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A NEW TROPOSPHERIC RADAR WIND PROFILER

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1. INTRODUCTION

A completely new, commercially designed and built, radar wind profiler system has been developed, tested and installed. The system was developed in response to a request for a wind profiler capable of on-site operational support for an aerostat system. An aerostat is a large tethered airship used for carrying aloft surveillance radars or other defensive electronics, and normally flies at 3,500 – 5,000 meters. While the wind profiler has design features specifically geared to aerostat support, these same features have also allowed this system to be a highly capable system for more general wind profiler requirements. The first two systems have been installed in India, with a third system scheduled for installation in Kuwait in Fall 2005. A full system description will be presented along with data products and comparisons.

2. DESCRIPTION

The new system is modern pulse Doppler radar system and operates at 449 MHz (see Table 1 for radar specifications). It is unique in that the antenna uses a Yagi element array (see Illustration 1), each with their own phase-shifter. The antenna can point anywhere within a cone above the radar, up to 25° off of vertical. The ability to continuously and actively steer the antenna beam is used to enable the radar to avoid pointing its main beam at the aerostat—thus preventing any significant illumination of the aerostat payload, and greatly reducing interfering backscatter to the wind profiler. The antenna and transmitter systems were both designed for scaled use, so that other sizes of antennas and transmit power levels are available depending on data requirements.

Table 1 Radar Specifications

Frequency	449 MHz
Power	2 kW Peak, up to 15% duty-cycle
Antenna	Phased array, 11 x 11 m ground plane, with 192 elements in circular pattern
Antenna Element	Yagi-Uda, each with 4-bit solid-state phase-shifter
Antenna Pointing	Fully steerable
Range	<120 m to 4 km (~90% data availability)
Range Resolution	User selectable, starting at 50m
Data System	14-bit ADC with digital IF, programmable STC, and complementary phase coding
Spectral Resolution	User selectable to >128K FFTs
Software	Multi-peak picking, time-height continuity analysis,advanced QC screening
Data Rates	5-60 min. avg. w/ 2-60 min. updates

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Other important features of the system are the use of a digital intermediate-frequency (IF) receiver, Advanced Signal Detection (ASD) algorithms, and completely health/status monitoring. With the digital IF, the receiver is greatly simplified and is very reliable. The ASD software utilizes multiple peak-picking and identification routines, and time-height continuity analysis to screen out radio frequency interference, aerostat caused or other interfering clutter, birds, and other non-atmospheric backscatter signatures. The ASD routines also allow for shorter averaging times and higher data update rates than traditional processing. The hardware monitoring continuously measures significant voltages, currents, temperatures, RF power, and various status bits. See Illustration 4 for a picture of the radar electronics rack.

2.1 Antenna

The traditional type of antenna used at this frequency (and lower) for radar wind profiling is the coaxial-collinear (co-co) element (see Beran and Wilfong 1998, or Law et al 1997), arranged in two

Illustration 1. Yagi element array on ground plane.

perpendicular arrays over a ground plane. This arrangement also uses a separate mechanical phase-shifter, to shift both the relative phase of each row, and to shift back and forth from the lower to the upper array. While very effective for simple Doppler Beam Swinging (DBS), the co-co array can not be steered except in previously determined static positions (fixed zenith and azimuth). Additionally, high-power mechanical relays required for switching the phase and transmit array are typically only rated for 1 to 2 million cycles. Since RWP systems typically switch their beams approximately every 30 seconds, this means in only one year, it is likely that some of the 20-30 relays will have failed in some manner.

This new design utilizes full solid-state beam switching with no moving parts, thus enabling full beam steering and extreme reliability. Rather than use a centralized high-power mechanical phase-shifter, each of the 192-Yagi elements is switched with its own 4-bit phase shifter (see Illustration 2), inside of the tube used to hold the Yagi elements and protect the phase-shifter. While PIN diode phase-shifters have been used at 915 MHz for full beam steering capability (see Law et al 2002), they have rarely been used at lower frequencies for wind profilers. Each antenna is uniquely controlled through a simple communications scheme, utilizing DC power and control cables under the array. The operation of this new antenna has proved to be robust.

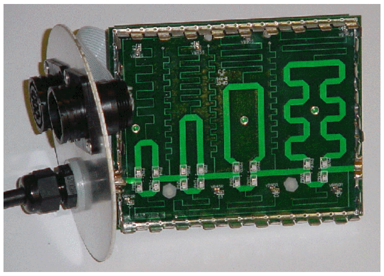

Illustration 2. 4-bit Phase-shifter

The identical antenna elements are placed on the array in a carefully derived “sparse” or “thinned” circular pattern, on an 11m x 11m ground plane. As evident in Illustration 1, the overall pattern of elements in the array has openings, and looks somewhat random. This element distribution pattern is actually designed to give the array an amplitude taper, which greatly reduces sidelobes, and a more random nature to the sidelobes (rather than symmetrical “hot spots”). In co-co arrays, this can be accomplished to a much lessor degree with uneven RF dividers and co-co stick placement, but here the divider outputs are all of equal power and thus are simpler and cheaper to manufacture. The amplitude taper can be controlled to a very fine degree, and in this case is a 32-dB circular Taylor. Illustration 3 shows a calculated antenna pattern cut (directivity) for a 15° oblique beam.

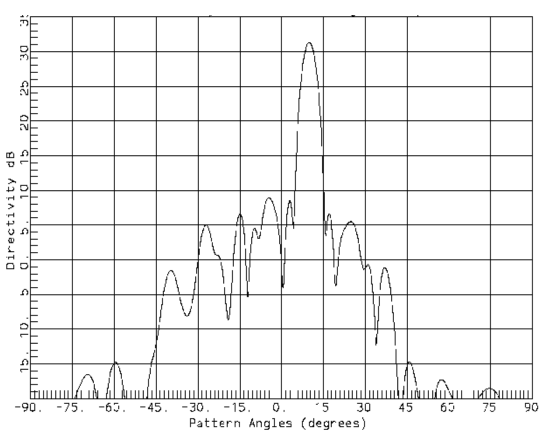

Illustration 3. Example calculated antenna array radiation pattern cut, showing low sidelobes.

With the low sidelobes and full beam steering, the antenna can be pointed anywhere in a cone of about +/-25° above the radar (and is less susceptible to ground clutter and other interference such as birds). Currently, this feature is used to prevent the wind profiler from illuminating the aerostat with the main lobe of the antenna pattern, and to significantly reduce the reflection of the aerostat from interfering with the wind profiler. In the latter case, by keeping the main beam of the antenna beam pointed *away* from the aerostat, potentially a 60 dB (two-way) reduction of the reflection can be accomplished.

In the future, the full beam steering capability will be used for other more meteorological data related advantages such as multiple zenith angle, and multi-point VAD (velocity azimuth display) scans. Also, since the beam is controlled through solid-state means, it can also be switched quickly (~10 Hz), and thus even more interesting beam switching techniques will be explored in the future such as “lug-nut” switching, where all beams are built up simultaneously.

2.2 Data System

The data system developed for the radar is completely new and utilizes state-of-the-art software radio data acquisition cards along with modern graphics-rich software. Software radio is a relatively new field of radio signal creation and demodulation and has pushed the use of high-speed analog-to-digital and digital-to-analog converters to a level suitable for use in modern radar systems. Because of the wider software radio market, these new 14-bit high-dynamic range cards are well supported and can be used in a radar wind profiler system as an off-the-shelf commodity. Most previous and many current RWPs rely on in-house proprietary designs for the ADC card and timing generators.

Illustration 4. Radar electronics

The software used is a combination of executables generated from C++ and LabVIEW® (see www.ni.com). Each has its strengths and weaknesses, but through the use of LabVIEW, the complete application could be completed in only 18 months, and with a significant number of intuitive graphics for both diagnostics and normal data acquisition. In normal operation, all facets of data flow can be viewed (and saved for replay or analysis) in real time. Most displays can also be setup to accumulate data for 24 hours or more, so any trends can be easily seen. Illustration 5 shows the time series plot for a single coherent dwell of a single gate, with corresponding unclipped spectra below. Long time series are used, enabling FFT lengths of 64k or more (used to help filter interference such as RFI). Illustration 6 shows spectra from the Dwell software, both with line graphs of range gates (on the left) and color contours (on the right).

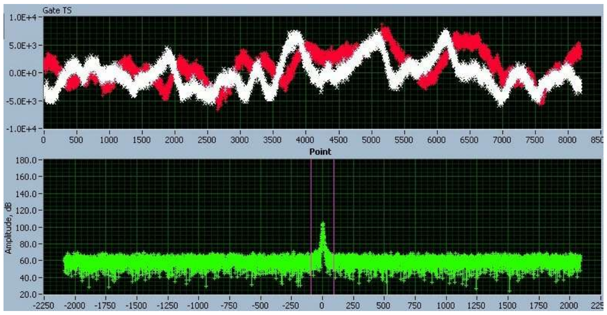

Illustration 5. Time series and unclipped spectra

The data system software is actually composed of two main programs. The first is the Dwell module, which controls the radar hardware and performs initial data processing. The second is the Advanced Signal Detection (ASD) module, which is a new implementation of published techniques developed by NOAA researchers over the last several years (see Wolfe et al 2001, and Weber and Wuertz 1990). The Dwell acquires the data and sends clipped spectra to the ASD for every acquisition cycle. ASD then performs multi-peak picking through the use of time-height continuity analysis with built-in automatic quality control (QC) to reduce outliers and erroneous data due to birds, radio frequency interference, etc. The quality and staleness of the data is extremely important to aerostat operations, as is keeping the total averaging time small (<10 minutes) and update rate high (updates at least every 2 minutes). Through the use of ASD, short averaging and update time data products (wind and turbulence) can be continuously produced to alert operators of possible meteorological threats.

2.3 Aerostat Avoidance

With the unique feature of full beam steering, the radar uses position information of the aerostat, and then correspondingly moves the main beam away. This is accomplished automatically, and slowly, so that the time-height QC algorithms can continue to track the wind spectra signal. Fortunately, the aerostat also moves slowly, so very little data are lost during normal flight operations. In addition to the aerostat avoidance

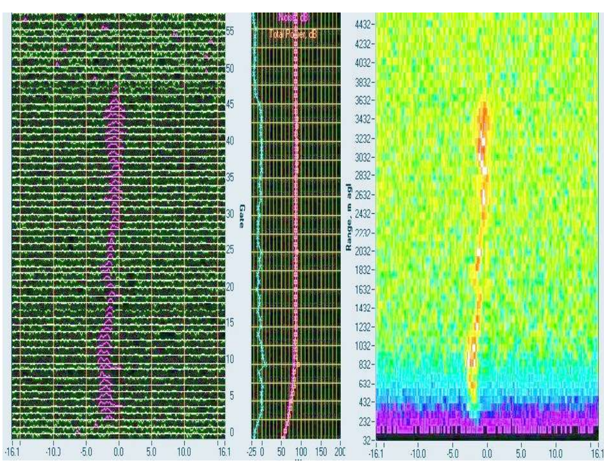

Illustration 6. Stacked spectra display of the Dwell software

though the use of beam steering, the system also uses a programmable sensitivity time control (STC), which attenuates the front-end of the receiver, and tracks the aerostat radial distance, to further prevent saturation of the wind profiler receiver, particularly when the aerostat is near the ground. The STC is also used to prevent receiver saturation in the first few gates caused by close-in ground clutter.

2.4 Radar Hardware Monitor

The radar system is fully monitored to detect equipment failures, by the Radar Hardware Monitor (RHM). The RHM also points the antenna via commands received from the Dwell software. The RHM is composed of a simple and reliable microprocessor, and various interface boards for sampling the DC power, RF power, and digital status bits. It runs independently of the Dwell computer, but provides status data to the Dwell software for review by the operators. The data are displayed in real-time in the Dwell software and on a front LCD of the RHM chassis. Values out of specification are recorded and the radar can be shut down if a faulty subsystem is detected.

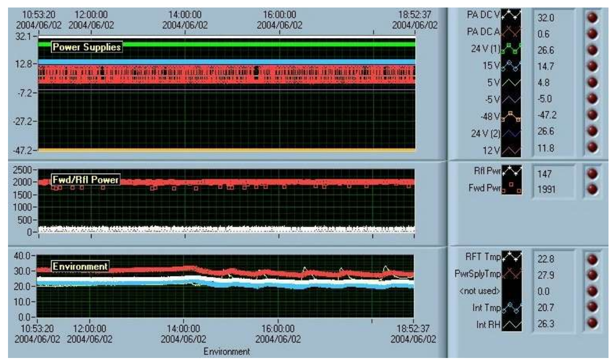

Illustration 7. Sample RHM screen.

2.5 Miscellaneous

Overall the system was designed for ease of maintenance, with most maintenance connections (and fuses) on the front of the rack-mounted equipment. This allows quick checks of values with a volt meter or oscilloscope without having to remove equipment from the rack or be forced to make connections on the back, where the software cannot be seen or controlled. Surge-suppression is also built into virtually all external interfaces.

3. RESULTS

First results were obtained in the Spring of 2004 at a field site in Erie, Colorado, with the first of two system installed in northern India in Fall of 2004. Illustration 8 shows a graphical comparison of data from the Platteville, CO NOAA NPN 449 system, located approximately 28 km NE of the ATI system. Very good agreement has been found between the two systems, although, due to the proximity of the Rocky Mountains, localized weather effects were also seen. More data comparisons and statistical comparisons will be published at a future date.

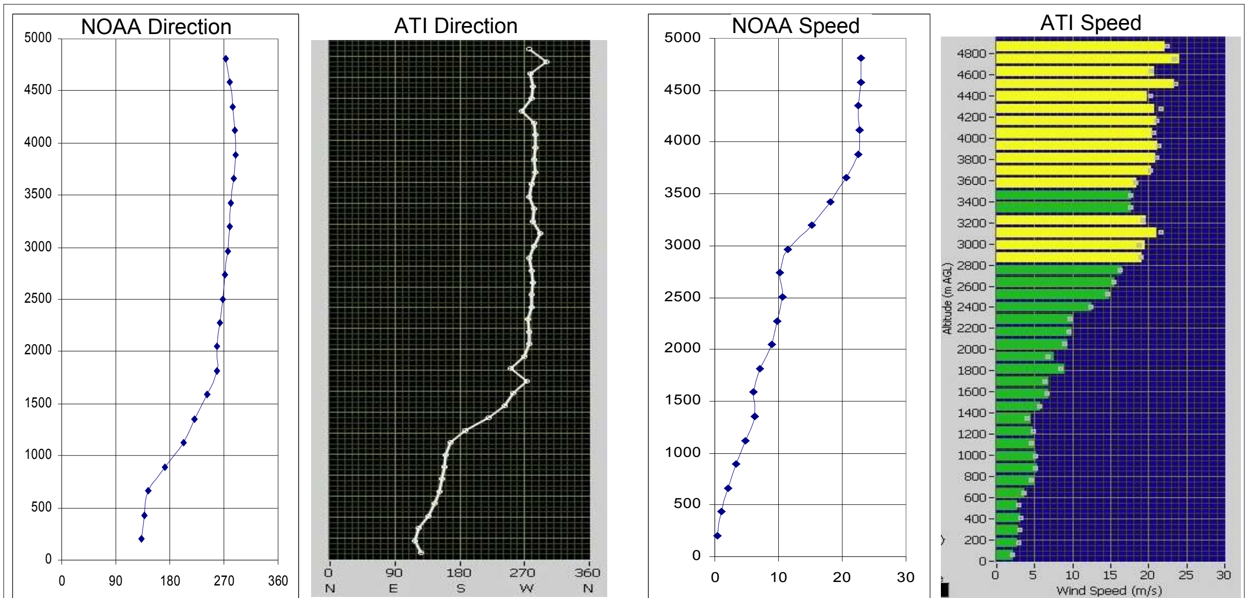

Illustration 8. NOAA 449 MHz Platteville data and ATI 449 MHz data , for May 15, 2004, 1700 UTC. In order from left to right: NOAA wind direction, ATI wind direction, NOAA wind speed, ATI wind speed. Note that the NOAA profiler data is for an entire hour average while the ATI system was set for single 10 minute average. The systems are about 20 km apart.

The ATI profiler displays have been carefully designed for easy “quick looks” by the aerostat flight directors. As such, there are several features built into the displays to aid the operators, such as the histogram-like plot of the winds in Illustration 8. Here the histogram changes color depending on the preset wind speed values determined by the aerostat manufacturer.

In Illustration 9, 0th moment (return signal power) data are shown. The data has been range-corrected and shows clear-air layers shortly before a rain shower. This moment data are raw data (unaveraged from all 4 beams). The power roll-off at the lowest gates is due to the STC, which was set for high attenuation at the lowest gates. Power and speed information is still present, but the data has not been corrected for the extra attenuation.

Illustration 10 shows first data of the wind profiler running while an aerostat is out-hauled (raised) in India. Because of the large radar cross section of the aerostat, its Doppler shift is seen by the radar, even with the beam steering and the STC. But, once at normal flight altitude (4-5 km), the aerostat is “hidden” in the 0 m/s FFT bins and is not seen to effect the data. Tests with the STC and aerostat-avoidance beam steering did show their efficacy though, as turning them off could greatly increased the power into the receiver (making data capture difficult at the same height as the aerostat). The aerostat spends most of its time at altitude though, and the total time to in-haul or out-haul is quick enough so as not to be a factor for aerostat operation.

4. SUMMARY

A new radar wind profiler, based on modern electronics and software, has been developed. While designed to address the needs of an operational aerostat site, these new design features also benefit

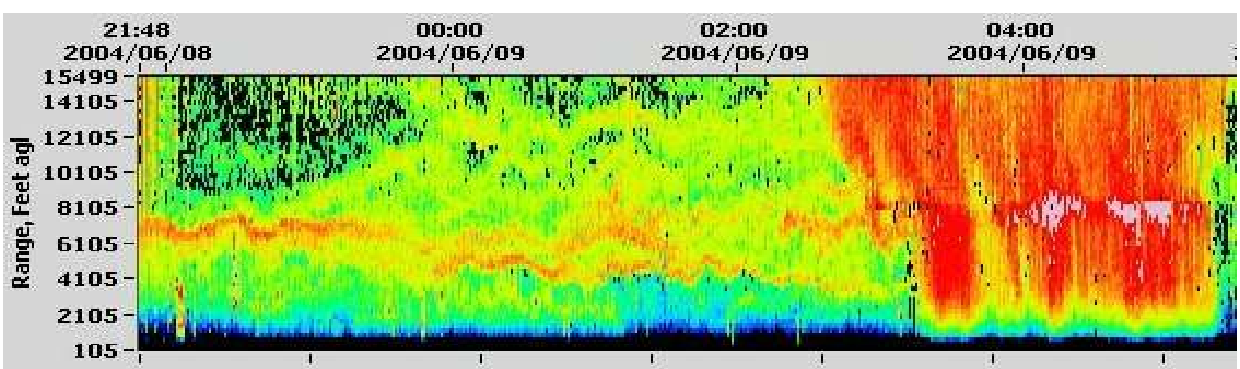

Illustration 9. Range-corrected 0th (power) moment data. The low signal values in the lowest gates are due to the STC. While not shown here, the 1st moment data is still available and is used for the wind calculation.

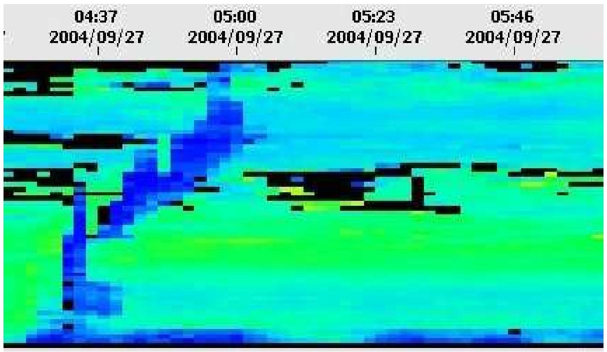

Illustration 10 Wind speed contour, showing aerostat gaining altitude.

more traditional uses such as research and weather forecasting. These new capabilities do not significantly effect the relative price of a wind profiler system (with the same data height capturability), and yet enhance the overall reliability (e.g., solid-state phase shifters) ease of maintenance (e.g., no legacy or proprietary acquisition cards or software) and data quality.

The system processes all data in real-time utilizing advanced multi-peak detection and QC software. The new software makes extensive use of graphics displays to show the data in its various states, as it is used for wind calculations, and to help the operators determine the validity of the data and health of the radar system.

Further data comparison and improvements to the software will be made in the coming year. A third system is being built for another overseas location, and additionally, the same data system and electronics has been applied to successfully upgrade two older 915 MHz radars, and to upgrade a previously built ATI 915 MHz system.

5. REFERENCES

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