SOUND PICKUP IN THE PRESENCE OF DIFFRACTION EFFECTS

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INTRODUCTION

Microphones are an essential part of telephony. With the growing popularity of teleconferencing, videoconferencing, and handsfree telephony, the appropriate placement of microphones in a product can be important: the effects of scattering and diffraction of sound can lead to significant spatial variations of the sound pressure level (SPL). Furthermore, for many applications, a directional microphone response is required to reduce the effects of room reverberation and background noise. Whether directional microphones with two ports on the surface of the device or an array of several microphones are used to achieve this directionality, the placement of the microphones and allowance for diffraction effects is even more important.

An example of a situation where spatial effects can be important is shown in Fig. 1. We consider an array of microphones built into the top frame of a computer monitor. The use of multiple microphones permits the preferential pickup of speech signals from a zone located at the position of the user's head, significantly reducing the auditory effects of ambient noise and room reverberation.

Consider first a single microphone. Because of the effects of scattering of incident sound and diffraction there will be spatial variations of the sound pressure.[1] Different locations of a microphone will lead to different signals. These physical effects depend strongly on frequency. Hence, coloration of the frequency response curves will occur. Some locations may be more sensitive than others. For the example shown, the distance between the top edge of the monitor and the microphone position should not be selected too casually.

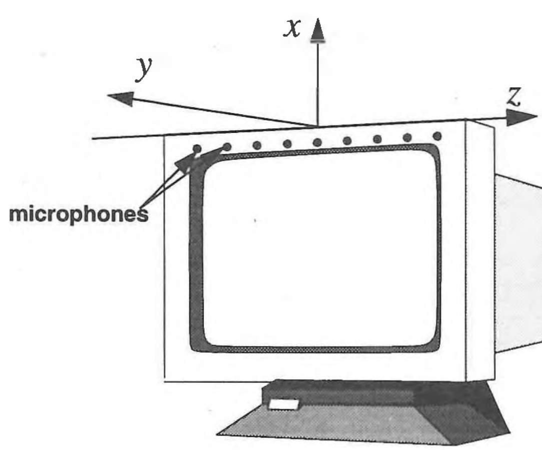

Figure 1. Sketch showing a microphone array intended for computer telephony. The sound field about the monitor can have large spatial variations which need to be accounted for in the beamforming procedure

When beamforming using multiple microphones, it cannot be assumed that all microphones receive the acoustic signal with the same magnitude. With a source in the near field[2,3], there will be different magnitude responses because of different propagation distances and diffraction effects will not necessarily affect all microphones the same. For example, the microphones closest to the sides of the monitor will experience a different sound field because of effects due to the side edges of the monitor.

SOUND FIELD CALCULATION

The variability of the SPL due to diffraction will be illustrated here. We consider microphone positions near the vertical center plane of the monitor, i.e., near $z = 0$ on Fig. 1. Above about 300 Hz, these positions will be essentially independent of the side edge conditions. We can then apply the exact theoretical formulation of Hadden and Pierce[4] for a rigid wedge to calculate the SPL. Choosing a wedge angle of 90°, four integrals, corresponding to direct and diffracted paths from actual and image sources, need to be evaluated. The quadrature is straightforward although some care needs to be taken to ensure convergence.

The results of a calculation are shown in Fig. 2. A point source radiating sound of frequency 1000 Hz is assumed to be located 50 cm in front of the "monitor" and 10 cm below the top edge (a typical location for a user's mouth). The sound pressure level, relative to the free field sound pressure, is calculated at a number of points distributed around the monitor and presented graphically in the 2D grayscale plot of Fig. 2

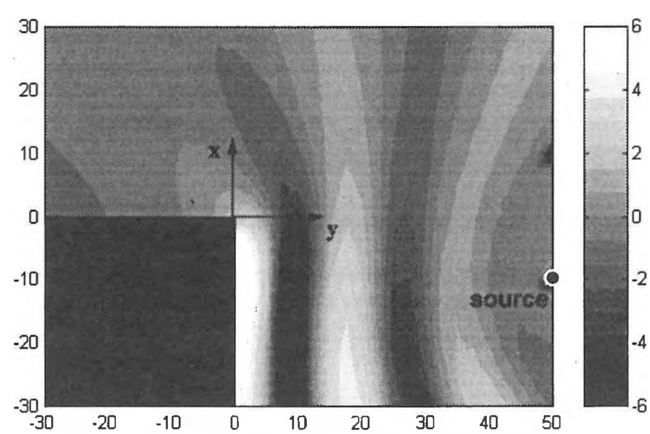

Figure 2. Grayscale plot showing the variation in sound pressuure level around a right-angled wedge, representing the $z = 0$ slice through the monitor of Fig. 1. The panel on the right shows the SPL (dB) corresponding to the different gray levels. The source is at (-10 cm, 50 cm).

Along the front face of the wedge ($-x$ axis), except near the vertex positon, the SPL is 6 dB, as indicated by the white area on the front face in Fig. 2. This is pressure doubling due to reflection of the incident acoustic signal. Out from this face a distance corresponding to a quarter wavelength is seen the dark interference null between incident and reflected waves. The positions along the top of the wedge ($-y$ axis) are in the acoustic shadow of the source and the sound pressure level drops smoothly. Near the vertex of the wedge, the SPL changes quite rapidly.

The pressure variation along the front face, particularly near the vertex, is examined more closely in Fig. 3. The relative sound pressure level is plotted as a function of the position x, for $y = 0$. For $x \gg 0$, far from the monitor, the diffraction effects are minimal and the relative SPL is nearly 0 dB. For $x \ll 0$, pressure doubling gives a level 6 dB above free field. The rapid transition between the two limiting regimes, through the vertex at $x = 0$, is evident. Right at the vertex, the SPL is 2.5 dB. Oscillations in the curve, due to interference between the incident and the edge-diffracted waves, are also noted.

The effects of diffraction are known to be dependent on the sound frequency so it is not surprising if anomalous frequency variations are introduced. For Fig. 4, we consider a small number of positions on the surface of the wedge (all for $z = 0$) and compute the SPL as a function of frequency. The source location is the same as that used in the previous figure. The labels on the various curves give their (x, y) coordinates. The frequency response for the vertex position $(0, 0)$ is found to be absolutely flat. For positions on the top surface of the wedge, in the diffractive shadow, a high frequency rolloff is found that increases with distance from the vertex. If the source was lower, these positions would be deeper in the shadow and levels would be lower still. On the front face, the transition from 0 to 6 dB, observed in Fig. 3, is found to occur at different frequencies for different positions and oscillations in the frequency response are noted.

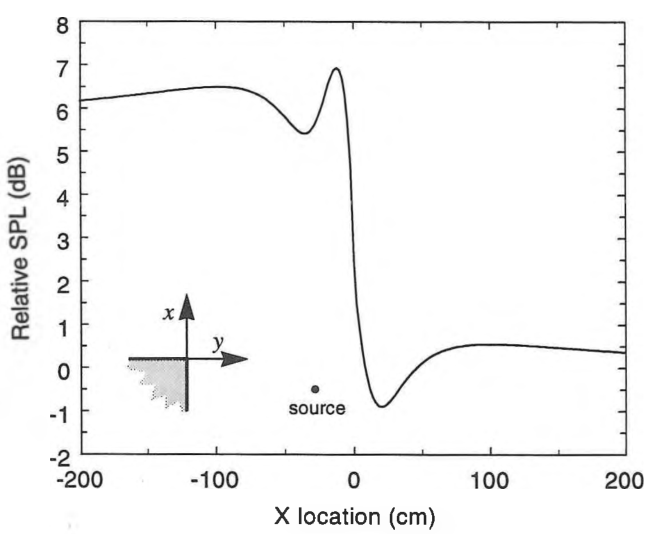

Figure 3. Relative sound pressure level along the front face of a right-angled wedge, with the same source location and frequency (1000 Hz) as in Fig. 2.

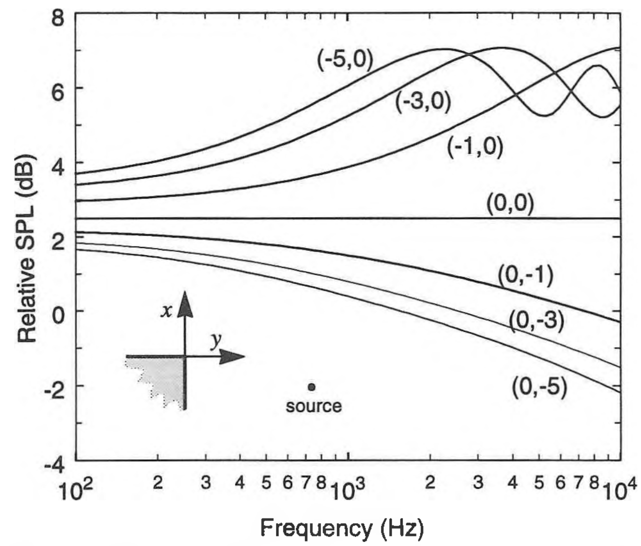

Figure 4. Frequency response functions for various microphone positions on a right-angled wedge, with same source location as in Fig. 2. Coordinate pairs next to the curves indicate the microphone positions.

DISCUSSION

The calculations here demonstrate the considerable variation in SPL near the vertex of a right-angled wedge. For a device such as a computer monitor, different microphone locations can lead to differences of several dB, particularly true at higher frequencies. If a directional receiver with two ports is used, account must be made of possible differences in received signal strength or the assumed directionality could be lost. Similarly, for an array of receivers, the effects of diffraction at each receiver location need to be determined to ensure effective beamforming and desired performance.

The use of the right-angled wedge was convenient here for the computer monitor application. For other applications, analytical formulations for other simple shapes, including wedges of different angles, spheres, and cylinders, can be applied. More complicated shapes or environments can also be considered but will require numerical techniques such as the boundary element approach.

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