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# Determination of Sound Reduction Index by impulse response measurements

P. Bonfiglio, P. Fausti

*Dipartimento di Ingegneria di Ferrara, Via Saragat 1, 44100 Ferrara,Italy,*
*(pbonfiglio, pfausti} @ing.unife.it*

**ABSTRACT:** The Sound Reduction Index of a partition can be measured according to the method described by ISO 140. This paper reports experimental results obtained with a new measurement method based on the determination of the impulse response in two rooms separated by the partition. In fact, it is possible to show that, by evaluating the Schroeder integral plot, we can calculate energy levels and reverberation time. The Sound Reduction Index is then calculated by using the relationship proposed by the ISO 140 series.
The determination of the impulse response is made by using the exponential sine sweep signal excitation. These test signals guarantee high accuracy and repeatability in levels and reverberation time measurements. In this paper, the advantages and the drawbacks of the new technique will be discussed and the comparison with the traditional technique will also be shown.

## 1. INTRODUCTION

The Apparent Sound Reduction Index $R'$ of a partition is generally measured according to the method described by ISO 140-4 [1]. The measurement of $R'$ can be made also by using the Acoustic Intensity based method (ISO 15186 [2]) or the Vibration Velocity based technique [3,4]. A further technique, described by ISO/CD 18233 (draft version) [5], is based on the determination of the impulse response in both the sending and the receiving rooms. It is possible to demonstrate that, by evaluating the Schroeder integral plot, we can calculate the energy levels and the reverberation time. The Sound Reduction Index is then calculated by using the relationship proposed by 140-4.
The impulse response can be determined by using impulsive signals, MLS sequences and sine sweeps. In this work, preliminary results regarding the measurement of $R'$ are shown. The measurements make use of the analysis of the impulse response by using Exponential Sine Sweep excitation.
The results thus obtained are analysed and compared with the traditional technique. Considerations about signal to noise ratio in energy level measurements are also presented.

## 2. PHYSICAL BACKGROUND

The relation proposed by ISO-4 for the determination of the Apparent Sound Reduction Index of a partition is the following:

$$R' = L_1 - L_2 + 10 Log_{10}\left(\frac{S_p}{A}\right) \qquad [\text{dB}] \qquad (1)$$

in which:
$L_1$ is the energy level in the source room;
$L_2$ is the energy level in the receiving room;
$S_p$ is the area [m$^2$] of the partition;
$A$ is the equivalent sound abpsorption area in the receiving room.

$$A = 0.161\frac{V}{T} \qquad [\text{m}^2] \qquad (2)$$

where:
$V$ is the volume [m$^3$] of the receiving room;
$T$ is the Reverberation Time [s] of the receiving room.

The new method is based on Schroeder's backward integration of the impulse response.
It can be shown [6] that, in a room, the expected response $n(t)$ to a noise excitation switched off at the time t=0 is related to the impulse $h(t)$ by the following equation:

$$\left\langle n^2(t)\right\rangle = N\int_t^{\infty} h^2(u)\,du \qquad (3)$$

in which $N$ is a constant related to the excitation level.
Consequently the expected energy $\left\langle n^2(0)\right\rangle$ due to the continuous noise excitation is obtained by integrating the impulse response over the observed time.

$$\left\langle n^2(0)\right\rangle = N\int_0^{\infty} h^2(u)\,du \qquad (4)$$

If the logarithmic curve $L(t)$, which is related to $\left\langle n^2(t)\right\rangle$, is considered, the corresponding energy level is simply:

$$L(0) = 10 Log_{10}\left[\left\langle n^2(0)\right\rangle\right] \qquad [\text{dB}] \qquad (5)$$

Moreover, the reverberation time may be computed by evaluating the slope of this curve.

$$T = -60 \cdot \left( \frac{dL'(t)}{dt} \right)^{-1} \qquad [\mathrm{s}] \qquad (6)$$

in which $L'$ is the linear fit of $L(t)$ function.

The use of MLS signals for $R'$ measurement is already developed and used in some commercial instrumentation [7] .
In this work an Exponential Sine Sweep was chosen as test signal. It is possible to show [8] that if an Exponential Sine Sweep is used as input signal, the impulse response of a room (supposed Linear and Time-Invariant) is expressed as:

$$h(t) = y(t) * f(t) \qquad (7)$$

where $y(t)$ is the output signal and $f(t)$ is the inverse filter of the input signal.

## 3. TEST SET-UP AND MEASUREMENT PROCEDURE

The set-up consists of :

- omnidirectional dodecaedric source Look Line mod. 300;
- sound level meter B&K Type 2260 Investigator;
- DAT Tascam DA P1;
- Audio device type Digigram VX Pocket®;
- Adobe Audition® software with plug-in Aurora® and Dirac® software.

Figure 1- *Photo of the experimental set-up*

Figure 1 shows the instruments used for the field measurement of $R'$.
In order to allow a comparison with the traditional technique, records are also made with a sine sweep signal excitation, during a period of 20 s, and ranging from 40 to 6000 Hz.
The DAT waveforms are digitally transferred to hard disk WAV files by a proper digital interface installed on the PC. The post-processing operations (convolution products, wideband filtering, signal level and Reverberation Time calculation) are done using the Aurora® package and Dirac® software.
Regarding the measurement procedure and requirements (such as minimum distances between the different microphone positions or between the microphones and the sound source, room boundaries or diffuser, or the number of necessary positions for evaluating average sound pressure level and average reverberation time) the guidelines provided in ISO 140-4 were used.

## 4. EXPERIMENTAL RESULTS

In this section, experimental results related to a vertical partition whose area is 10.2 $m^2$ are shown. The volume of the receiver room is 34.2 $m^3$ .
Figure 2 reports the frequency domain curves showing the level difference ($D=L_1-L_2$) for the cases of both the new and the traditional technique.
Comparison in the Reverberation Time obtained by the two methods is presented in Figure 3.
Finally, a comparison in the Apparent Sound Reduction Index calculated with the techniques previously described is shown in Figure 4. Also, the values of the single number quantities measured according to EN-ISO 717-1 [8] are reported in Figure 4.

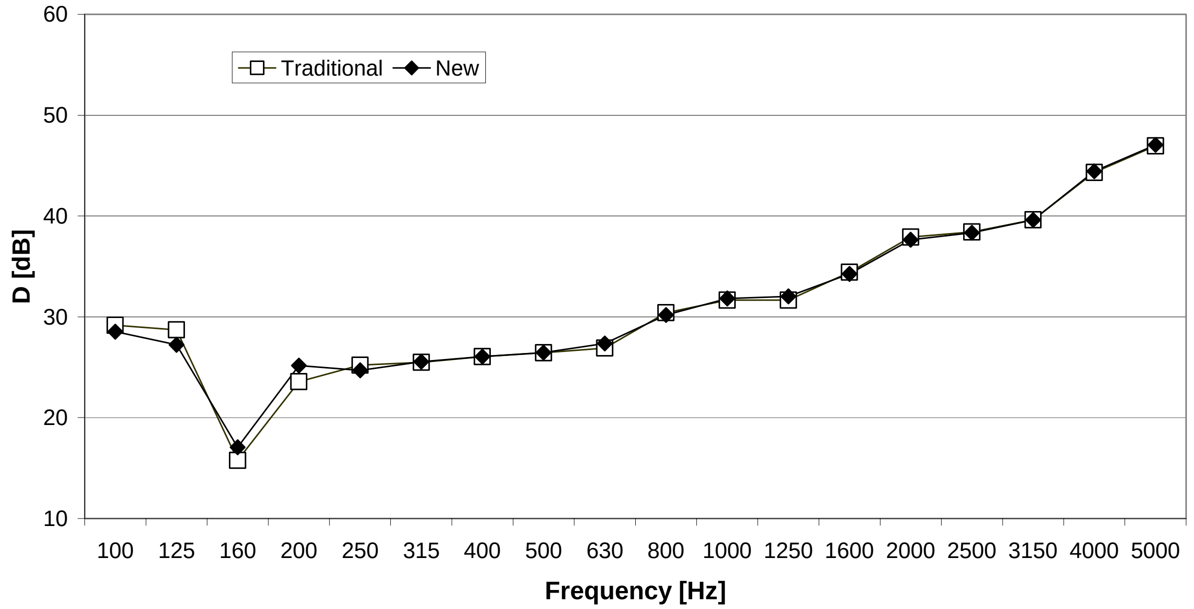


Figure 2 - *Level difference. Comparison between New and Traditional techniques*

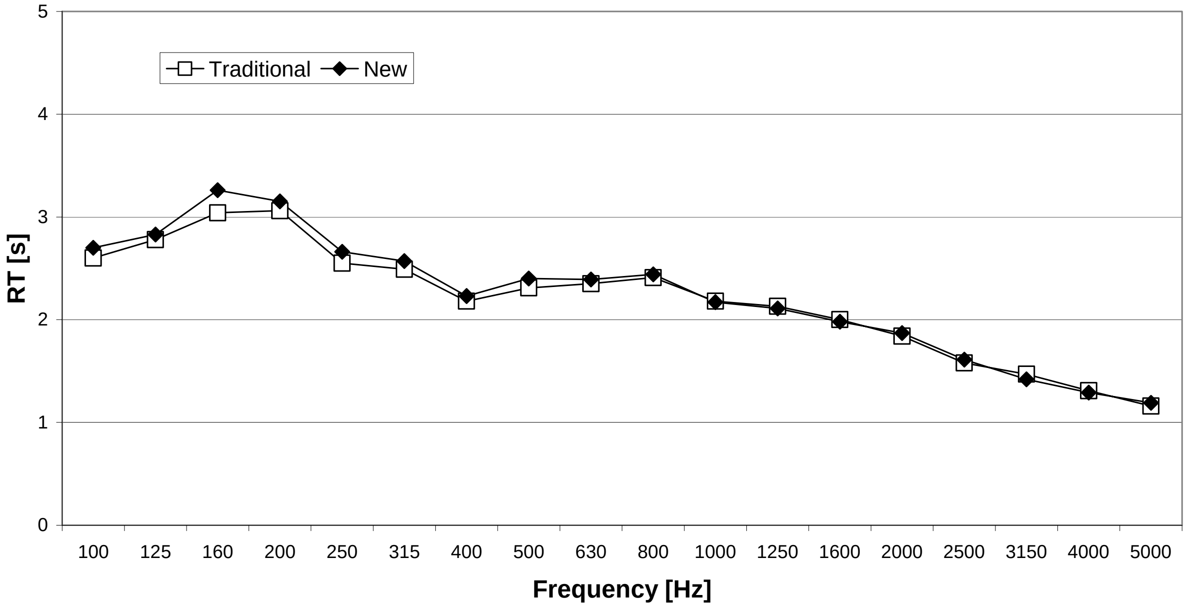


Figure 3 - *Reverberation Time. Comparison between New and Traditional techniques*

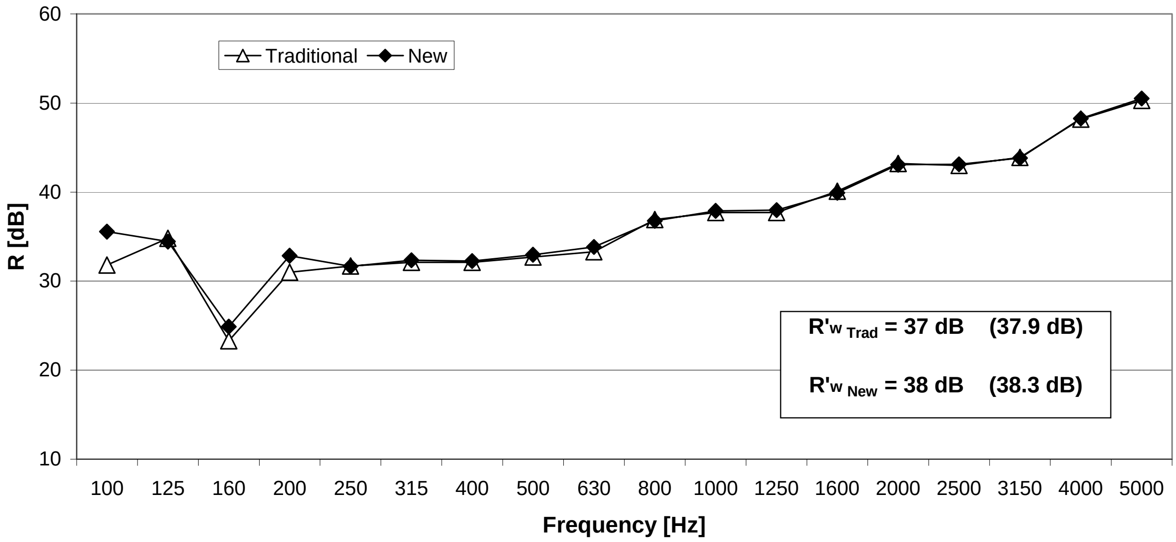


Figure 4 – *Apparent Sound Reduction Index. Comparison between New and Traditional techniques*

Figures 2, 3 and 4 all show very similar results whether the traditional or the new technique is used. Discrepancies between the results obtained with the two techniques are only noticed at

low frequencies, say below 200 Hz; an explanation is that both methods are sensitive to background noise in the receiving room.
The Sine Sweep method seems to be less sensitive to extraneous noise.
Figure 5 shows a comparison, for *D* values, with high background noise concentrated at low frequencies. It indicates the impossibility of determining the value of *D* if the traditional method is used. Further measurements with high noise background will be carried out in order to show/demonstrate the reliability of a Sine Sweep excitation in these particular situations.
It should be noticed that the Reverberation Time was measured with different methods:

- “balloon” method for the traditional technique
- dodecaedric source for the new technique

Both these sources suffer from a low efficiency at low frequencies, which can be the reason for the differences noticed.
It is possible to note that, in all the figures, the agreement is quite satisfactory and discrepancies are found only at low frequencies (below 200 Hz) because of the different sensitivity to background noise, in the receiving room, of the two methods. In particular the Sine Sweep method seems to be less sensitive to the extraneous noise. Figure 5 shows a comparison, for *D* values, in high background noise (at low frequencies) condition. It puts in evidence that it is not possible to determine the value of *D* through the traditional method. Further measurements in high noise conditions will be carried out in order to stress the potential of the Sine Sweep in such situations.
Moreover it must be emphasized that the Reverberation Time was measured with different methods: with balloons in the traditional technique and with a dodecaedric source in the new technique. Both these sources have low efficiency at low frequencies and this can be a reason for the differences noticed.

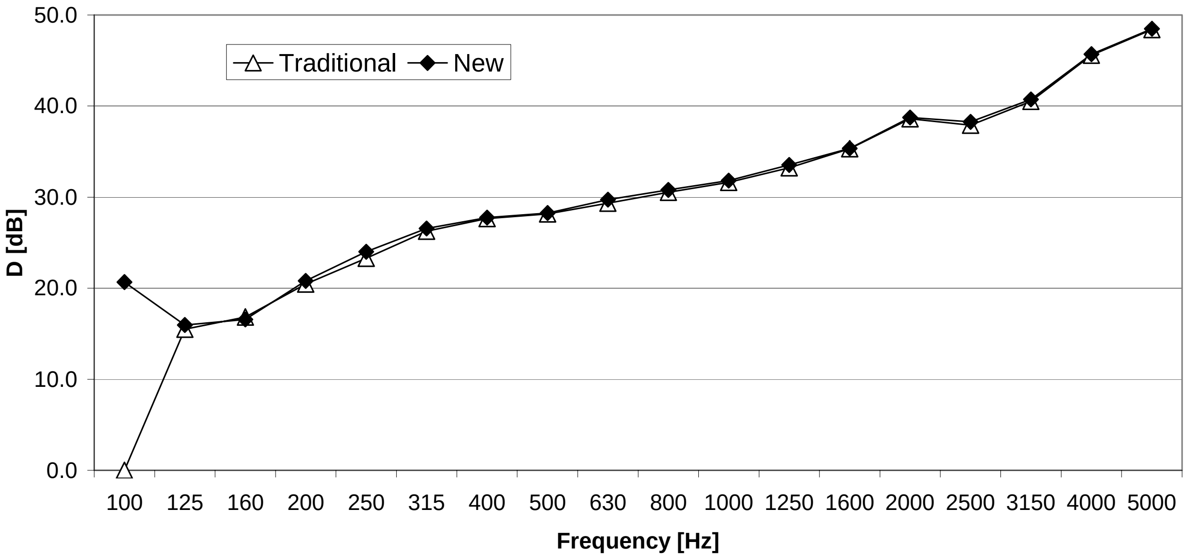


Figure 5 - *Level difference. Comparison in high extraneous noise condition*

## 5. ADVANTAGES AND DRAWBACKS OF THE NEW TECHNIQUE

Finally, the advantages and limitations of the new method with respect to the traditional method, described by ISO 140-4, and the MLS method are explained in this section.
As said previously, the new technique guarantees a high accuracy and leads to good repeatability regarding levels and reverberation time measurements. Besides, the utilization of the Exponential Sine Sweep allows impulse response measurements in high background noise conditions.
However, the new proposed method is limited because of the linearity and time-invariance of the system. The Theory of Signals requires a linear system.
By using an MLS signal it is possible to show that if non-linear terms are present in the system, the impulse response does not decrease asymptotically to zero as should be the case for a linear system. This effect is visible in the impulse response as irregular noise. An increase in the number of averages will not limit the effects of this error.
An advantage of the exponential sine sweep compared to the MLS method is that the harmonic distortions can be separated. It is recommended to use approximately four times the length of the sweep for the FFT in order to avoid distortion components. Moreover it is very easy to construct the inverse filter of the Sine Sweep; this facilitates the post-processing calculations.
Regarding Time-invariance, it must be emphasized that the system has to remain unchanged during the measurement. Therefore it is not [10] possible to move the microphone in order to obtain spatial averaging of the parameters using the MLS and Sine Sweep techniques. On the contrary, this is possible with the ISO 140-4.
Also, the effects of changes in temperature and humidity on the time variance of the system must not be neglected. With the MLS method, these effects are significant if the measurement is performed over a long period of time. The sine sweep method is not sensitive to slow time variations, but this is only true for a single sweep. Hence averaging of sine sweep signals should be avoided.

## 6. CONCLUSION

This paper reports the results of the calculation of the sound reduction index based on the analysis of the impulse response obtained by using the exponential sine sweep.
The comparison between the new technique and the traditional technique was satisfactory.
It was shown that the use of an exponential sine sweep allows energy levels and reverberation time measurements in high background noise conditions.
Further tests will be carried out in order to verify repeatability al low frequencies in different extraneous noise conditions. The application of the new method to airborne sound insulation of façades has also been programmed.

## ACKNOWLEDGEMENTS

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