11th International FASE Symposium
Valencia 15-17 Noviembre 94

EVALUATION OF VERY SHORT REVERBERATION TIMES

J. Algaba and T. Zamarreño

Instituto Universitario de Ciencias de la Construcción. E. T. S. de Arquitectura.
Universidad de Sevilla. Avda. Reina Mercedes, 2. 41012-SEVILLA

1. INTRODUCTION

In order to credit an anechoic room located in the Acoustic Laboratory of *Centro Nacional de Medios de Protección (Sevilla, Spain)* and devoted to the subjective assays compiled in the national standard *UNE 74-011-91*, we have evaluated its reverberation time. That standard stablishes *1.6 s* as the higest value allowable for teverberation time (RT) of the room in each interesting band.

The room has an aproximate useful volume of *5'5×4×4* m^3. It is framed by a concrete parallelepiped mounted on elastic elements and lined by *80 cm* length fiber-glass wedges.

2. MEASUREMENT METHODS

There are not suitable methods in order to determine RT as short as the usual ones in a room with these characteristics. The international standard *ISO 3382*[1], or the related *UNE*[2], describe the reverberation time measurements but guidelines for the measurement of very short reverberation times are not included.

Consequently, the measurement method has been defined according to other experiences performed in similar situations (talk studios)[3].

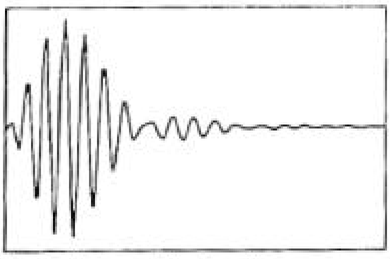

Fig. 1 Caracteristic impulse response of ⅓ octave filters.

In the traditional method a broadband noise source is used and after the source is switched off the decay curve is registered. In order to avoid the aleatory signal fluctuations it is necessary to average several decay curves in each point. To obtain a more precise description of the inherent reverberation of the room, spatial averaging for different positions source-microphone are necessary. Therefore two source points with three microphon positions for each one have been used.

Another method uses a gun shot as impulsive excitation to obtain the room impulse response. As Schröeder showed[4], the room decay curve can be calculated from a backward integration of the squared impulse response. The main advantage of the last method is the removal of the stochastic signal fluctuacions. In this case one excitation is enough in each point to achieve an equivalent decay curve to the average curve obtained by infinite excitations using the interrupted noise. Additionally, the spatial averaging is also recommended in this case.

2.1. Limitations Caused by the Bandpass Filters

The reverberation time measurements are usually analized in $^1/_1$ or $^1/_3$ octave bands. However, such filters may modify the measurements owing to the characteristic deadening of its response. In agreement with the reference[5] adecuate decay curves will be obtained only if:

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

where B is the filter bandwidth and T_{60} is the reverberation time to be measured. If the previous requirement is not verified the obtained value for T_{60} may be lower or higher than the real one.

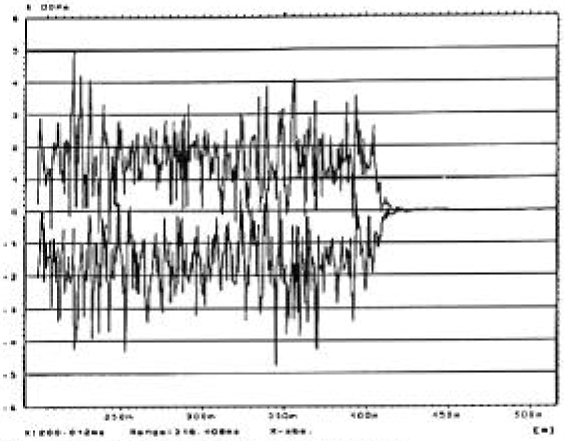

Fig. 2 Characteristic decay time process.

If the signal is time-reversed applied to the filters, it has been showed[6] that a much lower distortion in the decay curve is obtained. If the first *5 dB* are not considered in the decay curve evaluation, the requirement (1) can be replaced by

$$B \cdot T_{60} > 4 \qquad (2)$$

The advantage obtained by reversing the signal in the time ~~is due to~~ the asymetrical impulse response filters. In the Fig. **1** is shown the characteristic response curve produced by a $^1/_3$ octave band filter. The response tail produces a decay that must be smaller that the decay to be measured in order to dispose reliable results.

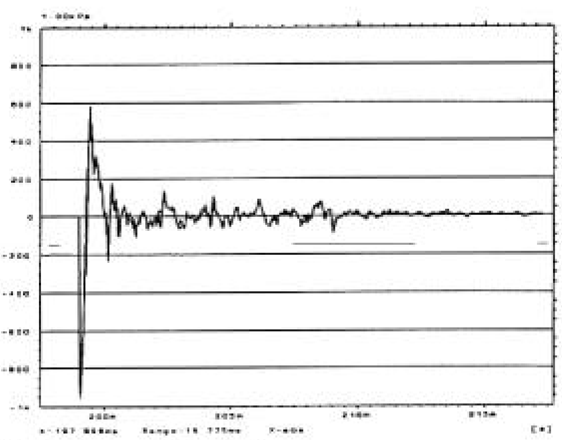

Fig. 3 Characteristic time impulse response.

2.2. Limitations Due to the Detector

It has been shown [5] that to avoid the detector influence, wich has a time constant τ_d, in the extinction the average time, T_{av}, must verify the condition:

$$T_{av} = 2\tau_d < \frac{T_{60}}{14} \qquad (3)$$

where T_{60} is the reverberation time to be measured. If this requirement is not observed the measured value will be higher than the correct one.

In this case is also better to apply the time-reversed analysis because the detector response is faster when the signal increases.

If this method is applied, acording to [6], the condition (3) can be replaced by:

$$T_{av} = 2\tau_d < \frac{8 \cdot T_{60}}{14} \qquad (4)$$

If the conditions (1)–(4) are observed and the first *5 dB* are removed, has been showed[7], that the measured reverberation time differs less than *1%* from the right value.

2.3. Limitations Related to the Measurement Method

The detector averaging time is connected with the filter bandwith so that $B \cdot T_{av} \geq 1$ to obtain significative results. This is a well known relation for the stationary signal analysis. The possibility of averaging decay measurements allows to fulfill this requirement in the extinc–

tion processes: the number of excitations, N_{exc}, must be:

$$B\cdot(N_{exc}\cdot T_{av}) \geq 1 \quad \rightarrow \quad N_{exc} \geq \frac{1}{B\cdot T_{av}}. \tag{5}$$

In order to minimize the number of excitations, the average time must be as large as posible, provided that (3) or (4) conditions are observed. The reversed time analysis has an additional advantage because it allows to choose a higher T_{av} value. In our case $T_{av}={}^{1}/_{128}$ s and $N_{exc}=6$ where selected.

For the impulse response method is not necessary to consider condition (5), so that only one excitation in each point is enough.

2.4. Limitations Caused by the Sampling Time Interval

One of the advantages of the exponential averaging is the possibility to choose the sampling time interval T_s and the averaging time T_{av} independently. If we like to have, at least, n sample points for the regression line for a D dB range, in the decay curve, must be verified:

$$T_{mue} \leq T_{60}\cdot\frac{D}{n\cdot 60}. \tag{6}$$

The characteristic/minimun practical values are $D=20$ dB and $n=3$. Then, if $T_s=5$ ms, is possible to evaluate a 10 dB range for $T_{60}\geq 0.1$ s.

3. EQUIPMENTS

A *Brüel&Kjær 21233* real time analyzer has been used for the measurements. The method of measurements and analysis was automatized through the corresponding analyzer autosequences.

The time response to noise interrupted or impulse was registered on disc for its time-reversed analysis.

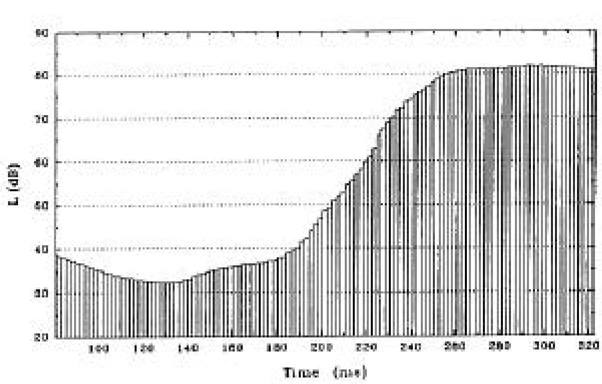

Fig. 4 Time-space averaged decay curve at 100 Hz.

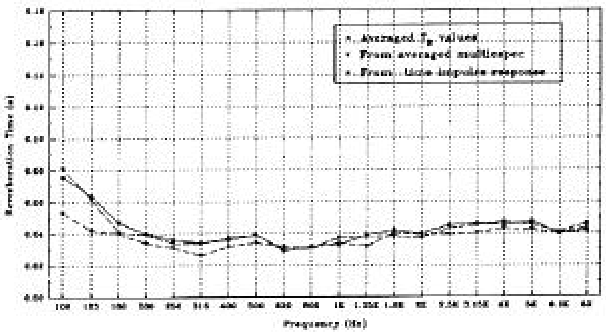

Fig. 5 T_R versus frequency.

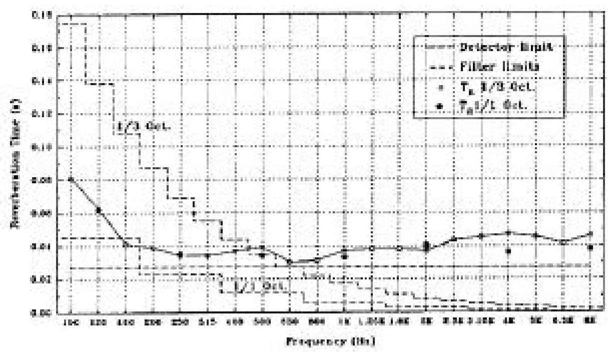

Fig. 6 Filter and detector limits for reliable T_R results.

The detector averaging time has been chosen so that the limit for reliable results of reverberation time was *13.7 ms*, (4).

In order to observe the requirement imposed by (5) for the lower interesting band (*100 Hz*), *6* excitations in each point has been used (only reversed analysis has been used).

The noise was generated by the analyzer itself, amplified by the *B&K E5001* amplifier and transmited inside the room by the *B&K BR112TA* source.

4. MEASUREMENTS RESULTS

For the interrupted noise method the *S/N* was about *50 dB*, in all interesting bands. Fig. 2 shows a característic time decay process and Fig. 3 a characteristic time impulse response.

The reverberation times have been evaluated using the time (*6* extintions por each source–microphone position) and spatial (*2* source × *6* microphone positions) averaged decay curves. In this method has been used a lineal regression with a *25 dB* interval starting *5 dB* under the stationary signal level.

The averaged decay curve for *100 Hz* $^1/_3$ octava band is shown in Fig. 4.

The reverberation time values versus frequency are shown in Fig. 5. These values have been obtained applying the diferent methods that have been described before.

Finally, in the Fig. 6 appear the measured averaged values, and the filters and detector limits in order to obtain reliable results.

5. CONCLUSIONS

From the data plotted in Fig. 5 we can notice that the two measuring methods (interupted noise and integrated impulse) give concordant results in all the interesting frequency bands, except for the values that are lower than *125 Hz*. In this last case the interrupted noise method give higher reverberation time values.

For frequencies above *400 Hz* the measured values are over the filter and detector imposed limits. This fact allow us to accept the obtained results as reliables.

For frequencies below *400 Hz* the measured values are slightly lower than the limits imposed by $^1/_3$ octave band filters. For this reason the registered time signal was again analized using $^1/_1$ octave filters. The obtained results (black points, Fig. 5) correspond with the $^1/_3$ octave band measured values and consequently, practically for all bands, the results are now over the limits imposed by the filters.

Finally, taking into account the precision of the used method, we can conclude that the room verify widely, concerning reverberation times, the requirements imposed by *UNE 74–011–91* for all interesting bands. In fact, the measured values represent only the *3.5%* from the highest allowed value (in the worst case).

6. REFERENCES

1. ISO 3382 (1975): *Acoustics Measurements of Reverberation Time in Auditoria.*

2. UNE 74–043–80: *Medida del Tiempo de Reverberación en Auditorios.*

3. RASMUSEN, B.; RINDEL, J. H. & HENRIKSEN, H.: *Design and Measurement of Short Reverberation Times at Low Frecuencies in Talk Studios.* Audio Eng. Soc. Conv., 1989, New YorK.

4. SCHRÖEDER, M. R.: *New Method of Measuring Reverberation Time.* J. Acoust. Soc. Am. **37**, p. 409–412. 1965.

5. JACOBSEN, F.: *A Note on Acoustic Decay Measurements.* J. Sound Vib. **115**, p. 163–170. 1987.

6. JAKOBSEN, F. & RINDEL, J. H.: *Time Reversed Decay Measurements.* J. Sound Vib. **117**, p. 187–190. 1987.

7. RASMUSSEN, B. & PETERSEN, F.: *An Automated Instrumentation for Measurements of Very Short Reverberation Times.* Westpac III Conference, Shangai, China. Proceedings p. 929–932. 1988.