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NONLINEAR EFFECTS IN AIRBORNE SOUND INSULATION MEASUREMENT

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Abstract

The level difference (D) between a source and receiving room should be independent of the source's sound power level if the acoustic system (including the building fabric) is linear and time-invariant (LTI) and the signal to noise ratio is adequate. Furthermore, various measurement signal types such as white noise, maximum length sequence, and swept sinusoid (to derive impulse responses) should also yield equivalent results in an LTI system with adequate signal to noise ratio. This study investigates the presence of non-linear effects in a case study of a real building by measuring D using a range of sound power levels and signal types. This follows on from previous work which suggested that substantial non-linearities could affect measurements in the very low frequency range (20-100 Hz), so the present study includes these very low frequencies, but also investigates the usual frequency range for airborne sound insulation measurement. In this study, fixed source and receiver positions were used to measure D (without spatial averaging) between a pair of adjacent rooms. Three test signals were used: maximum length sequence (used both as white noise, and deconvolved to impulse responses), a linear swept sinusoid and a logarithmic swept sinusoid (deconvolved to impulse responses).

1. INTRODUCTION

Nonlinear effects occur when wave amplitude is high or, time and distance over wave propagation is great [1]. A change in the speed of wave propagation can also result in nonlinear propagation with deformation of wave shape [1]. Even though small disturbance occurs locally, waveform distortions accumulate and become obvious over a long time or large distance.

In airborne sound insulation measurements, a powerful soundfield is established in a source room, which is measured in both source and receiving rooms. The level difference (D) is the spatially averaged difference between the sound pressure levels of these soundfields, and is the simplest way of characterizing airborne sound insulation in field measurements. However, with the production of high sound pressure levels, there is the potential that non-linearities in the building fabric could affect the measured level difference. Marshall *et al.* [2] compared D for various signal levels in an effort to explain eccentric results of an experiment examining low frequency airborne field sound insulation measurement methods. Three different signals were used with four settings of source's power level; 15 s of white noise, 15 s and 60 s of sinusoidal sweeps. The experiments used one fixed source and receiver position rather than spatial average to obtain level difference. Results suggested that nonlinearities were affecting D measurements because, with an adequate signal to noise ratio, D was neither independent of power level or test signal.

The application of a long duration sinusoidal sweep in sound insulation measurement is suggested by Satoh *et al.* [3,4]. They examine the effects of excess delay and harmonic distortion using variations of this technique and the maximum length sequence (MLS) technique. MLS or sinusoidal sweep methods are advantageous in adverse background noise conditions. Experiments indicate that appearance of the harmonic distortion on impulse response of both MLS method and sine sweep method are obvious as sound power level of the sources increases, and the worst signal to noise ratio in MLS method was seen with the highest sound power level due to the influence of distortion.

The effect of distortion on various impulse response measurement methods is different [4]. For a linear swept sinusoid, the distortion results in noise distributed around the impulse, as illustrated in Figure 1. For a logarithmic swept sinusoid, harmonic distortion products form pseudo-impulse responses prior to the true impulse response, as illustrated in Figure 2. For a maximum length sequence signal, distortion is expressed as noise or spurious peaks within the measured impulse response (Figure 3).

Figure 1. Effect of distortion for a deconvolved linear sinusoidal sweep

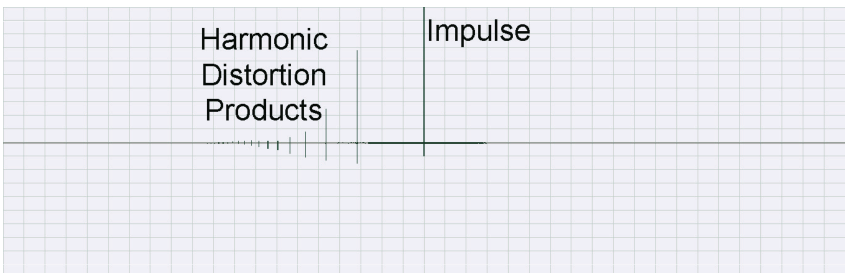

Figure 2. Effect of distortion for a deconvolved logarithmic sinusoidal sweep

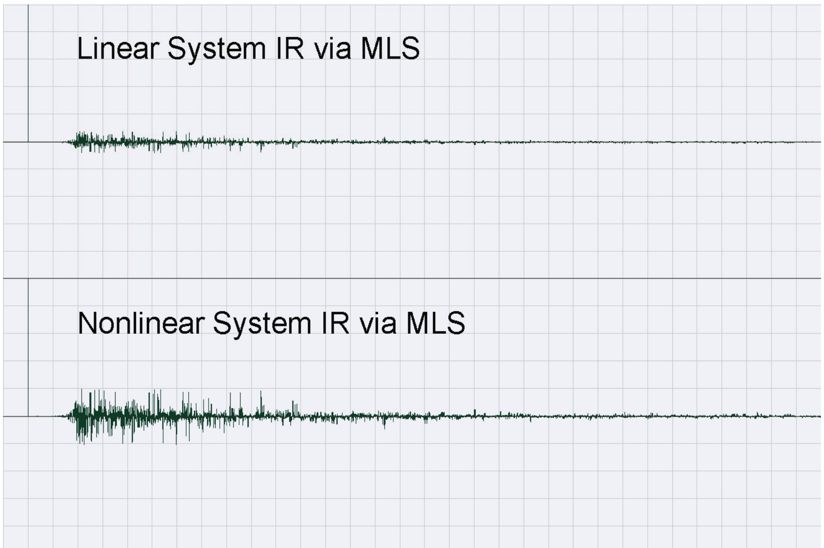

Figure 3. Effect of distortion for a deconvolved MLS signal for the same linear system

2. EXPERIMENTAL PROCEDURE

The objective of this study is to examine variation in level differences with source power level and type of test signal. One fixed source and receiver position were used (rather than spatial averaging in rooms), using the same pair of rooms as Marshall *et al.* [2]. The source room volume was 155 m^3, and the receiving room 123 m^3. The partition placed between the source room and the receiving room is a double surface partition 6.48 m x 3.96 m. Each surface is made up of 10 mm thickness plasterboard. A steel stud frame is between two panels. Three signals were generated; MLS white noise (47.5 s), linear sinusoidal sweep (60 s) and logarithmic sinusoidal sweep (60 s). Each signal duplicated twenty two times with 2 dB decrease at each time of duplication. Room reverberation times are shown in Table 1.

Table 1. Octave band reverberation times of source and receiver rooms (T_{20})

Frequency Band (Hz)	32	63	125	250	500	1 k	2 k	4 k
Receiving Room (s)	1.5	0.5	0.8	0.8	0.7	0.8	0.7	0.8
Source Room (s)	1.6	0.9	2.4	1.6	1.1	0.8	0.8	0.8

The low frequency and normal frequency range were measured using separate measurement signals and different loudspeakers. The low frequency loudspeaker was a Whise 319A subwoofer (test signal from 16 Hz – 100 Hz), and the normal frequency range loudspeaker was a Brüel & Kjær Omnipower dodecahedral loudspeaker (80 Hz – 6 kHz). A Brüel & Kjær type 2250 sound level meter was used as the microphone in each room, with the sound simultaneously recorded from the two rooms.

The sound pressure level at the measurement microphone in the source room for each signal for gain setting 1 (the highest signal level) is shown in Figure 4, giving a rough indication of the degree to which the room was excited. Greatest levels were produced in the very low frequency range, although the MLS signal had a substantially lower sound pressure level.

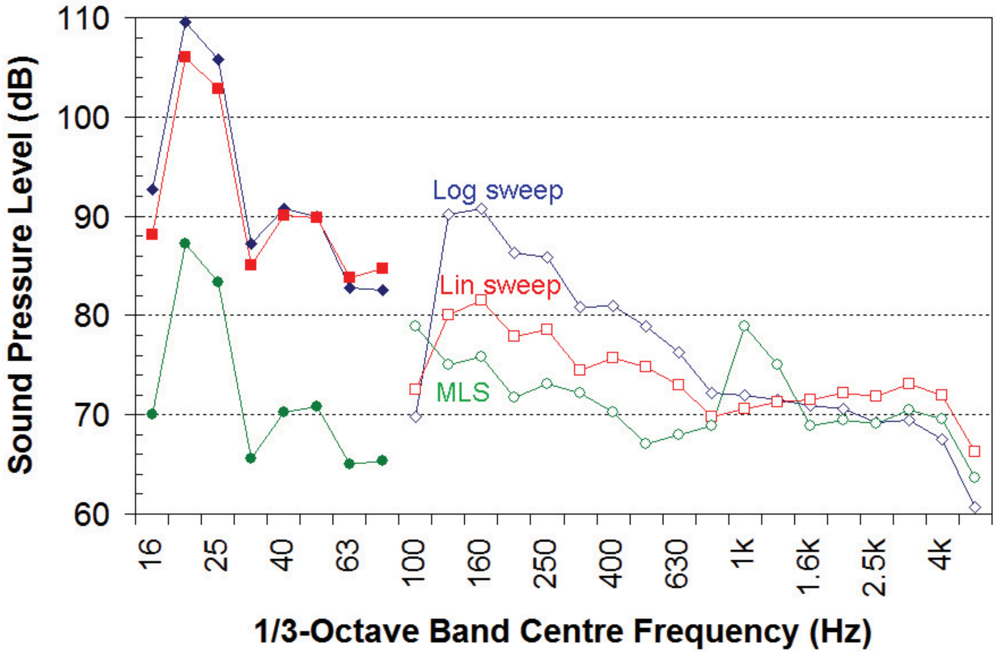

Figure 4. Sound pressure levels (L_{eq} of the measurement signal) at the microphone position in the source room. Open symbols are for the medium frequency sound source, and filled symbols are for the low frequency sound source.

For the analysis, the swept sinusoid and MLS signals were deconvolved to yield impulse responses from the source to the microphone in each room. The MLS signal, which is a type of white noise, was also used as a conventional noise source (without deconvolution). The level difference between the signals at the two microphones was then calculated. The effective background noise was assessed in each instance by processing a background noise recording in the same way as the signal recordings (i.e., by 'deconvolving' the background noise). Corrections for steady state background noise were applied to the level differences for all signal levels (these corrections are very small for high signal to noise ratio conditions). Instances where the measured signal was less than 6 dB above the effective background noise level were excluded from the analysis.

3. RESULTS

3.1 Level Difference

Figure 5 shows the level difference as a function of frequency for the four measurement methods. In the high frequency range the swept sinusoid and MLS have near-identical level differences. MLS without deconvolution has a slightly higher level difference throughout that range. In the low frequency range, the deconvolved MLS measurements deviate substantially from the other measurement signal.

3.1 Effect of Distortion

Systematic changes in level difference as the signal power is reduced are likely to be either due to distortion or signal to noise ratio effects. A distortion effect will be most evident for high signal levels, whereas a noise effect will be most evident for low signal levels. Results indicate that distortion has greatest effect for the highest sound pressure level signals (20 Hz and 25 Hz for the swept sinusoidal signals). An example of this result is shown in Figure 6.

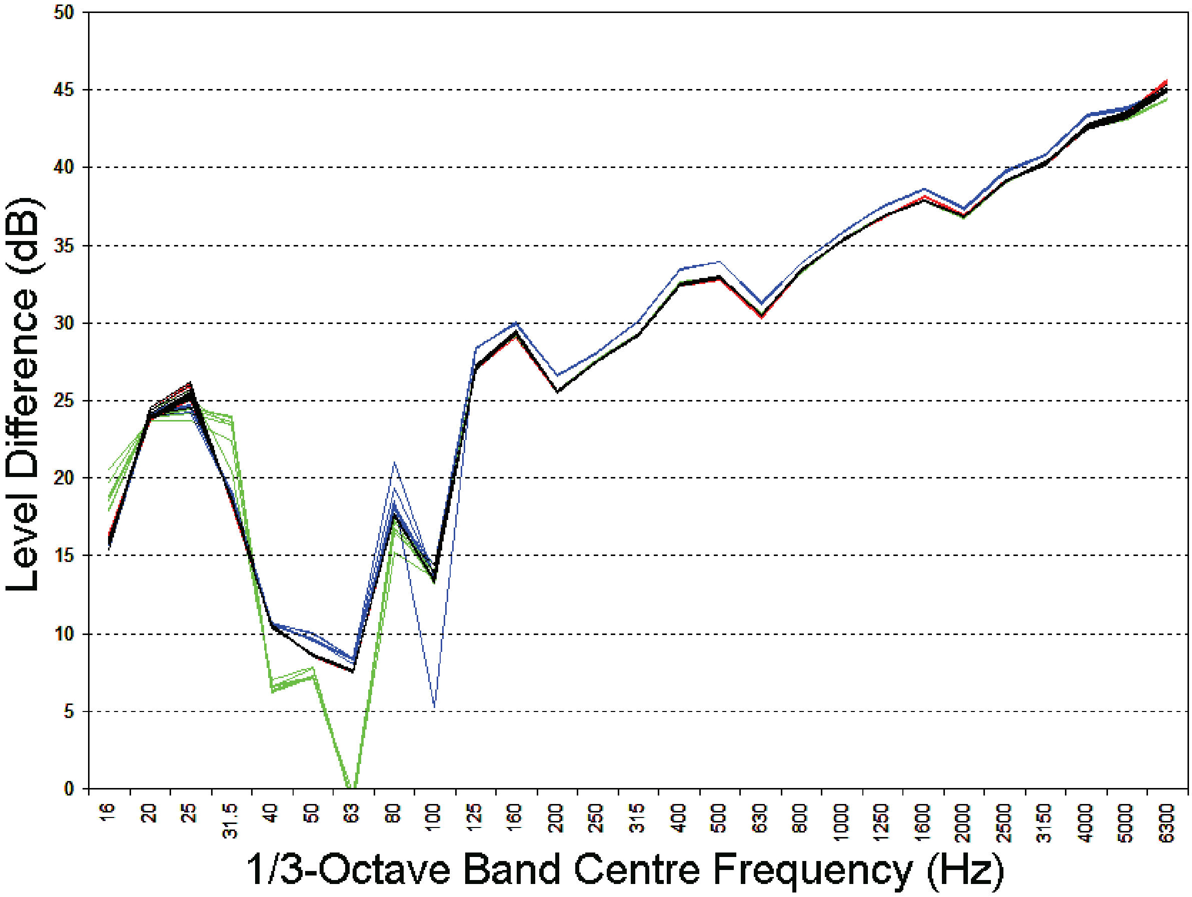

Figure 5. Level difference as a function of frequency for the highest nine source power levels: black – logarithmic sweep; red – linear sine sweep; blue – noise; green – MLS.

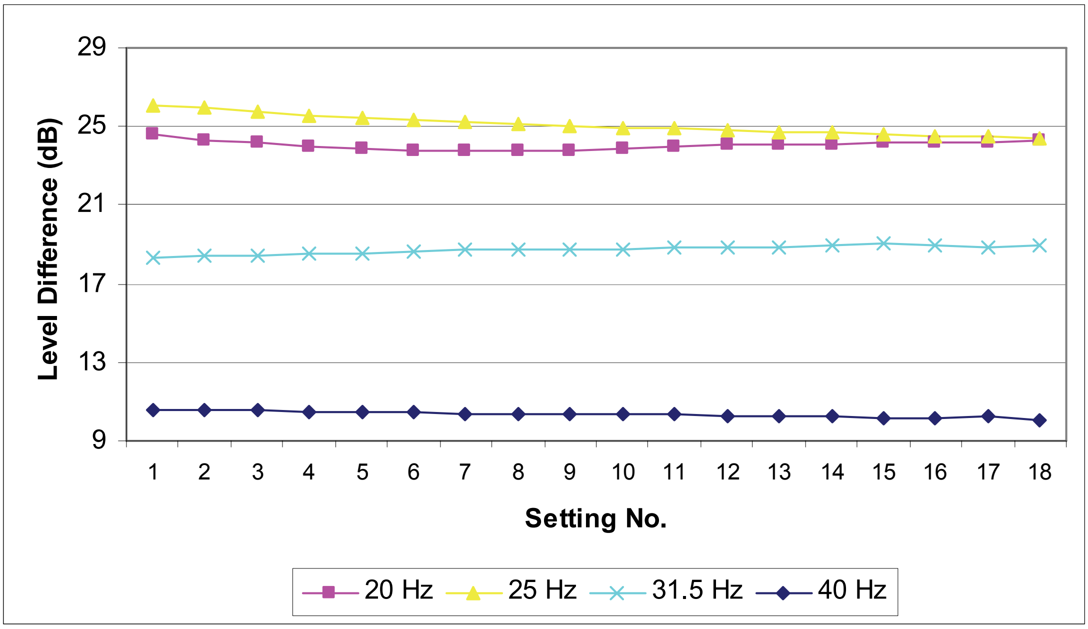

Figure 6. Level difference as a function of signal level for low frequency bands of the logarithmic sweep.

Apart from the 20 and 25 Hz bands, distortion effects were less than 1 dB in all measurements. Distortion was less evident in the MLS level differences than the swept sinusoids presumably because of the former's relatively low sound pressure level.

3.3 Total Harmonic Distortion

When an impulse response is measured using a logarithmic sinusoidal sweep, harmonic distortion takes the form of spurious peaks in the time domain prior to the linear impulse response (when linear rather than circular deconvolution is used) [5]. The distortion of individual harmonics can be calculated from these pseudo impulse responses, or more simply, the total harmonic distortion (THD) may be calculated. THD is the square root of the ratio of distortion power to total power (expressed as a percentage) as given by Equation 1. For our measurements, we have combined the THD for all frequencies of the test stimulus.

$$THD = \sqrt{\frac{P_{2f} + P_{3f} + P_{4f} + ... + P_{nf}}{P_f + P_{2f} + P_{3f} + P_{4f} + ... + P_{nf}}} \times 100 \qquad (1)$$

(where f is the frequency of the test stimulus, and P_{nf} is the power or magnitude squared at integer multiples of f)

Some distortion may be expected from the loudspeaker, but this will not affect level difference measurements. It is additional distortion in the building fabric that could affect level difference, and one way of detecting this is to observe the extent to which THD in the receiving room is greater than in the source room. Figure 7 clearly shows that there is substantially more harmonic distortion in the receiving room for both the low and high frequency logarithmic sinusoidal sweeps. The THD decreases with signal gain, as would normally be expected for a nonlinear system. Distinct distortion peaks were not evident in the source room response for gains of less than −16 dB for the low frequency sweep and −6 dB for the high frequency sweep.

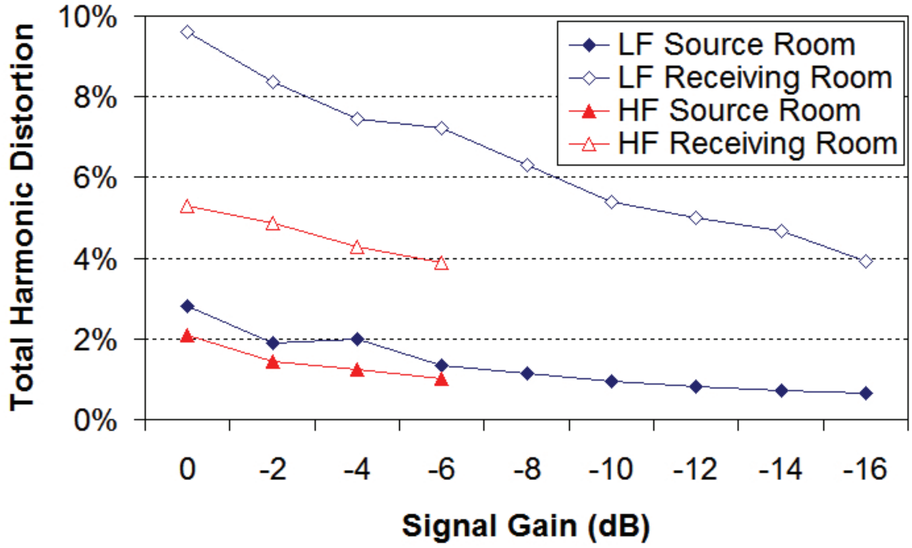

Figure 7. Total harmonic distortion measured using the logarithmic sweep for low frequency (LF) and high frequency (HF) signals.

Similar THD values would be expected for the linear sweep at the same short term sound pressure levels – however, deconvolution of a linear sweep does not allow simple measurement of harmonic distortion products. Distortion for the MLS signal is more complex, because it consists of many simultaneous frequency components, and so may suffer intermodulation distortion. However, the relatively low sound pressure level of the MLS signal means that it is less prone to distortion within the building fabric than had it been the same as the swept sinusoids.

4. DISCUSSION

A major limitation of this study is that only moderate sound pressure levels were tested, and the sound pressure level of the MLS signal was low in the low frequency range. Therefore, while greater distortion effects would be expected with MLS for a given sound pressure level, the experiment did not make this comparison. Effects of distortion within the sound pressure level range tested were small. With 10% total harmonic distortion, a level difference error of about 0.8 dB might result. The study implies that the measurement discrepancies observed by Marshall et al. [2] are not due to nonlinearity.

5. CONCLUSION

If the system is linear and signal to noise ratio is adequate, results should yield same level difference regardless source's power level or type of signal. Results show small gradual changes in level difference accompanying changes of source's power level. Although gradual distortion-related changes in level difference were found in some frequency bands, the variation was less than 2 dB.

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