Heterodyne DIAL at high repetition rate: a solution for the data acquisition problem.

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© Holger Linné, Jens Bösenberg
Max-Planck-Institut für Meteorologie
Bundesstraße 55, D-20146 Hamburg, Germany
Phone: +49(0)40 41173-252, FAX: +49(0)40 41173-269
E-mail: Linne@dkrz.de

Introduction

Water vapor is one of the most important trace gases in the atmosphere. Knowledge of its vertical distribution and redistribution by transport processes is crucial for studies of most physical and many chemical atmospheric processes.

- Vertical transport of water vapor is best determined by correlated measurements of humidity and vertical wind speed (eddy correlation technique).
- We suggest to measure water vapor and vertical wind simultanously with a single system, using DIAL with heterodyne detection.

Requirements

A reasonable set of required performance parameters for a heterodyne DIAL system is:

- 10 s temporal resolution
- 100 m vertical resolution over a range of 10 to 12 km
- 0.25% precision of the signal power estimate for use in the DIAL retrieval
- 0.1 m/s precision of the vertical velocity estimate.

Due to the speckle noise inherent in heterodyne signals the precision goal for the signal power requires laser operation at about 1 kHz repetition rate.

Method

The phase of return signals is not preserved with heterodyne detection from shot to shot, therefore some type of incoherent signal averaging is required. The method we have chosen is the calculation and accumulation of power spectra.

The basic algorithm we use is outlined in figure 2:

- The signal is digitized directly after amplification and anti–alias filtering to achieve maximum reliability and accuracy. No further analog processing is applied.
- A special detector is used for the determination of the center frequency of the transmitted pulse. Switching between the 2 detectors occurs in the blind range < 200 m.
- For each shot power spectra are calculated for each height bin of 64 data points corresponding to 48 m. These bins are interleaved by 24 m.
- The single shot power spectra are shifted to a common center frequency f_0 and accumulated for each height bin.
- The averaged power spectra are written to disk.

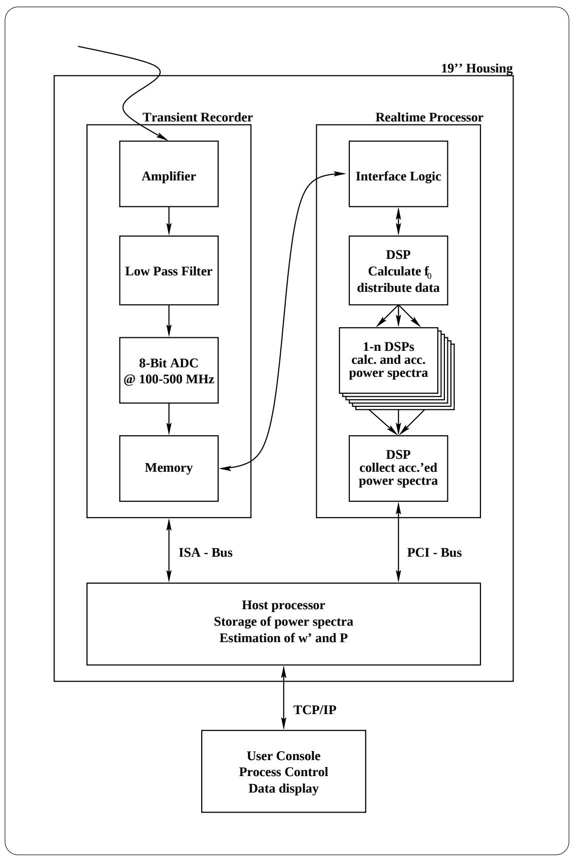

Figure 1: Layout of the data acquisition system hardware.

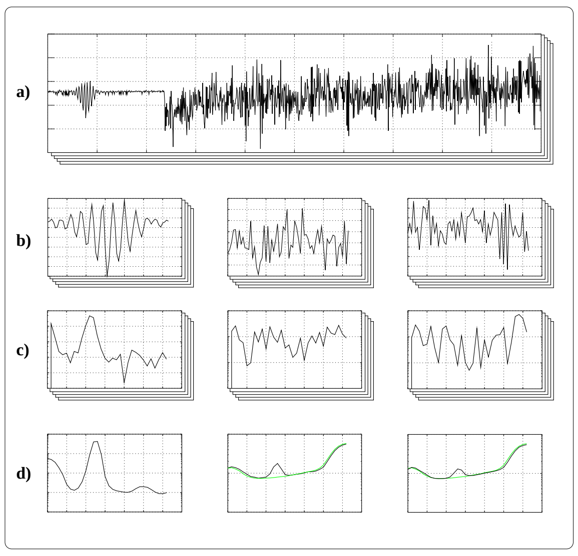

Figure 2: Data flow in realtime processing.

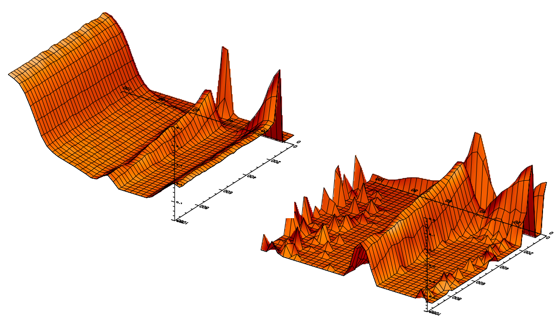

Figure 3: Uncorrected (left) and noise corrected (right) profiles of power spectra.

A common noise spectrum is subtracted from the averaged power spectra (fig. 3). The center frequency and the total backscatter energy for each height bin are estimated using the calculation of the center of gravity and narrowband integration around the peak, respectively.

Realization

Digitizing at 200 MHz sample rate is performed by a standard high speed transient recorder fitting into a slot of the ISA bus of a PC. The transient recorder is interfaced to the realtime processor via a single field programmable gate array (FPGA).

The realtime processor has been built using a modular system based on SHARC processors. This approach allows a very flexible expansion of the system to as many processors as needed. The final design of the realtime processor contains 10 SHARCs: 1 for control and readout of the transient recorder, 8 for calculation and accumulation of power spectra and 1 for process synchronization and communication with the PC.

For test purposes a downscaled version using only 2 SHARCs is used. This system already achieves the following performance:

- 200 Hz repetition rate for 1 s averages of power spectra with a range of 6 km.
- 200 Hz repetition rate for single shot raw data when storing a range of ≈ 3 km.
- 250 Hz repetition rate for single shot raw data when storing a range of ≈ 1.5 km.

Extrapolation of these data to the fully featured system gives an attainable repetition rate of up to 1 kHz with a range of 10 km.

Conclusion

A data acquisition and processing system has been presented which is able to calculate and accumulate power spectra from the return signal of a coherent laser system running at very high repetition rates. This system has been built with industrial components only.

The algorithms realized in this data acquisition system are based on spectral processing of the returned signal. This is the first time a general purpose online processor is fast enough to calculate power spectra at very high repetition rates in realtime with a high spatial resolution.

The flexibility and high processing speed of this system will allow us to examine a variety of schemes for processing heterodyne signals.

Examples

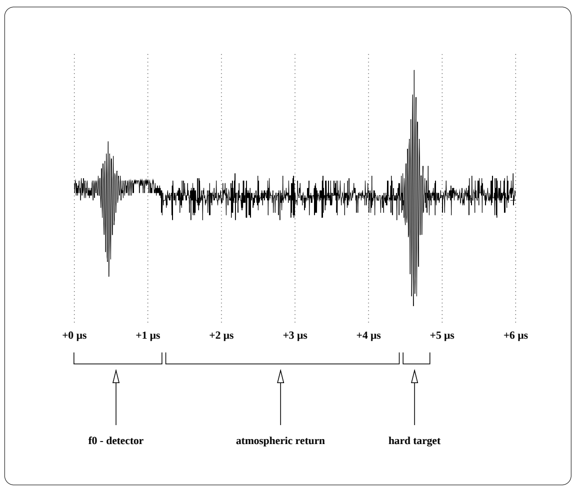

Figure 1: Example of a return signal from a hard target (single shot).

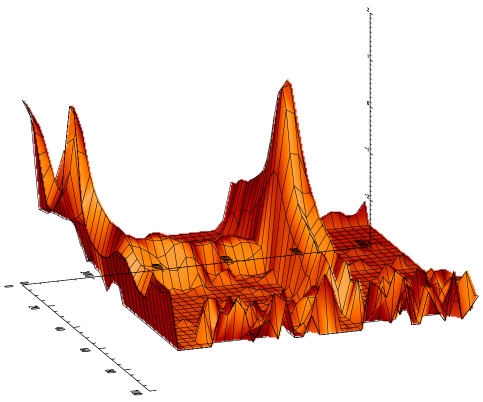

Figure 2: Example of power spectra from a measurement containing a hard target. The power spectra have been averaged over 10,000 shots (≡ 40 seconds).

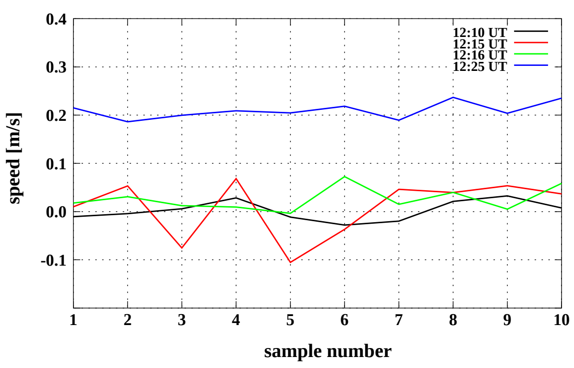

Figure 3: Apparent speed of the hard target vs. the laser system.

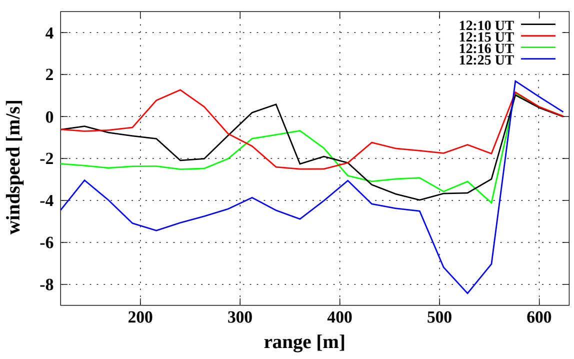

Figure 4: Horizontal wind speed profiles calculated from the measurements shown above.

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E-mail: Linne@dkrz.de

Hard Target Measurements

Horizontal measurements have been performed with a hard target at a distance of 620 m. To avoid overload of the A/D–converter by the return signal from the hard target, the preamplifiers in the receiver path have been switched to very low gain.
Several variations for the optical and electronic setup have been tested for the f_0 determination. The results are shown in figure 3:

- The apparent speed of the hard target using the first ('best') setup was 0 cm/s ± 2 cm/s.
- The speed calculated from the first 3 measurements was 1 cm/s ± 3.9 cm/s.
- The 'worst case' using a poor setup of the detection path was 21 cm/s ± 1.7 cm/s.

In spite of the low gain the wind speed could be retrieved from the atmospheric part of the signal. These profiles show very reasonable values when compared to in situ measurements performed at the lidar site.

Vertical Measurements

Vertical measurements at a repetition rate of 200 Hz have been performed for 12 minutes recording single shot raw data. The Doppler shifted frequency and backscattered energy are estimated from power spectra averaged over 1,000 shots. Time/height diagrams for these retrievals are shown in figure 7.
The aerosol distribution clearly reveals the boundary layer structrure with broken cumulus clouds forming around 1,200 m. Visual observations showed a rapid development of individual clouds at this time. The observed vertical wind field is consistent with the common view of flow patterns below active cumulus clouds.
To study the attainable accuracy of aerosol backscatter for large numbers of shots the power spectra have been further averaged over 15,000 shots. The results are shown in figure 5 and 6. The comparison of aerosol retrieval using 100 MHz 'broadband' integration and a 15 MHz tracking filter shows considerable noise reduction. The resulting signal to noise ratio is also displayed in figure 6 and shows values > 50 for most of the boundary layer.

Outlook

The most important next step is the validation of wind and aerosol retrievals by comparison with other well established remote sensing techniques. A first attempt will be made in the next weeks during the LACE'98 experiment at the Meteorologisches Observatorium Lindenberg.
Improvements in the accuracy of the estimators for wind speed and aerosol backscatter are expected from:

- increasing the repetition rate of the laser and data acquisition system from 250 Hz to 1 kHz,
- more reliable detection of f_0
- optimization of the narrow band tracking filter.

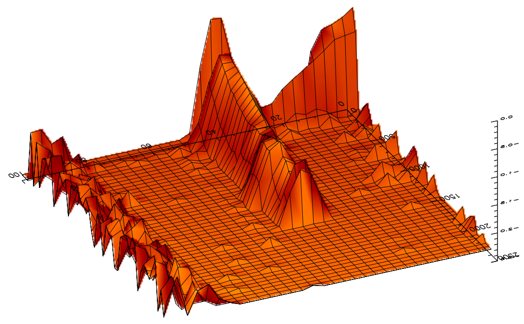

Figure 5: Profile of power spectra from a vertical measurement. The power spectra have been averaged over 15,000 shots (≈ 73 seconds).

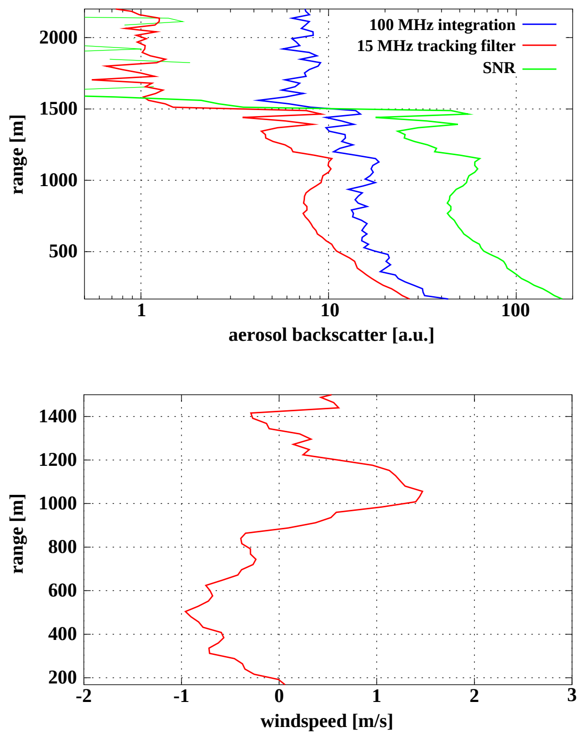

Figure 6: Aerosol backscatter (top) and wind speed (bottom) calculated from the power spectra shown above.

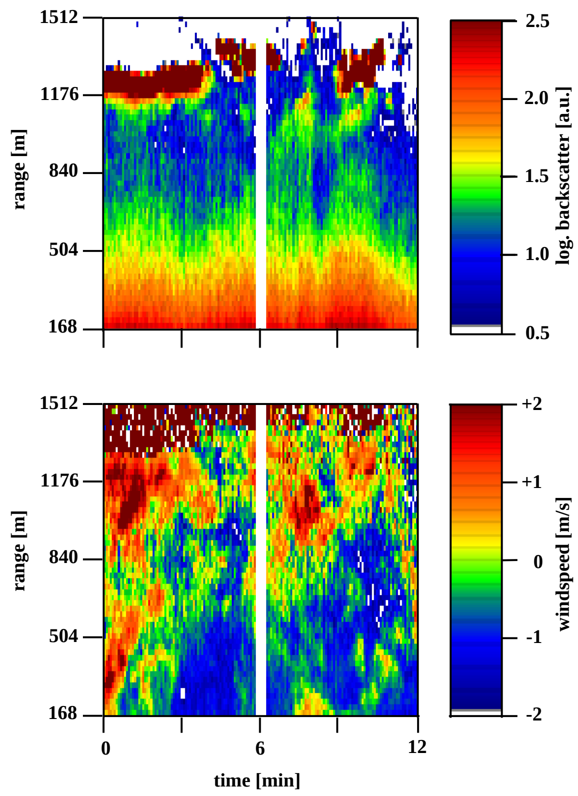

Figure 7: Aerosol backscatter (top) and wind speed (bottom) of 12 minutes of vertical measurements. Each profile has been calculated from 1,000 shots (≈ 5 seconds). No further averaging has been applied.