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Radar Observation of Wind Farms in Various Weather Conditions

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ABSTRACT: This article presents a calculation of condition detection wind farm by ship's radar. The authors used computer programme CARPET 2 for simulation different propagation condition. Wind farm echoes are visible in significant distance and can be advantage to ship position mark.

1 INTRODUCTION

Currently specialists are examining possibilities of using objects on the shore or at sea to determine ship position during emergency situations or in case of interference in the functioning of satellite systems. To that end using DGPS stations and AIS base stations is being considered. In the authors' opinion, wind farms constructed at sea could also serve this purpose, especially since more and more of such objects are appearing on coastal areas and are detected by ship radars at long distances. This research paper includes the calculations of the probability of detecting a wind farm via ship radar within the function of distance from the antenna. Due to the limited size of the publication only extreme cases are presented on the graphs: favourable conditions – sea state 3 (wind speed 8m/s and wave height below 1m) and adverse conditions – sea state 7 (wind speed 15m/s and wave height of up to 5 m). The sea states were examined without precipitation and during low rainfall (with the intensity of 4mm/h) and intense rainfall (20mm/h).

2 METHOD OF CALCULATING THE RANGE OF RADAR DETECTION

To conduct the calculations the authors used the computer programme CARPET (Computer- Aided Radar Performance Evaluation Tool) [1], which was developed by the TNO Physics and Electronics Laboratory (TNO-FEL) in Holland. The programme is an acknowledged tool for calculating the range of various radars and used among other things in designing and trials of marine traffic monitoring systems. The equation of the range was programmed as follows and allows analysing the impact of many factors on the detection capabilities of radiolocation devices, not only marine ones, thus the assumptions and initial parameters have to be defined. The equation looks as follows: [1]

$$\mathrm{P_t} = \frac{P_{peak} G_t G_r G_{pc} \lambda^2 \sigma_t F^4}{(4\pi)^3 R_t^4 L_t L_{bs} L_r L_{atm}} \tag{1}$$

where:
P_{peak} – peak power (W),
$G_t G_r$ – antenna power gain in the transmitter and receiver,

λ – transmit wavelength (m),
σ_t – radar cross-section (m2),
F – wave interference ratio,
R_t – range,
L_t – transmitter/antenna path loss,
L_{bs} – radiation pattern main lobe distance,
L_r – receiver path loss,
L_{atm} – atmospheric attenuation (oxygen, rainfall, water vapor).

3 RESEARCH CONDITIONS

The research method for this paper was a computer simulation using the programme CARPET v2.0. The purpose of the research was to assess the possibility of detecting a wind farm in various hydro-meteorological conditions at sea. To make the calculations, the authors used the parameters of Raytheon NSC34 radars (Table 1), which can be deemed typical for the devices currently utilized in the navy.

Table 1. Parameters of Raytheon NSC34 radar of X band and S band[6]

Band	X	S
Horizontal width of characteristics [°]	1.0	1.5
Vertical width of characteristics [°]	23	23
Gain [db]	29	28
Polarization	Horizontal	Horizontal
Frequency [MHz]	9410	3050
Pulse length [μs]	0,8	0,8
Pulse frequency [Hz]	1000	1000
Bandwidth [MHz]	4	4
Peak power [kW]	25	30

During the research the authors used a wind farm whose radar cross-section of a single wind farm equals 300m², whereas the height of one turbine is 60m. Offshore structures with such a surface area and height are well detected by ship radars. The big height value of the wind generators' turbines and their metal structure render the radar cross-section huge and thus, multiple indirect echoes and echoes from side lobes can appear, but also shadow sectors are generated. [5]

In the case of a radar operating in X band there is 100% likelihood of detecting a wind farm at a distance of 5 Nm, however, the distance grows to 10 Nm for a radar operating in S band. Within this range if we are approaching a wind farm, we will obtain a better image in S band than in X band. Nevertheless, at a distance of less than 1 Nm from the antenna, the S band radar will start registering a high volume of noise resulting from signals received in the directions of the side lobes. The image on the radar operating in S band will be corrupt, with multiple jamming signals. An antenna of a radar operating on longer waves has worse characteristics out of necessity, as the level of side lobes decreases with the increase of the antenna's dimensions calculated in relation to the wavelength. At small distances from the wind farm the radar operating in X band is more useful than the S band radar due to its higher antenna parameters. The assumed height of the antenna of the utilized radar was 20m above sea level, which is compatible with the height of the radar antenna installation on a small ship. On larger ships the maximum observation ranges will be bigger, but upon high sea states the interference from the sea surface will be more intense.

During the research the authors used tables from the CARPET 2.0 User Manual, in which the scale of sea states and the Beaufort scale are presented. The simulations were conducted for the following hydro-meteorological conditions presented in table 2 and the results are shown in the consecutive figures. For the simulation the conditions presented in table 2 were chosen. The values for each sea state are consistent with the data of the programme. 80% of the time at sea the sea state does not exceed 3, in storm conditions the possibilities of radar detection are limited, and that is why these sea states were chosen for analysis. Rainfall decrease the echo signal, thus the rainfall in the conducted analyses was taken into consideration.

Table 2. Hydro-meteorological conditions for all the cases under research

No.	Wind	Sea state
1	15w	3
2	29,14w	7
3	58,4w	8

The radar cross-section is defined as the surface of the metal plate which gives the same level of radio-location signal as in the case of a real object and is introduced into the range equation as a point gain parameter, thus it was assumed that it is a square and its height is located at the point where diagonals intersect. Because the radar cross-section of the windfarm is large, it was assumed that it is the same for both radar bands and equals 300 m2 and is located at the height of 60 m above sea level.[2]

4 SIMULATION OF WIND FARM DETECTION

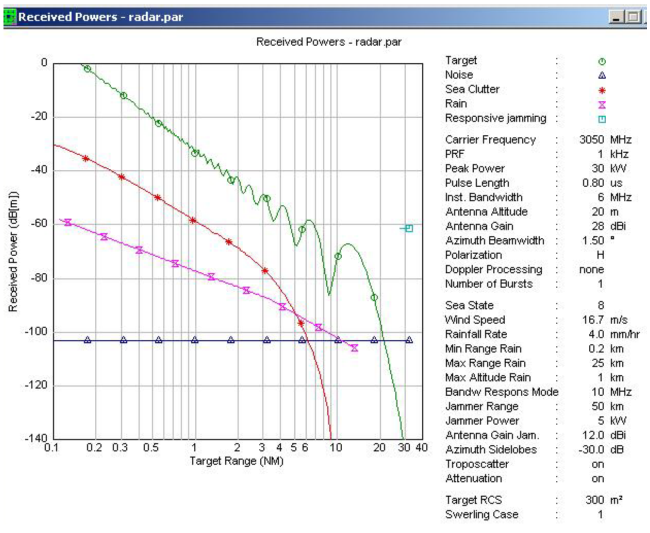

Figure 1. The course of object signal and noise for S band

In fig. 1 one can observe the course of radar signals within the function of the distance from the antenna for S band upon sea state 8. The course of the signal reflected from the windfarms' windmill, interference reflected from the sea, rain and noise are shown. A signal reflected from an object is bigger than a signal reflected from waves of approximately 20dB and the interference disappears at the distance of approximately 4 NM. A signal reflected from rainfall of low intensity (4mm/h) is over 40 dB smaller than that of the echo, so it does not influence the possibility of echo observation. The echo signal fluctuates at the distance between 3 and 8 NM, disappears at the distance of 9 NM, and appears above 10 NM, and subsequently decreases quickly, because beyond the radio horizon the signal is reflected by a smaller and smaller fragment of the windmill, and for the radar under research the distance to the radar horizon equals approximately 10 NM.

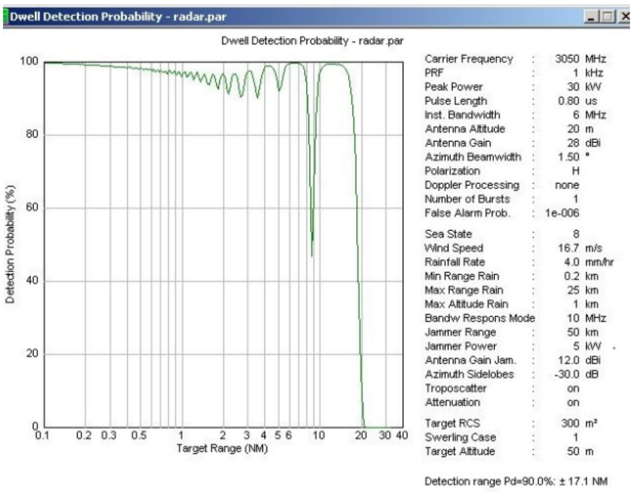

Figure 2. The distribution of probability of detecting a band S radar

In figure 2 the authors presented the function of the probability of detecting wind farms in the same conditions which are shown in figure 1. The course emerges as a result of adding the above-mentioned courses and it is easier to interpret. One can see that the wind farm is clearly visible on the radar screen from the smallest distances to 17 NM with one case of disappearance (up to 50% probability, so in this case it is visible at every second antenna revolution) at the distance of 9 NM.

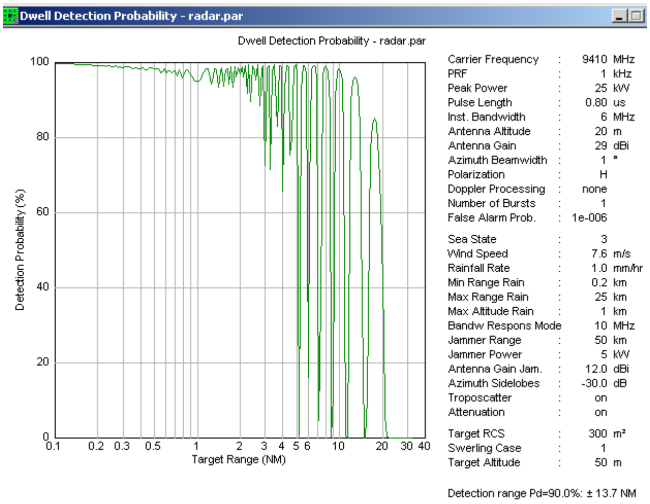

Figure 3. The distribution of probability of detecting a band X radar

Figure 3 shows the probability of detection for radar X band in good propagation conditions, with sea state 3 and no rainfall. The signal fluctuates as near as 3 NM from the antenna, but it does not pose any problems up to 5 NM. Over the 5 NM distance signal loss is detected caused by its interference with the signal reflected by the sea surface. The echo signal from the power plant appears and disappears from the screen. The situation persists until the distance reaches 20 NM. In this area, it is possible to set own position based on the power plant echo, but it requires lengthier radar observation. On the radar working in band S the wind farm echo is visible without disappearing, whereas in X band the loss of echo complicates matters.

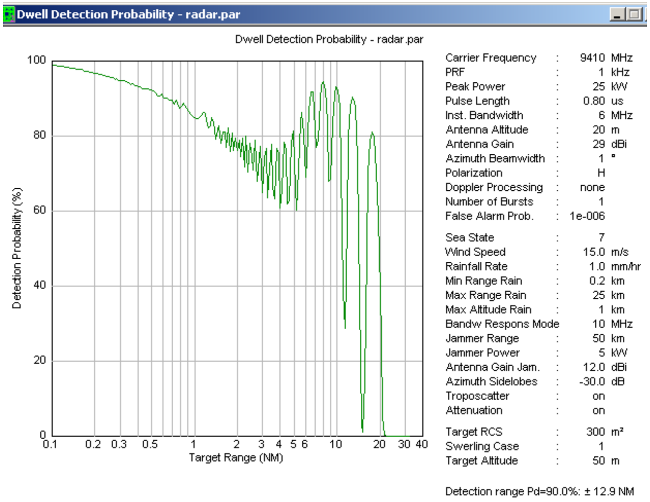

Figure 4. The probability of detecting X band radar

In figures 4 and 5 the probability of detecting the power plant during observation of X band in adverse weather conditions, i.e. the wave height is 5m, the wind speed over 15m/s and moderate rainfall, is shown. In figure 4 the probability is shown for a lower sea state and without rainfall. Up to 2NM, the power plant is visible (probability between 60 and 80%), and after that, the visibility improves, as the interference from sea waves diminishes. Over 10 NM large signal loss can be detected.

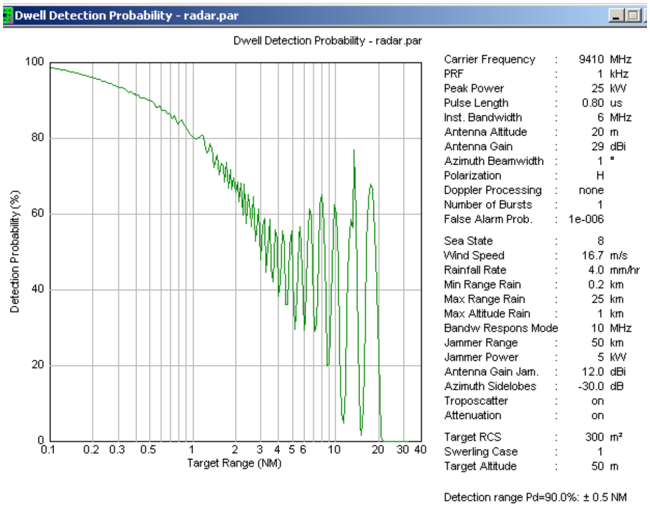

Figure 5. The probability of detecting band X radar

Fig. 5 shows the probability function of band X detection for very adverse weather conditions (sea state 8 and 4mm/h rainfall). High waves and low rainfall nullify the possibility of observing the wind farm. The probability for a distance below 1 NM is over 60%. For distance from the antenna over 2,5 NM the probability of detection fluctuates between 50 and 30% up to 8 NM, after which the wind farm's echo disappears and can only be seen for brief moments. The maximum range of detecting the power plant in X band is lower than in the S band by about 20%.

Table 3. Observations for S band and X band

Sea state	S band Max range [NM]	Losses	Rainfall [mm/h]	X band Max range [NM]	Losses	Rainfall [mm/h]
3	17.1	8.0-9.0	no	13.7	3.0 fluctuation	1
3	17.2	8.0-9.0	4			
7	17.1	8.0-8.5	1	12.9	2.0-5.0 (60%)	1
7	17.1	9.0-10.5	4	12.9	2.0-5.0 (40%)	4
7	17.1	9.0-10.5	20	10.2	2.0-5.0 (below 20%)	20
8	17.1	8.0-9.0	1	10.2	1.5-6.0 (60%-70%) 6.0-11.0 (do80%)	1
8	17.2	8.0-9.0	4	0.5	1.0-4.0 (50%) 5.0-10.0 (30%-50%)	4
8	17.2	8.0-9.0	20	0.3	Up to 1.5 (50%) Further (0%)	20

Based on the results presented in table 3 it must be stated that in S band the radar observation of wind farms is possible in all weather conditions and the detection range is sufficient. In X band, however, the muffling of the signal by rainfall is high and limits the range of wind farm detection. Observation during high sea state in X band is difficult but achievable. However, if in such sea state rainfall also appears, even slight, then the possibility of detection is limited or even impossible. Results like these have been recorded while research was conducted in the vicinity of other wind farms. [3] [4].

Comparing the results obtained utilizing the CARPET software with the wind farm observation during cruises it must be stated that the farms are easily visible in X band at distances over 20 NM. It is probably the result of a simplified model of radar cross-section for the wind farm. It must be stated that wind farms are clearly visible from the sea and can be used to reinforce the position of the ship. No additional ship equipment is necessary for this purpose.

5 CONCLUSION

Wind farms, due to their large size, are clearly visible to the naked eye and to the radar from a significant distance, but they can also cause a false echo to appear on the screen and mask other objects and navigational signage.

The Carpet 2 simulation software, which was utilized for this research, enables the analysis of radar signal detection from a significant distance, from different objects and in different weather conditions. Utilizing this software allows for a quick analysis of the influence on the operation of the radar of meteorological conditions and other parameters, such as radar cross-section, the height of the antenna. The Carpet 2 software can be successfully utilized as a teaching method for naval radiolocation.

As a result of the simulations performed, it can be stated that the distance from the radar and meteorological conditions influence the probability of detection of the wind farm. The wind farm, treated as an area where wind turbines are situated, is visible on the radar from a significant distance thanks to its size. It is a non-moveable construction, clearly visible and one that can function as navigational assistance.

The calculations made in this research show the probability of detection of the wind farm by a ship radar in diminishing weather conditions, here the only way for safe cruising is the radar, and the distance at which the wind farm is detectable can have a significant influence over the performed navigation.

The research was done for a radar working in the bands X and S. Based on the analyzed scenarios, it is clear that there is a significant difference in detection of the wind farm between those two bands. For X band the probability of detection of the farm below the distance of 4NM is around 80%. In this range, the possibility of detection of the wind farm is high regardless of the weather conditions.

The larger the distance between the wind farm and the radar the more fluctuations occur, meaning that the image appears and disappears.

In the range between 4NM and 8NM the possibility of detection falls below 50%, and in the range of up to 20NM there are areas of high probability of detection alongside areas where the echo disappears.

For the radar working in S band usually only a few occurrences of lack of detection of the wind farm appear. Comparing the analyzed scenarios, it can be observed that the lack of visibility of the wind farms is the highest in mild meteorological conditions and falls alongside the diminishing of the weather conditions. The conclusion is that radars provide better visibility and detection in diminishing weather conditions.

The probability of detection for this band was around 75 to 90% with the sea state at 8. In these research conditions, the object is better detectable in S band.

The great height of the wind generator turbines and their metal construction make for a wide radar cross-section, that is why the occurrence of indirect multiple echoes is possible from side lobes as well as generating shadow sectors.

In the case of the radar that works in the X band, a large possibility of detecting a wind farm at the distance of 5 NM exists, however, this distance is prolonged to 10 NM for a radar working in S band. In that range one would get a clearer image on the approach to the wind farm using S band rather than X band. However, if indirect distance is smaller than 1NM, the S band radar will register a high volume of interference caused by the signals received on the side lobes' direction. The image on the radar working in S band will be unclear, and interfering signals will be plentiful. The antenna of the radar that works in a longer wavelength by definition has worse characteristics, as the level of side lobes diminishes concurrently with the antenna's growth in size as calculated in relation to the wavelength. At small distances from the wind farm the radar working in X band is more useful than S band radar due to the antenna's higher parameters. The antenna of the radar used is situated 20m above sea level.

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