EXPERIMENTAL STUDY OF NONLINEARITY IN FREE PROGRESSIVE ACOUSTIC WAVES IN AIR AT 20 kHz

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Résumé . - On a étudié expérimentalement la propagation d'ondes d'amplitude finie dans l'air à 20 kHz.
La source utilisée est un générateur aérien de puissance d'un type nouveau, capable d'atteindre avec une grande directivité des niveaux quasi-monochromatiques de l'ordre de 160 dB.
Les expériences en ondes entretenues ont été conduites dans une chambre de dimensions 7,4 x 5,5 x 5,5 m^3.
Les mesures essentielles ont porté sur les amplitudes du fondamental et des trois premiers harmoniques pour différents niveaux d'émission et à des distances variables dans le champ éloigné. Les formes d'ondes et les diagrammes de directivités correspondants ont été également enregistrés.
Les résultats obtenus confirment la limitation d'amplitude transmissible par propagation non linéaire. On a pu mettre clairement en évidence le phénomène de saturation acoustique.
L'évolution des formes d'ondes et des diagrammes de directivité illustrent également ce comportement non linéaire.

Abstract. - This paper describes an experimental investigation of the propagation of periodic waves of finite amplitude in air at 20 kHz.
The acoustic source used in our experimental work is a new high-power ultrasonic transducer for use in air. This transducer, which emits a directive radiation, is able to generate a nearly pure sinusoïdal wave up to sound pressure levels over 160 dB.
The experiments were done in a 7.4 m long, 5.5 m wide and 5.5 m high anechoic chamber, using cw mode. They consisted essentially of measuring the amplitude of the fundamental component of the wave and its first three harmonics for different source pressure levels and at different distances in the farfield. In addition, oscillograms and directivity patterns were recorded.
The obtained results confirm the strong limitations in the transmission of intense waves due to nonlinear distortion. The phenomenon of acoustic saturation at high source levels is clearly observed. Also the evolution of waveforms and the changes in the radiation patterns show the effect of nonlinear behaviour.

1. Introduction. - The experimental studies on periodic waves of finite amplitude in air have been enhanced by the interesting researches about their outdoor propagation carried out recently by Dr. Blackstock's group at The University of Texas at Austin /1,2/. These works were undertaken with periodic sources (an array of 7 to 10 horn drivers and a siren) at frequencies in the range 6 to 8 kHz and source levels SPL_{1m} from 140 dB to 149 dB. On the other hand, indoor experiments in air were conducted by C.H. Allen in 1947-195o, but the obtained results have been reported for the first time in the former International Symposium on Nonlinear Acoustics /3/. In C.H. Allen's experiments a sound field at 14.6 kHz was generated into à 2m long anechoic chamber by a St Clair generator which acted as a baffled piston at a maximum SPL of 161 dB. With the exception of these studies, very few measurements have been published on the propagation of periodic waves of finite amplitude in air. Particularly, the lack of experiments appears more evident at high audiofrequencies and at ultrasonic frequencies despite the nonlinear effects are more significant. This fact may probably be due to difficulties in disposing adequate high-power sources. In this paper we present some experiments on the free field propagation in air of sinusoïdal waves of finite amplitude at 20 kHz. The acoustic source used is a new high-power ultrasonic transducer which emits a high directional radiation at sound pressure levels greater than 160 dB /4/.

2. Experiments and results. - The experimental work consisted of measuring the amplitude of the fundamental component of the wave and its first three harmonics for different input powers on the transducer and at different distances in the far field. In addition, oscillograms and directivity patterns were recorded. The relative pressure level of the source was measured by a monitor microphone mounted off-axis near the source and in such a way that the sound waves impinged at 90° incidence.

The experiments were performed in a 7.4 m long, 5.5. m wide and 5.5 m high anechoic chamber, using

cw mode. A block diagram of the measuring arrangement is shown in Fig. 1.

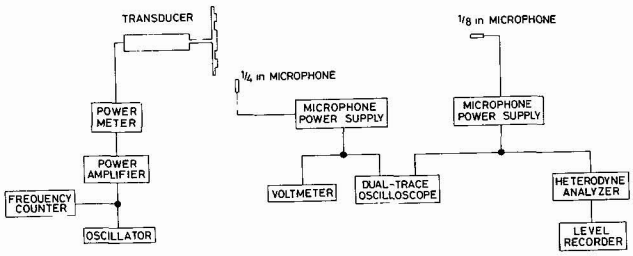

Fig. 1. - Block diagram of the experimental apparatus.

The new transducer, used as acoustic source, is a resonant device designed for a working frequency of about 20 kHz. It consists essentially of a piezoelectric element of transduction, in a sandwich configuration, a solid horn, which acts as a vibration amplifier, and a radiator consisting of a stepped circular plate which oscillates flexurally with three nodal circles. The points of maximum stress in the mechanical amplifier and in the radiating plate are water cooled in order to avoid fatigue failure and local overheating of the material. A view of the transducer, with its cooling system, is shown in Fig. 2. The special shape of the stepped plate allows one to generate an acoustic field quite similar to that of the theoretical piston of the same radius /5,6/. In addition with this transducer it is possible to generate a nearly pure sinusoïdal wave up to sound pressure levels over 160 dB. Fig. 3. shows the axial pressure distribution for the transducer with electrical input powers of 1 W, 100 W, and 200 W. The resonant frequency is of 20.4 kHz.

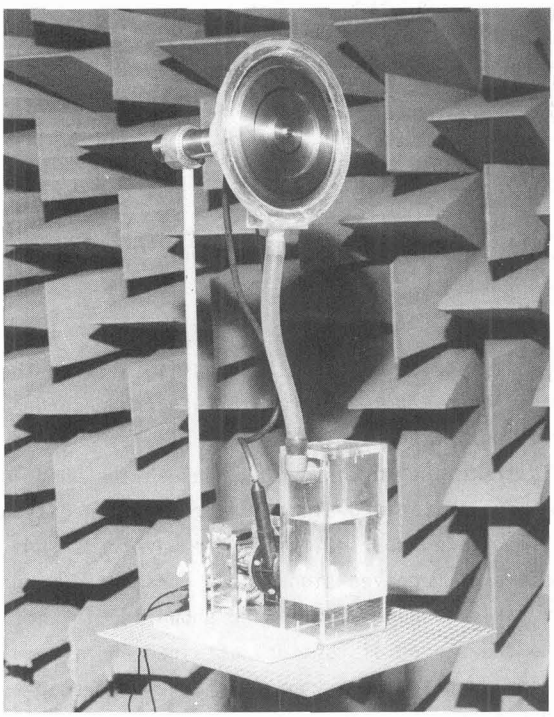

Fig. 2. - Photograph of the transducer with the water cooling system.

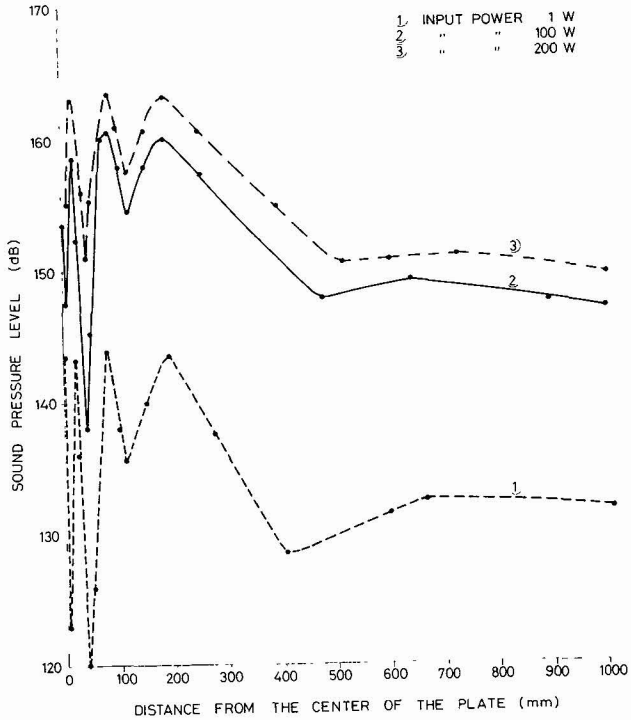

Fig. 3. - Axial sound pressure distribution of the transducer radiation in the near field.

Amplitude response curves for fundamental, second, third and fourth harmonics were taken at different, fixed distances from 1.2 m to 5.7 m. The relative pressure levels of the source, measured by the monitor microphone at about 12 mm, varied from 96.5 dB to 153 dB. In Figs. 4a, 4b, 4c and 4d four such curves are shown. The phenomenon of acoustic saturation at high source levels is clearly observed. Also the changes in saturation with distance are evidenced. In fact, it may easily be seen that while the extra attenuation for the fundamental frequency at 1.2 m is about 11 dB, at 5.7 m it is 20 dB. The later value represents a power loss, due to nonlinear effects, as high as 99%.

Propagation measures were made in the distance range 0.9 to 5.7 m (far field) for the fundamental frequency component and its first three

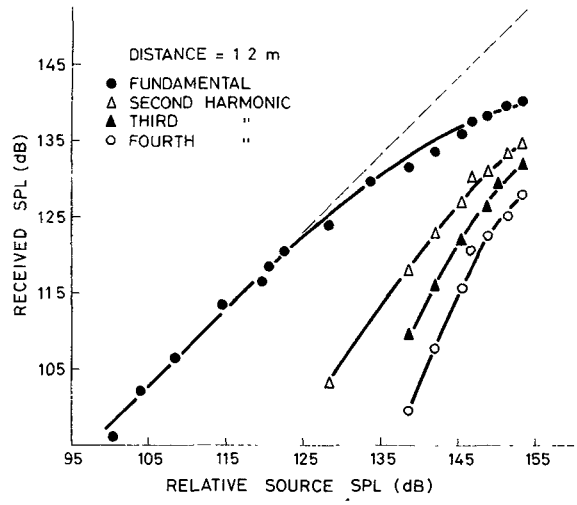

Fig. 4a - Amplitude response curves at 1.2 m.

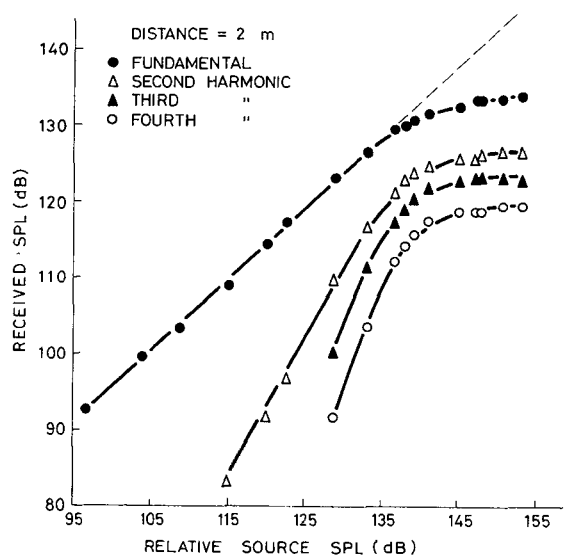

Fig. 4b. - Amplitude response curves at 2 m.

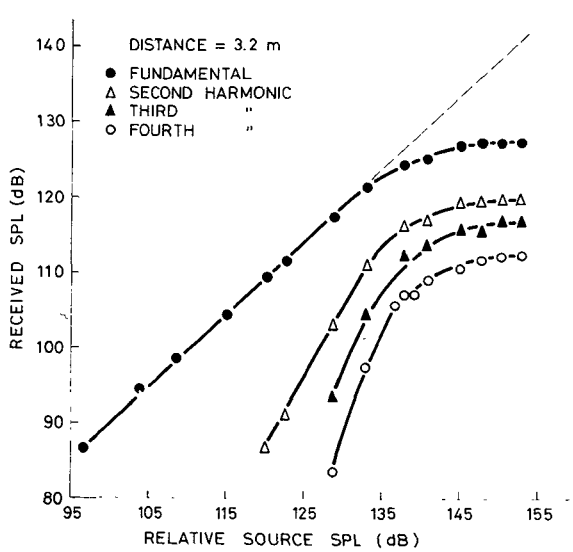

Fig. 4c. - Amplitude response curves at 3.2 m.

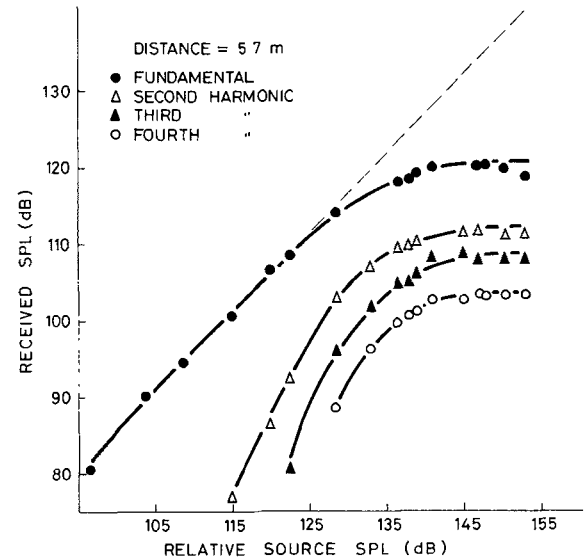

Fig. 4d. - Amplitude response curves at 5.7 m.

harmonics. Fig. 5. shows propagation curves obtained with the transducer operating at high amplitudes.

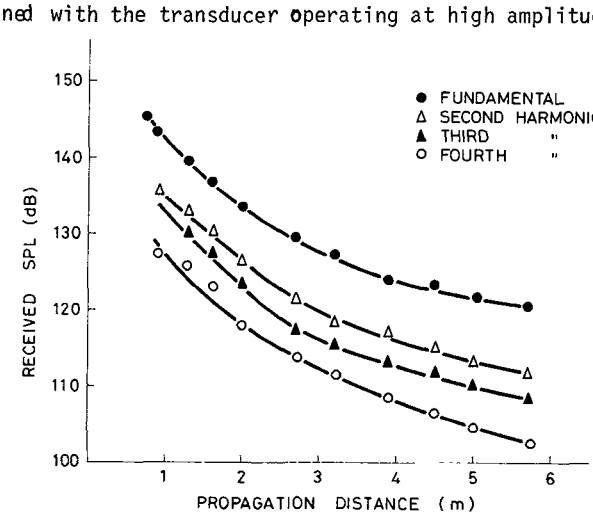

Fig. 5. - Propagation curves.

It is also of great interest to observe the évolution of the waveforms through the recorded oscillograms and their spectra. Figures 6a. and 6b. illustrate the successive changes in the shape of the wave originated along the propagation distance for two fixed source levels. The waveforms and spectra of received signal at a constant distance for various source levels are shown in Fig. 6c. Note the strong distortions attained and irregularities such as the asymmetry of the wave shapes and pulsations at the middle of the wave. It seems that dispersion is responsible for the formations of these two effects /7,8/.

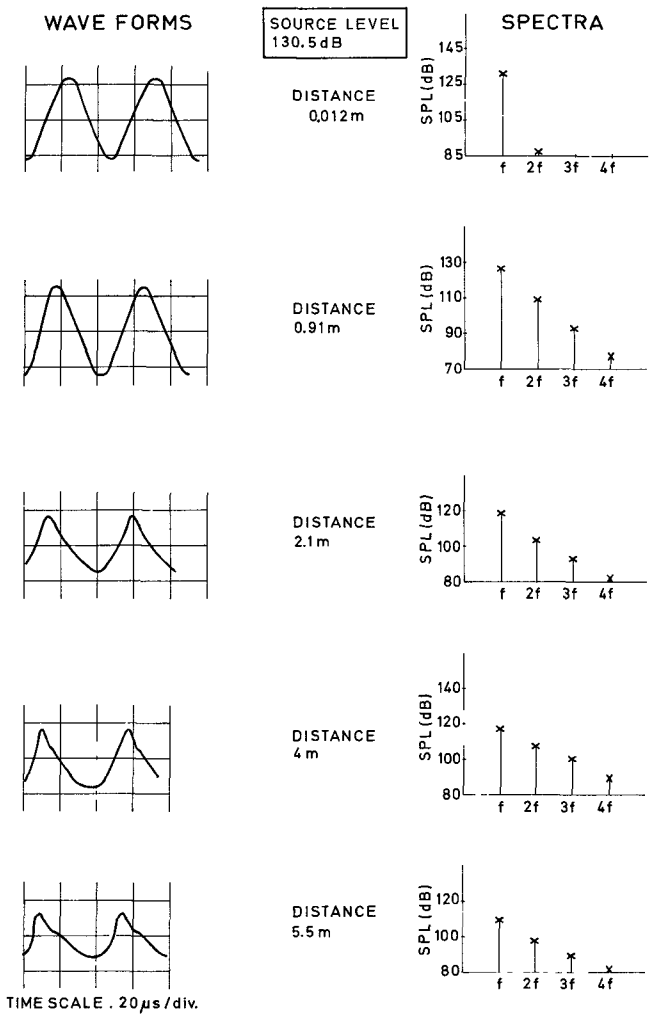

Fig. 6a. - Evolution of waveforms and spectra with propagation distance.

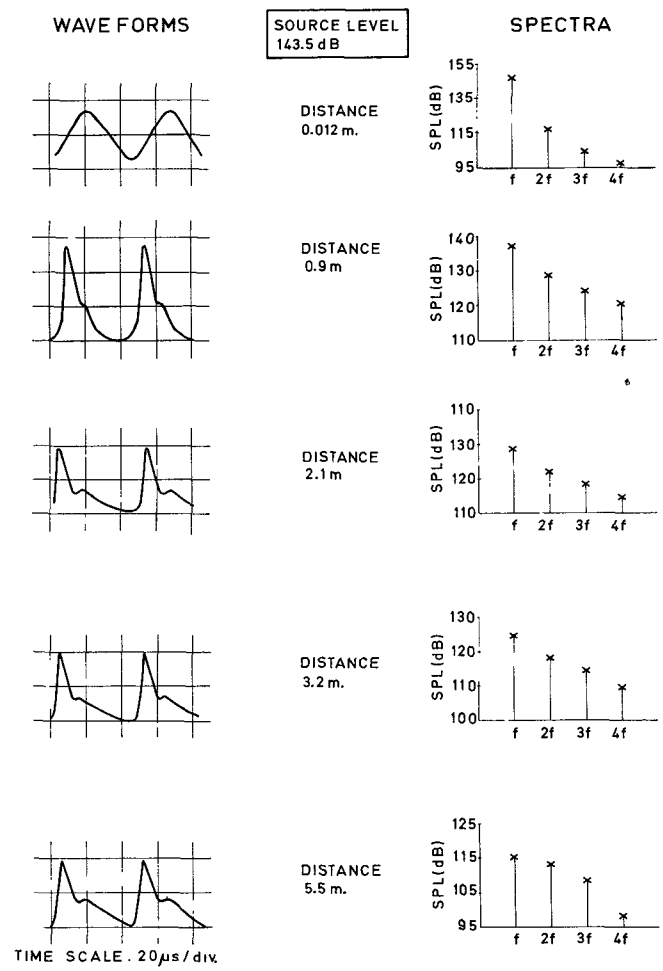

Fig. 6b. - Evolution of waveforms and spectra with propagation distance.

Finally, we present the directional characteristics of the fundamental, second, third and fourth harmonics at two distances in the farfield and for two different source levels (Fig. 7). In these patterns, the broadening of the major lobe and the growing of minor lobes with increasing amplitude can be observed. Also the effects of finite-amplitude attenuation on major lobes give rise to a relative increase of minor lobes with propagation distance.

3. Conclusion. - The propagation of finite-amplitude waves in air generated sinusoïdally at 20 kHz by a directive source, has been considered.

The obtained results confirm the strong limitations in the transmission of intense waves due to nonlinear distortion. The wave saturates at sufficiently high amplitudes and the saturation level decreases with propagation distance. Power losses induced by nonlinearity can be as high as 99 % at relatively short distances. The évolution of waveforms and the changes in the radiation patterns also show the effects of the nonlinear behaviour.

In conclusion, the experimental data here presented offers a contribution to the knowledge of high-amplitude wave propagation and they can be very useful in examining the different established theoretical models.

Acknowledgements. The authors wish to thank Dr. D.T. Blackstock for his encouragement and suggestions to initiate this work.

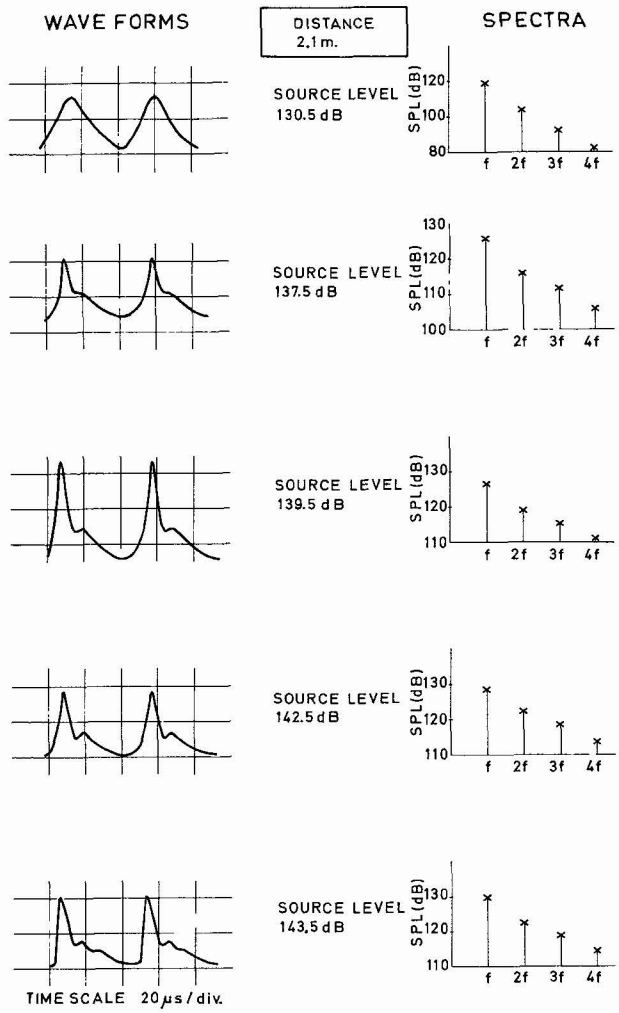

Fig. 6c. - Waveforms and spectra for various source levels.

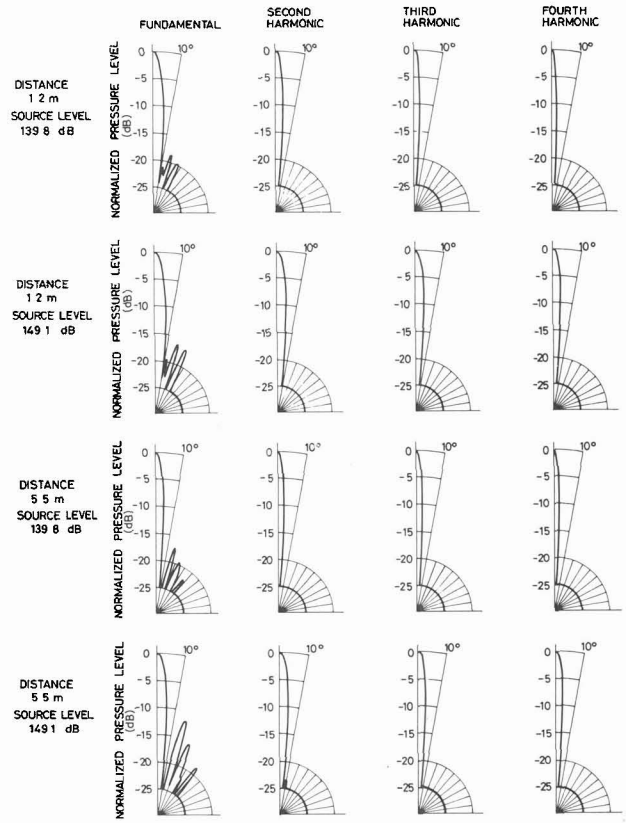

Fig. 7. - Directivity patterns.

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