POLARIMETRIC-INTERFEROMETRIC SEA SCATTER RESEARCH USING THE NRL FOPAIR RADAR

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1. INTRODUCTION

The Naval Research Laboratory has recently begun a new basic research program designed to lay the foundation for future Navy applications of high-resolution polarimetric and polarimetric-interferometric radar systems. Despite many years of research, there is a serious lack of high-resolution, polarimetric ocean backscatter data in the radar community from which to fuel advanced applications, such as the detection of low-observable targets and radar-based ship stabilization systems. In the case of polarimetric interferometry, in which polarimetric and interferometric data are collected simultaneously and combined synergistically, there is a *complete* lack of ocean data: all research to date in this promising new field has been devoted to terrestrial applications. To address these serious deficiencies, the new NRL program will generate a database of high-resolution polarimetric and interferometric radar imagery of the ocean surface, characterize it, and derive an understanding of the observed correlations. With regard to interferometry, we will focus on polarimetric *cross-track* systems with a resulting sensitivity to surface height and angular coherence. In this paper, we describe the radar that will be used in this research, the NRL Focused Phased Array Imaging Radar (NRL FOPAIR), and present preliminary target and ocean imagery generated by this system.

2. RADAR SYSTEM DESCRIPTION

The NRL FOPAIR is an X-band, polarimetric, imaging radar based on a concept originally developed by researchers at the University of Massachusetts-Amherst in the 1990's [1, 2]. The radar uses single antennas to illuminate the scene, while two linear arrays of 128 flared-notch antennas, one array for vertical polarization (V) and one for horizontal (H), are used on the receive side. Data from these array elements are coherently combined during post-processing to form coherent range/azimuth images. Signals from only one vertically polarized and one horizontally polarized receive antenna are collected per pulse repetition interval (PRI), but a fast switching network and a high pulse repetition frequency (PRF) are used to step across the 128 elements rapidly. The PRF is typically 100 kHz, which allows signals from all 128 elements to be collected in 1.28 ms. The image frame rate achievable by the system is thus 780 Hz. In the fully polarimetric mode, switching between H and V must also occur on the transmit side, and thus the per-polarization frame rate is reduced to 390 Hz. (Two PRIs are required to collect a complete set of polarimetric images.) Since each resolution cell of the imagery is coherent and the data throughput capacity is high (>400 MB/s), full Doppler processing can be performed with this high frame-rate data, at each and every position within the image. This is in contrast to the original FOPAIR system developed by UMass, which was forced by data acquisition throughput limitations of the 1990's to use a pulse-pair algorithm for velocity estimation. A linear FM chirp with a bandwidth of 200 MHz is used to provide range resolution better than 1 meter.

Currently, the antenna pedestal is undergoing modifications to allow interferometric operation. Once these construction modifications are completed, 64 elements from the H and V arrays will be located approximately 1 m above the remaining 64 elements. This will allow collection of interferometric pairs of imagery with sensitivity to the surface or target height. (Azimuth resolution will be degraded by a factor of two relative to imagery collected with all 128 elements.) Similar modifications have also been made to the UMass FOPAIR in the past, although the data collected was not polarimetric. [3]

Figure 1. Photograph of the NRL FOPAIR system

Figure 1 shows a photograph of the NRL system. During this particular deployment, the 128 elements were split into separate left- and right-looking halves to increase the field of view at the expense of azimuth resolution. The white, linear structures contains the receive antennas. The transmit antennas are mounted on the staffs near the midline of the left- and right-looking subarrays.

3. EXAMPLE IMAGERY

Figure 2 shows examples of NRL FOPAIR imagery of the Chesapeake Bay, offshore of the NRL Chesapeake Bay Detachment (NRL CBD) in Chesapeake Beach, MD. Both VV and HH data are presented. The "spiky" character of the HH backscatter (Fig. 2b) relative to that at VV (Fig 2a), observed by many researchers over the past several decades, is apparent. (Here, HH refers to the image collected when both the transmit and receive polarizations are H, while V refers to that collected when both are V. Similarly, HV and VH refer to transmitting H while receiving V, and vice versa.) But unlike any other data collected to date, fully polarimetric Doppler spectra can be computed at each and every pixel. VV and HH spectra from two particularly bright HH pixels, computed from 32 consecutive images, are shown in Figs 2c and 2d.

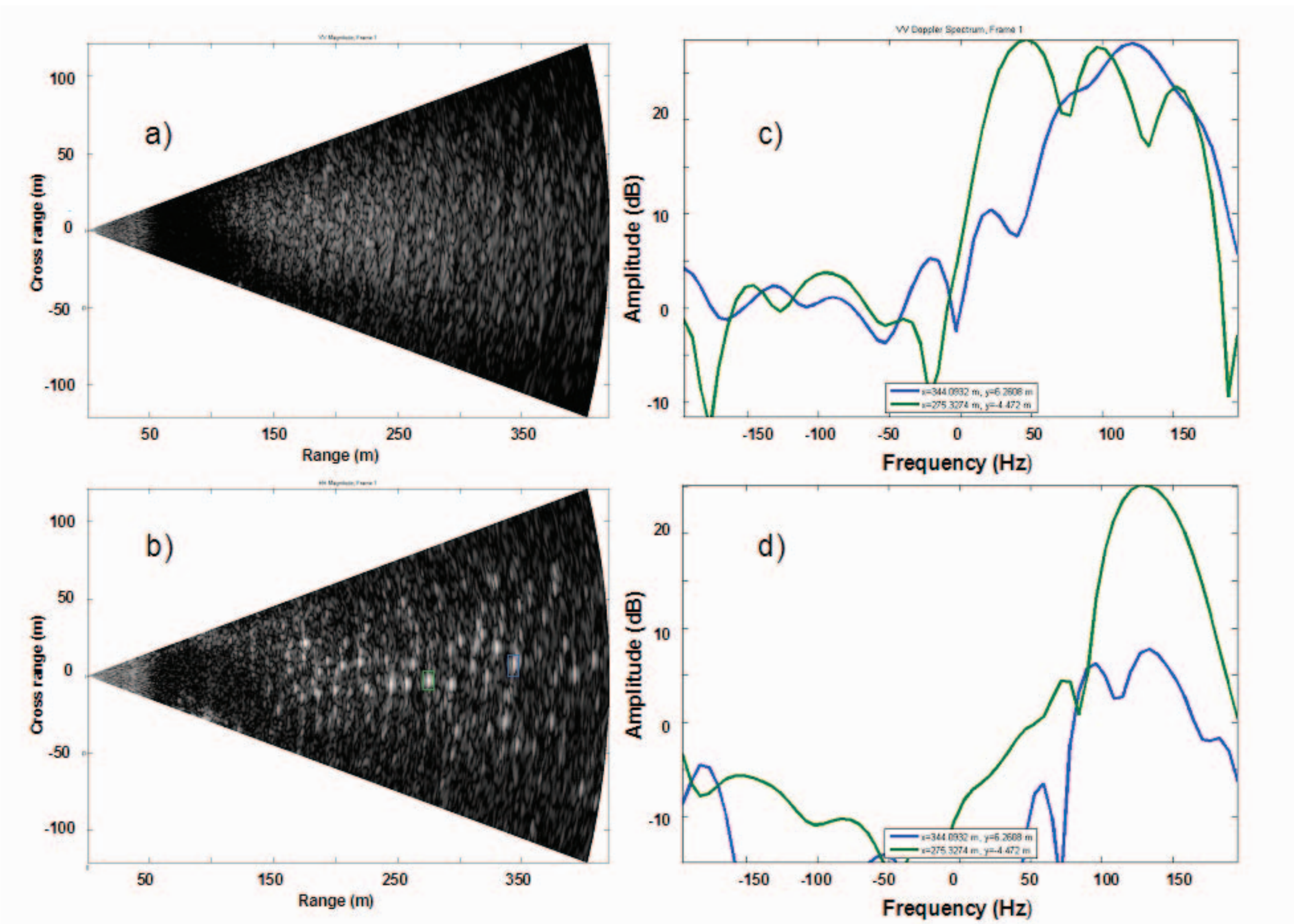

Figure 2: Example images of the water surface of the Chesapeake Bay: 2a) VV 2b) HH. Doppler spectra corresponding to the two bright pixels outlined by the small boxes in 2b: 2c) VV 2d) HH.

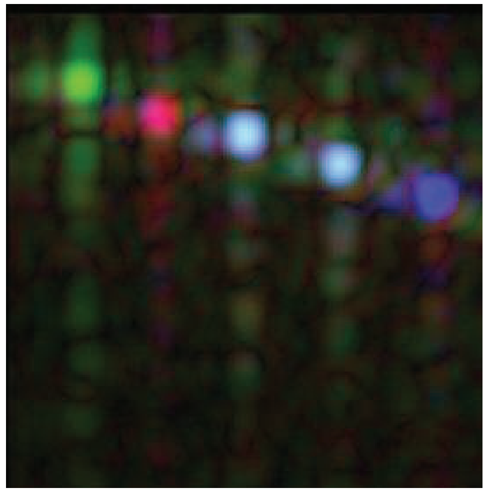

Figure 3: Pauli basis representation of a set of five polarimetric calibration targets

Figure 3 contains a section of a fully calibrated, polarimetric NRL FOPAIR image. Shown is a color composite image of five polarimetric calibration targets, located on a research pier at NRL CBD. In order from left to right, the targets are a dihedral rotated at 22.5°, a dihedral rotated at 0°, two depolarizing dihedral corner reflectors (one left-handed, the other right-handed), and a normal trihedral corner reflector. (The depolarizing trihedrals are trihedral corner reflectors modified with a polarizing grid that allows the target to generate co-pol (VV and HH) as well as cross-polarized (HV and VH) backscatter.) The color scheme follows the Pauli basis in which | HH-VV| is encoded in red, |HV+VH| is encoded in green, and |HH+VV| is colored in blue. Using this polarimetric basis and color scheme, four different targets can be distinguished in the plot. (Polarimetry can also distinguish between the left- and right-handed depolarizing trihedrals, but this additional information is not apparent in a color plot of this type.)

As part of the new NRL program, surface height will also soon be available through the added interferometric capability. The combination of full polarimetry and interferometric height promises to provide a means to better understand the physics behind radar backscatter from the sea surface while also providing the basis for new ocean remote sensing and hard-target detection techniques.

4. REFERENCES

[1] R.E. McIntosh, S.J. Frasier, and J.B Mead, “FOPAIR: A Focused Array Imaging Radar for Ocean Remote Sensing”, IEEE TGARS, Vol. 33, No. 1, January 1995.

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[3] J.V. Eshbaugh and S.J. Frasier, “Measurement of Sea Surface Displacement with Interferometric Radar”, J. Atmos and Oceanic Technology, Vol. 19, July 2002.