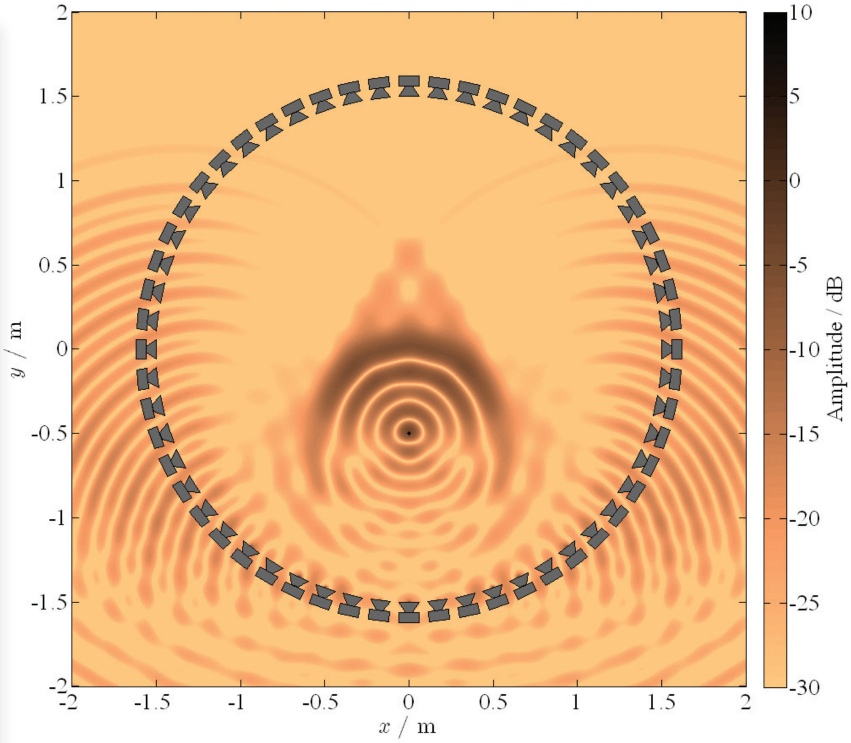
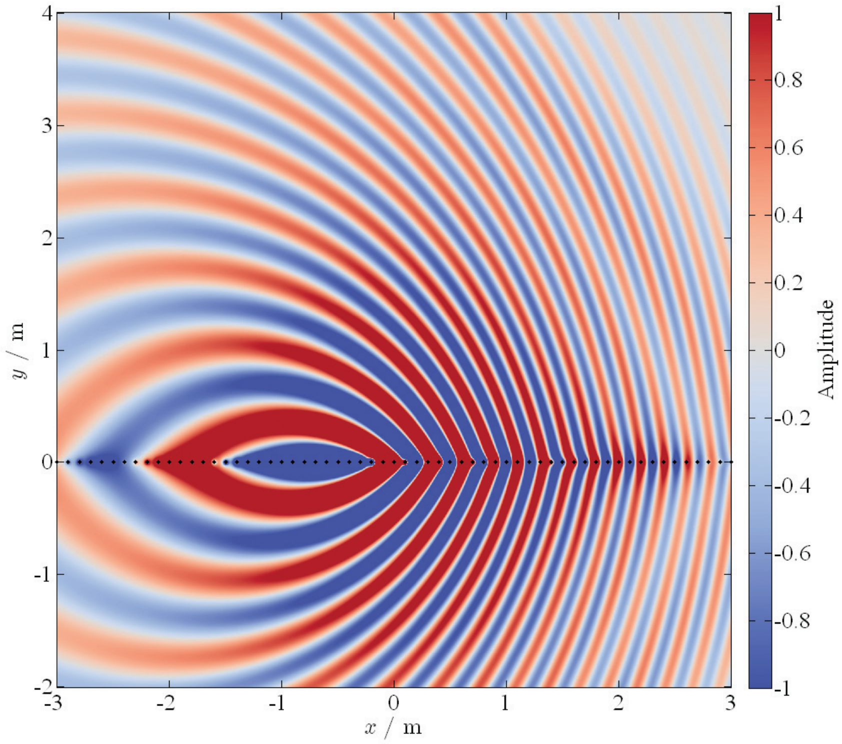
Volume 10 | Issue 2 Spring 2014

Acoustics Today

A publication of the Acoustical Society of America

This Issue





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Bottom figure : *Monochromatic simulation of a moving monopole sound source of 1000 Hz moving parallel to the x–axis at a velocity of 240 m/s. The marks represent the positions of the loudspeakers.*

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Acoustical Society of America

The Acoustical Society of America was founded in 1929 "to increase and diffuse the knowledge of acoustics and to promote its practical applications." Information about the Society can be found on the Internet site: **www.acousticalsociety.org.**

The Society has approximately 7,000 members, distributed worldwide, with over 30% living outside the United States.

Membership includes a variety of benefits, a list of which can be found at the website:
www.acousticalsociety.org/membership/membership_and_benefits.

All members receive online access to the entire contents of the *Journal of Acoustical Society of America* from 1929 to the present. New members are welcome, and several grades of membership, including low rates for students and for persons living in developing countries, are possible. Instructions for applying can be found at the Internet site above.

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From the Editor | Arthur N. Popper

This is the first issue where I solicited all of the articles, and I hope you find them diverse and interesting. And, we have increased focus on making articles more readable by the whole ASA membership rather than specialists. Writing for a more general audience is not particularly easy for those of us in STEM areas, but I have been encouraging authors to provide high quality information, and yet write articles that read more like, for example, an article in *New Yorker* and the *New York Times* science section. While not always achieved, I thank all for working hard to reach this goal.

The issue is rather eclectic in the topics covered including superconductivity, DOSITS.ORG, risk analysis for fish sound exposure (note, I am co-author of this article), sound field synthesis, and the international competition in signal processing. I also invited 2013-2014 ASA President Jim Miller to write about ASA from his perspective and ASA Executive Director Susan Fox to bring us up to date on a number of interesting ASA plans. I will be encouraging Susan and future ASA Presidents to regularly contribute to *Acoustics Today* in order to ensure that members are well aware of what is happening, and what will be happening, in our Society.

I have also started to work on future issues. Promised articles include a discussion of the "evolution" of the flute from prehistoric times, climate change and bioacoustics, microphone arrays, and a special fall issue honoring a truly exceptional colleague on a "big" birthday.

If you have an idea for an article please don't hesitate to contact me. And, I have also put out an invitation to all Technical Committee chairs to suggest articles or potential authors. That invitation is permanent, with the goal of ensuring that material of greatest interest to all members of ASA will be found, over time, in the magazine.

AcousticsToday.org

By now, many of you will have seen the new *Acoustics Today* web site (www.AcousticsToday.org). We are quite proud of the site, and grateful for the many positive comments we have received since it was launched. We have also received a number of suggestions for "tweaks" on the sites and many of these have already been instituted. We are grateful for these suggestions, and we have tried to respond to each person who has taken the time to contact either our web master Dan Farrell or me. We also have ideas for future additions to the site, and these will be forthcoming over time.

I do want to express my thanks to Dan Farrell, the (relatively) new web master for ASA. Dan is responsible for design and implementation of the site. Indeed, Dan was truly creative in his design for the site and all I had to do was make suggestions and "critique" what was done. Dan is great to work with and I know we will all benefit from his imagination and skills in web design for future ASA projects.

Of course, the primary purpose of developing a site was to make *Acoustics Today* easily available to ASA members and to others interested in acoustics. To that end, all issues of the magazine are now on the site, open access, and beautifully displayed in a PDF reader that, appropriately for ASA, includes sounds as one turns the pages. The site search engine will return material from all articles, and so searching for particular topics within *Acoustics Today* is now quite easy.

We are particularly hoping that the site and magazine become a "go to" place for information about acoustics. To help accomplish this, Dan will be working on the "back end" of the site to make sure that it is found by major search engines. We will also, over the next months, be working to improve the metadata on each journal article so that they are more easily found by search engines.

An additional feature of our site is that we can now have multimedia associated with magazine articles. Thus, some of the articles in this issue have URL's for images and sounds, while the pdf on our web page has live links to the material. We are encouraging authors to consider providing multimedia with their articles as appropriate.

Another feature of AcousticsToday.org is an RSS feed of news about a wide range of acoustics.

The site also includes announcements, but these are limited to items of broad appeal (and perhaps with some focus on items that would appeal even beyond ASA).

Books

As I mentioned in the last issue of *Acoustics Today*, we will no longer do announcements about new books. Rather, we will be co-publishing book reviews with our sister publication, the Journal of the Acoustical Society of America. Our purpose here is to ensure that book reviews, which are the product of very hard work by the reviewers, get more widely seen, and that *Acoustics Today* readers are made aware of new publications in our disciplines.

At the same time, we are starting to get new books from our own ASA Press. Starting with this issue, we will have listings and information about each of these books.

Moreover, I think it is important that we do continue to at least list new books by ASA members and so we will start to mention books by title. If any member of ASA publishes a new book or monograph please submit the title and other publication information (including a URL) to me and we will include that information in *Acoustics Today*.

Cartoons

Acoustics Today is looking for members of ASA who like to create cartoons about acoustics and acoustics-related topics (e.g., anything that would fit within the breadth of ASA) and who would like to be published cartoonists. The goal is to use cartoons to fill otherwise empty space in the magazine at the end of articles or other otherwise blank space. The cartoonist would get full credit for her/his work. No pay is involved, but the cartoons would be distributed widely and also be in our web and print versions of the magazine.

If you want to contribute a single cartoon or perhaps become a regular "*Acoustics Today*" cartoonist, please contact (apopper@umd.edu) with a sample of your work and/or your ideas. The only "criteria" are that the cartoons: have some kind of acoustics-related focus; be funny; be no more than a page wide and a few inches high (or one panel); and not be "off-color."

Acoustics Today Interns

In the winter 2014 issue we talked about having *Acoustics Today* Interns (ATI). These are to be graduate students or people within three years of their advanced terminal degree who will work with the magazine in special capacities. The goal is for the ATI to learn something about working on a magazine and about publishing, while at the same time let them contribute to some specific aspect of the magazine.

I am pleased to announce that our first ATI is Dr. Laura Kloepper. Laura introduces herself on page 64 of this issue and we are really excited about having her work with us. As you will learn, Laura has strong scientific interests in echolocation, while also having a passion for education and outreach. Her primary role as an ATI will be to help move *Acoustics Today* into social media, with the goal of helping the magazine be better known, and increase its, and ASA's, influence in the field of acoustics.

I am hoping that Laura will be the first of a cadre of ATIs. If you are interested in becoming an ATI, please drop me a note and I'll send you application material. While we had originally given a May 1 application date, we would be willing to consider applications at any time. You can also find more information about becoming an ATI at AcousticsToday.org.

Follow us on Twitter @acousticsorg

Input

Finally, we have already benefitted from input about our web site from ASA members. We continue to ask for your ideas, and that goes for the magazine as well. If you have ideas for articles (or want to write an article), suggestions for new sections, letters to the editor, or anything else, please don't hesitate to contact me. I look forward to hearing from you.

Arthur N. Popper

I would like to thank *Acoustics Today* editor Arthur Popper for the opportunity to share some thoughts about the ASA and the challenges the society faces. The Providence meeting of the ASA has just wrapped up and things are starting to settle down. My term as President has ended and my very good friend Judy Dubno has taken the reins. I hope that a President's (or a Past President's) column will be a regular feature in *Acoustics Today*. In this piece, I would like to discuss the tension between tradition and change. Connecticut native, political scientist and breast cancer activist Pauline R. Kezer wrote that "Continuity gives us roots; change gives us branches, letting us stretch and grow and reach new heights." By the end of the column, I hope I convince you that 1) ASA is a successful, well run and financially-solvent scientific society, 2) this success is due in no small part to the fine-tuned collaboration between the dedicated volunteer members and the paid, professional staff of the society, and 3) challenges lie ahead that may require ASA to do some things differently than we have done in the previous 85 years.

The Acoustical Society of America is in great shape, measured both by reputation and financially. As we state on our web site, the ASA is the "premier international scientific society in acoustics, dedicated to increasing and diffusing the knowledge of acoustics and its practical applications." I think you agree with that statement given your membership in the ASA. On the financial front, Treasurer David Feit reports that the society has net assets of more than $16M. In addition to those members who have made generous gifts to the Society over the years, we need to also thank the stewardship of David, recently-retired Executive Director Charles Schmid, the Acoustical Society Foundation's past and present leadership including Mahlon Burkhard, Anthony Atchley, and Carl Rosenberg and all those members who have served as officers and on the Executive Council. As I discuss below, the *Journal of Acoustical Society of America* generates most of the income and JASA has been very ably managed by Editor-in-Chief Allan Pierce.

But while we should be congratulating ourselves, there are storm clouds on the horizon. Open Access, the unrestricted online access to scientific journals, is, at least, a threat to the society's business model. This business model is very easy to explain. JASA, from its institutional subscribers, mainly university libraries, generates about $1M each year in net income. These funds are used to support the mission of the society mentioned above including acoustics education, enhancing our meetings while keeping them affordable, especially for students, and supporting the very important work the ASA does in Standards. In addition to the risks posed by Open Access to the Society's business model, our total membership has, at best, been flat at approximately 7,000 for the last few years.

Right now, the *Journal of Acoustical Society of America* is not an Open Access journal. However, there is much discussion about Green, Gold, Gold-Hybrid and other Open Access variants. Green Open Access is the label given to the process of authors uploading articles to Open Access repositories. Gold Open Access refers to online journals that are open to the public. Gold-hybrid is used to refer to journals in which only papers whose authors or their institutions have paid an Open Access publishing fee are available without charge. Whatever we decide, I suggest that we keep in mind the meaning of the word member. Currently, Students, Associates, Corresponding Electronic Associates, Members, and Fellows can get access to the Journal as well as many other benefits for varying fees. Other societies such as the American Geophysical Union have separated journal access and membership. We need to have a dialogue on what kind of society we want to have and what a member of ASA means in the future. In other words, what will be the relationship between the member and Society in terms of journal and standards access, meeting costs, and other services? We have now what might be termed a "full service" society. Is there another model for a scientific society in which benefits are separately delivered? One of the ideas I have been discussing with many of you is a new journal dedicated to applied acoustics. The audience for this applied acoustics journal would be primarily practitioners but also academics. If this journal were to be established, what would be its business model?

Today, the business of publishing science is like the wild west of the 1800's. Predatory publishers, fully Open Access, are luring authors away from reputable journals. These publishers have no goals except to extract the most money from authors; and these proceeds are not supporting a comparable mission like the ASA's. There is even the "Beall's List of Predatory Publishers"[1] which warns authors of substandard journals. One of journals on that list recently accepted a paper composed purely of computer-generated nonsense.

This segues naturally into a discussion of change. The theme of my term as President could be "change." After 23 years of effective leadership, Charles Schmid retired as Executive Director (ED) of the Society. Following a national search by a committee chaired by former President Mardi Hastings, Susan Fox was selected by the Society as our new ED. Also, Editor-in-Chief (EIC) Allan Pierce announced his retirement after 14 years in that position, and a search for an EIC is underway by a committee chaired by Christy Holland. That search should be concluded in a few weeks. The Society also hired a Web Developer as a new staff member, Dan Farrell, based on the recommendations of a search committee chaired by incoming President Judy Dubno. Arthur Popper took over as Editor of *Acoustics Today* this past January 1 after founding Editor Dick Stern passed away. Brenda Lonsbury-Martin chaired the AT Editor Search Committee. These search committees did, and are doing, a fine job of finding the best possible candidates for these crucial positions. Thanks to the committee chairs and their members for all their hard work.

So, we have a financially healthy ASA and a legion of new and energetic people who believe strongly in the mission of the Society, but storm clouds including Open Access and the ramifications of a flat membership are ahead of us. In addition, the Society's governance is a worthy issue for debate. Let me describe how the Society is managed right now. The Acoustical Society of America is a 501(c)(3) not-for-profit organization incorporated in the State of New York. ASA is governed by its Bylaws which are available online[2]. The most important section of the bylaws describes the role of the Executive Council:

> *The affairs of the Society shall be managed by an Executive Council which shall consist of the President, the President-Elect, the Vice President, the Vice President-Elect, the Treasurer, the Editor-in-Chief, the Executive Director, the Standards Director, the immediate past President and immediate past Vice President, and six members elected from the Members and Fellows of the Society. The Treasurer, the Editor-in-Chief, the Executive Director, and the Standards Director shall be members of the Executive Council without vote.*

The President chairs the Executive Council and serves as the Chief Executive Officer (CEO) of the Society. The Executive Director manages the ASA staff and is in charge of the offices of the ASA, among other duties. The President and ED bring the best of both worlds to management of the Society - a CEO democratically elected by the membership each year and a professional ED who has the "corporate memory" and the skills to implement the instructions of the Executive Council. The President's term starts after the spring meeting and ends on the Friday of the spring meeting of the following year. The Executive Director serves a three-year term renewable if both the ED and EC agree. Judy Dubno's term as President started on May 9. Christy Holland was elected as President and has started her term as President-Elect. You can see in the above description of the EC that it includes six elected members from the Members and Fellows. Two of these members are elected each year. Michael Bailey and Christine Shadle were elected to join the EC after the Providence meeting. Paul Schomer serves as the Standards Director, Allan Pierce as the Editor-in-Chief, and David Feit as Treasurer.

The staff of the Acoustical Society of America is one of the reasons we are in such a strong position. In Melville, Long Island, New York, Office Manager Elaine Moran works with the staff of Jolene Ehl, Kelly Quigley, and Lou Vollmer, and Web Developer Dan Farrell. The Standards Office, also in Melville, includes Standards Manager Susan Blaeser, Ewa Koguciuk, and Caryn Mennigke. In West Barnstable, Massachusetts, on Cape Cod, the ASA Publications Office includes Publications Manager Mary Guillemette and Helen Wall Murray. Saana McDaniel assists in the production of JASA Express Letters.

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[1] *"Beall's List of Predatory Publishers", http://scholarlyoa.com/2012/12/06/bealls-list-of-predatory-publishers-2013/*

[2] *http://acousticalsociety.org/sites/default/files/docs/bylaws.pdf*

In many respects, the Technical Council (TC) is as important to the members of the ASA as the EC. The members of each TC are elected by their respective Technical Committees. The bylaws described the Technical Council as follows:

The Technical Council shall consist of the Chairs of the Technical Committees, the Vice President, the Vice President-Elect, and as ex officio members without vote, the immediate past Vice President, the Chairs of technical groups appointed by the President, and the other officers of the Society. The Technical Council shall be responsible for coordinating the policies and activities of the Technical Committees and technical groups, and advising the Executive Council by formal resolutions on matters of policy concerning technical considerations. The Technical Council shall be presided over by the Vice President, or in his or her absence, by the Vice President-Elect.

Barbara Shinn-Cunningham took over as Vice President as Peter Dahl completed his term. Lily Wang was elected Vice President and she becomes Vice President-Elect. The Technical Council is the direct line from the members and the Society's leadership.

As you know, the Technical Committee meetings at each ASA meeting are similar to New England town meetings. You may be familiar with Norman Rockwell's painting entitled "Freedom of Speech."[3] Like the ideal represented in that painting, anyone can speak at a Technical Committee meeting. Often, the membership is asked about their opinion on a potential change to our Society's operations. If you have attended any Technical Committee meetings lately, you know what I mean. When members of a Technical Committee have something to say, that information, if appropriate, is passed to the Technical Council and then to the Executive Council for consideration. And, of course, all of the officers of the society, both elected and appointed, are glad to hear directly from anyone about a new idea, a concern, or a suggestion for improving the ASA. Many of our members are very forthright in letting the leadership know directly what they are thinking.

This bicameral governance structure with strong input from the membership together with highly qualified and hard working staff has enabled ASA to reach its status as the premier scientific society in acoustics and with its presently strong financial position. The renewed leadership from the membership on the Executive Council along with a new Executive Director is up to the challenges faced by the society. But how best should we address these challenges? At the recommendation of Executive Director Susan Fox, the ASA has engaged the services of consultants Cate Bower and Marybeth Fidler on scientific society practices and governance. This process will likely take 18 months to complete. They have worked with a number of scientific societies including the American Geophysical Union and the American Physical Society.

Michael McFadden is a past President of the American Geophysical Union. I wrote to him about his appraisal of Cate Bower and Marybeth Fidler. He replied almost immediately with a very positive recommendation. A portion of his reply is as follows:

We are now into our fourth year of exercising the new AGU governance structure and strategic plan (the details of both you can find on the AGU website)[4]. … As with any transformation, the way it works out in practice is not exactly as was originally envisioned. However, the governance principles, governance tools, and strategic plan that Cate and Marybeth helped us develop have enabled us to successfully navigate the twists, turns, and bumps along the way. As an organization, we have a new confidence in our ability to serve our members better and a clarity about what's critical to our mission.

We have started the discussions with Cate and Marybeth. The Executive Council continued the conversation with them in Providence. It is likely that the ASA will convene a "summit" with their help outside of the regular meeting schedule in early 2015. Soon, President Judy Dubno will be asking some of you to help the Society study and perhaps revise its business model to address the challenges of Open Access, find ways of increasing membership and the scope of the Society, and look closely at governance. Everything about the ASA that I described in this column can be changed if we, as a Society, decide to change. Nothing is written in stone as they say. But, I'll think you agree with me that ASA has

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[3] *http://en.wikipedia.org/wiki/Freedom_of_Speech_(painting)*

[4] *http://leadership.agu.org/*

Carrying the Torch

"The Acoustical Society of America is in a state of evolution. We don't know what the form of the Society will be or what the subject matter of the papers will be at the Hundredth Anniversary Celebration. We wish that we could look into the crystal ball. There is a crystal ball up here [pointing toward the movie camera], but it is only half a crystal ball, it's a one-way affair, posterity is able to look at us, but we can't look back through that lens and see you on the other side. I wish we could. I know that we would find you as strange and quaint and amusing, in your ways, different from us as you find us as you look at our faces on the screen. However, you are our descendants, you carry the torch; and with this salute to posterity, I declare this meeting, our Twenty-Fifth Celebration, adjourned."

Hallowell Davis
June 1954, New York City

As I pick up the torch as ASA's newest Executive Director, I do so with respect and admiration for the members and leaders of this eminent Society, past and present. From the solid stewardship of the founding visionaries to the conscientious commitment of present day leaders and members, ASA stands apart. What makes ASA unique among professional societies is our embodiment of a set of core values evident since our founding in 1929.

I will elaborate on these values below, but first allow me to discuss what drew me to this position. I come to you as a professional association executive. What that means is that I've built my career managing and co-leading professional membership organizations with the goal of helping them to become transparent, nimble, and accountable both to members and to society-at-large. I felt an immediate attraction to ASA, at first because I find the field of acoustics endlessly fascinating then, after digging deeper into the Society's records and reports – especially the award citations – I fell in love with ASA's culture and values.

The warmth and humanity in the citations told me this is a special place. The citations speak not just to an individual's impressive professional accomplishments. They go deeper to include families, hobbies, wit and passions, providing a rounded, humane, and an appreciative view of the individual. Every award citation contained as much respect for the heart as for the head. After reading a series of these citations, I knew I found my professional home.

Core Values

Throughout the interview process, and carried forward through the Montreal and San Francisco meetings, several ASA core values became clear to me. I saw four that stood out the most:

Collegiality – Members exhibit great respect for each other and for the breadth of disciplines regardless of specialty. We pride ourselves on being a big tent that enfolds dozens of disciplines, both theoretical and applied. In reviewing Wallace Waterfall's oral history this is a value embraced from the Society's very beginning:

> *"Well, you can thank Harvey Fletcher for this,"* Waterfall said, *"because when we first started talking about a society it was to be a society of architectural acoustical engineers. He said, why don't you expand, why don't you increase the scope. I think you will benefit your architectural acoustical engineers too because they are much interested in speech and hearing, that has to be a part of it, you'll get in a wider circle of people without diluting the thing."*

This wider circle, to my mind, strengthens not just the organization but the scientific enterprise. The prescience on the part of Fletcher, Waterfall, and others helped establish bedrock collegiality into our culture. This is especially important because as science becomes interdisciplinary and synthesized, the value of big tent Societies such as ASA expands and pushes the field forward.

Collaboration – A high degree of collegiality inevitably yields a higher degree of collaboration. ASA members do not hesitate to get the work done and to tackle goals regardless of size and ambition by working together in diverse groups large and small. This enduring attitude of "let's roll up our shirtsleeves and get this job done" is what elevates ASA's stature as the premier international scientific society in acoustics. The amount of intellectual energy and enthusiasm in our ranks is some of the highest I've ever seen in a professional society. It's a joy to experience and observe, and best yet, to be a part of something bigger than ourselves.

Commitment – ASA members do what they say and say what they do. The commitment to the Society and the profession is profound, demonstrated by the capacity to mount year after year two large meetings just six months apart. It's this commitment that results in a large number of committees, task forces, formal and informal work groups all dedicated to advancing acoustics and the work of ASA.

Conscientiousness – similar to commitment, conscientiousness about the importance of the work at hand and the responsibility of carrying it out underscores the depth of engagement throughout ASA. Our work embodies integrity, with a focus on doing the right thing for the greater good.

Challenges

These values undergird ASA's core strengths that include a competent and equally committed staff, fiscal stability, global credibility, and longevity. This is a solid foundation from which to build our future. It gives us the stability needed to address some of the challenges we will and are encountering. According to the American Society of Association Executives (ASAE), chief among them are:

Increased competition and atomization: Several organizations serve as prime competitors to ASA, such as the Audio Engineering Society and the Institute of Electrical and Electronics Engineers, among many others. ASA risks becoming an incubator for spin off organizations, or losing members to related associations. If realized, this risk will diminish the robust nature of our big tent.

Increased demand for member time: All of us place high value on our time, especially when demands for it keep multiplying. Where we spend our time and how become more critical and often tough decisions enter the mix. Will ASA continue to be a factor? If so, in what manner and can the current level of activities be sustained as newer generations enter the fold?

Changing expectations: More and more often society members, not just with ASA but across the board, expect a high return on investment for time spent, fees paid, and services received. As a consequence, ASA needs to constantly assess the value we provide our members and to be aware of ways to increase the value so that we remain relevant. Professionally administered member surveys, strategic visioning processes, and nimble responsiveness will help us identify and counter changing expectations with appropriate responsiveness.

Changing technology: The fastest change occurring today is the pace of change itself, and that especially applies to technology. Keeping up with the platforms, the delivery systems, the fluid and disruptive technological innovations are crucial for our future. Which platforms should we adopt? Which need to be abandoned? How far ahead of the curve do we need to be and still be cost-effective?

In addition to these fundamental challenges we face tactical challenges of a serious nature.

Open Access: our primary scholarly journal, the *Journal of the Acoustical Society of America*, is fundamental to all that we aspire, intellectually and economically. How will the drive toward open access affect the journal? How do we mitigate the inevitable loss in revenues to the Society when the journal becomes accessible without subscription fees? This, to my mind, is our most pressing concern.

Outdated Systems and Processes: It's not just our technology that needs updating. We need to examine all of our systems and processes with an eye toward efficiency and economies. This is especially important as demand on member time rises. No one has the patience or certainly the will to tolerate unnecessary duplication of effort or red tape.

Aged Web Presence: Fortunately, this is a tactical challenge with a relatively easy fix. Within two weeks of my hiring we hired Dan Farrell as our full-time web developer. He is just the antidote to our weak and vastly outdated digital presence. While our Google PageRank is an impressive 7 on a 0-10 scale, the optics and back end of our web site needs a great deal of work, to say nothing of our need to address social media platforms. Dan's just the professional we need at this particular helm. You can expect to see exciting results of his work soon, particularly with the new Acoustics Today.org.

This will give you a preview of a more vibrant and exciting presence for ASA on the web.

Bifurcated Demographics: ASA is impressive in our work with, and attention to, students. This is an investment well worth the time and effort. Nonetheless, the demographics show a stark bifurcation between the distribution of younger and older members. We appear to be missing the mid-career acousticians, a problem that many other societies also face. Why is that? Are Millennials simply not joiners? Is there anything we can do to attract them in and what do we need to do to retain students once they become early career professionals?

International Partnerships: Fully a third of our members are international. Science and society alike recognize the importance of developing international partnerships in furtherance of the research, applied acoustics, and development of the field. This requires a thoughtful approach on how best to deploy finite resources to gain as much impact from the partnerships and to strengthen our presence in those areas where the field is growing fastest, such as China, which accounts for 11% of the manuscripts submitted to JASA.

Executive Director Transition: Having a new Executive Director on board after Charles Schmid's laudatory 23 years in this position is a significant change for ASA. Opportunities abound, but it is also a challenge for the Society. I will spend a good part of the first year – and every year – listening carefully to members, leaders, staff and stakeholders in order to fully understand the wants and needs of the Society and the profession it serves. This regular column is a first effort of many that I will use to open communication channels. You are always welcome to email me, call, or invite me to your meetings. I welcome all efforts that put me in touch with all members at all levels of ASA. Email me at sfox@aip.org or call the direct line to my office at 516-576-2215.

Grand Challenge: Finally, I come to ASA's grand challenge. We must maintain and enhance our relevance as a professional society. Our work and actions must resonate, reflecting authenticity and the value ASA brings to our members and the profession. We must continue to strive for modernity. Last and perhaps most important, we need continuity with the past as we move forward into the future. Continuity insures smooth operations and results from a clear focus on the core values established 85 years ago that remain relevant today.

Our Way Forward

One of my favorite Saul Steinberg *New Yorker* covers depicts a tiny man rocketing forward atop a jet powered "Yes" about to hit a solid wall of "BUT," his shock expressed by his fedora 10 ft. above his head. How do we move forward without slamming into an unexpected BUT? The answer is, through proper planning. The Executive Council recently approved our bringing on board two well-respected consultants to help ASA develop and execute a strategic plan. Cate Bower and Marybeth Fidler of Cygnet Strategy, LLC have worked with dozens of scientific societies, helping them develop a clear, collaboratively developed, vision, mission, purpose and goals. Most notably they worked with the leadership of the American Geophysical Union (AGU) in developing their new direction and purpose when they experienced a similar transition in Executive Directors.

We are very early in the process; in fact we are in the "plan for the plan" phase of work which will take about 18 months to fully complete. You can be assured that this visioning will be developed transparently and cooperatively with all of ASA's stakeholders and beyond. We will conduct a professionally administered member needs assessment, a business model analysis and once we have a solid set of data and feedback, we will put all of that to use in developing the plan for our future. We will be communicating with you about this at each stage of the process and asking for your input in a number of ways so be alert for more information, on the web and here in Acoustics Today, as well as other means as appropriate.

Once we have the framework and clarity of purpose and goals in place we will be in a position to develop or enhance our governance structure so that it is based on a foundation of knowledge, trust, nimbleness and clear role delineation.

It's an exciting time to be engaged with the work of ASA. ASA is vibrant, always in a state of evolution. Together we carry the torch so that when we celebrate our 100^{th} anniversary in 2029 we will do so knowing that as we salute the past we succeeded in embracing the future.

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Letter to the Editor

Robert Dobie's letter regarding Salt & Lichtenhan
(*Acoustics Today,* Winter 2014)

Arguing that inaudible infrasound from wind turbines (WTs) might be harmful, Salt and Lichtenhan list five possible mechanisms that may lead to harm, but without mentioning the sound levels in the experiments they cite:

1. Biasing of audible sounds: the cited study used 50 Hz tones (≥ 84 dB SPL).
2. Endolymphatic hydrops: one cited study used ≥ 50 Hz tones (≥ 95 dB); the other used 30 Hz (120 dB).
3. Excitation of outer hair cell afferents: neither cited paper reported sound-evoked responses of these afferents.
4. Exacerbation of noise-induced hearing loss: the cited study used 30 Hz tones (100 dB).
5. Infrasound stimulation of vestibular sense organs: no studies were cited, but the VEMP test is mentioned. This test requires loud sounds (typically 500 Hz, > 100 dB).

All of these sounds would be audible and at least moderately loud (> 60 phons). In addition, their levels are at least 30 dB greater than those measured at the same frequencies at residential distances from WTs (O'Neal et al., 2011). Without evidence of effects at more realistic sound levels, the relevance of these mechanisms to WT sound is unsupported, as is the authors' statement that "we know this [lack of effect of inaudibleinfrasound from WTs] is highly unlikely."

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O'Neal RD, Hellweg RD, Lampeter RM 2011. Low frequency noise and infrasound from wind turbines. Noise Control Engineering Journal 59 (2): 135 – 157.

Commentary | James H. Miller

Continued from page 10

performed its mission very well since 1929. "Best practices" at one society may or may not be appropriate for the ASA. I hope that Marybeth and Cate challenge us, prompt us to think outside of the box, and share the experiences they have had with other scientific societies. ASA has very strong roots and meeting these challenges I described will require some change. Successfully branching out into new areas, reaching new heights, and "diffusing the knowledge of acoustics and its practical applications" will need your energy, your ideas, and your collegiality. When President Dubno calls for help later this year, I hope you will respond affirmatively.

As I leave the office of President of ASA, I would like to express my gratitude to The University of Rhode Island and the NATO Centre for Maritime Research and Experimentation in La Spezia, Italy. These organizations were most supportive of my work as President. While I have been President, I have had the additional duty as Co-Chair of the Providence ASA meeting. Co-Chair Gopu Potty and Meeting Administrator Gail Paolino, with much help from our local committee, shouldered most of the load in getting this meeting organized. I would like to thank so many people in the ASA for their encouragement and guidance. Former Executive Director Charles Schmid was so kind with his help and vision. Past-President Dave Bradley was a font of wisdom and I now am very thankful I followed most of his advice. Then President-Elect Judy Dubno said something inspirational in the Officers and Managers Meeting in Melville a few weeks ago. She said she would do almost anything for the Society. I couldn't agree more. Executive Director Susan Fox and I have worked closely since she joined the Society. She has brought a new point of view and skills in scientific society management and I have learned much from her. I look forward to working with, and learning more from, Susan for many years. Finally, I would like to thank Elaine Moran for her advice over these past 11 months. As all Presidents know after their year of service, she is an indispensible asset.

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Figure 1b: *Photo of loudspeaker system used for research on sound field synthesis. Pictured is a 64-channel rectangular array at Signal Theory and Digital Signal Processing Group, University of Rostock*

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Sound Field Synthesis for Audio Presentation

The use of loudspeaker arrays for audio presentation offers possibilities that go beyond conventional methods like Stereophony.

In this article, we describe the use of loudspeaker arrays for sound field synthesis with a focus on the presentation of audio content to human listeners. Arrays of sensors and actuators have played an important role in various applications as powerful technologies that create or capture wave fields for many decades (van Trees, 2002). In acoustics, the mathematical and system theoretical foundations of sensor and transducer arrays are closely related due to the reciprocity principle of the wave equation (Morse and Feshbach, 1981). The latter states that sources and measurement points in a sound field can be interchanged. Beamforming techniques for microphone arrays are deployed on a large scale in commercial applications (van Veen and Buckley, 1988). Similarly, arrays of elementary sources are standard in radio transmission (van Trees, 2002), underwater acoustics (Lynch et al., 1985), and ultrasonic applications (Pajek and Hynynen, 2012). When the elements of such an array are driven with signals that differ only with respect to their timing then one speaks of a phased array (Pajek and Hynynen, 2012; Smith et al., 2013). Phased arrays have become extremely popular due to their simplicity.

We define sound field synthesis as the problem of driving a given ensemble of elementary sound sources such that the superposition of their emitted individual sound fields constitutes a common sound field with given desired properties over an extended area. As discussed below, phased arrays in their simplest form are not suitable for this application and dedicated methods are required.

The way electroacoustic transducer arrays are driven depends essentially on what or who receives the synthesized field. Many applications of, for example, phased arrays aim at the maximization of energy that occurs at a specific location or that is radiated in a specific direction while aspects like spectral balance and time-domain properties of the resulting field are only secondary (Pajek and Hynynen, 2012; Smith et al., 2013). The human auditory system processes and perceives sound very differently from systems that process microphone signals (Blauert, 1997; Fastl and Zwicker, 2007). Human perception can be very sensitive towards details in the signals that microphone-based systems might not extract and vice versa. Among other things, high fidelity audio presentation requires systems with a large bandwidth (approximately 30 Hz – 16,000 Hz, which corresponds to approximately 9 octaves) and time domain properties that preserve the transients (e.g. in a speech or music signal). Obviously, the extensive effort of deploying an array of loudspeakers for audio representation only seems reasonable if highest fidelity can be achieved given that Stereophony (stereos: Greek firm, solid; fone: Greek sound, tone, voice) and its relatives achieve excellent results in many situations with just a handful of loudspeakers (Toole, 2008).

At first glance, we might aim at perfect perception by synthesizing an exact physical copy of a given (natural) target sound field. Creating such a system obviously requires a large number of loudspeakers. Though, auditory perception is governed by much more than just the acoustic signals that arrive at the ears; the accompanying visual impression and the expectations of the listener can play a major role (Warren, 2008). As an example, a cathedral will not sound the same when its interior sound field is recreated in a domestic living room simply because the user is aware in what venue they are (Werner et al., 2013). We will therefore have to expect certain compromises when creating a virtual reality system. But we still keep the idea of recreating a natural sound field as a goal due to the lack of more holistic concepts.

The most obvious perception that we want to recreate is appropriate spatial auditory localization of the sound sources a given scene is composed of. The second most important auditory attribute to recreate is the perceived timbre, which is much harder to grasp and control. On the technical side only the frequency response of a system can be specified. As Toole (2008) puts it: "Frequency response is the single most important aspect of any audio device. If it is wrong, nothing else matters." Actually his use of the term "frequency response" encompasses also perceptual aspects of timbre, like distinction of sounds (Pratt and Doak, 1976) or identity and nature of sound sources (Letowski, 1989).

Why Sound Field Synthesis?

The undoubtedly most wide-spread spatial audio presentation method is Stereophony where typically pairs of loudspeakers are driven with signals that differ only with respect to their amplitudes and their relative timing. Obviously, sound field synthesis follows a strategy that is very different from that of Stereophony. So why not build on top of the latter as it has been very successful?

Remarkably, methods like Stereophony can evoke a very natural perception although the physical sound fields that they create can differ fundamentally from the "natural" equivalent. Extensive psychoacoustical investigations revealed that all spatial audio presentation methods that employ a low number of loudspeakers, say, between 2 and 5, trigger a psychoacoustical mechanism termed summing localization (Warncke, 1941), which had later been extended to the association theory (Theile, 1980). These two concepts refer to the circumstance that the auditory system subconsciously detects the elementary coherent sound sources – i.e., the loudspeakers – and the resulting auditory event is formed as a sum (or average) of the elementary sources. In simple words, if we are facing two loudspeakers that emit identical signals then we may hear one sound source in between the two active loudspeakers (which we interpret as a sum or the average of the two actual sources, i.e., the loudspeakers). This single perceived auditory event is referred to as phantom source (Theile, 1980; Blauert, 1997).

Whether and where we perceive a phantom source depends heavily on the location of the loudspeakers relative to the listener and on the time and level differences between the (coherent) loudspeaker signals arriving at the listener's ears. All these parameters depend heavily on the listener's location. Thus if it is possible to evoke a given desired perception in one listening location (a.k.a. sweet spot) then it is in general not possible to achieve the same or a different but still plausible perception in another location. Note that large conventional audio presentation systems like the one described by Long (2008) primarily address the delivery of the information embedded in the source signals rather than creating a spatial scene and are therefore no alternatives.

At the current state of knowledge it is not possible to achieve a large sweet spot using conventional methods because all translations of the listener position generally result in changes in the relative timing and amplitudes of the loudspeaker signals. Interestingly, large venues like cinemas still employ Stereophony-based approaches relatively successfully. This is partly because the visual impression from viewing the motion picture often governs the spatial auditory one (Holman, 2010). Closing the eyes during a movie screening and listening to the spatial composition of the scene often reveals the spatial distortions that occur when not sitting in the center of the room. The focus lies on effects rather than accurate localization of individual sounds. Additionally, movie sound tracks are created such that they carefully avoid the limitations of the employed loudspeaker systems in the well-defined and standardized acoustic environment of a cinema.

Figure 1a: *Photo of loudspeaker system used for research on sound field synthesis. Pictured is a 56-channel circular array at Quality and Usability Lab, TU Berlin*

In conclusion, satisfying an extended listening area with predictable and plausible perception requires approaches different than those based on Stereophony. Sound field synthesis tries to physically recreate natural sound fields so that human hearing mechanisms are addressed.

A Brief History

The cornerstone of modern sound field synthesis theory was laid by Jessel (1973), whose work is based on some of the most fundamental integral equations in the physics of wave fields such as the Rayleigh Integrals or the Kirchhoff-Helmholtz Integral. Having been ahead of his time, Jessel did not have the means of creating a practical implementation of his work. Concurrent with Jessel, Gerzon (1973) worked with momentum on an approach that he termed Ambisonics (ambo: Greek both together; sonare: Lat. to sound). Gerzon's work used a much simpler and more intuitive theory compared to Jessel's, but Gerzon was soon able to present analog implementations based on a small number of microphones and loudspeakers.

The next big push of sound field synthesis started in the late 1980s with the work of Berkhout (1988) and coworkers (Berkhout et al., 1993) who created an approach that they termed Wave Field Synthesis. Having a background in seismology, Berkhout did not seem to have been aware of Jessel's work but he followed very similar concepts. His ideas were pursued over more than two decades and the team was able to present a ground breaking realtime implementation in 1992 featuring as many as 160 loudspeakers and dedicated digital signal processing hardware (de Vries, 2009).

The comprehensive availability of personal computing and suitable audio hardware led to the latest practical and theoretical push of sound field synthesis from the mid 2000s on resulting in more than 200 commercial and research systems worldwide. The largest one comprises more than 832 independent channels on a quasi-rectangular contour with a circumference of 86 m and fills an entire lecture hall at the University of Technology Berlin, Germany, with sound (de Vries, 2009). Refer to Figure 1a and Figure 1b for photographs of selected systems.

Especially the advancements during the last couple of years led to a mature theoretical and practical understanding of sound field synthesis and the next logical chapter is actively worked on in the audio community: The psychoacoustical study and perceptual evaluation of synthetic sound fields (Spors et al., 2013).

Theory

Several ways of deriving an analytic solution for the loudspeaker driving signals in sound field synthesis have been presented in the literature (Berkhout, 1993; Poletti, 2005; Spors et al. 2008; Fazi et al., 2008; Zotter et al., 2009). All these solutions start with the assumption of a continuous distribution of elementary sound sources (a.k.a. secondary sources) that encloses the listening area on a boundary surface. Starting with a continuous distribution has the advantage that concepts can be developed for which a perfect solution exists. Other (imperfect) solutions can then be treated as a degenerated problem based on the perfect ones.

An obvious imperfection of practical systems is the circumstance that a continuous distribution of secondary sources is impossible to implement. We always have to use a finite number of discrete sources. Due to technical constraints it is often desired to reduce the two-dimensional boundary surface to a one-dimensional enclosing contour, preferably in a horizontal plane leveled with the listeners' ears.

The imperfections of real-world systems lead to artifacts in the generated sound field which can be described analytically or can be measured for an implemented system. However, they are not always perceptible by human listeners and can thus be tolerated. For convenience, we postpone the discussion of these imperfections and their perception and start the discussion with the ideal case.

Assuming a simply connected enclosing surface $\partial\Omega$ of secondary sources that encloses our target volume Ω, we can formulate the *synthesis equation* in the temporal-frequency domain as

$$S(\boldsymbol{x},\omega) = \oint_{\partial\Omega} D(\boldsymbol{x}_0,\omega)G(\boldsymbol{x}-\boldsymbol{x}_0,\omega)\mathrm{dA}(\mathbf{x}_0)$$

$D(x_0, \omega)$ represents the driving signal of the secondary source located at point $x_0 \in \partial\Omega$ and $G(x-x_0, \omega)$ represents the spatio-temporal transfer function of that secondary source. We use the letter G because this function can be interpreted as a Green's function. The product $D(x_0, \omega)\, G(x-x_0, \omega)$ describes the sound field that is evoked by the considered secondary source. Integration over the entire surface $\partial\Omega$ yields the synthesized sound field $S(x, \omega)$ by summation of all contributions from the elementary sound sources. Usually, one is not interested in what sound field is created when the secondary source contour is driven in a specific way. One would rather want to know how to drive the system that a specific desired sound field arises, i.e., we want to dictate $S(x, \omega)$ and solve (1) for $D(x_0, \omega)$. It can indeed be shown that a perfect solution exists when the boundary $\partial\Omega$ encloses the target volume and is simply connected (Poletti, 2005; Zotter et al. 2009; Ahrens, 2012; Zotter et al. 2013).

There are two different fundamental approaches for this task: 1) an implicit solution, i.e., we analyze the situation from a physical point of view and exploit our knowledge on the relation between the sound field on the boundary $\partial\Omega$ and the sound field inside the target volume Ω to derive $D(x_0, \omega)$, and 2) we manipulate (1) mathematically so that we are able to solve it explicitly for $D(x_0, \omega)$. Both approaches are outlined in the following two subsections.

Implicit Solution

There are several ways of deriving an implicit solution to equation (1) leading to identical results, all of which start from well-known integral representations of sound fields (Berkhout, 1993; Spors et al. 2008). Here, we chose to derive the implicit solution via the Rayleigh I Integral. This derivation appears hands-on at first sight but rigorous treatments exist that prove the appropriateness of the applied approximations (Zotter and Spors, 2013).

The Rayleigh I Integral describes the sound field $P(x,\omega)$ in a target half-space Ω that is bounded by a planar surface $\partial\Omega$ and is given by (Williams, 1999).

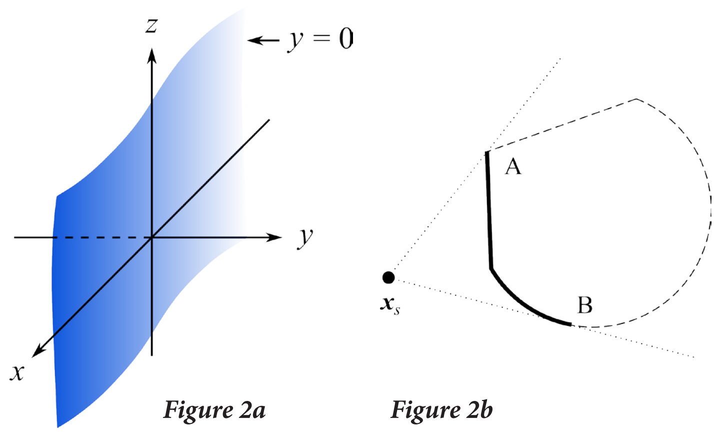


Figure 2a *Figure 2b*

Schematics illustrating the theory of sound field synthesis.

Figure 2a: *Planar distribution of secondary sources. The distribution is continuous and of infinite extent.*

Figure 2b: *Illustration of the secondary source selection that has to be performed when the physical optics approximation is applied. The virtual monopole source is located at x_S. The thick solid line represents the active part of the contour; the dashed part represents the inactive part.*

The geometry is depicted in Figure 2(a). In words, the integral in (2) states that we can perfectly recreate a sound field $S(x,\omega)$ that is source-free in the target half-space Ω if we drive a continuous planar distribution of monopole secondary sources with a signal that is proportional to the directional gradient $\frac{\partial}{\partial n}$ of $S(x,\omega)$ evaluated along the secondary source distribution.

So we actually have a solution for our problem assuming that we are able to implement a continuous distribution of monopole sound sources. This latter assumption is actually fulfilled sufficiently well by small conventional loudspeakers with closed cabinets (Verheijen, 1993). The inconvenience related to the above solution is that the secondary source distribution has to be planar and of infinite extent. Ideally, we want to enclose the target area with a secondary source distribution in order to be able to immerse the listener.

$$P(\mathbf{x},\omega) = \iint_{-\infty}^{\infty} \underbrace{-2\frac{\partial}{\partial \mathbf{n}} S(\mathbf{x},\omega)\Big|_{\mathbf{x}=\mathbf{x}_0}}_{=D(\mathbf{x}_0,\omega)} \cdot G(\mathbf{x}-\mathbf{x}_0,\omega)\mathrm{d}x\mathrm{d}y; \quad P(\mathbf{x},\omega) = S(\mathbf{x},\omega)\ \forall \mathbf{x} \in \Omega$$

If we are willing to accept a far-field/high-frequency solution we can apply the physical optics approximation (or Kirchhoff approximation) (Colton and Kress, 1992). The latter is based on the assumption that a curved surface may be considered locally planar for sufficiently short wavelengths. We can then locally apply the Rayleigh-based solution. Only those secondary sources must be active that are virtually illuminated by the desired sound field as illustrated schematically in Figure 2(b).

Conveniently, the secondary source contour does not need to be smooth. Even corners are possible with only moderate additional inaccuracy (Verheijen, 1997; Ahrens, 2012). When the boundary of the illuminated area is not smooth (like case A in Figure 2(b)) then tapering has to be applied, i.e., a windowing of the amplitude of the driving function towards the end-points to smear the truncation artifacts (Verheijen, 1997).

An essential aspect is of course that the physical optics approximation holds when the dimensions of the secondary source distribution are much larger than that of the considered wavelength. This prerequisite is not always fulfilled in practice at low frequencies where the wavelength can reach several meters.

This approximated solution is much more flexible than the one based directly on the Rayleigh integral but it still requires two-dimensional surfaces of secondary sources. Implementing a surface of secondary sources is a massive effort (Reusser et al., 2013). Recall that we have to approximate a continuous distribution. A densely-spaced placement of the loudspeakers results in channel numbers that are nearly impossible to handle even for moderate sizes of the target space.

In many situations it has been shown to be sufficient to present only the horizontal information with high resolution. All other signals can be delivered by simpler conventional presentation methods or can even be fully discarded. So we seek for a solution that is capable of handling one-dimensional secondary source distributions like rectangles and circles. This solution can be obtained from our previous one by applying another approximation referred to as stationary phase approximation and that reduces the integration of the vertical dimension in Eq. (2) to a single point in the horizontal plane (Berkhout et al., 1993; Vogel, 1993). The result is then termed a 2.5-dimensional solution because it is neither 2D nor 3D, but in between.

The major limitation of the 2.5D solution is the fact that the amplitude decay of the synthesized sound field is typically faster than desired, which turned out to be inconvenience with large systems. However, we still have extensive control over the curvature of the wave fronts in the horizontal plane. Refer to Figure 3 for an illustration.

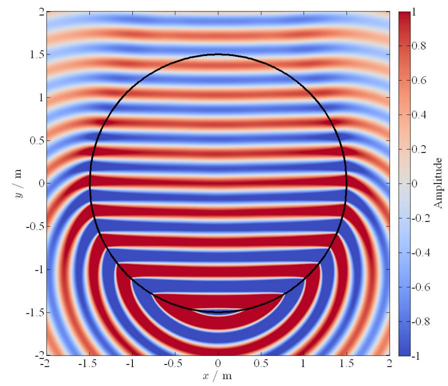


Figure 3: *2.5-dimensional synthesis of a monochromatic plane wave of 1000 Hz by a continuous circular distribution of monopole sources. The synthesized plane wave travels into positive -direction. The unintended amplitude decay along the plane wave's travel path is evident. (an animation of Figure 3 is available at: https://acousticstoday.org/sounds/#.U4ihSJRdUto*

A very convenient property of the solution is the fact that it can be implemented extremely efficiently: In order to drive a virtual sound source with a specific signal like a speech or music signal, one single static common filter has to be applied to the input signal: The latter is then delayed and weighted individually for each speaker (Verheijen, 1997). This implementation may be regarded as an advanced phased array.

The 2.5D solution described in the previous paragraph corresponds to the Wave Field Synthesis approach mentioned in the Introduction and proposed in (Berkhout et al., 1993). The vast majority of the existing realtime implementations nowadays use it and can handle hundreds of virtual sources using standard personal computers as processors, for example (Geier et al., 2008).

Explicit Solution

As an alternative to the implicit solution described in the previous section, it is also possible to solve the synthesis equation (1) explicitly for the unknown function $D(x_0, \omega)$. Taking a second look at (1) reveals that the integral actually constitutes a convolution of the driving function $D(x_0, \omega)$with the radiation function $G(x-x_0, \omega)$ of the secondary sources. For simple contours $\partial\Omega$ like spheres, circles, planes, and lines a convolution theorem can be found that allows for representing (1) in a suitably chosen transformed domain with spatial frequency ν as

$$\breve{S}(\nu,\omega) = \breve{D}(\nu,\omega)\breve{G}(\nu,\omega)$$

Eq. (3) can be solved directly for the driving function $\breve{D}(\nu,\omega)$ by rearranging the terms. 2.5D cases are handled by referencing the synthesized sound field $\breve{S}(\nu,\omega)$ to a *reference contour or point* (Ahrens, 2012).

The explicit and implicit solutions are almost equivalent for simple 3D scenarios. For some secondary source geometries – for example spheres – only the explicit solution is exact (Schultz and Spors, 2014). For 2.5D scenarios, the explicit solution is exact on the reference contour or location, where the implicit solution is only an approximation. The latter aspect is not significant in practical scenarios but has been very helpful in analyzing the fundamental properties of synthetic sound fields. Most explicit solutions cannot be implemented as efficiently as Wave Field Synthesis. They rather require designing and applying an individual filter for each combination of virtual sound source and loudspeaker. Nevertheless, realtime performance is still possible (Daniel, 2003; Spors et al., 2011).

The particularly popular explicit solution for spherical and circular secondary source distributions constitutes a modern formulation of Gerzon's *Ambisonics* approach mentioned in the Introduction. The domains into which the synthesis equation is transformed by the according convolution theorems are the spherical harmonics and the circular harmonics coefficients domains, respectively.

Spatial Discretization

As mentioned previously, practical implementations will employ a finite number of discrete loudspeakers, which constitutes a substantial departure from the theoretical requirements for the solutions outlined above. The consequences of this spatial discretization for the synthesized sound field have been studied extensively in the literature (Start, 1997; Spors and Rabenstein, 2006; Ahrens, 2012). In summary, the synthesized sound field is exact or at least well approximated up to a certain frequency termed *spatial aliasing frequency.* Above this frequency, two fundamental cases can be distinguished:

1) Additional wave fronts arise, which are termed spatial aliasing. Wave Field Synthesis belongs to this class of approaches. Refer to Figure 4(a) and (b) for an example.

2) A region of high accuracy is still apparent at the center of the secondary source distribution but whose size diminishes with increasing frequency. Outside this region artifacts occur that are different than those in case 1). Modern formulations of Ambisonics belong to this class. Refer to Figure 4(c).

Intermediate cases can also be created. It is not clear at this stage which approach is perceptually preferable in a given scenario so that we leave this question undiscussed. We want to emphasize here that discretization artifacts are not a downside of a given driving method. They rather represent practical restrictions of the loudspeaker arrangement under consideration. The driving method only has influence on how and at what locations artifacts occur.

Typically, the loudspeaker spacing is chosen such that the aliasing frequency lies between 1500 Hz and 2000 Hz. Then the desired sound field is synthesized correctly in that frequency range where the powerful localization mechanisms based on the interaural time difference are active (Blauert, 1997). The resulting loudspeaker spacings of 9-15 cm have been shown to be a good compromise between accuracy and practicability. Recall also the systems shown in Figure 1.

Perception of Synthetic Sound Fields

Extensive knowledge on the perception of natural sound fields has been gathered during the last century, for example (Blauert, 1997; Bronkhorst, 1999; Beranek, 2008; Toole, 2008), and simple situations are well understood. If we were able to build systems that are able to create a perfect copy of a given natural target sound field, ignoring other modalities, then we were able to predict the perception based on this existing knowledge. Looking at Figure 4 suggests that the task is not that easy because whenever we intend to create one single wave front we effectively create an entire set of wave fronts carrying closely related signals.

Fortunately, it is not necessary to create a perfect physical copy of the target sound field when human listeners are addressed. Instead a sound field is sufficient that sounds exactly like the target field (*authentic* reproduction) or which evokes a perception that is indiscernible from an implicit or

Figure 4a

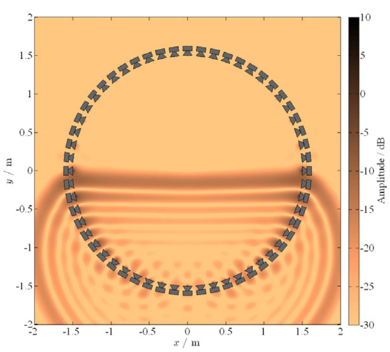


Figure 4b

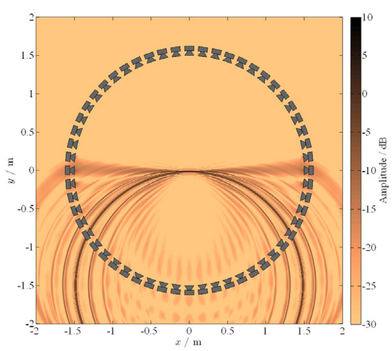
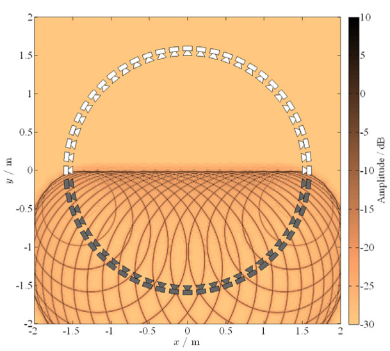


Figure 4c



Time-domain simulations of a circular distribution of 56 monopole loudspeakers synthesizing a plane wave that propagates into positive -direction. (animations of Figure 4(a)-(c) are available at: https://acousticstoday.org/sounds/#.U4ihSJRdUto

Figure 4a: *Bandwidth from 0 Hz to 2000 Hz, explicit solution (all loudspeakers are active); The non-zero components behind the straight wave front are due to the bandwidth limitation and are not artifacts of the driving function.*

Figure 4b: *Full bandwidth, case 2), explicit solution (all loudspeakers are active).*

Figure 4c: *Full bandwidth implicit solution, case 1); gray loudspeaker symbols represent active loudspeakers, white symbols represent inactive loudspeakers.*

explicit internal reference (*plausible* presentation) (Blauert and Jekosch, 2003). We discuss here in how far it has been proven or refuted that this goal has been achieved.

Sets of coherent wave fronts occur also in rooms where the sound emitted by a given source reaches the listener on a direct path followed by reflections off the room boundaries. After the floor reflection, the wave fronts impinging on the receiver follow the direct sound with a delay of several milliseconds or more. This is because the path of a reflection is usually at least a few meters longer than that of the direct sound and sound travels roughly one meter every 3 ms. However, the wave fronts that we are dealing with in sound field synthesis may have differences in the arrival times in the order of a fraction of a millisecond. This suggests that other hearing mechanisms than in the perception of natural reverberation might be triggered.

As indicated in the Introduction, there is a multitude of perceptual attributes that can be essential when perceptually assessing a spatial audio system. The scope of this article limits our discussion to the two most important attributes: localization and timbral fidelity.

When investigating human auditory perception it is important to distinguish the sound event that describes an event in the physical world and the *auditory event* that represents the perceived entity (Blauert, 1997). Note that a sound event does not always translate directly into an auditory event. Recall that in Stereophony we have two sound events (the loudspeakers) that are perceived as one auditory event (the phantom source). We want to achieve a similar situation in sound field synthesis as well. We would like the individual wave fronts of the loudspeakers to fuse into one auditory event. It has been shown in various places in the literature that this is indeed the case in most situations. Furthermore, it has been shown that auditory localization is accurate and reliable, for example (Vogel, 1993; de Bruijn, 2004; Wierstorf et al., 2012).

The auditory localization properties of a spatial audio system are fairly straightforward to investigate. User studies can be performed in which the listener reports the perceived location via a suitable pointing method. The perceived timbre on the other hand is composed of more abstract perceptual dimensions and can neither be measured directly nor can it be represented by a numerical value. A number of studies have been presented in the literature but the topic is still under active research so that no ultimate conclusion can be drawn. We summarize two representative sample studies in the following.

One way of assessing perceived coloration is making the subjects compare a given stimulus to a reference and making them rate the difference on a given scale (for example *no difference – extremely different*). The reference is typically a single loudspeaker at the position of the virtual source. Assuring equal conditions for all subjects – especially identical listening positions – is difficult with a real loudspeaker array. Most experiments therefore employ headphone simulations of a given loudspeaker array whose head-related impulse responses had been measured (a.k.a. *binaural simulation*) (Wittek, 2007). So did the studies mentioned below.

De Bruijn (2004) investigated the variation of timbre in Wave Field Synthesis over the listening area without assessing the actual absolute coloration. The motivation for skipping the latter was the assumption that it should be possible to compensate the system for absolute systematic coloration. This assumption is only partly true as coloration is not exclusively determined by the frequency response of a system but can also occur due to the presence of more than one coherent wave front (Theile, 1980). No methods for compensation in the latter situation are known. De Bruijn found that the variation of timbre is negligible for a loudspeaker spacing of 0.125 m but perceivable for larger spacings.

Wittek (2007) measured the variation of timbre of Wave Field Synthesis and Stereophony for different positions of the virtual source. He also included a single loudspeaker as stimulus. This gives indications on the absolute coloration of the tested methods as the coloration introduced by the loudspeakers themselves is ignored. His findings are that the coloration of Stereophony in the sweet spot and the coloration of WFS for loudspeaker spacings of 0.03 m are not stronger than the coloration produced by a single loudspeaker. Coloration is similarly strong for all larger loudspeaker spacings (tested up to 0.5 m) for the listening position that he investigated.

Above cited results give a first indication of what we can expect from sound field synthesis when it is used for audio presentation. These results are partly encouraging and partly discouraging. A fundamental problem is that it is not clear how the human auditory system integrates the various occurring coherent wave fronts into one auditory event. It is therefore not clear how we should shape the unavoidable spatial aliasing artifacts such that their perceptual impact is minimal. More fundamental psychoacoustical work is need.

Meanwhile another important aspect is under investigation: Artificial reverberation is an extremely essential component of high fidelity spatial audio signals (Izhaki, 2007). "Dry" virtual scenes lack spaciousness and plausibility (Shinn-Cunningham, 2001). It has been proposed in Ahrens (2014) to design artificial reverberation in sound field synthesis such that the additional wave fronts that occur due to spatial aliasing make up a plausible reflection pattern to thereby "hide" the artifacts in the reverberation (or actually make the artifacts part of the reverberation).

Examples for other topics under investigation are the rendering of spatially extended virtual sources (Nowak et al., 2013) as well as the combination of stereophonic techniques with sound field synthesis (Theile et al., 2003; Wittek, 2007).

Extensions and Applications

Sound field synthesis can be performed both with virtual sound scenes, i.e., with sound scenes that are composed of individual sound sources that have an input signal, position, radiation properties, etc. that are described in metadata. Or, sound scenes can be recorded using appropriate microphone arrays such as spherical and circular ones. For convenience, we show two examples in Figure 5 of special virtual sound sources that can be used in the former case:

- *Focused* virtual sound sources: A synthesized sound field can be designed such that it converges in one part of the listening area towards a focus point and diverges behind that focus point (Verheijen, 1997; Ahrens and Spors, 2009). Refer to Figure 5(a). When a listener is located in the diverging part of the sound field they perceive a virtual sound source "in front of the loudspeakers."
- *Moving* virtual sound sources (Ahrens and Spors, 2008; Frank, 2008): As evident from Figure 5(b), it is possible to synthesize the sound field of a moving sound source so that the Doppler Effect is properly recreated, not only the frequency shift as it is the case with conventional methods.

This history of sound field synthesis as well as the overview presented in this article have been guided by a traditional application: the presentation of audio content to human listeners. This is also the application that the vast majority of the commercial systems mentioned in the Introduction focus on. However, there are also emerging applications that go beyond entertainment and infotainment. A few of these are mentioned here briefly:

- While visual rendering in the planning stage is a state-of-the-art feature of architectural software, the corresponding audio rendering of the expected noise exposure of new industrial or traffic infrastructure is still in its infancy. Here the purpose is not to please the listener with sound, but to create a virtual acoustic environment that conveys the correct level of annoyance for assessment by human listeners (Vorländer, 2010; Ruotolo et al., 2013).

Figure 5a

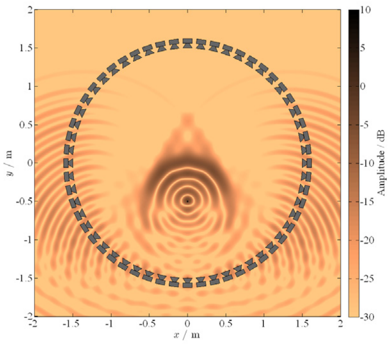
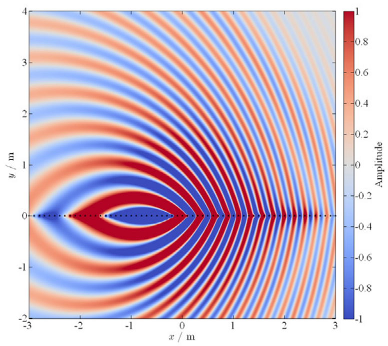


Figure 5b



Simulations of synthetic sound field originating form virtual sound source with complex properties
(Animations of Figure 5a and 5b are available at: https://acousticstoday.org/sounds/#.U4ihSJRdUto

Figure 5a: *Time-domain simulation of a focused monopole source. The black mark represents the location of the focus point at (x, y) = (0, -0.5) m. The focused source radiates in direction of the positive y–axis.*

Figure 5b: *Monochromatic simulation of a moving monopole sound source of 1000 Hz moving parallel to the x–axis at a velocity of 240 m/s. The marks represent the positions of the loudspeakers.*

- Testing of mobile speech communication equipment has to include also the performance in adverse acoustical environments. Rather than conducting extended outdoor test drives, the spatial and spectral structure of street noise can also be reproduced in the laboratory with suitable sound field synthesis techniques.
- Noise rendering still tries to produce some kind of reality, but there are also attempts to create sound fields that have no counterpart in the real world. An example is the creation of zones of silence for a part of the listeners while exposing others nearby to an intended acoustic content (Wu and Abhayapala, 2011; Helwani et al., 2014). This approach can also be used to deliver different kinds of auditory events to users in different locations of the listening space, for example the different seats of a car. The challenge is to provide individualized sound events with minimal crosstalk.
- As robots of various kinds are introduced to replace or extend human functions also the acoustic perception of robots is investigated. Of course the hearing systems of robots are purely technical and their abilities are by far inferior to human perception. Further developments of robot audition require reproducing sound fields with well-defined physical properties, since psychoacoustics in the traditional sense does no longer apply (Tourbabin and Rafaely, 2013). Similarly, also the research on hearing aids requires the ability to synthesize complex sound fields under laboratory conditions (Vorländer, 2010).

Biosketches

Jens Ahrens received a Diploma in Electrical Engineering/Sound Engineering with distinction (equivalent to Master of Science) from Graz University of Technology and University of Music and Dramatic Arts Graz, Austria, and the Doctoral Degree with distinction (Dr.-Ing.) from University of Technology Berlin, Germany. From 2006 to 2011 he was member of the Audio Technology Group at Deutsche Telekom Laboratories / TU Berlin where he worked on the topic of sound field synthesis. From 2011 to 2013 he was a Postdoctoral Researcher at Microsoft Research in Redmond, Washington, USA. Currently he is a Senior Researcher at the Quality and Usability Lab at University of Technology Berlin, Germany.

Rudolf Rabenstein studied Electrical Engineering at the University of Erlangen-Nuremberg, Germany, and at the University of Colorado at Boulder, USA. He received the degrees "Diplom-Ingenieur" and "Doktor-Ingenieur" in electrical engineering and the degree "Habilitation" in signal processing, all from the University of Erlangen-Nuremberg, Germany in 1981, 1991, and 1996, respectively. He worked with the Physics Department of the University of Siegen, Germany, and

now as a Professor with the Telecommunications Laboratory at the University of Erlangen-Nuremberg. His research interests are in the fields of multidimensional systems theory and multimedia signal processing. Currently he is a senior area editor of the IEEE Signal Processing Letters and an associate editor of the Springer Journal Multidimensional Systems and Signal Processing.

Sascha Spors received the Dipl.-Ing. degree in electrical engineering and the Dr.-Ing. degree with distinction from the University of Erlangen-Nuremberg, Erlangen, Germany, in 2000 and 2006, respectively. Currently, he heads the virtual acoustics and signal processing group as a full Professor at the Institute of Telecommunications Engineering, Universität Rostock, Rostock, Germany. From 2005 to 2012, he was heading the audio technology group as a Senior Research Scientist at the Telekom Innovation Laboratories, Technische Universität Berlin, Berlin, Germany. From 2001 to 2005, he was a member of the research staff at the Chair of Multimedia Communications and Signal Processing, University of Erlangen-Nürnberg. He holds several patents, and has authored or coauthored several book chapters and more than 150 papers in journals and conference proceedings. His current areas of interest include sound field analysis and reproduction using multichannel techniques, the perception of synthetic sound fields, and efficient multichannel algorithms for adaptive digital filtering.

Prof. Spors is a member of the Audio Engineering Society (AES), the German Acoustical Society (DEGA) and the IEEE. He was awarded the Lothar Cremer prize of the German Acoustical Society in 2011. Prof. Spors is Cochair of the AES Technical Committee on Spatial Audio and an Associate Technical Editor of the Journal of the Audio Engineering Society and the IEEE Signal Processing Letters.

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International Student Challenge Problem in Acoustic Signal Processing

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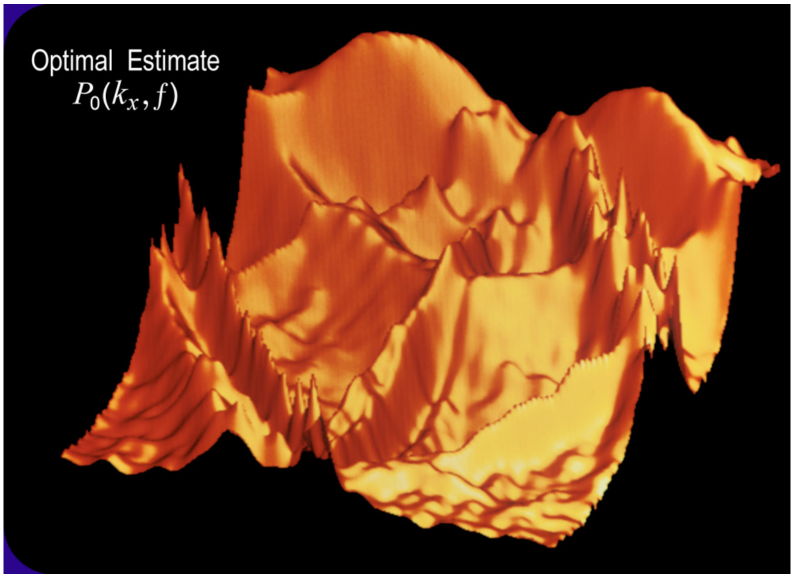
Time-frequency signal analysis provides information about a source from the sound that it makes.

A Student Challenge problem has been proposed under the auspices of the Technical Committee on Signal Processing in Acoustics (TC-SP) of the Acoustical Society of America (ASA). The problem is to estimate relevant parameters for a vehicle traveling along a road using a wav file recorded using a microphone located near the side of the road as the truck passes by. This problem, in which considerable information is to be extracted from a single sensor recording, is both realistic and relevant. Although sensor arrays provide directionality and under some conditions even range to a contact, in addition to array gain, sensors are expensive and a network of sensors is not necessarily easy to install and operate. Thus it is not uncommon to find that a signal of interest appears on only a single sensor recording. In this case it is important to extract as much information as possible from that recording.

In general there are two approaches to using acoustics to detect or determine information about an object: they are termed passive and active. Passive acoustic systems make use of the sound emitted by a source while active acoustic systems transmit sound and analyze the echo. Passive acoustic systems have the advantage that they generally do not reveal the position of the receiving system and, thus they are covert. The disadvantages of passive systems are that they usually provide only bearing to the contact and not range and they do not function well when the amplitude of the signal emitted by the target is low or when interfering background noise is high. In this case one must turn to active systems. Active systems are not covert except in very special cases where their transmissions are masked in some way. Active systems generally provide both bearing and range, which is very useful for tracking the source. And while active systems require that the echo from the contact be louder than the interfering noise (which consists of ambient noise and echoes from objects other than the contact, or clutter), they do not depend upon transmissions from the target and are thus useful for quiet targets.

TC-SP is one of thirteen Technical Committees in ASA and is the most recently established Technical Committee. It was created by conversion from an Interdisciplinary Technical Group in December 2000. Signal processing involves the representation, generation, transformation, and manipulation of signals. It can be thought of as an enabling technology for the extraction and interpretation of information about a source by processing its acoustic signature (i.e., the sound that it makes).

The TC-SP develops initiatives to enhance interest and promote activity in signal processing in acoustics. The first initiative was the Gallery of Acoustics which had its inaugural exhibition at the 130th Meeting of the ASA during November 27-December 1, 1995 in St. Louis, Missouri. The winning entry, Acoustic Dunes, became the



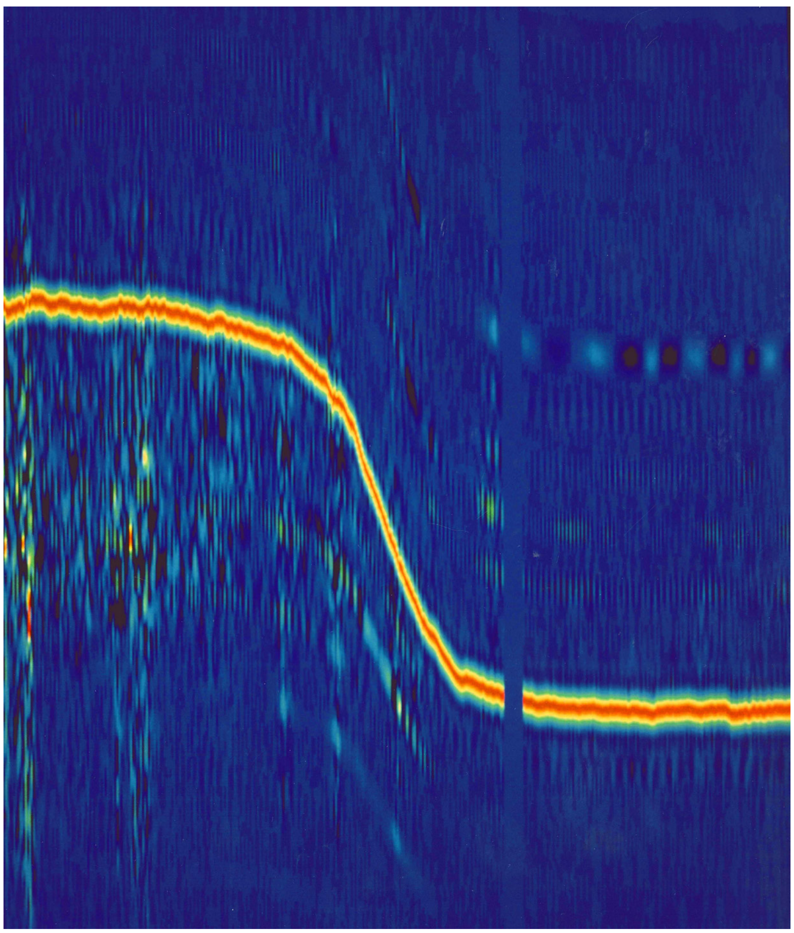


Figure 1: *Acoustic Dunes is a three-dimensional image of a multisource sound field.*

Figure 2: *Joint Wigner-Ville time-frequency distribution for the sound received by a microphone during the flyover of a propeller-driven aircraft; the vertical frequency axis spans 50 – 200 Hz, the horizontal time axis 0 – 3 s.*

Students are given an opportunity to distinguish themselves by solving a challenging problem in acoustic signal processing.

logo for ASA members with a common interest in acoustic signal processing – see Figure 1. The image shows the variation with frequency and wavenumber of the acoustic energy received by a line array of hydrophones towed below the sea surface. Each acoustic dune feature can be ascribed to a source of acoustic energy such as the tow vessel, surface ship contacts, or the array self-noise which propagates as extensional waves in both directions along the array structure. A discontinuity in a line of constant bearing is due to spatial aliasing, which occurs when the acoustic field is spatially undersampled (Ferguson, 1998).

The Gallery of Acoustics has endured and retained its popularity with the most recent exhibition at the 166th Meeting in San Francisco, December 2-6, 2013. At this Meeting another TC-SP initiative was realized, namely the Smartphone Acoustic Signal Processing Student Competition featuring innovative mobile phone applications created by our students. Also, the TC-SP organized a tutorial lecture on Time-Frequency Analysis which was given by Professor Leon Cohen of the City University of New York and Professor Patrick Loughlin of the University of Pittsburgh. The fundamental idea of time-frequency analysis is to describe situations where the frequency content of a signal is changing with time. Joint time-frequency analysis enables the frequency components of a signal to be determined at a particular time and uses a time-frequency distribution to display the frequencies that exist at each instant in time. An example in acoustics is the apparent change of frequency when a sound source and an observer move relative to each other. In 1842, Christian Doppler explained this phenomenon having noticed that sounds seemed to be of higher pitch when the listener and the source of the sound were approaching each other and of lower pitch when they were moving away from each other.[1] The Doppler Effect is readily experienced by a casual listener when a propeller-driven aircraft transits overhead. If the listener is replaced by a microphone and a time-frequency analysis method is applied to the digital time series output of the microphone, then a visual representation of the Doppler Effect can be displayed. Figure 2 is the Wigner-Ville time-frequency distribution of the acoustic energy received by a microphone during the fly-over of a turboprop aircraft. This joint time-frequency distribution shows the received energy as a function of both time (horizontal axis: 0 – 3 s) and frequency (vertical axis: 50 – 200 Hz). The dominant feature in the source spectrum is the spectral line corresponding to the propeller blade-passage rate, which is equal to the product of the shaft rotation rate and the number of blades on the propeller. The frequency of this line, when received by a stationary sensor on the ground, changes with time due to the acoustical Doppler Effect. This is clearly demonstrated in Figure 2. When compared with the emitted frequency, the received frequency is observed to be higher during the approach phase and lower as the aircraft recedes. From the variation with time of the Doppler-shifted blade rate, the speed and altitude of the aircraft are estimated to be 280 km/h and 215 m (respectively), with the source (or rest) frequency of the blade rate being 117 Hz (Ferguson and Quinn, 1994).

A New TC-SP Initiative

The tutorial lecture in Time-Frequency Analysis prompted a new TC-SP initiative to give students an opportunity to distinguish themselves by solving a challenging problem in acoustic signal processing. This latest initiative is called the International Student Challenge Problem in Acoustic Signal Processing for 2014. The idea is to provide a student with a sound file (truck.wav), which is a digital recording of some everyday acoustic phenomenon with which the student is familiar (the sound emitted by a passing truck). The student applies a signal processing technique (short-term Fourier transform) to the recorded data and then analyzes the output (spectrogram) to extract information about the source (e.g., its speed). The overall process is an example of time-frequency analysis and the problem (below) was posed by the authors on behalf of the TC-SP.

[1] *http://de.wikisource.org/wiki/%C3%9Cber_das_farbige_Licht_der_Doppelsterne_und_einiger_anderer_Gestirne_des_Himmels*

International Student Challenge Problem in Acoustic Signal Processing 2014

Background: A truck with a 4-stroke diesel engine travels along a straight road with constant speed. Near the road is a microphone that senses the radiated acoustic noise from the truck during its passage past the microphone. The output of the microphone is sampled at the rate of 12,000 samples/second and 30 seconds of data are recorded during the truck's transit which can be found in the attached file: truck.wav https://acousticstoday.org/international-student-challenge-problem-in-acoustic-signal-processing/#.U4igQpRdUto. During the recording of the data, the speed of sound propagation in air is a constant 347 m/s.

Problem: Assuming that the truck is a point source,
Plot the spectrogram of the acoustic data file truck.wav
Given that the strongest spectral line is the engine firing rate, calculate the:

(1) engine firing rate (in Hz),
(2) cylinder firing rate (in Hz),
(3) number of cylinders,
(4) tachometer reading (in revolutions/minute),
(5) speedometer reading (speed in km/hour),
(6) distance (in meters) of the closest point of approach of the truck to the sensor, and
(7) time (in seconds) at which the closest point of approach occurs.

Your solution should detail your approach and reasoning to solve the problem, as well as your best estimates of the above parameters.

Send your solutions (with your contact details) to asa@aip.org by 31 July 2014 with the subject line "Student Challenge Problem Entry."

Cash awards of $500 and $250 will be awarded to the first and second place winners, respectively. Winners are invited to prepare and present a poster no larger than 4' x 8' at the 168th Meeting of the Acoustical Society of America in Indianapolis, Indiana, October 27-31, 2014. A travel subsidy will be available.

Biosketches

Brian G. Ferguson is Principal Scientist and Engineer responsible for Acoustic Systems Science in the Maritime Division of Australia's Defence Science and Technology Organisation. He is Australia's national leader in Battlespace Acoustics under The Technical Cooperation Program (TTCP) between the Governments of Australia, Canada, New Zealand, the United Kingdom, and the United States. He is also an invited member of the NATO Sensors and Electronics Technology Panel TG-53. His work has been published widely in international scientific and engineering journals as well as the proceedings of relevant conferences. He was the General Chair of the OCEANS '10 IEEE Conference and Exhibition held at the Sydney Convention and Exhibition Centre, Darling Harbour, 24-27 May 2010. Dr Ferguson is a Fellow of the Acoustical Society of America, a Senior Member of the Australian Institution for Radio and Electronics Engineers, a Chartered Professional Engineer, a Member of the Australian Institution of Engineers and a Senior Member of the Institute of Electrical and Electronics Engineers. He was a recipient of the NATO Research and Technology Organisation 2009 Scientific Achievement Award and TTCP Sensors Group 2011 Engineering Achievement Award.

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Assessing the Impact of Underwater Sounds on Fishes and Other Forms of Marine Life

Until we gain more information on the impacts of man-made sounds on marine life, interim procedures will have to be developed to assess the risks to fishes.

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Effects of Sound on Aquatic Life

Current expansion of offshore industrial activities has led to concern about the impact of man-made sounds upon marine animals (Southall et al., 2007; Hastings, 2008; Popper and Hawkins, 2012, 2014). Offshore oil and gas exploration and developments, wind farm construction and operations, other renewable energy sources, dredging, construction activities, naval sonars, and increases in commercial shipping are all contributing to increased noise in the sea.

While most concerns have been focused on effects on marine mammals, similar issues arise with other marine life including fishes, turtles, and invertebrates.[1] While the basic principles we discuss, however, are applicable to all marine groups, the focus of this paper will be on fishes since that is our particular area of research interest.

Many marine animals use sound during their everyday lives to track prey, avoid predators, navigate, and communicate with one another (e.g., Hawkins and Myrberg, 1983). And even species that do not communicate by sound use the acoustic scene (or soundscape) to learn about and exploit their environment (Fay and Popper, 2000). Thus, anything in the environment that interferes with the ability of a fish to detect and use sounds of biological relevance could have a substantial impact on fitness and survival.

A succession of reports and scientific papers has now emphasized the potential risks to marine animals from exposure to man-made sounds or noise (Southall et al., 2007; Popper and Hawkins, 2012, 2014; Popper et al., 2014). Increasingly, environmental assessments of the impact of offshore developments and other activities have been required to consider the effects of underwater noise.

An environmental assessment essentially evaluates the effects of underwater noise in terms of mortality or any physical injury, impairment to hearing, or behavioral disturbance it might cause to animals in the ocean. The assessment end points are typically aimed at determining whether there is a significant impact on populations of marine animals and on the wider ecosystem. Often a threshold for an adverse effect is sought, and this can lead to conclusions about the likely severity of any impact. This process, referred to as risk assessment, can subsequently be used to construct "what-if" scenarios to evaluate methods for effective prevention, control, or mitigation of impacts, and to provide a reasoned basis for action to reduce risks.

[1] The invertebrate species most susceptible to man-made sounds have yet to be identified. The most likely candidates are those that may detect the kinetic components of sound. Many invertebrates have statocysts that may be involved with sound detection. These species include cephalopods (octopus, squid, and relatives) and crustaceans (crabs, shrimp, lobster, and relatives). For purposes of this discussion, we will refer to invertebrates, but recognize that those affected may form only a small part of this large and diverse group of animals.

Risk Assessment and Sound Exposure Criteria

As part of the risk assessment process, it is necessary to predict the levels of different types of sounds that may have potential impacts on marine animals, as well as those that are likely to be of no consequence. A criterion is usually provided as a threshold value, expressed in a particular acoustic metric, above which a particular level of damage may take place or behavioral change occur. The precise nature of any effects and the actual metrics that describe the sounds must be specified clearly, although there are many difficulties in achieving this. For example, not only the level of the sound but its frequency range, rise time, duration, repetition rate, and a number of other parameters can also be important in assessing its impact. Understanding the risk to animals therefore becomes more complex than just setting a single threshold value. But in all cases, the fundamental question must lie in understanding how animals respond to various sounds.

The first set of comprehensive sound exposure criteria for marine animals was recommended for marine mammals (Southall, et al. 2007). There is much less information available for other marine animals including turtles, fishes, and invertebrates, although recent guidelines, developed under the auspices of the Standards Group of the Acoustical Society of America (ASA), do provide directions and recommendations for ultimately setting criteria for fishes and turtles (Popper et al., 2014). Currently there is insufficient information to guide the setting of criteria for any invertebrate species.

However, impacts have to be assessed and interim procedures have to be developed until more direct information is available. There are both explicit and subtle pressures to achieve unity and consensus in preparing environmental statements, and because of legal considerations the assessments are not always based on the most recent or best science. There is strong dependence on criteria developed or utilized by government agencies, although these do not always reflect the latest scientific position. For example, the criteria for marine mammals suggested by Southall et al. (2007) have not yet been applied even within the legislative environment that led to that publication. However, many of the recommendations now form the foundation of the recent draft guidance issued by the US regulatory authority, the National Oceanic and Atmospheric Administration, (NOAA, 2013), but at a time when Southall and his colleagues are embarking upon a revision of their original recommendations.

Challenges in Developing Sound Exposure Criteria

There are a number of difficulties in achieving better sound exposure criteria for effects upon marine life. Chief amongst these is the lack of information on those aspects of underwater sounds that actually cause detrimental effects – whether the result is physical (or physiological) injury, hearing impairment, or changes in behavior. Sounds from various sources differ greatly in their characteristics (see chapters in Popper & Hawkins, 2012, 2014). Some sounds are continuous, such as the sounds from ships, dredging, drilling, operating wind and tidal turbines, and some naval sonar systems. These sounds may be tonal, or they may include a wide range of frequencies. Some may be ‘rougher’ than others, with a high crest factor.

Many of the sounds currently being produced in the sea and reaching high sound levels are short-lived or transient. They typically have a sharp rise time, are of brief duration, and may contain a wide range of frequencies. Examples are the sounds from explosions, seismic airguns, and percussive pile driving. Often the impulses are repeated for long periods and thus the duty cycle and total exposure duration need to be taken into account in assessing any effects upon animals. Inevitably, it is necessary to use a range of metrics to describe these sounds fully (Ellison & Frankel, 2012; Ellison et al., 2012).

Adding to the complexity is the diversity of animals, particularly among fishes and invertebrates, which have the potential to be affected by man-made sounds. There are relatively few species of marine mammal to consider (about 125). However, there are over 32,000 extant species of fish (www.fishbase.org) and tens of thousands of species of marine invertebrates. This diversity, particularly in body type and physiology, is likely to result in substantial interspecific differences in how sound affects different species, as has been shown for studies of effects of naval sonars (Popper et al., 2007; Halvorsen et al., 2012b) and seismic airguns on fishes (McCauley et al., 2003; Popper et al., 2005).

In setting sound exposure criteria there are a number of scientific options. It has been commonplace in the past to specify those sound levels that result in injury to animals, especially if these are likely to result in death. However, this level of damage occurs only very close to very intense sound sources like percussive pile drivers. For marine mammals it has been considered more relevant to estimate the received levels, or thresholds, above which individual marine mammals are predicted to experience changes in their hearing sensitivity (either temporary or permanent) from underwater anthropogenic sound sources. In its most recent guidelines for marine mammals, NOAA (2013) has designated acoustic threshold levels for the onset of both temporary (TTS) and permanent hearing threshold shifts (PTS) for different marine mammal groups, and for both continuous and impulsive sources. However, NOAA has stressed that these acoustic threshold levels do not represent the entirety of an impact assessment. Rather, they provide one of several tools (in addition to behavioral impact thresholds, auditory masking assessments, and other evaluations) to help understand the ultimate effects of any particular type of impact.

With fishes, it is effects on behavior that are considered most relevant in terms of effects upon populations (Popper et al., 2014). These effects can occur at much greater distances from the source than sound levels that can do physical harm, and they almost always involve a lower onset threshold than tissue injury or damage to the auditory system.

Metrics

Because of a general lack of information on the effects of sounds on fishes and other marine animals the sound exposure criteria that have been applied in practice do not always reflect the complexity of the sounds to which animals are being exposed or the hearing capabilities and behavioral responses of the animals themselves. For example, as a conservative measure, the NOAA Fisheries and the US Fish and Wildlife Service (USFWS) have used 150 dB re 1 µPa RMS (Root Mean Square) as the threshold for behavioral effects to fish species that are listed as being threatened or endangered. This criterion has been applied in many biological opinions evaluating percussive pile driving activities. The criterion was selected on the basis that sound pressure levels in excess of 150 dB re 1 µPa RMS could cause temporary behavioral changes (startle and stress) that might decrease a fish's ability to avoid predators (Woodbury and Stadler, 2008; Stadler and Woodbury, 2009). The scientific origin of this value is not known (Hastings, 2008). In addition, species differences have not been taken into consideration in applying this value.

Moreover, sound levels expressed as RMS values may be appropriate for some continuous sounds but they do not adequately describe more complex sounds, as the RMS simply averages out varying sound levels. Sounds that are transient (of short duration and high amplitude) can cause particular damage to tissues, and may also evoke strong behavioral responses. For impulsive sounds the instantaneous peak level has been used in a number of sound exposure criteria, although this metric does not account for the total energy within the sound and requires a fast sampling rate for effective measurement. The sound exposure level (SEL), which is related to the total acoustic energy, is used as a complementary metric. The SEL takes into account both level and duration of exposure (ANSI, 1994). This metric can be used to normalize a single sound exposure to one second, enabling sounds of differing duration to be compared.

The SEL can also be used to account for accumulated exposure to repeated sound energy over the duration of a repetitive activity such as pile driving, or for continuous activity over a specified period of time. The exposure is then expressed as the cumulative SEL (SEL_{cum}) (Popper and Hastings, 2009; Halvorsen et al., 2012a).

The criteria agreed upon by the US Fisheries Hydroacoustic Working Group (FHWG, 2009) for the onset of effects of percussive pile driving activities in terms of injuries to fishes identified the dual criteria of a peak sound pressure level of 206 dB re 1 µPa and an SEL_{cum} of 187 dB re 1 $\mu Pa^2 \cdot s$. The additional specification of a peak level recognizes that a cumulative SEL on its own may not be sufficient to account for all potential impacts. However, it is clear that even the use of these dual metrics cannot distinguish fully between a series of sounds that are damaging and those that are not. If the SEL_{cum} is to be used as a metric for a series of impulses, it is also important to specify the time period over which the SEL is accumulated, the number of impulses, the repetition rate (as there may be recovery between repeated pulses), and the rise time of individual pulses. Recent experimental evidence suggests that the basis for physical injury to fishes from percussive pile driving is a combination of energy in single strikes and the number of strikes, but these two are not related in a linear fashion (Halvorsen et al., 2012a).

Another issue is that in some cases, sound exposure criteria specify the level received by the animal. In others, they specify a level at a particular distance from the source (often neglecting the distributed nature of many real sources, whether they are large ships or extensive seismic airgun arrays). For simplicity, it is often assumed that animals remain at a constant distance from the source, but this may seldom be the case. Where animals are moving, perhaps to avoid the sounds, these movements may later take them outside the range of any effects. Some sources, like seismic airgun arrays and ships, are also moving. It can therefore be difficult

Sounds we make in the sea may interfere with the ability of fishes to detect and use sounds of biological relevance, and could have a substantial impact on their fitness and survival.

to model the actual sound levels received by the animals over time and space, or to define precisely the SEL_{cum} they experience. There is often insufficient information about the complexity of actual animal responses to understand when they will avoid sounds and when they will not.

While, as discussed above, sound levels are commonly expressed in terms of sound pressure, not all fishes can detect sound pressure. Fishes and all invertebrates capable of hearing are essentially sensitive to the kinetic elements of sounds (particle motion). Relatively few species of fish detect sound pressure (Popper and Fay, 2011). But it is still relatively rare to specify and measure sounds in terms of their particle motion levels, despite the importance of kinetic energy to these species.

Moreover, it is not only sound that travels through the water that is of interest, but sound may also be transmitted through the substrate as well, either through direct propagation or via interface waves. Pile driving and seismic airguns, in particular, may result in high levels of ground vibration to which many fishes and invertebrates are especially sensitive. Further complicating the issue is that ground vibrations may re-enter the water at some distance from the source at very high energy levels (Popper and Hastings, 2009), making standard propagation models less than useful in predicting signal levels at an animal distant from a source producing sound that penetrates the substrate.

Frequency Weighting

Animals do not hear equally well at all frequencies within their functional hearing range. They are more sensitive to some frequencies than others (Figure 1). Applying frequency weighting to measurements of man-made sounds offers a method for quantitatively compensating for differences in the frequency response of sensory systems. It minimizes the influence of extremely low- and high-frequency sounds sources that may be detected poorly, if at all, by the animal.

For marine mammals, generalized frequency-weighting functions have been derived for different functional hearing groups, distinguishing species that only detect lower frequencies from those that detect ultrasound. Thus, Southall et al. (2007) developed 'M-weighting' curves to compare the effects of man-made sounds upon different marine mammals.

The use of weighting curves is especially relevant when effects in terms of behavioral responses of animals are being considered. With tissue injury, or damage to the auditory system, frequencies falling outside the hearing range of the animals may still be important and cannot be eliminated. In this case weighting is not always appropriate. For example, although they may be inaudible, the high frequencies associated with rapid rise-times in impulsive signals may bring about or exacerbate injury. If an animal is subject to seismic airguns or pile driving, the higher frequency components may result in injury even if the animal cannot hear those frequencies. For this reason the latest draft NOAA guidelines for marine mammals do not recommend the use of weighting for measuring peak sound levels (NOAA, 2013).

In evaluating the impact of sounds upon humans, use is made of weighting curves based on equal loudness contours (Suzuki et al., 2004). Observers are asked to match sounds against one another to compare their subjective loudness. Such curves are applied in the evaluation of effects from environmental and industrial noise, and for assessing potential hearing damage and other noise health effects. Thus, the A-weighting curve is derived from the inverse of an idealized equal loudness hearing function across frequencies, standardized to 0 dB at 1 kHz (ANSI, 2006).

Equal-loudness contours are lacking for most marine animals and frequency-weighting functions are instead often based on hearing thresholds at different frequencies. Such weighting is not directly comparable to A-weighting. The hearing threshold (or auditory threshold) is the sound level that is just audible to an animal 50% of the time either under quiet conditions, or in the presence of a specified background noise level. Plotted as a function of frequency these threshold data provide an audiogram (Figure 1). Hearing thresholds are generally determined for pure tones (a single frequency), ideally against a low level of background noise.

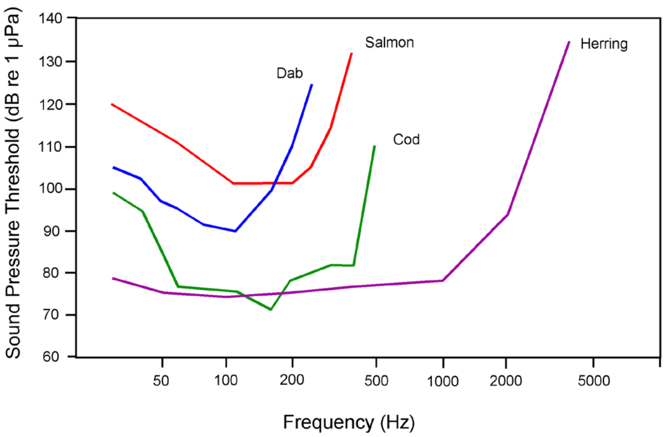

Figure 1: *Audiograms for four species of fish; the dab Limanda limanda (Chapman and Sand, 1974); the Atlantic salmon Salmo salar (Hawkins and Johnstone (1978); the Atlantic cod Gadus morhua (Chapman and Hawkins, 1973); and the Atlantic herring Clupea harengus (Enger, 1967). Auditory thresholds for the first three of these species were obtained by behavioral conditioning experiments carried out in the sea. Thresholds for the herring were obtained using auditory evoked potentials from the ear in experiments in the laboratory. Note that the audiograms for the dab and salmon are expressed in terms of sound pressure, for purposes of comparison, although both of these species are actually sensitive to particle motion. The values shown for these two species would only be valid under free-field conditions.*

Although measuring equal loudness levels in human listeners is relatively straightforward, it is much more difficult to examine loudness matching or perform loudness comparisons with aquatic animals. Nevertheless, some have aspired to determine such weighting curves for marine mammals. Thus, Finneran and Schlundt (2011) have relied upon objective measurements, such as response latency, to estimate equal loudness contours for the bottlenose dolphin (Tursiops truncatus). From their experiments they derived auditory weighting functions, which they have suggested could be used to predict the frequency-dependent effects of noise on odontocetes (toothed whales, including dolphins).

In the latest provisional NOAA guidance on sound exposure criteria (NOAA, 2013) marine mammals are divided into functional hearing groups (low-, mid-, and high-frequency cetaceans, and otariid and phocid pinnipeds). Marine mammal auditory weighting functions are incorporated into the setting of threshold criteria in the SEL_{cum} metric. Use is made of "representative" or surrogate individuals/species for establishing acoustic threshold levels for species where little or no data exist. This is done as a matter of practicality, as there are insufficient adequate data for all marine mammal species found worldwide.

Hearing Sensitivity Measures for Fishes

It is of course important that the audiograms on which weighting curves are based are obtained under acoustic conditions that give reliable and repeatable measures that truly reflect the performance of the animal's hearing system. Of the many extant species of fishes, very few have had their audiograms measured (e.g., Ladich and Fay, 2013), and of these only a very few have been measured under acoustic conditions that provided a calibrated acoustic field with valid measurement techniques. Hawkins (2014) and Rogers et al. (2014) have recently reviewed experiments aimed at providing those conditions. Most studies have been done without regard to the kinetic element of the sound field. Moreover, they have often been done in small chambers (often with glass or plastic walls) where the sound fields are highly complex and where it is almost impossible to set up and calibrate a reliable kinetic field (Parvulescu, 1964; Rogers et al., 2014).

In addition, there are methodological problems associated with the determination of hearing thresholds and the preparation of audiograms. Significantly, experiments to determine audiograms for fishes are often carried out in noisy aquaria where the thresholds determined to a particular sound may be greatly affected by the level of man-made background noise. Indeed, even when determined against natural aquatic noise backgrounds, detection of the stimuli may be masked, as shown by Hawkins and Chapman (1975). Here, the audiogram may parallel ambient noise levels, especially at the lower frequencies, where ambient noise is higher. Masking by noise may influence the curve used for weighting.

The techniques that have been used to obtain the actual thresholds from fishes also vary by investigator and laboratory (i.e., there is no standard protocol). Some thresholds have been determined using behavioral conditioning techniques. Here, the animal is trained to show a distinctive behavioral response when exposed to sounds (e.g., Tavolga and Wodinsky, 1963). Such threshold determinations require a significant investment of time in training each animal to respond, but they do provide a true measure of the best hearing capability to the sound (Sisneros et al., 2014). Behaviorally derived thresholds reflect the abilities of the animal to detect and process the sound, and give an indication of the lowest sound level to which an animal may give a behavioral response.

Many investigators have used physiological measures such as the auditory evoked potentials (AEP) to determine audiograms in fishes (reviewed by Ladich and Fay, 2013). The AEP is measured with electrodes close to the central nervous system or ear in response to short tone bursts, With repeated signal presentation and averaging of the response, the summed electrical activity in the vicinity of the electrode can be discriminated against the electrical background noise, and the "threshold" can be estimated as the minimum sound pressure required to elicit an electrical response visible to the investigator (or of a specified criterion magnitude).

It is important to recognize, however, that AEP measures of the audiogram can differ significantly from those derived using behavioral conditioning techniques (Sisneros et al., 2014). AEPs only reflect the responses to sound at the level of the hair cells of the ear, or the responses of particular groups of auditory nerve fibers, or in some cases the summed responses of cells within the central nervous system. Such physiological measures are very useful for comparing hearing mechanisms, or for determining differences before and after some intervention, such as exposure to loud sounds (e.g., Popper et al., 2005; Halvorsen et al., 2012b). But they are much less useful for determining the hearing capabilities of a particular species, or comparing the behavioral responses of different species.

Weighting and Sound Exposure Criteria for Fishes

The audiogram does not give a full indication of those sounds that will evoke behavioral responses or the magnitude of these responses in wild unconstrained animals. Nor does it provide information on the performance of the animal in more complex auditory tasks. As Liberman (2014) has pointed out, criteria for risk to the auditory system are usually constructed assuming that the audiogram is the gold standard functional test, and therefore that an exposure which causes only a temporary threshold shift is essentially benign. Liberman has shown that this assumption is not true for mice and guinea pigs, and we would predict that this would also be the case for aquatic vertebrates.

There are more than 32,000 extant species of fishes to be considered, and the choice of appropriate surrogate species or the definition of functional hearing groups is especially problematic. One solution is to divide fishes into several different categories based on the structures associated with hearing and then develop generalized guidelines that, at least for now, do not depend on the audiograms (Popper et al., 2014). The functional groups include:

- fishes without a swim bladder (these can only detect kinetic energy – e.g., sharks, gobies, flounder, some tuna including Atlantic mackerel);
- fishes with a swim bladder that is far from the ear and thus not likely to contribute to pressure reception, so the fishes are primarily kinetic detectors (e.g., salmon, cichlids); and
- fishes where the swim bladder or other air bubble is close to the ear and enables sound pressure to be detected, broadening the hearing range and increasing hearing sensitivity (e.g., goldfish, herring, sprat, catfish, cod).

Popper et al. (2014) considered that fishes showing sound pressure sensitivity are more likely to be affected by any increase in man-made noise since the sound levels are more likely to be well above their hearing thresholds than will be the case for fishes in the other groups.

Nedwell et al. (2007) proposed a systematic weighting approach for application to aquatic animals using a metric known as the dB_{ht} *(Species)*[2] as a tool for quantifying the level of sound experienced by individual marine species (including marine mammals). The dB_{ht} metric takes into account each species' hearing ability by referencing the sound to the hearing thresholds for that species. Since any given sound will be detected at different levels by different species (as they have differing hearing abilities) the species name is appended when specifying a level. For instance, the same sound may have a level of 70 dB_{ht} for the Atlantic cod (Gadus morhua) and 110 dB_{ht} for a common seal (Phoca vitulina). The dB_{ht} is said by the originators to be similar to the A-weighting that is used for human sound exposure in air. Actually, it is not strictly analogous to A-weighting as the dB_{ht} is based on the audiogram, whereas the A-weighting is based on subjective equal loudness contours.

The level of a man-made sound expressed as dB_{ht} (Species) is usually much lower than the un-weighted sound level, because the latter contains energy at frequencies that the species cannot detect. The weighting eliminates this energy. Where the energy within the received sound falls mainly within the hearing range of the animal, then the weighted level may be similar to the un-weighted level.

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[2] Strictly the use of such attachments to the dB is incorrect, and strongly deprecated by standards authorities. The use of such attachments is necessary here to enable us to refer to the work of others but we would emphasize that the symbol dB indicates a non-dimensional ratio and is neither a quantity symbol nor an abbreviation for level.

Essentially, the dB_{ht} (Species) metric is a frequency-dependent, non-dimensional ratio of measured sound level to the hearing threshold of an animal. The weighting is not just applying a frequency filter; it is providing a level that is weighted by the actual sensitivity of the animal to sound, as indicated by the audiogram. The level of a sound expressed in dB_{ht} will be higher for an animal with greater hearing sensitivity.

It is of course critical that the dB_{ht} *(Species)* be based upon accurate behavioral threshold determinations. Values based on AEP thresholds are often employed, although these thresholds rarely provide valid hearing measures for fishes, as cautioned earlier.

Moreover, as we have pointed out above, not all fishes and perhaps no invertebrates, respond to sound pressure. Many are sensitive to particle motion. In theory a dB_{ht} value can be determined for particle motion. However, the value is more commonly expressed in terms of sound pressure, even for animals that are known to be sensitive to particle motion. Particular care must be taken in doing this as the values will not be appropriate under all acoustical conditions, especially for low frequency sounds. Indeed, there are many circumstances where it will be inappropriate; for example close to a sound source, close to the sea surface, and in shallow water.

Despite the lack of high quality audiograms for the majority of marine animals, the dB_{ht} *(Species)* has often been utilized within the United Kingdom for assessing the effects of man-made sounds upon these animals, and it appears to have the tacit approval of some regulatory agencies. In particular, the dB_{ht} *(Species)* has been used to evaluate the likelihood of fishes responding behaviorally to sound exposure.

Nedwell et al. (2007) suggested that strong avoidance responses by fishes start at a level about 90 dB above the dB_{ht} *(Species)* thresholds, while different proportions of fishes respond at lower weighted levels. Mild reactions in a minority of individuals may occur at levels between 0 and 50 dB above the hearing threshold, and stronger reactions may occur in a majority of individuals at levels between 50 and 90 dB above the hearing threshold.

It must be noted, however, that these recommended levels are largely derived from the proportion of fishes reacting to sounds in only a very few studies on a few species of fish in very particular environments (Maes et al., 2004; Nedwell et al., 2007). There are very few other field data derived from wild fishes under different conditions to support the assumptions about the sound levels at which fishes will react . Moreover, the initial observations by Nedwell and his colleagues were based on fishes exposed to swept tonal sounds; sounds that are rather different from the sounds generated by, for example ships or percussive pile drivers. Clearly, substantial caution must be exercised in applying the dB_{ht} measure. Indeed, defining response criteria applicable to all species may be too simplistic an approach to evaluating behavior.

Behavioral Measures of the Responses of Fishes to Sound

A major problem in assessing magnitude of effect is how to interpret expressions used in the dB_{ht} approach such as *"strong avoidance reaction by virtually all individuals"* in terms of the effects on the behavior of particular fishes engaged in different activities. Avoidance reactions by cod, perhaps gathered in an area at a particular time of year for spawning, must be assessed differently to avoidance responses within a routine feeding area by dab (a species without a swim bladder).

Similarly, interruption of the annual coastal return migrations of a species may need especially careful consideration. Environmental statements often deal with these difficulties by constructing short verbal scenarios for the fishes concerned, outlining any effects upon animal populations and the wider ecosystem. So far, however, these scenarios have been mainly anecdotal and speculative, with a minimum of actual evidence being presented. Thus, the most important part of the risk assessment is often the least supported by quantitative data.

Application of a weighted and formulaic approach to impact assessment has the virtue of being relatively easy to use. The dB_{ht} *(Species)* , properly applied and based upon a legitimate audiogram, does permit the distance at which a sound is detected to be estimated. However, the use of this metric to forecast the level of response is too simplistic. In practice, very few studies have been carried out to investigate the levels of sound at which behavioral responses occur for the key species at risk. Those experiments that have been carried out have not always defined the actual responses of the fish in any detail. The assumption that particular levels of response occur at specific dB_{ht} levels for all species of fish requires validation if it is to be routinely applied in risk assessments. It is apparent from experiments in the field that the behavior of fishes and other animals can be greatly affected by a wide range of factors, including their previous experience of sound exposure, seasonal changes, day/night differences, and the very nature and condition of the animals themselves (e.g., their motivation). Where sounds are well above their hearing thresholds animals will not necessarily be constrained in their behavioral responses by their hearing abilities. As the NOAA (2013) guidelines point out, auditory weighting functions best reflect an animal's ability to hear a sound. These functions may not necessarily reflect how an animal will perceive and react behaviorally to that sound.

Based on this discussion, it is evident that there are major procedural difficulties in bridging the gaps between setting sound exposure criteria, estimating the distance and time over which specified effects upon behavior might occur, and then evaluating the actual risk to fish populations.

Behavioral Studies of Fishes

Supporting the need to better understand the actual behavioral responses of fishes is a recent series of experiments on the behavior of wild, pelagic fishes in response to sounds. These studies indicate that fishes can show strong behavioral reactions to impulsive sounds (Hawkins et al., 2014). The experiments also showed that the responses of a particular species to sounds can differ greatly from day to night *(Figure 2).*

Figure 2: *Atlantic mackerel Scomber scombrus (top) and European sprat Sprattus sprattus (bottom). Both species may gather in large schools in the sea.*

In these experiments, two species of fish, the sprat *Sprattus sprattus* (related to herring) and Atlantic mackerel *Scomber scombrus* (related to tuna) (Figure 2) were examined at the same coastal location. Schools of both sprat and mackerel were exposed to short sequences of repeated impulsive sounds, simulating the strikes from a percussive pile driver, at different sound pressure levels. The sound exposure experiments were carried out in a quiet area where fishes were not accustomed to heavy disturbance from shipping and other intense sound sources. Two small boats, tethered together, were allowed to drift silently over fish schools, and sounds, as well as silent control trials, were presented from an array of custom-built sound projectors (Figure 3).

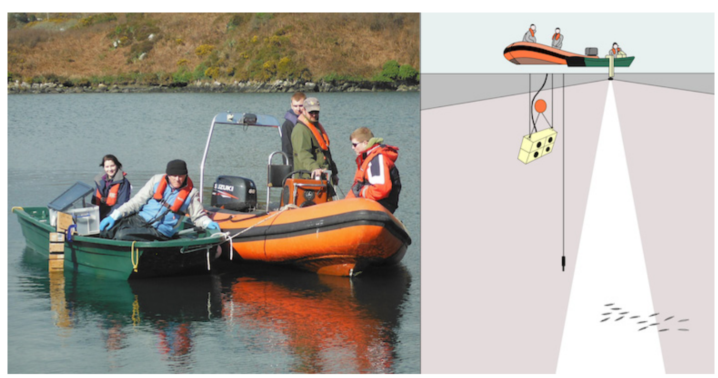

Figure 3: *Sound playback experiments were carried out from two boats, tethered together, drifting silently over fish schools. An array of four low frequency sound projectors was suspended from one boat, and a sonar system on the second boat used to observe fish schools. A short sequence of impulsive sounds (simulating percussive pile driving sounds) was transmitted and the subsequent responses of the fish followed on a combined echo sounder and side-scan sonar. A hydrophone was subsequently deployed at different depths to measure the received sound levels.*

Behavioral responses included the break up of fish schools and changes in the depth of the schools (Figure 4).

The incidence of responses increased with increasing sound levels, with sprat schools being more likely to disperse and mackerel schools more likely to change depth. The sound pressure levels to which the fish schools responded on 50% of presentations were 163.2 & 163.3 dB re 1 μPa peak-to-peak, and the single strike sound exposure levels were 135.0 & 142.0 dB re 1 $\mu Pa^2 \cdot s$, for sprat and mackerel respectively,

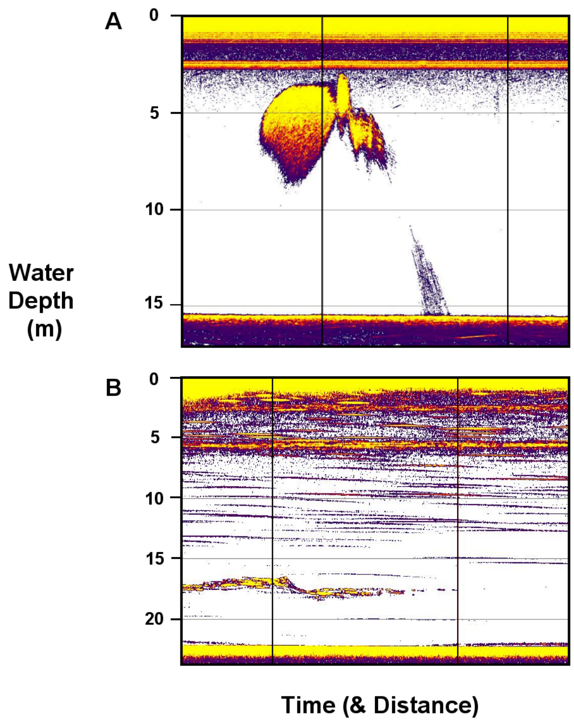

Figure 4: *Responses of a sprat school (A, at 5 m depth) and a mackerel school (B, at 17 m depth) to sound playback, observed on the echo sounder. The sound was a 20 s sequence of 10 impulses, occurring between the two vertical lines. After a short latency the sprat school breaks up and the fish disperse. The mackerel school changes depth.*

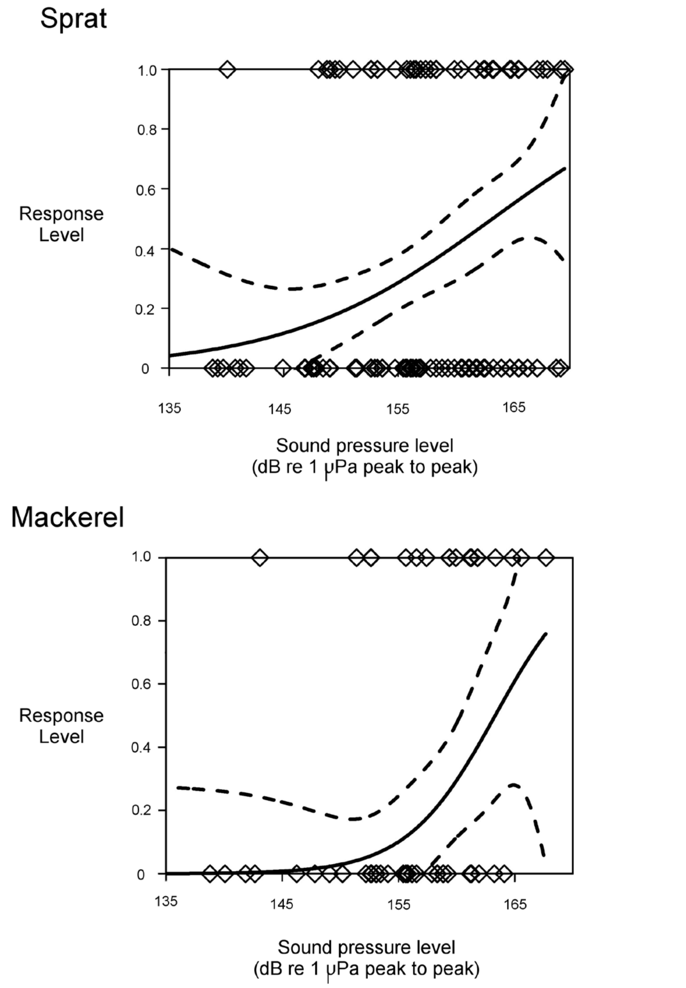

Figure 5: *Dose response curves showing the responses of sprat and mackerel schools to sounds at different levels. Each data point is derived from a single school exposed to sound, with a response designated 1, and a lack of response designated 0. The response level effectively represents the proportion of occasions on which the fish responded. In each figure the solid line represents the non-linear regression fit to the data, and the dashed lines are the 95 % confidence intervals. In both cases, the received sound pressure is expressed as peak-to-peak level. Results were also examined in terms of the single strike sound exposure level and showed the same trends. Note that the mackerel is likely to be sensitive to particle motion.*

estimated from dose response curves (Figure 5). These levels were remarkably similar for sprat and mackerel. It was of particular interest, however, that the fish responded strongly to sound playback during daytime when they were aggregated into schools, but did not respond at night, when the schools had already broken up and the individual fish were dispersed.

Mackerel and sprat are very different species. The mackerel is a fast-moving predator, able to move rapidly from one depth to another. It lacks a gas-filled swim bladder, an organ which serves as an accessory hearing organ in many other fishes and which enables them to detect sound pressure (Popper and Fay, 2011). The hearing abilities of mackerel appear to be relatively poor. Iversen (1969) examined hearing in a closely related scombrid fish lacking a swim bladder, the mackerel tuna *Euthynnus affinis,* and found that it was much less sensitive to sound than other scombrid fishes with swim bladders. The mackerel audiogram is likely to be similar to that shown for the dab in Figure 1.

In contrast, the sprat is a small forage fish, forming large dense schools. Clupeid fishes including the sprat are thought to be especially sensitive to sounds by virtue of specialized gas-filled bullae in the head, associated with the ear, that en ables them to detect sound pressure (Enger, 1967; Blaxter et al., 1981). The sprat audiogram is likely to be similar to that shown for the herring in Figure 1.

During the day, when sprat aggregated in schools as a defense against predation, they were especially sensitive to sounds. At dusk, when attacks from visual predators were greatly reduced, the sprat schools broke up and the individual sprat dispersed, perhaps allowing them to forage and feed more effectively (Hawkins et al., 2012). At night the individual sprat no longer responded to the playback of pile driving sounds. During daytime, responses by both sprat and mackerel to impulsive sounds occurred at similar and relatively low sound pressures, corresponding in level to those recorded at tens of kilometers from an operating pile driver. We would stress, however, that it would be premature to use these data to define sound exposure criteria for sprat and mackerel. Other schools of the same species, under different conditions, might respond differently. Moreover, although the response levels were provided in terms of sound pressure it is likely that the mackerel responds to particle motion.

The next step must be to assess the implications of the behavior observed from these fishes. Does the break up of sprat and mackerel schools result in lasting damage to their populations? To answer this question it will be necessary to examine the effects of repeated exposure of the same fish aggregations to sound over time, and to evaluate the energetic and other fitness consequences of their responses.

Examining the Impact and Significance of the Observed Changes in Behavior

More detailed studies of the behavior of the key species that are at risk are required to establish whether the responses observed are likely to result in adverse effects upon fish populations. Attempts have been made to model fish responses in the absence of direct information on their behavior when exposed to noise. Thus, Rossington et al. (2013) used an individual based model to predict the impacts on Atlantic cod from noise generated during a pile-driving event at an offshore wind farm in Liverpool Bay, UK. The model tracked individual "fish" within the population. Each "fish" was represented as a particle that was subject to advection by the tides and also had a set of behavioral rules, which governed their responses.

Compared with the "non-hearing" fish, the "hearing" fish were delayed in reaching their destination in the estuary as a result of the assumed behavioral changes. However, what significance can be attached to this finding? The assumption that cod were swimming towards a particular destination may not apply in practice. There are no available data on cod movements in the area concerned, and their movements may vary with season, time of day, and other factors. Moreover, the assumptions made on the responses of cod may not have been realistic representations of what would happen if cod were actually exposed to pile driving noise. Indeed, it is very likely that context plays an important role in determining the behavior of fish including their responses to sounds, as it does for marine mammals (Ellison et al. 2012). The significance of behavioral responses will vary, depending on whether animals are feeding, migrating, seeking particular habitats, spawning, or engaged in other activities.

The Way Forward

There is a need to examine more closely those sound exposure response patterns that give rise to significant detrimental effects on fish populations before a more complete risk assessment approach can be developed and incorporated into environmental statements. The development of specific sound exposure criteria, whether weighted or unweighted, is only the first step in performing risk assessment. It is important to specify in greater detail the characteristics of those sounds that result in effects. It is also necessary to describe the behavioural responses of the animals in greater detail and to assess the implications of those responses in terms of risks to populations. Significant changes in behavior might include abandonment of spawning behavior or spawning sites, movement away from preferred habitats, disruption of feeding, increased energy consumption, and diversion or delay of migrations.

There is also a need to reappraise the use of weighting curves, especially where these are used to assess the likelihood of behavioral responses from fishes (and other animals) to sound exposure. The use of the audiogram for weighting behavior, and its use to assess and compare responses at much higher sound levels is itself open to question. There is currently insufficient evidence to justify the establishment of a scale of weighted values, specifying the level of response for all species, to be routinely applied to environmental assessments.

Currently, our ability to model the levels of sounds from particular sources over space and time, although still imperfect, is improving. It is becoming possible to map the areas over which animals might experience effects and to assess the level of exposure of marine animals to sound under a range of circumstances. Predicting the effects of that exposure in terms of physical injury to fishes is now possible for some sound sources as a result of recent laboratory experiments (e.g., Halvorsen et al., 2012a; Casper et al., 2013). However, predicting effects upon behavior is much more difficult. Modeling behavior may offer scope for improving the objectivity of risk assessment, rather than relying on simple anecdotal scenarios for describing the impact of behavioral changes. However, what we really need are more behavioral observations and experiments on the behavior of wild fishes. Only if we know how and when they react, and are able to assess the significance of those reactions, can we estimate the risks to which they will be exposed in an objective and valid way.

Biosketches

Professor Anthony (Tony) Hawkins is a Director of Loughine, a small company carrying out marine research for government departments and other customers. Dr Hawkins' PhD thesis was on sound production by fish and resulted in a lead article in the journal Nature on the spawning behavior of haddock, an important food fish. He subsequently received the A B Wood Gold Medal and Prize from the British Acoustical Society for his work on the hearing abilities of fish. After carrying out further research on fish migrations, fish energetics and the behavior of fish in response to fishing gears, Dr Hawkins was appointed Director of Fisheries Research for Scotland in 1987 and served in that post until 2002. He is currently working with fishermen and other stakeholders to provide advice to the European Commission on the management of fisheries in the North Sea – one of the most intensively fished areas in the World. Dr Hawkins is a fellow of the Royal Society of Edinburgh and was appointed a Commander of the British Empire by Queen Elizabeth for his work on fisheries.

Arthur Popper is professor of Biology at the University of Maryland and editor of Acoustics Today. His research interests over his career have focused on hearing by fishes, and this has more recently evolved into a focus on applied issues on effects of man-made sound on aquatic animals. Dr. Popper is also the editor of the Springer Handbook of Auditory Research (SHAR), a series of over 50 books that are very widely used in the auditory community. Dr. Popper has also organized three international meetings on effects of noise on aquatic life (with Dr. Hawkins) and serves as consultant on the topic for government agencies and industry both in the U.S. and abroad. He is a fellow of the American Association for the Advancement of Science and of the Acoustical Society of America. Dr. Popper will formally "retire" from the University of Maryland at the end of June, 2014 but will continue his editorial and research activities as professor emeritus. And, in addition to his science-related activities, he will continue in his role as co-director of Terrapin Teachers (www.tt.umd.edu), a program that is focused on increasing the number, and improving the discipline-focused education, of college students who go on to become science and math teachers in U.S. high schools.

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High Temperature Superconductivity and Ultrasound

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Resonant ultrasound reveals a thermodynamic phase that may be important in understanding high temperature superconductors.

The phenomenon of superconductivity is one of the many great surprises of science. Building on the liquefaction of helium on 10 July 1908, on 28 April 2011 H. Kammerlingh Onnes (Onnes, 1911) cooled mercury to a low enough temperature that its resistance was "…near enough null". By 1986, the highest temperature T_c at which superconductivity had been observed was just above 20K. Work over the seven decades after the discovery of superconductivity revealed many unusual properties of superconductors. Of those properties, the most obvious is the vanishing of electrical resistance. The resistance was so low that no simple resistance measurement was found to be good enough to confirm this. Instead, a persistent current was induced in a closed loop of superconductor and the decay of the current was measured to a part in 10^5 over year time scales to put bounds on the resistance of the loop of less than 10^{-21} ohms, with million-year decay times. However the defining characteristic of superconductivity is the Meissner effect (Meissner and Ochsenfeld, 1933), which is the property that when a metal in a magnetic field is cooled to below its superconducting transition temperature, it expels the magnetic field from the interior of the superconductor (we'll come back to this later). This is not what a simple perfect electrical conductor would do--it has no problem with the magnetic field threading through it. The expulsion of the magnetic field by a superconductor requires energy and that can only come from a thermodynamic phase transition like that of water to ice. The difference in energy between the normal and superconducting state is the energy of the magnetic field in the volume of the material when it is in the normal state, just like the latent heat that must be removed from water at 273.15K to make ice.

To do this, persistent currents form on the surface of a superconductor in just the right way to cancel the interior magnetic field. The currents penetrate a small distance, the London penetration depth, λ_L, and for magnetic fields above some critical magnetic field H_c, superconductivity is destroyed. It is a curiosity that the Meissner effect is intimately related to "gauge symmetry" breaking. The phenomenon of gauge symmetry breaking, which we will not explain here, originally introduced for superconductivity in metals and reviewed by Anderson (Anderson, 1966), is now an important part of the "standard model" of particle physics and is the basis for the "Higgs mechanism" which gives mass to all elementary particles.

In 1986 scientists were stunned by the discovery of a superconductor with twice the transition temperature of the best superconductors found in the preceding seven decades. Adding to this baffling discovery was that this sudden jump in the usable temperature of superconductors occurred not in a conventional metal but in a copper oxide compound (a cuprate). The phenomenon was so outside the current thinking about superconductivity that it was distinguished with the name "high temperature superconductivity", or HTS. It is, today, still not understood.

Understanding high temperature superconductivity will require new theoretical insight outside the scope of the existing theory of metals. The success of the 1957 Bardeen, Cooper, and Schreiffer (BCS) theory of superconductivity (Bardeen et al., 1957) was a direct result of a deep understanding of the conventional metallic state. In cuprate HTS, the normal metallic state out of which HTS emerges is today not understood and this is the main scientific attraction. Even though theory is in the dark, HTS has motivated enormous advances in many measurement techniques that have also proved fruitful in understanding other condensed-matter systems. We review here some aspects of superconductivity, lay out incompletely and with bias some of the problems before us in the grand challenge to understand high temperature superconductivity, and briefly describe our recent insights (Shekhter et al., 2013) using Resonant Ultrasound Spectroscopy (RUS) that reveal a "pseudogap" and hint at the origin of the unusual metallic state in cuprates.

Important Ingredients for a Theory of Superconductivity

The microscopic theory of superconductivity is extensively reviewed and beyond our intended scope here. Here we only provide a broad sketch of the theory of conventional superconductivity that indicates how scientists direct work toward understanding HTS, and why acoustic measurements are relevant. This will also provide the context for our recent measurements using RUS. Let's begin with the theory of metals (Ashcroft, and Mermin, 1976).

In empty space an electron has well-defined momentum, "theory jargon" for an electron moving at constant speed in a fixed direction. It also has spin. Surprisingly, when an electron moves in a periodic array of atoms (crystal) that make up a metal, its quantum wavelike nature enables it to do this without losing energy just like sound waves diffracting in a phononic crystal or light through a diffraction grating.

We can imagine constructing a metal by adding electrons one by one to a fixed array of atoms (ions) whose position is determined by the crystal lattice structure. The first electron goes to the lowest energy state permitted by the lattice, almost a state of rest (~zero momentum). You can think of this like sound waves in a room. The lowest resonance of the room is a sound wave where a half wavelength fits in the longest dimension of the room. But we're dealing with electrons. No two electrons (fermions) can be in the same momentum (and spin) state. The second electron can also be in this low est energy state (but with opposite spin), however the third

> **"...Similar to magnetization, heat capacity, electric polarization, the elastic stiffness is fundamentally connected to thermodynamics and the free energy."**

electron is out of luck. It must be in a state of higher energy. The acoustics analogy is a half wavelength now fits in the second-longest dimension of the room. By the time we throw in 10^{23} electrons to make the metal electrically neutral, the last electrons have the highest energy in the metal (the Fermi energy) and are moving at about 300 times the speed of sound or about 1% of the speed of light.

Because the atoms in the crystal are equally spaced (periodic) there are only a finite number of meaningful solutions to the electron wave equation, and therefore only a finite number of allowed energy states for an electron in a solid. The acoustics and digital electronics analogy here has to do with aliasing and the Nyquist limit. Consider a digitizer acting on a sinusoidal signal. Let's say the digitization rate is exactly twice the sine wave frequency, and the digitization starts at the first zero crossing of the sine wave. The next data point will be at the next zero crossing and so on. The end result is that the digitizer output is all zeros. This is the Nyquist limit. For a sine wave of lower frequency, the digitizer more or less captures the sine wave. The curious effect occurs if the sine wave frequency is slightly higher than that half that of the digitizer. The digitizer captures a sine wave, but it is at a very low frequency—namely one that is at the difference between sine wave and half the digitizer frequencies. This is called aliasing, and is used in such things as cell phones so that the very high radio frequencies can be reduced to a lower value for processing (called an undersampling mixer). If we consider the ions as the digitizer for electron wave functions, then just as in the electronics case, any electron wave function with wavelength shorter than twice the lattice spacing is the same physically as a much shorter wavelength electron. This forces the system to have only a finite number of physically-meaningful allowed electron wavelengths, and therefore a finite number of allowed energies.

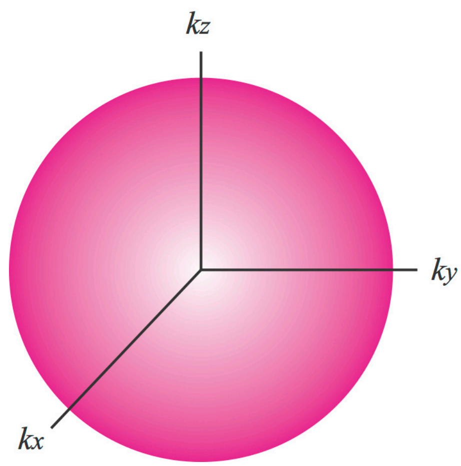

Figure 1. *The theory of metals takes the crystallographic array of nuclei and pours electrons in, each going into a different quantum state until enough go in to cancel the positive charge of the nuclei. When a plot is made of energy versus momentum, in the very simplest case, the electrons fill a sphere whose surface is at a single energy, the Fermi energy— ~30,000K, so that the electrons at the Fermi surface are moving on order 300 times the speed of sound.*

Electrons move in 3-dimensional space, their momenta are vectors. This is the starting point for any modern discussion of a metal. An important concept is the Fermi surface. It is a surface in a plot of electron energy versus momentum inside of which all electron energy states are occupied, and all states above it are empty (Figure 1). The difference between a metal and an insulator is that in a metal, not all the allowed energy levels are occupied, while in an insulator, every one is occupied, and, not surprisingly, in any particular direction for metal or insulator, there are an equal number of electrons moving one way as another, so there is zero net electrical current. The empty energy states in a metal are very close to the occupied ones, of order the Fermi energy divided by Avogadro's number. The tiny energy needed to shift an electron to an empty state makes it easy for an electric field to induce an electron to change its momentum, unbalancing the number of electrons moving in a particular direction so that an electric current is the result.

The shape of the Fermi surface and the properties of electrons very near this surface determine most metallic properties including electrical and thermal conductivity, heat capacity, magnetization, and more. The electrons with energy close to the Fermi surface are the only electrons that participate in superconductivity (note that we will, throughout, use temperature as the unit of energy where $E=k_BT=\hbar\omega$ and where E is energy, T is absolute temperature, $\hbar$ is Planck's reduced constant, and k_B is Boltzmann's constant).

There are several energy scales at play when we discuss superconductivity. The first energy scale is the one just discussed, the Fermi energy T_F, about 30,000K, the same order of magnitude as chemical binding energies. We see, then, that metals are very "cold", that is, the primary energy scale for electrons in a metal is 100 times room temperature.

The second energy scale is the Debye energy. Although this, as we will show, is connected to sound and ion motion, it is intimately also connected to electron motion. We've ignored electron and ion charge up to this point. Electrons and ions are charged and we would expect them to interact over long distances via the ordinary coulomb electrostatic force. However electrons near the Fermi surface in a metal can adjust their motion to screen all long range electrical forces. That is, if, say, a positive charge were placed inside a metal then a cloud of electrons would form around it so that the positive ion and its negatively charge electron cloud would appear electrically neutral some short distance away. This ensures that in the metal the "coulomb forces" act only over very, very short distances-less than a unit cell. Such screening makes the forces between ions short range so that a useful model of ions in a solid is an array of masses and springs, as diagrammed in Figure 2. This model of a huge array of masses and springs is of order Avogadro's number of quantum harmonic oscillators, and is responsible for all the acoustic properties of a metal. Each oscillator contains quanta of vibrational energy or phonons. The spectrum of phonons form the dispersion curve in a solid, Figure 3.

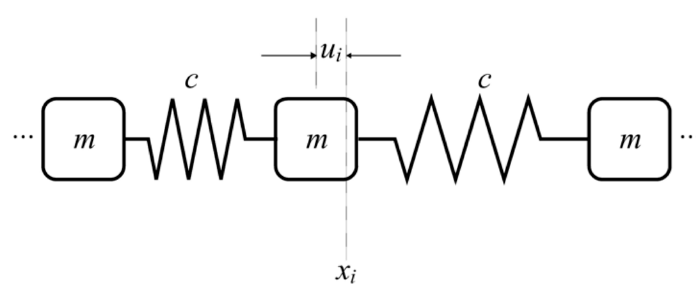

Figure 2. *Screening of charges from each other by weak dynamic motion of electrons shields the the positive ion motion u_i at x_i and makes a useful model of vibrations in solids to be that of masses m more or less connected within a few nearest neighbors by springs c.*

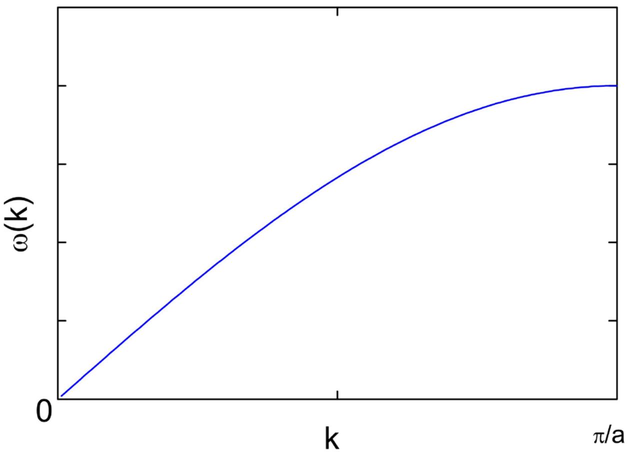

Figure 3. *The solution to an array of order Avogadro's number of simple quantum harmonic oscillators, called the phonon dispersion curve. The horizontal axis is the momentum in units of ħ. The maximum momentum is that of a vibration whose wavelength is twice the unit cell distance. The vertical axis is in arbitrary units of angular frequency. In a typical solid, the maximum frequency of a phonon is 300K or so and the solid line is really of order 10^7 discrete points.*

The allowed phonon wavelengths are also subject to a Nyquist-like argument but, because phonons are bosons, a solid can have as many phonons as you like. The hotter the solid, the more phonons there are. The maximum frequency of vibration in a solid (maximum energy for a single phonon) is of order 300K, or the Debye energy. Notable, the linear slope of the phonon dispersion curve at low momentum is the speed of sound.

In real metals, the coulomb interactions are not weak. However the short-range (screened) interactions enable a very successful description of metallic and elastic properties, the "Fermi liquid" theory of metals in which the ensemble of electrons is treated as liquid. In so-called "correlated" metals such as the HTS cuprates, the effect of coulomb interactions is not captured by Fermi liquid theory—electrons are no longer independent as they are in our simple description of the effects of screening. The breakdown of the Fermi liquid description is why we do not understand HTS and what makes the physics of cuprates a grand challenge of condensed matter.

There is another way to break the Fermi liquid ground state. Fifty years after the discovery of superconductivity, Cooper (Cooper, 1956) had the essential insight that the Fermi surface is unstable if electrons attract each other, no matter how weakly. He showed that two electrons above the Fermi surface form a bound state for any weak attraction, the famous "Cooper pair". That Cooper pair is no longer a part of the Fermi surface. Bardeen, Cooper, and Schreiffer (BCS) showed that in a real metal with an attractive inter-electron potential, then all electrons (of order Avogadro's number) will form pairs, and the liquid of these pairs forms a single quantum state, the so-called superconducting condensate, lowering the system energy. The properties of this condensate explain all superconducting properties. All Cooper pairs have zero momentum. To break up a pair takes a lot of energy, of order T_c, the so-called "superconducting gap". What this means is that for a single electron to change its state, it has to have not the tiny amount of energy needed in an ordinary metal to begin electrical conduction, but now a large amount of energy to jump across the superconducting gap. But the electrons in the condensate are a different story. Because the condensate is a single quantum state with a large number of electrons in it, and because it takes a lot of energy, of order T_c to break it up, it can move without resistance. That is, an electric field applied to it accelerates the entire quantum state as if it were a large chunk of electric charge in a vacuum. The explanation of this led to the second superconductivity-related Nobel Prize, the one for BCS. One important aspect of this condensate is that the number of electrons that participate in it is not well defined, or equivalently, for this state charge is not conserved (it is of course conserved for the totality of electrons). This breaks gauge symmetry, something we won't explain (Anderson, 1966). Though very controversial at the time, this idea led to the Higgs mechanism, at the basis of the standard model of particle physics.

What did BCS realize? If like charges repel, how can electrons attract each other? Bardeen, convinced by an ion-mass isotope effect, connected the missing "glue" to ion motion. The isotope effect for most superconductors known at the time is not the one that gave Bardeen this idea, nevertheless in the end his theory was proved correct and predictive for a restricted (BCS) class of superconductors. The pairing "glue" in BCS superconductors is phonons. How does this attraction work?

It was known before 1957 that electrons couple to phonons. What does this coupling look like? Electrons move at 300 times the speed of sound. The electrons tweak the lattice for short times (a non-resonant drive) creating a distortion in the crystal lattice that takes a long time to recover and so is "retarded" because ions are heavy. Other electrons will see that distortion as a brief increase in a local positive charge background, creating a weak interaction between electrons. To keep close to reality we must discuss the quantum mechanical form of this interaction (Abrikosov, 1965), with *ω(k)* the frequency for a given energy of an object with momentum *k*, *e* the electron energy, *p* the phonon momentum, *u(p)* the phonon dispersion curve. Figure 4 shows the energy

$$\frac{\omega_0^2\left(\vec{k}\right)}{\omega^2\left(\vec{k}\right)-\omega_0^2\left(\vec{k}\right)}=\frac{u^2\left(\vec{p}_3-\vec{p}_1\right)^2}{\left(e_3-e_1\right)^2-u^2\left(\vec{p}_3-\vec{p}_1\right)^2}$$

"landscape" for this expression and the "Feynman diagram" used to represent it. The second term in the denominator on the right of Equation 1 is the energy of the phonon that is exchanged between two interacting electrons, always less than the Debye energy ω_0 (300K). If the change in energy (e.g. *e3-e1*) of each electron is much less than the Debye energy, the phonons "mediate" an attractive interaction (the sign of the right side is negative). Figure 5 shows how the energy landscape is modified to form the superconducting gap in the energy spectrum of a superconductor.

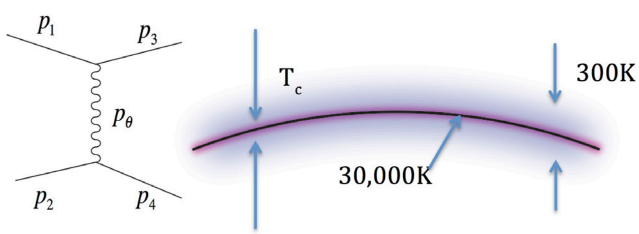

Figure 4. *The Feynman diagram used to describe the electron-phonon interaction, and the energy landscape for the process. For electrons within T_C of the Fermi energy, which is much less than the Debye energy of 300K, the phase shift from driving a harmonic oscillator (phonon) below resonance produces an attractive interaction.*

Superconductivity and Ultrasound

How does ultrasound connect to superconductivity? Similar to magnetization, heat capacity, electric polarization, the elastic stiffness is a fundamental thermodynamic susceptibility of the free energy (Migliori, 2008). The free energy difference ΔF between the superconducting and normal states is the energy of the (maximum possible) magnetic field expelled from the volume of the superconductor, proportional

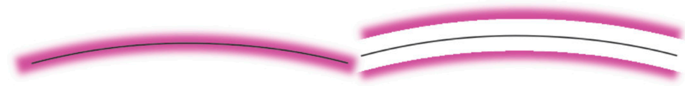

Figure 5. *A cartoon of the occupied energies of electrons above T_C (left) and below T_C (right). The bound pairs sweep out an energy gap. For electrons to show electrical resistance, they must dissipate energy, only possible if they are driven hard enough to cross the energy gap. Driving them gently produces motion of the entire superfluid without dissipation, resulting in zero resistance.*

to magnetic field squared. Because the superconducting phase transition is second-order or continuous, absolutely nothing seems to happen right at the phase transition so that

$$\Delta F\big|_{Tc} = H_c^2\left(T_c, B, P\right) = 0$$

where *T* is temperature, *B* is magnetic field, *P* is pressure (we have set all constants equal to unity). Equation 3 tells us the volume change across a superconducting phase transition ΔV is the derivative of Equation 1which is (pressure change times volume change is energy change)

$$\left.\frac{\partial \Delta F}{\partial P}\right|_{Tc} = \Delta V\big|_{Tc} = H_c\left.\frac{\partial H_c}{\partial P}\right|_{Tc} = 0$$

because at T_c the critical field H_c is zero. The change in volume with pressure is directly related to the elastic stiffness, Equation 4, and is at T_c.

$$-\left.\frac{\partial^2 \Delta F}{\partial P^2}\right|_{Tc} = -\left.\frac{\partial \Delta V}{\partial P}\right|_{Tc} = \Delta\frac{1}{c_{ij}} = H_c\left.\frac{\partial^2 H_c}{\partial P^2}\right|_{Tc} + \left.\left(\frac{\partial H_c}{\partial P}\right)^2\right|_{Tc}.$$

The first term on the far right of Equation 4 is again zero, but the last term is positive definite. For a continuous (or second-order) phase transition such as superconductivity (or the pseudogap), the elastic moduli c_{ij} are *discontinuous*--there is a step change downward upon entering the ordered (low temperature) phase. There is also a break in slope of moduli versus temperature. *Thus elastic moduli, and the sound speeds that they determine, are direct probes of a second order (or any) phase transition and reveal it with the very strong response of a discontinuous jump even though the phase transition is continuous.*

The method we used to study high temperature superconductivity, called Resonant Ultrasound Spectroscopy or RUS is reviewed extensively (Migliori and Maynard, 2005). In brief the mechanical resonances of a specimen of regular shape (easy to measure) are analyzed (difficult computational problem) to obtain the full elastic tensor. With good control over vibration and temperature, we can detect 10^{-7} changes in elastic moduli. We developed new and powerful techniques to determine accurately the frequency and width of resonances. Figure 6 illustrates part of this approach where the in-phase and quadrature response across the two resonances is shown. Balsa wood (we cannot seem to find anything less acoustically dead at 4K) for the cell improves vibrational isolation down to 4K. Even with these improvements, the measurements we were after required perfect detwinned single crystals (Shekhter et al. 2013), only recently available.

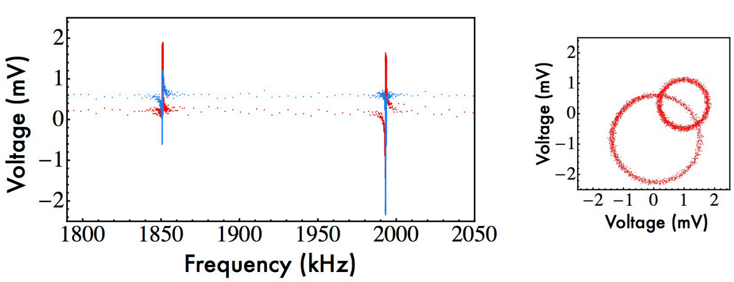

Figure 6. *Shown here are raw resonance in-phase and quadrature data for two YBCO resonances (left) and the plot in in-phase, quadrature space (ReV-ImV) of the same peaks (right). Note how by choosing the data point interval to be uniform in ReV-ImV space, the inset easily reveals that two peaks are present, while greatly reducing the time for a measurement with no compromise in signal to noise ratio.*

How big are the effects? At the superconducting transition, a fraction T_c / T_F of electrons change energy by the superconducting gap, proportional to T_c so it is expected that the fractional step discontinuity in moduli is of order $(T_c / T_F)2$ and this is about what we observed (10^{-4}) in $YBa_2Cu_3O_{6+\delta}$ (YBCO), Figure 7. This result is a first in that it suggests a rather conventional thermodynamic signature of superconductivity in cuprates. This means that this elastic properties of high temperature superconductivity in cuprates are not anomalous, an important result made possible by acoustics. Note that the transition we observed ultrasonically is very sharp for a HTS superconductor, indicating that the specimens we measured are nearly perfect. RUS is exceptionally intolerant of flaws of any sort, but produces exceptional results when flaws are absent.

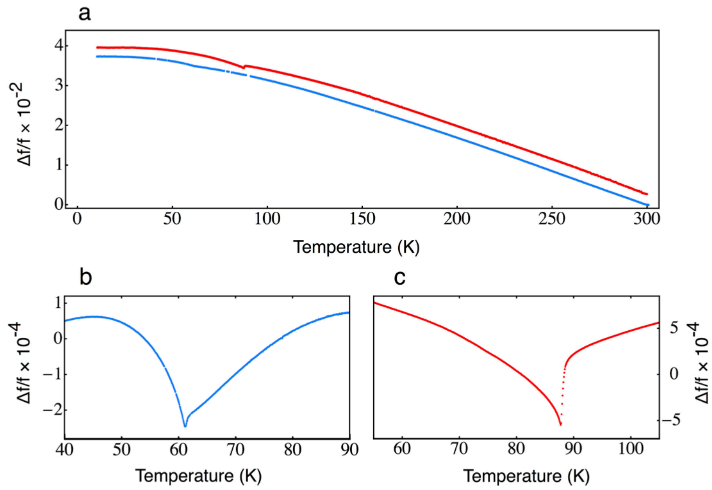

Figure 7. *The overall resonant frequency response (proportional to elastic modulus) of a compressional modulus of YBCO for both near-optimally doped (red) and underdoped (blue), left, and the superconducting transitions in expanded plots, right, measured with RUS.*

The Pseudogap and Ultrasound

The pairing glue in cuprates is not phonons. Instead, the pairing glue is mediated by electronic excitations, yet-unknown. It has long been recognized that the physics of superconducting pairing in HTS is related to the physics responsible for the anomalous metallic behavior in the normal state. Electrical conductivity and other measurements indicate a change in the metallic behavior in cuprates across a boundary in the temperature-oxygen-doping phase diagram. This boundary defines the so called "pseudogap" phase (Figure 8) (Shekhter et al., 2013). The conjecture is that the physics of the

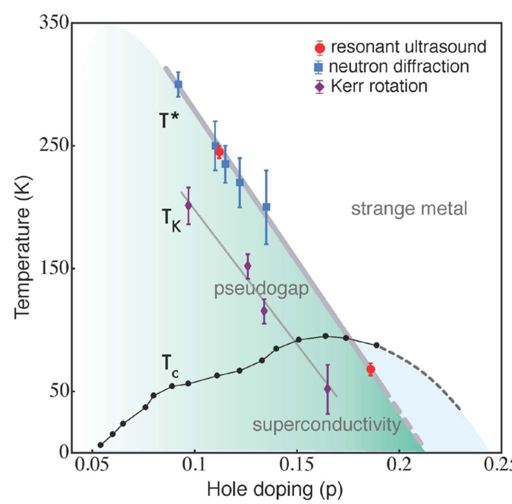

Figure 8. (Shekhter et al., 2013) *The various measurements indicating the presence of the pseudogap, with RUS results in red. The transition temperatures for superconductivity are shown by the solid black circles (left).*

"pseudogap" region of cuprates phase might provide insights into the physics of the anomalous metallic state in cuprates. Until it was not certain that the pseudogap was a thermodynamic phase. A few years ago polarized neutron scattering (Figure 8) measurements identified the onset of magnetic order at the pseudogap boundary. Recent resonant ultrasound measurements (Shekhter et al. 2013) reveal a thermodynamic signature at the pseudogap boundary that extends to where the superconductivity is strongest. Because fluctuations of the order parameter (basically the transition temperature) associated with the pseuodogap have a similar energy scale to that of phonons, those critical fluctuations just might act as a glue for pairing. The jury is still out.

Summary

Understanding the anomalous metallic state in cuprates and the high temperature superconductivity that emerges from it are grand challenges of condensed-matter physics today. Acoustics and RUS have proven to be revealing in studies of HTS. The acoustic observation of the pseudogap thermodynamic phase in HTS, though far from understood, and certainly not established as a mechanism for the glue of high temperature superconductivity, has the ingredients needed to replace phonons in assembling the pairs that upon formation become the charged superfluid of superconductivity.

Acknowledgements

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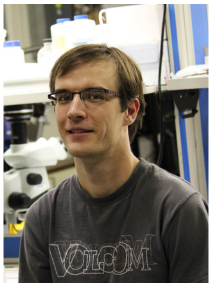
Biosketches

Albert Migliori received his B. S. in physics in 1968 from Carnegie Mellon University, his M. S. and Ph.D. in physics from the University of Illinois in 1970 and 1973. He is co-discoverer of acoustic heat engines, Co-Chair of the Science Advisory Council for the National High Magnetic Field Laboratory (UF, FSU, LANL), Director of the Seaborg Institute for Actinide Science at Los Alamos National Laboratory, and is a leading expert in the use of resonant ultrasound spectroscopy as a solid-state physics tool for which he has won RD100 awards in 1991 and 1994. He is a fellow of the Los Alamos National Laboratory, the American Physical Society, the American Association for the Advancement of Science, and the Acoustical Society of America. He is Chair, Physical Acoustics Technical Committee, Acoustical Society of America, and Chair, General Instrumentation and Measurement Topical Group, American Physical Society. He holds 25 patents, is the author of about 200 publications, six book chapters, and one book. Recent interests include elasticity of PU, and state-of-the-art research and development of new measurement techniques.

Arkady Shekhter received his PhD in theoretical condensed matter at Weizmann Institute in Israel in 2006 for his work on correlation effects in two-dimensional electron liquids. He continued his research of thermodynamic and transport phenomena in metallic cuprates as a postdoctoral research associate at UC Riverside. Challenging the boundary between theory and experiment he proceeded with experimental work as a Dirac Postdoctoral Fellow at the NHMFL-PFF. His work has been reported in peer-reviewed journals including Nature, Phys. Rev. Lett.



Brad Ramshaw got his PhD in experimental condensed matter physics from the University of British Columbia in 2012 working on quantum oscillations in the high temperature superconductor YBCO. Brad came to LANL in 2012 and has developed new resonant ultrasound spectroscopy techniques for looking at the symmetry breaking of phase transitions, and extended his previous work on quantum oscillations to 100 Tesla using the unique capabilities at the NHMFL. His publications have appeared in journals such as Nature, Nature physics, Nature Communications and Physical Review Letters.

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Underwater Acoustics for Everyone

Discovery of Sound in the Sea (www.dosits.org) makes underwater acoustics accessible for everyone from grade school students to reporters, the public, and natural resource regulators.

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Introduction

Seawater scatters and absorbs beams of light, making it difficult to see objects clearly and at far distances underwater. Light penetrates only a few hundred meters into the ocean, and trying to see underwater is similar to looking through fog on land. Sound travels faster under water than in air (1500 meters per second (m/s) versus 300 m/s), providing information after much shorter delays (for the same distance in air). Since sound travels far greater distances than light under water, sound is often used to accomplish many activities by both animals and people. Oceanographers, submariners, whales, dolphins, fishes, in short, all working or living in the ocean, use sound to sense their surroundings, to communicate, and to navigate underwater.

For example, humpback whales have learned to utilize sound in a unique feeding behavior, which researchers have studied using acoustic tools. Bubble-net feeding is a coordinated foraging technique in which multiple whales emit bubbles from their blowholes to restrict the movement of the forage fish. Whales then lunge from the seafloor through the column of bubbles to the sea surface with a mouth full of food (Figure 1). Researchers have designed digital suction cup tags that are attached to animals to measure their pitch, roll, heading, depth, and sound production (Johnson and Tyack, 2003). These tags were placed on feeding humpback whales to provide insight into the underwater behaviors associated with bubble-net feeding (Wiley et al., 2011). When and where in the behavior bubbles were produced were identified using sound, which allowed researchers to identify the habitat characteristics that constrain this unique feeding behavior.

While underwater sound is universally utilized for a wide variety of tasks, the science of sound can be complex and difficult to grasp. Children learn at an early age that by banging a spoon on a metal bowl, they are able to make wonderful sounds that garner attention. A love of music is also developed and hopefully encouraged throughout a child's life. A fundamental presentation of the science of sound and how it is described is often presented to students in 3rd or 4th grade in U.S. schools and again in physical science classes in 7th or 8th grade. However, beyond these rudimentary introductions, the study of the science of sound is not typically included in traditional public school curricula.

To provide consolidated resources on underwater sound, the Discovery of Sound in the Sea project (DOSITS; www.dosits.org) has been designed to provide accurate scientific information at levels appropriate for all audiences, including the general public, K-12 teachers and students, college students, regulators and policy-makers, and professionals in industry, education, and the media (Vigness-Raposa et al., 2008, 2012, 2014; Figure 2). The DOSITS website covers the foundational physical science of underwater sound and how sound is used by people and marine animals for a wide range of tasks and behaviors, from exploration to communication and survival. Three main science sections organize the content around key concepts. The site also has four galleries, which focus on underwater sounds (Audio Gallery), scientific equipment (Technology Gallery), acoustics related research (Scientist Gallery), and related careers (Career Gallery). A brief introduction to the foundational science and galleries included on the DOSITS website follows, as well as a more detailed discussion of the newly developed Career Gallery.

Figure 1. *Humpback whale feeding at the ocean surface on fish. The upper jaw is displaying baleen plates that are used to sieve fish from the water, while the lower jaw is displaying distended throat grooves that allow for large gulps of water to be processed. Photo credit David Csepp, NOAA/NMFS/AKFSC/ABL, National Oceanic and Atmospheric Administration/Department of Commerce.*

DOSITS has also developed specialized resources that target a wide variety of audiences. There is much interest in underwater sound in the general public, particularly as it relates to potential effects of anthropogenic noise activities on marine animals (Nowacek et al., 2007; Southall et al., 2007; Popper & Hastings, 2009; Ellison et al., 2012; Moore et al., 2012; Popper & Hawkins, 2012). The media widely covers marine mammal stranding events due to the public's interest and fascination with marine mammals. The pictures of dead animals on beaches can result in an understandable desire to know the cause of such losses and how they could be prevented. Misinformation in the media may mislead the public into thinking that scientists may know the cause(s) behind specific stranding events. The resources that are available for the media to appropriately report on the issues of underwater sound and how people's use of sound may coincidentally occur with the strandings of marine mammals have been limited. The media, including print, radio, Internet, and television reporters, need easy access to short, succinct recaps of the most up-to-date scientific research results on underwater sound and its effects on marine life to complement the latest news event that they are investigating.

As mentioned above, educators in both formal and informal settings address the science of sound. It is important that when they search for related materials that they are able to find proven, research-based information, founded on published, peer-reviewed literature. DOSITS provides this content, as well as educational resources that identify national science education standards. It is relatively straightforward for an educator to incorporate these resources into their learning environment once they have access to them.

Finally, natural resource managers and regulators are required to make decisions based on the best available science. However, they have limited time in which to find and/or follow the plethora of published scientific manuscripts. In addition, they may not have the backgrounds in science, much less acoustics, on which to understand the literature or to review the published scientific research and synthesize it, thereby integrating it into their decision-making.

This article will focus on the resources available on the DOSITS website for each of these user groups: media, educators/students, and regulators.

Foundational Science

DOSITS has three science sections that are the foundation upon which the remainder of the site is built: science of sound, people and sound, and animals and sound. These three major sections include approximately 400 pages of content, which provide a thorough introduction to underwater acoustics, its many uses, and the appropriate level of concern regarding potential effects on the environment and marine life with both basic level information as well as in-depth content. More advanced scientific discussions of key topics are also included.

Figure 2. *Screen shot of the newly redesigned front page of the DOSITS website (www.dosits.org).*

Content on the DOSITS website comes exclusively from published, peer-reviewed literature. On many pages, there are inline citations that acknowledge the science on which the content is based and provide the visitor with an opportunity to read the primary literature. In addition to a list of references, each page also contains links to additional resources for the enthusiastic user to delve deeper into a particular topic.

Beyond being based on peer-reviewed literature, the process used to develop DOSITS content includes an additional level of peer review. Twice a year, the DOSITS scientific advisory panel is convened to review new material and update existing content, as new literature is published. The DOSITS core team of scientific advisors is joined by additional subject matter experts who review and edit every word before it appears on the site. With such intense scrutiny, the DOSITS site offers a fair and balanced view of the best available science on topics related to underwater sound.

The Science of Sound section (www.dosits.org/science/sciencesummary/) provides a comprehensive overview of the science of underwater sound. It begins with very basic pages that describe what sound is; how it is characterized by intensity, frequency, and wavelength; and how sound is produced. There are extensive sections on sound movement and measurement. Several of the science pages include associated advanced topics that extend the knowledge from the basic level presented on initial pages to a level that is targeted for upper high school, undergraduate, and early graduate level students (Vigness-Raposa et al., 2014).

The People and Sound section (www.dosits.org/people/peoplesummary/) includes information on the many important everyday activities in which people engage and on the ocean that depend on sound for success. Navigation, fishing, communication, and research and exploration are just a few examples of the tasks that require the use of underwater sound. Throughout the People and Sound section, there are extensive links to the Technology Gallery, which is described in more detail below, to provide insight into the tools and equipment that people use to accomplish these tasks.

Animals and Sound in the Sea (www.dosits.org/animals/animalsandsoundsummary/) includes information on how marine animals produce and receive sound, and use sound to sense their surroundings, communicate, locate food, and protect themselves underwater (Figure 3). Sounds may be intentionally produced as signals to predators or competitors, to attract mates, to maintain group cohesion, or as a fright response, for example. Sounds are also produced unintentionally including those made as a by-product of feeding or swimming. The animals may intentionally slap their bodies on the water or slap body parts together to make distinct sounds, like the sounds produced by a humpback whale breaching (Figure 4). The Animals and Sound section also includes an in-depth discussion on the current state of knowledge of the effects of underwater sound on marine mammals, fishes, and invertebrates.

Eye (and Ear!) Catching Galleries

Four galleries have been developed to highlight fascinating aspects of underwater sound and capture the imagination of all audiences, particularly those without an extensive science background. The four galleries focus on underwater sounds (Audio Gallery), scientific equipment (Technology Gallery), acoustics related research (Scientist Gallery), and related careers (Career Gallery).

The Audio Gallery (www.dosits.org/audio/interactive) is one of the most popular places on the site, as it includes sounds, videos, and images of over seventy-five sound sources. Even

the youngest DOSITS user can spend hours listening and watching the variety of sound sources included in the Audio Gallery. Short descriptions of the sound sources support the media content, provided by over 150 generous acoustic researchers. Categories of sound sources include marine mammals, such as the humpback whale, Weddell seal, and killer whale; marine invertebrates, such as snapping shrimp and spiny lobster; natural sounds, such as lightning, rainfall, and waves; and anthropogenic sources, such as a torpedo firing, a transiting vessel, and Navy sonar. The Audio Gallery is continually being expanded to include new sources and new media files. Please review our current collection and if you are able to provide sound or video files of additional sources, we would love to talk with you!

The Technology Gallery (www.dosits.org/technology/techsummary/) highlights the tools and equipment that are used in underwater acoustics. Because light travels very short distances under water, sound is used for many tasks for which light would be used in air. To accomplish these tasks, unique equipment has been designed and engineered. The Technology Gallery highlights many of these, from broadly used gear such as hydrophones and projectors (sound sources) to very specialized technology such as Acoustic Doppler Current Profilers (ADCPs), archival marine acoustic recording units, acoustic fish tags, and multibeam echosounders. For example, the Automated Benthic Explorer (ABE) is an autonomous underwater vehicle (AUV) designed to collect data and samples, which uses multibeam echosounders for advanced seafloor mapping (Figure 5).

Figure 3. *French grunts produce underwater sounds. Photo credit Julie Bedford, NOAA Public and Constituent Affairs, National Oceanic and Atmospheric Administration/Department of Commerce.*

Figure 4. *Time series of a humpback whale breaching. Photo credit Holly Morin, University of Rhode Island Graduate School of Oceanography.*

The Scientist Gallery (www.dosits.org/scientist/scsummary/) is designed to capture and motivate the next generation of science, technology, engineering, and mathematics (STEM) scientists. Young students and the general public are curious about the paths scientists took to get to where they are and what their daily activities involve. The Scientist Gallery includes interviews with five leading scientists, who describe their research relating to underwater acoustics. It also includes the video transcripts of the scientist interviews along with questions focused on what brought them into science, and acoustics in particular, and what they would recommend for the next generation of science leaders. These very detailed interviews are a wonderful complement to the extensive, broad Career Gallery that will be launched in spring 2014.

Newest DOSITS Gallery: Careers

There is a need to draw students into science careers. Students are enticed by adventure and action, and a career in ocean sciences offers both. Sixty-five percent of U.S. naval scientists are 40 years old or older and will need to be replaced by well-educated, future scientists that are U.S. citizens. The Career Gallery provides a glimpse into the variety of careers related

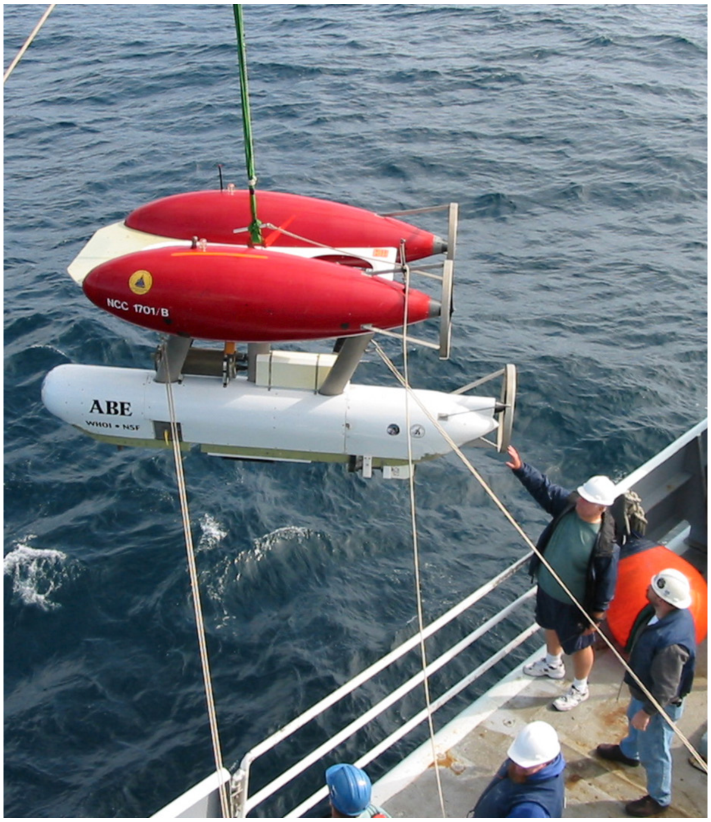

Figure 5. *The Automated Benthic Explorer (ABE) being launched for another night of data collection. Photo credit Submarine Ring of Fire 2002 Expedition, NOAA/OER, National Oceanic and Atmospheric Administration/Department of Commerce.*

to underwater sound. It is designed to help students gainan understanding of the diversity of career options, ranging from physical oceanographers, who map ocean currents, to ship operators and defense contractors.

DOSITS has developed material to encourage workforce development in STEM fields. The searchable career gallery describes over twenty ocean careers. Each career description includes details such as educational requirements, suggested knowledge and skills, possible duties and responsibilities, and estimated salary range taken from the U.S. Bureau of Labor Statistics (www.bls.gov). An example of a current person in each career is also included to provide real-world context to the reader. Links to the DOSITS Technology Gallery and other content pages are listed for each career description.

Resources for the Media

As mentioned above, reporters need straightforward resources that they can easily access (www.dosits.org/resources/). The media must often rapidly respond to events and quickly produce news content. DOSITS provides a Facts and Myths section to highlight the main questions that are continually posed by the general public on the science of underwater sound and to which media professionals are often responding. In a needs assessment with media and public affairs officers, an additional component to each quiz response was identified. Not only is it important to state the science facts, but the general public also wants a short explanation of how scientists know the given information. This explanation highlights the scientific process for understanding these critical questions. It also helps to educate the media and public affairs professionals, who will then transmit that knowledge to the general public.

In addition to the DOSITS Facts and Myths, there are several resources specifically designed for the media. There are two printed publications, a sixteen-page educational booklet and a trifold pamphlet. The educational booklet (www.dosits.org/resources/all/downloads/publications/booklet/) is designed for readers who may never get to the website. It includes summaries of the foundational science that is imperative for everyone to understand. It includes background information on the science of sound, sound production and reception by people and animals, recent scientific research highlights, and our current state of knowledge on the impacts of sound in the sea on marine animals.

The trifold pamphlet (www.dosits.org/resources/all/downloads/publications/brochure/) is designed as a teaser to the website content and is meant to pique the interest of the reader to explore the website for more details. It includes engaging pictures and brief statements focusing on critical points of underwater sound, but does not contain the rich knowledge found on the website or summarized in the educational booklet.

Most importantly, these printed publications have recently been translated into languages other than English, including French and Spanish. Work is ongoing to translate them into German and Italian. These printed materials have been distributed to members of Congress, public affairs officers, and other media outlets, as well as at scientific and educational conferences. All versions of the printed publications are available as PDF documents for download on the DOSITS website (www.dosits.org/resources/all/downloads).

An additional resource for the media is an FAQ (Frequently Asked Questions). This was created to focus on the most critical pieces of information about underwater sound, as well as those that are most difficult to understand and often misreported in media products. Eleven questions consolidate information on the site into succinct answers, with links to other DOSITS web pages for more detailed discussions. The topics range from "What are common underwater sounds?" which lists sound sources and their source levels for comparison purposes, to "How does sound in water differ from sound in air?" and "What do we currently know about the effects of sound on marine animals?". These are fundamental concepts that the media needs to understand to accurately report on underwater sound.

The final resource for the media is a backgrounder on the topic of how animals hear underwater. The backgrounder is written as a stand-alone document that summarizes the current state of knowledge on animal hearing, but with links back to specific DOSITS pages for a more in-depth treatment of topics. It begins with the basic question of why sound is important to marine animals, then summarizes how marine mammals, fishes, and marine invertebrates hear. There is a final section that asks "Why is this important?". As the introduction to this page states, without a fundamental understanding of how marine animals hear, researchers cannot address the larger and more pressing issue of potential effects of underwater sound on marine life. There is a short discussion of how potential effects are quantified and a federal research plan that outlines the steps that need to be taken to better understand the problem.

Resources for Educators and Students

Educators and students need specialized resources to meet their instructional needs (www.dosits.org/resources/teachers/). As part of the original development of the DOSITS website, a cohort of teachers participated in a summer institute in which they received comprehensive instruction in the science of underwater sound. Their capstone project was to write a short description of a chosen "feature sound" and to develop an educational activity focused on underwater sound that addressed national science education standards. The content and related educational activities include highly quantitative exercises such as "Thinking Inside the Box," which is a hands-on inquiry activity that allows students to discover how scientists and researchers use sonar to explore the seafloor. They also include "Humpback Whales: The Great Communicator of the Sea," which includes two activities that engage students in a creative understanding of how humpback whales communicate using sound by choreographing and performing message movement phrases and composing and performing songs.

Oceanographers, submariners, whales, dolphins, fishes, in short, all working or living in the ocean, use sound to sense their surroundings, to communicate, and to navigate underwater.

Other helpful resources for teachers include a series of structured tutorials. Since educational instruction occurs with a linear progression of content, intended on developing more and more complex knowledge, the "web" format of an educational website can be intimidating for someone with limited background on the topic. In a needs assessment of educators, teachers expressed that they thoroughly enjoy the DOSITS website, but with its 400+ pages of content, they often didn't know where to begin. To facilitate their use of the site and its content, structured tutorials were created on key topics of the science of underwater sound, the technology of underwater sound, and the effects of underwater sound on marine life. The topics begin with foundational knowledge, then build in complexity, providing the linear structure that educators need for classroom instruction.

Presentations have also been created for educators to easily integrate DOSITS content into their classrooms. The content of the site has been transferred into Power Point files, including embedding image, sound, and video files for multimedia presentations on subject topics. The Power Point files are updated to maintain consistency with updates to the DOSITS site after each advisory panel meeting.

In addition to content presentations, two games have been developed. The "Name that Sound" Power Point is a wonderfully engaging activity for all ages to pique their interest in underwater sounds. A sound file is played and participants are then given four choices for the source of the sound. The answer slide plays the sound again, identifies the correct sound source, and provides background information on the sound source. The other game is Jeopardy!, based on the popular American television game show, with three levels of difficulty. The game is played just as the Jeopardy game show is played on television, with appropriate sound-related categories and increasingly difficult answers to which participants must provide the correct question. This game is a great introductory activity to assess students' current understanding of the science of underwater sound before exploring the DOSITS site or beginning a sound module. It can also be used as an end-of-lesson assessment tool to determine the knowledge students have gained and retained during their sound studies.

As DOSITS has developed, there have also been requests from upper level high school and early level graduate instructors for materials that are more complex. While most pages on the DOSITS website do not contain equations or advanced mathematical functions, advanced topics have been written in each of the science sections to address more complex topics that are appropriate for advanced users. Recent topics that have been added to the advanced topic section include a discussion of explosive sound sources, statistical uncertainty, and detection threshold for sonar (as part of the sonar equation).

For those users who are not ready for advanced topics but would like to have a more comprehensive understanding of a given topic, each page on the website includes extension resources for expanded information. While the DOSITS site covers a broad range of topics, with over 400 pages of educational content, it is impossible to address each topic at the level of detail that every reader may desire. By providing extension resources, the enthusiastic user can use DOSITS as a jumping off point for their personal exploration of a topic in greater detail.

Resources for Regulators

It is clear that the regulator community needs easy to understand and rapidly accessible resources that are consistently available for reference. A web-based format is a logical go-to source for these stakeholders. The DOSITS team has had increasing inquiries for resources from the regulator community. Initial discussions with these stakeholders have identified several key resources that will aid regulators in making decisions related to underwater noise. Over the next two years, the DOSITS team will respond to this international need by developing two new resources: structured tutorials for regulators and an interactive iBook.

Similar to the problem that educators experience when first accessing the DOSITS website, the large abundance of scientific content in a web-based format, without consecutive structure, can be intimidating. For a non-science user of the site, the amount of information available may be overwhelming. In addition, regulators have specific informational needs compounded with impending deadlines that require a comprehensive, consistent, and easily accessible resource.

The planned structured tutorials on key topics will include a progression of sequential knowledge using existing DOSITS content. These topics will be identified through a needs assessment of the regulator community, to be conducted in spring 2014. The structured tutorials will be supported by additional existing pages within the DOSITS "Animals and Sound in the Sea" sections that maintain an up-to-date discussion of the most recently published peer-reviewed literature on the known effects on marine life from underwater sound exposures.

One tutorial topic that has already been identified is related to the process for determining the risk of marine animal exposure to noise. The basic question that regulators attempt to answer on a daily basis is "How do you determine if a sound source affects a marine animal?" The DOSITS site currently includes a single page that walks the reader through the basic steps of this risk assessment process. However, this does not adequately address the needs of the regulatory community. The corresponding tutorial will discuss underwater sound propagation; then progress to the coupling of the sound field to the potential field of marine life, including diving and movement behaviors, to predict exposure levels; and conclude with the range of potential effects that might occur based on those predicted exposure levels.

In addition to the structured tutorial, an interactive iBook is in development. The interactive Internet is widely recognized as the greatest learning tool in human history, with its impact broader than the printing press in knowledge dissemination and more rapid in its diffusions (Lewis et al., 2010). Web 2.0 features have enabled the developments of new digital media technologies that are not just the technical implementations themselves, but the frameworks that allow for direct participation and sharing of content (Jenkins, 2009). Digital media, particularly that used in hand-held devices such as smart phones, iPods, and iPads, are dramatically changing the science landscape, providing unprecedented opportunities for learning science content. The DOSITS interactive iBook will serve as a tool to make the science of underwater sound available to a wide audience of stakeholders, as well as people without Internet connectivity, via their hand-held and tablet devices. The iBook will utilize existing and updated content to provide a condensed electronic resource that will focus on how animals use, produce, and receive sound as well as an overview of the effects of sound on marine life.

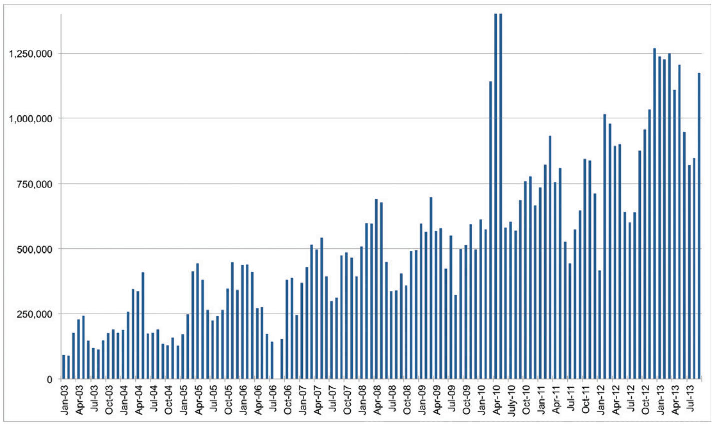

Figure 6. *DOSITS web traffic measured in number of hits per month from January 2003 to September 2013.*

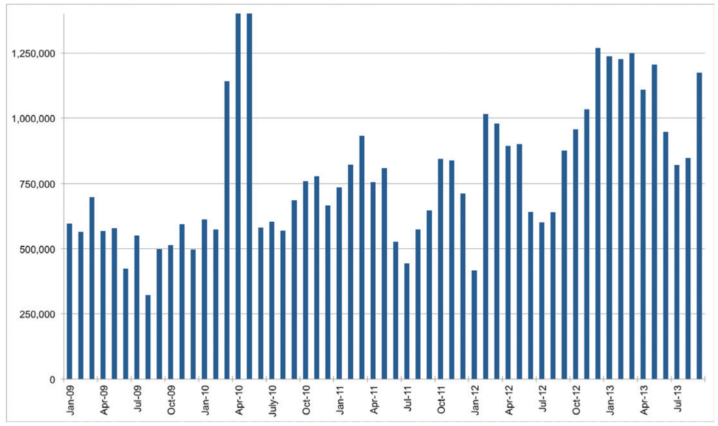

Figure 7. *DOSITS web traffic measured in number of hits per month from January 2009 to September 2013.*

DOSITS Traffic Summary

DOSITS was launched in November 2002. The site has experienced continued growth of visitor traffic each year, measured both in number of hits (Figure 6) and in amount of data served. Site traffic in the first few years exhibited a strong pattern that reflected the northern hemisphere school-year calendar, with the highest amount of traffic in the spring and the lowest amount in the summer and early fall. However, with additional international exposure and increasing use by media and regulator communities, the cyclical nature of visitor traffic has decreased.

In March 2010, DOSITS launched a thoroughly revised version of the website to take advantage of the advances in Internet capabilities since the original launch in 2002. The new version included an interactive front page, Audio Gallery, and Scientist Gallery, as well as adding video files to Audio Gallery pages and developing complex animations to the foundational science pages. In association with this launch, there was a huge media push that brought a large spike in traffic to the site.

Through September 2013, DOSITS has had over 68 million hits and over 5.9 million page views. In 2012, the DOSITS website saw a 20% growth in traffic to the site compared to 2011 and, through the first nine months of 2013, DOSITS saw approximately a 30% growth in traffic compared to the first nine months of 2012, measured in number of hits (Figure 7).

Visitors to the DOSITS website come from across the globe. Half the visitors during 2013 were from North America and close to a quarter of the visitors were from Europe (Figure 8).

One of the biggest changes to the traffic to the DOSITS site is due to the rise in use of mobile devices. Two years ago mobile devices represented only approximately 5% of the total traffic to the site. In the first nine months of 2013, mobile devices made up more than 27% of the site traffic (Table 1).

Since mobile devices are an increasing platform used by the DOSITS audience, the DOSITS team is making the site more mobile device friendly. Mobile devices, such as those running iOS platforms, cannot run Flash-based website material. To accommodate these devices, the DOSITS front page was recently redesigned to be Flash free and forward looking, enabling access for all devices (Figure 2). Other Flash heavy parts of the site (such as the current Audio Gallery) redirect mobile devices to non-flash equivalents.

Conclusions

All DOSITS information is based solely on published, peer-reviewed scientific research. Related research literature is continuously monitored for new information that is regularly incorporated into the website content and resources, ensuring that the most up-to-date research results can be found on the site. A new feature is the "hot topics" section, included on the front page. This feature is designed to highlight interesting and new developments provided by the research community that may occur between advisory panel meetings. Rather than waiting for new content to be written and reviewed by the advisory panel, which may delay its incorporation into the website for six months, if new peer-reviewed scientific papers are published in between advisory panel meetings that represent important, cutting-edge discoveries, a short summary of their results can be highlighted on the

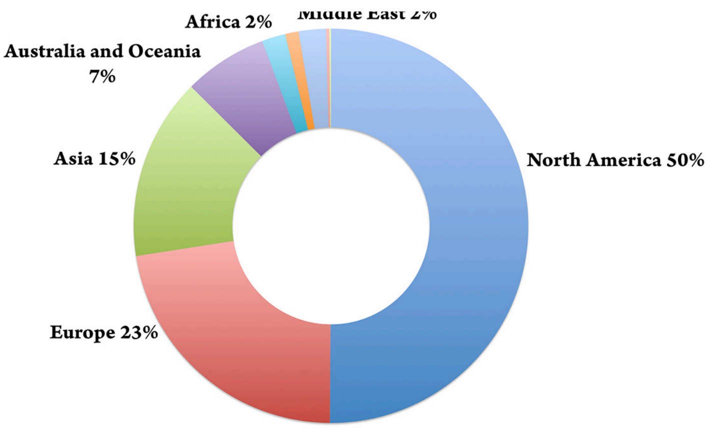

Figure 8. *DOSITS web traffic by region, measured as a percentage of total traffic for 2013.*

front page. More extensive content will then be reviewed by the advisory panel and incorporated into appropriate DOSITS sections following the regular procedure for content development.

In addition to DOSITS content being based on peer-reviewed scientific literature, the website itself regularly undergoes a thorough review by the DOSITS scientific advisory panel. Expertise in each of the major topic fields ensures the highest scientific accuracy and integrity possible for website content. Special thanks go to the Scientific Advisory Panel members: Dr. Peter Worcester of Scripps Institution of Oceanography, Dr. James H. Miller of the University of Rhode Island (current president of the Acoustical Society of America), Dr. Darlene Ketten of Curtin University, Dr. Arthur N. Popper of the University of Maryland (editor of Acoustics Today), Dr. Danielle Cholewiak of NOAA Fisheries Northeast Fisheries Science Center, and Dr. Peter Scheifele from the University of Cincinnati.

The model that DOSITS has developed to provide extensive science information, kept current and up to date with cutting edge, peer reviewed science, is unique among educational websites on the Internet. As the public turns to the Internet to explore any topic in which they have an interest, sites such as DOSITS need to be created and maintained to provide foundational science concepts and up to date information, which support educated decision-making about current events that may be occurring in the world around us.

The DOSITS project is currently in its 12th year. This longevity is possible only due to continued dedication we have received from funding agencies. The Office of Naval Research (ONR) has provided consistent support. This has been supplemented by the National Science Foundation (NSF) and the National Oceanic and Atmospheric Administration (NOAA) for the development of specific and/or timely content. Similarly, the DOSITS team offers the opportunity to other organizations to build on the project's foundation and the DOSITS well-established professional network as needs for expanded content on underwater sound develop.

In addition to monetary support, DOSITS would not be possible without the good will and expertise of the acoustics community of scientists, over 120 of whom have donated content, images, and audio files. Substantial contributions have also been made by Jill Johnen, Peter Cook, and Rebecca Briggs when employees of the University of Rhode Island. The site has been enhanced by the work and generous contributions from many individuals and organizations, as well as ten Rhode Island school teachers and over 40 independent scientific reviewers (www.dosits.org/about/). The DOSITS project continues to be a highly successful initiative that brings together scientists and education professionals to build and maintain a high quality resource for diverse audiences and stakeholders, ensuring that underwater acoustics is for everyone!

Mobile Operating System (OS)	Percentage of Total Traffic to DOSITS
iPhone	9.8
IPad	9.1
Android	6.2
Blackberry	0.4
Windows Phone	0.3
All Other Mobile OS	1.7
TOTAL iOS	**19.8**
TOTAL Mobile	**27.5**

Table 1. *Breakdown of mobile traffic to the DOSITS website in 2013*

Biosketches

Kathleen J. Vigness-Raposa is Vice President of Environmental Programs at Marine Acoustics, Inc. in Middletown, Rhode Island. She received her B.S. in Education from Miami University (Ohio), and her M.S. in Oceanography and Ph.D. in Environmental Sciences from the University of Rhode Island. Her research interests combine field measurements and predictive modeling of potential effects of underwater sound on marine life with effective communication to diverse audiences, earning her the nickname "Kathy DOSITS."

Gail A. Scowcroft is the Associate Director of the Inner Space Center at the University of Rhode Island Graduate School of Oceanography and Executive Director of the National COSEE Network, one of the largest networks of ocean science research and education institutions. A former paleoclimate scientist, she is an international leader in climate change and ocean science education. She has directed several large ocean science related initiatives and is currently serving a four year term on the U.S. Ocean Research Advisory Panel.

Holly Morin is a Marine Research Associate and Education Specialist with the Inner Space Center (ISC) at the University of Rhode Island's Graduate School of Oceanography (URI/GSO). Her work focuses on the development, coordination, and promotion of a variety of ocean science education programs, including the Discovery of Sound in the Sea (DOSITS) website (www.dosits.org). Before coming to URI/GSO, Holly worked at the Northeast Regional Office of NOAA's National Marine Fisheries Service, assisting with large whale management and fisheries interactions. Holly graduated from the University of New Hampshire with a Bachelor of Science (marine biology focus) in 2000. She then went on to receive her Master's Degree in Wildlife and Fisheries Science from Texas A&M University in 2005. Her graduate work focused on the diving behavior and movement patterns of young Steller sea lions in Prince William Sound, Alaska.

Christopher Knowlton is the Assistant Director of the Inner Space Center at the University of Rhode Island Graduate School of Oceanography. He received his B.A. in Geology from Colgate University and an M.S. in Oceanography from the University of Rhode Island.

Chris is interested in past climate on glacial-interglacial timescales but spends most of his time communicating science through modern devices and media to convey the science of the deep ocean, hurricanes, and underwater acoustics.

(left to right) *Christopher Knowlton, Gail Scowcroft, Kathleen J. Vigness-Raposa and Holly Morin*

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Acoustics Today **publishes news items that may be of interest to the acoustics community. News items should be sent to the Editor (apopper@umd.edu) and copied to the ASA Publications Office (maryguillemette@acousticstoday.org). The Editor and the Publications staff reserve the right to decide if material is appropriate for *Acoustics Today* NEWS and to rewrite or rephrase whatever is sent to make it compatible with the format of *Acoustics Today*. News items may include announcements of meetings, awards to ASA members, or anything else that might be of broad interest to the Acoustical Society community. In the future, news items will be posted, shortly after receipt, on the *Acoustics Today* web site.**

Acoustical Society Foundation Fund

The mission of the recently established Acoustical Society Foundation Board (ASFB) is to support the mission of the ASA by developing financial resources, namely the Acoustical Society Foundation Fund (ASFF), for strategic initiatives and special purposes.

Many years ago a number of dedicated and forward-looking ASA members established the Acoustical Society Foundation in order to develop and grow an endowment to support and enhance the goals of the Society. Starting from that base, ASA through its ASFB is expanding its efforts to grow the ASFF and is seeking philanthropic support to help the Society move forward and meet future challenges. Details concerning the ASFF can be found on the ASA website:

With funds from the ASFF, the Society makes grants for student stipends, makes service acknowledgment awards and prizes, and develops new outreach initiatives as directed by the Executive Council or the terms of donations. With new momentum the ASFB plans to expand these activities and help the Society focus on the growth of our profession.

This past year alone, contributions from general Society membership increased by 30%. And the ASFF also was augmented by the generosity and foresight of two of the society's most prominent recently departed members: Murray Strasberg and Stanley Ehrlich. Murray Strasberg left a bequest to ASA in his will; Stanley Ehrlich made a donation many years ago to the Pooled Income Fund (PIF); that contribution provided him with an immediate charitable tax donation and a life-time stream of guaranteed tax-free yearly income until his demise. Other tax-deductible opportunities to participate abound: check-off donations on the ASA dues renewal, direct donations, bequests, lifetime income with gift annuities or the Pooled Income Fund.

The ASFF activities are coordinated for the Society by the Acoustical Society Foundation Board, chaired by Carl J. Rosenberg. The Board plans to present its goals and aspirations to the ASA membership in future issues of ASA publications. Anyone with ideas or questions to share should send an e-mail to the Board's Chair, using the email address asa@aip.org.

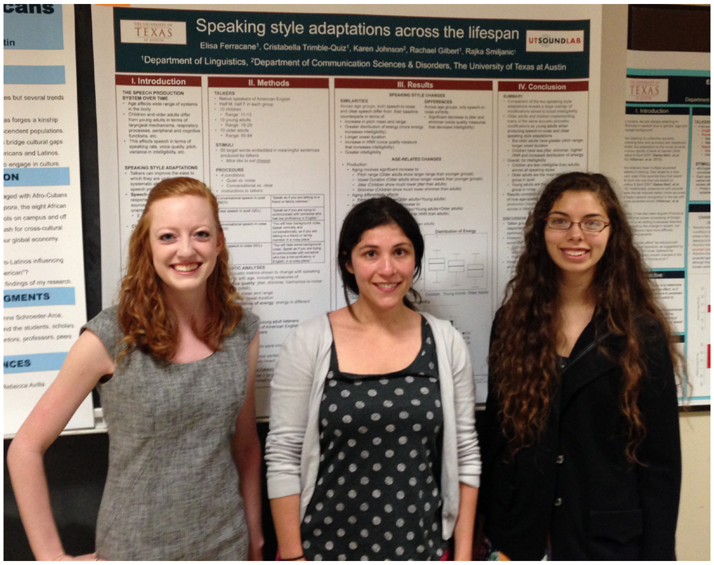
On behalf of all the Society, the ASFB recognizes and appreciates the service and generosity of all the donors to the Fund.

From the Student Council

Ahoy from Providence! What a great week of student research. We had a huge turnout at all the events: about 40 students at the Intro to the Technical Committees Session, as well as to the New Student Orientation. We had about 80 students at the Monday night meet-n-greet, and about 150 at the Wednesday night reception! Thanks to all of the presenters who volunteered their time and expertise to make this Intro. to the Technical Committees session possible, and thanks to the sponsors for the Wednesday night social!

Students, if you would like to nominate your professor for the ASA Student Mentoring Award, nominations will be coming up in the fall. The next award will be presented at the Pittsburgh meeting. More details on Mentoring Award and how to nominate a deserving mentor can be found on the ASA Student Zone website at www.acosoc.org/student.

For the Indianapolis meeting in October, look forward to the new Résumé Help Desk service. It will be offered 12:00-1:00 pm on Tuesday-Thursday, located near registration desk. Swing by for an unbiased expert review of your resume! The Student Council will also be hosting a special session highlighting graduate programs in acoustics. Also new are



Karen Johnson, Rachael Gilbert, Cristabella Trimble-Quiz, all graduate students at University of Texas, Austin.

the student feedback form (QR code on the student bulletin board) and the colored stickers to represent your TC. Swing by the bulletin board or contact your representative for more information.

Additionally, all students and new post-docs are encouraged to attend the student events and to join us for the student outings. It's a great way to socialize with your fellow students and learn about the great research they are doing. As always, for all up-to-date news subscribe to our twitter feed @ASAStudents and like us on Facebook, facebook.com/asastudents.

Hope to see everyone in Indianapolis!
Rachael Gilbert

ASA Inspired Future Acoustic Scientists and Engineers in DC

Acoustical Society of America presented the world of acoustics to thousands of students and teachers at the third USA Science & Engineering Festival in Washington, DC from April 25-27, 2014. The largest educational event to promote science, technologies, engineering, and math for future generations attracted more than 325,000 people of all ages in this 3-day family event. The ASA exhibition was one of 900 exhibitions from the world's leading professional scientific and engineering societies, universities, government agencies like NASA, NSF, NIH, NSA, to large corporations like Lockheed Martin and 3M, high tech companies and STEM outreach and community organizations, to celebrate science at the Walter Washington Convention Center.

The ASA special exhibition was jointly organized by the DC chapter of ASA (represented by Diego Turo) and the Philadelphia chapter of ASA and Women in Acoustics (represented by Kyoko Nagao). "We were able to cover a lot of topics in acoustics: wave propagation, passive and active noise control, Doppler effect, ultrasound, elastography, speech/voice analysis, speech synthesis, ear anatomy, cochlear implants, and hearing tests," said Diego Turo. The hands-on activities utilized from very simple toys like boom-whackers to very high-tech techniques like ultrasound images and speech synthesis. The children played with the different lengths of tubes to learn resonances and bounced a slinky to get an idea about sound propagation and cancellation. "Kids were simply amazed by the sound generated by a spinning wrinkled pipe" said the volunteer Valeria De Giorgi. Demonstrations of acoustic applications such as tympanometry, acoustic reflexes, ultrasound imaging of the carotid artery and elastography were very popular not just among kids, but for adults as well. It was not surprising that in such crowded environment the most appreciated items were the noise cancellation headphones. One of the ASA volunteers, Felicia Doggett, said she loved to see the reaction on the children's faces when the power was turned on and the background sound all but disappeared. Twenty volunteers made the ASA booth a great success. Event photos and hands-on activities will be available from the Women in Acoustics website (http://acosoc.org/WIA/).

Diego Turo is explaining to children how noise cancellation headphones work.

ASA Announcements

***Acoustics Today* regularly publishes announcements of ongoing and future activities that may be of interest to the acoustics community. Anyone having an announcement they would like to have considered for inclusion should send the relevant information via e-mail to the Editor (apopper@umd.edu), with a copy to the ASA Publications Office (maryguillemette@acousticstoday.org). The Editor and the Publications staff will routinely rewrite or rephrase whatever is sent to make it compatible with the format of *Acoustics Today*.**

I am very excited and honored to be appointed as the first *Acoustics Today* Intern (ATI). I am in the final year of my NSF-funded postdoctoral fellowship at Brown University and at the University of Massachusetts Dartmouth. I have been an active member of the ASA since my first year of graduate school at the University of Hawaii. Over the years I have enjoyed becoming more active with the Society, both at meetings and with the Journal, and value everything it has given me in my development as a scientist. Becoming an ATI is an exciting opportunity, and I look forward to helping further promote *Acoustics Today*.

My interest in acoustics began at an early age. In an attempt to deter the neighbor's dog from traipsing through his garden, my father installed an ultrasonic dog deterrent outside our home. I told my parents I could hear the deterrent; my parents told me I was crazy. After a thorough (for a seven year old) World Book and Encyclopedia Britannica search, I learned about species and age differences in hearing and proved to my parents that no, I was indeed, not crazy.

My love of bioacoustics continued throughout university. I attended Boston University, majoring in biology with a specialization in marine science. During my semester "abroad" at the Marine Biological Laboratory in Woods Hole, I took a course on marine mammals and learned about echolocation and research using DTAGs. At the end of the course, we took a field trip to Dominica to study sperm whales. I chose to work on a project investigating the timing and pattern of click production among individuals. From the moment I heard my first hydrophone recording I was hooked. I returned from my semester fascinated with echolocating whales and digested all the literature I could find.

After graduation I worked for one year aboard various fishing and marine construction vessels in New England and the Gulf of Mexico as a fisheries and endangered species observer, and then spent two years as a high school teacher in Ocala, Florida, where I taught introductory biology, AP biology, and marine science. I also began consulting with the National Science Teachers Association (NSTA) as a curriculum developer. This began my passion for scientific education and outreach and helped solidify the importance of effective scientific communication to people of all ages, backgrounds, and abilities.

Despite my love of teaching, the allure of research led me to graduate school. In 2007, I began my Ph.D. at the University of Hawaii with Professor Paul Nachtigall. Working in collaboration with an incredible network of international researchers, animal trainers, and facilities, I participated in research investigating odontocete sound production and hearing using hydrophone arrays and auditory evoked potentials. Ultimately my research narrowed to investigating the dynamics of echolocation in odontocetes, and I defended my thesis in 2012.

I decided to continue my research on the dynamics of echolocation with a different species and in a different medium. I am currently an NSF-funded Postdoctoral Fellow working on a project titled "Understanding bat biosonar performance using the Cramér-Rao lower bound and adaptive beamforming." This interdisciplinary fellowship allows me to work with two mentors at two different institutions: Bioacoustician Professor James Simmons at Brown University and Signal Processing Engineer Professor John Buck at the University of Massachusetts Dartmouth. Both are Fellows of the Society.

My role with *Acoustics Today* will be promoting the magazine through our brand-new Twitter account, @acousticsorg. The editorial team understands the importance of an active online presence, and we look forward to using our twitter account to publicize articles in *Acoustics Today*, connect with acousticians worldwide, and help make the science of acoustics accessible to everyone.

If you'd like to learn more about me, I encourage you to check out my website at www.laurakloepper.net. Most importantly, I encourage you all to follow @acousticsorg on Twitter!

- *Laura Kloepper*

Acoustics Today Interns

Acoustics Today has openings for additional *Acoustics Today* Interns (ATI). This is an opportunity for graduate student and early career acousticians (individuals within three years of their terminal degrees) who are members of ASA to serve the Society in a unique and different way, and, at the same time, gain experience in publication of a major scientific magazine. Intern appointments will be for one year and will be expected to devote 10-20 hours/month to their internship responsibilities.

Interns will work directly with an individual mentor in ASA on a specific project directly related to the magazine. Mentors might be the *Acoustics Today* editor, publications manager, IT manager, etc. The specific role of each ATI will depend on her/his interests and experience and the needs of the magazine. The expectation is that the interns will enhance the value of the magazine by taking on specific tasks. For example, an ATI intern may be assigned gathering and writing sort news articles that will appear on the forthcoming *Acoustics Today* web site and/or in the magazine, helping *Acoustics Today* develop a presence in social media, etc.

Interns will be selected competitively the *Acoustics Today* Advisory Committee of ASA. Selected individuals will receive a small honorarium at the end of their internship as well as free registration at ASA meetings (if they attend) while they are interns. Interns will also be listed on the magazine masthead during their internship and will be invited to participate in meetings of the Advisory Committee.

Individuals interested in becoming *Acoustics Today* Interns should contact the magazine editor to discuss their interests and for an application packet (apopper@acousticstoday.org).

Book Reviews

These reviews of books and other forms of information express the opinions of the individual reviewers and are not necessarily endorsed by the Editorial Board of the *Journal of Acoustical Society of America* and *Acoustics Today*.

Philip L. Marston, Book Review Editor

1

Book Review

REVIEW BY
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High Intensity Focused Ultrasound in Medicine

Editor: L. R. Gavrilov
Publisher: PHASIS (www.phasis.ru)
ISBN: 978-5-7036-0131-2
Pages: 656 pp.
Binding: Hardcover
Publication Date: Moscow 2013
Price: 1300 rub

The author of the monograph is Leonid R. Gavrilov, D.Sc., Ph.D., Principal Research Scientist of the N.N. Andreyev Acoustics Institute, Moscow, Russia. One of the experienced Russian experts in medical ultra-sound, he began investigating applications of High Intensity Focused Ultrasound (HIFU) in medicine and physiology in the late 1960s. The monograph summarizes the results of investigations carried out in this field, including the very first studies performed in the USA by Professors W. Fry and F. Fry, work conducted in the USSR in the 1970s and 1980s (almost unknown to the colleagues in the West), and more recent studies performed in the USA, Europe, and Asia.

The main content of the monograph is the investigation of the physical and technical foundations of HIFU applications in medicine. The potential to focus ultrasound energy deep in the human body to noninvasively target and ablate remote tissue sites without making any incisions or causing harm to other organs and tissues is extremely important in medicine. The book particularly is devoted to active applications of HIFU that aim to induce various biological effects, such as stimulating neural structures, increasing the permeability of cell membranes, and generating local thermal necrosis of tissues.

Especially during recent decades, the successes achieved in HIFU applications are very impressive. Currently, MR-guided focused ultrasound has been approved in the USA and other countries for the treatment of uterine fibroids. A similar approach has been approved in Europe for the treatment of pain due to metastatic bone cancer. HIFU devices are also used clinically for noninvasive, minimally traumatic prostate surgeries and for treating various types of cancer (kidney and liver, breast, sarcoma of soft tissue, etc.). Several tens of thousands of cancer patients across several countries have been treated with HIFU over the last 10–15 years. There are clinical trials for the treatment of low back pain, tremor, and other neurological disorders. HIFU has also been demonstrated as a potential treatment for many other applications: control of bleeding, vascular effects, dissolution of blood clots to restore flow through blocked vessels, liposuction, targeted drug delivery, gene therapy, and manipulation of neural structures. Finally, there are good prospects for HIFU in cardiology and neurosurgery despite the presence of acoustic barriers such as the skull and ribs. All of these possible applications are discussed in the book.

The monograph begins with a foreword written by the scientific Editor, the President of the Russian Acoustic Society and an Academician of the Russian Academy of Sciences, Victor A. Akulichev. Another foreword is written by the author. The book includes four chapters, a list of publications, and a subject index.

Chapter 1 is devoted to the physical foundations of focused ultrasound as applied to various fields of medicine, with a consideration for the mechanisms underlying biological effects. The basic relations for a single focusing radiator are given along with the acoustic parameters of biological tissues. Other topics related to the physical actions of ultrasound include thermal effects, mechanical effects including cavitation, radiation forces, acoustic streaming, microstreaming, shear stresses, and chemical effects. Safety aspects and threshold doses for ablation are also discussed.

Chapter 2 is devoted to how ultrasound can be focused in tissues, with consideration of possible focusing systems. Among these systems are single-element transducers (either curved or flat with acoustic lenses) and powerful, multi-element phased arrays. Both linear and two-dimensional arrays are described, and two-dimensional arrays with randomly distributed elements are emphasized as a subject of particular scientific interest to the author.

In Chapter 3, methods for generating and controlling ultrasound are considered. The tissue-mimicking phantoms are discussed as well as approaches for monitoring and controlling temperature and cavitation. Because the irradiation of tissue with focused ultrasound is inherently noninvasive, it would be ideal to use remote and non-damaging methods of feedback and control. Therefore, noninvasive methods for measuring acoustic fields, cavitation, and temperature in biological tissues are considered in detail.

Finally, Chapter 4 discusses numerous applications of high intensity focused ultrasound in clinical and experimental medicine. Applications in neurosurgery with ultrasound radiation through an open or intact skull are considered in addition to other types of surgery that require sonication through the rib cage. The surgical applications discussed include hyperthermia of tumors, sonosensitisation and sonodynamic therapy of tumors, treatment of prostate tumors, control of bleeding, vascular effects, treatment of blood clots, drug delivery, gene therapy, reversible changes in neural structures, and neuromodulation of brain structures. Other applications are also described involving ophthalmology, cardiology, uterine fibroids, liposuction, intervertebral disks, essential tremors, and physiotherapy. The author is known as an expert in the application of focused ultrasound for activation of different peripheral receptor structures and the use of these effects for diagnosis of various skin, neurological and hearing diseases; accordingly, this field of investigation is described in detail. The conclusive part of this chapter includes a tabular summary of biological effects of HIFU, associated mechanisms, and also prospective directions of future work.

The length of the book is 656 pages, including 128 figures and 1140 references. On the very last page the author notes that the rate of progress for HIFU applications in medicine is increasing very rapidly, as indicated and by the corresponding number of publications each month. Consequently, even the reasonably large size of the book did not permit the inclusion of many very important topics that are essential to the field of medical ultrasound. Building on this statement, it is worth noting that a separate book could be written on investigations of nonlinear effects arising with the use of HIFU. In fact, in modern devices used in ultrasound surgery, the intensity in the focal region often reaches tens of kW/cm^2, which leads to the generation of higher harmonics in the propagating wave, distortion of its profile, the formation of shocks, and additional absorption of wave energy at the shock fronts. In these cases, local and very fast heating can occur—overheating of tissues to temperatures higher than 100° C and the initiation of boiling are possible within a few

Continued on page 73

2 Book Review

REVIEW BY
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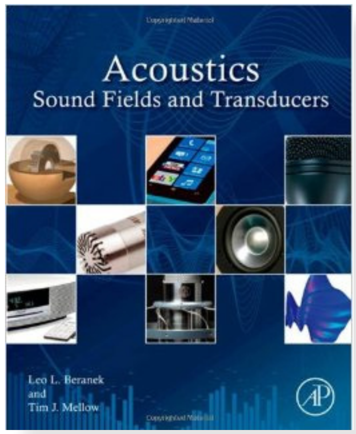


Acoustics: Sound Fields and Transducers

Authors: Leo L. Beranek and Tim J. Mellow
Publisher: Academic, an imprint of Elsevier
ISBN: 0123914213
Pages: 492 (with 281 illustrations)
Binding: Hardcover
Publication Date: 2012
Price: $119.95

Acoustics: Sound Fields and Transducers is an update/sequel to the legendary 1954 work Acoustics by Leo Beranek. It contains more recent and additional material, including material that is difficult to find elsewhere. Some examples of the latter are a discussion of the "slip" boundary condition in narrow tubes (Chap. 4), cell phone acoustics (Chap. 8), and steps to produce satisfactory listening room acoustics (Chap. 11). However, some topics like noise control, hearing, speech, and psychoacoustics are not carried over into the new edition.

The authors clearly define the scope of the work, covering transducers and sound fields in the audio range of frequencies and sound propagation in air. Thus the special properties of infrasonic, ultrasonic, and underwater transducers are not included as well as underwater sound propagation.

The book will be of interest to three classes of reader: Those who manufacture transducers (industrially or in-house), those who wish to understand transducers and wave propagation (students and researchers), and those who have transducer applications in mind (e.g., in theaters, public address systems, home entertainment). Acoustical consultants may be included in the last group. The book will serve as an informative text to both the novice and expert and as a handbook for information on specific issues.

The mathematical background level required of the reader varies with the nature of the text. In the first part of the book, dealing mostly with transducers, the level of a senior electrical engineering student should be sufficient, but in the latter part, dealing with fields, expertise at more advanced levels is required. A Green's function appears for the first time in Chap. 13.

The introductory chapters (Chaps. 1–4) prepare the reader for the advanced analyses to follow later. Here applicable acoustical terminology is carefully defined. Then the discussion proceeds to the wave equation in various coordinate systems, mechanical and acoustical circuit elements, impedances and admittances and their interconversion, monopole and dipole sources in various configurations, directivity, viscous and thermal losses, and application to several familiar examples. Here "directivity index" and "directivity factor" are defined, and several directivity patterns for familiar configurations are shown.

Chapters 5–9 describe transducers in detail (microphones, loudspeakers, loudspeaker systems, cellphones, and horns). All follow a common pattern. A phenomenological description of the transducer is given and then details of its construction and component parts, together with photographs and sketches. The governing equations lead to comprehensive small-signal circuit models, which are often later simplified for special cases. The models are used to determine specifications like input and output impedance, frequency response, efficiency, and other specifications as applicable. The issue of directivity is referred back to the discussions of Chap. 4. The topic of nonlinearity is limited to loudspeakers, horns, and large-amplitude waves. Metrology issues, e.g., transducer calibration, lie beyond the scope of the book.

Chapter 5 deals with microphones with emphasis on pressure-gradient and combined pressure and pressure-gradient microphones. Because these microphones are highly directional, directivity patterns are shown. However, the authors do not mention that pressure microphones also have a directional response, which leads to a distinction between "pressure" and "free-field" microphones. Further, the excellent description of microphone reciprocity calibration is not carried over from the 1954 edition.

Chapters 6 and 7 describe loudspeakers and loudspeaker systems. The authors demonstrate that the low-frequency drive unit can be completely modeled by just six "Thiel–Small" parameters. If these are not provided by the manufacturer, the authors show how they can be measured in the laboratory. To augment low-frequency response, the authors describe in great detail the closed-box baffle, the bass-reflex enclosure, and the transmission-line enclosure and include a nice discussion of enclosure materials. Because "loudspeaker enclosures are the subject of more controversy than any other item connected with modern high-fidelity music reproduction," the authors offer the advantages and disadvantages of the various enclosures to assist the enclosure designer. The discussion concludes with crossover filters.

The brief Chap. 8 on cellphone acoustics is mostly descriptive but includes a discussion of approval ratings ("3GPP" Technical Specification).

Chapter 9 describes parabolic, conical, exponential, and hyperbolic horn loudspeakers, both infinite and finite, together with their advantages and disadvantages. They will be of interest to those requiring large acoustic power radiated with some control over sound direction (e.g., in theaters, concert halls, sports arenas). The chapter includes an extended discussion of horn materials and their impact upon performance.

Chapters 10 and 11 will be of interest to those designing enclosures and listening rooms. Here "enclosures" has a different meaning from that previously, namely the space surrounding the source and listener. Normal modes and reverberation are the key concepts; Chap. 10 is concerned with the concert hall and Chap. 11 with the living room. The time-honored equations of Eyring and Sabine are discussed in detail. The authors point out the subjectivity of response. In other words, satisfactory listening comprises a partnership, so to speak, among the source, listening space, and human ear.

The mathematically demanding Chaps. 12 and 13 discuss radiation and scattering of sound, Chapter 12 by the boundary value method and Chapter 13 by the boundary integral method. In the boundary value method, solutions of the wave equation plus boundary conditions are found for several geometries like cylinders, spheres, and special geometries. Some of the latter have practical applications. For example, radiation from a point source on a sphere can be used to model "the diffraction effects of the human head on sound arriving at one ear." In the boundary integral method, solutions are based on the Rayleigh integral, Green's functions, and the Kirchoff–Helmholtz integral for various geometries and coordinate systems. Here the authors distinguish between a "rigid object," where the velocity distribution is given over the surface, and a "resilient object," where the pressure distribution is given over the surface. It is up to the interested reader to determine whether any of the preceding solutions can be applied to underwater sound. The chapter briefly mentions the principle of reciprocity, near-field holography, and time-reversal.

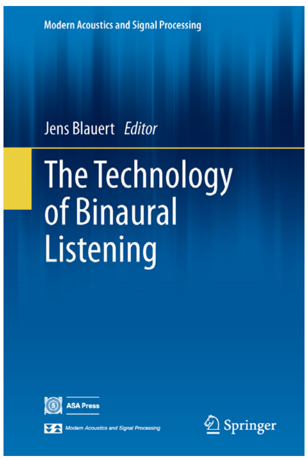
The final Chap. 14 is a review of state variable theory as applied to acoustics, especially useful for the development of computer codes. Several worked examples are based on a loudspeaker in an enclosure with a bass-reflex port.

The reader will appreciate the clarity of writing and attention to technical detail. In sum, this highly recommended book is a treasure of information and problem-solving technique for both the novice and expert in the areas of acoustical transducers and fields.

NEW Books from ASA Press

ASA Press is a meritorious imprint of the Acoustical Society of America in collaboration with the major international publisher Springer Science + Business Media. All new books that are published with the ASA Press imprint will be announced in Acoustics Today. ASA Press books are selected by the ASA Press Editorial Board and then published through an agreement with Springer. ASA Press will publish books of broad interest to members of the acoustics community. Individuals who have ideas for books should feel free to contact the ASA Press Publications Office to discuss their ideas.

The first books from ASA Press are listed below.

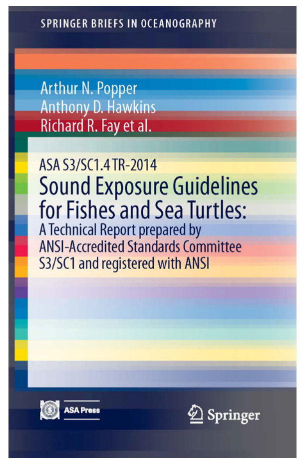


The Technology of Binaural Listening

Editor: *Blauert, Jens*
Publisher: *Springer Publishing*
www.springer.com/engineering/BOOK/978-3-642-37761-7
ISBN: *978-3-642-37762-4*
Pages: *511 pp., 198 illus.*
Available Formats:
eBook $139.00 and Hardcover $179.00
Publication Date: 2013

This book reports on the application of advanced models of the human binaural hearing system in modern technology, among others, in the following areas: binaural analysis of aural scenes, binaural de-reverberation, binaural quality assessment of audio channels, loudspeakers and performance spaces, binaural perceptual coding, binaural processing in hearing aids and cochlea implants, binaural systems in robots, binaural/tactile human-machine interfaces, speech-intelligibility prediction in rooms and/or multi-speaker scenarios. An introduction to binaural modeling and an outlook to the future are provided. Further, the book features a MATLAB toolbox to enable readers to construct their own dedicated binaural models on demand.

ASA S3/SC1.4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI



Series: Springer Briefs in Oceanography

Authors: Popper, A.N., Hawkins, A.D., Fay, R.R., Mann, D., Bartol, S.,Carlson,Th., Coombs, S., Ellison, W.T., Gentry, R., Halvorsen, M.B., Løkkeborg, S., Rogers, P., Southall, B.L., Zeddies, D.G., Tavolga, W.N.
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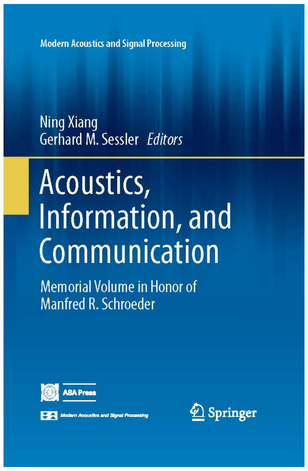
Publication Date:
Due June 30, 2014

This Technical Report presents the outcome of a Working Group that was established to determine broadly applicable sound exposure guidelines for fishes and sea turtles. After consideration of the diversity of fish and sea turtles, guidelines were developed for broad groups of animals, defined by the way they detect sound. Different sound sources were considered in terms of their acoustic characteristics and appropriate metrics defined for measurement of the received levels. The resultant sound exposure guidelines are presented in a set of tables. In some cases numerical guidelines are provided, expressed in appropriate metrics. When there were insufficient data to support numerical values, the relative likelihood of effects occurring was evaluated, although the actual likelihood of effects depends on the received level. These sound exposure guidelines, which are based on the best scientific information at the time of writing, should be treated as interim. The expectation is that with more research the guidelines can be refined and more cells in the tables completed. Recommendations are put forward defining the research requirements of highest priority for extending these interim exposure guidelines.



Acoustics, Information, and Communication
Series: Modern Acoustics and Signal Processing

Memorial Volume in Honor of Manfred R. Schroeder

Authors: Xiang, Ning, Sessler, Gerhard M. (Eds.)
Publisher: Springer Publishing
www.springer.com/physics/classical+continuum+physics/book/978-3-319-05659-3
ISBN: 978-3-642-37762-4
Pages: 5412 p. 164 illus., 29 illus. in color
Available Formats: eBook $139.00 and hardcover $179.00
Publication Date: 2014

This book explores the life and scientific legacy of Manfred Schroeder through personal reflections, scientific essays, and Schroeder's own memoirs. Reflecting the wide range of Schroeder's activities, the first part of the book contains thirteen articles written by his colleagues and former students. Topics discussed include his early, pioneering contributions to the understanding of statistical room acoustics and to the measurement of reverberation time; his introduction of digital signal processing methods into acoustics; his use of ray tracing methods to study sound decay in rooms; and his achievements in echo and feedback suppression and in noise reduction. Other chapters cover his seminal research in speech processing including the use of predictive coding to reduce audio bandwidth which led to various code-excited linear prediction schemes, today used extensively for speech coding. Several chapters discuss Schroeder's work in low-peak factor signals, number theory, and maximum-length sequences with key applications in hearing research, diffraction gratings, artificial reverberators, and de-correlation

Continued on page 73

Laymon N. Miller

1918-2013

Laymon N. Miller passed away on 21 October 2013 after a 37-year career in noise and vibration control.

He participated in a diverse range of projects starting with the acoustic homing torpedo developed in 1942 at the Harvard Underwater Sound Lab; researched methods to predict noise from fans, cooling towers, and other mechanical equipment; helped usher in the jet age for the Port of New York Authority in the late 1950's; developed subway vibration isolation and HVAC noise control for New York's Philharmonic Hall (later called Avery Fisher Hall); provided noise control for manufacturing plants aimed at meeting OSHA employee noise exposure regulations; and created the first commercial training seminars in noise and vibration control, among numerous other achievements. During his 27 years at Bolt, Beranek and Newman (BBN), Laymon completed nearly 2,000 consulting assignments. He modestly described his life and accomplishments as "a collection of happy and rewarding surprises.

Laymon was one semester short of completing his Ph.D. at the University of Texas when Professor Ted Hunt selected him (at the suggestion of Professor Charles Boner) to go to Harvard University in October 1941 to work on acoustic homing torpedoes. After the war the Harvard research group was transferred to Pennsylvania State University and became the Ordnance Research Lab (ORL), which later became the Applied Research Laboratory. Laymon decided to relocate with his Harvard colleagues rather than return to the University of Texas to complete his Ph.D. At ORL from 1946 to 1954, Laymon was head of the Acoustics Section and was on the faculty at the Engineering School, advancing from Assistant Professor to full Professor of Engineering Research.

Leo Beranek of BBN recruited Laymon in 1954 to work there, where he remained until retirement in 1979. At BBN, Laymon's projects included both practical consulting and research and development. His research work included the acoustic characteristics of wind tunnel noise control for subsonic, sonic, and supersonic speeds and the generation of cooling tower noise. This latter research resulted in an industry standard reference book for engineers and specifiers.

During a BBN sabbatical in 1968, Bill Cavanaugh suggested to Laymon that he develop a course in practical noise control techniques. Laymon developed the course material, and from 1969 to 1979 traveled the country with a Winnebago trailer outfitted with acoustic instruments, teaching the class to hundreds of engineers, architects, and facility managers.

Upon retirement in 1979, Laymon remained active volunteering his time with community, religious, and cancer advocacy groups. His generosity was extended to the National Council of Acoustical Consultants (NCAC) for which he wrote nearly 60 articles between 1994 and 2013 for the organization's Newsletter. His writings, along with his collected industry publications, will be released in book form by NCAC in 2014.

Laymon became a member of the Acoustical Society of America (ASA) in the late 1940s and was elected Fellow in 1956. He was a member of the ASA Committee on Noise from 1958 to 1961 and Technical Editor of NOISE Control magazine from 1960 to 1961.

Laymon was the recipient of many awards in recognition for his professional contributions. He became Board Certified by the Institute of Noise Control Engineering (INCE) in 1993. NCAC made Laymon an Honorary Member in 1994. He gave the "Distinguished Lecture" at the 75th Anniversary ASA meeting in 2004. NCAC again honored Laymon at its 2007 meeting with the "Paul Boner Award." In 2009, Laymon and his wife Lucy were honored with the INCE "2008 Outstanding Educator" Award.

Laymon is survived by his beloved wife Lucy, children Robert, Arthur, and Lucy Lee, 12 grandchildren, and 10 great-grandchildren.

Indeed his was a life of surprises. Those honored to know Laymon will miss his humbleness and willingness to share of his experiences and wisdom. The acoustics and noise control community has lost one of its founders.

Neil Thompson Shade
Acoustical Design Collaborative, Ltd
Peabody Institute of Johns Hopkins University

Article Citations Laymon N. Miller

Miller, L. and Beranek, L. (November 1957). "Noise characteristics of the Caravelle airliner and conventional propeller-driven aircraft," NOISE Control, 42-47.

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Miller, L. (February 1971). "Controlling air system and mechanical equipment noise," Heating, Piping and Air Conditioning, 63-70.
Miller, L. (January 2007). "The squeaky wheel and other serious things," Sound and Vibration, 40-50.

Book Reviews

Continued from page 67

milliseconds. The use of non- linear regimes of sonication could lead to the development of new HIFU technologies. The use of lithotripters and associated mechanisms for destroying stones and tissues is discussed very briefly in this book, as well as the problems of ultrasound medical metrology. However, it would be useful to have further description of precise methods for measuring and calculating the fields of focused ultrasound transducers. The list of similar gaps in the content of this book could be continued. So a task of future authors is to write new books and fill these gaps.

There are not that many books devoted to applications of HIFU in medicine. One such book is the second edition of Physical Principles of Medical Ultrasonics (edited by C. R. Hill, J. C. Bamber, and G. R. ter Haar, John Willey & Sons, London, 2004). This well-known book describes all aspects of medical ultrasound, including, first of all, its application for visualizing diagnostic information by acoustic methods. However, particular issues associated with HIFU applications are discussed rather briefly in this book. Another recent book is MRI-Guided Focused Ultrasound Surgery (edited by F. A. Jolesz and K. H. Hynynen, Informa Healthcare, USA, 2008). In accord- ance with its title, this book concentrates mainly on ultrasound surgery and the use of MRI in surgical procedures. These specific problems are not considered in details in the reviewed book by Dr. Gavrilov.

The monograph will be useful for Russian specialists in physical and medical ultrasound, for engineers developing new devices for medical applications, for physicians applying these devices in different fields of clinical and experimental medicine, and for physiologists and biophysicists.

Students and graduate students of all these specialties will also find the book to be useful. A characteristic feature of the book is that it is written in plain and clear language understandable to representatives of these different specialties. Thus, this informative and useful book certainly merits translation into English.

NEW Books

Continued from page 71

techniques for enhancing subjective envelopment in surround sound. In style, the articles range from truly scientific to conversationally personal. In all contributions, the relationship between the current research presented and Manfred Schroeder's own fields of interest is, in general, evident. The second part of the book consists of Schroeder's own memoirs, written over the final decade of his life. These recollections shed light on many aspects not only of Schroeder's life but also on that of many of his colleagues, friends, and contemporaries. They portray political, social, and scientific events over a period that extends from pre-war to the present. These memoirs, written in an inimitable and witty style, are full of information, entertaining, and fun to read, providing key insight into the life and work of one of the greatest acousticians of the 20th century.

ACOUSTICS TODAY RECRUITING AND INFORMATION CLASSIFIED ADVERTISEMENTS:

Positions Available/Desired and Informational Advertisements may be placed in ACOUSTICS TODAY in two ways: — display advertisements and classified line advertisements.

Recruitment Display Advertisements:

Available in the same formats and rates as Product Display advertisements. In addition, recruitment display advertisers using 1/4 page or larger for their recruitment display ads may request that the text-only portion of their ads (submitted as an MS Word file) may be placed on ASA ONLINE — JOB OPENINGS for 2 months at no additional charge. All rates are commissionable to advertising agencies at 15%.

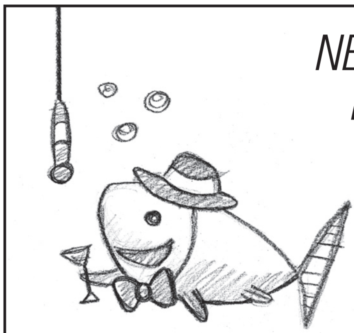
Classified Line Advertisements:
2014 RATES: Positions Available/Desired and informational advertisements

One column ad, $38.00 per line or fractions thereof (44 characters per line), $200 minimum, maximum length 40 lines; two-column ad, $50 per line or fractions thereof (88 characters per line), $350 minimum, maximum length 60 lines. (**Positions** desired ONLY – ads from individual members of the Acoustical Society of America receive a 50% discount)

Submission Deadline: 1st of month preceding cover date.

Ad Submission: E-mail: Christine DiPasca at cdipasca@aip.org; tel. : (516) 576-2434. You will be invoiced upon publication of issue. Checks should be made payable to the Acoustical Society of America. Mail to: Acoustics Today, Acoustical Society of America, 1305 Walt Whitman Road, Suite 300, Melville, NY 11747. If anonymity is requested, ASA will assign box numbers. Replies to box numbers will be forwarded twice a week. Acoustics Today reserves the right to accept or reject ads at our discretion. Cancellations cannot be honored after deadline date.

It is presumed that the following advertisers are in full compliance with applicable equal opportunity laws and, wish to receive applications from qualified persons regardless of race, age, national origin, religion, physical handicap, or sexual orientation.



Advertisers Index

Advertising Sales & Production

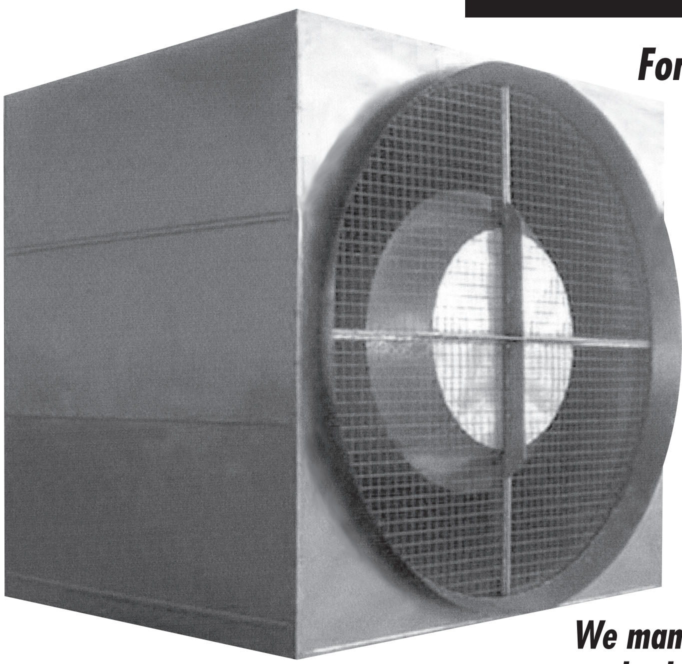
For advertisement reservations or further information please contact:

Debbie Bott
Advertising Sales Manager
Acoustics Today
c/o AIPP Advertising Department
1305 Walt Whitman Road
Suite 300
Melville, NY 11747-4300
Phone: (800) 247-2242
(516) 576-2430
Fax: (516) 576-2481
Email: dbott@aip.org

For advertisement production inquiries, please contact/send files to:

Christine DiPasca
Sr. Advertising Production Manager
Acoustics Today
c/o AIPP Advertising Department
1305 Walt Whitman Road
Suite 300
Melville, NY 11747-4300
Phone: (516) 576-2434
Fax: (516) 576-2481
Email: cdipasca@aip.org

PROVEN PERFORMANCE



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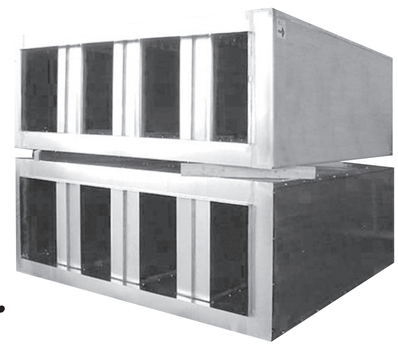

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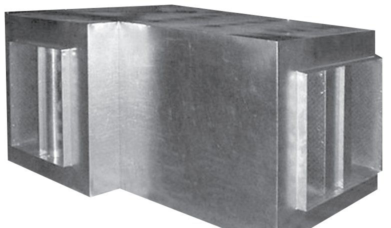

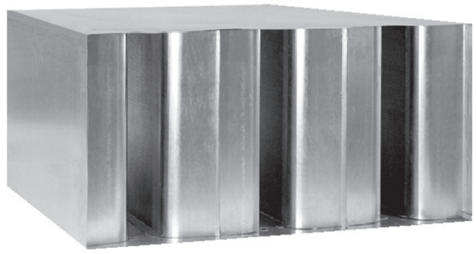

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