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Newsletter

OES

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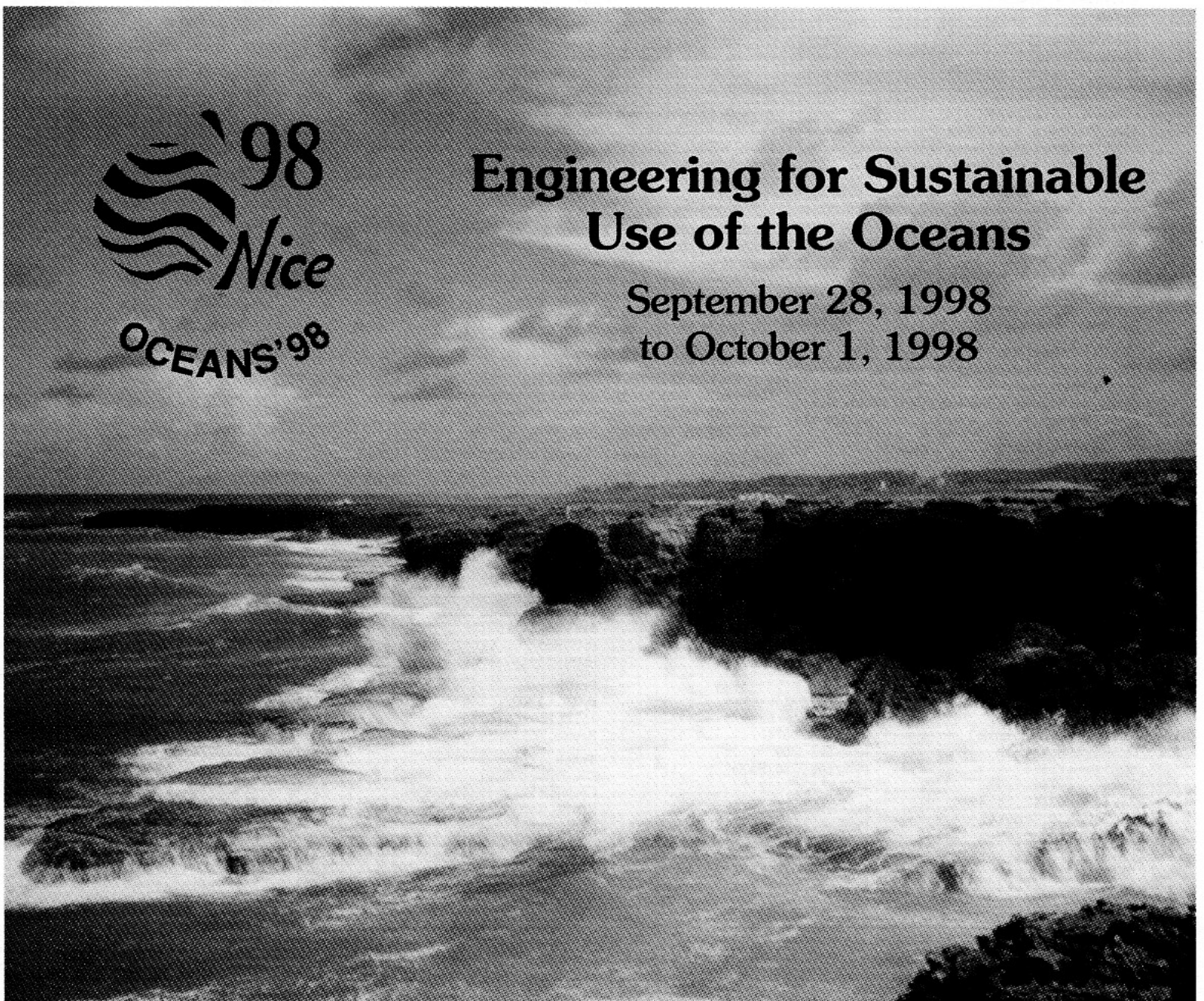

IEEE OCEANIC ENGINEERING SOCIETY

(Continued on back cover)

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UNDERWATER TECHNOLOGY '98

IEEE
Networking the World™

Underwater Technology '98

OES

UT 98

SEIKEN SYMPOSIUM

FOR IMMEDIATE RELEASE

UNDERWATER TECHNOLOGY '98 ANNOUNCES DATE CHANGE

December 24th, 1997 - The Institute of Electrical Engineers (IEEE) Oceanic Engineering Society (OES) and the University of Tokyo's Institute of Industrial Science, in cooperation with the Office of Naval Research Asian Office, announces a slight date change for the premier of the Underwater Technology '98 symposium. The three day event is scheduled for 15-17 April 1998 in Tokyo, Japan - 5 days earlier than previously announced.

Conference organizers indicated that over twice the number of abstracts were submitted to the conference than originally expected - 132 abstracts from 14 countries. To accommodate the many excellent papers, the conference venue was moved to the New Sanno Hotel in Tokyo where two to three parallel sessions can be held. The Advance Program will be available in January, 1998.

The technical sessions will address the conference theme: "Key Issues for the Global Underwater Environment" Under this thematic umbrella, attendees will discuss the problems and potential solutions which concern not only the Pacific Rim countries, but the world in general in areas which include underwater acoustics, observation, telemetry, positioning, vehicles & robotics and signal & information processing. Additional details on the full range of presentations will be available in the Advance Program, to be issued in January, 1998. Details are also available on the conference world wide web site.

The UT '98 world wide web site has been established at:

http://underwater.iis.u-tokyo.ac.jp/ut98/

To obtain a copy of the advance program, or additional information on the conference, visit the world wide web site, or contact the following technical program chairmen directly:

Prof. Tamaki Ura
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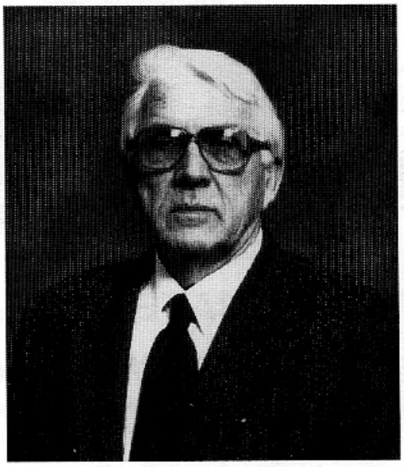
The Year In Review



As President of the Institute of Electrical and Electronics Engineers (IEEE) Oceanic Engineering Society (OES), the past year has been a very busy one. Besides the day-to-day OES issues, I have had the opportunity to participate in the IEEE Board Meeting that are held three times per year. IEEE is a large organization supporting 316,000 members world wide. The working elements of IEEE are the Technical Activities Board (TAB) and the Regional Activities Board (RAB). As President of OES, my major involvement has been with TAB. All society Presidents attend the TAB Board meeting to discuss societal issues, vote on new concepts, and allocate funds. We also discuss issues like membership and Chapters. OES is one of the smallest society. It is instructive for me to hear about how other societies handle membership and chapter development. There is a common element with their methodology, they establish a goal. If you have no goal, you have no direction. I will continue to attend the Board Meetings, especially now that the society Presidents elected me to be a member of the TAB Management Committee.

The OES had only one conference in 1997, The OCEANS '97 MTS/IEEE conference in Halifax, Nova Scotia. The conference was well attended and the technical quality was very high. The conference committee are to be complimented for the excellent job they did.

1998 will be a busy one for the OES. We have Underwater Technology '98 in Tokyo, Japan, on 15 - 17 April. AUV '98 will take place as a workshop on AUV navigation systems in Cambridge, Massachusetts on 20 - 21 August. OCEANS '98 will take place in Nice, France on 28 September through 1 October. This is a conference that should not be missed. All the conferences are headed up by hard working very capable people, and their reward will be a successful conference.

OCEANS '99 will be in Seattle with the proposed theme "Pacific-Rim of Future Ocean Science and Technology". OCEANS 2000 is schedule for Providence, Rhode Island. OCEANS '01 will have Hawaii as the venue. The last OCEANS conference there was extremely well attended. Beyond '01, ideas are being formulated. Consideration is being given to the Gulf Coast for '02. Europe is a candidate for '03.

The OES Newsletter will start to change. With this issue, the membership will be advised the Spring issue will be formated as a regular mail-out and on the OES web site. The OES membership is requested to comment on this new format. Also, we will have more news from our members and officers.

The Journal of Oceanic Engineering (JOE) continues to maintain its high technical quality and is respected by all members of the ocean community. We truly must continue to maintain this position.

Membership and chapters have remained stagnant and even declined slightly. These two areas need immediate attention for the future stability of out society. A much greater effort will be placed in these areas with new assistance and support from the officers and the IEEE. By the end if 1998, there will be a marked improvement in the status of our membership and chapters.

In 1998, I plan to delegate more societal assignments and responsibilities to the Administrative Committee (AdCom) members. Also, I would like to have more interaction with the membership and AdCom. I am always available at *c.brancart@ieee.org*.

1998 will be a good year for the OES. Our finances are strong, two conferences and a workshop are underway. We will continue to maintain the technical quality with the leadership of the Technical Committee Chairman and the JOE Chief editor. I will do my best to be of service to the OES as your President.

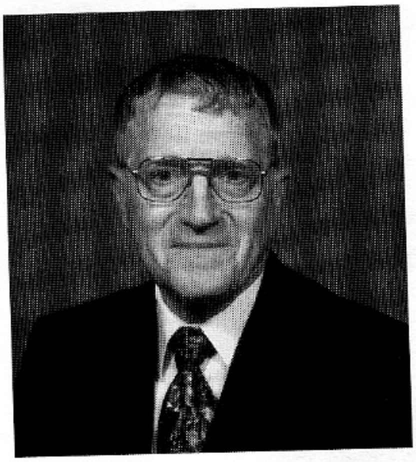
Claude P. Brancart

EDITOR'S NOTE

The age of electronic information is here. Several socities have converted to web versions of their newsletters. This spring we also will have an electronic version on the web. This will be in addition to the print version of the newsletter. The web versions are usually available on line several weeks after the printed copies have been mailed. In the spring issue mailing of our newsletter, I will have some web site information, including useful URL's and links. Your comments will be appreciated. Send them to me, f.maltz@ieee.org.

Frederick H. Maltz
OES Newsletter Editor

PACE and its Importance to Technical Societies



For the past several years you have seen articles on PACE activities and wondered why we discussed professional activities in a technical newsletter. Dr. Mehmet Toy, Chair of the IEEE PACE Divisional Committee put together and excellent description of PACE that I would like to share with you.

What is PACE? - Professional Activities Committees for Engineers (PACE) is a communications network and action arm for the dissemination of information about IEEE resources and services to IEEE members, chapters and sections. PACE conducts programs at the region, section and chapter level for professional and career development. The PACE network provides a line of communication from members to IEEE officers.

What is the purpose of PACE Activities? PACE Activities are designed to improve the quality of work life for IEEE members.

What types of issues does PACE deal with? There are many areas where PACE committees are active and helping the working engineer:

Career Issues such as;

- Employment Trends
- Career Maintenance and Development
- Pensions
- Discrimination
- Immigration Policy

"Engineering Practice" Issues;

- Licensure and Registration
- Continuing Professional Education
- Intellectual Property Protection

Public Policies for Advancement of Technology;

- Support of Funding Research and Development
- Communications and Information Policy
- Medical Technology Policy
- Energy Policy
- Aerospace Policy

What types of services are available from IEEE-USA?

- Employment Assistance
- Consultants' Networks
- Careers Conferences and Publications
- Biennial Salary Surveys
- Professional Awareness and Training

Norman D. Miller
OES PACE Representative

OCEANIC ENGINEERING SOCIETY

Distinguished Technical Achievement Award

1975	Robert Frosch
1976	Werner Kroebel
1977	Howard A. Wilcox
1978	Richard K. Moore
1979	David W. Hyde
1980	Neil Brown
1981	No Award
1982	Ira Dyer
1983	Alan Berman
1984	John B. Hersey
1985	William N. Nierenberg
1986	Robert J. Urick
1987	James R. McFarlane
1988	Chester M. McKinney
1989	Victor C. Anderson
1990	Robert C. Spindel
1991	Henry Cox
1992	Arthur B. Baggeroer
1993	William J. Plant
1994	Edmund J. Sullivan
1995	Mack O'Brien
1996	Frederick H. Fisher
1997	Newell Booth

Distinguished Technical Achievement Award

Oceanic Engineering Society

Newell Booth

The IEEE Oceanic Engineering Society Distinguished Technical Achievement Award is presented to Dr. Newell Booth for his outstanding contributions to the field of high resolution matched field processing.

Over the last 10 years, Dr. Booth led the Ocean Acoustics community in conducting several experiments which have demonstrated that Matched-Field Processing (MFP) is a robust method of beamforming vertical aperture arrays which improves signal-to-noise ratio and provides target localization. He was instrumental in the engineering development of acoustic -sources and large receiving array systems necessary for implementing high resolution matched field processing.

Dr. Booth's career has been with the US Navy at the Space and Naval Warfare Systems Center and its predecessor laboratories. He has served in several managerial and technical positions in the Ocean Engineering, Environmental Sciences, Ocean Surveillance and Communications Departments, developing the broad expertise notable for most "Oceanic Engineers".

On assignment to the Office of Naval Research between 1997-1990, Dr. Booth established and organized the High Gain Initiative, a research and exploratory development program in undersea target surveillance. This focal project, which involved three different Navy laboratories in addition to several contractor and university organizations, sponsored related research and development in Ocean Acoustics, Acoustical Oceanography, Signal Processing, and Ocean Engineering. The project demonstrated the feasibility of MFP at long range in the deep ocean. As recognition for this work, he was awarded the Naval Ocean Systems Center, Technical Directors Award in 1989.

For the last four years, Dr. Booth has managed the Environmentally Enhanced Array Processing project, which pioneered the application of broadband adaptive MFP in shallow water. Under his leadership a consortium of Navy, university and industrial laboratories and sponsors conducted the SW:11EX series of acoustic experiments. These experiments demonstrated the feasibility of applying adaptive MFP techniques in littoral waters to detect and localize low-level submerged sources.

Dr. Booth received his B.S. in 1961 and M.S. in 1966, both in Physics, from the University of California at Berkeley and his Ph.D. in Plasma Physics from UCLA in 1970.

Distinguished Service Award

Oceanic Engineering Society

Ferial El-Hawary

The IEEE Oceanic Engineering Society Distinguished Service Award is presented to Dr. Ferial El-Hawary for her leadership in expanding the international horizons of OES and promoting OCEANS conferences beyond the USA and Canada.

Dr. El-Hawary has served die IEEE Oceanic Engineering Society in many capacities. She has been on the AdCom since 1989. In addition, she was the past chairman of the Membership Development Committee, Co-Chairman of the Workshop on Neural Networks in Ocean Engineering held in Washington, DC in 1991, and Guest Editor of a special issue of the IEEE Journal of Oceanic Engineering dedicated to advanced applications of control and signal processing in the ocean environment. She organized and chaired the international series of Panel Sessions on the "Future of Oceans Science and Engineering" at the OCEANS' conferences. She completed two terms as the inaugural Vice President for International Activities, a position established to promote the OES and IEEE goal of globalization. Dr. El-Hawary was instrumental in defining the initial scope of our international activities. She was responsible for establishing the first chapter outside North America, the French Chapter. She was also responsible for initiating the activities leading to OCEANS '94 OSATES in Brest, France, the first time that the OCEANS conference was held outside of North America. She was instrumental in guiding the chapter formation in Norway.

Dr. El-Hawary is the Chairman of the first Canadian Atlantic Chapter of the IEEE Oceanic Engineering Society and a Founding Chairman of the first Canadian Maritime Section of the Marine Technology Society. Presently, she is Chairman of the Student Activities Committee for the Eastern Canada Council of IEEE. Ferial was most recently recognized by the Engineering Institute of Canada by being elevated to the grade of Fellow of the EIC. She is a Registered Professional Engineer in the Province of Nova Scotia, a Senior Member of IEEE, and a Fellow of the Marine Technology Society. She is also a member of Signia Xi, and the Canadian Society for Exploration Geophysics.

She has published widely, and made numerous presentations in underwater applications of advanced signal processing and estimation techniques. She established the Modeling and Signal Analysis Research Laboratory in the Faculty of Engineering at the Technical University of Nova Scotia, now DalTech of Dalhousie University. She is the Co-founder and President of B. H. Engineering Systems Limited (BHES) in Halifax.

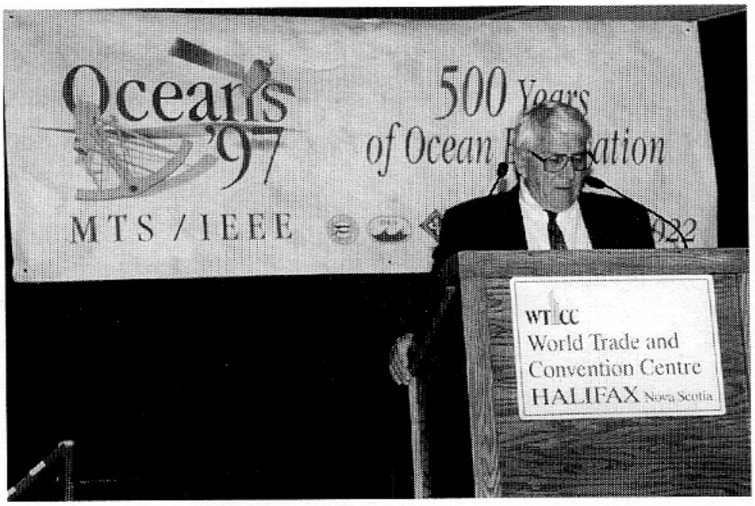
Ferial holds a B.Eng. and M.Sc. degrees in Electrical Engineering from the Universities of Alexandria and Alberta respectively. She also has a Ph.D. degree from Memorial University of Newfoundland in Oceans Engineering.

OCEANIC ENGINEERING SOCIETY

Distinguished Service Award

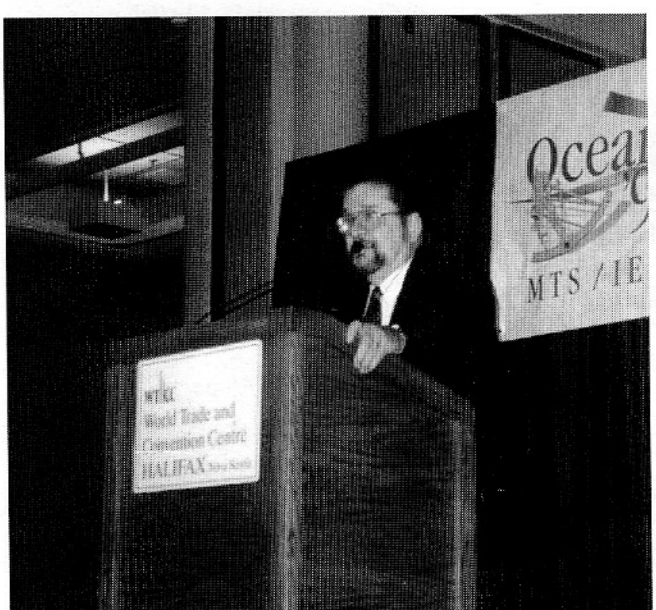
1975	**Arthur S. Westneat**
1976	**Frank Snodgrass**
1977	**Calvin T. Swift**
1978	**Edward W. Early**
1979	**Richard M. Emberson**
1980	**Donald M. Bolle**
1981	**Lloyd Z. Maudlin**
1982	**Arthur S. Westneat**
1983	**Elmer P Wheaton**
1984	**John C. Redmond**
1985	**Joseph R. Vadus**
1986	**Stanley G. Chamberlain**
1987	**Stanley L. Ehrlich**
1988	**Harold A. Sabbagh**
1989	**Eric Herz**
1990	**Anthony I. Eller**
1991	**Frederick H. Fisher**
1992	**Gordon Raisbeck**
1993	**Edward Early**
1994	**Daniel Alspach**
1995	**David Weissman**
1996	**Glen Williams**
1997	**Ferial El-Hawary**

Halifax, Nova Scotia, Canada

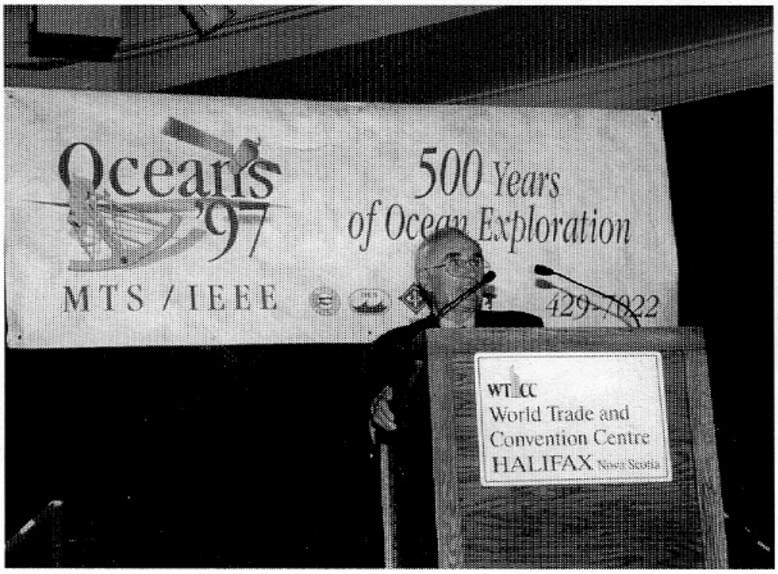


Claude Brancart, OES President

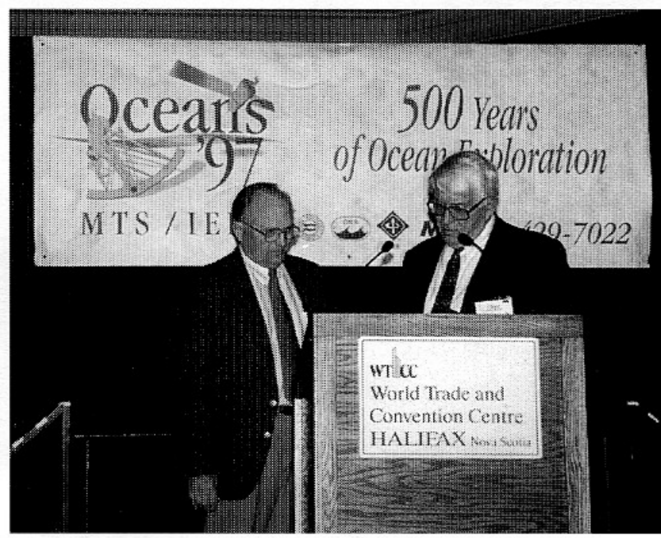
Ferial El-Hawary



Joseph Vadus, Vice-President Technical Activities

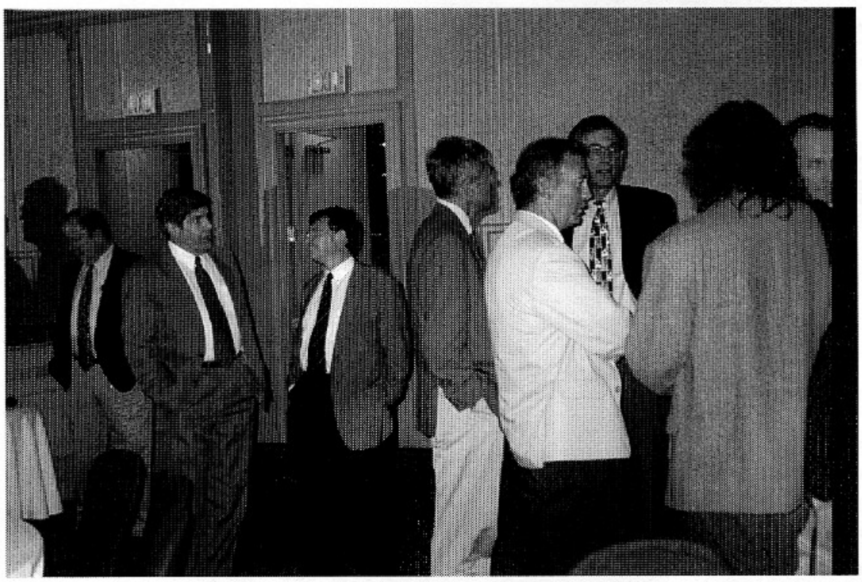


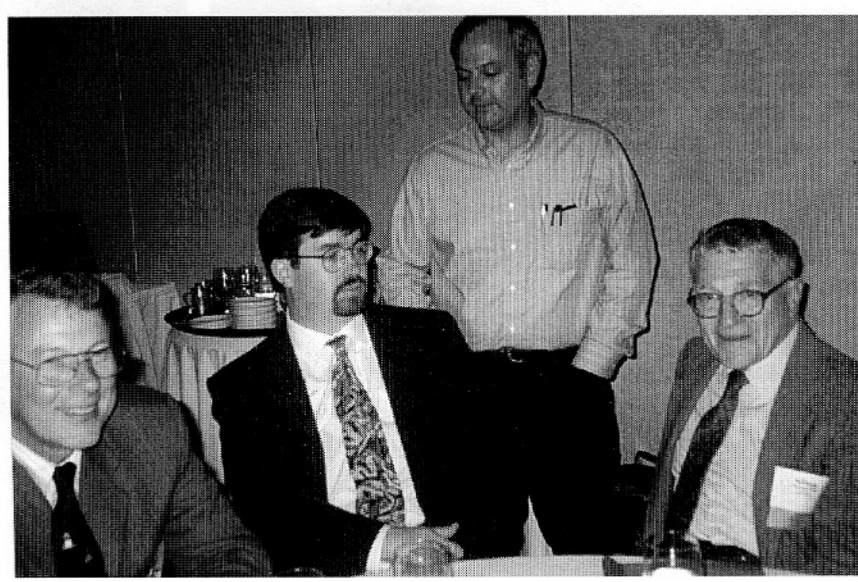
Piérre Sabathe, Vice-President International Activities

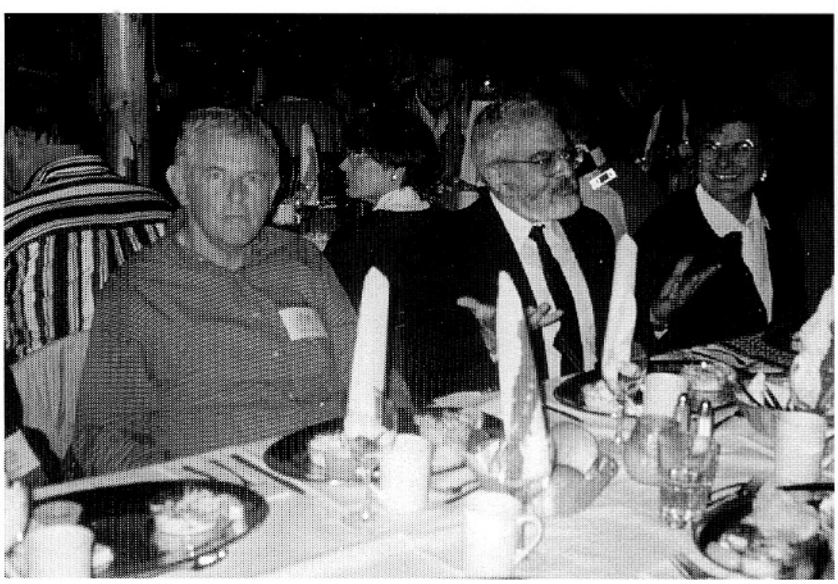


Fred Fisher accepting "Distinguished Technical Achievement Award" for Newell Booth

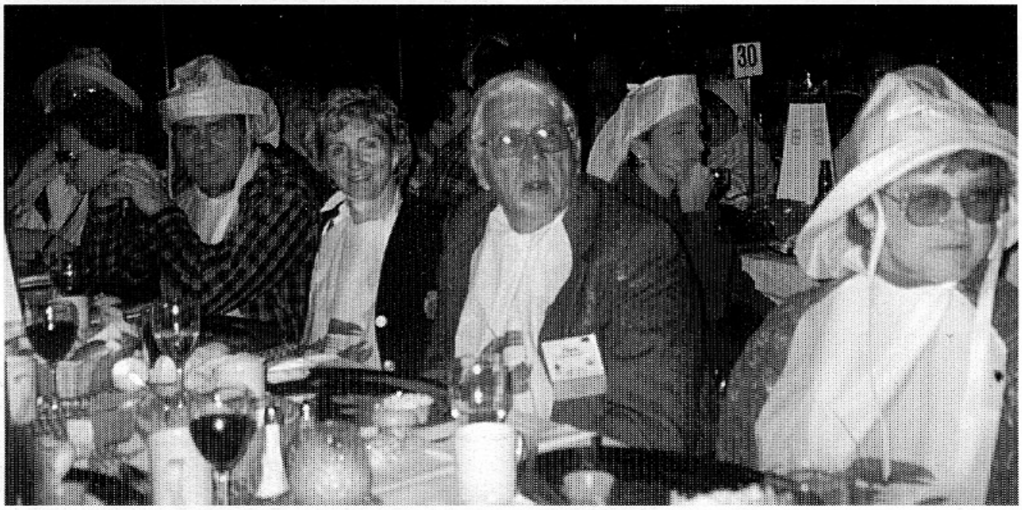
Ferial El-hawary accepting "Distinguished Service Award"







Nova Scotia Ceilidh



"Parade of the Lobster"

OCEANS 97 Student Program

In case you were wondering, there were students at OCEANS 97 in Halifax this year. It was decided that the invited student papers would be integrated into the regular paper sessions. Consequently the students were seen only during the session in which their paper occurred. Six students were selected for a special student presentation session and a judging was made for the top papers. OCEANS 97 received 21 student paper abstracts and twenty students came to the Conference. There was a good geographic distribution of students with students from Canada, France, the United States, Great Britain, Italy, Spain, Germany, and Australia. The students were recognized at the IEEE/OES Awards luncheon and invited to stand for a round of applause. The students and their papers were as follows:

Andrea Trucco - University of Genoa, Italy
"Synthesis of Aperiodic Planar Arrays by a Stochastic Approach"

Douglas Perrault - University of Victoria, Victoria, BC, Canada
"Simulation and Active Control of Towed Undersea Vehicles"

Gabriel Thomas - University of Texas at El Paso, El Paso, Texas
"Noise Suppression and Component Extraction of Underwater Acoustic Signals"

Alberto Oriz-Rodriguez - University of the Baleares Islands, Spain
"A Vision System for Underwater Real-Time Control Tasks"

Lorenzo Pollini - University of Pisa, Italy
"Robust Feedback Linearization with Neural Networks for Underwater Vehicle Control"

Justin E. Manley - MIT, Cambridge, MA, USA
"The Development of the Autonomous Surface Craft ACES"

Euan W. McGookin - University of Glasgow, Glasgow, Scotland
"Non-linear Tanker Control System Parameter Optimization using Genetic Algorithms"

Alexei Nekrasso - Max-Plank Institute for Meterology, Hamburg, Germany
"Measurement of Sea Surface Wind Speed and its Navigational Direction from Flying Apparatus"

G. Connan - University College London, London, England
"FMCW-SAR Development for Internal Wave Imaging"

Thomas Sheasby - University of Leicester, Leicester, England
"The Use of "in-situ" Radiometric Measurements for Validating Satellite Derived Sea Surface Temperatures"

Hayri Sari - Loughborough University, Loughborough, UK
"Underwater Acoustic Voice Communications Using Digital Pulse Position Modulation"

Patrice Danduran - Telecom Bretagne, Brest, France
"Near Realtime use of RADARSAT SAR Imagery Combined With AVHRR Images for Ship Navigation in Antarctica"

L. Aouf - Laboratoire Interactions Ocean - Atmosphere, Marseille, France
"A Model of Wave Propagation Over A Sloping Bottom"

Manuel Aineto - University of Warwick, Coventry, UK
"Narrowband Signal Detection in a Reverberation-Limited Environment"

Enrico Piazza - University of Florence, Firenze, Italy
"Multispectral Images Error Correction"

Jonathon Dunlop - University College London, London, England
"Statistical Modelling of Sidescan Sonar Images"

S.K. Khatri - University of New South Wales, Canberra, Australia
"In Search of a Coastal Ocean Wave Model"

Xiaodong Chen - Florida Atlantic University, Boca Raton, FL, USA
"6 DOF Nonlinear AUV Simulation Toolbox"

Laurent Hellequin - IFREMER, Plouzane, France
"Postprocessing and Signal Corrections for Multibeam Echosounder Images"

Emanuel Radoi - ENSIETA, Brest, France
"A Robust Discriminant Parameter Set for Underwater Ferromagnetic Object Classification"

The winners of the student presentation competition were:

First Place - Andrea Trucco, University of Genoa

Second Place - G. Connan, University College London

Third Place - Justin E. Manley, MIT

Synthesis Of Aperiodic Planar Arrays By A Stochastic Approach

Andrea Trucco
Department of Biophysical and Electronic Engineering (DIBE), University of Genoa, Via Opera Pia I I A, I - 16145 Genova, Italy.

Abstract - Two dimensional arrays offer the potential for producing three-dimensional acoustic imaging. The major problem is the complexity arising from the large number of elements in such arrays. In this paper, a synthesis method is proposed that is aimed at designing an aperiodic sparse two dimensional array to be used together with a conventional beamformer. The stochastic algorithm of simulated annealing has been utilized to minimize the number of elements necessary to produce a spatial response that meets given requirements. The proposed methods is highly innovative, as it can face very large arrays, optimize both positions and weight coefficients, synthesize asymmetric arrays and generate array configurations that are valid for every scan direction. Several results are presented, showing a notable improvement in the array characteristics and performances over those reported in the literature.

1. Introduction

Three-dimensional (3D) acoustic imaging is one of the main innovations in both underwater and medical applications in the last few years. To obtain 3D electronic focusing and beamforming, i.e., 3D imaging capabilities, a two-dimensional (2D) aperture should be used to generate and/or receive the acoustic field. When such an aperture is spatially sampled, the adoption of a 2D array antenna (also called planar array) is assumed. To prevent grating lobes, i.e., aliasing effects due to spatial undersampling, a half-wavelength (λ2) spacing between the elements of the array should not be exceeded. At the same time, in order to obtain a fine lateral resolution, the array should have a wide spatial extension. The λ2-condition together with the fine resolution requirement will often result in a 2D array composed of some thousands of elements. As an acquisition channel is associated with each array element, the cost of a 2D array of this type (i.e., a fully sampled array) is prohibitive.

One of the most promising approaches to reducing the number of array elements (for both linear and planar arrays) is based on the concept of aperiodic arrays. A fully sampled array is thinned by removing a fraction of the original set of elements, thus obtaining a sparse array. Aliasing effects are avoided because there are no periodicities in the positions of the sparse array elements. The main drawback of the thinning operation is an often unacceptably high level of the side lobes present in the beam pattern (BP) (i.e., the spatial response of the array). Therefore, the thinning should be an optimization operation aimed at reducing the number of elements, while maintaining adequate BP properties for the addressed application.

As the distribution and the height of side lobes depend on the positions of the sparse-array elements and on the weight coefficients assigned to such elements, the optimization problem can be approached from different points of view: (1) to optimize the positions of the elements and to keep unitary weights; (2) to *a-priori* fix a pattern of non-uniformly spaced elements (e.g., a random array) and to optimize the element weights; (3) to optimize both the positions and the weights of the elements simultaneously.

To optimize both positions and weights is the most ambitious and effective way of sparse-array synthesis and, for this reason, it is the aim of some techniques facing linear arrays. In particular, in [1,21, one tries to minimize the level of side lobes when the number of elements and the aperture of the sparse array are fixed. Instead, in [3-51, one tries to minimize the number of elements on condition that the related BP will fulfil some *a priori* fixed constraints.

Although the thinning of planar arrays is more computationally demanding than that of linear arrays, it is of much greater importance. If an increase in the mean spacing from λ/2 to 2λ reduces the elements of a linear array by a factor of 4, the same increase in spacing reduces the elements of a planar array by a factor of 16. Some recent papers faced the synthesis of 2D arrays by applying different methods. Starting from a fully sampled array, the authors of [3,4] proposed methods of thinning based on a linear programming able to yield the positions and the weights of the minimum set of elements that allows one to attain a BP that fulfils some *a priori* fixed constraints. These methods yield the optimum problem solution but, unfortunately, they exhibit two major drawbacks that reduce their practical utility: they cannot face arrays with more than about one hundred elements (due to the enormous memory requirements) and can synthesize only symmetric arrays in order to force the BP equation to be realvalued. To overcome such limitations, stochastic optimization methods, like genetic algorithms, were applied to the synthesis of very large 2D arrays. In [6,7], genetic algorithms were used to optimize only the positions of a sparse array with a fixed number of elements. The major limitations are that neither the optimization of weights nor the minimization of the number of elements can be obtained. Moreover, although the BP of a 2D array is a 3D surface, both papers considered only the BP profile along one axis or two axes to evaluate the performances of an array configuration, thus sharply reducing the validity of results. It is important to note that the synthesis methods proposed in [3. 4. 6] assume a fixed scan direction; therefore, the obtained configurations are not valid any more when the scan direction is modified. Another optimization approach is possible when two different planar arrays are used to transmit and to receive. As the overall BP is the product of the two specific BPs, one can study periodic sparse geometries in which aliasing effects are strongly reduced thanks to their different position, as suggested in [8]. Finally, in [9,10], the properties of 2D sparse arrays with randomly distributed elements are evaluated for the wide-band acoustic pulses [11] used in medical imaging.

In this paper, a synthesis method is proposed that is aimed at designing a sparse and aperiodic array to be used as a planar antenna for a narrow-band beamforming processor. The purpose of the method is to minimize the number of elements able to generate a BP that fulfils some *a priori* fixed constraints by acting on the positions and weights of the elements. The stochastic method proposed in this paper is based on simulating annealing (SA) and is an evolution of the method devised by the author for the synthesis of linear arrays [2,5]. The main features that represent innovations with respect to other methods are the following: (1) very large 2D arrays can be faced; (2) both weights and positions can be optimized; (3) the number of elements can be minimized; (4) asymmetric arrays can synthesized, thus exploiting a larger number of degrees of freedom; (5) the overall total extent *of* the 3D BP can be considered. The last-mentioned feature means that the *a priori* fixed constraints are defined over a full 2D domain, and that the resulting configuration is valid for each possible scan direction. To the best of the author's knowledge, no other methods exhibit all the above features at the same time.

This paper is organized as follows. In Section II, the basic concepts of SA are summarized. Section III presents the BP formulation, outlines some symmetry-related properties, and defines the energy function. Section IV describes the proposed method of synthesis; the obtained results are reported in Section V. Finally, some conclusions are drawn in Section VI.

II. The Simulated Annealing Algorithm

Initially, SA aimed to simulate the behaviour of the molecules of a pure substance during the slow cooling that results in the formation of a perfect crystal (minimum-energy state) [12]. The use of this technique to solve other types of problems is based on the analogy between the state of each molecule and the state of each variable that affects an energy function to be minimized. This function is called the energy function, $f(\mathbf{Y})$, $\mathbf{Y}$ being the vector of state variables. The algorithm is iterative: at each iteration, a small random perturbation is induced in the current state configuration $\mathbf{Y}_j$ (j being the iteration). If the new configuration, $\mathbf{Y}_n$, causes the value of the energy function to decrease, it is accepted ($\mathbf{Y}_{j+1} = \mathbf{Y}_n$). Instead, if $\mathbf{Y}_n$, causes the value of the energy function to increase, it is accepted with a probability dependent on the system temperature, in accordance with the Boltzmann distribution. The higher the temperature, the higher the probability that the state configuration that caused the energy function to increase may be accepted. In short, the probability that $\mathbf{Y}_n$ may be accepted as a new configuration, $P\{\mathbf{Y}_{j+1} = \mathbf{Y}_n\}$, can be expressed as:

$$P\left\{\mathbf{Y}_{j+1} = \mathbf{Y}_n\right\} = \begin{cases} e^{\dfrac{f(\mathbf{Y}j)-f(\mathbf{Y}_n)}{kT}} & \text{, if } f(\mathbf{Y}_n) > f(\mathbf{Y}_j) \\ 1 & \text{, otherwise} \end{cases} \tag{1}$$

where k is the Boltzmann constant and T is the system temperature. As the iterations go on, the temperature T is gradually lowered, following the reciprocal of the logarithm*of* the number *of* iterations [12], until the configuration freezes in a certain final state. Thanks to its probabilistic nature, this method represents a notable improvement over classic methods of local descent, although it is computationally demanding. "Me repetition of the process, using different initial configurations, increases the reliance on the quasi-optimality of results, even though a full optimality cannot be proved.

III. BP and Energy Function Formulation

If an array is planar, made up of M punctiform and onmidirectional elements on the plane $z = 0$, then the BP, $p(u,v)$, can be expressed as:

$$p(u,v) = \left| \sum_{i=1}^{M} w_i \cdot e^{j\frac{2\pi}{\lambda}(x_i \cdot u + y_i \cdot v)} \right|, \tag{2}$$

where:

$$u = \sin\alpha - \sin\alpha_0, \tag{3}$$

$$v = \sin\beta - \sin\beta_0, \tag{4}$$

the pairs (α,β) and (α_0, β_0) indicate the arrival direction and the scan direction, respectively, x_i and y_i, are the coordinates of the i-th element, and w_i, is the related weight coefficient. Figure I shows the described geometry.

The variables u and v can assume only real values included between -2 and 2, for any combination of the arrival and scan directions. However, the load for the analysis of the BP can be reduced by keeping into account the following symmetryrelated properties.

- The BP is even, i.e., $p(u,v) = p(-u,-v)$; hence, without loss of information one can restrict the domain of the BP to $u \in [-2,2]$, $v \in [0,2]$.
- if the coordinates of each element are integer multiples of $\lambda/2$, then $p(1 + \delta u, 1 + \delta v) = p(1 - \delta u, 1 - \delta v)$ and $p(-1 + \delta u, 1 + \delta v) = p(-1 - \delta u, 1 - \delta v)$; hence the domain of the BP can be restricted to $u \in = [-1,1]$, $v \in [0,2]$.
- Under the above hypothesis, $p(\delta u, 1 + \delta v) = p(-\delta u, 1 - \delta v)$; hence the domain of the BP can be restricted to $u \in [-1,1]$, $v \in [0,1]$.

When the BP is plotted as a function of u and v, the main lobe is always in $(u,v) = (0,0)$ and its width does not depend on (α_0,β_0). The expression in decibels for the BP, normalized to 0

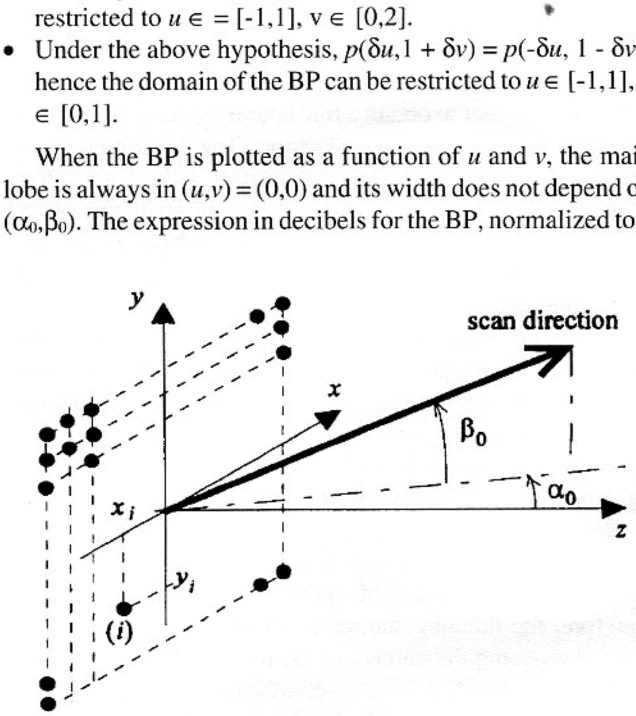


Fig. 1. Array geometry and adopted notation.

dB, is $20 \cdot \log[p(u,v)/Q]$, where Q is the sum of all the w_i's.

The use of SA to synthesize a 2D sparse array requires the choice of an energy function, $f(\mathbf{X},\mathbf{W})$, that depends on the vector of the positions of the elements, **X**, and on the vector of the weights, **W**. Once a desired normalized BP, $p_d(u,v)$, has been fixed, the energy function must be able to penalize the army configurations that yield a great difference between the desired BP and the current one and the configurations that are composed of a large number of active elements (5]. To this end, one can choose:

$$f(\mathbf{X},\mathbf{W}) = \left[k_1 \iint_{(u,v)\in S} \left(\frac{p(u,v)}{Q} - p_d(u,v) \right) du dv + k_2 M \right]^2, \quad (5)$$

where S is the set of values of (u,v) satisfying the relation $p(u,v)/Q > p_d(u,v)$, M is the number of current active elements, and k_1, and k_2 are two constants denoting the relative importance assigned to the discrepancy between the actual BP and the desired one and to the number of array elements. In (5), the energy function is equal to the square of the sum of an integral plus one term. Another possibility is to sum the square of each term. The reason for preferring the formulation in (5) has no theoretical foundations and is mainly due to the higher quality of the obtained results.

The constants k_1, and k_2 can be fixed on the basis of a heuristic reasoning about the range of expected descents of the two addends in (5); however, also some practical experiences can be very useful to set such values. Moreover, there is no guarantee that the obtained BP perfectly fulfils the imposed constraints, but, if the integral in (5) represents the main contribution to the energy ftinction, one can verify *a posteriori* that the value of such an integral is very often lowered to zero (i.e., the constraints are perfectly fulfilled).

IV. The Optimization Procedure

In this section, the peculiarities of an efficient SA implementation devoted to the minimization of (5) are presented. Figure *2* shows a flow-chart of the optimization procedure.

One can start the synthesis by considering a fully sampled array, i.e., a planar array composed of N $\lambda/2$-equispaced elements. Then, according to the process behaviour, the elements are separated into two sets: an active set (i.e., having weights different from zero) and an inactive set (i.e., having weights equal to zero). The number of active elements is M and the relation $M \leq N$ is always verified. The initial temperature, T^{start}, is chosen high enough and such that the first configuration perturbations may almost always be accepted, even though they lead to a sharp increase in energy.

When one starts the iteration j, one chooses randomly an element i (both active and inactive elements are visited according to a random sequence that does not any further visit the same element before all the elements have been visited once). If the chosen element is active, one can move it to the inactive condition by following a fixed death probability, whereas, if the chosen element is inactive, one can activate it (with a random weight) by following a resurrection probability. On the basis of the temperature T^j, such state transitions

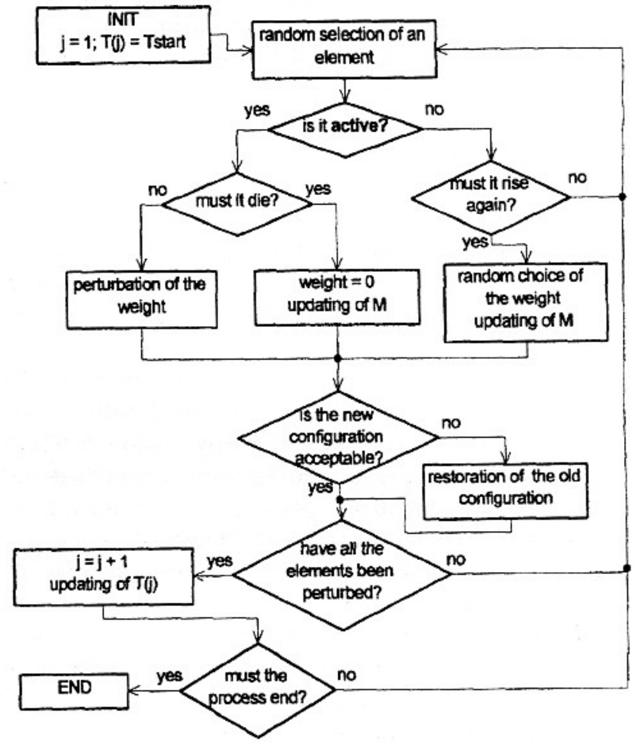


Fig. 2. Flow-chart of the optimization procedure.

can be accepted or not. If one of these ftansitions is accepted, the number of active elements M must be updated. If the element i is active and the its death does not occur, the weight w_i is perturbed and, on the basis of the temperature T^j, the perturbation can be accepted or not.

During the optimization procedure, a constraint is imposed to limit to low values the current taper ratio (CTR), which is the ratio between the maximum and minimum weight coefficients [1,2]. This constraint makes it possible to avoid any consequences of possible unforeseen occurrences regarding the elements with the largest weight coefficients. To limit the CTR value, one should perturb each weight coefficient in a random and continuous way; but one should make sure that the coefficient value is included in an *a priori* fixed range $[w_{min}, W_{max}]$.

The number of iterations, j, is increased every time all the N elements have been perturbed once. The process terminates when a state of persistent block (freezing) is reached, due to the temperature lowering. Alternatively, according to previous experiences, one can perform a number of iterations that is large enough to ensure that a block state will be reached.

Owing to the probabilistic nature of SA, different temperature schedulings and random initial configurations may lead to different final results. However, if a logarithmic scheduling is chosen, almost all the process runnings give slightly different results in terms of both energy values and array characteristics. This means that the resulting array configuration is stable and close to the optimal one.

V. Results and Comparisons

In order to assess the efficiency of the proposed method, different tests were performed for the purpose of verifying that the method: (1) is able to yield array configurations having performances close to those obtained by methods of optimal synthesis (3,41 (referred to as small 2D arrays); (2) performs better than other stochastic methods [6,71; (3) performs better than optimal methods [41 that face only the weighting of the elements that were randomly positioned.

A. Small 2D arrays

Concerning the first point, in [41 the method of optimal synthesis was applied to a 12x12 array with a $\lambda/2$ spacing. The array was first inscribed in a circle, thus giving 112 elements. Then, such a fully sampled array was optimally thinned and weighted in order to constrain the side-lobe peak under a fixed target. As an example of the obtained results, a side-lobe peak of -24.5 dB was not exceeded by employing 62 elements and with a main-lobe width (measured by considering the distance between the two points at -6 dB along a given axis) of about $u_{-6dB} = v_{-6dB} = 0.296$. Obviously, the same level of side-lobe peak may be reached by weighting the fully sampled array. The larger number of sensors is compensated for by a slightly narrower main lobe [4], i.e., $u_{-6dB} = v_{-6dB} = 0.234$.

To test the quasi-optimality of the proposed method, the desired BP was defuied as a constant level of -24.5 dB for each pair (u,v) that was out of a circle of radius 0.25, i.e., $u^2 + v^2 >$ 0.252. The other parameters were fixed as follows: $k_1, = 1600$, $k_2 = 0.2$, death probability = 0.2, resurrection probability = 0.4, $T^{start} = 500$, number of iterations = 10000, $w_{min} = 0.25$, and $w_{max} = 1.75$.

One of the best results obtained by some runnings of the proposed algorithm was an array of 67 elements with a side-lobe peak of -24.3 dB, a main-lobe width of about $u_{-6dB} = v_{-6dB} =$ 0.314, and a CTR of 2.8. Figure 3 shows the position lay-out and the BP of such an array configuration. From these data, one can deduce that the proposed algorithm was able to find an array configuration with performances very close to the optimal ones, in terms of side-lobe peak and main-lobe width, even though with a small increase in the number of elements (i.e., 5 more elements). Other comparisons between the optimal and the obtained configurations, for different values of the side-lobe peak, confirmed the reliance in the quasi-optimality of the proposed method.

B. Large 2D arrays

To face the position optimization of a planar array composed of more than one hundred elements, stochastic approaches seem necessary [6,7]. The numerical evaluation of the BP profile during the optimization process requires the computation of the BP on a dense grid on the plane u-v.

Moreover, the larger the number of array elements, the fimer the grid necessary to consider all the side-lobe peaks. As this operation is highly demanding, some authors evaluated the BP considering only its profile along the u- and v-axes. For instance, Haupt (71 adopted two simplifications: he faced 2D arrays symmetric with respect to the x- and y-axes (thus acting only on a quarter of the elements and obtaining a realvalued BP) and computed the BP only along two axes. As a result, he thinned a fully sampled 20×10 rectangular array to 108 elements, keeping the side-lobe peak at -20 dB along the two axes but admitting a peak of -14.4 dB on the u-v plane.

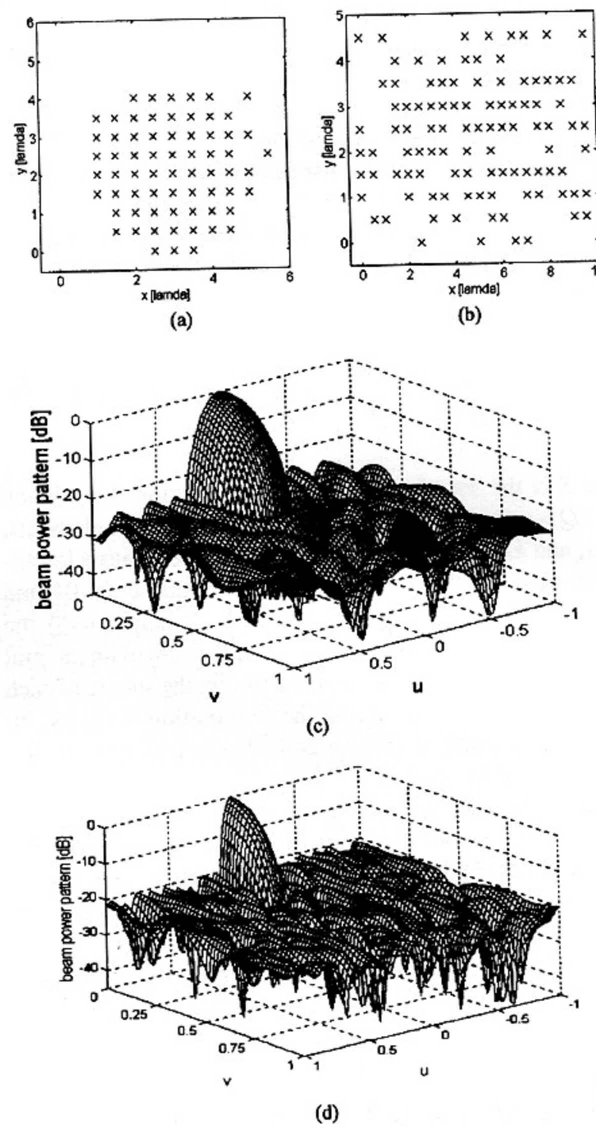


Fig. 3. (a) Optimized positions of a 67-element array, and (c) the related BP with a side-lobe peak of -24.3 dB. (b) Optimized positions of a 101-element array, and (d) the related BP with a side-lobe peak of - 19.8 dB.

In order to test the potentialities of the proposed method in this case, the desired BP was defined as a constant level of -20 dB for each pair (u,v) that was out of a rectangle centered in (0,0), with a 0.24-long side along the u-axis and a 0.44-iong side along the v-axis. The other parameters were fixed as follows: $k_1, = 5000$, $k_2 = 0.2$, death probability = 0.2, resurrection probability 0.4, T^{start} 500, number of iterations = 10000, $w_{min} =$ 0.25, and $w_{max} = 1.75$.

One of the best results obtained by some runnings of the proposed algorithm was an array of 10 1 elements, with a side-lobe peak of -19.8 dB, a main-lobe width of $u_{-6dB} = 0.065$ and $v_{-6dB} = 0.\ 146$, and a CTR of 6.3. Figure 3 shows the position lay-out and the BP of such an array configuration. To clarify the relation between the side-lobe peak and the number of elements, one can consider that the proposed method is able to limit the side-lobe peak at -21 dB by using about 115 elements.

As a consequence, a reduction of 5.4 dB in the side-lobe peak and a reduction of 7 active elements were possible thanks to the proposed method. The main-lobe width of the obtained BP was very similar to that in [7]. Therefore, the advantages of optimizing both positions and weights and of synthesizing asymmetric arrays are evident.

Finally, the proposed method was employed to synthesize very large arrays composed of several thousands of elements. In [4], a 64×64 array with a λ/2 spacing is considered. The array was first inscribed in a circle, thus giving 3228 elements. Such a fully sampled array was randomly thinned to 404 elements (87.5% thinning); then, the linear programming approach was applied to optimize the weight coefficients. As a result, a side-lobe peak of -17.4 dB and a main-lobe width of $u_{-6dB} = v_{-6dB} = 0.05$ were obtained.

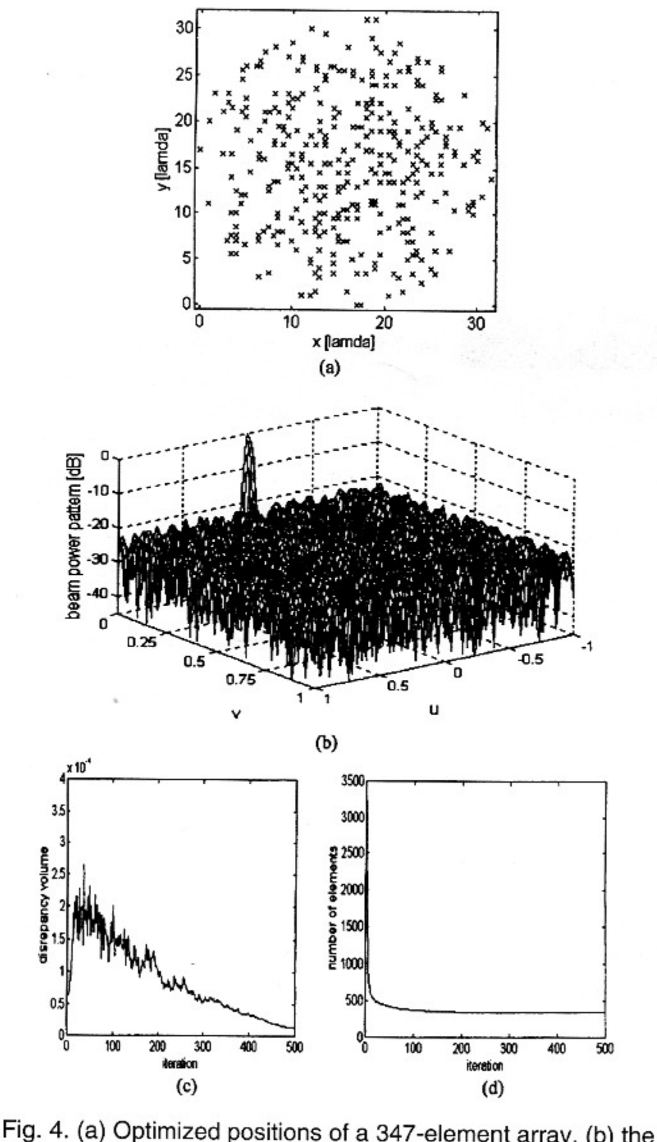


Fig. 4. (a) Optimized positions of a 347-element array, (b) the related BP with a side-lobe peak of -19.8 dB, (C) the discrepancy volume, and (d) the number of active elements M versus the iteration.

Thanks to the stochastic nature of the proposed method, the optimization of both positions and weights is possible also for very large arrays also. The desired BP was defmed as a constant level of -22 dB for each pair (u,v) that was out of a circle of radius 0.03, i.e., $u^2+v^2 > 0.03^2$. The other parameters were fixed as follows: $k_1 = 10000$, $k_2 = 0.1$, death probability = 0.2, resurrection probability = 0.4, $T^{start} = 20$, number of iterations = 500, $w_{min} = 0.25$, and $w_{max} = 1.75$.

One of the best results obtained by some runnings of the proposed algorithm was an array of 347 elements (89.3% thinning), with a side-lobe peak of -20.8 dB, a main-lobe width of about $u_{-6dB} = v_{-6dB} = 0.05$, and a CTR of 4.7. Figure 4 shows the position lay-out and the BP of such an array configuration.

As a consequence, a reduction of 3.4 dB in the side-lobe peak and a reduction of 57 active elements were possible thanks to the proposed method. The main-lobe width of the obtained BP was equal to that in [4]. Therefore, also in this case, the advantages are evident. Finally, to show the behaviour of the two addends in (5) during the minimization, Fig. 4(c) shows the values of the integral, i.e., the discrepancy volume, and Fig. 4(d) shows the number of active elements M versus the iteration.

C. Overall remarks

The improvement in the results related to large 2D arrays, as compared with those presented in the literature, can be explained by the following reasons. First of all, the proposed method allows one to minimize the number of active elements and, at the same time, to optimize their positions and weight coefficients. Then, thanks to the potentialities of SA, the possibility of designing asymmetric planar arrays, i.e., with a larger number of degrees of freedom, is fully exploited.

An important consideration concerns the stability of results with respect to the values of the process parameters, i.e., k_1, k_2, T^{start}, number of iterations, death probability, and resurrection probability. Although the chosen values have been given in the text, experience has shown that also by using different values one can obtain results that are similar to those reported above (even remarkable differences can often be acceptable). Therefore, the effectiveness of the proposed method cannot be considered strictly dependent on the parameter values.

Concerning the optimality of results, two speculations are possible.

- When an adequate statistic shows that many process runnings give slightly different results (on condition that random initial configurations and a high initial temperature are used), the confidence in the quasioptimality of such results is encouraged.
- Due to the probabilistic nature of SA, the final result of a process running can show a higher energy than a configuration visited during the iterations. The confidence in the quasi-optimality of results is reinforced if the final result shows always an energy close to that of the best result obtained before the freezing state occurred.

The results obtained by many runnings of the proposed method (applied to a specific synthesis problem) present slight differences, and the final results are often equal to the best results. Therefore, the quasi-optimality that was observed for small 2D arrays can also be confirmed for the synthesis of large planar arrays.

VI. Conclusions

The synthesis of aperiodic: planar arrays that are very large and have an average spacing many times as large as $\lambda/2$ exhibits some difficulties related to the control of the side lobes. The application of SA to solve the problem of minimizing the number of elements, while keeping the desired side-lobe profile, yields better results than those obtained by other methods proposed in the literature. Satisfactory results can be achieved mainly by the simultaneous optimizations of positions and weight coefficients.

Considerations concerning the quasi-optimality of results and the robustness of the method to the tuning of some parameters have also been presented.

Future work will concern the application of the stochastic synthesis to wide-band sparse arrays. Due to the different definition of the BP, wide-band sparse arrays involve specific problems [9-11] different from those related to the narrow-band case faced in this paper and in the literature. In this context, the development of an optimization method based on SA might be very advantageous.

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From 1987 to 1990, Andrea Trucco was three times a finalist for the Philips Awards for European Young Scientists, and ranked third twice. In 1995, he won the Student Paper Competition organized by the 9th International Symposium on Unmanned Untethered Submersible Technology. In 1997, he won the Student Paper Competition organized by the MTSAEEE Oceans'97 International Conference.

Andrea Trucco is a member of IEEE and IAPR.

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Chapter Activities

On November 3, 1997, the IEEE Oceanic Engineering Society Seattle Chapter and the Marine Technology Society Puget Sound Section co-hosted a social event at the Seattle Aquarium as part of the 28th Annual Underwater Mining Institute. The event was open to the membership of both societies, as well as the participants in the UMI. It provided an opportunity for the local membership to interact with professionals involved in seabed surveying and mapping, seafloor sampling, and environmental impacts of ocean mining. The event was well attended, with over 60 participants.

The 28th Annual Underwater Mining Institute was held in Seattle, WA, from November 2-5, 1997 and was hosted by the Marine Minerals Technology Center, Ocean Basin Division at the University of Hawaii and Sound Ocean Systems, Inc. of Redmond, Washington.

Photo left to right: Charles Morgan, Marine Minerals Technology Center, University of Hawaii, Program Co-chair; Paula Lau, Sound Ocean Systems, Inc., Chair, Seattle Chapter Oceanic Engineering Society; Jerry Wilson, Racal Pelagos Corp., Marine Technology Society Vice-president, Western Region; Ted Brockett, Sound Ocean Systems, Inc., Program Co-Chair and Vice-chair, Puget Sound Section Marine Technology Society; and Michael Cruickshank, Marine Minerals Technology Center, University of Hawaii, Marine Technology Society Vice-president, Technical Affairs.

Oceans '98
IEEE Conference & Exhibition

28 September - 1 October 1998

Call for Papers

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OCEANS'98, organized by the IEEE Oceanic Engineering Society in Nice on the French Riviera celebrates the second venue of the Conference in Europe. This OCEANS will be set under the theme of Engineering for Sustainable Use of the Oceans which is also the main theme for the European Union Marine and Science Technology (MAST) programme. Prospective authors are solicited for papers dealing with new technology concepts, developments and applications which describe advances in science and engineering in the ocean environment.

Proposed technical sessions at the Conference will focus on the following technical topic areas:

Underwater Acoustics
- Detection
- Classification & Localization
- Tomography
- Transducers & Arrays
- Propagation

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- Water current measurements
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- Marine GIS
- Modeling & Simulation
- Data Compression & Data Bases
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Remote Sensing
- Active Instruments
- Passive Instruments
- Air/Sea Interactions
- Physics of Remote Sensing

Signal, Image, Information Processing
- Non Acoustic & Acoustic Image Processing
- Sonar Signal Processing
- Neural Networks
- Localization & Tracking