Wind Farms Impact on Radar Systems

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BIOGRAPHY

Maria Greco graduated in Electronic Engineering in 1993 and received the Ph.D. degree in Telecommunication Engineering in 1998, from University of Pisa, Italy. From December 1997 to May 1998 she joined the Georgia Tech Research Institute, Atlanta, USA as a visiting research scholar where she carried on research activity in the field of radar detection in non-Gaussian background.

In 1993 she joined the Department of "Ingegneria dell'Informazione" of the University of Pisa, where now she is Assistant Professor since April 2001. She is IEEE Senior Member since June 2004, she was co-recipient of the 2001 IEEE Aerospace and Electronic Systems Society's Barry Carlton Award for Best Paper and, in 2008 she received the IEEE/AESS 2008 Fred Nathanson Young Engineer of the Year Award for contributions to signal processing, estimation, and detection theory. She has been co-general-chair of the 2007 International Waveform Diversity and Design Conference (WDD07), Pisa, Italy, June 2007 and she was in the Technical Committee of the 2006 EURASIP Signal and Image Processing Conference (EUSIPCO), Florence, Italy, and in the Technical Committee of the 2008 IEEE Radar Conference, Rome, Italy, and now she is in the Organizing Committee of the CAMSAP09, Aruba, December 2009. She was guest co-editor of the special issue of *the Journal of the IEEE Signal Processing Society on Special Topics in Signal Processing* on "*Adaptive Waveform Design for Agile Sensing and Communication*," published in June 2007 and lead guest editor of the special issue of *International Journal of Navigation and Observation* on *"Modelling and Processing of Radar Signals for Earth Observation* published in August 2008. Since April 2008 she's an Associate Editor of IET Proceedings – Sonar, Radar and Navigation and a member of the Editorial Board of the Hindawi Journal of Advances in Signal processing (JASP) and since January 2009 member of the IEEE Signal Processing Theory and Methods (SPTM) committee.

Her general interests are in the areas of statistical signal processing, estimation and detection theory. In particular, her research interests include cyclostationarity signal analysis, bioacoustic signal analysis, clutter models, spectral analysis, coherent and incoherent detection in non-Gaussian clutter and CFAR techniques. She authored or co-authored two book chapters, more than 35 journal papers and 40 conference papers.

1. INTRODUCTION

The Renewable Electricity Directive (77/2001/EC) established in 2001 that the target for the European Union (EU) about energy is to have renewable energy sources provide 20% of EU electricity consumption by 2020. Following this EU Directive, in September 2007, the Italian government presented in Brussels the "Renewable Energy Position Paper". This paper set a potential electricity production in 2020 of up to 22.6 TWh (with an installed capacity of up to 12 GW), compared with 2.35 TWh in 2005 and 3 TWh in 2006. Wind-generated energy, as a percentage of national electricity demand, increased in 2007 to 1.23 %, about 25% more than in 2006. A similar growth rate is expected for the end of 2008. Based upon the tables published on the 2007 International Energy Agency (IEA) annual report[1] [1], the cumulative number of on-line wind turbines at the end of 2007 was 2,943 with a capacity of 2,726 MW. With this numbers, Italy is the forth European country for the production of wind energy after Germany, Spain and Denmark. Most of the wind turbines are located in Apulia, Sicily, Campania and Sardinia, that is in the Southern Italy and in the islands, the windiest part of the country. An example of "saturation" of windfarm sites in Southern Italy is shown in Fig.1.

[1] The 2008 IEA annual report has not been yet published.

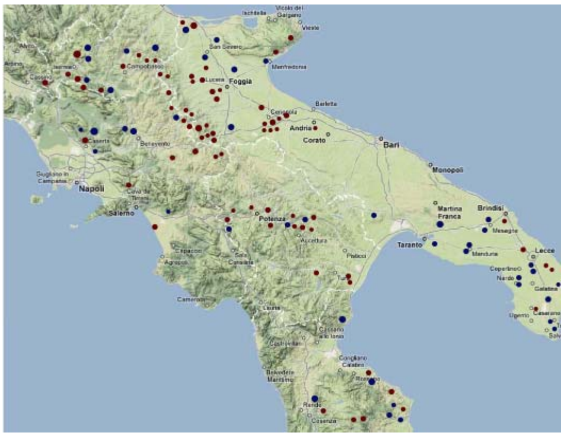

Fig.1. – Wind farms in Southern Italy. In red operating windmills, in blue in construction.

So far, technical problems hampering the exploitation of potentially good sites for wind farms are mainly related to the fact that most of the best wind areas are located in mountainous terrain, which makes it more difficult to transport wind turbines and connect them to a grid. Other more complex problem is sometimes the unfavorable perceptions of wind technology by some regional or central authorities, as well as some environmentalist associations [1]. Unfortunately there is another aspect that must be considered: The impact of wind turbines on both civil Air Traffic Control (ATC) and military Air Defense (AD) radars. The negative effects observed in presence of wind farms have been clearly described in [2]. The wind farms can cause an increased number of unwanted returns (wind farm clutter), a reduced probability of detection for wanted aircraft in region extending around wind turbines (desensitization) and a consequent loss in the performance of trackers of wanted targets in wind farm areas.

In this paper we approach the problem of aircraft target detection with classical CFAR receivers. We propose a simplified statistical model of wind turbines and we investigate how the presence of wind farm clutter affects the performance of Cell Averaging (CA), Greatest Of (GO), Smallest Of (SO), Ordered Statistics (OS) and Trimmed Mean (TM) CFAR detectors, by processing simulated data.

2. WIND TURBINE CLUTTER MODEL

There are different turbine manufacturers producing a variety of turbine types. In Italy, the most active manufacturers are Vestas Italia, Gamesa, Enercon and GE Wind. However, despite the number of existing models, all modern turbines typically have a very similar physical configuration, consisting of a tower topped by a nacelle, supporting three moving blades. The length of the blades is 30-40 m, the height of the tower ranges from 60 m to 100 m. The nominal wind speed is around 15 m/s, the maximum speed of the blade tip is 60-80 m/s. Wind turbine blades are most often fabricated using multiple layers of fiberglass cloth. Towers for large wind turbines may be either tubular steel towers, lattice towers, or concrete towers. The most common are the first. It is evident that, due to the electrical characteristics of its material, the Radar Cross Section (RCS) of the tower can be very large. As reported in [2], at the S-band (2.7-2.9 GHz) and L-band (~1.3 GHz) operating frequencies the peak RCS of turbines can be as much as 300 000m^2 (55 dBm^2) total. Turbine blades can have a peak RCS of 30 000m^2 (45 dBm2) each. To understand how big are these values it is useful to notice that the fighter jets may have an average RCS of only around 1-10 m^2 (0-10 dBm^2), and a large civil aircraft (Boeing747) has average RCS around 10-1000 m^2 (10-30 dBm^2). The RCS of a wind turbine is similar to that of a space shuttle. It is evident that with these RCS values the wind turbines can hide even a strong target in the mainbeam and can enter in the radar detector even if illuminated by the sidelobes of the antenna. Part of the power due to the turbine tower can be filtered by a Moving Target Indicator (MTI), so reducing the impact of the fixed part of the windmill on the radar. Unfortunately, the blades rotate, spreading the scattered power on higher frequencies. The effect of the blade rotation on the scattered signal can be briefly explained as follows. Concerning the RCS, we can observe that as the blades move their returns combine with the returns of the tower and of the nacelle in a way that depends on the interference constructive or destructive between the different parts of the windmill. Moreover we should also consider that the illuminated surface of the blades, due to their inclination, change with the rotation. These two phenomena give rise to maxima and minima in the RCS behavior in a cyclic fashion. The period depends on the number of blades (generally three), the pitch and yaw angles of blades and turbine with respect to the radar and on the speed on the wind [3].

In this work we use a very simple stochastic process for modeling the wind turbines effect on the radar received signal. Observing from [3] that the main contribution to the spectrum of windmill is due to one blade at time together with the tower, we simulate the wind turbine clutter (WTC) as a Gaussian distributed process with a Power Spectral Density (PSD) given by

$$S_{WTC}(f) = \frac{K_T}{\sqrt{2\pi\sigma_T^2}} \exp\left(-\frac{f^2}{2\sigma_T^2}\right) + \frac{K_B}{\sqrt{2\pi\sigma_B^2}} \exp\left(-\frac{(f-f_{DB})^2}{2\sigma_B^2}\right) \qquad (1)$$

where K_T and K_B are the RCSs of the tower and the blade respectively, σ_T is proportional to the bandwidth of tower spectrum and σ_B proportional to the bandwidth of the blade spectrum. The central Doppler frequency f_{DB} of the blade has been assumed as a random variable, uniformly distributed in the interval [-0.2-0.2]. In eq. (1) the first term is the contribution of the tower, the second one the contribution of the rotating blade.

3. SIMULATION RESULTS

We analyzed the impact of the WTC on the performance of classical adaptive detectors for ATC radars [4], [5] that adopt the CA-, SO-, GO-, OS- or TM-CFAR algorithms [6]. We supposed to have six turbines at the same azimuth but different ranges. The radar detectors should decide for each range cell under test (CUT) between the two hypotheses:

$$\begin{aligned} H_0:&\quad \mathbf{x} = \mathbf{c} + \mathbf{w} \\ H_1:&\quad \mathbf{x} = \mathbf{s} + \mathbf{c} + \mathbf{w} \end{aligned} \qquad (2)$$

where $\mathbf{x}$ is the N-dimensional observation vector, $\mathbf{c}$ is the WTC, $\mathbf{w}$ the thermal noise and $\mathbf{s}$ the target signal.

In Fig. 2 we plot the range-Doppler map before the CFAR detector. The range-Doppler map is obtained from the observed data by Fast Fourier Transforming each N-dimensional vector $\mathbf{x}$ of each range cell. The wind turbines are in the range cells # 11, 22, 31, 36, 41 and 46 on an area of 64 range cells. The Doppler bins are N=16. The range-Doppler map is then processed by each of the quoted mono-dimensional CFAR detector working along the range dimension. We do not detail here the structures of these classical devices and refer for explanations to [6].

In Fig. 3a-e we plot the probability of false alarm (in logscale) calculated on the range-Doppler maps after the CA-, SO-, GO-, OS-, and TM-CFAR detectors. The thresholds of the CFAR detectors have been fixed such that the probability of false alarm, in presence on thermal noise only, is $P_{FA}=10^{-4}$. The moving window of the CFAR device is $M_1=2M+1$ long, with M cells preceding and M cells following the CUT. From Fig. 3 it is clear that the range-Doppler map is heavily affected by the presence of the wind turbines that are clearly visible in each frequency bin. The clutter-to-noise power ratio CNR has been set equal to 25 dB.

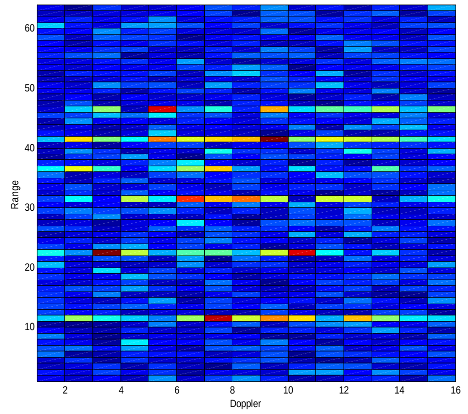

Fig.2 – Range-Doppler map before the CA-CFAR detector

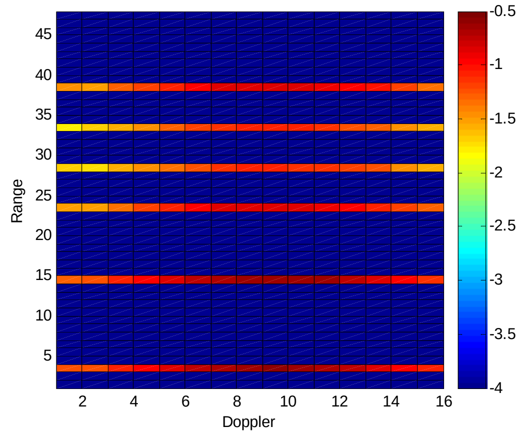

Fig.3a – Log-probability of false alarm as a function of range and Doppler after CA-CFAR detector.

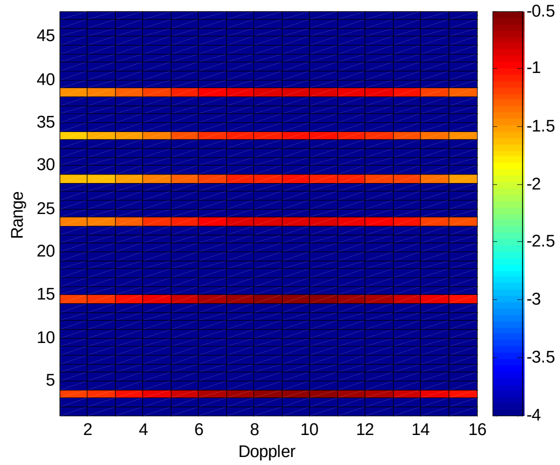

Fig.3b – Log-probability of false alarm as a function of range and Doppler after GO-CFAR detector.

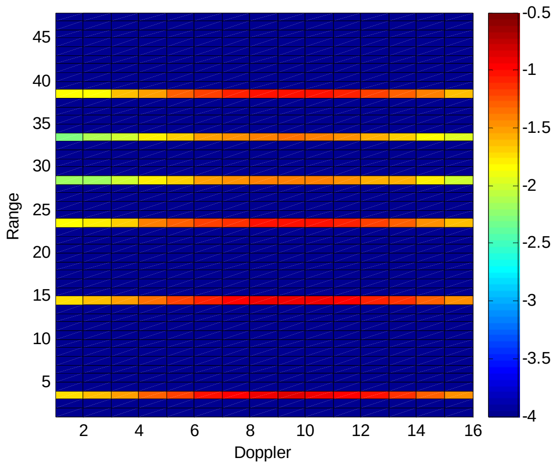

Fig.3c – Log-probability of false alarm as a function of range and Doppler after SO-CFAR detector.

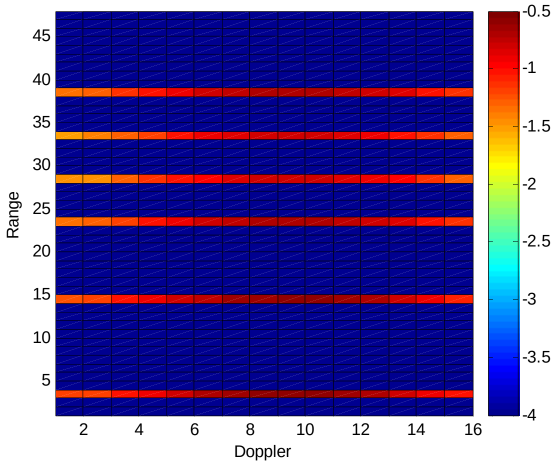

Fig.3d – Log-probability of false alarm as a function of range and Doppler after OS-CFAR detector.

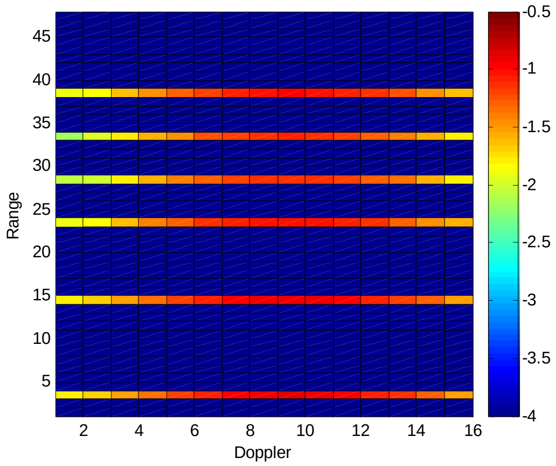

Fig.3e – Log-probability of false alarm as a function of range and Doppler after TM-CFAR detector.

In the CUT where a wind turbine is present the P_{FA} can increase of more than 3 orders of magnitude. Practically, the radar sees the wind turbines as targets.

From Fig. 4 it is evident that the probability of false alarm is greater in the low frequency bins (7-11) where the contribution of the clutter is greater and in the range cells where the distance between wind farms is larger (3 and 14). We obtained similar plots for the other CFAR detectors.

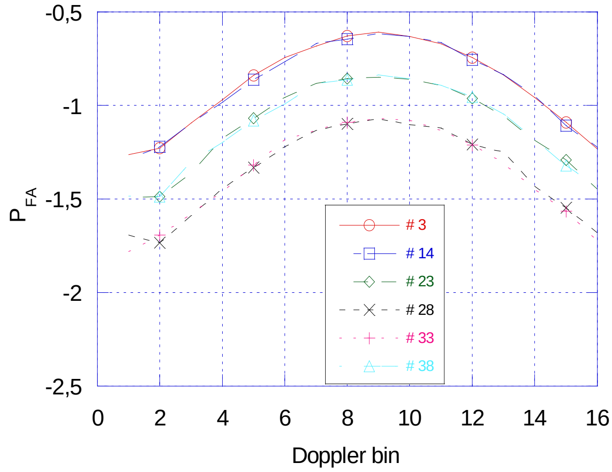

Fig.4 – Log-probability of false alarm as a function of Doppler bins after CA-CFAR detector.

In Figures 5, 6 and 7 we plot the probability of detection of the 5 tested CFAR detectors as a function of the position of the cell under test, for a probability of false alarm $P_{FA}=10^{-4}$. In Fig. 5 the signal-to-disturbance power ratio is *SDR*=-10 dB, in Fig.6 *SDR*=0 dB, in Fig.7 *SDR*=10 dB.

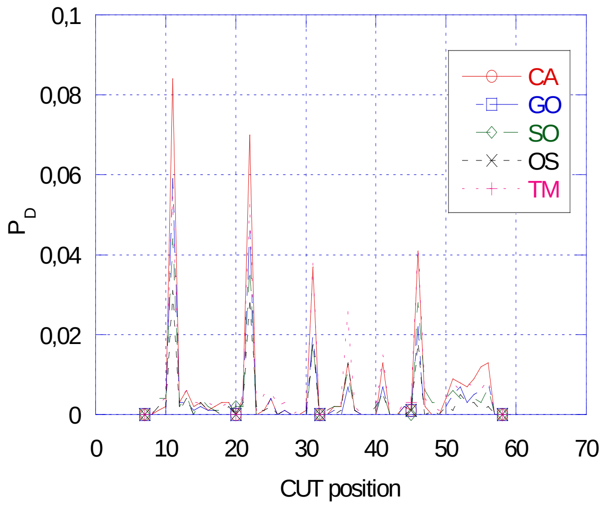

Fig.5 – Probability of detection as a function of cell under test position, *SDR*=-10 dB.

For SDR=-10 dB the P_D is generally very low. We observe some peaks, particularly for the CA-CFAR detector, when the target is in the same range cell as a wind turbine. In that case, actually the radar detects the windmill instead of the true target. In the range cells close to the wind turbines the radar is desensitized because the CFAR device, in the attempt to cancel the wind farm clutter, increases the threshold so blinding the detector to the true target. The effect is particularly evident in Fig. 6 for a medium *SDR* in the range cells between 28 and 45. In that area the wind farms are closer, the CFAR threshold is higher and the radar is less sensitive to the presence of a target in the CUT between windmills.

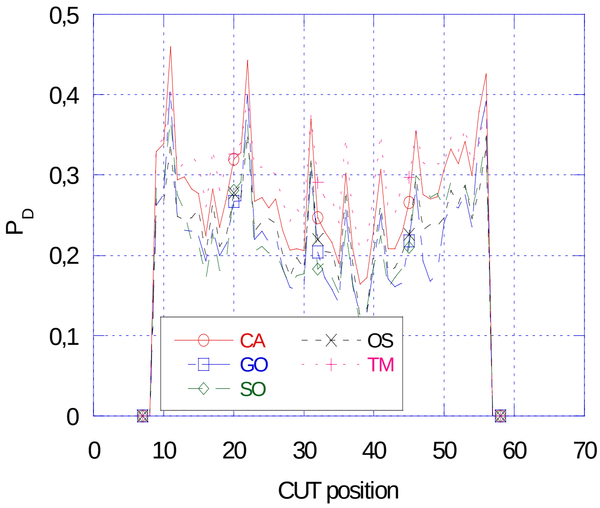

Fig.6 – Probability of detection as a function of cell under test position, *SDR*=0 dB.

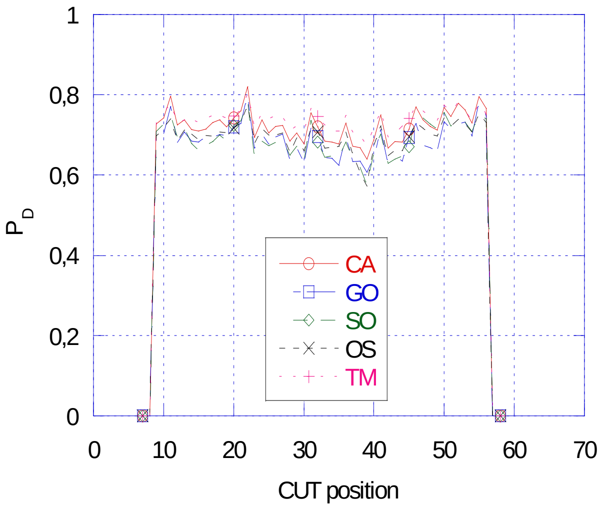

Fig.7 – Probability of detection as a function of cell under test position, *SDR*=10 dB.

4. CONCLUSIONS

In this paper we have approached the problem of aircraft target detection with classical CFAR receivers in presence of wind farm clutter. We have introduced a simple statistical model for the WTC, and based upon simulated data, we have tested the performance of CA-, SO-, GO-, OS- and TM-CFAR detectors. We verified an unacceptable increasing of the probability of false alarm (more than 3 orders of magnitude) and a large decreasing of the probability of detection in the cells under test close to the wind farms.

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