SACLANTCEN Memorandum SM -187

# SACLANT ASW RESEARCH CENTRE MEMORANDUM

# APPLICATION OF BEAM-FORMING TECHNIQUES TO MEASUREMENTS OF ACOUSTIC SCATTERING FROM THE OCEAN

by

Jonathan M. BERKSON
Hendrik J. KLOOSTERMAN
Tuncay AKAL
and Jean-Louis BERROU

OCTOBER 1986

NORTH ATLANTIC TREATY ORGANIZATION

SACLANTCEN
LA SPEZIA, ITALY

**Report no. changed (Mar 2006): SM-187-UU**

SACLANTCEN MEMORANDUM SM-187

NORTH ATLANTIC TREATY ORGANIZATION

SACLANT ASW Research Centre
Viale San Bartolomeo 400,
I-19026 San Bartolomeo (SP), Italy.

tel: national 0187 540111
international + 39 187 540111

telex: 271148 SACENT I

# APPLICATION OF BEAM-FORMING TECHNIQUES TO MEASUREMENTS OF ACOUSTIC SCATTERING FROM THE OCEAN

by

Jonathan M. Berkson
Hendrik J. Kloosterman
Tuncay Akal
and
Jean-Louis Berrou

*[Reprinted from IEEE Journal of Oceanic Engineering, Vol. OE-10, No. 3, July 1985]*

October 1986

This memorandum has been prepared within the SACLANTCEN Underwater Research Division as part of Project 05.

R. Thiele

R. THIELE
Division Chief

# Application of Beam-Forming Techniques to Measurements of Acoustic Scattering from the Ocean Bottom

JONATHAN M. BERKSON, HENDRIK J. KLOOSTERMAN, TUNCAY AKAL, AND JEAN-LOUIS BERROU

*(Invited Paper)*

***Abstract*—Signals from an explosive source backscattered from the seafloor and received at long range by hydrophones of a towed array are processed to estimate the directional distribution of energy for a given time increment. As assembly of these data shows the time and amplitude of scattering features, and after conversion to distance, the geographic location of the return. A frequency-domain beam-forming procedure is used in which beam levels are averaged over a given band of a broad-band source. The processing is applied to experimental data obtained in the southern Tyrrhenian Sea. The major backscattering occurred at the Baconi Seamounts and the coastal margin of Sardinia.**

## I. INTRODUCTION

A HORIZONTAL line array receiving acoustic energy from a broad-band source scattered by the ocean bottom may yield important information about the nature of the seafloor. Such a system can be used for long-range studies of large-scale features of the seafloor [1]–[4] and in estimating the scattering strength of specific features of the seafloor [3], [4].

The choice of whether to have a simple processing system (e.g., side-scan) or a more complex one (e.g., forming many beams) is influenced by the nature of the sound source, the recording and processing capability, and experimental geometry. However, for systems using long arrays and explosive sources, it is often desirable to use the full capability of the receiving array and form beams from forward to backward endfire. Beam forming may be accomplished either by the method of time delay or, in the case of narrow-band analysis, by phase shift. In frequency-domain beam forming, the latter is accomplished in the frequency domain by using the fast Fourier transform (FFT). The high speed of the FFT's available now makes such an approach practical. An advantage of this type of beam forming is that it is possible to store only the Fourier coefficients in the bands of interest rather than a large number of multichannel time series. In this paper, we describe an application of frequency-domain beam forming for a line array of equally spaced elements receiving broad-band acoustic backscattering from the seafloor. A limitation is that, if hydrophones become faulty at sea, increased sidelobe levels may decrease the quality of the measurement. Thus, when the method is used, the conditions of the hydrophones should be monitored and if necessary corrected. If not, the response of missing elements could be estimated in the frequency domain by interpolating the spectra of nearby sensors [7], [8], or perhaps another method, such as cross-spectral beam forming [9], may be more effective in providing sidelobe surpression [10].

The result of this processing is a beam/time history of the backscattered sound. It is possible to further process data of this form to obtain high-resolution estimates [4], make estimates of the scattering strengths [3], [4], and remove artifacts due to right/left ambiguity of the array [5].

## II. METHOD

An explosive source is placed near a horizontal line array. The hydrophone signals from sound reflecting and backscattering from the seafloor are split into time increments. For each processing time increment, a beam-forming procedure is performed to obtain the angular distribution of the acoustic energy within a certain frequency band. An assembly of all distributions over the entire reverberation period yields a record of the location and amplitude of scattering features, after conversion from travel time to distance.

The insonified area of the seafloor at small grazing angles is approximately defined by the intersection of the receiving beam and the processing increment. In the angular direction the dimension is $\phi r$, where $\phi$ is the beamwidth and $r$ the range, and in the radial direction the dimension is about $cT/(2 \cos \theta)$, where $c$ is the sound speed and $\theta$ the grazing angle at the bottom. For certain types of topography within the insonified area, one of three processes may return energy to the array: a) backscattering, b) reflection, and c) diffraction. By the Rayleigh criterion, roughness of heights greater than about $\lambda/(8 \sin \theta)$, where $\lambda$ is the acoustic wavelength, would appear rough to the incident sound. If an area greater than a Fresnel zone is oriented toward the array, sound would be reflected. If a feature within the area contained an edge, a diffraction might occur. In any case, energy returned to the array by one or more of these processes would be observed as an image in a display if the signal-to-noise ratio, the display resolution and display dynamic range are not limitations. Acoustic propagation conditions and measurement geometry may prevent certain areas of the seafloor from being insonified. The range

Manuscript received December 3, 1984; revised April 29, 1985.

J. M. Berkson and T. Akal are with the Saclant ASW Research Centre, La Spezia, Italy.

H. J. Kloosterman was with the Saclant ASW Research Centre, La Spezia, Italy. He is now at the Laboratory for Seismics and Acoustics, University of Technology of Delft, Delft, Holland.

J. L. Berrou was with the Saclant ASW Research Centre, La Spezia, Italy. He is now with Thomson-CSF, Cagnes-sur-Mer, France.

0364-9059/85/0700-0299$01.00 

accuracy of the method depends on the incorporation of information about the sound speed. Ideally the procedure should involve incorporation of a range-dependent acoustic model. In practice, an average speed in sound-channel propagation is often assumed. Errors in range are typically about 3 percent [1].

## III. APPLICATION

The beam-forming procedure is a simple application of frequency-domain beam forming based on the FFT [11]. This procedure was implemented in a processing system (Fig. 1) and applied to signals received by 32 hydrophones of an array-receiving low-frequency backscattered sound from the seafloor. An explosive SUS (signal underwater sound) source (0.8-kg TNT) was detonated at 245-m depth near the linear hydrophone array towed at 100-m depth at the location in the Tyrrhenian Sea shown in Fig. 2. The experimental area was chosen because it was convenient and it contains two major types of physiographic features. The hydrophone channels were sampled at 1.5 kHz in the 10–750 Hz band. An example of the raw hydrophone signals is shown in Fig. 3. The signals for each sensor are processed in segments of 0.34 s with a 512-point time-to-frequency FFT yielding Fourier coefficients of 3-Hz resolution. For each frequency, the coefficients from the elements are gathered into a space/frequency series and input into a 128-point complex FFT, yielding 128 values equally spaced in wavenumber. Using suitable interpolation and averaging, these data are processed into averaged beam-power levels for azimuth directions corresponding to the 128 azimuths of the central frequency of a 60-Hz band. Repeating the procedure for successive time segments gives a display of averaged beam-power level versus time for a particular band.

The beam-time histories are displayed for two frequency bands as a function of wavenumber in Figs. 4 and 5 and as a function of azimuth in Figs. 6 and 7. The scattering features of the seafloor appear in greater detail in the higher frequency records, primarily because of increased spatial resolution. At 715 Hz the array length is 14.5 wavelengths, whereas at 217 Hz it is only 4.5 wavelengths. In the beam-time histories, the explosive source arrival is followed by events due primarily to reflection and scattering of sound at the seafloor. However, other events also occur. The events between beam angles 60° and 90° are due to the direct and bottom-reflected noise from the towing ship. The feature at 0° is due to noise from another ship. The direct arrival from the explosive source (at $t = 10$ s) is followed by signals from multiple reflection at high grazing angles from the sea surface and seafloor. The events appear at high levels on all beams because of sidelobes from beam forming on the overloaded signals. Following these initial events there are features primarily due to backscattering of sound from the seafloor back to the array. A gray-scale display of a record shown in Fig. 8 displays the location of the scatterers in angle and time. After conversion from travel time to distance, these records show the location and amplitude of the scattering features plus their respective right/left ambiguity images. An interpretation of the geographic position of the scattering features is shown in Fig. 2. It

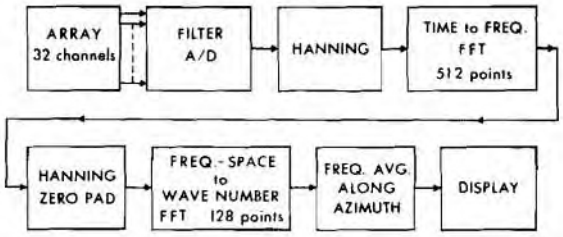


Fig. 1. Processing system.

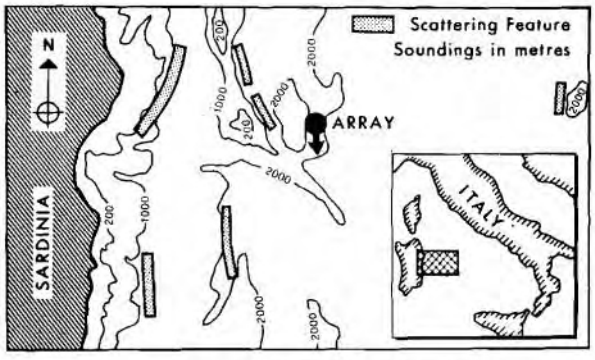


Fig. 2. Location of experiment.

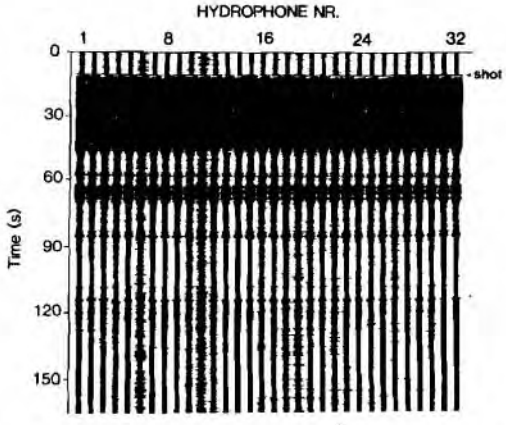


Fig. 3. Raw hydrophone signals from SUS explosive shot.

indicates that the scattering features occur primarily at the large physiographic features nearby: the Baconi Seamounts and the coastal margin of Sardinia. The seamounts also appear to block propagation and/or reception by many of the beams to the coast north of the source/receiver position.

We have shown an application of the frequency-domain beam-forming procedure to obtain beam/time histories of backscattering from the seafloor. However, data of this type may be further processed with other techniques to improve the images or to obtain scattering strengths. For example, the potential for improvement of the angular resolution of data by further processing the data with the high-resolution method of Wagstaff and Berrou [6] was shown in [4]; a processing procedure for removing right/left ambiguity of beam-formed data from a linear array by averaging sets of data obtained with different array orientations was used by Schifter *et al.* [2] and Erskine *et al.* [5]; and quantitative estimates of scattering strengths of specific physiographic features were obtained

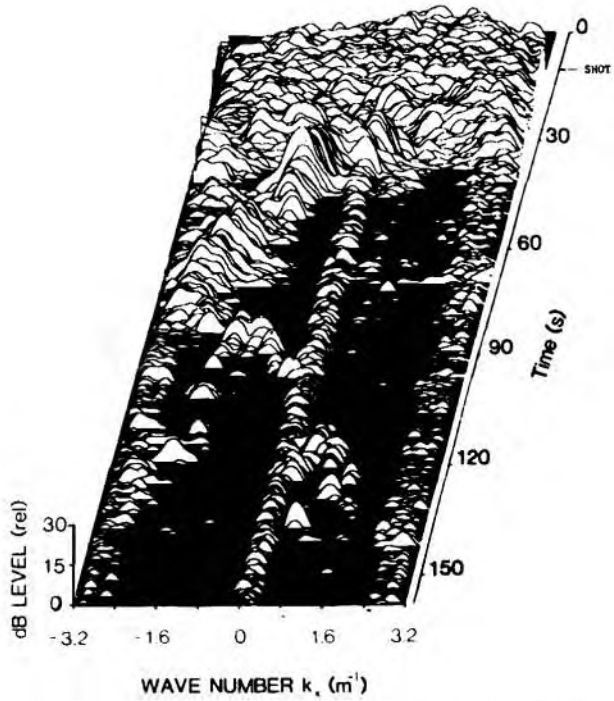


Fig. 4. Beam-time history as a function of wavenumber for 715-Hz 60-Hz bandwidth.

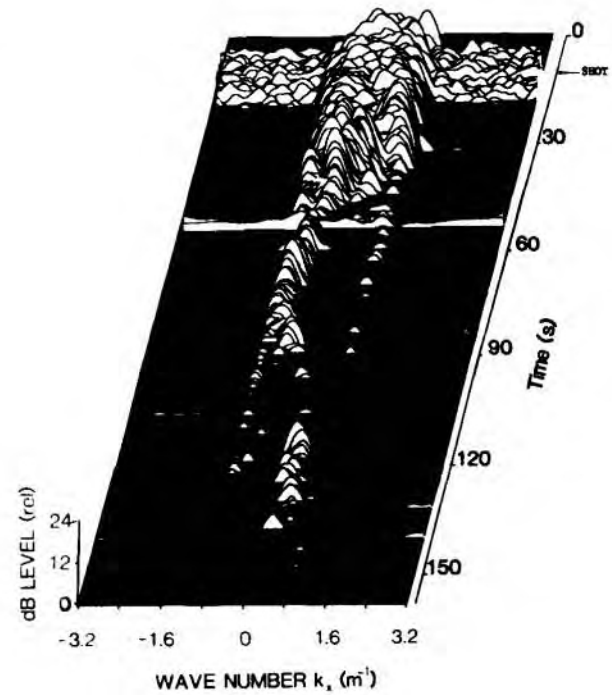


Fig. 6. Beam-time history as a function of wavenumber for 217-Hz 60-Hz bandwidth.

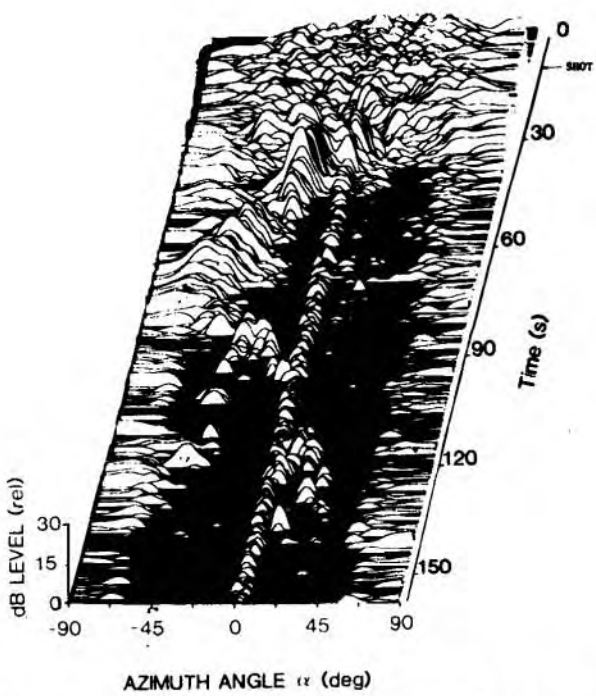


Fig. 5. Beam-time history as a function of azimuth for 715-Hz 60-Hz bandwidth.

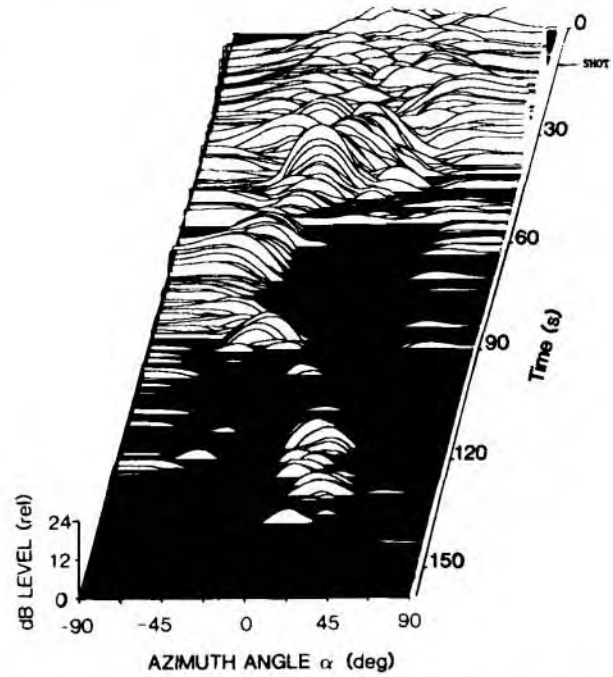


Fig. 7. Beam-time history as a function of azimuth for 217-Hz 60-Hz bandwidth.

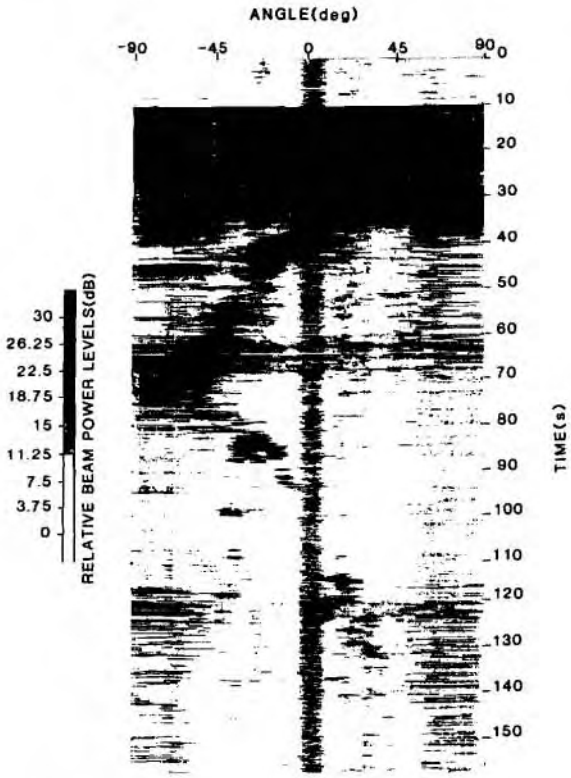


Fig. 8. Gray-scale display of beam-time history as a function of azimuth for 715-Hz 60-Hz bandwidth.

from beam-formed low-frequency backscattering data by Dyer *et al.* [3] and by Berkson *et al.* [4].

## IV. CONCLUSION

A procedure for processing signals received by hydrophones of an array receiving low-frequency backscattered sound from the seafloor uses an interpolation and averaging procedure to obtain beam-power levels over a given frequency of the broad-band sound. The method was applied to data obtained in the Tyrrhenian Sea. The primary scattering occurred at the coastal margin of Sardinia and the Baconi Seamount chain.

## REFERENCES

[1] R. C. Spindel and J. R. Heirtzler, "Long-range echo ranging," *J. Geophys. Res.*, vol. 77, pp. 7073–7088, 1972.

[2] D. E. Schifter, E. R. Franchi, J. M. Griffin, and B. B. Adams, "Hydrographic reconaissance of large undersea topography using scattered acoustic energy," in *Rec. IEEE Electron. and Aerosp. Syst. Conv.*, 1980, pp. 270–274.

[3] I. Dyer, A. B. Baggeroer, J. D. Zittel, and R. J. Williams, "Acoustic backscattering from the basin and margins of the Arctic Ocean," *J. Geophys. Res.*, vol. 87, pp. 9477–9488, 1982.

[4] J. M. Berkson, T. Akal, and J. L. Berrou, "Techniques for measuring backscattering from the sea floor with an array," in *Adaptive Methods in Underwater Acoustics*, H. Urban, Ed. Dordrecht, Netherlands: Reidel, 1984.

[5] F. T. Erskine, G. Bernstein, and E. R. Franchi, "Imaging techniques for analysis of long range acoustic backscatter data from ocean basin regions," in *IEEE Proc. 3rd Working Symp. Oceanographic Data Syst.*, 1983, pp. 160–164.

[6] R. A. Wagstaff and J. L. Berrou, "A fast and simple nonlinear technique for high-resolution beamforming and spectral estimation," *J. Acoust. Soc. Amer.*, vol. 75, pp. 1133–1141, 1984.

[7] R. Heitmeyer, 1976, unpublished.

[8] M. E. Weber and R. Heisler, "A frequency-domain beamforming algorithm for wideband, coherent signal processing," *J. Acoust. Soc. Amer.*, vol. 76, pp. 1132–1144, 1984.

[9] H. B. Pucker, "Cross-sensor beamforming with a sparse line array," *J. Acoust. Soc. Amer.*, vol. 61, pp. 494–507, 1977.

[10] D. J. Ramsdale and R. A. Howerton, "Sensitivity of cross-sensor beamforming to random errors in amplitude and phase," *J. Acoust. Soc. Amer.* (abstr.), vol. 76, p. S80, 1980.

[11] J. R. Williams, "Fast beam-forming algorithm," *J. Acoust. Soc. Amer.*, vol. 44, pp. 1454–1455, 1968.

★

KEYWORDS

ACOUSTICS
BACONI SEAMOUNT
BEAM-FORMING
FAST FOURIER TRANSFORM
SARDINIA
SCATTERING
SEAFLOOR
SIGNAL UNDERWATER SOUND
SUS
TOWED ARRAY
TYRRHENIAN SEA

# INITIAL DISTRIBUTION

| MINISTRIES OF DEFENCE | Copies |
|---|---|
| JSPHQ Belgium | 2 |
| DND Canada | 10 |
| CHOD Denmark | 8 |
| MOD France | 8 |
| MOD Germany | 15 |
| MOD Greece | 11 |
| MOD Italy | 10 |
| MOD Netherlands | 12 |
| CHOD Norway | 10 |
| MOD Portugal | 2 |
| MOD Spain | 2 |
| MOD Turkey | 5 |
| MOD U.K. | 20 |
| SECDEF U.S. | 68 |

| NATO AUTHORITIES | |
|---|---|
| Defence Planning Committee | 3 |
| NAMILCOM | 2 |
| SACLANT | 10 |
| SACLANTREPEUR | 1 |
| CINCWESTLANT/COMOCEANLANT | 1 |
| COMSTRIKFLTANT | 1 |
| COMIBERLANT | 1 |
| CINCEASTLANT | 1 |
| COMSUBACLANT | 1 |
| COMMAIREASTLANT | 1 |
| SACEUR | 2 |
| CINCNORTH | 1 |
| CINCSOUTH | 1 |
| COMNAVSOUTH | 1 |
| COMSTRIKFORSOUTH | 1 |
| COMEDCENT | 1 |
| COMMARAIRMED | 1 |
| CINCHAN | 3 |

| SCNR FOR SACLANTCEN | Copies |
|---|---|
| SCNR Belgium | 1 |
| SCNR Canada | 1 |
| SCNR Denmark | 1 |
| SCNR Germany | 1 |
| SCNR Greece | 1 |
| SCNR Italy | 1 |
| SCNR Netherlands | 1 |
| SCNR Norway | 1 |
| SCNR Portugal | 1 |
| SCNR Turkey | 1 |
| SCNR U.K. | 1 |
| SCNR U.S. | 2 |
| SECGEN Rep. SCNR | 1 |
| NAMILCOM Rep. SCNR | 1 |

| NATIONAL LIAISON OFFICERS | |
|---|---|
| NLO Canada | 1 |
| NLO Denmark | 1 |
| NLO Germany | 1 |
| NLO Italy | 1 |
| NLO U.K. | 1 |
| NLO U.S. | 1 |

| NLR TO SACLANT | |
|---|---|
| NLR Belgium | 1 |
| NLR Canada | 1 |
| NLR Denmark | 1 |
| NLR Germany | 1 |
| NLR Greece | 1 |
| NLR Italy | 1 |
| NLR Netherlands | 1 |
| NLR Norway | 1 |
| NLR Portugal | 1 |
| NLR Turkey | 1 |
| NLR UK | 1 |

| | |
|---|---|
| Total initial distribution | 248 |
| SACLANTCEN Library | 10 |
| Stock | 22 |
| Total number of copies | 280 |