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SPATIAL INFORMATION OF SOUND FIELDS FOR AUDITORIA DIAGNOSTICS

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ABSTRACT

Numerous subjective aspects of the listening experience in auditoria, particulary concert halls can be described well by contemporary room-acoustic indicators based upon sound pressure measurements [1,2], but subjective response is also influenced by the spatial distribution of sound energy. Directional information would also be useful to design halls, or to correct an acoustical defect in an existing enclosure. The objective of the present summary paper is introduce a directional measurement method and to demonstrate the importance of utilizing sound spatial information for acoustical defects diagnosis. The potential for the objective quantification of sound field diffuseness is also presented and the prospect of developing new directionally relevant indicators will also be addressed.

1. INTRODUCTION

In the late seventies a new field of acoustic measurement was introduced, that of intensommetry. Intensity is an energy vector thus true energy and direction are measured, however the early measurement systems were confined to steady state conditions and also involved some limitations in both frequency and sound field, in particular highly reverberant spaces were to be avoided. Very recent advances in personal computers, signal acquisition boards, related signal processing and reliable phase-matched transducers now support the development of transient intensity measurement over most frequencies and in most fields from free to highly reverberant. Thus the acoustic temporal history can now be combined with direction to completely describe the response of a space via a new characterizing measurand, the "Intensity Impulse Response" (*IIR*).

2. TRANSIENT SOUND INTENSITY MEASUREMENT

The equipment typically required to perform transient sound intensity measurements is shown in *Figure 1*. A trigger initiates two synchronised processes, an output and an input; each is dependent upon a digital signal processing board, presently a National Instruments *AT-DSP 2200*. The output process retrieves a prepared m-sequence from memory, passes it to the *DSP* which performs a Digital to Analogue (*D/A*) conversion and subsequently excites the space via an amplifier and omnidirectional speaker. The input process acquires analogue signals from each microphone of an intensity probe pair, performs *A/D* and commits the resulting data stream to memory for subsequent processing i.e. calculation of the pressure impulse responses for both microphones along an axis and subsequently the intensity impulse response for that axis.

Combining the three mutual *IIR* (i.e. *3-D measurement*) now allows a complete time, energy, directional representation to be depicted. An alternative to the overall view is to consider either single axial views, or cumulative time period polar plots for a given plane. The polar plots can be dB scaled (typically 0 to -20 dB) as might be significant for subjective response, or linear (typically 1 to 0) ratio; for example a ratio of given vector within the time period to the maximum at any time is proving most useful. The complete description of the measurement method and system is reported in reference [3].

2. ACOUSTICAL DEFECTS DIAGNOSTICS

IIR measures may be processed for many purposes, for example, *1*. The Determination of Cause and Effect, and Fault Resolution; *2*. Spatial Field Categorization (Diffuseness, Balance, and Envelopment); and *3*. The Development of New Objective Indicators.

As an illustration of diagnostic assessment, the results of *Figure 2* apply to a particular position within a concert hall of 5000 m^3, seating 620. The position in the theatre is roughly mid way but slightly off centre towards a left side wall within which is located a recessed lounge. The hall is managed by musicians and they report this position to be acoustically irritating, however contemporary indicators were found to be within acceptable bounds although LEF was slightly higher than suggested optimal.

The two polar plots detail the energy arriving in the lateral plane at 4 kHz, for the time periods 0-50 ms, and 50 to 100 ms. A particularly strong reflection is seen from the left in the early time period, and this may be identified as resulting from the recessed lounge; by comparison the later time period shows a relatively diffuse field of low energy content. The characteristics of the later time period are typically desirable and explain why conventional indicators would judge this position as acceptable. By comparing the angle of the strong reflection occurring in the first time period to the subjective preference angles suggested by Ando and Kurihara [4], we find that this reflection is outside of acceptable bounds. Similar reflections are detected at lower frequencies but at lower frequencies a wider band of angles are acceptable, thus we conclude that the problem is specific to 4 kHz, and the lounge area can be treated accordingly.

3. DIFFUSENESS QUANTIFICATION

3-D measurements described earlier allow a time segmented sound directional distribution to be isolated and visually examined for spatial uniformity. If the sound is fully diffuse, the received intensity vectors tend to be equally distributed in both magnitude and incidence angle thus forming a smooth round envelope in a plane about the measurement location. Three planes can be examined for directional irregularity or otherwise. *Figure 3* [5] shows an example where the directivity patterns (dB scale) in the horizontal plane are observed in time windows of 0-50, 50-100 and 100-200 ms; the transition from a directive sound in the first time window to a generally diffuse sound in the second and third time windows can be readily visualized. We can now develop a single number indicator based, for example, upon the standard deviation of the sound intensity magnitudes taken at small angular intervals, over 360° for the given time window, as a measure of diffuseness.

Diffusion of the sound field can also be viewed as the sound being isotropic in all directions so that, in the case of uniform spatial distribution of absorptive materials and equal probability of incidence, the sound decay in all directions should exhibit the same decay rate. Deviations of a directional decay component from the others indicates a lack of spatial homogeneity. This can be verified by examining the decay curves of sound intensity components compared to each other. *Figure 4* illustrates sound intensity decay curves for component direction intensities in a reverberant field and a small room at 500 Hz. The decay curves are obtained applying the "*Schroeder*" backward integration to the absolute values of the intensity response which expresses the total received sound energy in the plane. It can be seen that the instantaneous intensity component decays are close to each other in the case of a reverberant field and the slopes are similar compared to the case of a small room, the decay in the Y direction is sagging at some periods of time while the Z direction sound intensity decay deviates in manner which indicates unequal energy distribution; in the present case this can be attributed to absorptive suspended ceiling tiles and a variety of surfaces treatment and fittings in the test room. The reverberation time RT_x, RT_y or RT_z for a given axis may be determined in a manner similar to that applied to pressure (dB) decay results, however the best time evaluation for subjective effect, or for room characterization has not yet been established. It might be noted in passing that this particular measure could also be achieved by employing a standard figure of eight microphone in each cardinal orientation as used in *LEF* evaluation, that is, the measurement of directional decay does not in fact need sophisticated processing or instrumentation.

Other field applications will be addressed during the talk to illustrate the directional measurement method and system detection capability.

4. REFERENCES

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5. A. Abdou, "Transient Sound Intensity Measurement for Evaluating the Spatial Information of Sound Fields in Reverberant Enclosures," Ph.D. Thesis, Centre for Building Studies, Concordia University, Montreal, Canada, November 1994.

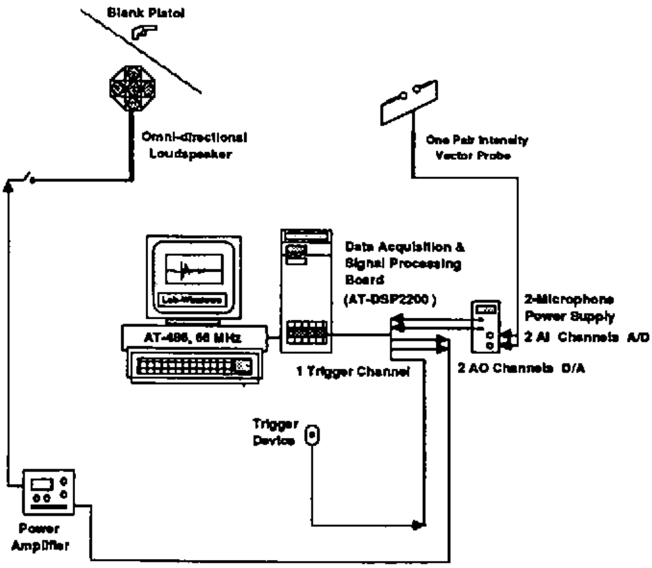

Figure 1. Transient sound measurement system.

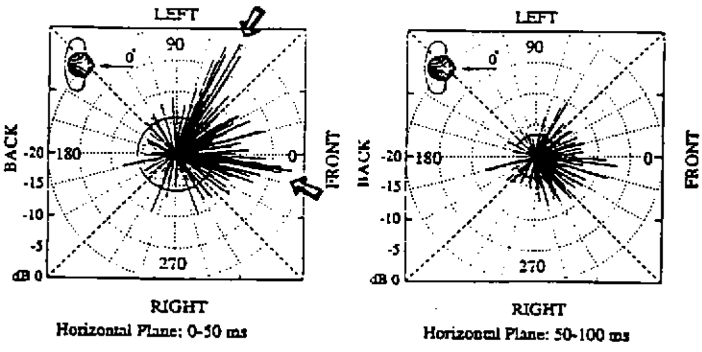

Figure 2. Directivity patterns in the horizontal plane, at 4 kHz, (0 to -20 dB).

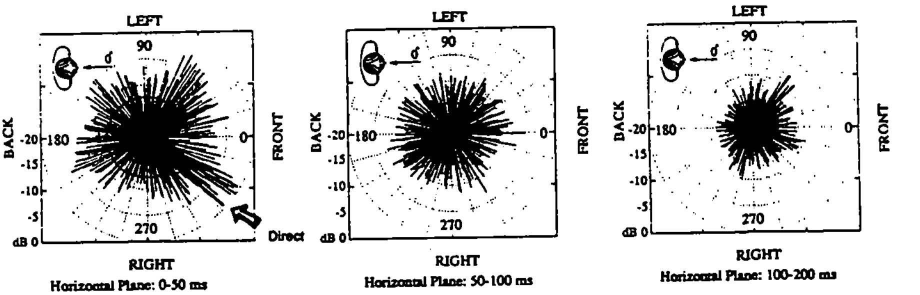

Figure 3. An example of Time-segmented directivity patterns for a measurement in a reverberant field at 2 kHz, shown in the horizontal plane. (0 to -20 dB)

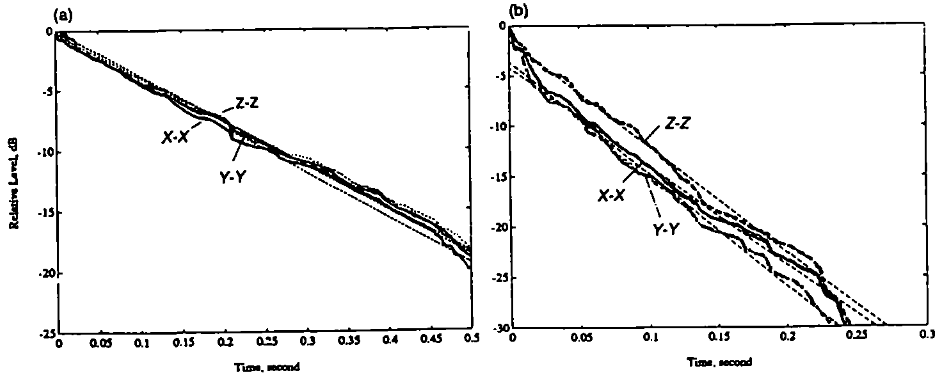

Figure 4. Orthogonal components "sound intensity" decay curves at 500 Hz in (a) Reverberant sound field, and (b) Small live room.