Measuring Sound Insulation under Extreme Conditions using Deconvolution Techniques

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1 Introduction

The traditional procedure for measuring the sound insulation of a construction is described in ISO 140-4 [1]. In accordance with this procedure a broadband noise source is used. Due to high sound insulation values or high background noise levels this procedure is not always possible. In addition it may be very inconvenient or even impossible to perform an accurate sound insulation measurement for all frequency bands. The application of the deconvolution techniques may be a solution to this problem. These techniques make use of a well-defined signal like MLS or swept-sine as described in ISO 18233 [2].

By using the deconvolution techniques the room is excited by an identified signal for a set time. Subsequently the impulse response can be computed from the response to the excitation. Distributing the excitation signal over a longer period of time will increase the total radiated energy and effectively increase the signal-to-noise-ratio (SNR), unlike using the traditional method. Consequently this will reduce the influence of extraneous noise and an efficient use of available sound power is possible.

A disadvantage of the deconvolution technique is the larger sensitivity to time-variance, which may reduce the effective SNR. This applies to a lesser extent to a swept-sine signal than for a MLS signal. An additional advantage of a swept-sine is the higher obtainable sound pressure level using the same power amplifier.

In a laboratory it can be investigated how to use MLS or swept-sine as a source signal and deconvolution as a measurement technique to obtain the sound insulation under noisy conditions. This has been investigated under moderately reverberant conditions, presented at the conference ‘Acoustics ’08 Paris’ [6], while this paper describes the same investigation under more extreme conditions.

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).

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 different extreme room conditions and with the guidelines of ISO 140-4. For this investigation two transmission rooms, both used in a reverberant situation and in a non-reverberant situation, in the laboratory of the Eindhoven University of Technology were used to distinguish the effect of the room acoustics on the measurements. An extra loudspeaker was used to simulate background noise (traffic noise).

The basic assumption for the measurements was a SNR of 0 dB. During the investigation, the following parameters were varied:

- Type of situation (reverberant versus non-reverberant);
- Type of test signal (MLS versus swept-sine);
- Measurement time and averaging (averaging 8 sequences of 10,9 s versus one long measurement of 87,4 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).

The main distinguishing feature of this study is the diversity of measurement conditions. Furthermore, a different building element was used to examine, only traffic noise was used as background noise and the mean sound pressure level was determined by averaging over five measurement positions instead of six positions in the preliminary investigation.

2 Background

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

$$D = L_1 - L_2 \qquad \text{[dB]} \qquad (1)$$

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:

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

Using this technique according to ISO-18233:

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

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 significantly 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. To distinguish the extreme conditions two different situations were used. The first part of the measurements was executed in reverberant transmission rooms and the second part in non-reverberant transmission rooms. In the reverberant situation transmission room 1, which is a reverberant room ($T_{avg} \approx 5$ s), was used as the source room. Transmission room 2 was used as the receiving room ($T_{avg} \approx 3$ s). In the non-reverberant situation the transmissions rooms were modified, by using absorbing materials, to obtain in both rooms $T_{avg} \leq 1$ s in each 1/3 octave band. In this situation transmission room 1 was also used as source room and transmission room 2 was used as the receiving room.

Between the rooms a 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 two source positions and five receiving positions (in the source room as well as receiving room) have to be used. 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 five 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, traffic noise was generated by a loudspeaker in the receiving room. The spectrum of the simulated background noise was shaped so as to obtain a 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 approximately 9 dB by averaging and increasing the measurement time.

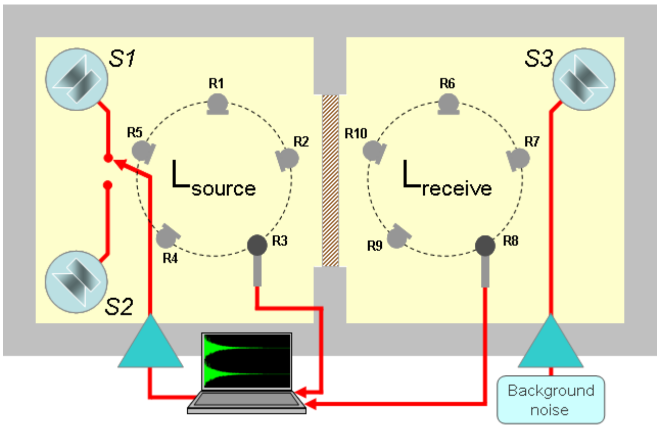

Figure 1: Measurement setup.

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.

3.2 Equipment

The measurement equipment consisted of the following components:

- *signals:* random white noise, MLS 10.9 s and 87.4 s, swept-sine 10.9 s and 87.4 s, traffic noise (urban motor way) 180 s;
- *input/output:* USB audio device (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	**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)
	Swept-sine (linear)	10.9 s	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 in two sets of four days. The first set of measurements was performed in the reverberant situation, all under the same room conditions (temperature: 20 ±1 °C, relative humidity: 48 ± 2 %), using the same measurement setup and measurement equipment. The second set of measurements was executed in the non-reverberant situation, all under the same room conditions (temperature 20 ±1 °C, relative humidity: 40 ± 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

4.1 Reverberant situation

Figure 2 depicts the spread in the results from the used methods in the reverberant situation without background noise. The basic assumption is the equality of the different techniques without background noise [7, 8].

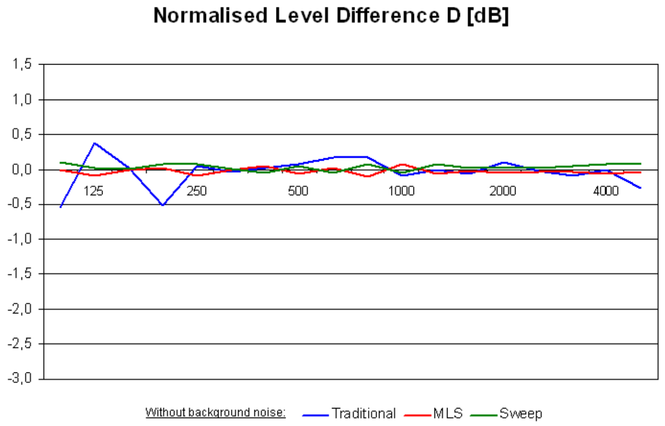

Figure 2: Reverberant situation: Normalised level difference D obtained from the traditional, MLS and swept-sine measurements, all without background noise: $INR_{min} >$ 50 dB.

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

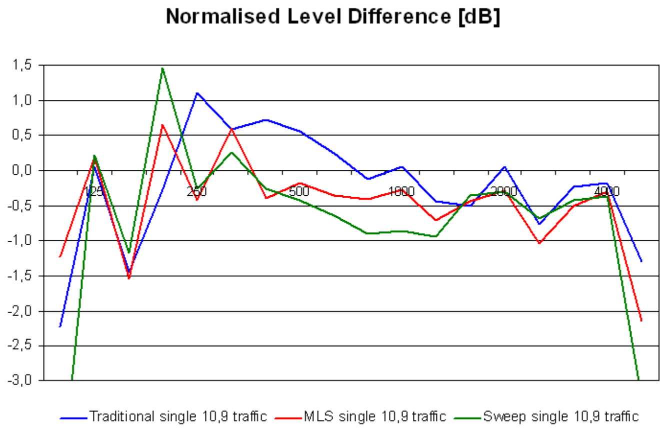

Figure 3: Same as figure 2, but for various source signals. Source signal length = 10.9 s.

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.

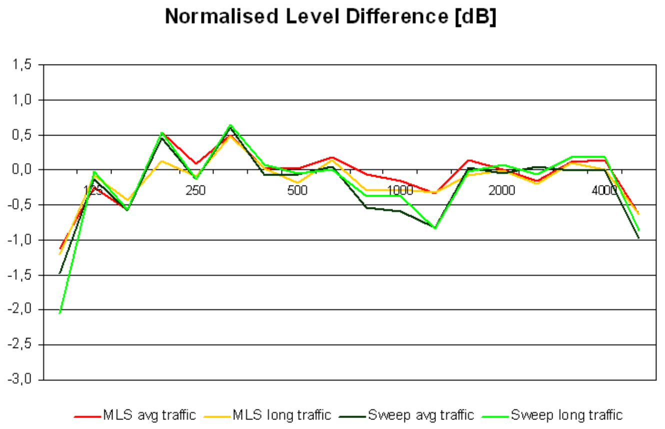

Figure 4: Same as figure 3, but source signal length = 87.4 s (long) and 8x10.9 s (avg).

To complete the study, figure 5 depicts the results of figure 4 but in full octave bands.

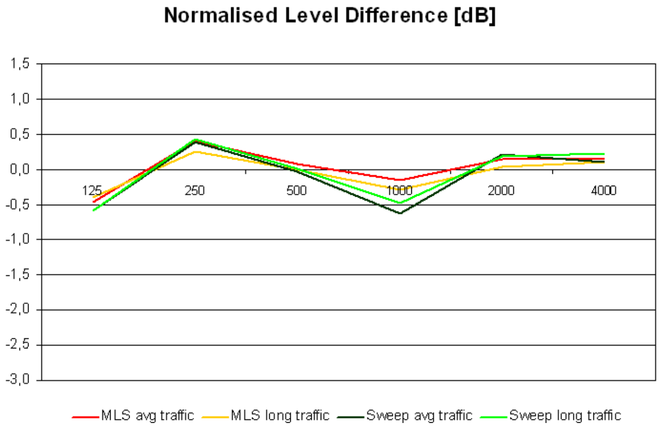

Figure 5: Same as figure 4, but measured in full octave bands.

4.2 Non-reverberant situation

Figure 6 depicts the spread in the results from the used methods in the non-reverberant situation without background noise. The basic assumption is the equality of the different techniques without background noise [7, 8].

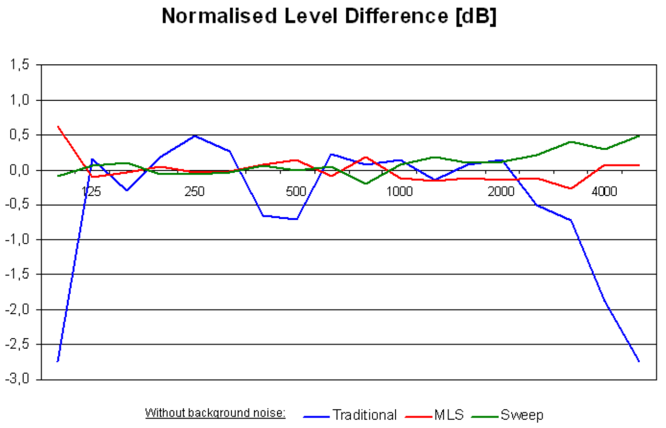

Figure 6: Non-reverberant situation: Normalised level difference D obtained from the traditional, MLS and swept-sine measurements, without background noise: $INR_{min} > 50$ dB.

Figure 7 depicts the normalised level differences D for single measurements with traffic noise. The results were all corrected for the background noise, i.e. raised by approximately 3 dB at the 0 dB SNR.

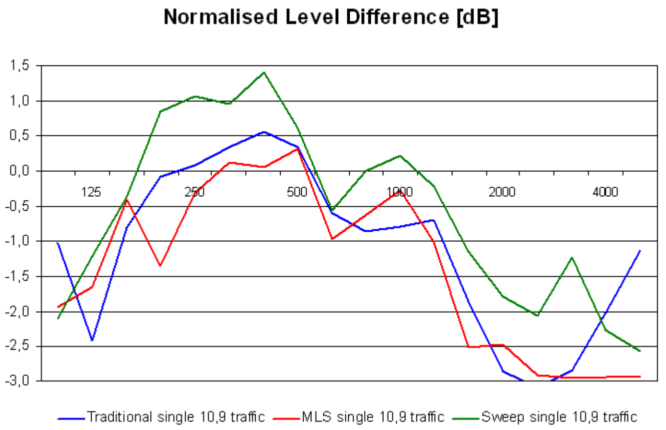

Figure 7: Same as figure 6, but for various source signals. Source signal length = 10.9 s.

Figure 8 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.

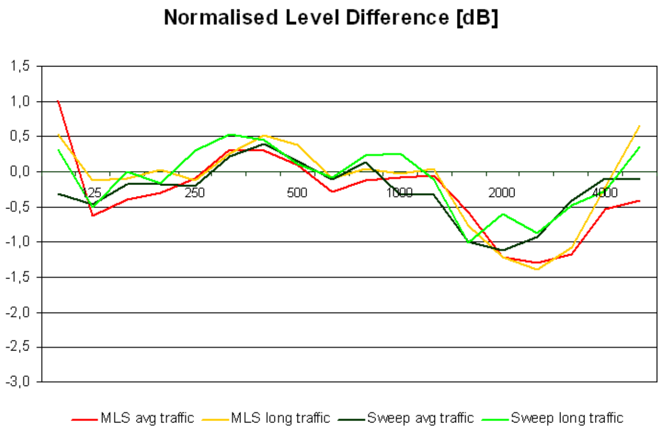

Figure 8: Same as figure 7, but source signal length = 87.4 s (long) and 8x10.9 s (avg).

To complete the study, figure 9 depicts the results of figure 8 but in full octave bands.

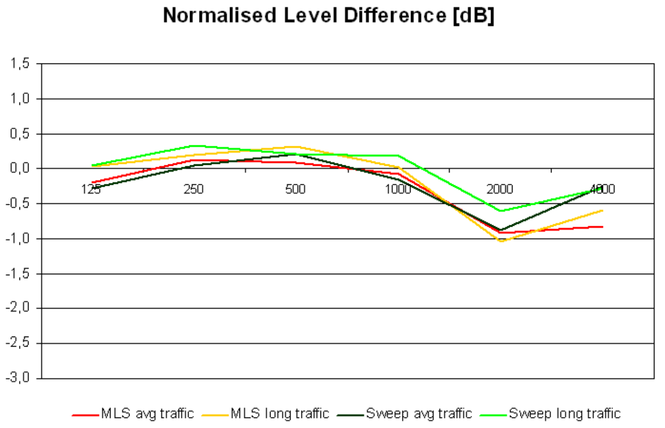

Figure 9: Same as figure 8, but measured in full octave bands.

4.3 General

In practice, the sound reduction is often expressed by single number quantities. Table 2 shows the maximum measured error of the level difference at several bandwidths within the range of the 250 to 2000 Hz octave bands.

Maximum level difference measurement error at several used bandwidths			
Sound field	1/1 octave	2 octaves	4 octaves
1. Reverberant	+/- 0.6 dB	+/- 0.3 dB	+/- 0.1 dB
2. Non-reverberant	+/- 1.0 dB	+/- 0.5 dB	+/- 0.2 dB

Table 2: Maximum error in normalised level differences from measurements using deconvolution techniques within the range of the 250 to 2000 Hz octave bands

5 Conclusions

1. Without background noise, the spread in D of the different measurement techniques of the reverberant situation stays below 0.2 dB for nearly all third octave bands. Concerning the non-reverberant situation this spread stays below 0.5 dB for nearly all third octave bands. Particularly the spread in the reverberant situation 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 methods and types of measurement time increase, staying below 0.8 dB for the reverberant situation for nearly all third octave bands and staying below 0.6 dB for the non-reverberant situation, with significant lower values up to -1.4 dB for 1600 to 3150 Hz for all source signals, when measuring time is increased by a factor of 8.
3. D values from averaged signals and from long signals deviate within 0.2 dB for nearly all third octave bands in the reverberant situation. In the non-reverberant situation D values from averaged and from long measurements of the MLS signal have a maximum difference of 0.3 dB for nearly all third octave bands. D values of the measurements of the swept-sine signal deviate within 0.6 dB.
4. With background noise, the D values from the various methods compare better as the considered bandwidth increases. The differences decrease down to 0.1 dB for the reverberant situation and to 0.2 dB for the non-reverberant situation when averaged spectrally over 4 octaves.

References

[1] ISO 140-4, “Acoustics - Measurements of sound insulation in buildings and of buildings elements, part 4: Field measurements of airborne sound insulation of building elements”, (1998)

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