ANGULAR RESPONSE OF A SOUND INTENSITY PROBE AT HIGH FREQUENCIES

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1. INTRODUCTION

A-weighting is used in the assessment of noise related to human health. The dominant frequencies in this weighting are from 630 Hz to 10 kHz. Yet, in most current standards, intensity measurements are restricted to frequencies below 6.3 kHz due to concerns related to finite difference approximation errors. Using a numerical simulation, Jacobsen[1] has shown that measurements are possible up to 10 kHz with a ½ inch p-p intensity probe and 12 mm spacer, with diffraction effects compensating for finite difference approximation errors. These findings were also demonstrated experimentally by Keith[2, 3].

In this study, the polar response of a ½ inch p-p intensity probe and 12 mm spacer was measured in 1/3-octave band frequencies. In agreement with Jacobsen's conclusions, the angular response of the probe showed no evidence of finite difference approximation errors. At frequencies up to 10 kHz, the intensity approximated the ideal cosine dependence on angle.

The results also showed an intensity probe could provide superior directivity compared to a ½ inch microphone.

2. METHOD AND APPARATUS

Measurements were made in the large (13 x 9 x 8 m^3) hemi-anechoic chamber at the Consumer and Clinical Radiation Protection Bureau. The measurements were made under hemi-anechoic conditions above a 9 x 13 m^2 hard floor constructed from 3 cm thick concrete tiles.

Measurements were made using GRAS 26AA preamplifiers and either ½ inch Brüel & Kjær (B&K) 4181 or GRAS 40AI 12 mm microphones with 12 mm spacer. Supplementary measurements used a single B&K 4165 free field microphone. A B&K type 2133 1/3-octave band Class 1 frequency analyzer was used for direct intensity and mean pressure measurement up to 10 kHz. A Hewlett Packard 35670A FFT analyzer was used for simultaneous measurements up to 25.6 kHz with 400-line resolution. Intensity was calculated from the cross spectrum [4], and mean pressure was calculated from the two channel auto spectra and inter-microphone phase. Bursts of 32 second duration pseudo random pink noise from the B&K analyzer were reproduced by a 25 mm diameter dome tweeter flush mounted in the concrete floor.

Calibration levels were checked using a B&K 3541 intensity coupler with pistonphone. This coupler was also used with a pink noise source to check the pressure-residual intensity index, δ_{pI0}, of the instrumentation[5]. Checks were made before and after measurements. In 1/3-octave bands, the minimum measured δ_{pI0} was greater than 18 dB for 1/3-octave bands ranging from 1 kHz to 10 kHz.

Estimation of δ_{pI0} from the FFT measurements relied on values obtained when the probe was oriented at 90° to the incident sound[6]. The minimum measured δ_{pI0} of the instrumentation was 14 dB for 1/3-octave bands from 1000 Hz to 12.5 kHz. These δ_{pI0} values were lower than above because the measurement chain was arranged to compensate for a known phase mismatch in the B&K analyzer.

Figure 1 shows the probe configuration with two ½ inch microphones on either side of the centre spacer (black), one 6 mm diameter preamplifier on the left, and another preamplifier on the right seamlessly joined to the 6 mm support rod. The probe was mounted 2.44 m above the tweeter sound source in a frame made of 6 mm diameter steel rods. Probe angle was varied from 0° to 95° in 1° increments using a B&K 9664 five axis microphone-positioning robot attached via cables. Maximum angular errors were less 2°. The alignment was checked i) at 0° by reflecting a laser off the microphone diaphragm, ii) at 90° by comparison with the δ_{pI0} calibration [6], and iii) at other angles by measuring the time delay between the probe and an additional microphone mounted on the rotating part of the frame.

3. RESULTS AND DISCUSSION

Comparison of Figures 1 and 2 shows small differences in the directivity of the B&K and GRAS microphone pairs. This suggests that the directivity may depend on small differences in probe configuration. Preliminary experiments also suggested similar differences due to preamplifier position and microphone body length.

At 10 kHz the intensity response is close to ideal. At 5 kHz, however, Figures 1 and 2 show that for angles exceeding 60° the intensity drops 1 dB relative to the ideal response. Angles over 60° are associated with half the sound power radiated from an omnidirectional source in half space. This suggests that sound power measurements at 5 kHz using large planar measurement surfaces could give lower results than obtained with the same measurement over a hemispherical measurement surface.

Above 60° at 12.5 kHz the differences from the ideal intensity responses are 3 to 4 dB in Figures 1 and 2. The worst-case measurement error in the intensity would also be 3 to 4 dB, and could occur with a highly directional source and planar measurement surface (ignoring effects of background noise). At 12.5 kHz, a 3 to 4 dB difference is also found in Figure 3, which shows the response of a ½ inch B&K 4165 free field microphone [7]. This would produce a similar magnitude worst-case error in the sound pressure level, (for a highly directional source and planar measurement surface in a free field).

Compared to a ½ inch pressure microphone, below 10 kHz, the mean pressure response of the intensity probe is more omnidirectional. Juhl and Jacobsen [8] have shown that the mean pressure directivity can be improved to 10 kHz using a weighted response from each microphone, i.e., $p_{mean} = x \cdot p_A + (1-x)p_B$ (where p_{mean} is the mean pressure, p_A, and p_B are the two time domain microphone pressure signals, and x is the weighting). Mean pressure is typically calculated using x =0.5 as shown in the left side plot in Figure 4. The right hand plot shows significant improvements are possible up to 16 kHz with x = 0.7.

4. CONCLUSIONS

This study has shown a ½ inch p-p intensity probe can approximate the ideal intensity response up to 10 kHz. The same probe can also have a more omnidirectional response than a ½ inch pressure microphone up to 16 kHz.

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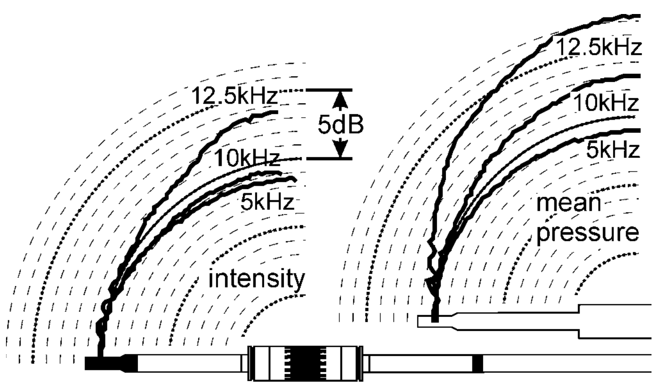

Fig. 1. Difference from ideal response for the intensity and mean pressure of the B&K probe (normalized to 0°, on axis, response).

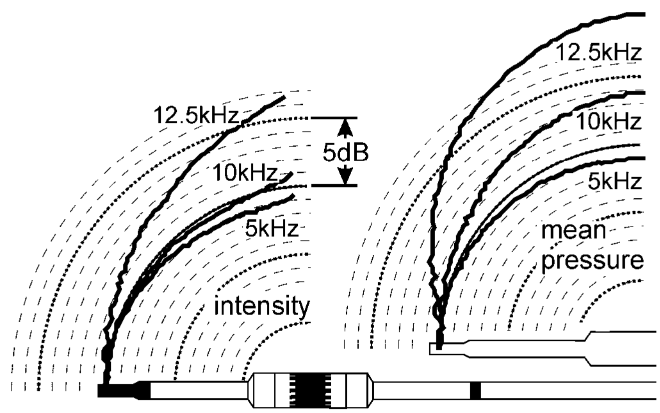

Fig. 2. Difference from ideal response for the intensity and mean pressure of the GRAS probe.

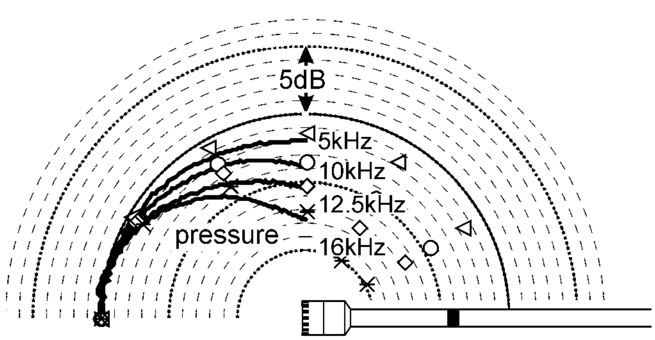

Fig. 3. Difference from ideal omnidirectional response for a free field microphone. Symbols are manufacturer's data.

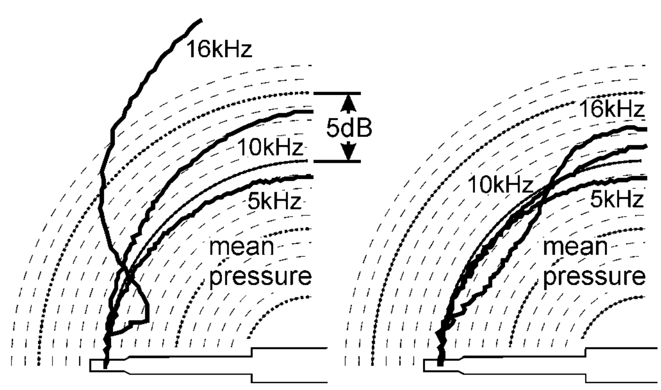

Fig. 4. B&K probe mean pressure response using weighted microphone signals: left side, x=0.5; right side, x=0.7.