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A VIRTUAL MICROPHONE ARRANGEMENT IN A PRACTICAL ACTIVE HEADREST

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1. INTRODUCTION

The zone of quiet created by cancelling the pressure at an error microphone position in the near field of a secondary source becomes larger as the error microphone is moved further away from the source [1]. To produce useful-sized zones, the error microphone may thus have to be at an inconveniently large distance from the secondary source and may then interfere with the movement of the listener's head. David and Elliott [2] investigated the use of an error microphone in the plane of a loudspeaker to generate a shell of quiet at low frequencies which extended some distance from the front of the secondary source. This was found not to be effective at higher frequencies, however, and in [3] another arrangement was proposed based on the idea of a virtual microphone that can 'project' the zone of quiet so that it is further away from the secondary source than the physical error microphone. Simulations using a 2-sphere model and experimental results are presented in this paper which show that this type of arrangement is suitable for practical applications such as a local active noise control system in a headrest.

Fig. 1 illustrates the block diagram of a single channel virtual microphone system. The complex pressure at the physical error microphone location may be written as

$$p_e = p_{p_e} + Z_e q_s , \tag{1}$$

where p_{p_e} is the complex primary pressure at this location, Z_e is the complex transfer impedance from the secondary source to the physical microphone location and q_s is the secondary source strength. Similarly, the complex pressure at a 'virtual' microphone location further away from the secondary source, can be written as

$$p_v = p_{p_v} + Z_v q_s , \tag{2}$$

where p_{p_v} is the primary field at this location and Z_v is the corresponding acoustic transfer impedance. At low frequencies the spatial rate of change of the primary field is generally small and, therefore, we can assume that $p_{p_a} \approx p_{p_v}$. However, the acoustic transfer impedances Z_a and Z_v can be substantially different. Under this circumstances, the pressure at the virtual microphone location can be estimated from that at the physical microphone location using the following expression [3]

$$\hat{p}_v = p_a - (Z_a - Z_v)q_s . \tag{3}$$

The estimated pressure at the virtual microphone location, $\hat{p}_v$, can then be cancelled by the action of the secondary source using only measurements from the closer microphone, i.e., p_a. Thus, knowing Z_a, Z_v and q_s, the output from the physical microphone, p_a, can be electronically processed, as illustrated in fig 1, to give $\hat{p}_v$ which can be driven to zero by the control system, thus producing a zone of quiet around the virtual microphone location.

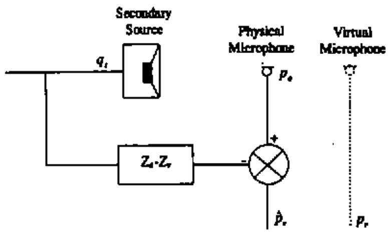

Fig. 1. A single channel virtual microphone arrangement

2. SIMULATIONS

Fig. 2 shows a possible arrangement for local active control in which the secondary source is modelled as a sphere with a vibrating segment whose source amplitude and phase are adjusted to cancel the pressure at a predetermined point and the listener's head is modelled as a rigid sphere [4]. This figure depicts the average zones of quiet produced by two possible arrangements of a single channel local active noise control system which cancel the acoustic pressure at an off axis physical microphone, '+' (a) and at a virtual microphone, '*' (b) near the diffracting sphere in a diffuse primary field. Both arrangements have the physical microphone in a non-interfering position, to allow free movement of the listener's head in the vicinity of the secondary source.

Although at low frequencies, kL = 0.2, arrangement (a) produces a larger zone of quiet near the diffracting sphere, at higher frequencies, kL = 1, only the virtual arrangement (b) is capable of locating the zone of quiet near the listener's head. For a loudspeaker diameter of 0.1 m these values of kL correspond to excitation frequencies of about 100 Hz for kL = 0.2 and

500 Hz for kL = 1. These simulations suggest that a virtual microphone system is capable of projecting a zone of quiet over a broader frequency range than a system using only a physical microphone. Another advantage of the virtual microphone arrangement shown in fig. 2 is that the secondary source strength required to produce the zone of quiet is smaller than that required by the arrangement in (a). This is due to the fact that the virtual microphone can be located on the axis of the secondary source and near the diffracting sphere where the acoustic coupling is higher than for off-axis points at the same distance from the centre of the active segment.

3. MEASUREMENTS WITH A TWO-CHANNEL VIRTUAL MICROPHONE SYSTEM

In order to carry out measurements of realistic zones of quiet achievable by a practical local active noise control system, the assembly shown in fig. 3 was built. This figure shows a headrest with two 100 mm diameter loudspeakers mounted on a passenger seat and a manikin with a rigid head and torso. The manikin dimensions were within 6% of the average human adult head and torso [5]. In order to monitor the acoustic pressure heard by this hypothetical listener, an electret microphone was located at the entrance of both ear canals of the manikin's head, since it is known that measurement at the entrance of the ear canal introduces an error of less than 1.5 dB compared with that at the eardrum for frequencies of less than 1 kHz [6]. The two adjustable brackets shown in fig. 3 are used to position the two error microphones in the desired location in the horizontal plane. The manikin rested on a surface at the level of the armrests which allowed the manikin to be moved horizontally to various positions.

In order to carry out the measurements of the zones of quiet achievable by the practical local active noise control system considered here, the assembly shown in fig. 3 was located in a listening chamber of dimensions 5 x 2.2 x 2.5 m which has anechoic characteristics above 200 Hz. The seat was located facing in the direction of the largest dimension of the room and a loudspeaker was positioned 2 m behind it, radiating noise towards the back of the seat to create the primary field. The primary acoustic field thus approximates a progressive plane wave. The phase and amplitude of the secondary loudspeakers were adjusted to cancel the primary acoustic pressure at the virtual microphone locations. The control was carried out in real time using a multi-channel active control system with virtual sensors. The signal driving the primary loudspeaker was generated by the control program so that the frequency of the signals fed to the secondary and primary loudspeakers were synchronised. In the measurements reported here, the identification of the acoustic path was performed with the head laterally centred with respect to the headrest and in contact with it. The frequency response measured from the loudspeaker to the actual and the virtual microphone locations was used by the control program to minimise the error signals for every other position of the head. Fig. 4 shows the measured attenuation at the manikin's ears after the control system was

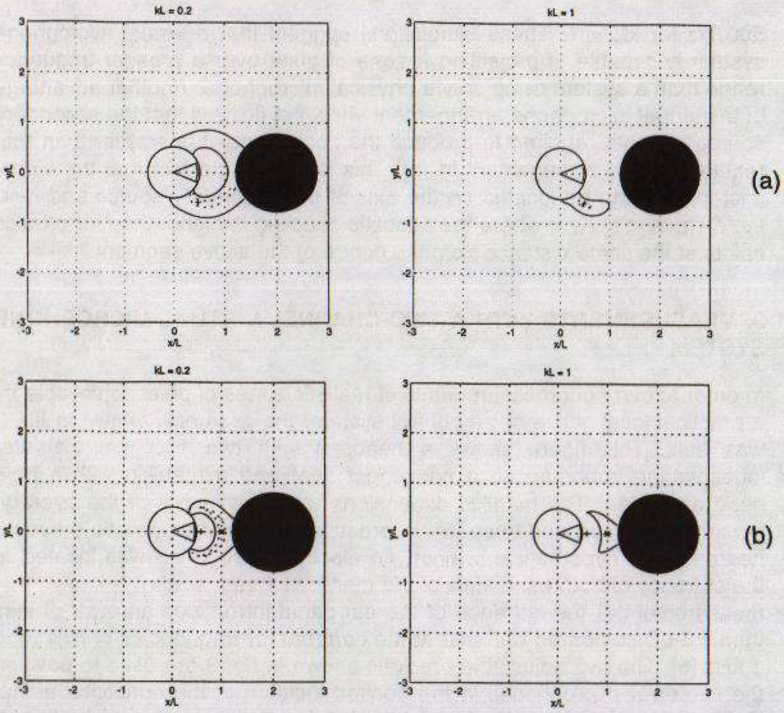

Fig 2. The calculated 10 dB (continuous) and 20 dB (dotted line) average zone of quiet due to the superposition of a primary diffuse field and the field due to a secondary spherical source with a 45 degree active segment and radius equal to L/2, cancelling the pressure at a physical microphone, '+' (a) and at a virtual microphone, '*' (b), near a diffracting sphere of radius 11L/15. L is the distance between the centre of the secondary source and the position of the virtual microphone in (b). The physical microphone in (a), '+', is located at (x/L, y/L) = (0.5, -0.5) and in (b), at (x/L, y/L) = (0.6, 0), and the virtual microphone in (b), '*', is located at (x/L, y/L) = (1,0).

Fig. 3. The headrest mounted on a passenger's seat and the manikin used in the measurements of the zones of quiet.

allowed to adapt after the manikin was moved to different positions in the x and y directions. The two plots at the bottom of fig. 4 could not be obtained with physical microphones located near the listener's head because they would restrict head movements in the y-direction. We note that the deepest minimum is very close to the virtual microphone location, i.e., 2 cm from the ears. Other measurements have shown that for frequencies below about 500 Hz the use of virtual microphones near a listener's head and ΔL = 0.075 m from the corresponding physical microphone gives very similar reductions to those obtained using error microphones in the virtual microphone position.

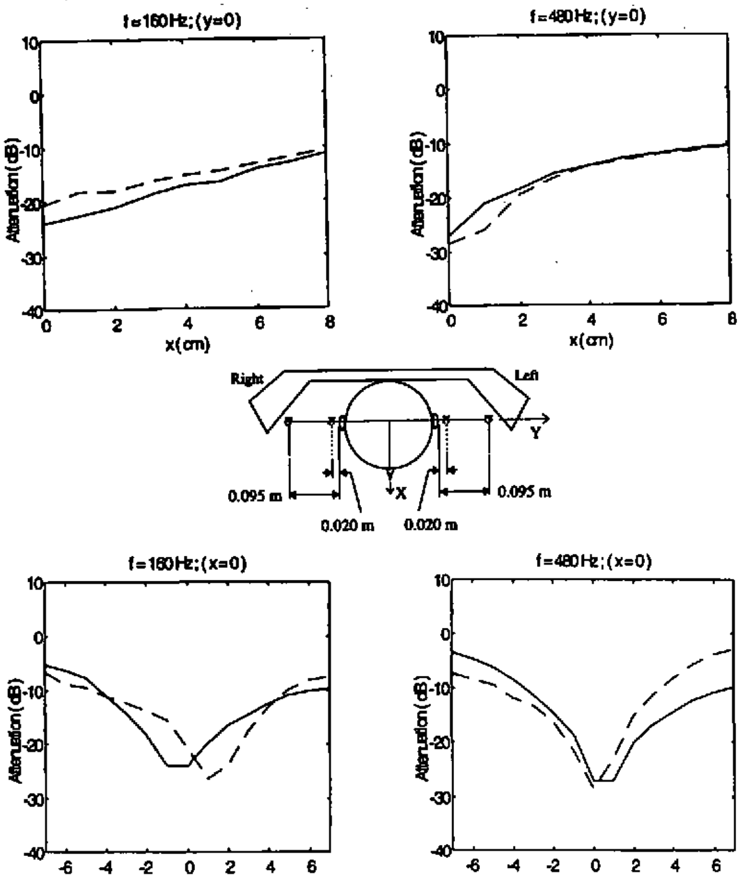

Fig. 4. The measured controlled field, at 160 and 480 Hz, in the right (continuous) and left hand (dashed line) ears when the two secondary loudspeakers are adjusted to cancel the primary acoustic field at the two virtual microphone locations, for different positions of the head and torso forward and backward (upper graphs) and side to side (lower graphs). The primary acoustic field is a plane wave propagating in the positive x-direction.

This corresponds to excitation frequencies for which ΔL is less than about one tenth of an acoustic wavelength. These results thus clearly show that a practical system using virtual microphones is capable of projecting the zones of quiet further away from the secondary sources than the position of the physical microphones.

4. CONCLUSIONS

The performance of a virtual microphone arrangement that 'projects' the zones of quiet further away from the secondary source than the position of the physical error sensor has been explored with a theoretical model and the performance has been measured in practice with and without the presence of a diffracting head and torso. These experimental results suggest that this sort of arrangement is suitable for practical applications, such as a local active noise control system in a headrest, up to excitation frequencies of about 500 Hz.

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