Polarimetric Radar Imaging of the Ocean Surface

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Introduction: Understanding the relationship between ocean surface waves and the radar backscatter they generate is key to the development of new radar-based techniques to measure ocean parameters, such as wave height and current speed and direction, of importance to both the Navy and the civilian sector. This knowledge is also needed to improve the Navy's ability to distinguish between signals generated by important, man-made targets and the competing radar backscatter produced by the ocean surface itself. The NRL Remote Sensing Division and Radar Division have collaboratively developed a unique radar, the NRL Focused Phased Array Imaging Radar (NRL FOPAIR), to investigate this relationship. The ability of this system to rapidly image the surface and determine the backscattered signal's sensitivity to polarization provides a powerful means to explore this important area of research.

System Description: The NRL FOPAIR is an updated version of a system first conceived and built by the University of Massachusetts–Amherst in the mid-1990s.[1] While typical land-based radars provide an "image" by mechanically scanning a narrow beam across the scene of interest, the FOPAIR accomplishes this by coherently combining data collected by many receive antennas arranged in a linear, side-by-side manner, an arrangement known as a phased array. A separate transmit antenna is used to illuminate the scene. Using this approach, the data required to build the entire image can be collected in less than a millisecond, as opposed to several seconds in the case of mechanical scanning. The NRL FOPAIR also employs both dual transmit antennas and dual receive arrays to allow collection of data spanning all possible combinations of transmit and receive polarizations. The relationship between the polarization state of the transmitted and received signals is intimately tied to the shape of the surface waves, and thus this "polarimetric" capability is an extremely valuable research tool. In addition, the NRL FOPAIR's data acquisition system (DAS) can support a sustained data rate in excess of 400 MB/s, providing the means to generate these polarimetric images at a high frame rate, i.e., to generate polarimetric "movies" that allow the relationship between the highly dynamic surface waves and the backscatter they produce to be studied in unprecedented detail.

Figure 1 is a block diagram of the NRL FOPAIR system. The basic transmit waveform (a linear, frequency-modulated chirp) is generated by a field programmable gate array (FPGA), converted to an analog signal by a Maxim digital-to-analog converter (DAC), and then multiplied up in frequency to 9.875 GHz before final amplification and routing through transmit switches and the horizontally (H) and vertically (V) polarized antennas. In the receive section of the system, three tiers of switches are used to individually select each of the 64 elements of the receive array and route its signal into the receiver. The entire bank of 64 receive elements is addressed sequentially in less than 1 millisecond. The analog receive signal is digitized and then stored by the DAS, which consists of analog-to-digital converters and a disk array for storage. In order to increase the angular coverage of the system, the radar is actually split into two identical halves, one looking 9° left, the other 9° right.

Figure 2 shows examples of the imagery produced by the system. These data were collected during system development when the radar was deployed on a bluff overlooking the Chesapeake Bay. Images for which both the transmit and receive signals are vertically polarized (VV) are shown in Fig. 2(a), while Fig. 2(b) shows the corresponding image when both are horizontally polarized (HH). The "spiky" character of the ocean wave backscatter in the latter is apparent and is generally attributable to breaking or near-breaking waves.[2] Characteristics like these can be fully exploited once a complete understanding of the radar ocean scattering mechanisms is developed.

Recent Hawaii Deployment: In August 2008, the FOPAIR system was deployed overlooking the Pacific Ocean at Makapuu Point State Wayside Park on the island of Oahu, where high quality data was collected over a wide range of wind and wave conditions. Figure 3 is a photograph of the system taken during this deployment. Significant effort was devoted to planning the installation of the radar, electrical power, and two personnel trailers near the edge of the 500-foot cliff at this remote site. Major effort was also required to address Hawaii State Park permitting requirements. Makapuu Point was chosen, despite its logistical and bureaucratic hurdles, due to its truly unique combination of deep water, extremely long fetch (that is, the distance over which the wind blows unimpeded by land), and strong, steady winds. These site characteristics in conjunction with the NRL FOPAIR's unique capabilities will make data analysis much more fruitful and tractable than for previous sea scatter experiments, which used less capable radars in more environmentally complicated locations.

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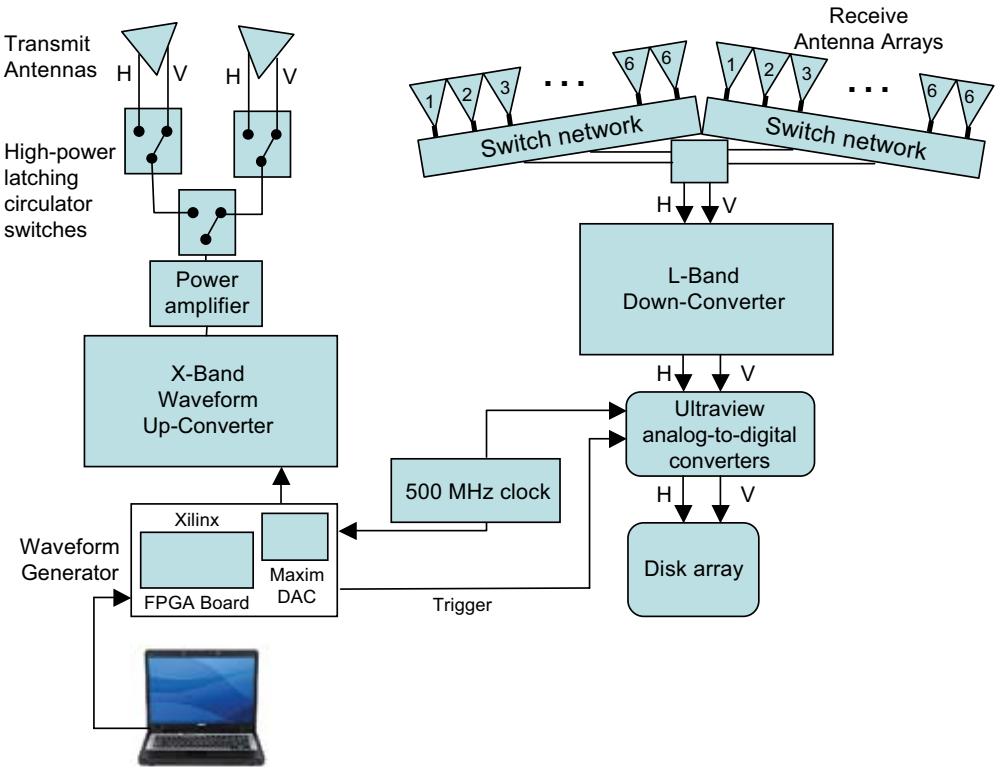

FIGURE 1
Block diagram of the NRL FOPAIR system.

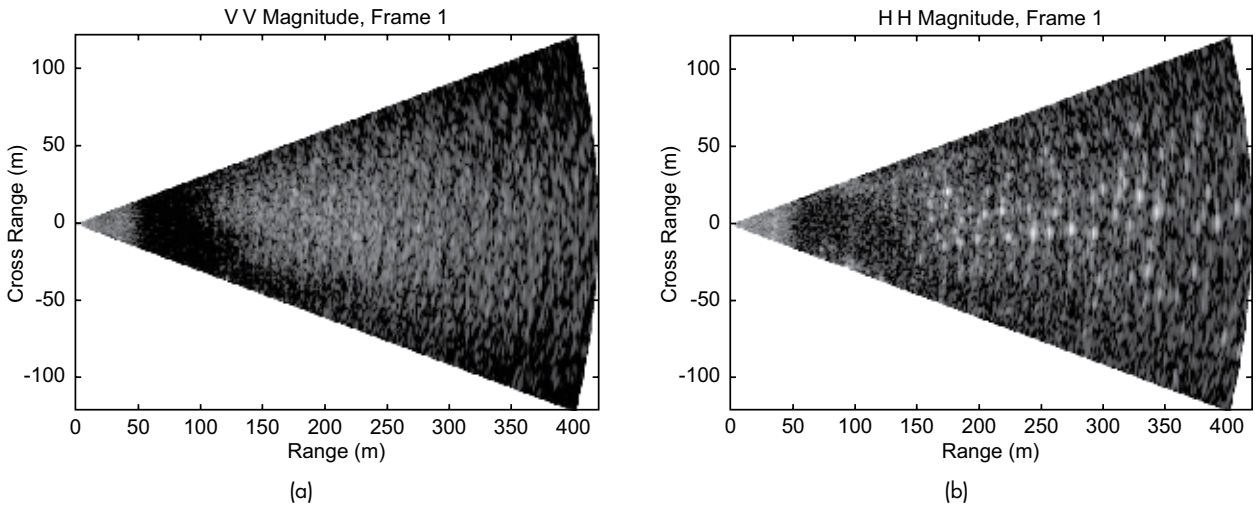

FIGURE 2
(a) Vertical-transmit vertical-receive image of the surface of the Chesapeake Bay. (b) Same as (a), but polarization is horizontal-transmit horizontal-receive.

FIGURE 3
Photograph of the NRL FOPAIR deployed at Makapuu Point on Oahu, Hawaii.

References

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[2] P.A. Hwang, M.A. Sletten, and J.V. Toporkov, "Analysis of Radar Sea Return for Breaking Wave Investigation," *Journal of Geophysical Research* **113**, C02003 (2008), doi:10.1029/2007JC004319.