Fluctuations in High Frequency Acoustic Propagation

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LONG-TERM GOALS

The long-term goals of this work are to understand the influence of environmental variability on fluctuations in the propagation of high frequency acoustic energy with applications to the improvement of acoustic data communications and active target detection processing.

OBJECTIVES

The objectives of this research are to demonstrate experimentally the feasibility of high frequency (3.5 kHz) phase conjugation in shallow water and the use of phase conjugation techniques to mitigate multipath in acoustic data communications and to enhance echo-to-reverberation-ratio in active sonars.

APPROACH

This project is a joint effort between MPL and the SACLANT Undersea Research Centre (T. Akal).

A phase conjugate "mirror" time reverses the incident signal precisely returning it to its original source location. This phenomenon occurs independent of the complexity of the medium. The time reversal process can be accomplished by the implementation of a retransmission procedure. A signal received at an array is time reversed and retransmitted. A full water column source array excited by the phase conjugated (time-reversed) signal received at the array position will focus at the position of the radiating target. The medium fluctuations are embedded in the received signal so that if retransmission can occur on a time scale less than the dominant fluctuations, the medium variability will be eliminated since one back propagates and "undoes" the variability.

Two low frequency (~450 Hz) phase conjugation field experiments previously were carried out (FY96 and FY97) in ~125 m water adjacent to Formiche di Grosseto (a small island approximately 100 miles SW of SACLANTCEN). These experiments demonstrated that phase conjugation is both feasible and stable at low frequencies in shallow water and that focusing of the retransmitted energy is possible at ranges of at least 30 km. Also demonstrated was the ability to shift the range of focus to ranges other than that of the probe source by a simple method involving a frequency shift of the received time series prior to retransmission. Lastly, the degradation of focusing with fewer than the full set of source/receive array (SRA) transducers was investigated and reasonable focusing was demonstrated with as few as 6 SRA transducers at a range of 15 km. Results from the April 1996 and May 1997 experiments appear in the publications listed below.

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As an outgrowth of the successful low frequency phase conjugation experiments, a high frequency (3.5 kHz) phase conjugation experiment was carried out with SACLANTCEN in July 1999. Central to the experiment was a new high frequency vertical array of 29 source/receive transducers operating nominally in the 3-4 kHz band, an underwater pressure case containing the source/receive electronics, and a surface buoy providing battery power, system control, and wireless local area network (LAN) connectivity (see Figure 1). The design and fabrication of the new source/receive array system was sponsored by the FY98 Defense University Research Instrumentation Program (DURIP).

WORK COMPLETED

The 1-24 July 1999 high frequency phase conjugation (HFPC) experiment (also known as FAF-99 for Focused Acoustic Fields Experiment) was carried out adjacent to both Formiche di Grosseto and Elba, Italy. The former provided a link to our previous experiments while the latter provided a brief opportunity to explore a new environment. FAF-99 had four major accomplishments.

- Demonstrated high frequency (3.5 kHz) phase conjugation focusing at ranges out to 14 km in both flat and sloping coastal regions.

- Data were taken to investigate the short-term temporal and spatial properties of the focal region in two different bottom regimes.

- Initial demonstration of phase-conjugation processing in acoustic communications.

- Demonstrated the technology of a source/receive array operating as a node on a wireless local area network (LAN).

RESULTS

A schematic of FAF-99 in the vicinity of Formiche showing actual data (10 ms pulse centered at 3.5 kHz) is given in Figure 2. Illustrated is the phase conjugation process. A probe source (PS) co-located with the vertical receive array (VRA) ensonifies the waveguide. The resulting signal received on the source/receive array (SRA) is time-reversed and retransmitted by the same transducers. The extent to which this retransmitted energy refocuses at the source (as observed by the VRA) is used as a measure of the ability to carry out phase conjugation processing.

Additional examples of time reversal focusing as a function of range are given in the composite illustration in Figure 3. The variation in vertical focusing is due to slight offsets between the PS and VRA at the four ranges. Similar results are available as a function of PS depth in the waveguide. In addition to exploring the range and depth characteristics of the focal region, we also investigated the temporal stability. Although clearly sensitive to environmental fluctuations, focusing was observed to be stable at least in the short-term. Figure 4 shows a sequence of 10 ms pulses observed by the VRA from SRA retransmissions of the same pulse over a 10 min period at a range of 13 km.

Working in the vicinity of Elba provided an opportunity to investigate focusing in a different bottom environment as well as to collect range-dependent data. A particularly interesting result was our ability to demonstrate focusing over a 10 km propagation path from 112 m deep water (SRA) into 32 m deep water (PS and VRA) as shown in Figure 5. The focus has a depth extent of ~2m.

Lastly, we were able to carry out an initial investigation of the application of time reversal to acoustic communications. As shown in Figure 6, the multipath spread for a 2 ms pulse transmitted over a relatively range-independent, 7.2 km propagation path in 110 m deep water near Elba was on the order of 30 ms. After time reversal and retransmission, the pulse was compressed nicely back to ~2 ms duration. Packets of 50 bits then were generated by convolving a random sequence of {+1,-1}'s with the time-reversed reception at the SRA of a 2 ms probe source pulse. The time series of these packets received at the VRA is being compared with the received time series of packets generated at the SRA simply by convolving the random sequence with a 2 ms pulse.

IMPACT / APPLICATIONS

Although this work is at the early concept demonstration stage, there are three natural transition paths for phase conjugation system concepts: (1) ONR (e.g. the Multistatic ASW Capabilities Enhancement (MACE) program), (2) SPAWAR (e.g. the Low Frequency Active (LFA) and Advanced Deployable System (ADS) programs), and (3) NAVAIR (e.g. the Air Deployable Active Receiver (ADAR), Air Deployable Low Frequency Projector (ADLFP), and Airborne Low Frequency Sonar (ALFS) programs).

TRANSITIONS

No transitions took place in FY99.

RELATED PROJECTS

This work is sponsored jointly by ONR Codes 321US, 321OA, and 322OM and is being carried out with the SACLANT Undersea Research Centre under the "Focused Acoustic Fields" Joint Research Project.

PUBLICATIONS

W.A. Kuperman, W.S. Hodgkiss, H.C. Song, T. Akal, C. Ferla, D.R. Jackson, "Phase Conjugation in the ocean: Experimental demonstration of an acoustic time reversal mirror," J. Acoust. Soc. Am. 103(1): 25-40 (1998).

H.C. Song, W.A. Kuperman, and W.S. Hodgkiss, "A time reversal mirror with variable range focusing," J. Acoust. Soc. Am. 103(6): 3234-3240 (1998).

W.S. Hodgkiss, H.C. Song, W.A. Kuperman, T. Akal, C. Ferla, and D.R. Jackson, "A long range and variable focus phase conjugation experiment in shallow water," J. Acoust. Soc. Am. 105(3): 1597-1604 (1999).

H.C. Song, W.A. Kuperman, W.S. Hodgkiss, T. Akal, and C. Ferla, "Iterative time reversal in the ocean," J. Acoust. Soc. Am. 105(6): 3176-3184 (1999).

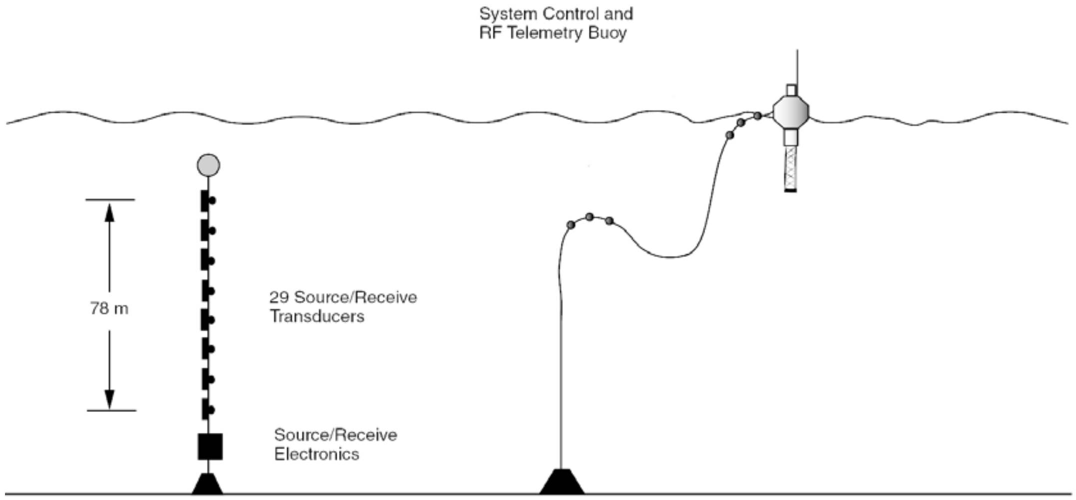

Figure 1. High frequency (3.5 kHz) source/receive array (SRA) consisting of 29 transducers, an underwater electronics pressure case, and surface buoy.

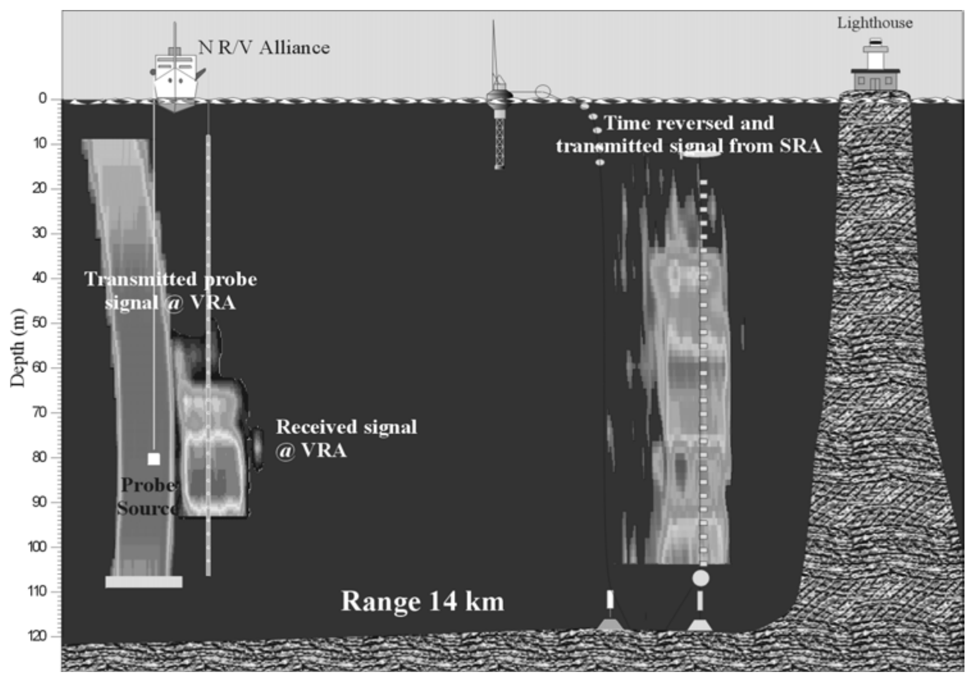

Figure 2. Schematic of the FAF-99 experiment in the vicinity of Formiche illustrating the phase conjugation process with actual data. A probe source (PS) co-located with the vertical receive array (VRA) ensonifies the waveguide. The resulting signal received on the source/receive array (SRA) is time-reversed and retransmitted by the same transducers. The retransmitted energy refocuses at the source as observed by the VRA.

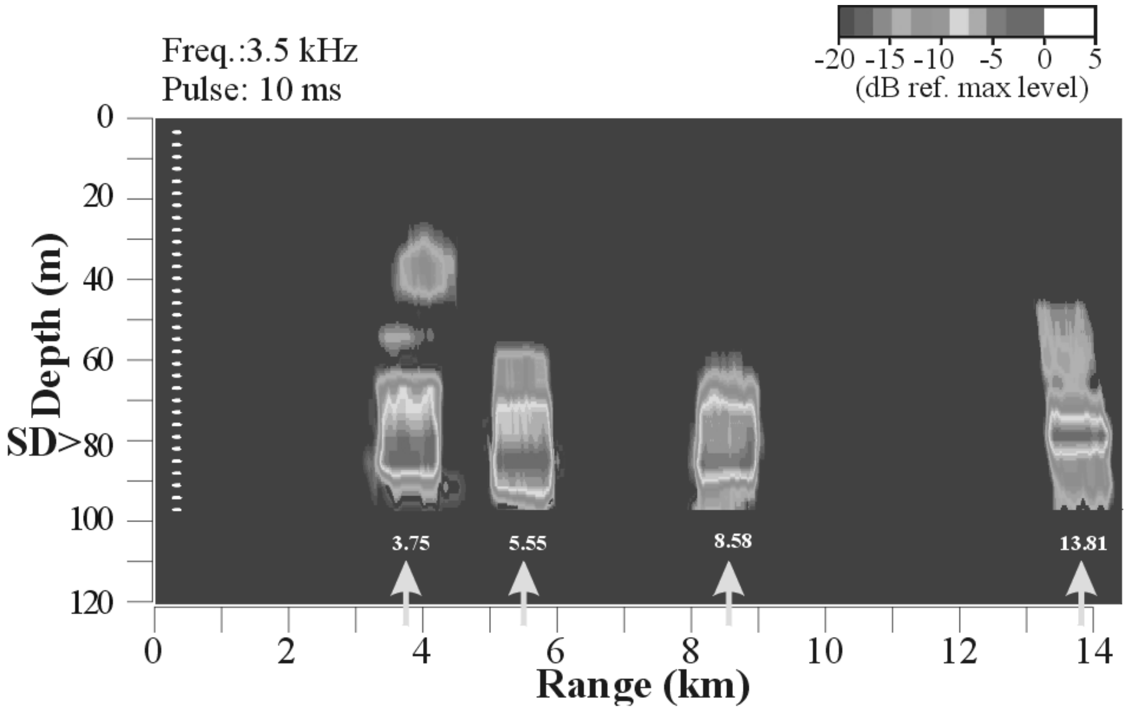

Figure 3. Examples of time reversal focusing as a function of range. The variation in vertical focusing is due to slight offsets between the PS and VRA at the four ranges.

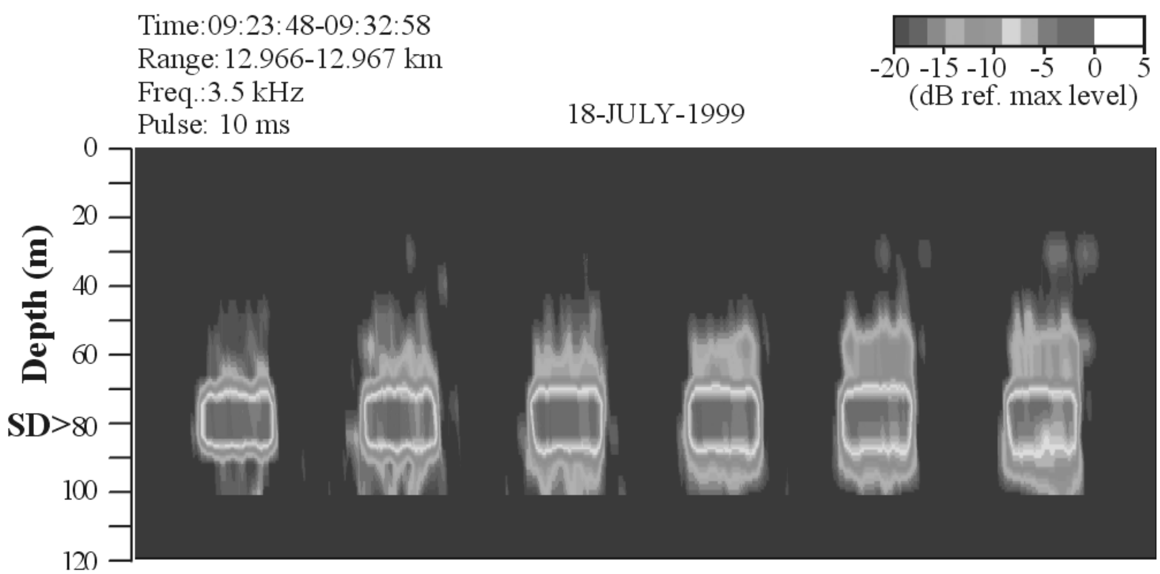

Figure 4. Sequence of 10 ms pulses observed by the VRA from SRA retransmissions of the same pulse over a 10 min period at a range of 13 km.

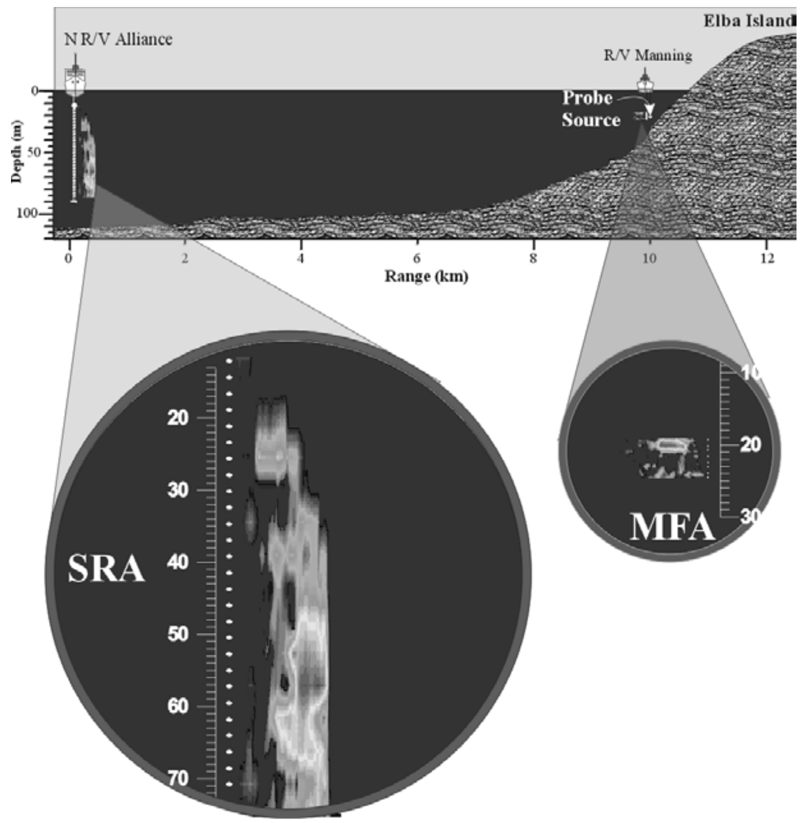

Figure 5. Upslope focus near Elba. The SRA was in 112 m deep water and the PS and VRA (MFA) were co-located in 32 m deep water. The focus has a depth extent of ~2 m.

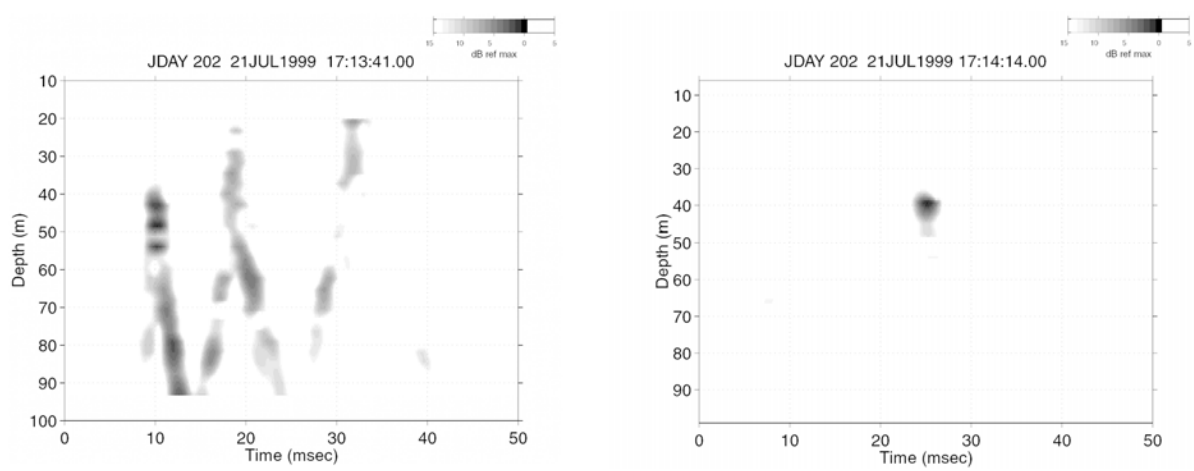

Figure 6. Multipath spread of a 2 ms PS pulse (source depth 40 m) observed at the SRA over a relatively range-independent, 7.2 km propagation path in 110 m deep water near Elba (left). Pulse received at the VRA after time reversal and retransmission (right).