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Research areas
Acoustics and Ultrasonics
(cf. Draft Agenda of 20/04/04, item 10.2)

"Click" reference thresholds for the calibration of audiometric equipment
Reference hearing thresholds for the calibration of audiometric equipment have been determined using "clicks" as test signals and different kinds of earphones, a loudspeaker and also a bone vibrator as sound transducers. The threshold measurements were carried out with groups of 25 normal hearing test subjects with an age between 18 and 25 years. The influence of click duration, repetition rate and polarisation mode on the results was studied. The type of ear simulator used for the calibration of the air conduction transducers has the largest influence on the results. Reference hearing thresholds of the eight air conduction transducers used varied as much as 21 dB when the ear simulators - or the free-field microphone - recommended by ISO were used. If, however, a particular head and torso simulator was used instead of the recommended microphone and ear simulators, the variation of the reference hearing thresholds for the loudspeaker and the different earphones was reduced to 3,6 dB.

A camera for ultrasound

The fabrication of piezoelectric ultrasound arrays which can directly deliver spatially two-dimensional images, remains an unsolved problem in spite of tremendous progress in the fabrication technology of ultrasound transducers. For this reason, in PTB's Ultrasonics and Medicine Working Group an optical alternative technique has been developed which enables the determination of spatially two-dimensional sound pressure distributions of ultrasound fields in water. It thereby utilizes a dielectric optical layer as sensitive element, the reflectivity of which is changed through the incident sound. With the aid of a scanned laser beam the sound pressure can be probed successively. This serial technique is supplemented by parallel probing. Here, the whole sensor is illuminated simultaneously and the reflection change is detected with the aid of a CCD camera. In this way, instantaneous images of the sound pressure can be obtained in two dimensions. A spatial resolution of under 100 µm and a bandwidth of up to 50 MHz are attained, which has not yet been possible using conventional techniques. An advantage over a scanner-hydrophone measurement setup also lies in the fact that practically no mechanically moved parts are used. Moreover, optical measuring methods are not susceptible to electromagnetic radiation.

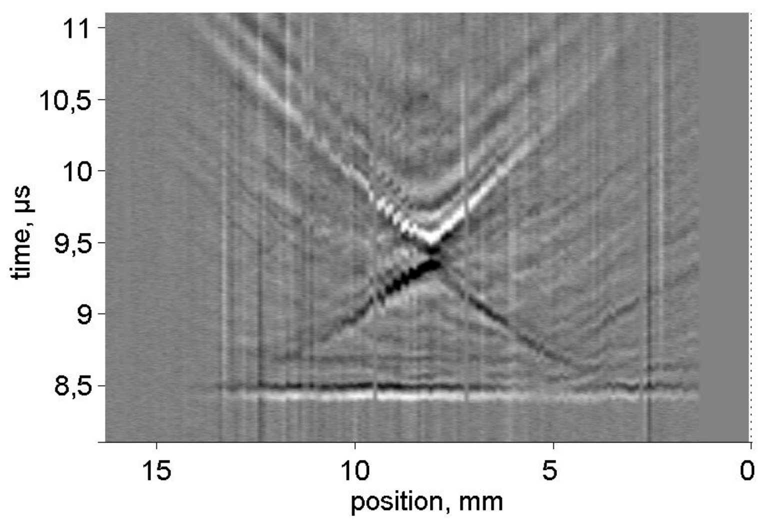


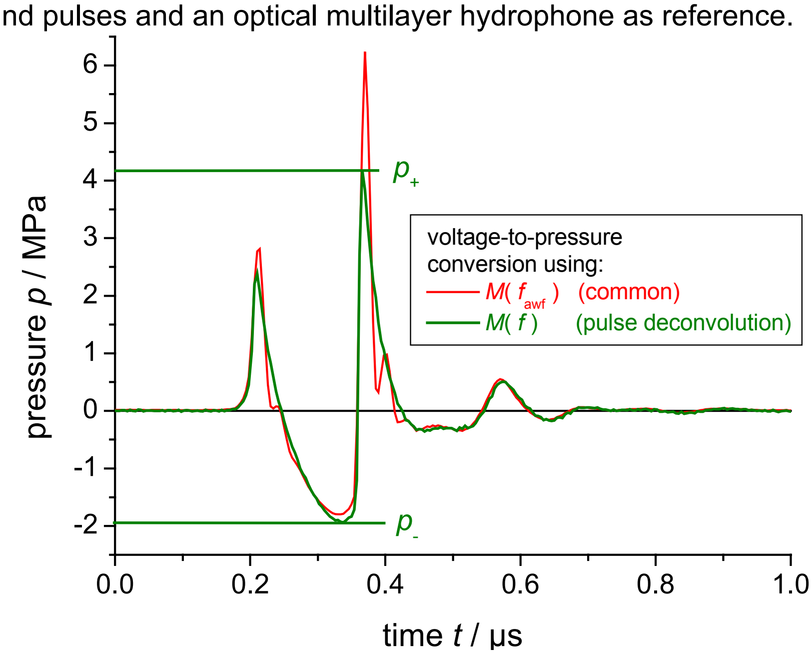
Fig. 1: Ultrasound pressure generated by a plane transducer along a line perpendicular to the sound propagation axis.

The optical multilayer hydrophone has so far been employed for the investigation of short ultrasound pulses in the MHz range. Such pulses are utilized e.g. in medical diagnostic devices – which one will find nowadays in every doctor's practice, instruments and systems for material testing and ultrasound process controls in the broadest sense. Fig. 1 shows a representation of the sound pressure in dependence on time (dark: high pressure, bright: low pressure) in a sectional plane vertical to the direction of sound propagation. The initial plane wave and the edge wave from the plane transducer are distinctly visible. Sound field measurements are needed for purposes of research and development, for the specification of technical data, for declaration and approval and for quality assurance. Here, the new technology can be employed to advantage.

Improved exposimetry on diagnostic ultrasound machines using broadband complex-valued hydrophone frequency responses

The acoustic output of medical diagnostic ultrasound equipment is characterized by standard parameters and indices to enable potential risks for the patient due to mechanical and thermal effects to be estimated. The basis of such device declarations and output displays on the monitor for the physician during ultrasonic examinations is provided by hydrophone exposure measurements in water where the ultrasonic pressure fields emitted at a multitude of operational settings of the diagnostic machine have to be determined.

To allow correct conversion of the voltage signals obtained with a piezoelectric hydrophone to pressure-time wave forms, individual hydrophone calibration is necessary. Up to now, the calculation of pressure-time wave forms is commonly performed using the calibration data $M(f_{awf})$ of the hydrophone at a single frequency corresponding to the working frequency f_{awf} of the device under test. This practise can induce quite large measurement errors since diagnostic pulses can be rather broadband due to nonlinear sound propagation and real hydrophones are non-ideal as regards their frequency response. Therefore, the inclusion of the complete broadband frequency response of the hydrophone in the voltage-to-pressure conversion procedure is expected to give improved measurement results. Exemplar exposure measurements on a diagnostic ultrasound machine show that correct pressure waveforms $p(t)$ and the associated standard pulse parameters such as positive peak pressure p_+ and rarefactional peak pressure p_- can be obtained by impulse deconvolution if the non-ideal frequency response of the hydrophone $M(f)$ is provided in an appropriate form (Figure). While todays calibration services provide only hydrophone amplitude responses, the calibration data required here in amplitude and phase with high frequency resolution (Δf = 100 kHz) in a broad frequency range (1 MHz $\leq f \leq$ 70 MHz) can now be obtained by a novel secondary hydrophone calibration technique which was recently developed and uses broadband nonlinearly distorted focused ultrasound pulses and an optical multilayer hydrophone as reference.



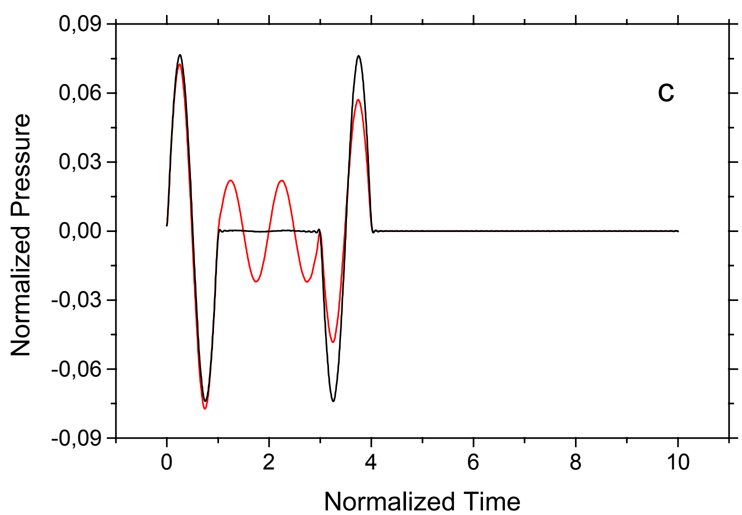
Typical pressure-time wave form $p(t)$ as measured by a membrane hydrophone in the focal region of a linear array transducer in M-mode with maximum peak- (p_+) and maximum rarefactional pressure (p_-).

Wilkens, V., Koch, C.: „Amplitude and phase calibration of hydrophones up to 70 MHz using broadband pulse excitation and an optical reference hydrophone“, J. Acoust. Soc. Am. 115, No. 6 (2004), in print.

Limits to the plane-wave approach of ultrasonic absorption for harmonic and transient acoustic fields

In many types of ultrasonic investigations, we are confronted with the question as to whether or not the straightforward plane-wave approach can be reliably used for sound propagation in absorptive media or if a more complex approach should be applied. This problem is dealt with by comparing the sound field in an absorbing fluid using the plane-wave approach (PWA) with that using the approach based on the Rayleigh integral (RIA) and by assuming that a plane circular piston source with sinusoidal, continuous-wave and transient-wave propagation is used for sound field simulation. It is shown that both the sound field structure and the time waveform will change considerably in the presence of high absorption coefficients. A simple formula is given for the estimation of the uncertainty involved. As a general rule, for moderate frequencies and moderate transducer radius to wavelength ratios ($f \leq 10$MHz; $a/\lambda \leq 50$ for water; $f \leq 0.1$MHz; $a/\lambda \leq 30$ for air and $f \leq 10$MHz; $a/\lambda \leq 15$ for benzene), the plane-wave approach can be applied without reservation. The uncertainty between the two approaches turns out to be $u_{rel} \leq 0.01$. Care must, however, be exercised if the transducer radius is of the order of the ultrasonic wavelength (large divergence of the sound beam) or if it is much greater than the wavelength. Provided that media of a very high absorption coefficient, e. g. some biological material or oil is used, the plane-wave approach may be inadmissible especially in the Fresnel zone of the ultrasonic field.

As an example, the figure shows the normalized on-axis time waveforms for the PWA (black) and the RIA (red) at the last axial minimum for a highly absorptive medium. It is assumed that the piston radius to wavelength ratio is $a/\lambda = 4$ and that the tone burst is of three circles duration.



R. Reibold, Proceedings of ICA 2004, Kyoto, 4-9 April 2004, Volume V, pages 3433-3436, ISBN4-9901915-6-0.