P-414

UNCERTAINTIES OF MEASURED PARAMETERS IN ROOM ACOUSTICS CAUSED BY THE DIRECTIVITY OF SOURCE AND/OR RECEIVER.

PACS 43.55.Mc

Behler, Gottfried K.
Institute of Technical Acoustics, Aachen University (RWTH)
D-52056 - Aachen
Germany
Tel: +49 241 8097987
Fax: +49 241 8092214
E-mail: gkb@akustik.rwth-aachen.de

ABSTRACT

Room acoustical parameters are usually measured with omnidirectional sound sources. This, as is known, is difficult to maintain at higher frequencies. Commercially available systems like dodecahedron loudspeakers (primarily designed for use in building acoustic measurements) deliver satisfactory results up to 2 kHz. At higher frequencies the sound radiation becomes more directional and the effect on the parameters cannot be neglected anymore. To quantify the influence of the sound source directivity on the single number ratings, measurements with different loudspeakers in a very well-known room have been carried out. The variation of the results will be presented and discussed.

INTRODUCTION

To investigate the room-acoustical quality of any kind of rooms, the parameters provided in ISO 3382 are commonly used. These parameters are derived from impulse response measurements carried out in the room of interest. Depending on the particular parameter it is necessary to measure the monophonic impulse response with energetic averaging (reverberation time, clarity etc.); in some cases two channels are required (lateral fraction), and very seldom the high resolution pressure impulse response with special microphone set-up (dummy head) is used (IACC). For all these measurements microphones and loudspeakers with specialised properties are used. Whereas for the microphones most of the technical properties are very well known and the standard is quite high, loudspeakers are the weak end of the chain.

As is stated in ISO 3382 the loudspeaker used as a sound source should be of omnidirectional type (a point source). Usually this is established by applying a dodecahedron speaker. Dodecahedron loudspeakers are commonly used for building acoustics. At higher frequencies the homogeneity of the spherical directivity cannot be guaranteed depending on the size of the loudspeaker cabinet. It is obvious that due to this some systematic error is introduced into the measured parameters. The amount of these errors and the error sensitivity of the individual parameters, however, is not clearly known at the moment. To clarify this, experimental investigations have been carried out, from which the results are presented in the following.

Error Sensitivity of the Parameters

The parameters described in ISO 3382 can be grouped into different categories which allows an estimate of the error sensitivity depending on the algorithmic derivation of the parameter. The table below shows all parameters of interest grouped with respect to the degree of averaging over time:

Treatment of the measured impulse response	Complete Integration along the time scale	Integration into different time slots	No integration but correlation
One channel with omni-directional microphone	Reverberation time EDT, T20, T30	D50, C80	
Two channels with directional microphones		LF, LFC	
Two channels with binaural microphone (dummy head)			IACC

From the upper left corner down to the right corner, the amount of time and directional dependency increases, therefore it is more likely for these parameters to be sensitive on the directivity of the source or the receiver. The parameter IACC will be affected more likely due to the fact that it takes account of the detailed impulse response, whereas the calculation for the reverberation time uses a higher degree of integration, which makes it probably less sensitive to directional variations. Nevertheless, even within the group of reverberation time the EDT probably seems to be more sensitive than the T30, since the integration interval is shorter and the drop between direct sound and reverberation is taken into account, which is not the case with T20 and T30.

EXPERIMENTAL INVESTIGATIONS

To investigate the dependencies, measurements have been carried out with different sources of omnidirectional type, all of them in accordance to the standards requirements as stated in ISO 3382 A3.1. Two loudspeakers have been used, the dodecahedron speaker B&K omnipower and a three-way loudspeaker using different sources for the low- mid- and high-frequency range, which was developed in the Institute of Technical Acoustics two years ago[12].

The ITA Measuring-Loudspeaker System

Fig. 1: The ITA measuring loudspeaker system. Left side with mid-range dodecahedron, right side with tweeter dodecahedron attached to the subwoofer cabinet. The subwoofer radiates frequencies from 50 Hz up to 250 Hz from a 10 cm opening on the top of the pyramid.

Fig. 1 shows the two application variants of the ITA loudspeaker system, on the right side with the mid-frequency unit attached to the sub-woofer, on the left side with the high-frequency unit.

To maintain coincident sound radiation for the entire frequency range, the mid-frequency unit and the high-frequency unit are used successively at the same position above the woofer and the measured responses are superimposed. The size of the dodecahedron spheres (mid-frequency unit ⌀ 25 cm, high-frequency unit ⌀ 8,5 cm) for each unit was realisable due to the reduced bandwidth. To accomplish a flat frequency response and easy-to-use measuring, a digital DSP-controller is used to divide the input signal into three bands. Moreover, the controller is used as an equalization system, thus providing a flat frequency response from about 50 Hz up to 12.5 kHz within reasonable limits. The FIR filter design of the controller also allows complex equalization of the phase response, which leads to an overall linear phase response. Measurements are carried out using either MLS or sweep-signals[3].

<u>Performance of the Measurements</u>

A comprehensive measurement session was executed at the studio of the PTB (Physikalisch Technische Bundesanstalt) in Braunschweig. The same room is used for the round robin actually performed on room-acoustical simulation software and therefore may be familiar to many people interested in this field [4]. The source and receiver positions have been chosen the same as in the round robin test except for one additional source position which was needed to place the additionally used third measuring loudspeaker, the artificial singer [2] from ITA. However, the data acquired with this source will not be discussed here. In Fig. 2 a photograph of the set-up in the studio is shown.

Fig. 2: The set-up of all measuring systems inside of the PTB-Studio. Note the three different sources: far left the ITA-loudspeaker equipped with the mid-frequency dodecahedron, at the rear wall the B&K omnipower, and to the right between the two windows the artificial singer called 'Caruso'. The receivers are somewhat more difficult to find: on the left side between the two dodecahedron speakers the ITA recording head seen from the back (oriented towards the ITA-LS), in front of the curtain, left from the windows a Neumann USM 69 with sphere and figure of eight directivity is placed for the assessment of the LF and LFC parameters. At the right edge of the picture an intensity microphone is placed, to record either the monophonic impulse response and on the other side to provide an ideal figure of eight receiver to be used alternatively for the derivation of LF and LFC.

Due to the permutation of all source and receiver positions a total amount of 9 S-R-combinations was realized. For the building acoustics dodecahedron (B&K) 6 measurements for each S-R-combination have been recorded; for each the loudspeaker was rotated by 20° to study the directivity influence at higher frequencies. Therefore a total number of 3 (different receivers) times 6 (different rotation angles) times 9 (S-R-combinations) impulse responses have been recorded for the B&K omnipower. For the ITA loudspeaker system a total number of 3 (different receivers) times 3 (different frequency bands) times 9 (S-R-combinations) impulse responses have been recorded. The directivity was checked with the same measuring procedure (rotation of the mid-frequency dodecahedron and the high-frequency dodecahedron by increments of 20°) but only for one S-R combination. The subwoofer was not moved or rotated.

<u>Analysis of the Measurements</u>

For the analysis of the impulse responses from both sources (B&K / ITA), the same algorithms have been used. The program MF (developed in the ITA) was used to calculate all parameters. The impulse responses of both systems recorded in the studio at the same S-R placements are shown in Fig. 3 and Fig. 4.

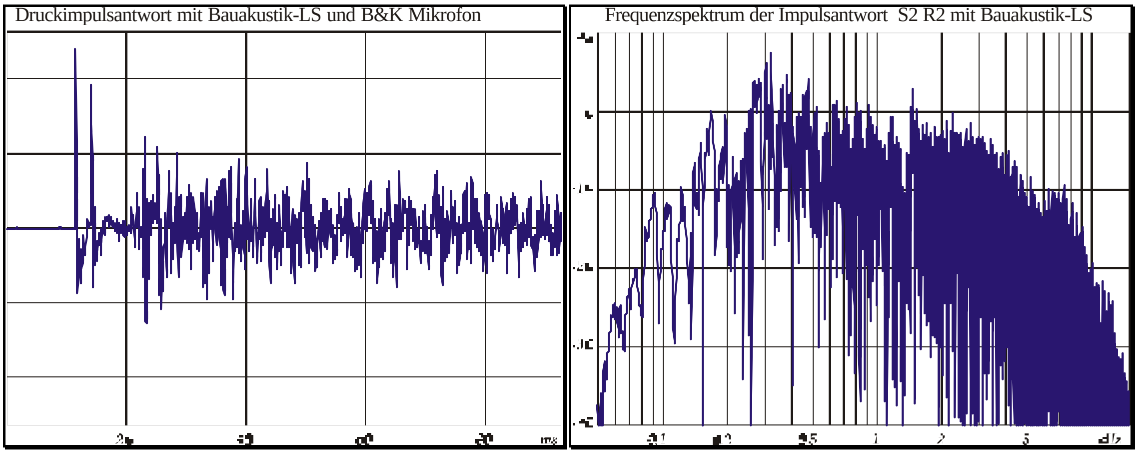

Fig. 3: Sound pressure impulse response and frequency response of the building acoustics dodecahedron measured in a real room. The frequency response on the right side shows the typical response of a passive non-equalized loudspeaker-system with a dynamic transducer in a rather small cabinet. This obviously is the reason for the roll-off (around 250 Hz) to lower frequencies. For the higher frequencies the typical low-pass behaviour of a wide-band cone-type loudspeaker is shown. The impulse response on the left side therefore shows a small peak and a short and well-damped ringing due to the lack of low-frequency components.

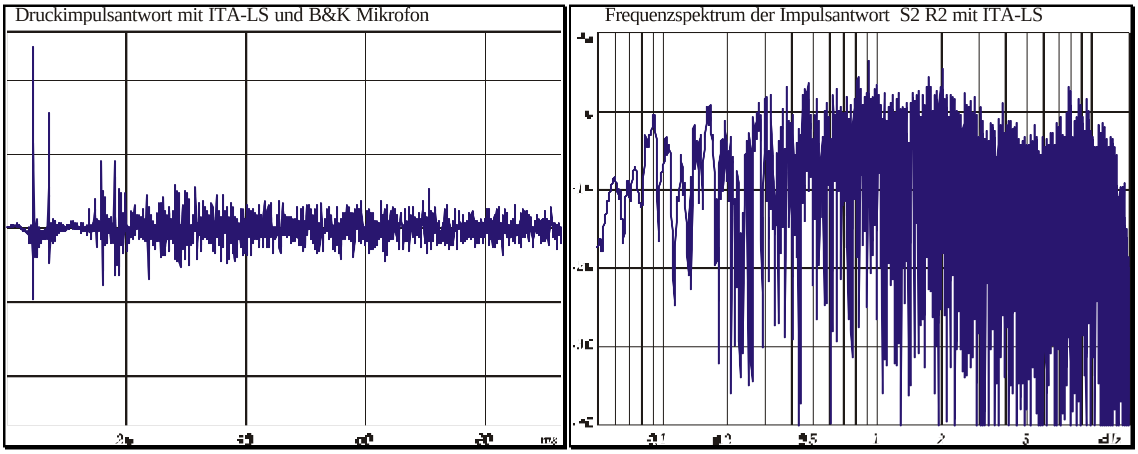

Fig. 4: Sound pressure impulse response and frequency response of the three-way loudspeaker system (ITA point source) measured in a real room. The impulse responses obtained in three different frequency bands (40 Hz – 223 Hz, 223 Hz –1414 Hz, 1.414 kHz – 15 kHz) are superimposed by complex addition. The frequency response was filtered by an appropriate band-pass filter and the inverse complex transfer function for each band, thus providing an overall linear phase response. This can be seen in the left plot of the impulse response, which more or less shows a symmetrical impulse for the direct sound and the floor-reflection. The equalised wide-band excitation makes it possible to auralize the measured impulse response and to use it for convolution with anechoic signals.

For each impulse response all parameters of interest have been calculated individually. From these results average values have been calculated for each S-R-combination. These averages have been subtracted from the individual results hence giving a figure of deviation of the measured parameter. In Fig. 5 the left figure always shows all 54 curves (9 S-R-combinations) for the building acoustics dodecahedron, and the right figure shows the 6 curves for the one S-R-combination of the ITA-loudspeaker.

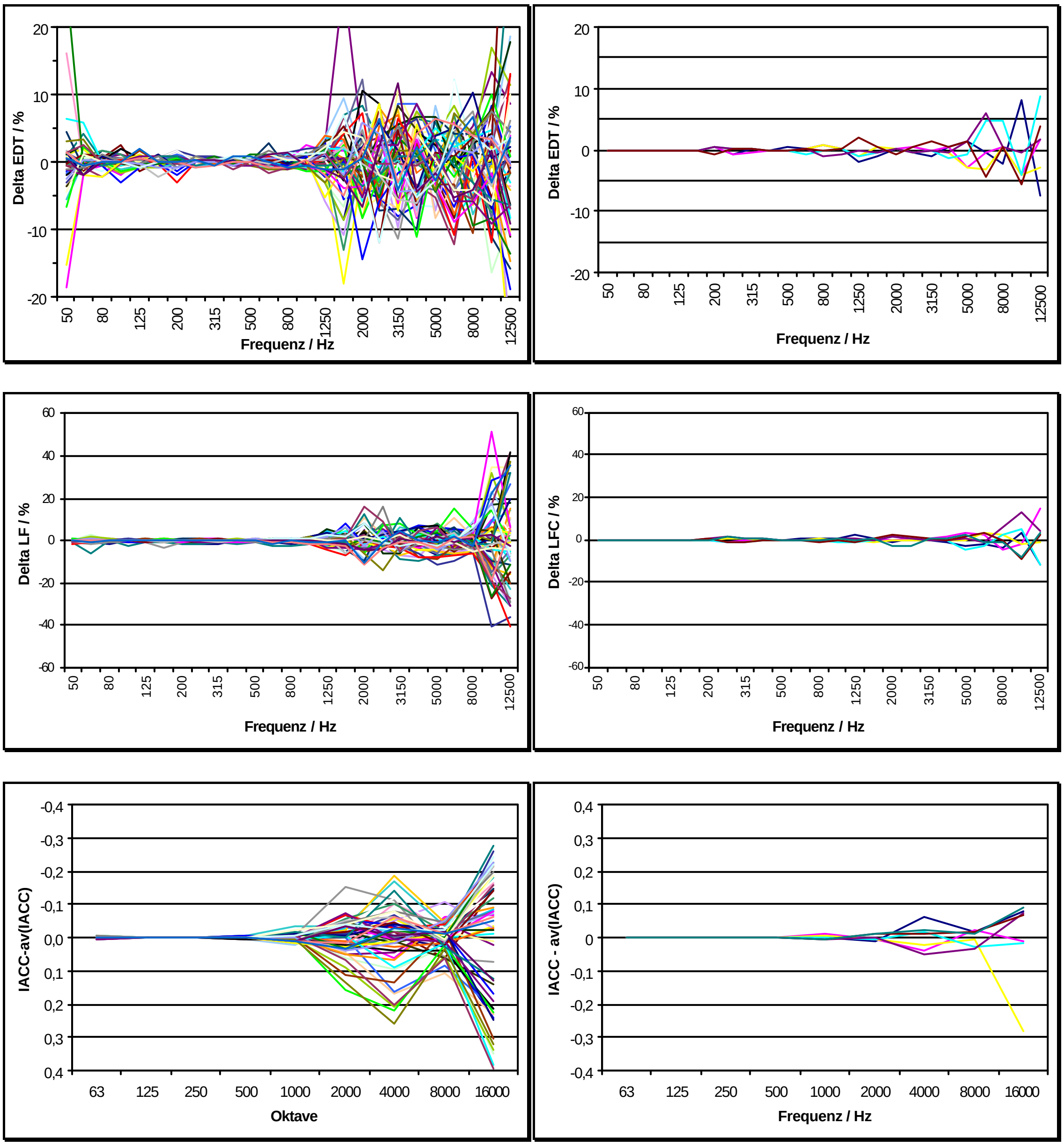

Fig. 5: Relative deviation of the measured reverberation time EDT (upper figures), relative deviation of the measured lateral fraction LF (centre figures), absolute deviation of the measured IACCa (lower figures). Left figures for the building acoustics loudspeaker, right figures for the ITA three-way loudspeaker system.

In general for all figures it can be stated that the directivity of the source has a great influence on the measured parameters. If the frequency range with omnidirectional sound radiation is investigated, a deviation of less than 5% for the measured parameter is found. On the other hand the deviations in the frequency range with directional radiation are relatively high, even for the parameters with presumably little sensitivity (reverberation). However, the assumption that the IACC might be more sensitive to the directional characteristic of the source was found to be true.

The total number of parameters that have been investigated was much higher, but the results in general were found to be the same or similar to those presented in Fig. 5.

<u>Absolute Deviation Between the Two Measuring Systems</u>

When comparing the absolute results derived from both measuring systems (the only difference is the type of the measuring loudspeaker) a surprisingly large difference is found. The expectation is that at lower frequencies both measuring systems have to deliver more or less the same result since the error due to the stated directivity variations is far below 5%. The graphs in Fig. 6 unexpectedly show the opposite dependency for the EDT results and a rather constant offset of 5% for the LF measurements.

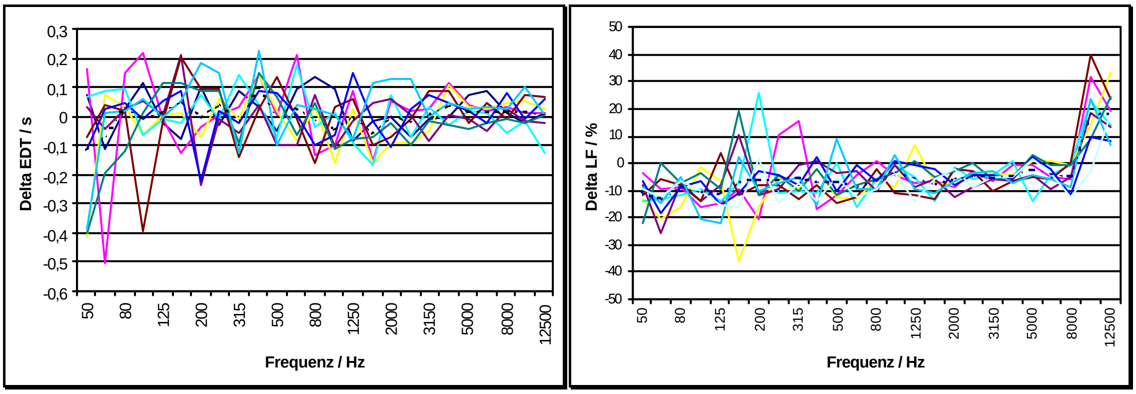

Fig. 6: Absolute difference of the measured parameters when comparing the results obtained with the building acoustics loudspeaker and the ITA three-way loudspeaker. Left figure shows the EDT results, right figure shows the LF results.

Unfortunately, it is not possible to give a solid reason for this behaviour at the moment. One possible assumption is that the linear phase equalisation for the ITA loudspeaker system and the flat frequency response introduces further differences in the time structure of the recorded impulse response. Nevertheless, it is doubtful that this gives any effect with 1/3-octave band filtered signals.

CONCLUSION

The assumed dependencies for room-acoustical single number parameter measurements on the directivity of the source have been validated by the presented investigations. The differences found between the averaged mean value and the individual result in most cases are higher than the supposed threshold of perception.

On the other hand, systematic differences between the results obtained with both sound sources have been found that are not related to the directivity or the used algorithms and measuring methods. It will be a task of future work to investigate these phenomena more precisely to gain deeper insight into the mechanisms involved here.

BIBLIOGRAPHICAL REFERENCES

1 Behler, G.K. — Ein neuer Messlautsprecher für die Raumakustik, Fortschritte der Akustik – DAGA 2000

2 Behler, G.K., Müller, S. — Technique for the Derivation of Wide Band Room Impulse Response, EAA Symposium on Architectural Acoustics, Madrid 2000, Número especial de la REVISTA DE ACÚSTICA, Vol.XXXI, 2000, aaq 11

3 Müller, S.; Massarani, P. — Transfer-Function Measurement with Sweeps, J. Audio Eng. Soc., Vol. 49, No. 6, June 2001, pp 443

4 Bork, I. — Raumsimulation zwischen Theorie und Praxis, Fortschritte der Akustik – DAGA 2001