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MEASUREMENT OF VERY SHORT REVERBERATION TIMES

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Introduction

In speech studios with reverberation times around 0,1 – 0,2 s it is not possible to use traditional measuring technique because of the ringing of 1/3 octave filters. A new measuring technique, which is based on a time reversed analysis, has been used in speech studios in the Danish Broadcasting House and the results have been compared with those from traditional methods. The interrupted noise method and the integrated impulse response method have been used, and the relation between limits for reliable results and the choice of measurement setup parameters have been closely regarded.

Measurement method

A suitable and convenient measurement method is not found in any standard. The international standard ISO 3382 (1975) [1] describes field measurements of reverberation time, but guidelines for the measurement of short reverberation times are not included. Further, the standard is completely out-of-date, since the main contents is more than 15 years old, and the measurement technique has developed considerably during this period. Some useful hints are found in ISO 354 (1985) [2], but measurement of short reverberation times in studios is outside the field of application and not possible using the method described. Consequently, the measurement procedure must be defined utilizing experience from other practical measurements and the new possibilities offered by modern instrumentation.

In the traditional method a broadband noise source is used and after the source has been switched off the decay curve can be recorded. However, this curve can have strong fluctuations due to the stochastic character of the excitation noise, and several decay curves should be evaluated in each position. Using the measuring technique of today, the decay curves from repeated excitations can be averaged into an ensemble averaged decay curve with much reduced fluctuations. Extending the ensemble averaging to include spatial averaging gives rather smooth decay curves, and it seems reasonable to assume that these curves are a good basis for the evaluation of reverberation time.

Another traditional method is the use of a pistol shot as an excitation signal. By this method the impulse response of the room is measured. As shown by Schroeder [3], the decay curve can be calculated from a backward integration of the squared impulse response. One major quality by this method is, that there will be no stochastic fluctuations, so one excitation in each position will be sufficient to get a decay curve equivalent to the ensemble averaged decay from an infinite number of excitations using interrupted noise. Spatial averaging can be made by ensemble averaging over all source and receiver positions as described above.

Evaluation of decay curves

Within the last years there has been a tendency to prefer an evaluation range of 20 dB. The last version of ISO 354 [2] has followed that tendency. However, the first part of the decay curve (5 dB or so) should not be used for the evaluation.

Limitations caused by bandpass filters

Reverberation time measurements are usually analyzed in 1/3 or 1/1 octave bands. However, such bandpass filters can influence the measurement due to the filter ringing, which can give rise to a characteristic waving of the decay. According to Ref. [4] reliable decay curves are obtained only if

$$B \cdot T_{60} > 16 \qquad (1)$$

where B is the bandwidth of the filter and T_{60} is the reverberation time to be measured. If requirement (1) is not met the evaluated reverberation time can be too short or too long, i.e. the sign and size of the error is not predictable.

However, in Ref. [5] it has been demonstrated that reversing the time signal to the filter leads to much less distortion of the decay curve. It has been found that if the upper 5 dB are excluded from the evaluation the requirement (1) can be replaced by

$$B \cdot T_{60} > 4 \tag{2}$$

It should be noticed that there is no distinct limit between acceptable and unacceptable decay curves.

For measurements in 1/3 octave bands the limit for reliable results at 100 Hz is changed from 0,7 s to 0,17 s when time reversed analysis is used instead of forward analysis.

Limitations caused by detector

When measuring short reverberation times it is important to choose the averaging time of the detector short enough to avoid any influence on the slope of the decay curve. Using a device with exponential averaging (time constant τ_d) it has been shown in Ref. [4] that the averaging time should obey the requirement

$$T_{av} = 2\tau_d < T_{60}/14 \tag{3}$$

Here again T_{60} is the reverberation time to be measured. If the requirement (3) is not met the evaluated reverberation time will be too long.

However, since response of the detector is much faster when the signal increases instead of decreasing, it will be of great advantage to use time reversed analysis. According to Ref. [5] requirement (3) can then be replaced by

$$T_{av} = 2\tau_d < 8 \cdot T_{60}/14 \tag{4}$$

Only the upper part of the decay curve is influenced when time reversed analysis and long averaging times are used. Further investigations reported in Ref. [6] have indicated, that the reverberation times deviate less than 1% from the correct values, if conditions (1) – (4) are fulfilled, and the evaluation range does not include the upper 5 dB of the decay.

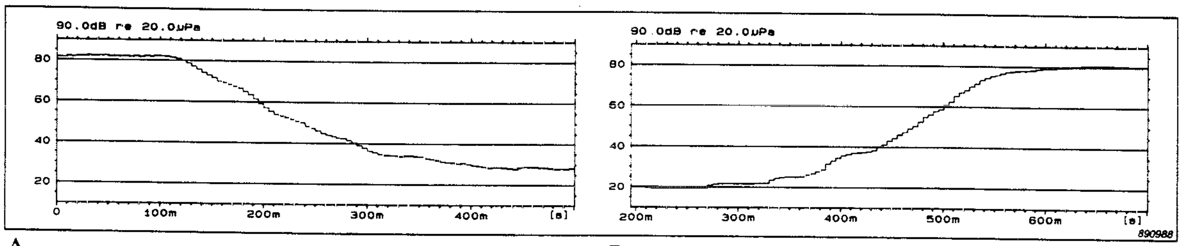
The averaging time is connected to the frequency bands so that $B \cdot T_{av} \geqslant 1$ to obtain reliable results. This is a well known condition for the analysis of stationary signals, but at the first glance it could seem to be difficult to meet in decay measurements. However, ensemble averaging offers a solution to the problem: using this technique a requirement for the number of repeated and ensemble averaged excitations N_{exc} should be

$$N_{exc} \geqslant \frac{1}{B \cdot T_{av}} \tag{5}$$

To minimize the number of excitations, the averaging time should be as large as possible but still fulfill (3) or (4). Looking at these requirements, it is seen that a much larger averaging time is allowed for time reversed analysis than for forward analysis. Hence, fewer excitations are necessary, which is an additional feature of the time reversed analysis. For the actual measurements $T_{av} = 1/128$ sec. and $N_{exc} = 12$ were used for forward analysis, while $T_{av} = 1/16$ sec. and $N_{exc} = 2$ were used for time reversed analysis.

When the method of integrated impulse response is regarded, this is equivalent to the use of a very long averaging time. So, in that case it will not be relevant to consider (5), and one excitation in each position will be sufficient.

Examples of measured decay curves in the actual studio at the 100 Hz 1/3 octave are shown in Fig. 1 for noise excitation and in Fig. 2 for impulse excitation.



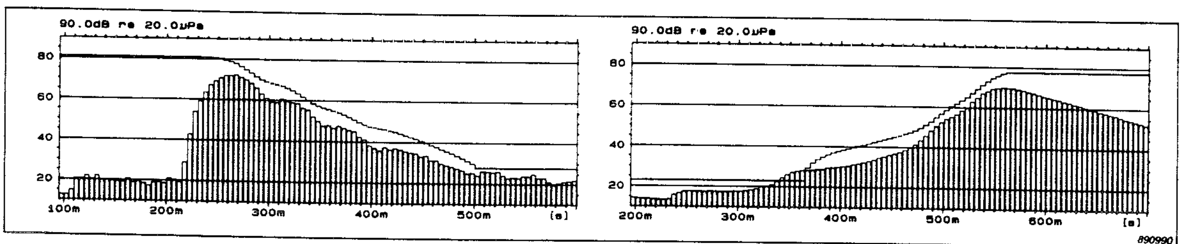
A.

B.

Fig. 1. Interrupted noise excitation in a 68 m³ studio. 100 Hz 1/3 octave band

A. Ensemble averaged decay curve using six source-microhone positions and forward analysis. 72 excitations in total. The requirement (1) is not met

B. Ensemble averaging as in A, but using time reversed analysis. 12 excitations in total. All requirements are met



A.

B.

Fig. 2. Impulse excitation in a 68 m³ studio. 100 Hz 1/3 octave band. Same positions as in Fig. 1. In both examples the decay curve (solid curve) has been calculated by backward integration of the impulse response (bar graph)

A. Ensemble averaged impulse response and the corresponding decay curve using six source-microphone positions and forward analysis. The requirement (1) is not met

B. Ensemble averaging as in A, but using time reversed analysis. All requirements are met

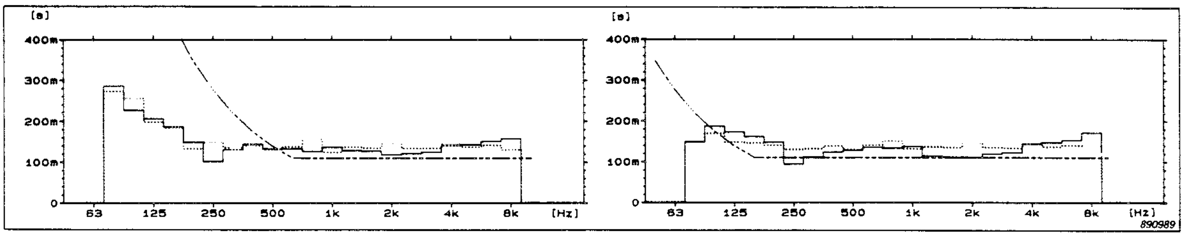
Description of the studio

A speech studio in the Danish Broadcasting House were selected as a measuring object because the reverberation time was expected to be very low. The volume of the studio was 68 m³ and the studio was furnished with a table and 6 chairs. Two source positions were used, one of them close to a corner with the centre of the loudspeaker 0,4 m from each of the nearest surfaces. Three microphone positions were distributed in each room, 1,0 m, 1,2 m and 1,4 m above the floor. Each source position was used in combination with each microphone position, making a total of six combinations, which were used for spatial ensemble averaging.

Instrumentation and measurement results

The measurements were carried out with the Brüel & Kjær Real Time Analyzer Type 2133. A more detailed description of the use of this instrument for measurement of short reverberation times is given in Ref. [6]. A 6 mm pistol was used for impulse excitation in combination with a −6 dB/octave filter. The latter did improve the signal-to-noise level at low frequencies, and so the pistol was usable in a wide frequency range.

The measured reverberation times in the studio are shown in Fig. 3. Compared with the limits discussed above it is seen, that only the values based on time reversed analysis are reliable at the lower frequencies (below about 500 Hz). There is a clear tendency that when the requirements for the forward analysis are not met, the results are longer than those from the time reversed analysis.



A. B.

Fig. 3. Measured reverberation times in a 68 m^3 studio using noise and impulse excitation. The results are compared with the lower limits for reliable results, (1) and (3) for forward analysis, (2) and (4) for time reversed analysis

——— *Using interrupted noise*
...... *Using integrated impulse response*
---- *Lower limit for reliable results*
A. Forward analysis
B. Time reversed analysis

Conclusion

The measurement results from a studio have demonstrated that the ringing of 1/3 octave filters can introduce errors in the reverberation times evaluated from the decay curves. These difficulties can be overcome when a time reversed analysis is used. In addition this method allows the number of excitations at each position to be reduced considerably if the interrupted noise method is used.

It has been demonstrated that the interrupted noise method and the integrated impulse response method do agree very well and that both methods can benefit from the time reversed analysis when very short reverberation times have to be measured.

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