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Fernandez-Grande, Efren

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Efren Fernandez-Grande

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JASA REFLECTIONS

The *Reflections* series takes a look back on historical articles from *The Journal of the Acoustical Society of America* that have had a significant impact on the science and practice of acoustics.

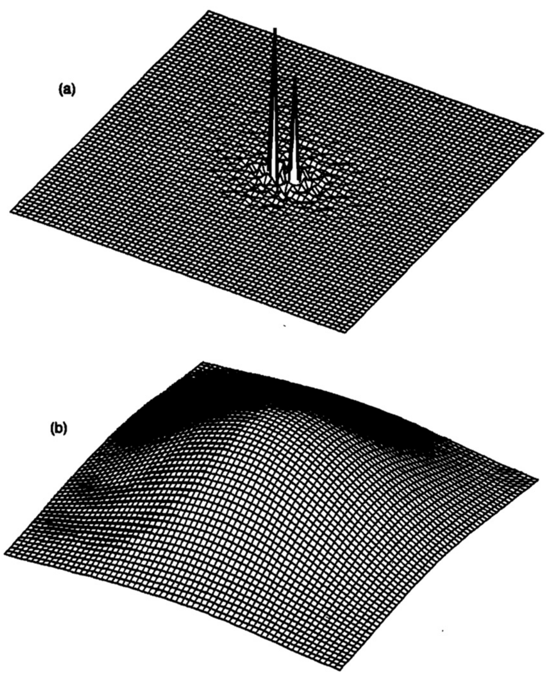
Four decades of near-field acoustic holography

Article: Nearfield acoustic holography: I. Theory of generalized holography and the development of NAH
Author: J. D. Maynard, E. G. Williams, and Y. Lee
Publication Date: October 1985 (JASA **78**, 1395); https://doi.org/10.1121/1.392911

THE KEY IDEA

It has been said that if a picture is worth a thousand words, then a hologram is worth $1000^{3/2}$ words. The principles of holography were discovered by Gabor in the field of optical microscopy, who reported that a three-dimensional representation of an object could be obtained from the interference between a reference beam of light and the waves scattered by the object.[1] Gabor was awarded the Nobel Prize in physics for his discovery. The fundamental principles of holography permeated rapidly from microscopy and optics into other fields, including acoustics. Early research on acoustical holography[2] aimed at capturing the properties of complex acoustic radiators and scatterers. Yet a fundamental issue encountered at the time was that most sound sources radiate waves that are larger than the source itself. This meant that the spatial resolution was too coarse and it was not possible to capture any meaningful details of the acoustic source. This was known as the wavelength resolution limit.

In a turn of profound scientific insight, a group of researchers put forward a groundbreaking idea: By capturing the evanescent acoustic fields radiated by acoustic sources, the wavelength resolution limit could be overcome, making it possible to image acoustic sources and scatterers with, in principle, infinite resolution.[3–5] They realized that although in optical holography evanescent wave information was not recorded, this need not be the case for acoustics. This idea challenged the established notions of holography and granted a major breakthrough in acoustics and physics in general. The resolution improvement is illustrated in Fig. 1.



Holographic reconstruction of two-point sources. (a) Near-field acoustic holography; (b) "conventional" holography (i.e., long-wavelength holography). Reprinted with permission from J. D. Maynard, E. G. Williams, and Y. Lee, J. Acoust. Soc. Am. 78, 1395–1413 (1985). Copyright 1985 Acoustical Society of America (Ref. 5).

ARTICLE OVERVIEW

The landmark article "Nearfield acoustic holography: I. Theory of generalized holography and the development of NAH" published in JASA in 1985,[5] presented in detail the newly discovered technique. It is an extraordinarily ambitious paper, which strikes a fine balance between breadth of scope and fine level of detail. It created the perfect substrate for all the research that followed in its aftermath. The paper introduces the principles of "generalized holography," demonstrating that including evanescent components in the hologram enables one to overcome the long-wavelength resolution limit. It presents a very clear and *general* formulation of the technique based on integral relations, spatial convolutions, and spatial Fourier transforms. It also presents a cornerstone of acoustic holography: it enables one to estimate all acoustic field quantities—sound pressure, particle velocity, sound intensity vector, the sound power radiated by a source, and its directivity pattern. It would seem fair to argue that an acoustic hologram is worth $5 \times 1000^{3/2}$ words. The paper also introduces the technique in cartesian, cylindrical and spherical coordinates, analyzes the sources of error and explains the practical implementation of the method (a 256-channel microphone array was developed, a tremendous technical feat at the time). The authors provide a series of examples of NAH reconstructions, demonstrating the extraordinary potential of this new technique and its underlying principles.

IMPACT OF THE ARTICLE

The implications of this work have been vast, and its applications continue to unfold. Numerous advances have been granted in terms of reconstruction methods,[6,7] measurement configurations,[8,9] and sensing principles;[10] too many to be listed here. The technique has enabled to address a large array of problems, ranging from fuselage vibration to tire-road interaction, design of loudspeakers, and radiation of classical guitars and of legendary historical violins.[9,11,12] Presently, NAH is enabling us to better characterize the acoustic properties of materials, analyze complex sound fields in rooms, understand principles of metamaterial design, or determine elastic properties of submerged bodies.[13,14] Furthermore, the formalisms developed in acoustic holography have been instrumental for advancing areas such as sound field control, sound field analysis and reproduction.[15]

The pioneering work from Maynard, Williams, and Lee continues to be crucial to advancing our field, as their method enables to examine complex acoustic phenomena that cannot be observed by means of conventional measurements or simulations. In the final paragraphs of their article, the authors point out that "holography provides the fastest, most thorough amount of information available per unit effort." The remark stands the test of time after almost four decades. There are no comparable techniques that confer so much information about a sound field, based on a measurement that lasts as little as a fraction of a second.

By EFREN FERNANDEZ-GRANDE
Department of Electrical Engineering, Technical University of Denmark, Kongens Lyngby, Denmark,

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