

A 150-MHz-Bandwidth Membrane Hydrophone for Acoustic Field Characterization

Paul Lum

Michael Greenstein

Edward D. Verdonk

Charles Grossman, Jr.

Thomas L. Szabo

To measure the beam parameters of intravascular ultrasound imaging transducers with operating center frequencies exceeding 20 MHz and beamwidths below 200 μm , a hydrophone with a spot diameter less than 50 μm and a bandwidth greater than 150 MHz is required. The hydrophone described in this article is a step towards meeting these requirements.

Diagnostic ultrasound imaging is used routinely in a growing number of medical applications. Hewlett-Packard manufactures a range of ultrasound imaging systems that use digital beamformers for cardiology and multipurpose imaging and mechanical beamformers for cardiology, general-purpose, and intravascular imaging.

At the heart of an ultrasound system is a transducer, an electroacoustic device that converts electrical signals into a focused mechanical wave and reconverts reflected mechanical echoes from organs and tissue for subsequent real-time image construction. The transducer is a resonant device that has a bandpass filter frequency response. Currently available transducers have a center frequency in the range of 2 to 30 MHz. A phased array of individual transducers, typically consisting of 30 to 300 elements, is electronically focused and steered to provide a beam with the dimensions desired for a selected medical application.

Current trends in imaging are to the following higher-frequency applications:

- Intravascular imaging for plaque detection in blood vessels such as the coronary arteries
- Contrast-agent-assisted harmonic frequency imaging to view blood flow and perfusion in the heart

- Small parts imaging for near-surface high-definition examination of burn injuries, skin lesions, and cancers
- Laparoscopic surgery (ultrasound-guided interventional surgery)
- Ocular imaging (high-resolution visualization of anomalies and repairs of the eye).

These trends pose challenges in the characterization of the transducers used. By law, ultrasound imaging system manufacturers are required to measure the acoustic output of their systems at the transducer. To characterize the acoustic waves of these systems, small calibrated transducers called hydrophones are used. To avoid altering the acoustic fields they are measuring, hydrophones must be as nonperturbing as possible and must far exceed the bandwidth and the spatial resolution of the transducers being measured. This paper describes a new membrane hydrophone that provides the performance needed for these exacting applications.

The hydrophones presently used in the industry have -3 -dB bandwidths of 15 to 20 MHz and effective spot sizes of 500 μm . They are appropriate for characterizing acoustic medical imaging transducers up to about 7 MHz. However, even transducers at these frequencies generate, through nonlinear propagation effects in water, higher harmonics that extend in frequency beyond the -3 -dB bandwidths of the available hydrophones. To fully characterize a transducer, detection of the fifth harmonic is needed. Furthermore, there are new ultrasonic imaging modalities, such as intravascular ultrasound (IVUS) in the 30-MHz frequency range with 50- μm wavelengths. These transducers cannot be adequately characterized by 15-to-20-MHz-bandwidth hydrophones. (IVUS gives a cross-sectional view of the interior of coronary arteries to assess coronary atherosclerosis.)

Peak pulse parameters calculated from hydrophones with inadequate frequency response show large errors. Hydrophones with effective spot sizes that are too large underestimate the critical parameter of peak pressure because they average the pressure over the hydrophone's active area.

The IEC¹ and NEMA² standards regulate the characterization of medical ultrasound transducers by specifying the

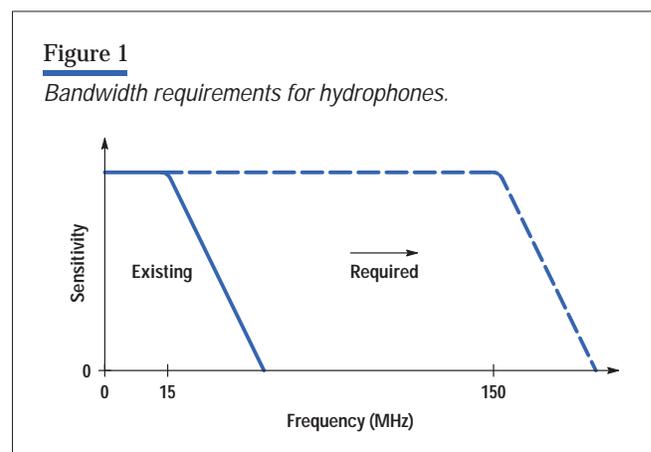
parameters of the hydrophones used to measure these transducers. The required effective spot diameter is 50 μm for a hydrophone to measure a 30-MHz IVUS transducer with a typical 1-mm aperture and a transducer-to-hydrophone range of less than 2 mm. For more details on transducer characterization, see the box on page 8.

In view of these considerations, there is an important need for hydrophones capable of characterizing transducers with frequency components in the range of 150 MHz and a spatial resolution of typically less than 50 μm . This is illustrated in **Figure 1**, which is a plot of sensitivity as a function of frequency for both existing and required hydrophones.

This article describes the modeling, fabrication, and initial characterization of a membrane hydrophone capable of meeting these more exacting bandwidth and spatial requirements. The hydrophone is fabricated from a 4- μm -thick film of spot-poled* PVDF-TrFE piezoelectric polymer material. It has on-membrane electronics, a -3 -dB bandwidth in excess of 150 MHz, and a measured effective spot diameter of less than 100 μm .³

* Poling refers to the process of aligning the directions of the ferroelectric domains in a ferroelectric material so that a net polarization occurs. The polymer material used for the hydrophone comes with random ferroelectric polarization. By applying an electric field at an elevated temperature we can rotate the directions of the individual polarization vectors so that they are all aligned along the electric field direction. The higher temperature lowers the work required. When the material returns to room temperature the domains stay aligned, thus creating an active region. Spot-poling is poling confined to selected areas.

Figure 1
Bandwidth requirements for hydrophones.



The Hewlett-Packard Medical Products Group Acoustic Output Measurement Laboratory

The control and display of acoustic output have important performance and quality implications for medical diagnostic ultrasound equipment. The acoustic output of these devices should be optimized to provide image quality sufficient for a clinician to make a diagnosis, while at the same time, must be limited to U.S. Food and Drug Administration (FDA) approved levels. The FDA has set limits for acoustic output, and requires reporting of maximum output levels before marketing these devices and as part of the device labeling. Output measurements on production units are performed to ensure manufacturing process control and to establish compliance with FDA Quality System Regulations (QSR). Recognizing that measurement of acoustic output is an essential part of the design, manufacture, and marketing of this equipment, the HP Medical Products Group (MPG) in 1985 established a dedicated, state-of-the-art, acoustic output measurement laboratory at Andover, Massachusetts.

Laboratory Description. The laboratory has instruments required to perform measurements of acoustic pressure, intensity, frequency, and power in the range of 1 to 20 MHz, and is staffed by managers, support engineers, and highly skilled measurement technicians.

The primary measurement system used to measure pressure, intensity, and frequency consists of a water tank, hydrophone, motorized precision positioning system, high-speed sampling oscilloscope, system controller, and associated measurement software. The positioning system provides repeatable positioning of the acoustic beam relative to the hydrophone in the water tank and allows automatic scanning of the acoustic field. The oscilloscope captures the hydrophone output and transfers the sampled data to the system controller for parameter computation (pressure, intensity, frequency).

A radiation force balance is used to measure total acoustic power. This device consists of a small sound-absorbing target attached to one arm of a microbalance suspended in a water column. To perform a power measurement, the source transducer is coupled to the water column and the acoustic beam is directed at the target. The resulting force on the target, as measured by the microbalance, is proportional to the total acoustic power.

The methodology for performing these measurements conforms to those specified in the *NEMA UD-2 Acoustic Output*

Measurement Standard, the *NEMA/AIUM Standard for Real-Time Display of Thermal and Acoustic Output Indices on Diagnostic Ultrasound Equipment*, and international standards.

Laboratory Mission. The laboratory's mission is fourfold. The first mission is to support the development of new ultrasound products. Before clinical studies, measurements are performed on prototype equipment to characterize the acoustic field, and maximum acoustic output is verified to be at or below FDA approved limits for pressure and intensity. Later, after more systems are manufactured, output control and display are optimized and validated, and additional measurements are performed to establish the output variability of newly designed products. Finally, production test protocols and test limits are established.

The second mission is to collect acoustic output data required for regulatory labeling. This includes collection of data for premarket notification and other international requirements.

The third mission is to support manufacturing engineering. The laboratory is responsible for addressing all aspects of acoustic output measurement related to FDA-GMP and ISO requirements, including the establishment of production test procedures and test limits and calibration and maintenance procedures of unique test equipment.

Finally, the laboratory is committed to advancing ultrasonic exposimetry, acoustic output measurement science, and associated measurement standards. The laboratory provides a real-world environment for the development of new measurement devices, such as the HP wideband hydrophone described in the accompanying article, and laboratory engineers are actively involved in national and international measurement standards committee work (NEMA, AIUM, IEC, etc.).

To accomplish these missions, the laboratory maintains close, cooperative working relationships with MPG's ultrasound product design team as well as MPG's manufacturing engineering and regulatory staffs.

Charles Grossman, Jr., Thomas L. Szabo,
Kathleen Meschisen, and Katharine Stohlman
Imaging Systems Division

Acoustics

The basic structure of a membrane hydrophone is shown in **Figure 2**. Here, a portion of a thin membrane is shown with an electrode and a trace on each side of the membrane. The center frequency is inversely proportional to the thickness of the piezoelectric membrane. The spatial resolution of the hydrophone improves as the diameter of the electrode decreases, and the sensitivity and bandwidth are determined by the piezoelectric coupling of the membrane. The active area of the hydrophone is determined by the overlap of the top and bottom electrodes. In practice, one of the electrodes is extended over a large portion of the membrane to serve as a ground plane.

Acoustic modeling was used to characterize the effects of spot size, film thickness, mass loading from the thin-film electrodes, and directional sensitivity (directivity). The major differences in the properties of the piezoelectric polymer materials between the copolymer PVDF-TrFE used here and the more commonly used PVDF are the increased dielectric constant, the increased effective coupling constant, and the decreased electrical loss tangent of the copolymer.

The thickness-mode resonant frequency, f_0 , of the membrane hydrophone is given by:

$$f_0 = \frac{c}{2t}, \quad (1)$$

where c is the acoustic velocity and t is the thickness of the membrane. This relation comes from the requirement that the thickness dimension of the membrane film must be a half wavelength. In general, it is important to have the thickness resonance of the membrane beyond the

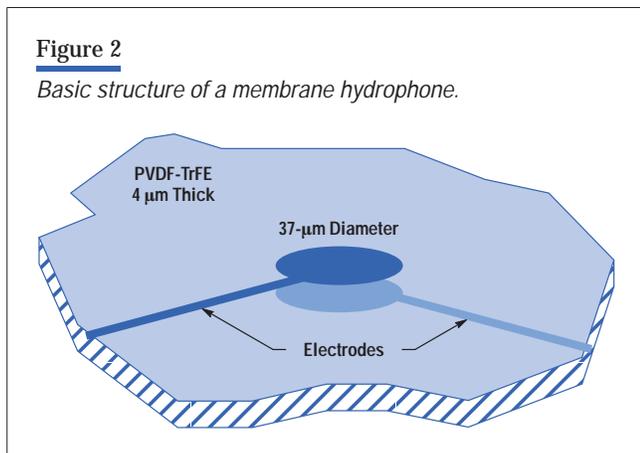
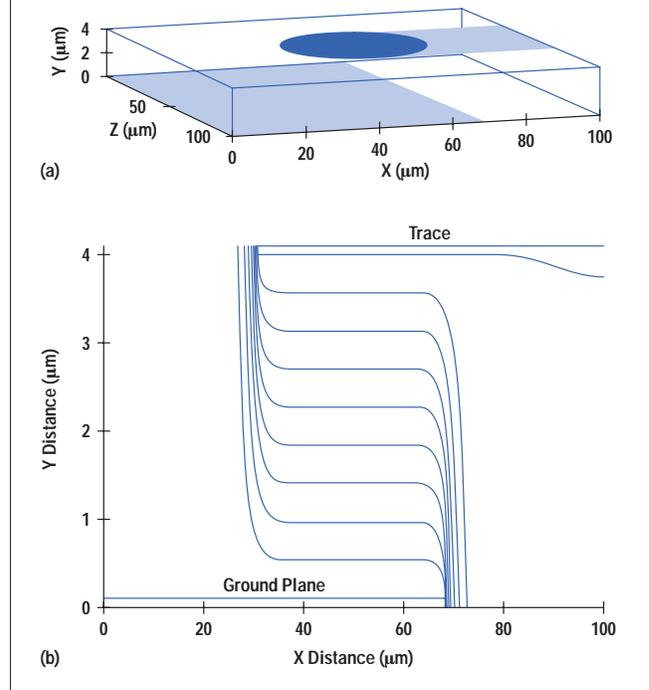


Figure 3

- (a) Hydrophone structure for 3D electrostatic modeling.
(b) Contours of constant potential at $Z = 50 \mu\text{m}$.



measurement range to maximize the flatness of the sensitivity. A 4- μm film satisfies this requirement by placing the thickness resonance frequency at 150 MHz. The thickness resonance is also affected by the mass of the metal electrodes. For a 4- μm membrane, conventional 3000 \AA electrodes degrade the peak frequency of the sensitivity and the fractional bandwidth. A choice of 1000 \AA for the electrode thickness is a good compromise between a corrosion-resistant electrode with adequate conductivity and adequate bandwidth.

Electrostatic Fringe Fields

During the spot-poling process, the applied electric fields fringe beyond the edge of the spot electrode and can pole areas of the piezoelectric polymer beyond the intended spot electrode. Electrostatic field modeling was used to model the electrical field patterns to estimate the extent of the fringe field. Voltages on the three-dimensional structure are specified and Poisson's equation is solved iteratively. The geometry of the model is shown in **Figure 3a**. A 37- μm -diameter electrode spot and trace

are patterned over a semi-infinite ground plane. These are on opposite sides of a 4- μm -thick polymer film. In **Figure 3b**, 10% incremental contour plots of the electrical potential are shown for a central cross section in the X-Y plane, through the trace at the top, the polymer film, and the bottom ground plane. An additional 10 μm is poled at greater than 50% of the maximum potential on the electrode. Therefore, this model predicts a larger total active diameter of about 50 μm .

Electrical Matching

The effects of spot size and film thickness are seen by approximating the electrical impedance by capacitive reactance. This reactance is:

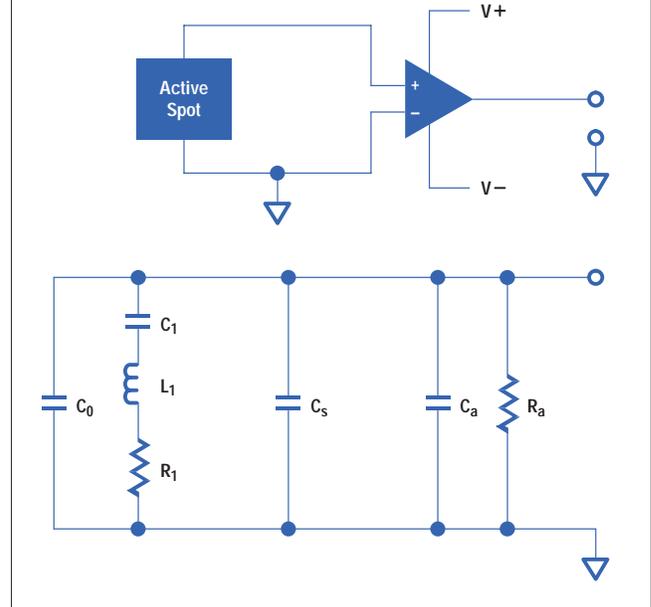
$$Z = \frac{-j}{2\pi f_0 C_0} = \left(\frac{-j}{c\epsilon} \right) \left(\frac{2t}{\pi D} \right)^2, \quad (2)$$

where t is the thickness, D is the diameter of the spot, ϵ is the clamped dielectric constant, and c is the speed of sound in the membrane. Thus the electrical impedance of the membrane hydrophone increases with the square of the membrane thickness and inversely with the square of the spot diameter. For a 4- μm -thick membrane with a 37- μm -diameter spot, Z is 100,000 ohms. This high impedance presents a challenge for matching the transducer to the 50-ohm impedance of the cable used to connect the hydrophone to an oscilloscope.

Figure 4 shows the schematic diagram and equivalent circuit for a membrane hydrophone with an adjacent amplifier. At the far left of the overall equivalent circuit is the equivalent circuit for the piezoelectrically active area resonator. This circuit yields two conditions for resonance. A series resonance condition exists when C_1 , L_1 , and R_1 resonate to produce an electrical impedance minimum, and a parallel resonance condition exists when the C_1 - L_1 - R_1 branch is inductive and tunes with C_0 to produce an impedance maximum. In the middle, C_s represents the stray capacitance of the connecting electrode. The adjacent amplifier is represented by a capacitance C_a and a real impedance R_a . Not shown is the 50-ohm coaxial cable that connects the amplifier output to additional electronic circuitry. On-membrane electronics are used to avoid corrupting the frequency characteristics and to match a 50-ohm cable properly.

Figure 4

Schematic and equivalent circuit for the membrane hydrophone.



Spatial Resolution

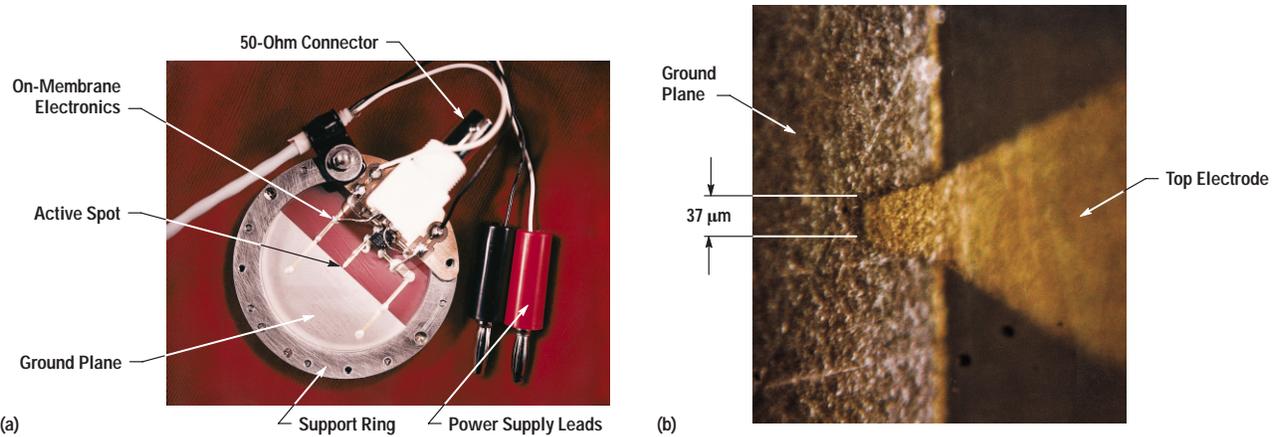
The spatial resolution of a hydrophone is determined by the effective spot size. The effective spot size is in turn determined by the geometric spot size and other electrical and acoustic factors. If the spot size is significantly larger than the size of the acoustic beam being measured, spatial averaging occurs (a hydrophone measures pressure, not energy). Averaging by the hydrophone results in overestimating the size of the beam and underestimating the absolute pressure levels of the beam. These two effects will be illustrated and discussed later in this article for both large-diameter and small-diameter hydrophones.

Fabrication

The fabrication of a membrane hydrophone begins with the raw PVDF-TrFE film in a roll form. An evaporator is used to deposit metal electrodes onto both sides of the film. Shadow masks establish the electrode patterns. One side is patterned for the active spot electrode and the on-membrane electronics connections. The other side is patterned for the ground plane. Alignment of the ground plane relative to the spot electrode is necessary to correctly establish the overlap of the spot electrode.

Figure 5

(a) Photograph of the rear side of the hydrophone. (b) Photomicrograph of the active spot, showing the 37- μm geometric diameter.



The membrane is then mounted onto a ring support structure. In its raw state, as received from the vendor, the piezoelectric PVDF-TrFE film is unpoled with unaligned ferroelectric domains. To align these domains and create the piezoelectric active area, the film is spot-poled at a temperature of 130°C and an electric field strength of 70V/ μm .

A film thickness of 4 μm and a spot size of 37 μm result in a device with an electrical impedance of about 100 kilohms. Such a hydrophone is not well-matched to the 50-ohm cable typically used to connect the hydrophone to an oscilloscope input. This substantial electrical impedance mismatch issue is resolved by mounting a wideband, low-distortion buffer amplifier directly on the membrane. The selected amplifier, a surface mount device, has a frequency response that is flat within ± 1 dB from dc to 500 MHz and an input impedance on the order of 450 kilohms. To avoid distorting the acoustic field, the amplifier is surface mounted directly onto the membrane at a distance of 10 mm from the spot electrode. The electronics are encapsulated with a cast backing of silicone resin that also acts to protect the fragile 4- μm -thick film. After the backing is cured, the hydrophone is characterized.

A photograph of the rear surface of the hydrophone is shown in **Figure 5a** with several of the key structures highlighted. Normally the back side of the hydrophone is encapsulated in a silicone gel to support the membrane and protect the electronics from the water environment.

The membrane is stretched taut over the 60-mm diameter stainless steel support ring. The ground plane can be seen on the bottom left half of the membrane. The active spot is at the end of the trace pointing toward the center of the membrane. The on-membrane electronics are located in the upper right portion of the photo, with the two power supply leads shown on the right side of the photo. The hydrophone is terminated into a standard BNC 50-ohm coaxial connector. **Figure 5b** is a photomicrograph of the active area. Here the top surface electrode is seen on the right as it tapers down to a 37- μm diameter. The ground plane is located in the left half of the picture, under the piezoelectric film, just overlapping the 37- μm -diameter spot. The spatial overlap of the top electrode and the ground plane defines the active spot, once it has been poled.

Bandwidth

One of the key design goals is a -3 -dB bandwidth of at least 150 MHz. Several potential methods for measuring the bandwidth include calibration against a known standard hydrophone, interferometry, reciprocity, and the nonlinear distortion method. The first three are generally accepted calibration methods but are currently limited to a maximum frequency of 50 MHz. The nonlinear distortion method, although not considered a standard method, is capable of measurements above 150 MHz, and was chosen to evaluate the new hydrophone.

In the nonlinear distortion method, a source transducer is used to produce nonlinear effects in the water propagation medium. In a fully developed shock wave, such as the familiar one generated by a jet airplane, a classic N wave, or N-shaped waveform, may be formed. The N wave gets its name from its very steep compressional rise time and its more gradual rarefaction fall time. As the waveform propagates, a shock front develops, which generates new frequency components not present in the original waveform. The frequency spectrum of an ideal N-shaped shock wave has frequency harmonics at multiples n of the fundamental, where $n = 1, 2, 3, \dots, \infty$. In the classic N wave, each harmonic amplitude falls off as $1/n$. Perfect N waves are rarely achieved in the fields of medical ultrasound transducers because of diffraction phase effects in the beam. However, nonlinear distortion methods can still provide an extremely broadband signal to aid in the evaluation of hydrophone bandwidth.

An imperfectly shaped N waveform is shown in **Figure 6a**. This waveform is from a 20-MHz, 6.4-mm-diameter transducer excited in a tone-burst mode, as recorded by an HP 54720A digital oscilloscope and an HP 54721A plug-in amplifier with a 1-GHz analog bandwidth. The hydrophone is placed at the focal plane distance of 19 mm. In the focal plane, the intensity is sufficient to exploit the nonlinear properties of water to generate useful nonlinear distortion. The waveform exciting the transducer is a 20-MHz sinusoidal tone burst. Because of the nonlinear properties of the water propagation medium, the positive

compressional half-cycles exhibit very fast rise times, while the negative rarefaction half-cycles exhibit slower fall times. The higher frequencies generated this way do not suffer significant propagation-related attenuation because they are generated right where they are detected.

The -3 -dB bandwidth can be estimated from the sharp compressional portion of this waveform. From the 10%-to-90% rise time, a bandwidth of 150 MHz is calculated. The related frequency spectrum is shown in **Figure 6b**. The harmonics from the fundamental at ~ 20 MHz up to ~ 800 MHz can be seen. The peaks, corresponding to the harmonics at 20-MHz intervals, show the extent of the nonlinear distortion of the waveform. Without the nonlinear distortion, most of the energy would be located at the fundamental frequency of 20 MHz. At ~ 700 MHz, the -3 -dB bandwidth of the buffer amplifier limits the measured frequency response of the hydrophone. Thus, this hydrophone can detect acoustic frequency components out to at least 800 MHz.

The superior bandwidth of this membrane hydrophone relative to hydrophones currently in use can be demonstrated by performing comparative measurements on acoustic fields generated by medical diagnostic ultrasound equipment. Comparative waveform measurements were made with a Hewlett-Packard SONOS 2500 diagnostic imaging system and a 5-MHz phased array transducer as the source. Two hydrophones were used to measure the acoustic waveform at focus. A calibrated reference

Figure 6

(a) Received nonlinear waveform from a 20-MHz transducer. (b) Spectrum of the nonlinear waveform with harmonics up to 800 MHz.

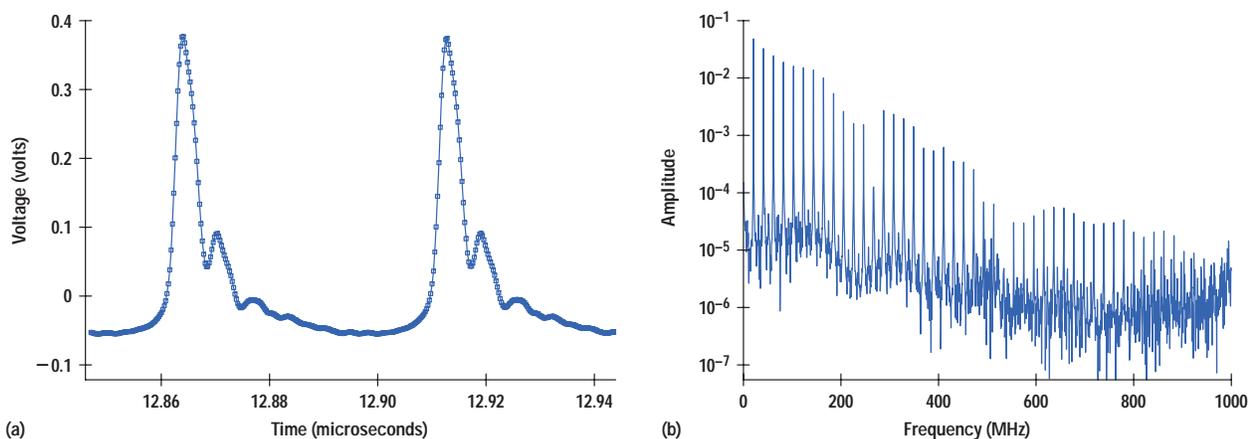
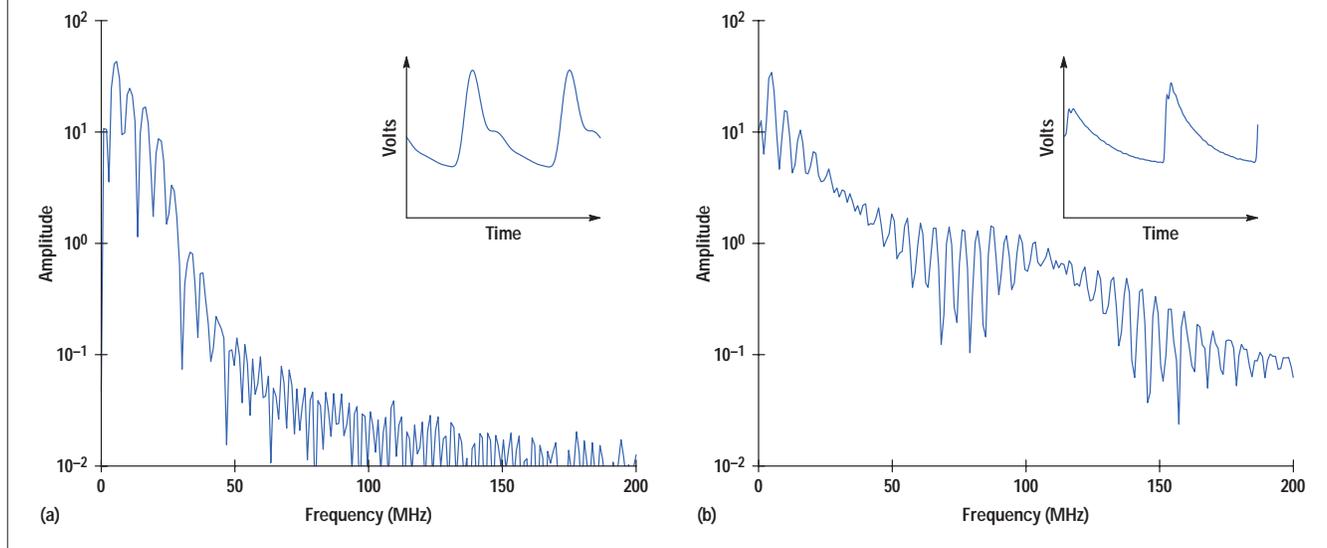


Figure 7

Waveforms (insets) and spectra for (a) 500- μm -diameter hydrophone and (b) new HP 37- μm -diameter hydrophone.



membrane hydrophone with a 500- μm spot diameter on a 25- μm -thick bilaminar PVDF membrane was compared with the new HP high-frequency membrane hydrophone with a 37- μm spot on a 4- μm -thick membrane. **Figure 7a** shows the frequency spectrum using the 500- μm -diameter hydrophone, and the inset shows the measured nonlinear waveform. The spectrum shows the fundamental at 5 MHz and three harmonics at 10, 15, and 20 MHz. **Figure 7b** shows the frequency spectrum using the new HP 37- μm -diameter hydrophone, and the inset shows the respective waveform that has greater detail and a sharper rise time because of the greater bandwidth. The spectrum shows the fundamental at 5 MHz and the subsequent 40 harmonics out to 200 MHz. This frequency data correlates well with the spectra shown in **Figure 6**, given the lower excitation frequency of the SONOS system.

Sensitivity

The sensitivity of a membrane hydrophone can be determined by two fundamental parameters. The first is the thickness resonance of the membrane film. The second is the response determined by the electrical and piezoelectric properties of the material. For a hydrophone the receive voltage sensitivity, M , is given by the ratio of the developed voltage to the incident acoustic pressure, that is, $M = V/P$.

Although the open-circuit voltage sensitivity is the most direct measure of the sensitivity of a hydrophone, it is difficult to measure with the new HP hydrophone and its required on-membrane amplifier. Consequently, the loaded-end-of-cable sensitivity, M_L (relative to 1 V/MPa), was measured and found to be -23 ± 2 dB, within -1.5 dB of the reference 500- μm -diameter hydrophone. This comparison was done with the reference hydrophone configured with a 6-dB external amplifier and the wideband hydrophone driving an external 25-dB amplifier. In each case the circuits are optimally tuned with the external amplifiers in place. Although sensitivity calibration measurements are needed out to 150 MHz, there is not yet a satisfactory calibration procedure for the required range.

Effective Spot Size

When the hydrophone diameter is significantly larger than the beam it measures, spatial averaging occurs. To compare the spatial resolution of the HP high-frequency hydrophone with a reference hydrophone with a 500- μm spot size, the tightly focused beam of a 20-MHz, 6.4-mm-diameter transducer was measured by both hydrophones close to the focal plane. The measured beam of this transducer at its focal length is close to the ideal predicted by theory provided that a sufficiently small hydrophone is used to make the measurement. The measured field can be

modeled to a good approximation as the spatial average of the theoretical field over the hydrophone area. Because of radial symmetry, the area averaging simplifies to a running mean across the theoretical beam.

Measured beamwidths for the two hydrophones are compared to theoretical calculations of the spatially averaged and unaveraged beamwidths in **Figure 8**. In **Figure 8a** the data from the 500- μm reference hydrophone is shown, and the comparable data for the HP hydrophone is given in **Figure 8b**. These curves demonstrate that the reference hydrophone underestimates the on-axis pressure at the beam peak by 40% and overestimates the beamwidth by 50%, whereas the new HP high-frequency hydrophone provides a faithful replica of the beam shape and pressure.

Angular measurement techniques can also be used to estimate the effective spot size of a hydrophone. In the angular response method, the hydrophone is swept through an arc about the reference transducer. In this way, directional response can be measured and used to estimate the effective diameter. In this method the actual beamwidths at -3 dB and at -6 dB are compared to those expected from theory. From the theoretical beamwidth, for a given frequency, the effective hydrophone spot diameter can be inferred from the beamwidth data. The same 20-MHz focused transmitter was used to perform a directivity

measurement. The resulting measured half angles, when applied to the theoretical model, indicate a spot diameter upper bound of 100 μm for the device measured.

Intravascular Ultrasound Application

As an example of the application of this new hydrophone, a 30-MHz IVUS catheter transducer excited by an HP IVUS system under normal system settings was characterized. In use, a stationary sheath is used to protect the intimal lining of the blood vessel (one monolayer of cells thick) from the rotating catheter and transducer. The sheath both attenuates and focuses the beam. In **Figure 9a**, the waveform is shown as received by the hydrophone after a 1.9-mm path in water. The hydrophone was carefully placed on the axis of sound propagation. The thick line is the waveform with the 110- μm -thick polymer sheath, and the thin line is the waveform without the sheath. The beam that is focused by the sheath arrives at the hydrophone earlier. The disparity in the rise and fall times of these signals is an indication that nonlinear distortion has developed in the water medium. The frequency spectra of these waveforms in **Figure 9b** indicate the presence of nonlinear distortion both with a sheath and without a sheath. There are frequency components of this waveform out to at least 150 MHz, which cannot be measured by a conventional 20-MHz-bandwidth hydrophone.

Figure 8

Linear scans of a 20-MHz ultrasound transducer beam with two hydrophones: (a) a 500- μm -diameter reference hydrophone and (b) the 37- μm -diameter HP hydrophone. In each case, the theoretical transducer beam shape, the theoretical beam shape as spatially averaged by the hydrophone spot size, and the discrete hydrophone measurement data are shown.

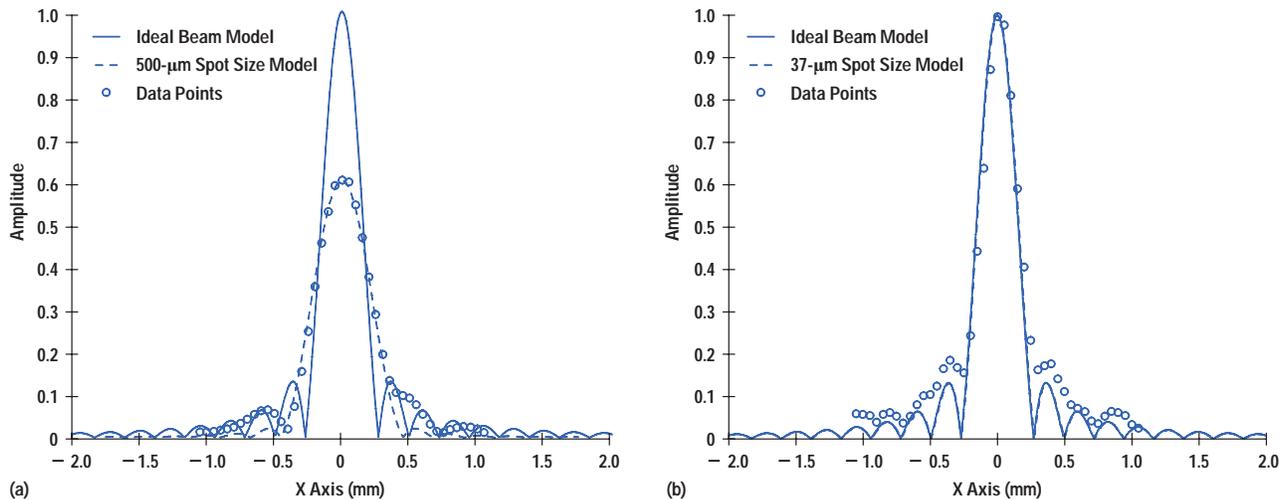
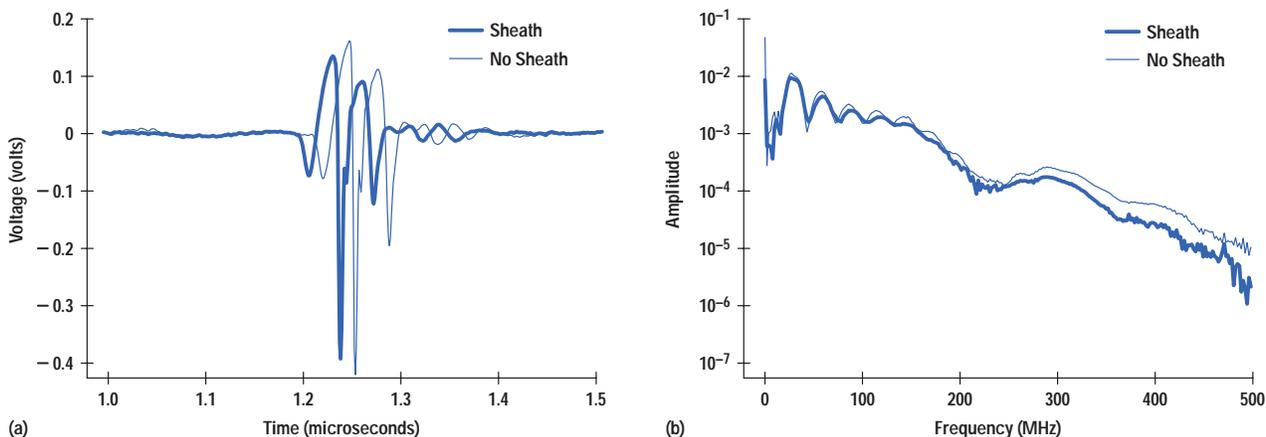


Figure 9

HP membrane hydrophone measurements of nonlinear data from a 30-MHz IVUS catheter. (a) Time-domain waveforms. (b) Frequency-domain spectra.



Summary

With the increasing use of intravascular ultrasound imaging transducers with operating center frequencies exceeding 20 MHz and beamwidths below 200 μm , smaller-spot-size and higher-frequency hydrophones are needed. Characterizing transducer acoustic pressure fields according to the AIUM/NEMA standards requires a hydrophone with a spot diameter less than 50 μm and a bandwidth greater than 150 MHz. The hydrophone described in this article is a step towards meeting these requirements.

Acoustic modeling was performed to provide a general guideline for selecting the membrane thickness, electrode diameter, electrode conductor metal thickness, electrode interconnect lead length, and placement of the amplifier. Fabrication of the hydrophone required characterization of the material, electrode patterning, spot poling, and assembly. The nonlinear distortion method was used to evaluate the bandwidth. Directivity measurements were used to determine an upper limit for the effective spot diameter. The substitutional method was used to evaluate the hydrophone sensitivity up to 20 MHz. As an example of the capability of the hydrophone, the on-axis signal from a 30-MHz IVUS transducer in water was characterized.

The result of this work is an acoustic hydrophone fabricated on a 4- μm -thick membrane film of PVDF-TrFE, having an effective active spot less than 100 μm in diameter, an on-membrane buffer amplifier within 10 mm of the active spot, and a loaded end-of-cable sensitivity of -23 dB relative to 1V/MPa in the range 5 to 20 MHz. Additional characterization is needed to determine the absolute hydrophone response in the range of 20 to 150 MHz, and to measure the effective spot size more accurately. Further details on this hydrophone and a more complete set of references are given in reference 3. This hydrophone has been licensed to an external vendor for commercialization, and is expected to be available in the spring of 1998.

Acknowledgments

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Paul Lum

Paul Lum is a member of the technical staff of the analytical medical laboratory of HP Laboratories, specializing in

medical sensors, actuators, transducers, and instrumentation. With HP since 1977, he holds an MS degree in electrical engineering and computer science from the University of Santa Clara. A native of San Francisco, he is married and has two children.



Michael Greenstein

Michael Greenstein received his PhD degree in experimental solid-state

physics from the University of Illinois Urbana-Champaign in 1981 and joined HP Laboratories in 1982. He is currently a project manager for diagnostic sensors and devices. His work has resulted in 18 patents and 26 publications. Born in Oakland, California, he is married, has a daughter, raises bonsai trees, and plays soccer.



Edward D. Verdonk

Ed Verdonk is a member of the technical staff of the analytical medical

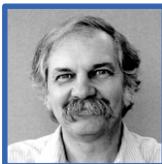
laboratory of HP Laboratories, specializing in ultrasound imaging. He received his PhD degree in physics in 1992 from Washington University of St. Louis and joined HP in 1993. He is married, has a daughter, and comes from Edmonton, Alberta, Canada.



Charles Grossman, Jr.

Charlie Grossman is a manufacturing development engineer at the HP

Imaging Systems Division and supports the Acoustic Output Measurement Laboratory. He joined HP in 1979 after ten years in circuit design with GTE. His BSEE degree (1969) is from the State University of New York at Buffalo. Born in Munich, Germany, he enjoys photography and travel.



Thomas L. Szabo

Tom Szabo joined HP in 1981 after 12 years of research activities with the

U.S. Air Force. A senior R&D engineer with the HP Imaging Systems Division, he is involved in transducer array design, beamforming, and acoustic output characterization. He received his PhD degree in physics from the University of Bath (UK) in 1993. He has published 65 papers and his work has resulted in three patents. A native of Budapest, he is married, has a son, and enjoys photographing megalithic sites and gargoyles and training cats to do tricks.

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