For many decades Lidar has been used for the determination of physical quantities like gas and aerosol concentrations, temperature, pressure and humidity. Therefore, it can be called the backbone of remote sensing in atmospheric research. In the 21st century it conquered a new field of application with major economic and ecologic impact: real-time wind velocity forecast for turbine control with a leadtime of 10 seconds or more so that turbines can be adapted with ample time to varying wind conditions. In particular, the pitch of the blades can be controlled to achieve a better efficiency, to avoid damage to the gear units, and—ultimately—to prevent destruction by peak gusts. To this end the Lidar systems—preferably mounted on the nacelle—are operated in a forward-looking mode and measure wind speed up to several hundred meters ahead of the turbine.

Unlike most Lidar systems for atmospheric research the wind sensing Lidars used nowadays have small footprints. The main reason is that they are nearly exclusively based on photonic components used in optical communication technology: laser diodes, single-mode fibers, circulators, directional couplers, frequency shifters, modulators, fiber optical amplifiers and photodiodes. For the same reason they tend to be reasonably priced—an indispensable precondition for becoming a widely used product in the wind-energy industry.

Wind sensing by Lidar means detection of scattered light from atmospheric...
aerosol particles. With only a few exceptions, the optical frequency shift between transmitted and received light—the well-known Doppler shift—is evaluated which is done in most cases via an interferometric superposition. The Doppler shift is a direct measure of the line-of-sight velocity of the scattering particles which are moving with the wind.

The next question to be answered is how to spatially resolve the velocity along the line-of-sight. One answer is: Choose a pulsed Lidar which yields the required velocities one after the other according to the round-trip time of the light! An alternative answer is: Focus a continuous-wave (CW) laser beam onto the location of interest since it can be shown that the scattered light from the focal zone will be the dominant contributor to the detected signal!

As extensively discussed in the literature (see e.g. the comprehensive report [1]) both of these range resolving approaches have their specific pros and cons. Accordingly, systems of both kinds are available in the marketplace and no decision has been made to date on which one will ultimately prevail. The benefit of our approach is a substantial strengthening of CW wind Lidars with only moderate modifications. In our opinion the weak points of CW Lidars can be overcome while maintaining their undisputed advantages.

The weak points of current CW wind sensing Lidars are related to range resolution: the spatial resolution is given by the length of the focal zone (called Rayleigh range), it depends on the aperture of the transmitting lens/telescope, it deteriorates roughly quadratically with range and refocussing is required for changing the location of the target zone. To remove these limitations we recommend the use of a standard CW wind-sensing Lidar with three add-ons:

- an optical phase modulator after the laser source
- a fiber-optic delay line in the reference path of the interferometer (which is even dispensable, see below) and
- some additional electronic data processing.

The key to our approach is coherence—strictly speaking limited or low coherence. With a broadband source as shown in Figure 2 a coherent interferometric signal, i.e. a narrowband electrical signal, is only obtained if the optical path in the atmosphere equals the optical path given by the fiber-optic delay line to within the coherence length. This way spatial resolution is established and the length of the resolution element can be chosen by selecting the spectral width of the source corresponding to the intended coherence length. A straightforward way of shifting the location of the resolution element is changing the length of the delay line fiber in the reference path.

Actually, selecting a natural laser source with a desired coherence length is cumbersome and not particularly practical. Therefore, we have built a
A synthetic broadband laser source. It consists of a narrowband laser diode which is readily available and, in addition, an optical phase modulator which is driven by a predetermined noise-like electrical signal. This signal is stored in an electronic data memory. After passing the modulator the optical wave is no longer narrowband but exhibits an optical spectrum of finite width which is governed by the phase noise signal.

Common sense tells us that phase modulation with a fast varying signal will yield a broad spectrum and vice versa (cp. Figure 3). It remains in question, however, what electrical drive-signal is necessary in order to obtain an optical spectrum of finite width which is governed by the phase noise signal.

Figure 3: Making a synthetic broadband source with defined spectral shape by applying a predetermined electrical signal to an optical phase modulator.

A second feature, brought about by our synthetic broadband source, is equally important: range scanning can be done without physically changing the arrangement and without repeated measurements. Instead, the detailed velocity distribution along the line of sight is already contained in one single measurement. That distribution can be unveiled by digital processing of the data after having taken a measurement. This feature—amazing at first glance—is based on the fact that the phase noise of the source as a function of time (which is also present in the electrical signal) is precisely known since it is predetermined and impressed on the optical field of the laser diode.

The two main features stated above—spatial discrimination and numerical shift of the target location to any desired distance—are both in sharp contrast to conventional CW Lidar systems. The last named feature is also useful to remove spurious reflections by using a shift/notch filter/backshift algorithm. This procedure is of considerable importance because reflections from inside the measurement system are unavoidable and they are often huge as compared to the weak scattering signals to be detected.

If (i) the fiber-optic delay in the reference path of our system is chosen so that it equals the delay to beam focus in the atmosphere and back and (ii) the phase modulator induced bandwidth is chosen so that the coherence length is equal to or larger than the focal length (Rayleigh range) our system Figure 2 is completely equivalent to a conventional wind sensing CW Lidar and the signal processing is also identical. Therefore, it need not be proven that it is fully functional if engineered appropriately. It needs to be proven, however, that—if our add-ons are installed—

- the spatial resolution is electronically adjustable and constant along the line-of-sight
- signal contributions from different locations are strongly discriminated, i.e. the resolution zone is excellently defined
spurious reflections can be effectively suppressed
• no moving parts are necessary
• repeated measurements are not necessary since numerical range scanning can be done after the measurement.

These unique properties have been verified and confirmed in a number of recent publications [2-5]. The last mentioned property is illustrated by the results of a lab experiment shown in Figure 4.

In conclusion, we believe that low-coherence CW-Lidars with synthetic broadband sources such as those described above are well suited for remote wind sensing and remote vibration analysis, and have what it takes to outperform pulsed Lidar systems.

References