Ship echo discrimination in HF radar sea-clutter

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1. INTRODUCTION

HF radar can provide Over the Horizon detection of ships on very large oceanic areas, making use of the ionospheric refraction of radio waves. The Doppler spectrum of the sea clutter is composed of the first-order Bragg lines with a second-order continuum, as described in [1]. Normally, the Doppler shift produces by ships is small, of the same order of magnitude of the Doppler shift of the sea clutter. Consequently, it is not always easy to discriminate a ship line from a sea clutter line only on a velocity basis, though dual frequency operation can enhance ship detectability [2]. Different sources of ionospheric contamination often increase the difficulty by introducing smearing effects of the Doppler spectrum. Sometimes, these deleterious effects can be corrected by using adapted signal processing methods (see e.g. [3]-[5]).

Using HF radar with large antenna arrays, it should be possible to find arrangement in radar data manipulation to obtain two signals coming back from the sea with low coherence, while the signal from a discrete target would stay relatively coherent. If verified, this property would allow the discrimination of discrete targets against sea clutter. In this paper the coherence of sea clutter is considered in the context of a radar interferometer. It is shown that the coherence function can be useful to discriminate between a ship line and sea clutter spectral peaks. The dependence of the coherence value with the signal to clutter ratio is also studied.

2. THE COHERENCE FUNCTION

The coherence between two signals s_1 and s_2 can be computed using the ratio of the cross-spectrum and the product of the square roots of the power spectra:

$$C_{s_1 s_2}(f) = \frac{\left\langle s_1(f) s_2^*(f) \right\rangle}{\left\langle \left| s_1(f) \right|^2 \right\rangle^{1/2} \left\langle \left| s_2(f) \right|^2 \right\rangle^{1/2}} \qquad (1)$$

In the HF radar application there are several possibilities to obtain the signals s_1 and s_2, each of them with advantages and drawbacks. The processing method used to obtain s_1 and s_2 must be chosen according to the possibilities offered by the hardware and the software of the radar. In the next part, details are given about the data processing used in this study with the NOSTRADAMUS radar data.

3. DATA PROCESSING

The receiving antenna of the HF radar NOSTRADAMUS is a surface antenna that allows 360° coverage in azimuth. The antenna elements form 18 sub-arrays. For the purpose of the experiment the signal at the sub-array outputs were combined to obtain s_1 and s_2 by

$$s_1 = \sum_{j=1}^{9} s_j \quad \text{and} \quad s_2 = \sum_{j=10}^{18} s_j \qquad (2)$$

s_1 and s_2 thus represent the signals at the output of 2 antennas with different phase centres, both pointed with the same azimuth and elevation.

With this experimental set up, the antennas in A and B receive sea clutter under slightly different angles. This principle has been used in VHF radar interferometers to study the coherence of ionospheric regions containing plasma instabilities (e.g. [6, 7]). If s_1 and s_2 are the signals at the output of the two antennas, coming from an assembly of Gaussian scattering centres, with eventually a localized target, as depicted in figure 1, the coherence is [6, 7]:

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$$C_{s_1 s_2}(f) = \exp(ikD\Phi_f)\exp(-\frac{1}{2}k^2 D^2 \sigma_f^2) \quad (3)$$

where σ_f^2 is the angular spread of the target, Φ_f is the position of the target, k is the wave vector and D is the interferometer baseline.

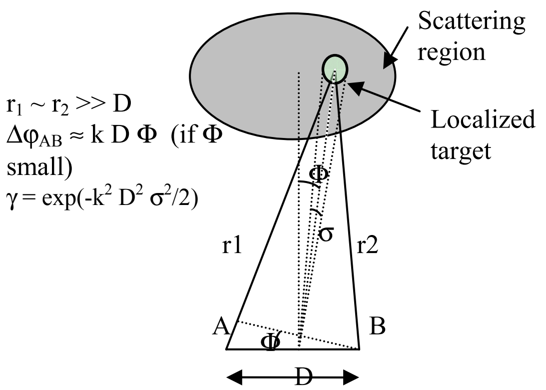

Figure 1. Radar interferometer experiment.

Equation (3) indicates that for a small size target (small σ_f^2), the modulus of the coherence is close to unity. In this way, a high coherence is expected on a ship echo while the widely distributed scattering region (sea clutter) would result in a low coherence.

In practice, we have observed that with our experimental configuration the coherence of the sea signal received by the two antennas of the interferometer is not decreased enough thus, to further decrease the coherence of the clutter, the frequency band occupied by the waveform has been split in two sub-bands. Of course this processing yields a poorer range resolution since the bandwidth is divided by two. To summarize the data processing, the coherence has been computed between two signals received by two antennas with different phase centres and in adjacent frequency bands.

4. RESULTS

A Doppler-range-intensity display obtainned at a frequency near 13.5 MHz is presented in figure 2. The Doppler scale is ±2.5 Hz and the range extends from 800 km to 1250 km. At short ranges the spectra are smeared by the propagation effects that usually happen near the skip zone. At ranges larger than 900 km the two Bragg lines can be identified very clearly. Island echoes appear near 1070 km up to the last gate. On the negative Doppler side a ship echo is detected at -1.7 Hz and range 1055 km. The ship spectral line corresponds to a fast ship that establishes a link between the main land and the island. We use these data to compute the coherence function. One must note that in this particular case, the Doppler shift is large enough to ensure that the ship can be easily detected because the spectral line is well outside the clutter spectrum.

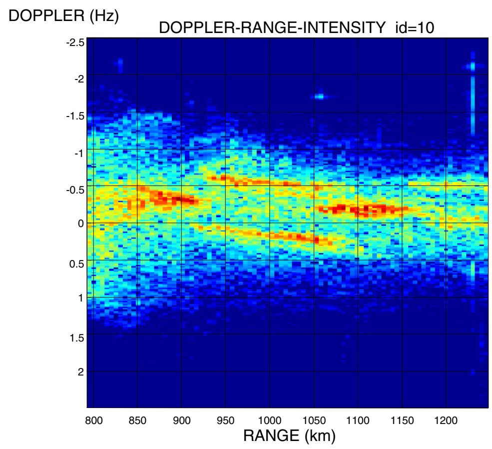

Figure 2. Doppler range intensity display. A ship echo is detected at range 1055 km at a negative Doppler shift of 1.7 Hz.

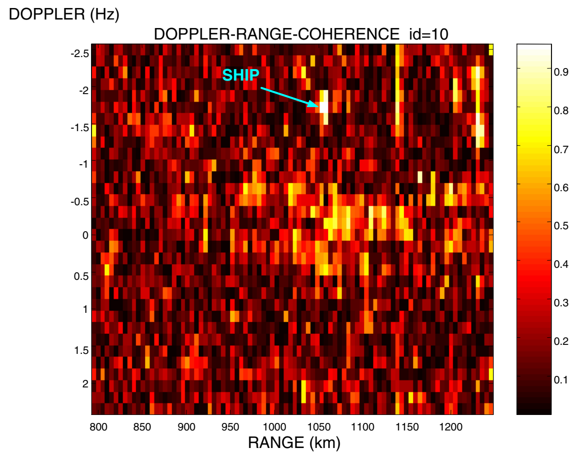

Figure 3. Coherence computed using the signal at the two antennas. The ship line can be identified by the white spot with coherence near unity.

The coherence function of the previous data was computed using the Welch method. Basically this method consists to split a time series of length L in m time series of length L/m and then averaging the individual spectra to decrease the variance of the estimate. The coherence obtained in this way is presented in figure 3. In this example, L=256 points and m=8 averages, consequently, as compared to figure 2, the Doppler resolution is degraded by a factor 8.

In figure 3 it is observed that, due to the smaller coherence of the sea signal, a part of the clutter (but not all) is rejected. On the contrary, the ship echo stays very coherent and it produces a white spot which can be identified easily. Figure 4 shows the variation of the coherence versus Doppler shift for the range gate containing the ship. The maximum value of the coherence is 0.96 for the ship echo and 0.72 for the sea clutter. Better rejection of the clutter could probably be obtained using adapted processing of radar data and a greater number of averages.

The coherence of the ship echo depends on the signal/clutter ratio (S/C). In the example presented in figure 2 the S/C is about 25 dB (figure 5) and the coherence of the ship echo is close to unity.

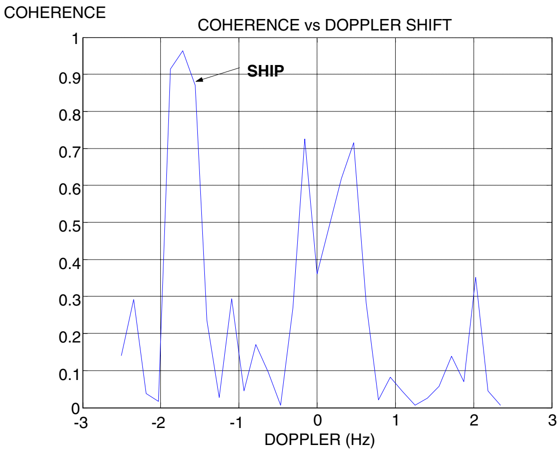

Figure 4. Coherence versus Doppler shift for the range gate with the ship line.

When S/C decreases, the coherence also decreases. The variation of coherence with S/C has been studied using simulations. Figure 6 shows an example of a Doppler spectrum with a ship line at a -0.8 Hz Doppler shift and 13 dB S/C. In this particular case, the coherence of the ship line is only 0.65 so, in such a case, it would be necessary to decrease the coherence of the sea clutter to be able to discriminate the ship echo from the clutter. The coherence is plotted in figure 7 versus S/C ratio. The coherence is close to unity for an S/C larger than 18 dB. For smaller S/C values the coherence decreases and it is about 0.4 for a 10 dB ratio.

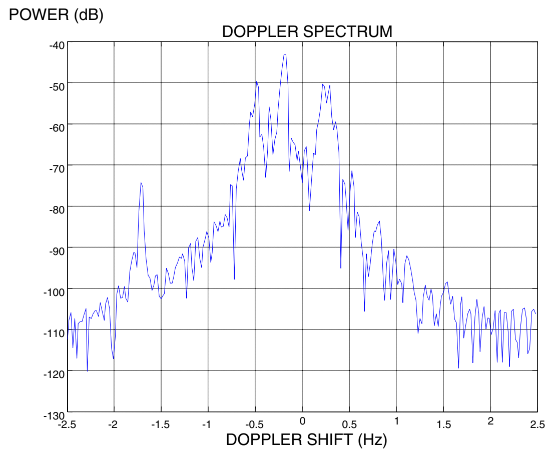

Figure 5. The Doppler spectrum shows a ship line with a 25 dB signal to clutter ratio.

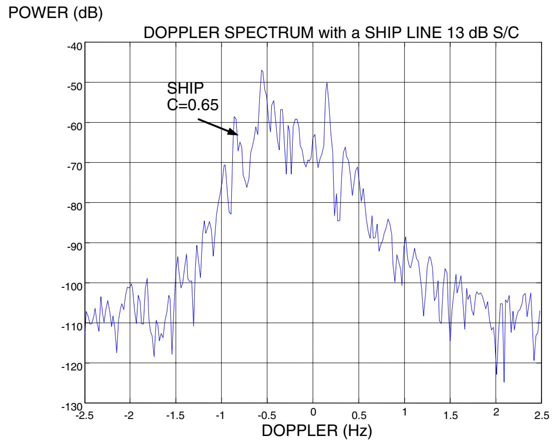

Figure 6. Example of a Doppler spectrum with a ship echo (S/C=13 dB, Δf= -0.8 Hz). The coherence of the ship line is 0.65.

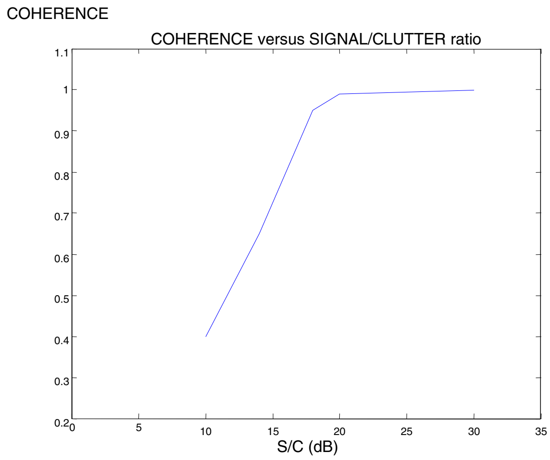

Figure 7. Variations of coherence versus signal to clutter ratio.

5. DISCUSSION AND CONCLUSION

The coherence function could be a convenient tool to discriminate between localized targets, as ships, and spectral peaks of the sea clutter spectrum. The coherence function can be computed using an experimental set up similar to an interferometer, though this is not the only one possibility. This arrangement produces sea clutter signals with coherence smaller than unity. The coherence of the clutter can further be lowered by splitting the frequency band into two sub-bands. In this way, a ship line with an S/C larger that 18 dB gives coherence close to unity which can be easily discriminated from the sea clutter spectral peaks. The discrimination would become more difficult for an S/C near or smaller than 13 dB, unless the coherence of the clutter can be decreased. The reduction of the coherence of the sea clutter signal could possibly be obtained using two different radar frequencies sufficiently close to maintain the coherence of ship echoes but spaced enough to lower the coherence of clutter. For now we haven't yet tested this hypothesis.

Though this is not the subject of this paper, it is noted that in the interferometer configuration, the phase of the coherence function contains information on the position of the discrete target thus its time variations can be used to measure the transverse velocity of the target. It is an interesting possibility since, in the normal radar mode, only the radial component of the velocity can be measured by Doppler analysis.

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