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GROUND-BASED DOPPLER LIDAR OF INCREASED LASER INSTABILITY: CONCEPTION AND DESIGN

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1. **INTRODUCTION.** The pulsed CO_2 Doppler lidars are effective tools for ground-based atmospheric wind sensing, but the high cost of the lidar transceivers mainly due to the required high frequency stability (better than 10^{-9} or 100 KHz) is a restriction factor to their widely use in meteorology. The best approach to overcome this problem is to develop Doppler lidars effective at increased laser instability. This work is based on the results in [1], where a new scheme for Doppler lidar detection by the use of frequency synthesis in wide fluctuation bandwidth of laser instabilities is described. A ground-based system, using this approach is under development in the Institute of Electronics - BAS.

2. **BLOCK-SCHEMES OF THE DOPPLER LIDAR.** As known, there are two block-schemes of the CO_2 coherent lidars: 1) by an injection seeding TE-laser transmitter [2] and 2) by a hybrid TE-laser [3]. These schemes, adapted to our approach, are represented in fig. 1a and 1b. The local oscillator (LO) in fig. 1a is stabilized around the peak of the gain curve (fig.2a). The CW injection seeding laser is stabilized at some mean frequency offset $\bar{\omega}_o$ within the bandwidth $\Delta\omega_{CW}$ in respect to the LO using the reference mixer PD-2 and further the TE-laser cavity is tuned to the CW laser frequency. In the hybrid scheme as shown in fig.1b,2b, the CW laser is stabilized within the gain curve, but the LO is further stabilized at some offset $\bar{\omega}_o$ in respect to the CW-frequency. Here the quenching of the CW-lasing during the TE-pulse requires to stabilize the frequency within the intervals after the recovery of the CW lasing. Because of the wide tolerable fluctuation bandwidth, the timeconstant of the stabilization may be essentially short.

As shown in [1] the tolerable laser instability $\Delta\omega_o$ may be reduced to the order of 10^{-7}- 10^{-6} (10 - 100 MHz). It is of interest to estimate how to choice the parameters of LO and CW lasers in order to realize the all advantages of the method [1] to operate in wide fluctuation bandwidth. The tolerable instability on the intermediate frequency is $\Delta\omega_o^2=\Delta\omega_{LO}^2+\Delta\omega_{CW}^2$, where $\Delta\omega_{LO}$ and $\Delta\omega_{CW}$ are the instabilities of the CW and LO lasers. We will accept that the frequency fluctuations within the time intervals of 100 - 200 μs (usually of interest in ground-based lidars) may be neglected. The LO-instability $\Delta\omega_{LO}$ on fig. 2a may be accepted to be of order of 10 MHz and further the LO gain bandwidth $\Delta\omega_{gLO}$ may be chosen to be 100 - 200 MHz thus, the pressure of 20 - 40 Torr is required. The gain bandwidth of the CW laser may be determined by the following conditions: 1) $\omega_L > 3\ \omega_{Dm}$ and 2) $\omega_H=\omega_{max}=\bar{\omega}_o+\frac{1}{2}\Delta\omega_o$, where $\omega_L=\bar{\omega}_o-\frac{1}{2}\Delta\omega_o$ and ω_H are the lower and higher frequency extrema on the fluctuating intermediate frequency ω_o, ω_{Dm} is the maximum expected Doppler frequency, ω_{max}-the maximum tolerable intermediate frequency. As an example, if $\omega_{Dm} \lesssim 5$ MHz, $\omega_{max} \lesssim 100$ MHz, $\bar{\omega}_o \sim 45$ MHz, $\Delta\omega_o \sim 50$ MHz. Therefore, the CW gain bandwidth must be of order of 300 - 400 MHz (60-90 Torr gas pressure). It must be noted, the above parameters are usually used in Doppler lidars.

In the hybrid lasers the CW-gain bandwidth is usually chosen 50 - 100 MHz (gas pressure 20 Torr), because of the longer resonators (>1 m, ~ 150 MHz mode spacing). It is evident, the parameters of the LO are the same as of the CW-laser in the injection seeding transmitter.

As it is evident, the requirements to the frequency stability of the laser sources, transmitter and LO, are very simple, 10^{-7}-10^{-6}, which effects on the total price of the lidar.

3. **DOPPLER DETECTION ON THE INTERMEDIATE FREQUENCY.** The problem of operation at higher instability may be solved using an appropriate technique for signal detection on the intermediate (reference) ω_o frequency and processing of data. At wideband fluctuations the use of a quadrature detector for an extraction the Doppler signals is a serious problem, because of the effect of frequency dependence of the 90^o-phase shifter. The main advantages of the method [1] are due to the nonstrictly tracking of the frequency ω_o and thus to the use of frequency synthesis without the 90^o-phase shifters.

The Doppler detector is shown on fig.3. It may be applied to the both block schemes in fig.1. Timing diagrams are given in fig.4 and in [1]. The reference frequency ω_o by the photomixer PD-2 is fed to the tracking synthesizer, where the frequency ω_o is measured during the pulse τ_1 and then a decision is made to generate one of the frequencies ω_i of the previously determined set $\{\omega_i\}$, i = 1..I in the synthesizer [1].The measured frequency ω_o and ω_1 are recorded in the lidar processor as a reference data at final processing. The signal from the synthesizer is used as a reference in the receiving mixer 1 and then by the low-pass filter the Doppler information may be extracted, as was experimentally tested in [1]. The TE-laser pulse is triggered after the recording the all reference data in the processor. Further by the photomixer PD-3 the entire TE-laser pulse is coherently detected and sampled, including the high peak, which affects essentially on the measurement accuracy. Now, using the sampled data from the receiving photomixer PD-1 the Doppler spectra may be calculated as shown in [1].

4. **LIDAR PROCESSOR.** The lidar processor consists of two channels A/D converter for both the lidar data and the laser pulse (20 MHz/8 bits), additional channels to record the frequencies ω_o and ω_1 for each shot and a personal computer with a specialized software.

5. **PROCESSING ALGORITHMS.** The processing of lidar data is in principle the same as in other Doppler lidars, with some peculiarities due to the new principle of the Doppler detection on the intermediate frequency. The value and the sign of the mean frequency of the Doppler spectra may be determined as shown in [1]. The precisely recorded laser chirp history may be used to increase the accuracy of Doppler measurement. Some new inverse algorithms are tested to improve the temporal resolution, which is important at lower heights for ground based systems.

6. **CONCLUSIONS.** It is shown here, that using the method of Doppler detection, developed in [1], the low cost ground-based Doppler lidars may be developed. The main effect is due to the application of laser sources of higher instability (10^3 times lower) and a simpler detection technique on the intermediate frequency using the frequency synthesis without phase-shifted coherent oscillators. In the ground-based system, developed in the Institute of Electro--nics-BAS a TEA-hybrid laser (Edinb.Instr.) is used. The detection block was tested at the frequency fluctuation bandwidth $\Delta\omega_0 > 10$ MHz corresponding to a relative instability of order of 10^{-7}. The frequency step in the synthesizer is 1 MHz. For further comparison two Doppler detectors are incorporated in the system: by the new method and by quadrature detection. It must be noted the very easy tuning of the new detection scheme at operation in the wide frequency range in respect to the case, when quadrature detector is used.

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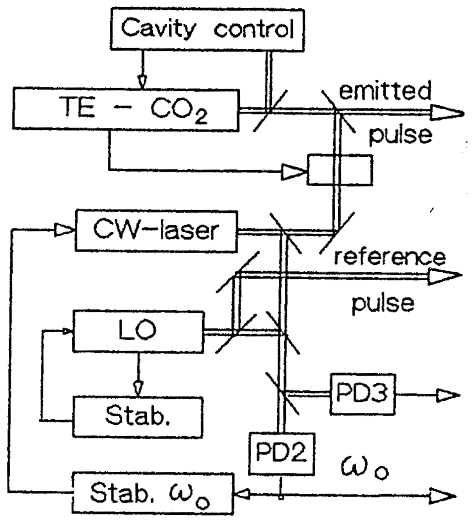

Fig. 1a

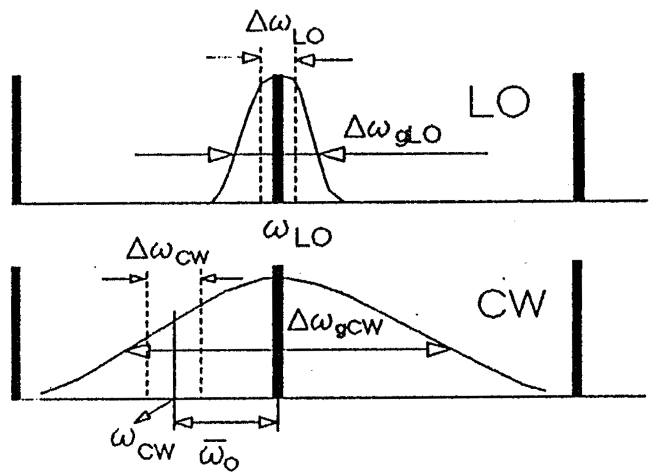

Fig. 2a

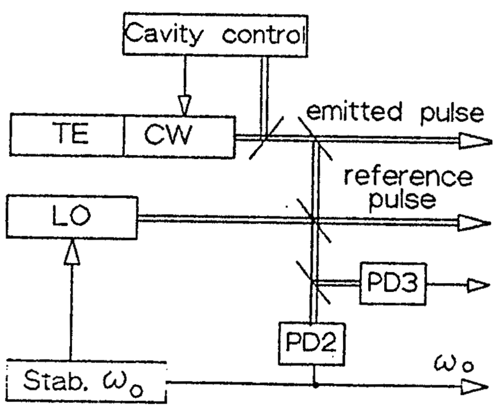

Fig. 1b

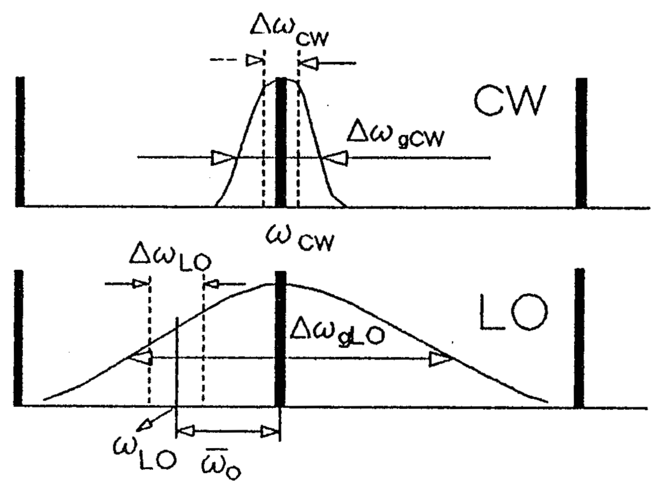

Fig. 2b

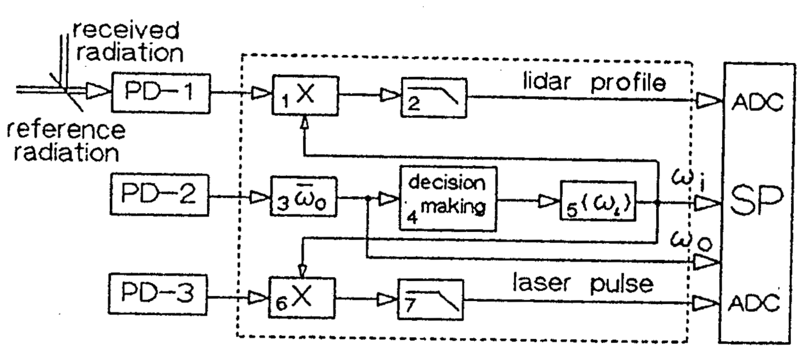

Fig. 3

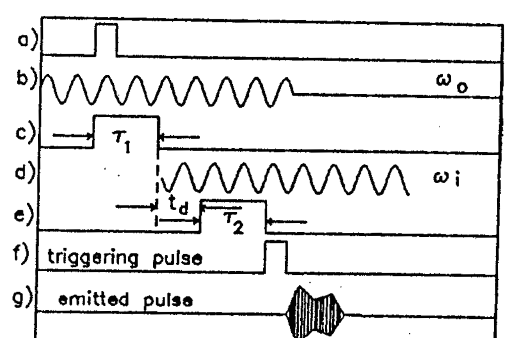

Fig. 4