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An acoustic filter for parametric loudspeaker in air

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1. Introduction

The parametric loudspeaker is based on parametric array theory, which has been widely applied in underwater acoustics for a few decades. Since the first experiments of parametric array in air performed by Bennett and Blackstock,[1)] the development of a parametric loudspeaker has attracted much attention.[2-4)] The accurate measurement of a parametric loudspeaker is important for understanding the principle of the parametric array and the practical design in audio engineering. Spurious difference-frequency sound is generated as a result of nonlinearity at the receiving transducer, including the nonliearity of the preamplifier circuit of the transducer and the radiation pressure at the surface of the transducer. It is hard to discriminate between transducer nonlinearity and radiation pressure of the transducer because both signals are proportional to the product of the two primary waves amplitudes. In the near field of a parametric loudspeaker, where sound pressure levels of the primary waves are more than 120 dB, the audible difference-frequency sound generated by the parametric loudspeaker is much weaker than the spurious noise. Therefore, an acoustic low-pass filter can be used to remove the contribution of sprious noise. A dome-shaped acoustic filter constructed from cellophane plastic was used by Bennett and Blackstock.[1)] But the structure details and the character of the acoustic filter were not clearly illustrated. Toda used four polymer films with half-wavelength spacing as an acoustic filter to attenuate the primary waves strongly.[5)] However, this structure was too complex for practical implementation. A thin sheet of Saran film was ulitilied by I. O. Wygant,[6)] but the structure and the acoustic character of this filter were neither detailed. In this study, a new acoustic filter for parametric loudspeaker was constructed from aluminum plate. The transmission losses of the simple acoustic filter at audible frequency and ultrasonic frquency were measured respectively. The exprimental results demonstrated the effectiveness of the acoustic filter.

2. Acoustic Filter and Experimental Results

A new acoustic filter for parametric loudspeaker was fabricated as shown in **Fig. 1**. A 16-mm-diameter aluminum plate was set in front of the transducer. To avoid the resonant effect of ultrasound in the surface of the plate, its diameter should be larger than 12 *mm*, corresponding the wave length of ultrasound at 30 kHz. Preliminary experiments were carried out to measure the transmission loss of the acoustic filter in an anechoic chamber to verify this method. A 1/4” G.R.A.S transducer (type: 46BE) was placed at 3 *m* from the acoustic source (conventional loudspeaker and ultrasonic transducers array). The difference of sound pressure levels of the transducer with and without the acoustic filter was shown in **Figs. 2** and **3** at audible frequency and ultrasonic frequency, respectively. The attenuation in the 30-50 kHz range was averagely more than 15 dB. In the vicinity of the carrier frequency 40 kHz of the parametric loudspeaker, the attenuation was up to 35 dB. However, in the audible frequency range, the curve was almost flat within a 5-dB deviation. The low pass characteristic of the acoustic filter was confirmed in the experiments.

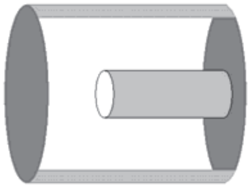

Fig. 1 Configuration of the acoustic filter.

The experiments of parametric loudspeaker were conducted in an anechoic chamber. The parametric loudspeaker had a regular hexagon aperture with a side length of 10 *cm*, consisting of 91 small commercial ceramic transducers (Shanghai Nicera Sensor Type ZT40-16) of 16 *mm* diameter. The double-sideband modulation (DSB) technique with carried frequency of 40 kHz was adopted in our experiments. The same transducer used in the prior experiments was placed at 3 *m* from the parametric loudspeaker in the axial direction. The frequency response of parametric loudspeaker was measured without and with the acoustic filter as shown in **Fig. 4**. It was clearly confirmed that the spurious noise was independent of the difference frequency, in the case of without the acoustic filter. The audible sound generated by parametric loudspeaker is proportional to f_d^n, where $1 \le n \le 2$. The index number *n* depends on the ratio of

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Rayleigh distance to absorption length. In the Westervelt model, where the ratio is large, the index number n is nearly two. In the Berktay's solution, where the ratio is small, the index value n is approximately one. As shown in **Fig. 5**, the experimental results indicated $n \approx 1.5$, which was a good approximation of the difference frequency dependence.

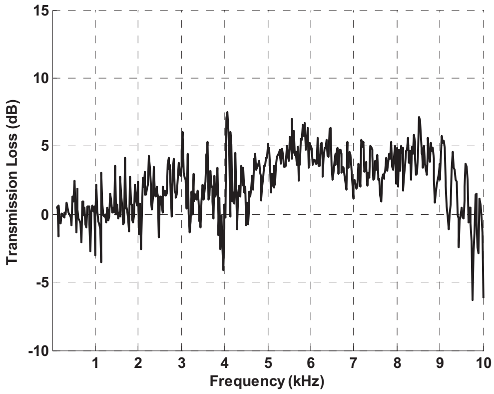

Fig. 2 Transmission loss of acoustic filter at audible frequency.

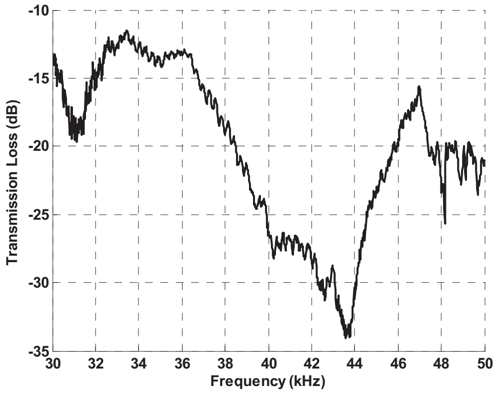

Fig. 3 Transmission loss of acoustic filter at ultrasonic frequency.

In order to further distinct the audible sound generated by the parametric loudspeaker from the spurious noise of the transducer, the axial sound pressure levels of the difference frequency sound was measured as well. The parametric loudspeaker was excited at 40 and 38 kHz. The spurious noise including the transducer nonlinearity and radiation pressure was modeled by $p_{sn} = Kp_a p_b$, where p_a and p_b were the peak amplitudes of the primary waves at the transducer location, respectively. The constant number $K = 2.8 \times 10^{-4} Pa^{-1}$ was determined by curve fitting from the measurement results shown in **Fig. 5**. The SPLs of unfiltered spurious noise decreased 12 dB per doubling distance. After the acoustic filter was installed, the SPLs of difference frequency sound showed a slope of 5 dB per doubling distance. The spurious noise dominant in the near field as the SPLs of primary wave were more than 120 dB. However, the effect of spurious noise was negligible as the measurement distance was beyond 6 m. The same conclusion was observed in ref. 6, where a parametric loudspeaker was constructed by capacitive micromachined ultrasonic transducers.

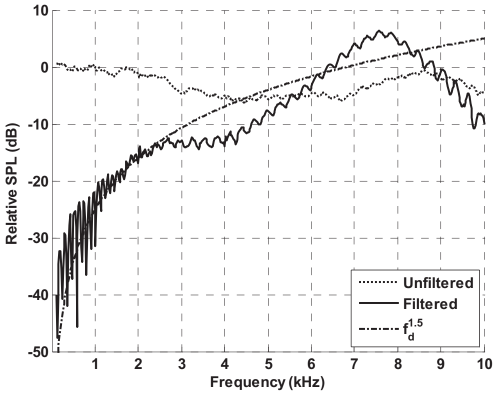

Fig. 4 Frequency response of parametric loudspeaker.

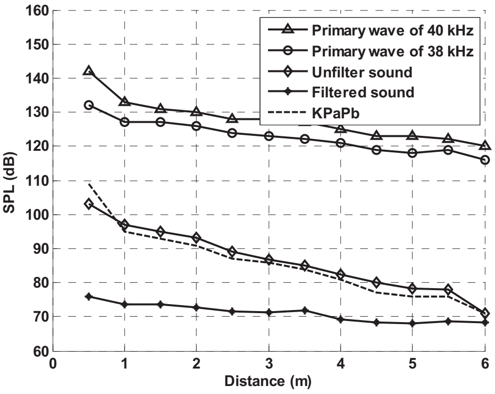

Fig. 5 Axial SPLs of parametric loudspeaker.

4. Conclusion

A new acoustic filter for parametric loudspeaker in air was constructed in this study. A 16-mm-diameter aluminum plate was set in front of the transducer to attenuate the ultrasound more than 15 dB. However, the acoustic filter has negligible effect on audible sound. Experimental results validated the effectiveness of the acoustic filter. In the near field of parametric loudspeaker, where the SPLs of primary waves was more than 120 dB, the spurious noise was dominant in the measurements. In the far field, as the primary waves decreased, the audible sound generated by parametric loudspeaker was detectable by the transducer without acoustic filter.

References

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