superposition technique without any broad band electrical heterodyning.

In order to extract the Doppler frequency optically, undesired mixing products have to be avoided. The realisation of this concept is based on the superposition of four light waves on one photodetector, where only two pairs of light waves are able to interfere forced by polarisation or by optical adjustment. Thus the photodetector acts as an optoelectrical element to superimpose two optical beat signals, so that the envelope of the resulting output signal directly delivers the Doppler frequency (see figure 1(a)).

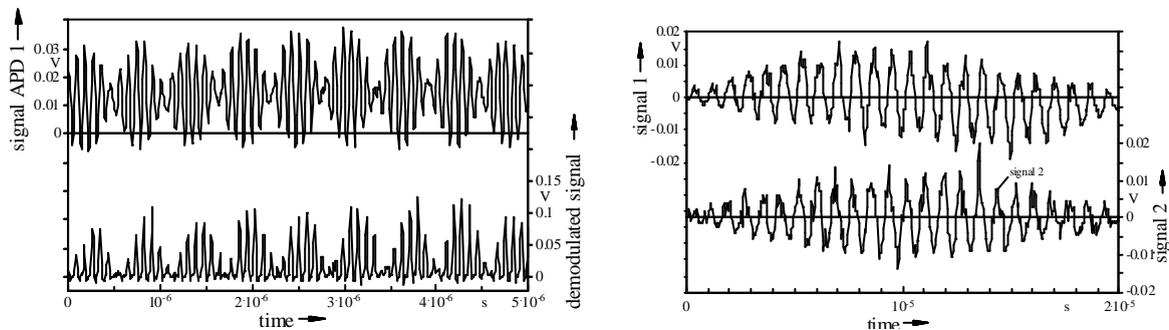


Fig. 1: (a) photodetector output signal (i) and demodulated signal (ii), filtering of (ii) delivers the burst signal periods in fig. 1(b)

(b) quadrature LDA-burst signals after filtering of the demodulated quadrature burst signals

In order to get the desired directional information by generating quadrature signals (see figure 1(b)), a second photodetector is required. The quadrature signal generation can easily be realised either by an optical path length difference between the light waves or by positioning the photodetectors against each other in the expanded wavefront of the reference beams. Different concepts of a directional LDA based on the application of two lasers and the described optical superposition technique have been realised.

## 1 INTRODUCTION

Recent developments in laser Doppler anemometry cover the application of integrated optical devices, fiber optical components and new laser sources as well as the investigation of novel techniques in order to realize compact sensors for the measurement of velocities in fluid flows. Several applications require LDA systems with frequency shifting, especially when investigating recirculating flows. For highly accelerated, or quasistatic flows, where it is necessary to perform a timely resolved LDA signal processing of single burst signals or to evaluate single signal periods of a LDA burst, the evaluation of quadrature signals has been described as an advantageous and promising signal processing technique.

The presented paper describes a novel technique which uses the optical frequency difference of two single frequency Nd:YAG lasers. In opposite to other novel techniques using the beat frequency of different laser sources, the presented technique extracts the Doppler frequency by an optical mixing technique delivering a quadrature signal pair. The quadrature signal generation is done optically and different methods are discussed.

### 1.1 State of the art – recently developed LDA-systems

A large number of integrated optical devices has been developed over the last years for telecommunication applications. Such devices can potentially be used for laser Doppler anemometers to decrease the size, the weight and costs. Although several systems have been proposed and demonstrated previously by Toda et al. (1989), they have not found widespread use, due to the low power levels admitted by the titanium diffused waveguides in Lithium Niobate substrates. Integrated optical devices for telecommunication are normally designed for the use at wavelengths of 1300 nm and 1500 nm but are available for 850 nm as well. Thus LDA set-ups based on conventionally used laser diodes and Avalanche photo diodes are well suited to incorporate integrated optical devices.

In recent investigations Resagk and Grabow (1998) described a two component LDA using integrated optical devices. Based on the application of a Y-fed balanced bridge modulator, optical multiplexing in a dual laser Doppler anemometer was realized to measure two components of a velocity by only one laser source, one integrated optical phase modulator for frequency shifting, one detector and one signal processing chain. The laser, the modulator, the multiplexer and the probe were connected by single mode fibers and the input powers of the integrated optical devices was limited to 5 mW. If it is possible to increase the guided optical powers drastically the application of integrated optical devices is promising for compact LDA systems.

In order to enhance the applicability of the LDA technique, compact lasers with a high efficiency, reliability and power have to be employed. Czarske et al. (1998 and 1997) proposed the use of diode pumped fiber lasers for the LDA technique as fiber lasers have a robust and simple design and emit up to about 30 W fundamental mode power. Furthermore, the launching into single mode fibers of a LDA measuring head can be saved. The combination of applying compact tunable lasers and optical fibers to realize promising LDA systems for the simultaneous measurement of several velocity components with directional discrimination has been presented by Czarske et al. (Optimized two-component directional laser Doppler velocimeter using a chirp frequency modulated powerful Nd:YAG miniature ring laser (1997)). This technique was based on the generation of heterodyne signals having different carrier frequencies, so that the different velocity components could be multiplexed. The carrier frequency modulation was achieved by a chirp frequency modulation of a Nd:YAG miniature ring laser in combination with fiber delay lines. This technique based on a completely spliced passive fiber optic unit without additional frequency shift elements resulting in a simple alignment insensitive chirp LDV system.

The realization of novel LDA techniques by the use of heterodyning and quadrature signal processing techniques has been presented by Müller et al. (1994). Using heterodyning and quadrature signal processing techniques, a powerful directional LDA system based upon the application of two 1 W master oscillator power amplifier lasers, one for each LDA beam could be realized (Müller et al., (1997)). The optical frequency difference of the two lasers was used as shift frequency acting as auxiliary carrier frequency for the generation of quadrature signals in the baseband containing the measuring information.

The presented technique allowed to achieve high laser powers in the measuring volume and to realize a compact and powerful directional LDA system, which could successfully be employed for in flight measurements (Grosche et al. 1999).

## **1.2 Aspects to the application quadrature signal processing**

Fast Fourier transformation (FFT) processors are potentially advantageous in processing LDV signals with poor signal to noise ratio (SNR) but have intolerably high measurement errors at low numbers of signal periods. The quadrature demodulation technique allows on-line, directional Doppler frequency measurements nearly independently of the number of signal periods (J. Czarske and O. Dölle, (1998)). Furthermore it is possible directly to evaluate the path time function of single tracer particles passing through the LDA-measuring volume (Müller et al. (1995), (1997)). As the quadrature demodulation technique especially allows to measure low frequency burst signals, having less than one signal period small velocities can be time-resolved measured in the base band (Czarske and Dölle, (1998)). Also for aerosol size measurements using a laser Doppler system and an acoustic excitation of the fluid flow (Strunck et al. (1998)) the quadrature analysis was presented as a well-suited tool for the observation and evaluation of the oscillation of particles moving with the flow towards the loudspeaker.

Providing a sufficient signal to noise ratio of the LDA signal, quadrature signal processing is an advantageous technique for the investigation of recirculating flows, the measurement of small velocities and velocity fluctuations as well as particle accelerations in the measuring volume. In any way quadrature signal processing is an appropriate technique for all kinds of applications where the location of the tracer particle has to be determined at each time during the passage through the measuring volume. Thus the generation of quadrature signals and the quadrature demodulation technique can advantageously be used for a variety of special applications in the laser Doppler velocimetry.

## **1.3 Quadrature signal generation in LDA-systems**

A conventionally used technique for directional velocity measurements is the generation of a frequency shift by applying acousto optical modulators (Drain (1986)). In any way an acousto optical modulator is an additional optoelectronic element in a LDA set-up increasing the alignment effort and reducing the laser power caused by the laser light transmitted into the not used diffraction orders.

An elegant method for generating a frequency shift without having to use additional optoelectronic components is the application of two tunable lasers one for each LDA beam and to use the optical frequency difference as frequency shift. This technique has firstly been presented by Müller et al. (1993) and allows to double the laser power in the measuring volume and to generate quadrature signals in the base band by optical and electronic heterodyning. A disadvantage of this technique is the relatively high bandwidth of the electronic system causing a high sensibility to high frequency disturbances. For example during inflight measurements the data rate was significantly reduced by disturbances of the carrier frequency measuring signals by high power transponder signals of the aircraft.

The new idea presented in this paper consists in a reduction of the electric bandwidth by replacing the electronic heterodyning for the correlation of the measuring and the reference signal by an optical correlation of scattered light and reference light beams. It will be shown, that a Doppler frequency extraction can be realized by superimposing two optical signal pairs differing in their polarization or geometrical orientation on the photodetectors. The output of each photodetector is a superposition of two optical beat signals and results in a carrier frequency signal with an amplitude modulation directly delivering the Doppler frequency. For the evaluation of the amplitude modulated beat signal a non-linear circuit has been used to extract the measuring information.

## **2 PRINCIPLE OF USING ONE LASER FOR EACH LDA-BEAM**

### **2.1 Quadrature signal generation based on electronic heterodyning**

The method for generating a frequency shift without having to use additional optoelectronic components by applying two tunable lasers and using the optical frequency difference as frequency shift can be illustrated by figure 2 and figure 3.

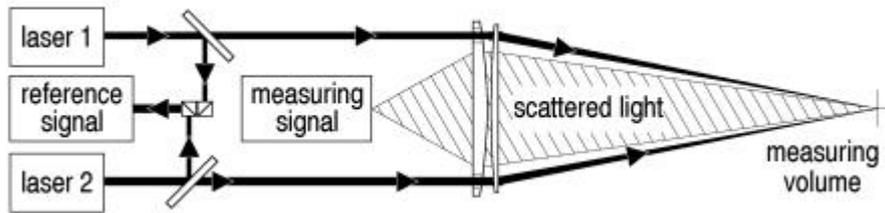


Fig. 2: Optical set-up of a LDA-system using the optical frequency difference of two tunable lasers

The measuring signal on the Avalanche photo detector is given by optical heterodyning of the scattered light of both LDA beams. Thus the measuring signal is a carrier frequency signal containing the Doppler frequency and the difference frequency between the two lasers. By correlating the measuring signal with the reference signal which is given by the beat frequency of the two lasers, the Doppler frequency can be extracted. This correlation can be performed by electrical heterodyning of the measuring and the reference signal. In order to generate a quadrature signal in the base band the electrical heterodyning can be realized by the application of a mixer unit shown in figure 3.

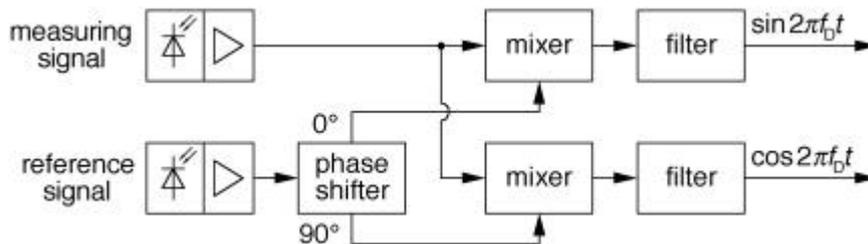


Fig. 3: Mixer unit for the quadrature signal generation in the base band

For the realization of this technique it is necessary to use broad band photo detectors with band widths up to over 100 MHz for detecting carrier frequency signals in the 100 MHz range. As the carrier frequency is eliminated when mixing the measuring signal with the reference signal pair, there are only negligible requirements on the stability and bandwidth of the carrier frequency given by the optical frequency difference of the two laser sources. The maximum carrier frequency is given by the bandwidth of the photodetector and the bandwidth of the analogous electronics whereas the carrier frequency fluctuations are limited by the working range of the hybrid coupler which delivers a broadband 90 degree phase shift for the quadrature signal generation. Depending on the used hybrid coupler the usable frequency range may be within 100 MHz with phase angle deviations of only a few degrees.

Quadrature signal pairs in the baseband can be evaluated by appropriate LDA signal processors. The Doppler frequency of the resulting quadrature signal pair in the baseband is proportional to the magnitude of the velocity. The phase relationship  $+90^\circ$  or  $-90^\circ$  within the quadrature signal pair is determined by the sign of the velocity to be measured.

## **2.2 Quadrature signal generation based on the new optical technique**

Considering the new optical technique to replace electrical heterodyning by an optical correlation of scattered light and reference light beams, optical four wave mixing has to be discussed. Possibilities to avoid

the typically generated four wave mixing products to extract the Doppler frequency have to be found. Solutions based upon the polarization of the light beams and their geometrical adjustment are described as well as different ways to generate a phase shift (phase shift by optical delay line, phase shift by adjustment of wavefronts in the reference beam) for the quadrature signal generation using two photodetectors.

The LDA with a quadrature signal processing has two different optical paths, the scattered light and the reference light. In those optics, both of these optical paths were terminated by photo detectors and each of the beats on the electromagnetic field was transformed into alternating voltage signal. The reference signal is divided into two lines and given a certain delay time with each other. The quadrature signal pair is a result of the mixing between these signals and the detected signal. Thus, we can interpret these processes to be optical paths by dividing reference beam, appending a certain path difference and mixing with the scattered light before the photo detectors. This interpreting is very simple, however, the replacement is not very easy in the following reason.

Fig. 4 shows a directly interpreted concept of quadrature signal processing LDA with optical mixing. The symbol style means the origin of the light source. The light sources B and b transmit coherent beams to the single particle. The symbols M and m represent the scattered light sources virtually located on the particle because the property of the scattered lights originated by the independent light sources are different from each other. Reference beams from both light sources are overlapped by half mirrors just before the aperture of the optics. These beams are divided into two paths to be detected by the receivers R and r. One of them has a delay path that is an interpretation of the hybrid coupler circuit in the quadrature signal processing unit. Thus, the scattered lights and the reference beams should be mixed on the receivers.

It is necessary to consider the fact that the quadrature signal processing with an electric circuit uses only the result of the optical interference. This means that the information of uniqueness of interfered lights has been lost when the operation is executed. The carrier frequency is extracted from the two overlapped lights and the received frequency is generated by the interference of two scattered lights. Thus, a pair of 4 lights' bundle is appeared on the receivers R and r. On the discussion of an optical mixing system, one should consider the light properties remained in the each beam.

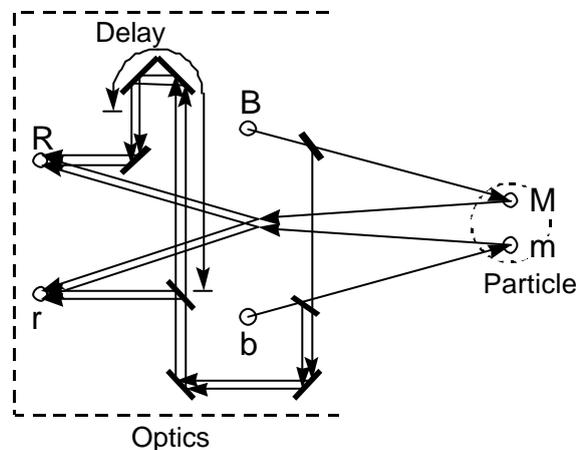


Fig. 4: Interpreted concept of quadrature signal processing LDA with optical mixing

Fig. 5 is an arrow diagram model to understand the light relationships in the concept above. This diagram is very simple because it shows only the topological connections of the light paths. It is easy to find the symmetry of the diagram, as the groups of B-M-R and b-m-r. It is because the topological relationship starting at the light source b is completely the same as the lights generated by B.

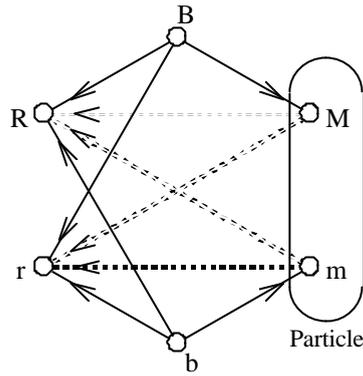


Fig. 5: Arrow diagram model of quadrature signal processing LDA by an optics with optical delay

We can trace the diagram to make clear the relationships between each of the lights. The scattered light from M received by R and r, are originated by the light source B. These scattered lights are interfered with the reference beams from b. Thus, the light paths B-M-{R or r} and b-{R or r} represent the same meaning as a reference beam type LDA. To use the symmetry of the diagram, we can also extract the light paths of b-m-{R or r} and B-{R or r} easily from Fig. 5. There are no other paths because the diagram in Fig.2 has 10 paths. So, we can determine the optics in Fig. 4 as a pair of reference beam type LDA with symmetry configurations constructed at the same place.

It is possible to treat them as superposing of a reference beam type LDA optics pair, however, these interfering processes are very complicated because the receivers R and r are illuminated by four different lights. On each of the reference optics, the observed velocity component would be tilted in quarter of the intersection angle of incident beams when the scattered light is received on the center of the optics aperture. Therefore it is not very easy to extract the normal velocity information from the signal obtained from the optics in Fig.4.

The problem mentioned above was caused by the difficulty of the interference of four beams. It is necessary to use the properties of the four beams but the desired information is only the mixing results from two sets of the interference; scattered lights and reference beams. Thus, the lights on the path {M or m}-R and {B or b}-R, or {M or m}-r and {B or b}-r should be interfered, and the affect of the other combinations should be removed.

One of the reasonable solution of this problem is an intensity adding of two sets of interfered lights. The presented paper reports the following two kinds of optics, and try to compare their properties to make clear their performances.

### **2.2.1 Solutions for Doppler signal extraction**

Generally, there are two ways to reduce any kinds of disturbance, such as obstruction of its source or rejection of its result. In the former section, the disturbing source has been determined as the unexpected interference. Thus, it is possible to obtain the only desired signals by two methods; avoiding the interference itself or wasting the result of the interference.

The most reasonable method to avoid the unexpected interference is the disturbing of the polarization conditions of the lights that should not be interfered. In this purpose, the light superposing in the perpendicular polarization condition is utilizable. It is enough to rotate the polarization of either the scattered light or the reference light, because the polarization changing of scattered light is very small on a dielectric small particle. The optics of figure 4 is easily modified by this method because the scattered lights and the reference beams are already interfered by themselves before the photo detector. The process of the light superposing in perpendicular polarization does not have the same meaning as the voltage mixing of the quadrature signal processing, because the voltage mixing is a multiplying operation. The signals are superposition of the carrier frequency and the shift frequency without product.

The signal visibility of the interferometer with fringe system depends on the size balance between the fringe spacing and the aperture of the photo detector. Thus, we can waste the signal quality by making the fringe spacing much smaller than the size of detector. This situation is easily realized by only increasing the intersection angle between the lights that creates the unexpected interference. So, we can modify the optics drawn in Figure 4 by optimizing the intersection angle between the scattered light and the reference beam. After this arrangement, the obtained signals from the photo detectors will change to be the superposed wave form of the scattered lights and the reference beams. The signals are expected to have almost the same characteristics as the other method.

These solutions are very reasonable, however, their output signals require some special arrangements because the wave forms do not have the same properties as the output signal of the conventional LDA. As above mentioned, the operations before each of the photo detectors have no product value between the reference and the received signal. Even this situation, it is expected that the phase difference of superposed two signals assigns the flow direction. So, envelope extraction from the superposed signal is necessary to extract the beat frequency.

### **2.2.2 The expected signal wave form**

The difficulty of the mixing of the scattered light and reference light was solved optically. It is necessary to understand the general property of the signal itself to evaluate the availability of the optics because this LDA has an additional process of the light superposing. The signal frequency depends on the oscillation properties of the light sources and is considered to be very high. The wave form of the APD output signal has been analyzed to use for the evaluation of the result obtained by the preliminary test.

The signal wave form is possible to be predicted by the principle that discussed above. A simple numerical calculation was done in the ideal condition, such as its SNR over 30dB with white noise on each of the photo detectors. Figure 6 shows one of the typical wave form of the detected signal obtained by the optical mixing. The time was normalized by the period of the Doppler shift that is included in the burst signal. The signal wave form is a simple beat that has an envelope with periodic changing. This kind of beat signal could be observed generally in the mixing process of two signals in the near frequency. This means that the detected signal has a power spectrum distribution of twin peaks.

It is necessary to know the circumstances of the signal deformation when the flow direction is changed. Some calculations in various conditions have been done and it has been observed that the phase of the envelope is shifted in  $180^\circ$  by the Doppler shift direction. This means that the flow direction is possible to be assigned by the phase shifting of the signal envelope.

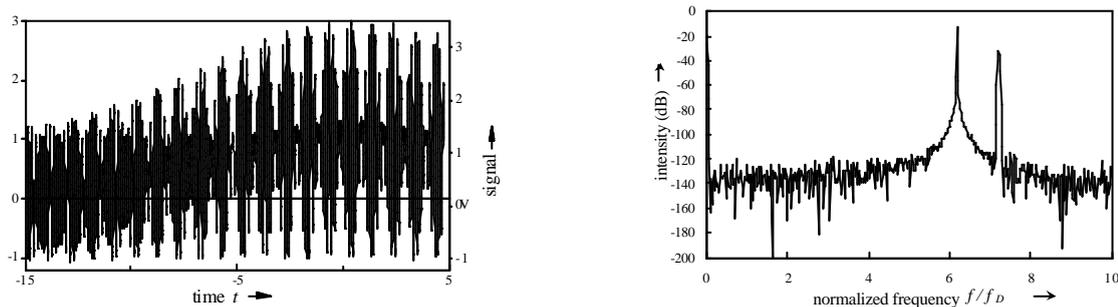


Fig. 6: Typical wave form of the detected signal obtained by the optical mixing LDA

## **3. EXPERIMENTAL SET-UPS**

### **3.1 Forward scatter LDA (Superposition optics with perpendicular polarized beams)**

It was discussed how to achieve the delay time by the path length difference between the reference beams for photo detector pair. In practice, this method has a problem of the sensitivity for its alignment because this part of optics is an arrangement for coherent beam bundle. The visibility of the carrier signal is also influenced by the alignment of beams to be overlapped.

The carrier frequency appearance in the reference beam bundle is modeled by the motion of the fringe whose spacing can be varied by the alignment changing of overlapped beams. The aperture size of the photo detectors should be smaller than the stripe pattern to get good visibility, however, the signal phase difference of the photo detectors becomes sensitive for geometrical setting with decreasing the effective aperture. In positive point of view, it means that we should better control the phase difference between the photo detectors not by the path length but by the position changing. Thus, the expanded reference beams are used to obtain the phase difference on the photo detectors.

Figure 7 shows the schematic apparatus of the optical quadrature signal generation in the perpendicular polarization. Forward scattering optics with tunable Nd:YAG laser was formed for the preliminary test. The phase difference between the carrier signals is determined by this fringe spacing.

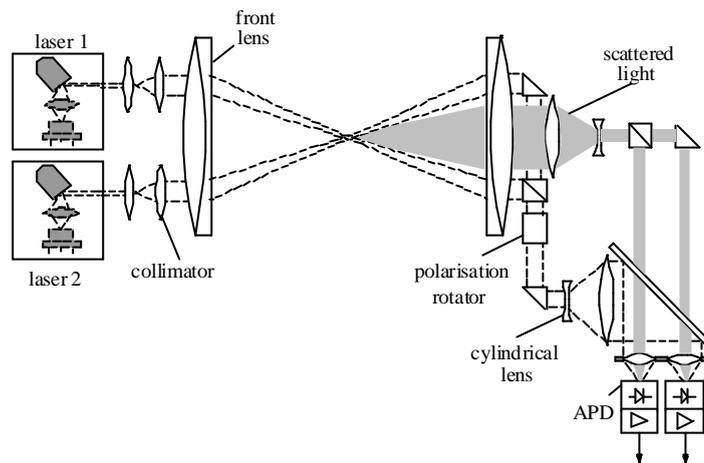


Fig. 7: Set up for an optical quadrature signal generation in the perpendicular polarization

The forward emitted light from the LDA probe is sampled and used for the reference beams in the receiving optics. The reference beams are superposed and their polarization conditions are rotated in  $90^\circ$ . Partial reflection is used to reduce the light intensity of the reference beams. The scattered light is collimated by the front lens of the receiving optics, and compressed to achieve a beam light. The beam of scattered light is divided into 2 beams to illuminate the photo detectors. The distance between the photo detectors is fixed by the frame of the receiving optics. The fringe spacing of the expanded reference light is modified by the reference beam alignment, and optimized with the position of the detectors. This alignment was easily done with the observation of the detected signal to achieve the phase delay. Each photo detector receives the beat signal with a background of the reference signal. Thus, the flow direction is expected to be assigned by the phase shifting direction of the envelope of each signal.

### **3.2 Back scatter LDA (superposition optics with inclined reference beams)**

The experimental set-up to investigate the quadrature signal generation is illustrated in figure 8. As laser sources two frequency doubled Nd:YAG ring Lasers were used. For LDA-systems, which work with two lasers one laser source for each beam this type of Laser is well suited (Kramer et al. (1994)). With the advantageous features of these lasers, the nearly Gaussian laser beam shape, the narrow linewidth in a range of 20 kHz and tuning range of the emission frequency of up to 2 GHz without mode hopping it is possible to realize a beat frequency in the range between 1 MHz and several hundred MHz. For the investigation of the new concept a beat frequency of 12 MHz was used so that all interesting signals, the reference signal, the superposition signal and the demodulated signal could be observed in the time and in the frequency domain.

The laser sources were attenuated down to 6 mW in each beam and fixed in a distance of 65 mm. To achieve two parallel beams with matched waist position and a diameter of 4 mm two collimators were used. The front lens with a focal length of 310 mm focuses the parallel beams into the measuring volume with a diameter of 100 microns.

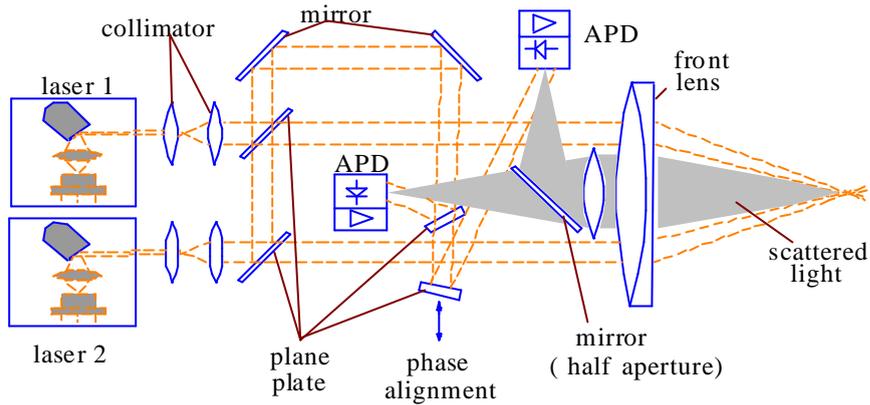


Fig. 8: Set up for the quadrature signal generation by an optical technique according to figure 4

To create a collinear aligned reference beam two cardanic declineable plane plates were applied, which worked as beam splitters. This reference beam was splitted up by two further plane plates to provide each photodiode with low power reference light. To match the light power of the reference beam to the scattered light from the particles, inside the beam path of reference light a neutral density filter with a transmittance ratio of 1000:1 was applied. By adjusting one of the beamsplitters used to provide the photo diodes with the reference light, a phase shift of 90 degrees between the resulting carrier frequency signals can be generated.

In order to investigate the behavior of the set up a two channel transient recorder was used. The transient recorder digitizes the signals from both diodes simultaneously. If a particle passes through the measuring volume inside the photo diodes two photo currents, one from the reference light and a second caused by the scattered light, will be created. At the output of the diodes a superposition signal can be measured. If the phase difference of the carrier realized at the two photo diodes is exactly 90 degrees then envelope of the two signals is also 90 degrees phase shifted. Thus the envelopes of both signals deliver a quadrature signal pair in the base band. The phase relationship of the envelopes changes if the direction of the velocity is changed.

Figure 9 shows the signal pair which was detected by the described system. Water droplets with a diameter in the micron range were used as tracer particles (droplet generator TSI 9302). The transient recorder was triggered by burst signals from one of the receiving ADP.

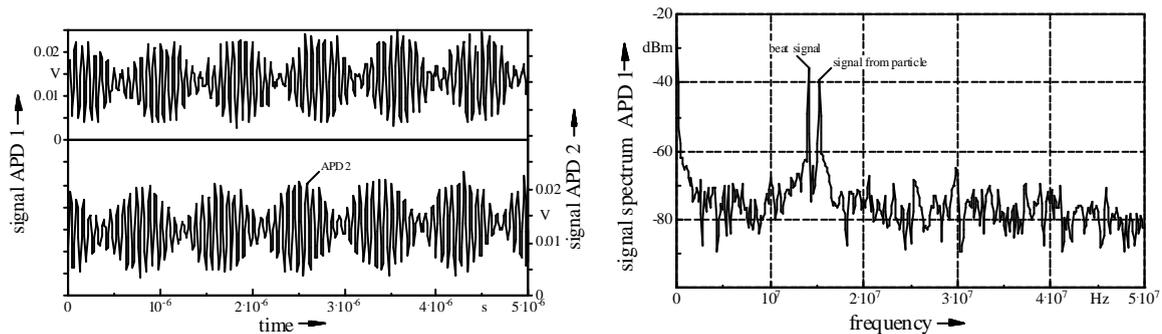


Fig. 9: Unfiltered photodetector signals (APD 1, APD 2) in the time domain and in the frequency domain

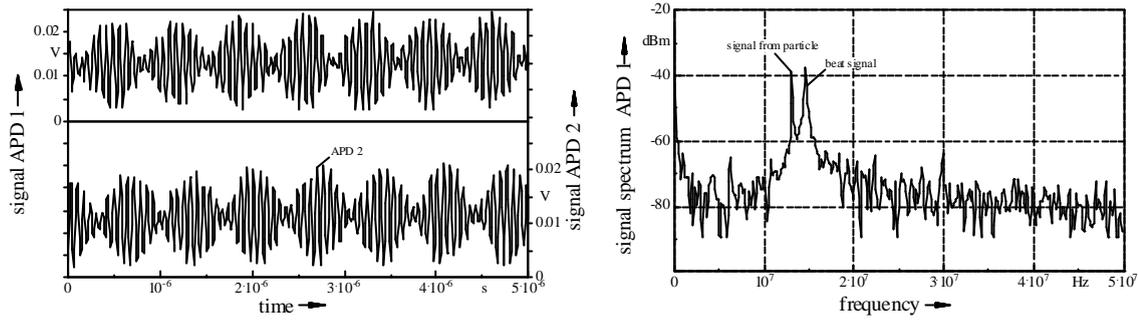


Fig. 10: Unfiltered photodetector signal (APD 1, APD 2) in the time domain and in the frequency domain (the flow direction of the particle is opposite to the direction shown in Fig. 9!)

The evaluation of the of the superposition signals require a demodulation. Therefore a non-linear element is necessary. Experiments were carried out with an square method as well with a one way demodulation by a Schottky diode. A very simple method of demodulation is the application of Schottky diodes as shown in figure 11. Schottky diodes are available with a bandwidth of several 10 GHz. That's why the usable reference frequencies are limited by bandwidth of the Avalanche diodes. Because of the one way rectification a loss in the SNR is to taken into account. As figure 12 shows, the signal peak in the frequency domain exceeds the noise floor 6 dB less signal peak.

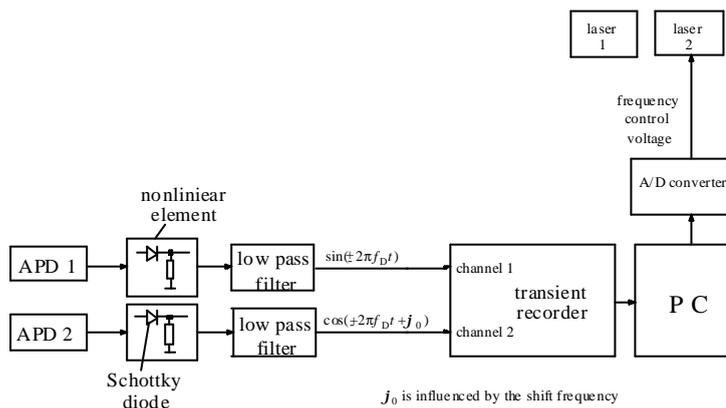


Fig.11: Acquisition of optical generated quadrature signal pairs

Typical quadrature signal pairs after the low pass filtering shows figure 13. The cut frequency of the low pass was 10 MHz. The signal peak in the frequency domain exceeds the noise floor more than 20 dB. A significant improving of SNR is to achieve if a band pass with restricted cut frequencies is used.

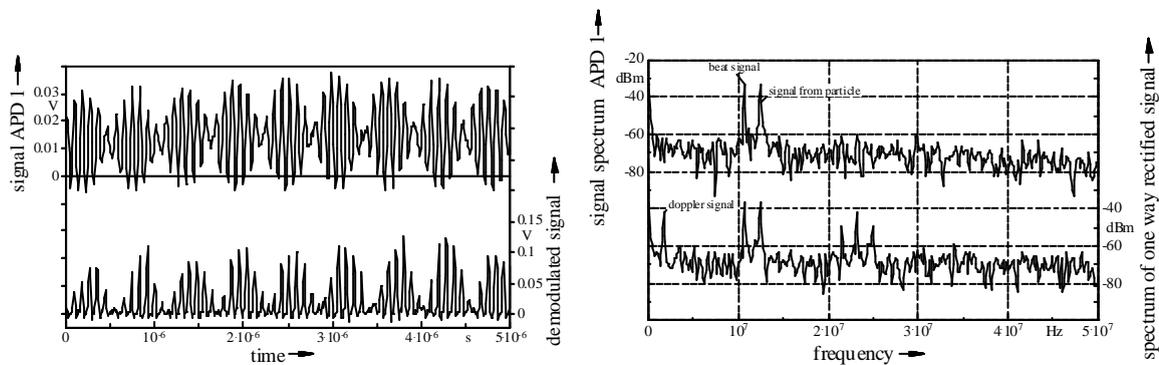


Fig. 12: Unfiltered electrical output signal of APD 1 and the amplified, one way rectified signal of APD 1 in the time domain and in the frequency domain.

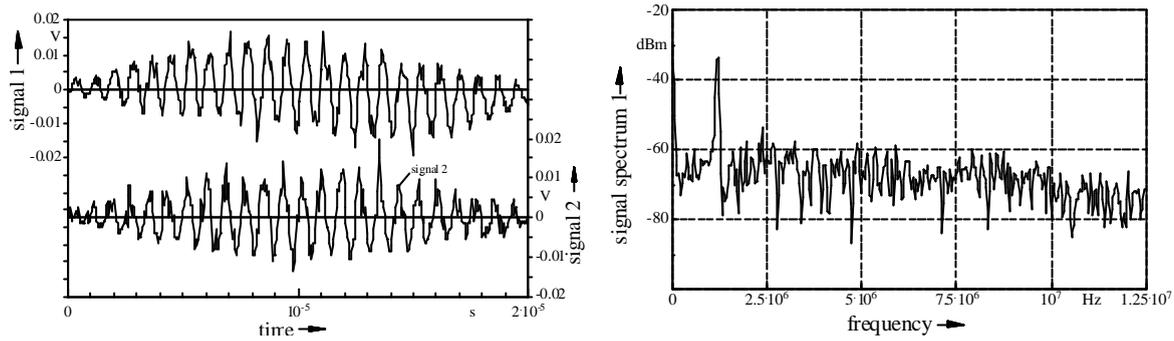


Fig. 13: Typical quadrature signal pairs in the time domain and in the frequency domain (the cut frequency of the low pass filter's were 10 MHz)

If the phase difference of the reference signals detected by the two photo diodes is not exactly 90 degrees, the phase difference of the quadrature signal pair in the base band (Doppler difference frequency) is in the same way shifted. This behavior is not critical for the validation of the velocity and the direction discrimination. The deviation from 90 degrees between the reference signals may be caused by a misalignment of the optics or by the change of the reference frequency itself. Especially if the phase difference of reference signals is realized by a difference in the optical path length, the influence of the reference frequency is high.

#### **4. DISSCUSSION**

The LDV-system investigated shows that the described technique is suitable to generate quadrature signal pairs in forward as well as in a backscatter arrangement. The two channel transient recorder for the evaluation of the quadrature signal pairs only needs a sample rate, which is necessary to measure the Doppler difference frequency. However the laser sources used for the experiments allow to realize a high performance LDV-system, which works similar to a conventional shifted LDV-systems. That's why the presented concepts are to taken as first steps to realize LDV systems which uses two Laser sources with tunable emission frequency and a linewidth of up to 2 MHz. Such sources are DFB-Laser diodes, which available with a light power up to 100 mW.

The described technique should be developed as an interesting alternative to conventional quadrature technique for well suited laser sources.

#### **5. CONCLUSIONS**

A new idea for the realization of a directional LDA, based upon the application of two tunable lasers, one laser for each LDA beam, has been presented. In contrast to frequency shift LDA systems using the optical frequency difference of two lasers by electrical heterodyning (electrical mixing) of the beat signal of the two lasers (reference detector signal) and the scattered light of the LDA beams (measuring detector signal), the paper describes interesting possibilities of an optical mixing technique. In order to extract the Doppler frequency (measuring information) it has to be considered how the undesired mixing products of a four wave mixing process can be avoided. The realization of this concept is based on the superposition of four light waves on one photodetector, where only two pairs of light waves are able to interfere forced by polarization or wavefront conditions. Thus the photodetector acts as an optoelectronic element to superimpose two optical beat signals, so that the envelope of the resulting output signal directly delivers the Doppler frequency. In order to get the desired directional information a second photodetector for a quadrature signal generation is required. This can easily be realized by optical path length differences between the light waves or by positioning the photodetectors against each other in the expanded wavefronts of the reference beams.

Different concepts of a directional LDA based on the application of two lasers and the described optical

mixing have been realized. Experimental results have exemplarily been presented for one of the investigated LDA set-ups described in section 3. The experimental results are in a good conformity with the theory and promising for novel LDA systems based on optical mixing.

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