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 first several publications listed below.

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14. ABSTRACT
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.

15. SUBJECT TERMS

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As an outgrowth of the successful low frequency phase conjugation experiments, ONR sponsored two high frequency (~3.5 kHz) phase conjugation (HFPC) experiments which were carried out with SACLANTCEN in FY99 and FY00. Central to these experiments 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 (WLAN) connectivity. The design and fabrication of the new high frequency source/receive array system was sponsored by the FY98 Defense University Research Instrumentation Program (DURIP).

The July 1999 HFPC experiment (also known as FAF-99 or Focused Acoustic Fields 1999) 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 demonstrated high frequency (~3.5 kHz) focusing at ranges out to 14 km, provided an initial look at the use of phase conjugation processing in acoustic communications, and demonstrated the technology of a source/receive array operating as a node on a wireless local area network. A second HFPC experiment was carried out north of Elba, Italy, in May/June 2000. FAF-00 further demonstrated high frequency phase conjugation focusing at ranges out to 21 km in both flat (~125 m deep water) and sloping (~125 m deep water shoaling to ~40 m deep water) coastal environments. Also measured was the stability of the focal region (observed to be on the order of 30 min). Lastly, the use of phase conjugation processing in both active target detection and acoustic communications was demonstrated. Results from the July 1999 and May/June 2000 experiments appear in the last two publications listed below.

WORK COMPLETED

Analysis of the data from the FAF-00 (Focused Acoustic Fields 2000) experiment has resulted in the following major accomplishments:

- Demonstrated (artificial) target echo enhancement and reverberation reduction through time reversal focusing.

- Demonstrated the use of phase conjugation processing in acoustic communications with the transmission and bit error rate analysis of BPSK and QPSK sequences.

RESULTS

The FAF-00 time-reversal data were collected as follows. A probe source (PS) collocated with the vertical receive array (VRA) ensonifies the waveguide. The dispersed pulse with all its multipath structure is received by the source/receive array (SRA), time-reversed, and retransmitted by the same transducers. The extent to which the retransmitted energy refocuses at the PS (as observed by the VRA) is used as a measure of the ability to carry out phase conjugation processing. As an example, Figure 1 shows the multipath structure received by the SRA for a 2 ms PS pulse transmitted from 40 m depth over a relatively range-independent, 7.2 km propagation path in 110 m deep water. After time-reversal and retransmission, the highly dispersed pulse has compressed nicely back to ~2 ms in duration and ~4 m in depth.

The potential for reducing reverberation through time-reversal focusing was investigated by carrying out the focusing procedure described above along with recording the backscatter (reverberation) received by the SRA after the retransmission. As an illustration, Figure 2 compares the power received by the VRA at 4.7 km range from both time-reversal focusing of a 100 ms PS pulse at 60 m depth and a simple broadside transmission (no time-reversal) of a 100 ms pulse by the SRA. Also shown is the power observed on each element of the SRA for 8 sec after transmission along with the time series of instantaneous power from a single (mid-array) element. The dip in the time-reversal return at ~6.3 sec corresponds to the range of the PS thus demonstrating that focusing the SRA transmission mid-water column leads to a reduction in the returning reverberation from this range.

In a communications context, the severe multipath spread (~30 ms) shown in Figure 1 leads to serious intersymbol interference for acoustic data telemetry. However, the retransmission from the SRA received at the PS location is relatively free of dispersion. By using the time-reversed reception at the SRA of the 2 ms PS pulse as the generic single symbol transmission waveform, information then can be coded into the phase of each symbol. Although the transmission is very complicated at the SRA due to the substantial overlap of the symbol waveforms, its structure is simple and easily decoded at the receiver located at the PS position. As an illustration, Figure 3 compares the received power at the VRA and symbol decoding (in-phase and quadrature scatter plots) for BPSK (binary phase shift keying) for both a single-element SRA transmission (no time-reversal) and a full-SRA time-reversal transmission. A random sequence of 4976 bits was transmitted over a 10 sec interval with the PS at 60 m depth and 10 km range from the SRA.

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 FY01.

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).

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G.F. Edelmann, T.Akal, W.S. Hodgkiss, S. Kim, W.A. Kuperman, and H.C. Song, “An initial demonstration of underwater acoustic communication using time reversal,” submitted to J. Oceanic Engr. (September 2000).

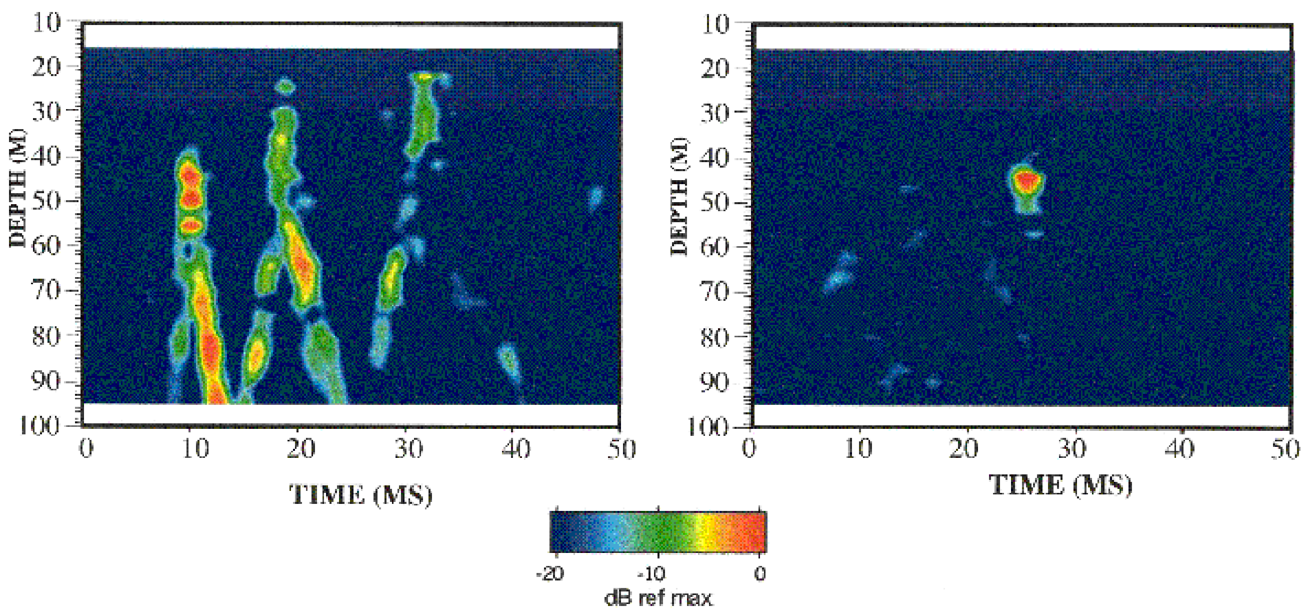

Figure 1. Multipath spread (~30 ms) of a 2 ms PS pulse (source depth 40 m) observed at the SRA over a relatively range-independent 7.2 km propagation path in 110 m deep water (left). Pulse received at the VRA after time reversal and retransmission (right). The highly dispersed pulse has compressed nicely back to ~2 ms in duration and ~4 m in depth.

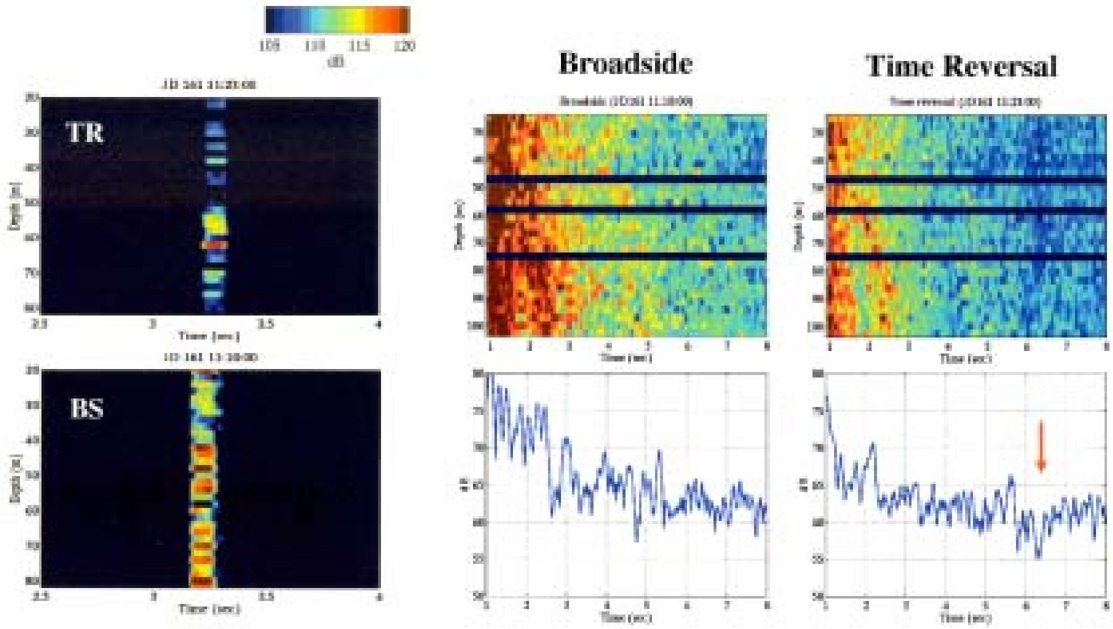

Figure 2. Comparison of the power received by the VRA at 4.7 km range from both time-reversal focusing of a 100 ms PS pulse at 60 m depth and a simple broadside transmission of a 100 ms pulse by the SRA which results in the pulse being spread across the entire water column at the VRA (left). Also shown is the reverberation observed on each element of the SRA for 8 sec after transmission and that from a single (mid-array) element (right). The dip in the time-reversal return at ~6.3 sec corresponds to the range of the PS.

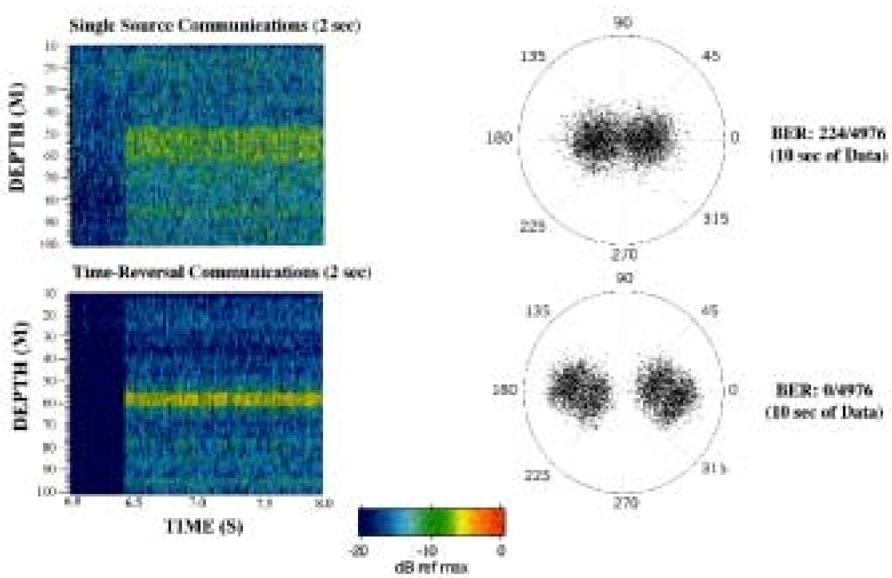

Figure 3. Comparison of the power received at the VRA (left) and symbol decoding (in-phase and quadrature scatter plots) (right) for BPSK (binary phase shift keying) for both a single-element SRA transmission (no time-reversal) and a full-SRA time-reversal transmission (PS at 60 m depth and 10 km range from the SRA). The time-reversal transmission is focused at the PS depth and results in no bit errors over the 10 sec (4976 bit) transmission.