VAISALA / WHITE PAPER

With Vaisala Dual Polarization Enhanced Reflectivity - Radars See More!

Increasing sensitivity without the disadvantages of a more powerful transmitter.

With the first use of Radio detection and ranging, (RADAR) it quickly became evident the technology was useful in surveying atmospheric conditions. With dual polarization significant effort has been made to improve the quantitative value of the radar measurement. Examples of such research include advances in rainfall estimation, identification of hydrometeors and removal of non-meteorological targets, correction for attenuation, and self-consistent estimations of calibration. These are all indeed useful methodologies with a high amplitude signal near the radar, generally less than 150 km from the site.

This paper introduces a new signal processing technique to enhance reflectivity detection, improving the surveillance capabilities of a simultaneous transmit and receive (STAR mode) dual polarization radar. The technique improves the detection of low amplitude signals, common at distances farther than 150 km from the radar site. It is exclusive to Vaisala Weather Radar WRM200, Vaisala Weather Radar WRK200 and Vaisala Sigmet Digital Receiver and Signal Processor RVP900™.

Background

In order to make dual polarization radars cost effective, manufacturers choose to use the simultaneous transmission and reception (STAR mode) of the two polarization states. The STAR mode offers a simpler design increasing the reliability and lowering the lifetime costs of the system versus other dual polarization concepts. The STAR mode also has a specific technical advantage that the horizontal and vertical data are sampled simultaneously. Therefore the STAR mode radar can achieve higher correlations with observed hydrometeors than other types of dual polarization systems.

A major disadvantage of the STAR mode is splitting the transmitter power into two channels. This effectively cuts the average output power of the radar by ½ or 3 dB. The amount of power received back to the radar is directly proportional to the transmitted power. When the transmitter power is cut in half the radar's minimum detectable signal is also reduced by half, thus some sensitivity is lost. This has a negative impact to the surveillance role of a weather radar!

The traditional methodology to overcome this loss in sensitivity is to increase the transmitter power. Today with the commercial C-band radar market, one-megawatt transmitters are available to overcome the problem. However, higher transmit power does have important technical and economical disadvantages that need to be considered:

1. Increasing the transmitter output power also increases the amount of returned ground clutter power. This causes a need to use stronger ground clutter filtering algorithms. When ground clutter filter algorithms remove more data, they also negatively impact valid meteorological data.
2. Increasing the transmitter power increases the probability the receiver becomes saturated at near ranges to the radar site. With a saturated receiver distinguishing ground clutter from a weather signal becomes impossible.
3. The higher power transmitter has higher lifetime costs in the form of replacement spare parts, increased specifications to infrastructure like backup power generators and uninterruptable power supplies. The difference in a lifetime power consumption alone may be over USD 50,000 given today's cost of energy. The cost of energy is only expected to rise.
4. With higher power transmitters it may become more difficult to obtain a broadcasting license.

The Vaisala Solution Increases Detectability without the Disadvantages of a more Powerful Transmitter

The amplitude of the received power is determined from the electrical voltages received through the antenna. These voltages are expressed as complex numbers in order to solve problems not possible with only real numbers. In weather radar signal processing correlations are performed by measuring the similarity of the received energy with itself. It is a mathematical tool for finding patterns, such as signals buried under noise. Traditionally the power estimators used in dual polarization radars is to compare the horizontal antenna voltages with itself, or compare the vertical antenna voltages with itself. The output of these power estimators are then used to computer horizontal reflectivity, Z_h, and vertical reflectivity, Z_v, respectively.

The Vaisala solution to the problem of splitting power is to make use of a new input to the echo power estimation techniques. It is commonly known through the radar community that precipitating particles have a high correlation between the H and V polarization states. It is typical to have co-polar correlation ($\rho_{HV}(0)$) values greater than 0.85 for almost every type of hydrometeor. In liquid rainfall it is common for the WRM200 to measure $\rho_{HV}(0)$ at 0.996. Therefore it is just as feasible to compare the H channel antenna voltage with the V channel antenna voltage and call the resultant enhanced reflectivity, Z_{hv}. But why does this give better detectability?

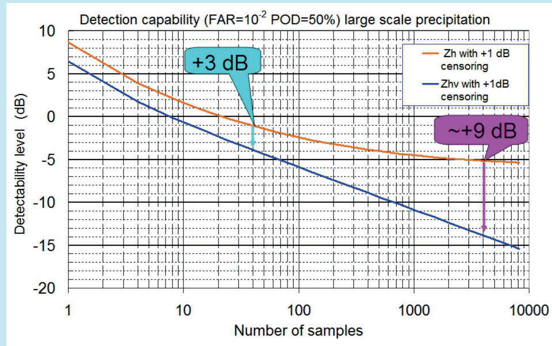

Figure 1 is a comparison of the detection capabilities of the Zh and Zhv power estimators as a function of samples when using data censoring techniques to remove residual noise. The difference between these two lines represents the increase in detection capability of the H&V power estimator over the H-only estimator.

The power returned to the radar is composed of energy from clutter, signal, and noise. There are many algorithms in use today to remove the clutter power, leaving us with the signal and noise power. When obtaining the signal power, the traditional methodology simply subtracts the estimated mean noise value. The noise estimate comes from routine samplings performed during calibration or when the radar is operating. If we can lower the expectation value of noise and its variance, weaker signals can be measured. The noise cancellation mechanism being described provides us with both lower and narrower residual noise levels. This allows us to relax the censoring or thresholding criteria used to remove bad data, while keeping equivalent data quality.

Noise is composed of background earth and atmosphere radiation and noise within the radar system. This noise has random power at any frequency. When cross-correlating the H channel voltages to itself, the random noise is also correlated as it is the same signal. When performing cross-correlation between the H and V channels the noise is uncorrelated as it is a different signal. Yet the weather signal between H and V is highly correlated. Thus when doing this correlation over an infinite amount of samples, the noise expectation value of the H-only correlation will settle to some value while in the H&V cross-correlation the noise expectation value settles to zero. As we need to discern our signal from the noise and the noise in H&V case settles to zero we suddenly have ability to detect a weaker signal.

In reality we do not have an infinite sample size; we are limited to some finite quantity of samples. But the more samples we give as input to the Z_{hv} power estimator the better the probability of detection.

Under typical operational scan strategies sample sizes are ~40 pulses. This would give an increase of ~3 dB detectability of the Z_{hv} versus Z_h power estimator, which is equivalent to the 3dB lost due to splitting power. At far distances from the radar we could be able to use samples from several range bins as inputs to this new power estimator. This would significantly increase our sample size. For example, it is possible to perform range integration of 16 contiguous bins each with 64 pulse samples giving us 1024 total samples. As Figure 1 shows the improvement in detectability over traditional processing is ~6 dB, while sacrificing some range resolution. However, as the radar beam is always expanding at far ranges we have already lost spatial resolution. It is not a bad trade-off to observe large scale precipitation with lower spatial resolution, instead of no data at all!

Enhanced Reflectivity Also Gives Greater Detectability Versus a Single Polarization Radar Functioning at Full Power.

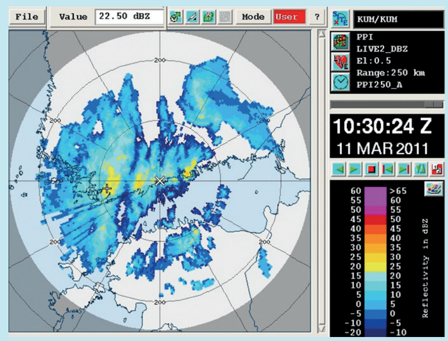

Figure 2: Volume scan data from Vaisala's Kerava radar in horizontal only transmission.

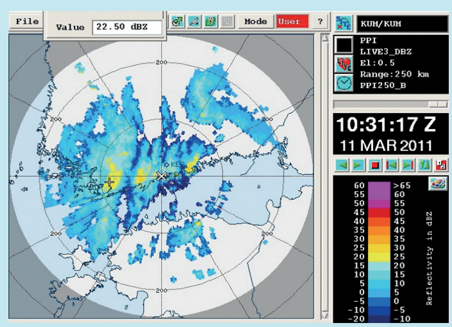

Figure 3: Volume scan data 53 seconds after data in figure 1 using STAR mode transmission. With legacy processing, 3dB of sensitivity is lost due to splitting power to horizontal and vertical channels.

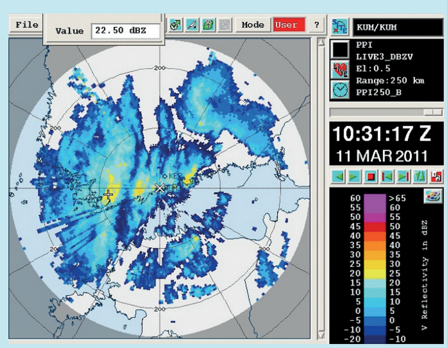

Figure 4: Same volume scan data as in Figure 2 except with enhanced reflectivity. By not having correlated noise in the power estimator there is the ability to exceed the detectability possible in single polarized radars at full power (Figure 1). The cursor position is showing a value of 22.5 dB at the same position for all figures again indicating no bias in power estimates.

Enhanced Reflectivity is an Unbiased and Equivalent Measurement Compared to Traditional Horizontal Reflectivity

Essentially Z_{hv} is a different physical measurement than the traditional Z_h. As Z_h is very commonly used as a decision maker, it must also be shown that Z_{hv} is an equivalent or unbiased measurement. It is also fortunate that Z_{hv} can be calibrated with attenuation corrections in the same manner as Z_h. Figures 5-7 show comparisons of the Z_h and Z_{hv} values within the same scan.

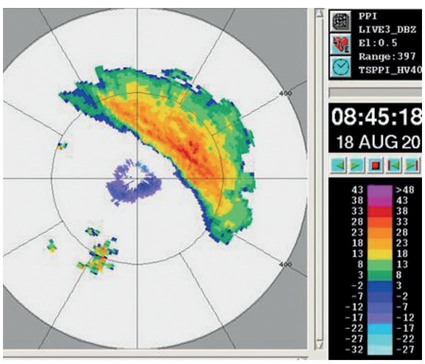

Figure 5: Horizontal reflectivity (Z_h) obtained during STAR mode operations with Vaisala's Kerava radar.

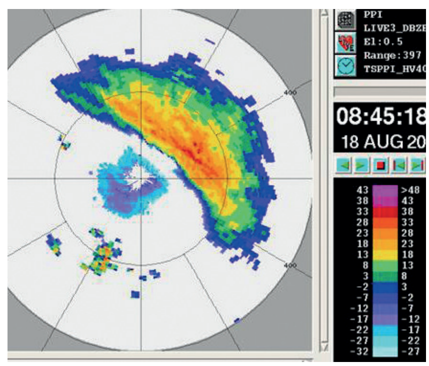

Figure 6: Enhanced reflectivity (Z_{hv}) computed from the same scan as in Figure 5. Higher rate of detection is again seen but same low false detections.

Vaisala Weather Radars Providing More Value

Here is a summary of the benefits

- Using similar scan configurations commonly used in dual polarization, an increase in detectability of 3 dB, to having a 500 kW transmitter in the competitions radar but with lower lifecycle costs.
- Total detectability increased by 10 dB which is equivalent to 2.5 MW transmitter.
- Longer range surveillance capability for use in aviation and meteorological decision making.
- Less susceptibility to total attenuation due to the higher detectability and V component, ie less attenuation loss.
- No hardware changes to weather radar system required.

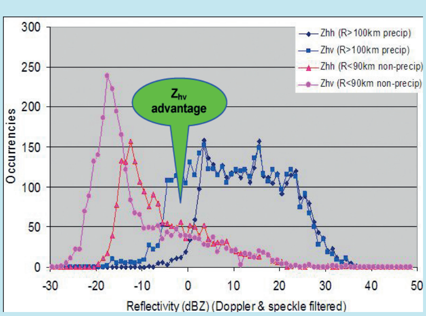

Figure 7: The number of occurrences for a specific Z_h and Z_{hv} reflectivity level for entire PPI scan. The dark and light blue lines are for horizontal and enhanced reflectivity, respectively at ranges greater than 90 km. This is the location outside the clear air returns evident near the radar in Figures 2 and 3. It is seen at higher amplitude values, the enhanced reflectivity has very little bias compared to the traditional horizontal reflectivity. The gain in sensitivity is also apparent where the horizontal reflectivity increase around 0 dB.

The red and pink show large biases but this is expected as the targets are non-meteorological having low correlation in dual polarization.

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For more information, visit www.vaisala.com or contact us at sales@vaisala.com