Development of a Mobile Wind Profiler

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ABSTRACT

The Physical Sciences Division (PSD) of NOAA's Environmental Systems Research Laboratory (ESRL) is developing a small mobile wind profiler capable of measuring high resolution boundary layer winds in extreme clutter environments. This profiler will use spaced antenna technology coupled with NOAA's low sidelobe antenna design to produce high time resolution wind profiles in locations where there is too much ground clutter interference for traditional wind profilers. In addition, the profiler will be designed as a Frequency Modulated-Continuous Wave (FM-CW) radar. FM-CW radars allow for wind measurements at lower altitudes and with higher range resolution than traditional profilers. FM-CW radars are also capable of better sensitivity than pulse modulated radars; therefore, the mobile profiler can be designed with a lower transmit power than other spaced antenna radars. Planned uses for the new profiler are fire weather forecasts and dispersion model initialization.

1. INTRODUCTION

UHF boundary layer wind profiling radars were developed in the 1980s (Ecklund et al. 1988). Since that time, they have found many uses including air quality, weather forecasting, and aircraft safety. For some applications, such as fire weather and urban winds, boundary layer profilers are hampered by the high ground clutter environments usually encountered. In addition, boundary layer winds need to be measured at lower altitudes and at a higher range resolution than current wind profilers are able to provide.

The Physical Sciences Division (PSD) of NOAA's Earth System Research Laboratory (ESRL) is developing a new mobile boundary layer profiler designed to be used in high clutter environments. This new profiler will also be mobile enough to be deployed to forest fires to help with fire weather forecasts or urban settings to provide data for dispersion models.

To accomplish this, the profiler is designed with a new antenna that has dramatically reduced low angle sidelobes compared with current profiler antennas. This reduces the radar return from low angle clutter targets. The profiler is designed as a spaced antenna radar (Briggs 1984) which allows for rapid update wind estimates in a turbulent boundary layer. Also, the profiler will be a Frequency Modulated-Continuous Wave (FM-CW) design (Richter 1967). FM-CW radars are capable of measuring return at closer ranges and higher range resolution than pulsed radars. Additionally, they are capable they have a higher sensitivity than pulsed radars.

2. LOW SIDELOBE ANTENNA

Most boundary layer profilers currently use a rectangular array of square micro-strip patches as their antenna. These patches are arranged in one meter square modules, each of which contains 16 elements. These antennas are relatively inexpensive to build, easy to steer, and easy to transport. However, the square orientation of the patches gives rise to relatively large sidelobe levels, especially near the horizon where most ground clutter targets are.

The new antenna design also uses micro-strip patches arranged in about one square meter modules. However, the new antenna is built using circular patches arranged on a hexagonal grid. Eighteen micro-strip patches are contained in a module. These are arranged in a circularly symmetric pattern which results in reduced low-angle sidelobes. This arrangement has no patch at the centre.

Calculated antenna patterns for the new antenna design are shown in Fig. 1. Figure 1a shows the E plane pattern and Fig. 1b the H plane pattern. In both figures, the pattern for the new antenna is shown as a solid red line and the pattern for the old antenna as a dashed blue line. Below 30 degrees above the horizon, the new antenna has extremely low side lobe levels. A prototype of the new antenna is shown in Fig.2.

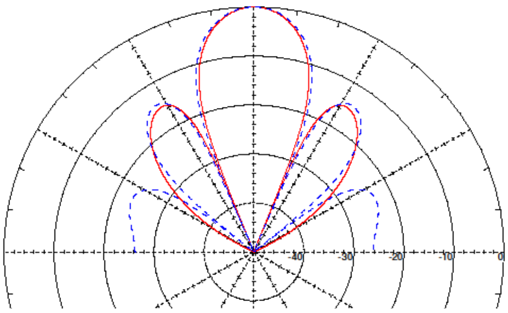

Figure 1a E plane antenna pattern. The red line is the new antenna pattern, blue line the old antenna pattern.

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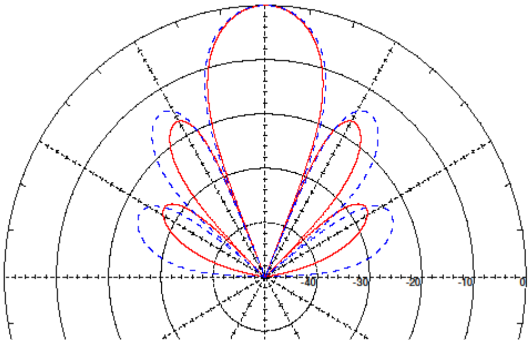

Figure 1b H plane antenna pattern.

Figure 2 Photograph of a prototype antenna module.

3. SPACED ANTENNA

Most profilers utilise Doppler beam swinging (DBS) to measure the winds. DBS profilers steer the antenna beam in multiple directions to measure components of the wind velocity to calculate the wind vector. DBS profilers assume that the atmosphere is homogeneous over the measurement volume. This assumption is true most of the time in the free troposphere; however, large, non-homogeneous vertical velocities in the boundary layer make it difficult for DBS profilers to measure boundary layer winds.

Spaced antenna (SA) profilers determine the winds by measuring the drift of the received diffraction pattern between two antennas separated by a known distance.(Doviack et al. 1996, Holloway et al. 1997) SA profilers determine the winds from a common time and volume. This means the requirements of homogeneity are removed. This makes SA profilers ideal for high time resolution wind measurements in the boundary layer. A UHF SA wind profiler has been built and operated at NCAR called MAPR (Cohn et al. 2001).

4. FM-CW

Most wind profiling radars employ a pulse modulated transmitter. Pulse modulation is easy to implement and transmit and receive functions can share the same antenna. However, the receiver electronics must recover after the transmit pulse before the first data point can be measured. This recovery time limits how low the profiler can measure the winds. For example, UHF profilers used at PSD typically have the lowest wind measurement at about 100 meters above the ground.

A different modulation scheme, frequency modulated-continuous wave (FM-CW), avoids the receiver recovery problem by constantly transmitting, CW, a frequency sweep, FM. This requires two antennas, one to transmit on and the other to receive on. There must be high isolation between the antennas to keep the transmitted power from saturating the receiver electronics. Since the receiver electronics doesn't need to recover, FM-CW profilers are capable of measuring winds at lower altitudes. The new mobile profiler will require four antennas, one to transmit and three to receive.

FM-CW radars can measure higher altitude resolution than pulsed radars given an allocated bandwidth. Pulsed radars require more necessary bandwidth than FM-CW radars for the same range resolution. In addition, FM-CW radars have a much narrower matched filter bandwidth than a pulsed radar. Therefore, FM-CW radars have about 20 dB more sensitivity than similar pulsed radars.

5. PREDICTED PERFORMANCE

Any new radar design is verified by calculating expected altitude performance using the radar equation. The radar equation used here was derived from VanZandt et al. 1978. Radar performance for wind profilers involves calculating the radars minimum detectable signal-to-noise ratio and comparing it to a model of the atmospheric C_n^2 profile. We use the boundary layer C_n^2 model developed by Fairall et al. 1991.

The predicted performance of the new radar based on the minimum detectable signal-to-noise ratio of a DBS profiler is shown in Fig. 3. The predicted minimum detectable C_n^2 for the new boundary layer profiler is plotted along with the model average C_n^2 profile for a Colorado summer day and winter night. If the minimum radar detectable C_n^2 exceeds the modelled C_n^2, the radar will detect winds. We expect the new radar to measure winds to the top of the boundary layer, here modelled at 2 km altitude, in the summer and about 300 m during winter nights, similar performance to the current UHF wind profiler.

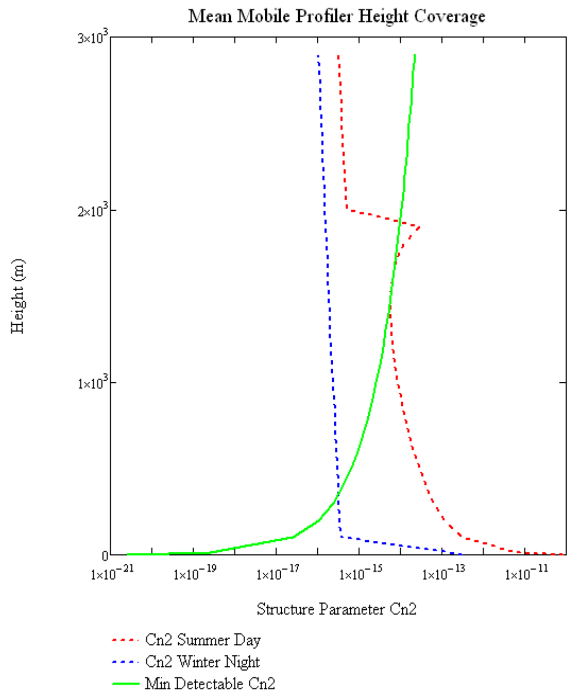

Figure 3 Predicted performance of the new wind profiler.

Unfortunately, SA radar performance is more difficult to predict than DBS radars. The performance of SA is influenced by the signal-to-noise ratio, antenna spacing, and atmospheric turbulence. (Zhang et al. 2004) The standard deviation of velocity estimates in a SA radars can be made nearly independent of system noise using advanced signal processing. Therefore, signal power, atmospheric turbulence and antenna spacing together will determine the real world radar performance.

6. CONCLUSIONS

There are tasks for which current wind profilers are not capable of providing useful data because of the high clutter environments encountered. Fire weather forecasts and urban dispersion models are two examples of such tasks. The mobile boundary layer wind profiler presented here will be able to provide quality wind measurements in high clutter environments due to its improved antenna design.

In addition, the mobile profiler will be able to measure boundary layer winds at lower altitudes since it uses frequency modulated continuous wave technology. The new mobile profiler will also produce higher time resolution data than previous profilers since new profiler uses a spaced antenna design.

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