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Measuring Sound Insulation using Deconvolution Techniques

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To compare the acoustic performance of a building element with given sound insulation requirements, measurements need to be done. Generally, a broadband noise source is used according to international standards. This method does not always work in practice due to high sound insulation values or high background noise levels. It is very inconvenient from a practical point of view or even impossible to perform an accurate sound insulation measurement for all frequency bands. A solution to this problem can be found in deconvolution techniques using MLS or sweep signals. It is possible to increase the signal to noise ratio with these techniques by averaging measurements and spreading out the spectral sound energy in time. As a result an efficient use of available sound power is possible. In a laboratory the use of MLS or sweep signals as a source signal and deconvolution as a measurement technique to obtain the sound insulation under noisy conditions was investigated.

1 Introduction

ISO 140-4 [1] describes the procedure for measuring the sound insulation of a practical construction using broadband noise. In addition to this traditional technique deconvolution techniques can be used to determine the sound insulation of a construction. The deconvolution technique makes use of a well-defined signal like MLS or swept-sine and is described in ISO 18233 [3]. Unlike using the traditional technique, the signal-to-noise-ratio (SNR) can effectively be increased by increasing the measurement time using the deconvolution technique. A disadvantage of the deconvolution technique is the sensitivity to time-variance, which may reduce the effective SNR. This holds less for a swept-sine than for an MLS signal. Another advantage of a swept-sine is the higher obtainable sound pressure level using the same power amplifier.

According to ISO 140-4 for a traditional sound insulation measurement in the field, a correction for background noise has to be applied if in the receiving room the difference between the total level of transmitted sound and background noise and the level of background noise only ($L_{(S+N)}$ - L_N) is 6 dB or more. At a difference of 10 dB or more, correction is not required. According to ISO 18233 the sound reduction D [Eq.(1)] obtained from an impulse response measurement is reliable if the decay range or INR [9] is at least 30 dB, (i.e. the background noise is negligible).

Is the measurement result still usable if this requirement is not met? In other words, is it possible to eliminate the background noise from the measured signal? And what is the impact of fluctuating background noise?

It was investigated whether it is possible to correct the measured signal from the receiving room for background noise using deconvolution techniques according to ISO 18233, under 'normal' room conditions and within the boundaries of ISO 140-4. For this investigation two transmission rooms in the laboratory of the Eindhoven University of Technology were used to simulate a practical situation 'indoors'. An extra loudspeaker was used to simulate background noise (random white noise and traffic sound).

The starting point for the measurements was an SNR of 0 dB. During the investigation, the following parameters were varied:

- Type of test signal (MLS versus swept-sine)
- Type of background noise (random white noise versus traffic noise)
- Measurement time and averaging (averaging 8 sequences of 10,9 s versus one long measurement of 87,9 s)

All results were compared with the results of traditional measurements carried out under the same measurement and room conditions, without background noise (SNR >30 dB).

2 Background

The sound reduction D between two rooms can be written as:

$$D = L_1 - L_2 \, [dB] \quad (1)$$

where:

L_1 = the energy averaged sound pressure level in the source room [dB]

L_2 = the energy averaged sound pressure level in the receiving room [dB]

A system impulse response h is obtained from its response y to an excitation signal s through deconvolution:

$$h = y \otimes s \quad (2)$$

Using this technique according to ISO-18233:

$$D = L_1 - L_2 = 10 \lg \left[\frac{\int_0^\infty h_1^2(t)\, dt}{\int_0^\infty h_2^2(t)\, dt} \right] [dB] \quad (3)$$

where:

$h_1^2(t)$ = the squared impulse response in the source room

$h_2^2(t)$ = the squared impulse response in the receiving room

The measured sound pressure level in the receiving room will be higher due to background noise. The value of D could therefore be seriously underestimated at low SNR values. As mentioned before, ISO 140-4 describes how to correct for this effect.

3 Measurements

3.1 Procedure

The measurements were carried out in two transmission rooms of the Eindhoven University of Technology. Transmission room 1, which is a reverberant room (T_{60avg} ≈ 5 s), was used as the source room. Transmission room 2 was used as the receiving room. To simulate a practical situation, the receiving room was semi-anechoic (T_{60avg} ≈ 1 s). Between the rooms a double layered glass construction was placed. All sound reduction measurements were done according to ISO 140-4, which describes the procedure for measuring the sound insulation of a construction in the field. According to this standard at least two source positions and 5 receiving positions (in the source room as well as receiving room) have to be used. For practical reasons the sound pressure level was measured in both rooms at 6 positions. Two channels were used to record the sound pressure levels in the source and receiving room simultaneously. The mean sound pressure level was determined by averaging over the 6 measurement positions.

The sound reduction between the two transmission rooms was measured with and without background noise by using the traditional and deconvolution method. For the measurements with background noise, noise was generated by a loudspeaker in the receiving room. Two types of background noise were used: white noise and traffic noise. The spectrum of the simulated background noise was shaped so as to obtain an SNR between -0.5 and 0.5 dB in each 1/3 octave band.

With background noise the SNR in the receiving room was 0 dB. Using the deconvolution technique, the SNR was effectively increased from 0 to ≈ 9 dB by averaging and increasing the measurement time.

The results of all measurements were normalised to D_0, where D_0 is defined as the average over the D values determined from the traditional, MLS and swept-sine measurements without background noise.

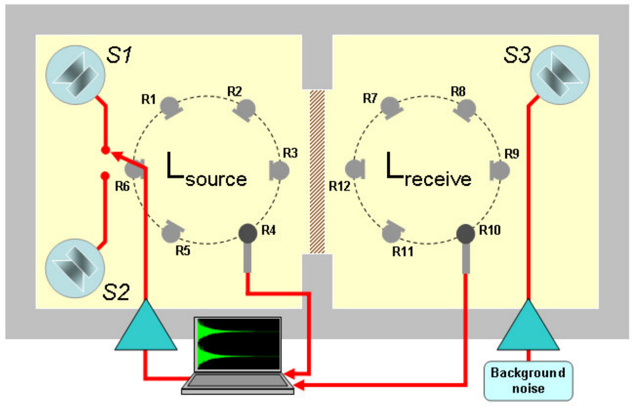

Figure 1 Measurement setup.

3.2 Equipment

The measurement equipment consisted of the following components:

- *signals:* random white noise, MLS 10.9 s and 87.4 s, lin swept-sine 10.9 s and 87.4 s, traffic noise (urban motor way) 180 s;
- *input/output:* USB audio device 1 (Acoustics Engineering - Triton);
- *power amplifier:* (Acoustics Engineering - Amphion);
- *sound sources:* omnidirectional (B&K Type 4292);
- *microphones:* ½" omnidirectional (B&K Type 4165);
- *software:* DIRAC 4.0 (B&K/Acoustics Engineering Type 7841).

3.3 Measurements

	Signal length	Background noise		
		No noise SNR >30 dB	**White noise** SNR = 0 dB	**Traffic noise** SNR = 0 dB
Source signal	Random noise (traditional)	10.9 s	10.9 s	---
	MLS	10.9 s	10.9 s 87.4 s (long) 8x10.9 s (avg)	10.9 s 87.4 s (long) 8x10.9 s (avg)
	Swept-sine (lineair)	10.9 s	10.9 s 87.4 s (long) 8x10.9 s (avg)	10.9 s 87.4 s (long) 8x10.9 s (avg)

Table 1 Used measurement signals, measurement lengths, types of background noise and SNR values.

The measurements were carried out over four days, all under the same room conditions (temperature: 20 ±1 °C, relative humidity: 46 ± 2 %), using the same measurement setup and measurement equipment. For every measurement session the spectrum of the background noise was reshaped as described in paragraph 3.1.

4 Results

Figure 2 depicts the spread in the results from the used methods without background noise. Starting point is the equality of the different techniques without background noise [7,8].

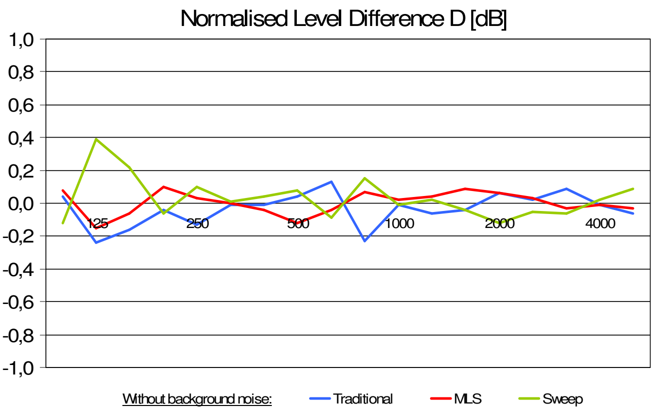

Figure 2 Normalised level difference D obtained from the traditional, MLS and swept-sine measurements, all without background noise: $INR_{min} > 50$ dB.

Figure 3 shows the normalised level differences D for all measurements. The results were all corrected for the background noise, i.e. raised by approximately 3 dB at the 0 dB SNR.

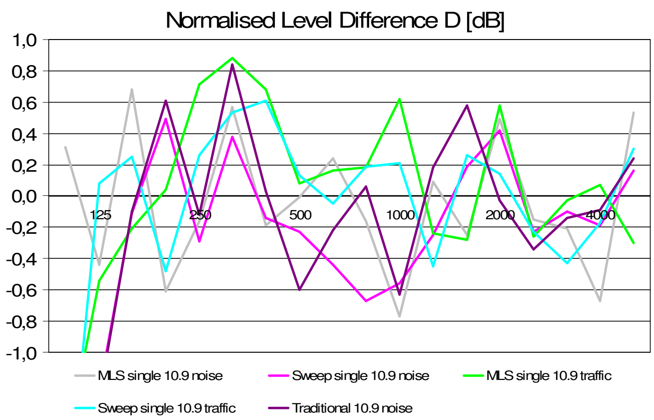

Figure 3 Same as figure 2, but for various source and background signals. Source signal length = 10.9 s.

Figure 4 shows the same results, but with 8 times longer measurement times, hence 9 dB higher effective SNR values. In this case the background noise correction of the results was reduced to approximately 0.5 dB.

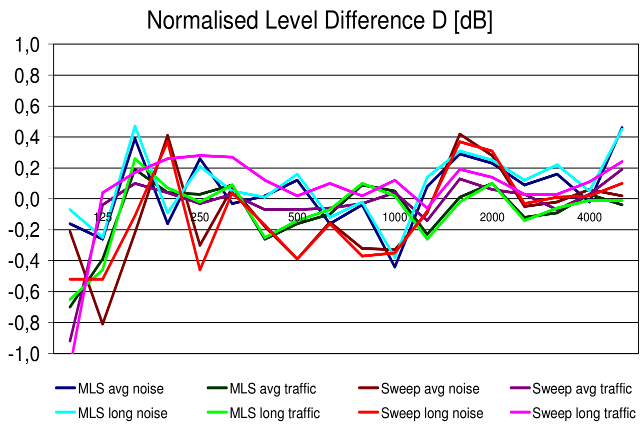

Figure 4 Same as figure 3, but for source signal lengths of 87.4 s (long) and 8x10.9 s (avg).

From figures 3 and 4 it is clear that the spread in D is reduced by the increased measurement time, as expected. In addition, figure 4 shows little difference between averaged and long source signals, except for the sweep with traffic noise. While the averaged sweep shows the smallest spread in D, the long sweep seems to be affected around 250 Hz, which indeed is the band containing the most energy of the traffic noise used. This difference is explained as follows. During the section containing 250 Hz a sweep can be disturbed by traffic noise. In case of multiple sweeps, the impact of this effect is reduced by the undisturbed periods, while a single long sweep will always be affected.

For the sake of completeness, figure 5 shows the same results as figure 4 but in full octave bands.

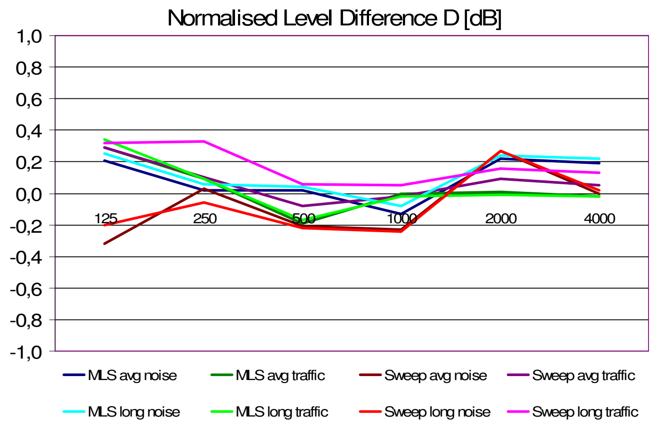

Figure 5 Same as figure 4, but measured in full octave bands.

In practice, the sound reduction often is expressed by single number quantities. Table 2 shows the maximum measured error of the level difference at several bandwidths.

Maximum level difference measurement error at several used bandwidths			
1/3 octave	1/1 octave	2 octaves	6 octaves
+/- 0.5 dB*	+/- 0.4 dB	+/- 0.3 dB	+/- 0.2 dB

*-1 dB for 100 and 125 Hz

Table 2 Maximum error in normalised level differences from measurements using deconvolution techniques.

5 Conclusions

1. Without background noise, the spread in D (measured over several days) of the different measurement techniques stays below 0.2 dB for nearly all third octave bands. This spread equals the spread in D of measurements carried out in a short measurement period, with only one measurement technique and under laboratory conditions.
2. With background noise resulting in SNR = 0 dB, the spread in D increases by a comparable amount over all deconvolution methods, background noise types and types of measurement time increase, staying below 0.5 dB when measuring time is increased by a factor of 8.
3. D values from averaged signals and from long signals compare very well (within 0.1 dB), except for sweeps with traffic noise.
4. Long sweeps are affected more by traffic noise than averaged short sweeps.
5. With background noise, the D values from the various methods compare better as the bandwidth considered increases. The differences decrease down to 0.2 dB when averaged spectrally over 6 octaves.

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