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OBJECTIVE ROOM ACOUSTICAL PARAMETERS USING 2-CHANNEL ANALYSIS

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INTRODUCTION

Traditionally most room acoustic measurements have been carried out as simple signal analysis using noise bursts or a non-ideal impulse. With these techniques the decay curve is measured and the reverberation time is derived, and if several measurements are carried out to obtain a spatial average, it will be possible to characterize the room by one single number.

In recent years, however, there has been an increasing interest in more advanced methods using the techniques of inverse filtering, time delay spectrometry or dual-channel FFT-analysis (system analysis), the latter being the subject of this article.

THE METHOD

Regard the impulse response as the Fourier transform of the frequency response function H(f):

$$h(\tau) \overset{\mathcal{F}}{\longleftrightarrow} H(f) \qquad (1)$$

The frequency response function is derived from:

$$X(f) \longrightarrow \boxed{H(f)} \longrightarrow Y(f) \qquad (2)$$

$$Y(f) = H(f)\ X(f) \qquad (3)$$

From this we see that measuring the impulse response is the same as performing a system analysis, in which case we should use either a well-defined input signal or, even better, measure both the input and output signals and then calculate the frequency response function by means of the cross-spectrum and the two auto-spectra. Using the dual-channel measurement enables us to optimize the excitation signal in the measurement situation or to use natural signals (music, speech).

As we have access to the cross-spectrum and auto-spectra it is also possible to calculate the coherence function, defined as:

$$\gamma^2(f) = \frac{|\,G_{AB}(f)\,|^2}{G_{AA}(f)\,G_{BB}(f)} \qquad (4)$$

The coherence function expresses the linear relationship between input and output, and since a room is a linear system, the coherence function quantifies the measurement's quality.

By the use of the Hilbert transform the envelope or magnitude of the impulse response is derived. The integrated impulse response used here is calculated as:

$$r(t) = \frac{\int_t^T |\,h(\tau)\,|^2\,d\tau}{\int_0^T |\,h(\tau)\,|^2\,d\tau} \qquad 0 < t < T \qquad (5)$$

where T is the record length of the Fourier transform. From this integrated response several objective parameters are calculated, which quantify the acoustical quality of a room.

From the magnitude of the impulse response it is also possible to calculate the modulation transfer function, which can be used to evaluate speech intelligibility [1,2]. The calculation is performed according to the definition by M.R. Schröeder [3]:

$$MTF(f_m) = \frac{\int_{-T}^{T} |h(\tau)|^2 e^{-j2\pi f_m \tau} d\tau}{\int_{-T}^{T} |h(\tau)|^2 d\tau} \qquad (6)$$

When measurements are carried out with the sound source at a given level and in certain frequency bands it is possible to calculate the Speech Transmission Index in a relatively short time, according to a method by T. Houtgast and H.J.M. Steeneken [1].

MEASUREMENTS

The measurements were performed in a special listening room at the Technical University of Denmark. The room is characterized by having a live and a dead end and a classical reverberation time close to 0,4 second. During the measurements the source was positioned in the dead end whereas the receiver was positioned in the line end.

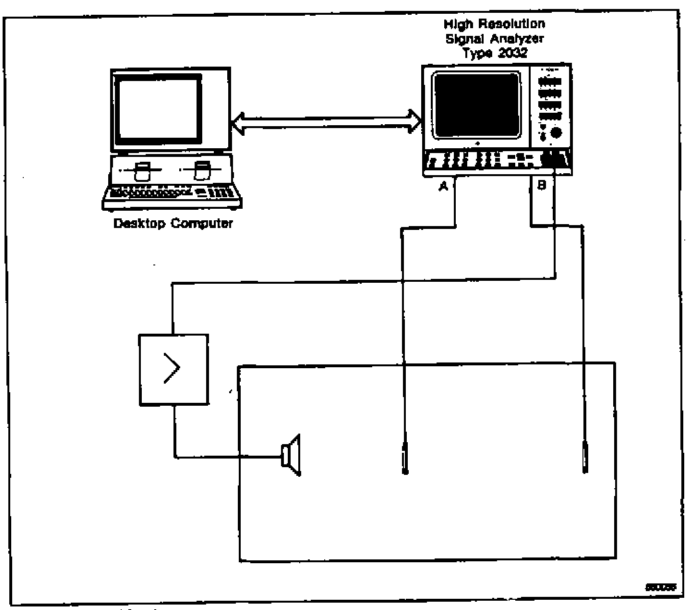

Fig.1. Measurement setup

The measurement setup is shown in Fig. 1. The instruments used are: two free-field microphones, B&K Type 4165, a dual-channel FFT-analyzer, B&K Type 2032, an HP series 200 computer, and a loudspeaker and power amplifier which were permanent equipment in the room. To improve the signal-to-noise ratio in the receiving channel, a 1/3-octave filter can be used in Channel B.

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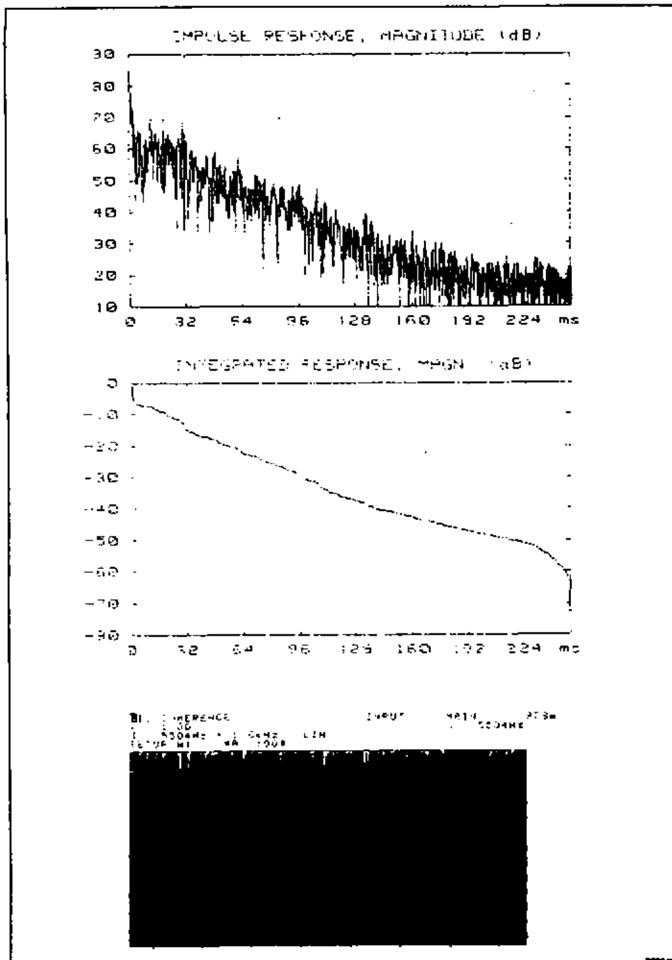

Fig.2. The magnitude of the impulse response, the integrated impulse response and the coherence function

In Fig.2 a measurement result in the 6300 Hz 1/3 octave band is given. First the magnitude of the impulse response is shown, and thereafter the integrated impulse response is shown. The latter clearly indicates two different slopes and a drastic decline in the level, which is a result of the loudspeaker being placed in the dead end of the room. The coherence function is very close to 1 which indicates that there is a nearly perfect linear relationship between the sound pressures in the two positions.

In Fig. 3 the modulation transfer function is shown. As a result of the very short Early Decay Time (EDT) and the source and receiver positions, the MTF has a very smooth and flat slope.

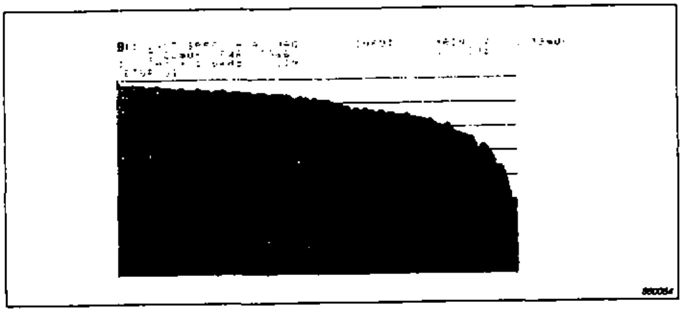

Fig.3. The modulation transfer function

The objective parameters which can be calculated are given in Fig.4. This example clearly shows how efficiently the integrated impulse response detects multiple slope decays, which can be quite difficult on the basis of the magnitude of the impulse response or just the numbers (EDT, RT_{60}). The table of parameters also give numbers, which quantify the room's acoustical quality with regard to the transmission of speech and music.

EDT 5	0 to -5 dB :	.01	Sec
EDT 10	0 to -10 dB :	.24	Sec
TA	0 to -20 dB :	.21	Sec
T60	-5 to -25 dB :	.23	Sec
T60	-5 to -35 dB :	.24	Sec
D :		.99	
C :		25.57	
Ts :		0.00	
DELTA L :		3.13	
ST1 :		-9.79	dB

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Fig.4. Table of calculated room acoustical parameters, important for the transmission of speech and music

CONCLUSION

By using the dual-channel FFT-technique for making room acoustical measurements (the room being regarded as a system), more detailed information is obtained than when classical methods are used. The modulation transfer function is a step further in the description and understanding of the transmission of speech and music.

LITERATURE

[1] H.J.M. Steeneken and T. Houtgast: *A physical method for measuring speech-transmission quality*. J. Acoust. Soc. Am. 67 (1), Jan. 1980.

[2] T. Houtgast, H.J.M. Steeneken and R. Plomp: *Predicting Speech Intelligibility in Rooms from the Modulation Transfer Function. I. General Room Acoustics*. Acoustica, Vol. 46 (1980).

[3] M.R. Schröeder: *Modulation Transfer Functions: Definition and Measurements*. Acoustica, Vol. 49 (1981).