

nals recreates the original source wave field at its original source location. In some measurement cases a background noise is created in the process of generating the source signal of interest; for example, wind and water tunnel acoustic experiments. By using time reverse acoustics, the signal-to-noise ratio can be improved. First, the source signal together with the background noise is recorded using an array of many reciprocal transducers. After the tunnel flow is stopped, the recorded signals are played in a time-reversed fashion through the reciprocal transducer elements of the array. If a receiver is located at the correct source location, only the source part of the rebroadcast signal is superimposed positively, with negligible influence from the background sources that originate elsewhere. Here, we describe noisy environment, free-field, time reversed acoustic simulations. The computer simulations show an improved signal-to-noise ratio. The advantages and disadvantages of using continuous or pulsed recorded signal are discussed. [Work supported by the Applied Research Laboratory E/F Program, and ONR, Code 333.]

9:45

3aSP6. Laboratory experiments of time reversed acoustics applied to sonar in shallow water waveguides. Mitchell N. Shipley (Appl. Res. Lab., Penn State Univ., State College, PA 16804), John Stokely, Kevin B. Smith, and Andres Larrazza (Naval Postgrad. School, Monterey, CA 93943)

Active sonar research at the Naval Postgraduate School Advanced Acoustic Research Laboratory (AARL) has focused on real time adaptation of the active sonar transmit signal. Recent work with Time Reversal Acoustics (TRA) has demonstrated the ability of this approach to adapt in real time to complex environments with little knowledge of the environmental parameters. The present work applies TRA techniques to shallow water active sonar to improve target echo SNR. The approach is to conduct scaled laboratory tank experiments of the TRA sonar and compare results to standard matched filter active sonar processing techniques. Results of laboratory TRA sonar experiments will be presented, to include the high SNR case, the effects of increasing noise levels, and the TRA sonar approach as applied to an active barrier concept.

10:00–10:15 Break

10:15

3aSP7. Preliminary results of water tunnel acoustic measurements using a time reversal mirror. Christopher Barber (Naval Surface Warfare Ctr., Carderock Div., 9500 MacArthur Blvd., West Bethesda, MD 20817-5700), Gerald C. Lauchle (Grad. Prog. in Acoust. and Appl. Res. Lab., Penn State Univ., P.O. Box 30, State College, PA 16804), and Nelson J. Kottke (Grad. Prog. in Acoust., Penn State Univ., P.O. Box 30, State College, PA 16804)

A concept demonstration test was recently conducted at the Garfield Thomas Water Tunnel at the Penn State University Applied Research Laboratory using a time reversal mirror to acquire acoustic measurements of a cavitation noise source. The objective of the test was to demonstrate improved acoustic measurement capabilities compared to conventional underwater acoustic measurement techniques. A preliminary analysis of the data indicates an increased signal-to-noise ratio resulting from the time-reverse playback of recorded data compared to real-time measurements made using either omnidirectional or sum-beam sensors. Experimental results are presented, including a novel method for source localization based on the difference between the time-forward and time-reverse playback of recorded data. [Work supported by ONR Code 334, Naval Surface Warfare Center Carderock Division, and the Applied Research Laboratory.]

10:30

3aSP8. Robust time-reversal focusing in a random ocean channel. Seongil Kim, W. A. Kuperman, W. S. Hodgkiss, H. C. Song, G. F. Edelmann (Scripps Inst. of Oceanogr., La Jolla, CA 92093-0238), Tuncay Akal (SACLANT Undersea Res. Ctr., 19138 La Spezia, Italy), Rick P. Millane (Purdue Univ., West Lafayette, IN 47907-1160), and Daniela Dilorio (Univ. of Georgia, Athens, GA 30602)

Since time reversal focusing utilizes the reciprocity of a static medium, its performance can be degraded in a nonstatic medium, where the propagation conditions change during the time of forward and backward propagations. In this study, a method for robust time-reversal focusing is investigated based on a method developed for matched-field processing [Krolik, J. Acoust. Soc. Am. **92**, 1408–1419 (1992)]. Instead of using a single probe source pulse, the robust method employs multiple probe source signals obtained over a period of time where each ping represents a different propagation condition. A singular value decomposition of the signal matrix of the received probe source pulses shows that over 90% of the acoustic energy is represented by the first few singular values, suggesting that the effective dimension of the pressure field resulting from the sound speed fluctuations is small. The back-propagated field weighted by the linear combination of the dominant singular vectors produces stable focusing for longer time than that with a single probe pulse. The method is useful in nonstatic propagation conditions and in a situation where frequent probe signals are not available. [Work supported by ONR.]

10:45

3aSP9. Shallow water performance of a moving time-reversing array. Karim G. Sabra and David R. Dowling (Dept. of Mech. Eng., Univ. of Michigan, Ann Arbor, MI 48109-2121)

Future active sonar and underwater communication systems for use in unknown shallow ocean waters may be developed from the automatic spatial and temporal focusing properties of time-reversing arrays (TRAs). Previous simulation results suggest that stationary TRAs will work well with moving sources when the source Mach number is low. This presentation describes simulation results for the case when the TRA is moving and the source is stationary. When the array is moving, the forward and backward propagation necessary for TRA operations is influenced by the Doppler effect in an asymmetric manner. Here, numerical results for the characteristics of the retrofocused field will be presented for a range-independent sound channel based on wide-angle parabolic-equation (RAM by Dr. M. Collins of NRL) or wave number integration (OASES by Professor H. Schmidt of MIT) calculations. Different combinations of array motion and geometry for acoustic center frequencies of several hundred Hertz and nominal ranges up to 10 km will be included, as well as the influence of random bottom roughness. Issues concerning the implementation of a moving TRA in a realistic environment will also be addressed. [Work sponsored by ONR.]

11:00

3aSP10. A model-based acoustic time-reversal mirror for robust variable focusing. Jean-Pierre Hermand (Dept. of Optics and Acoust., Université Libre de Bruxelles, av. F.-D. Roosevelt 50, CP 194/5, B-1050 Brussels, Belgium)

A natural extension of the acoustic time-reversal mirror (TRM) is investigated where *predicted* receive array signals are backpropagated to an arbitrary *virtual* source location. First, large time-bandwidth product (TB), broadband signals propagating from a *real* probe source to the array are processed iteratively by a model-based matched filter (MBMF) receiver in searching for the environmental parameters that best correspond to the measured acoustic-impulse responses. The process ends when most of the time-spread energy across the array is recombined *coherently* (processing gain). Second, the resulting acoustic-channel model is used to synthesize the transmit signals that will focus their energy at the desired range and depth (the virtual source). The procedure overcomes the noise and reverberation limitations inherent to the TRM operation. The at-sea, focusing performances of a model-based TRM were predicted from related MBMF experiments: range-depth localization of a distant towed source in a duct

(WEST SARDINIA 89–90) and bottom geoaoustic characterization in shallow water (YELLOW SHARK 94–95) [Hermand *et al.*, IEEE J. Oceanic Eng. **18**, 447–465 (1993); **24**, 41–66 (1999)]. Simulation results using YELLOW SHARK 94, large TB, broadband vertical array data will be compared with TRM 96–97 experimental results [Hodgkiss *et al.*, J. Acoust. Soc. Am. **105**, 1597–1604 (1999)] obtained along the same transect.

11:15

3aSP11. Decision-directed passive phase conjugation: A robust and simple architecture for array receivers in the underwater communications channel. John A. Flynn, James A. Ritcey (Dept. of Elec. Eng., Univ. of Washington, Box 352500, Seattle, WA 98105), and Warren L. J. Fox (Univ. of Washington, Seattle, WA 98105)

A decision-directed extension to the passive phase conjugation (PPC) technique of array demodulation for underwater communications channels is presented. The PPC method utilizes a probe signal from the transmitter to exploit the time-reversal concept in a one-way fashion at the receiver on subsequent unknown data signals [D. R. Jackson *et al.*, Conf. Rec. 34th Asilomar Conf. on Signals, Syst., and Comp., Vol. 1, 680–683 (2000)]. PPC demonstrated excellent equalization of communication bursts in shallow water with sparse array reception. The decision-directed extension to PPC presented here virtually eliminates the need for repeated channel probing, while improving channel estimation in rapidly varying, noisy environments. The technique utilizes decision-directed channel modeling in a fixed-window linear statistical framework, a deterministic least

squares optimization criteria, and robust conjugate-gradient numerical methods driving the PPC demodulator. The resulting architecture scales linearly with the number of sensors, has a per-sensor complexity competing with fast-RLS algorithms, and avoids performance limitations of both LMS and E-RLS. Three difficult shallow water demonstrations at 1–5 km show robust channel tracking with good BER and excellent equalization performance. [Work supported by ONR.]

11:30

3aSP12. Detection based on multiple time-reversal guide-sources. Charles F. Gaumond (Acoust. Div., Naval Res. Lab., Washington, DC 20375-5320)

The problem of inclusion of multiple guide-sources in a time-reversal detection system is discussed. The objective of the detector is the coverage of a given volume over range and depth in a known environment. This detector should rely on as few guide-sources as possible. This detection problem is analyzed in terms of a separable kernel receiver (SKR). The performance of the SKR in terms of the number and placement of guide-sources is shown to depend on the 2-D inner-product of the guide-source covariance with the expected signal covariance. This single number can be used as an overall measure of system quality. Numerical examples are shown for several shallow water environments with various numbers and placements of guide-sources. The use of extended reflectors for use in an active system is also considered. [Work supported by ONR.]

WEDNESDAY MORNING, 5 DECEMBER 2001

ROOM 304, 8:30 TO 11:45 A.M.

Session 3aUW

Underwater Acoustics, Acoustical Oceanography and Animal Bioacoustics: Ocean Research and Marine Mammal Regulatory Issues

David L. Bradley, Chair

Applied Research Laboratory, Pennsylvania State University, P.O. Box 30, State College, Pennsylvania 16802

Chair's Introduction—8:30

Invited Papers

8:35

3aUW1. Marine Mammal Protection Act (MMPA), Endangered Species Act (ESA), and regulations for Scientific Research Permits. Gene Nitta and Ann Terbush (Office of Protected Resources, Div. of Marine Mammal Permits, Conservation, and Education, Silver Spring, MD 20910, gene.nitta@noaa.gov)

The MMPA, ESA, and Fur Seal Act, mandate the protection and conservation of marine mammals and other protected species, and prohibit the taking, importation, and export of protected species. Exceptions for scientific research, enhancement, public display, and commercial and educational photography, are allowed under special exception permits or other appropriate authorizations issued under Section 10 of the ESA and Section 104 of the MMPA. Permit issuance must also meet NEPA, ESA Section 7, CITES, and where necessary, CZMA requirements. NOAA Fisheries develops and implements policies and regulations for issuance of permits and authorizations to take marine mammals for the activities noted above, and organizes and executes the national program for tracking captive marine mammals. Marine mammal permits are coordinated with NOAA Regional Offices, the Marine Mammal Commission, the Fish and Wildlife Service, and the Animal and Plant Health Inspection Service. Input on permit applications is received from other Federal, State, and local agencies, the academic community, public display institutions, nongovernmental organizations, and the general public. NOAA fisheries coordinates national policy for minimizing harassment from human recreational activities directed at marine mammals and conducts outreach to the public about the permit program and responsible wildlife viewing practices.