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Improving Lateral Fraction Estimation by FIR filtering correction of room impulse responses

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ABSTRACT

The Lateral Fraction (J_{LF}) objective parameter correlates well with the subjective impression of Spaciousness of concert halls and it is not difficult to estimate. The usual way of measuring J_{LF} consist in using a variable pattern microphone with matched gain between omnidirectional and bidirectional patterns. Sources of error of different microphones are shown to be high, especially depending on the spectral content of the lateral reflections and the gain matching process is not clear. This paper introduces an alternative method using a small diaphragm omnidirectional microphone and a bidirectional microphone corrected by the use of a FIR filter to minimize this problem.

Keywords: Room acoustics, Spaciousness, Measurement
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1. INTRODUCTION

Room impulse responses measured are standardized according to ISO 3382-1[1] from the measurement procedure, the apparatus needed, the coverage required, and the method of evaluating the data and presenting the test report. It is very detailed in case of the reverberation time (RT) while other room acoustical parameters require interpretation.

Early lateral energy measures are defined as J_{LF} and J_{LFC} (LF and LFC in previous versions) are defined as:

$$J_{LF} = \int_{0,005\,s}^{0,080\,s} p_L^2\,(t)\,dt \Big/ \int_{0\,s}^{0,080\,s} p^2\,(t)\,dt \quad \textbf{[1]}$$

And:

$$J_{LFC} = \int_{0,005\,s}^{0,080\,s} |p_L(t) \cdot p(t)|\,dt \Big/ \int_{0\,s}^{0,080\,s} p^2\,(t)\,dt \quad \textbf{[2]}$$

According to[2] J_{LFC} is subjectively more accurate than J_{LF}.

Spaciousness is a group of sensations that comprise Apparent Source Width (ASW) also known as Source Broadening and Listener Envelopment (LEV) created by the sound reflections coming from the boundaries of the hall where there is a source such as a singer or musician and a listener in their respective positions.

Some papers demonstrate ASW relates to early reflections while LEV depends on reverberant late reflections[3 4] and display some auditory sensations of reflections depending on delay and angle of arrival. The temporal border that separates early to late reflections for objective parameters is standardized in 80 ms while obviously the psychoacoustic sensations are much more complicated.

Measurements taken with an omnidirectional microphone and a cosine (figure-eight) pointing perpendicular to the source are less interesting for late energy as they tend (or should tend) to be diffuse, meaning they should be similar in different positions and not too big rooms.

2. SOURCES OF UNCERTAINTY

Uncertainty estimation in concert hall measurements has been researched before[5–8], it is not the aim of this paper to cover it in its full complexity but to deal with the uncertainties related to the microphones used. Previous research[9] show big differences in J_{LF} measured with different microphones.

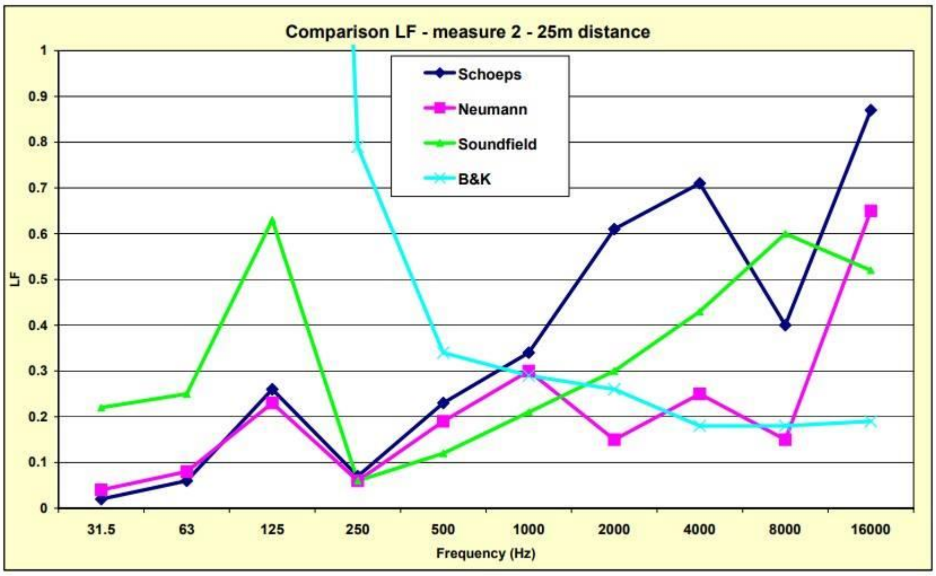

Figure 1. Results in one point with different microphone arrays according to[9]

Dr. A. Farina was asked if any equalization was used in those measurements and his answer was "*none of those microphones was equalized, I measured them "as they are". In the case of the Soundfield, the A2B conversion was the one done by the analog circuitry inside their "black box". That chart was the proof that every microphone should be individually measured, and a proper set of FIR filters designed for it*."

The usual method, as described in[10] states a variable pattern microphone is generally used, an AKG C414EB in their case, it is also said that a "*careful calibration of the relative sensitivities of the two directivities is needed with this sort of microphone*" without further explanation. Another paper by M. Barron explains[11] *"The maximum sensitivity of the figure-of-eight microphone at the measuring frequencies should be measured relative to that of the omni-directional microphone"* so this approach is to use free field on-axis measurements. In[7], an omnidirectional microphone is used together with the AKG bidirectional one; the sensitivities of the microphones were matched using a diffuse field calibration method.

AKG C414-EB user manual[12] shows quite flat frequency response charts meanwhile Townsend[13] reviews 11 different versions of AKG across its long history and displays large differences in frequency response. Iso standard[1] states the microphone should be as small as possible and preferably have a maximum diaphragm diameter of 13 mm. Variable pattern microphones are constructed with two capsules, most of the times bigger than 13 mm so their directivity in omnidirectional pattern is far from ideal at high frequencies.

There is some previous work about correction for spherical microphone arrays[6,7,14,15] but we have not found any information on the simpler task of correcting the bidirectional microphone by modern means like IIR or FIR filtering.

AKG C414 in its various versions is widely used for J_{LF} estimation, and an unit of C-414B XLII will be measured in anechoic chamber and presented in this paper as an example. No attenuation or hi-pass filters were used. A PCB 378B02 ½" measurement microphone was measured as reference.

Figure 2. Free-field measurements of the AKG C414 B XLII

2.1 Microphone directivities

Directivity responses normalized to 0 dB are shown. A theoretical cosine is displayed for comparison.

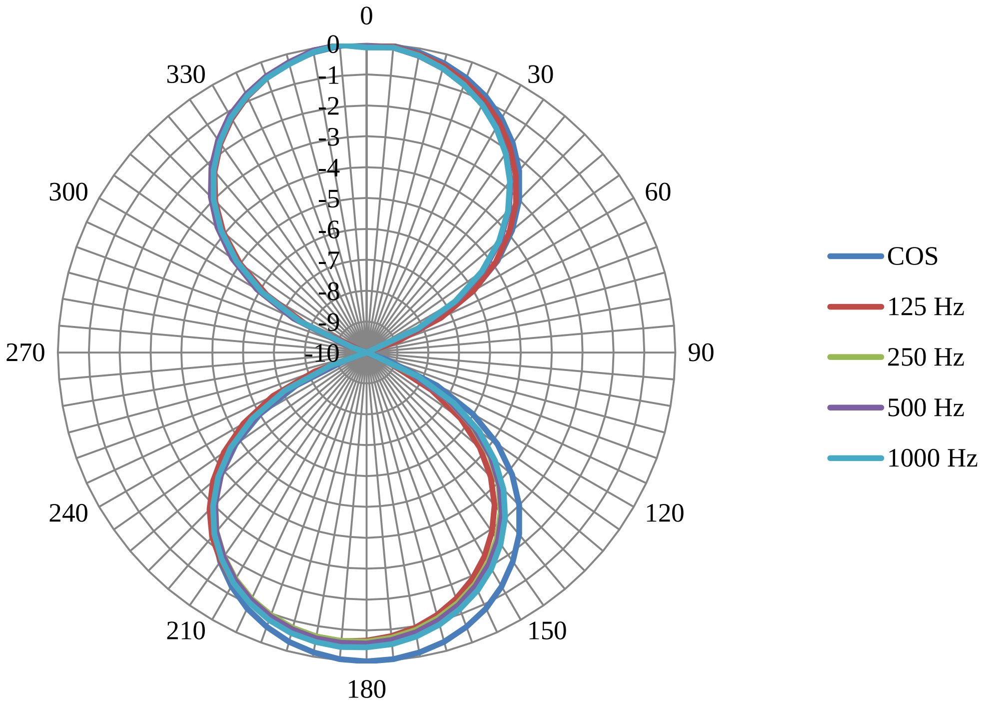

Figure 3. AKG C414 B XLII Directivity (figure 8)

This unit shows an asymmetry probably due to the mismatch of the sensitivities of the capsules around 0,5 dB for the rear part.

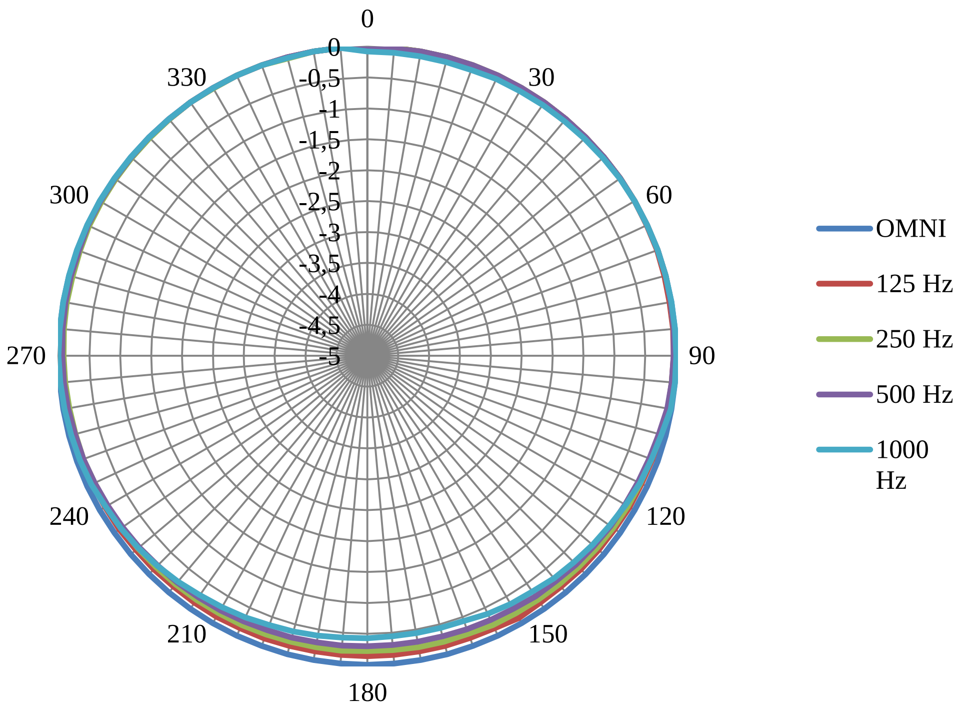

Figure 4. AKG C414 B XLII Directivity (omnidirectional)

The deviations from omni pattern are less than 0,5 dB in the range of interest. But it has to be remarked that +/-0,5 dB equals to a +12 or -11% error in lineal scale.

Deviation from theoretical patterns are greater when frequency increases.

2.2 Microphone frequency response

As the measurements were performed with a Genelec 8040, direct frequency responses include the influence of this studio monitor. A transfer function of the measurements is calculated to avoid the influence of the monitor.

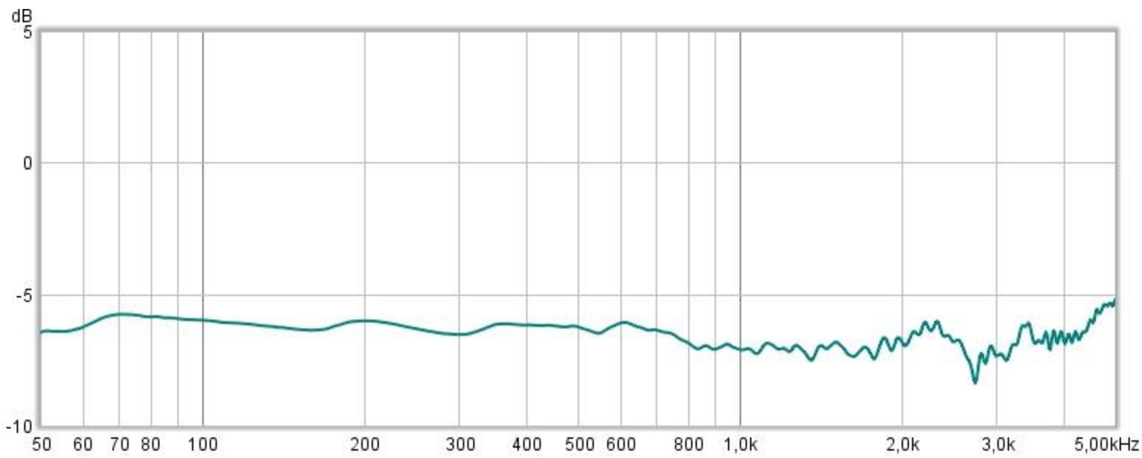

Figure 5. AKG C-414 Omnidirectional, transfer function (frequency) with reference microphone

Given the sensitivity of the 378B02 is -24,65 dB (V ref. 1 Pa at 250 Hz), the sensitivity of the C-414 can be estimated around -30 dB for the omni pattern

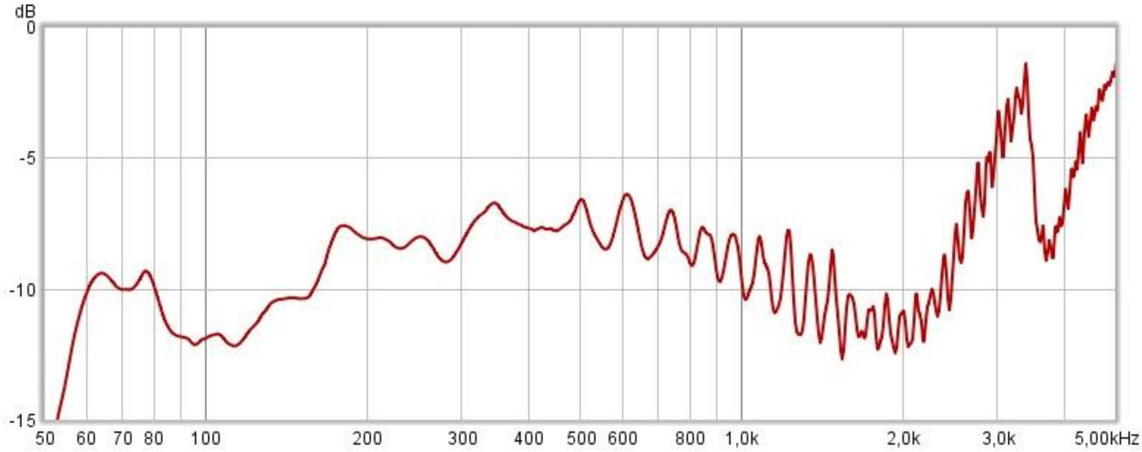

Figure 6. AKG C414 figure-8, transfer function (frequency) with reference microphone

Meanwhile omnidirectional frequency response is not bad, C-414 exhibits a poor bidirectional frequency response that leads to huge errors in J_{LF} estimation if not corrected.

In case of using the C-414 for both measurements, omni and sides, it is useful to calculate the transfer function between figure-8 and omni patterns.

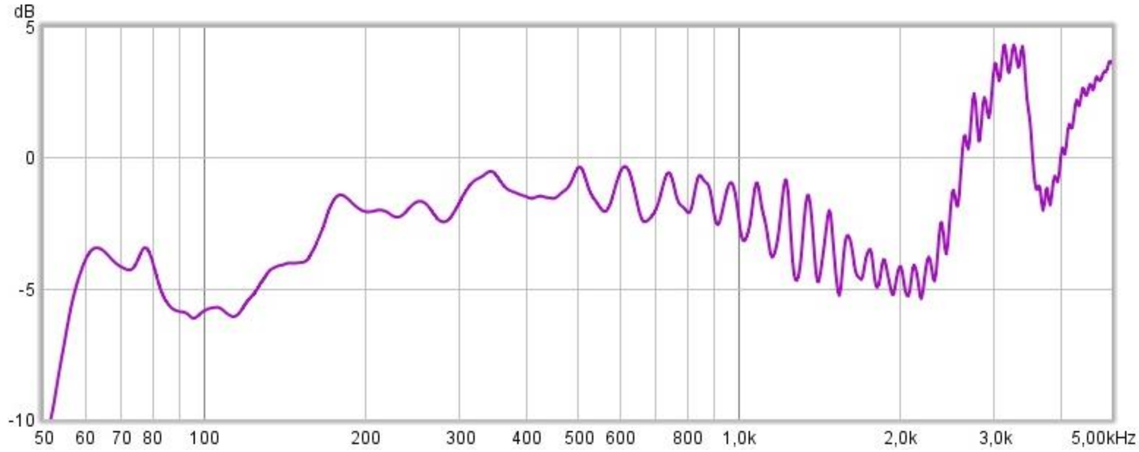

Figure 7. AKG C414 transfer function between 8 and O patterns

Figure 7 can be converted into an octave-band chart that can be useful as a free-field simple correction in case the measurement has been made switching omni-bidirectional patterns in two steps.

Table 1. FF correction to be applied to omnidirectional microphone

Frequency, Hz	**Correction, dB**
63	-1,9
125	**-4,9**
250	**-1,8**
500	**-1,9**
1.000	**-2,2**
2.000	-2,8
4.000	2,4
8.000	2,4

2.3 Microphone orientation

Using cheaper microphones it was noted that the construction axis and the acoustical axis of the Behringer C-3 had a mismatch of around 2,5º because of an inaccurate construction. This issue shall be taken into account during the measurement campaign but it wasn't observed in the unit of C414 tested.

2.4 Microphone phase mismatch

Phase differences are inherent to different microphones and add different delays that may affect the results since J_{LF} calculation involve the integration between 5-80 ms for the figure-8 and 0-80 ms for the omnidirectional signal. Group delay can be calculated from phase.

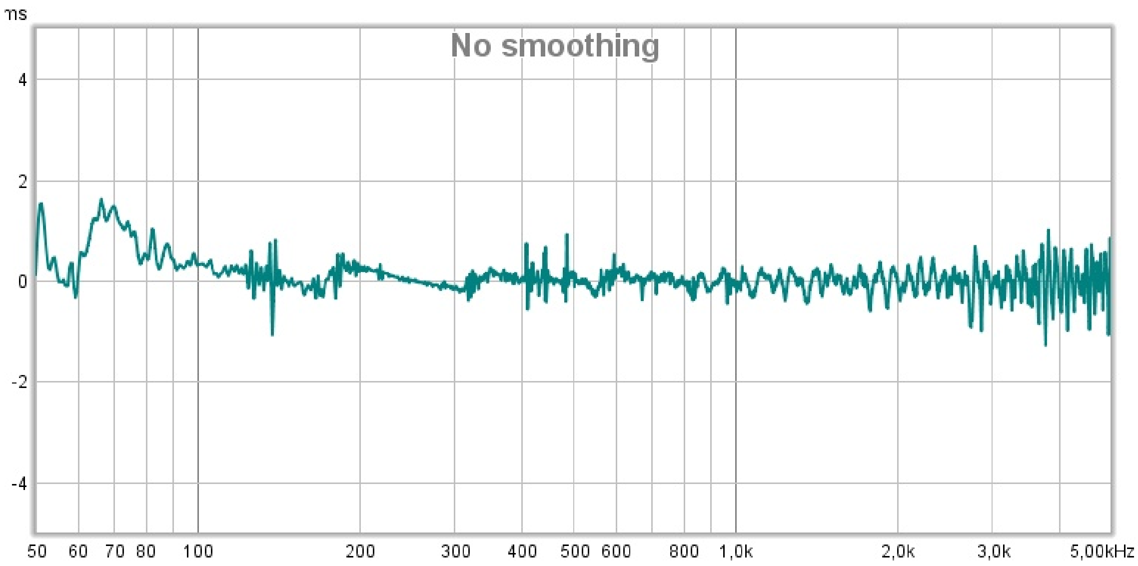

Figure 8. AKG C414 omni group delay compared to PCB 378B02

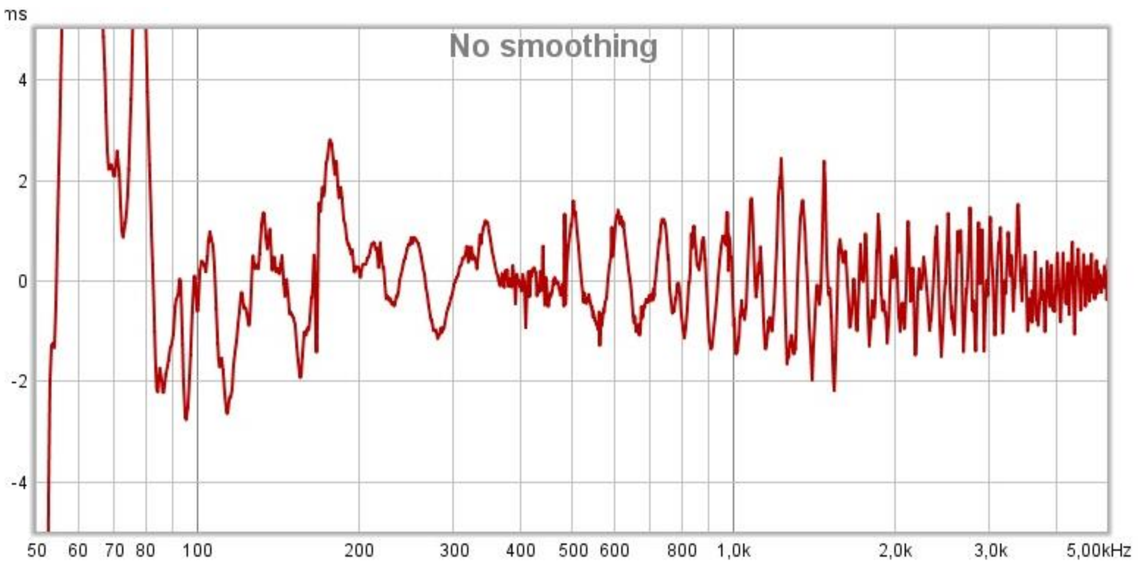

Figure 9. AKG C414figure-8 group delay compared to PCB 378B02

Group delay is not a meaningful source of error in case of the omnidirectional pattern when compared to frequency response.

3. MEASUREMENT CORRECTION

Different actions can be proposed. In this paper we advocate for a FIR filter applied by convolution to correct the free-field frequency response of the figure-8 of the microphone used to fit the frequency response of the omnidirectional microphone used. A simpler solution could be applying a correction to every octave of interest but since the frequency response has big changes across every octave it would be less accurate.

There are different ways to design a FIR filter to correct the frequency response of the microphone; they can be linear-phase and usually symmetrical. Using a symmetrical filter implies a delay of half its length is added to the signal so for J_{LF} measurements this has to be taken into account and either add that delay to the omnidirectional signal or subtract it to the figure-8.

Microphones are known to be minimum-phase devices so by correcting the frequency response, a phase-align effect must be accomplished between both signals.

Room EQ Wizard [16] software is used to calculate a set of parametric filters to equalise the dipole measurements. The target is to achieve +/- 1 dB flatness between 50 and 3000 Hz and a low pass filter when it is applied to the transfer function between the free-field measurement of the C414 and the reference microphone that will be used as omnidirectional in the J_{LF} measurements.

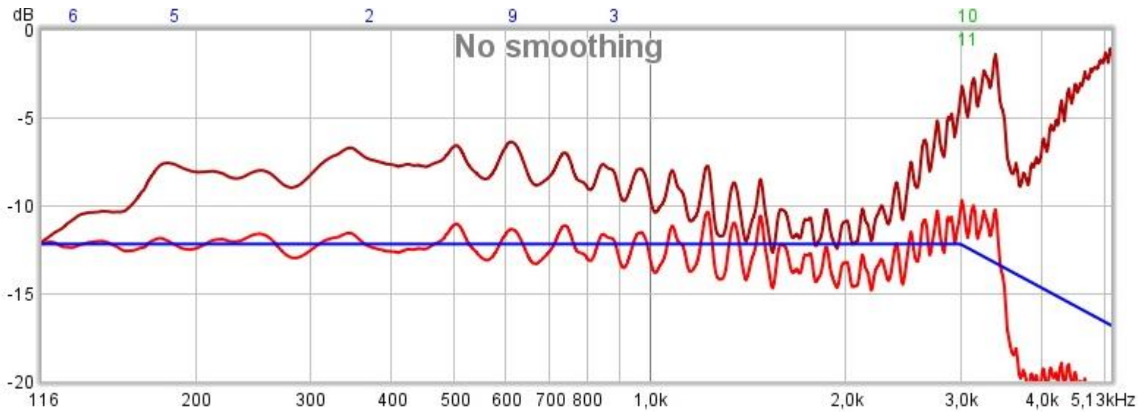

Figure 10. Proposed equalisation, prediction

Figure 10 shows the transfer function of the C-414 in figure-8 over reference omnidirectional microphone and the prediction of the result after equalisation, gain will be compensated later.

Table 2. Parametric filters used for figure-8 C414 correction

Type	fc, Hz	Gain, dB	Q
parametric	64,0	-2,8	5.406
parametric	77,9	-2,9	6.323
parametric	108,0	-4,7	3.130
parametric	116,0	7,4	2.033
parametric	129,0	-3,9	3.733
parametric	184,0	-3,8	2.583
parametric	367,0	-4,2	1.005
parametric	610,0	-1,1	5.000
parametric	875,0	-2,9	1.000
2nd order LP	3000,0	-	-

4. RESULTS

Every measurement taken with the bidirectional microphone is convolved with the filter before computing Lateral Fraction.

To check the consistency of the method it is calculated the transfer function between the reference microphone and the corrected C-414 and the group delay of the function.

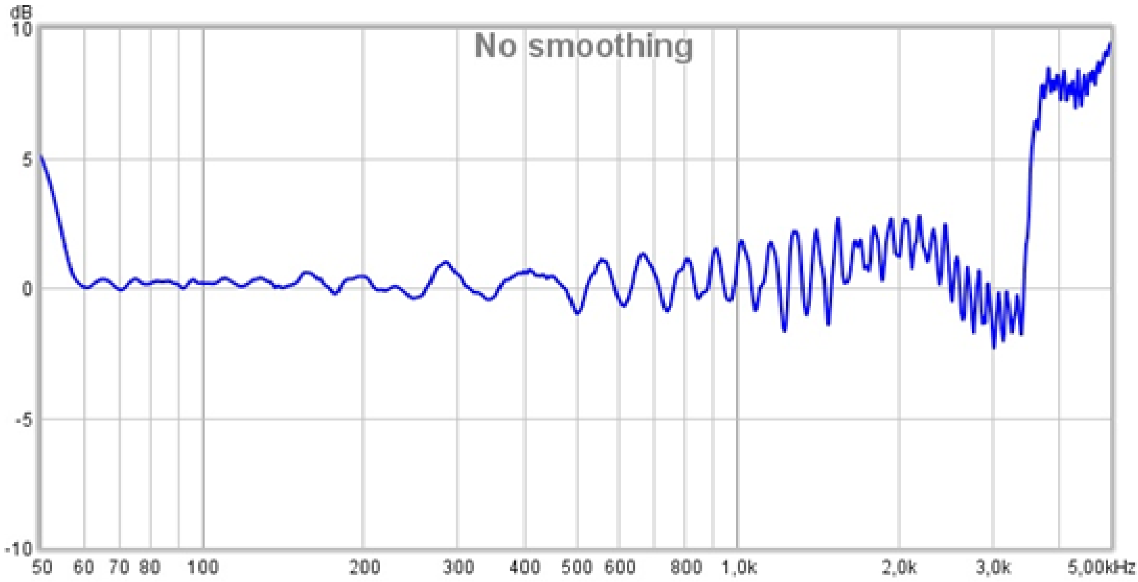

Figure 11. Reference microphone to filtered C-414 dipole transfer function (dB)

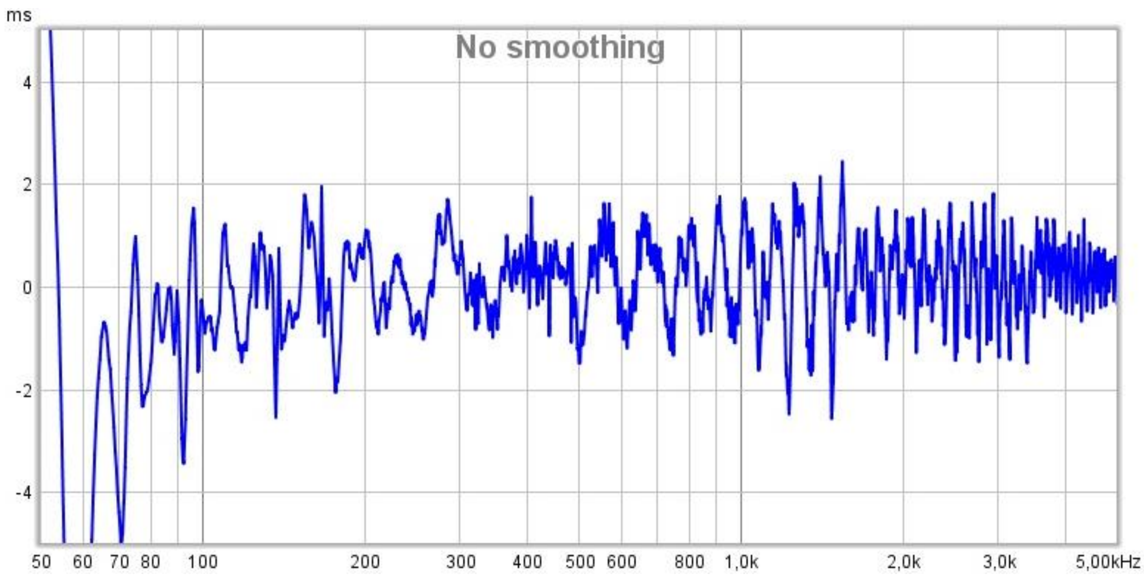

Figure 12. Reference microphone to filtered C-414 dipole group delay (ms)

5. CONCLUSIONS

Microphone frequency responses have shown to be causes of high uncertainties in the measurement of J_{LF} and J_{LFC} due to the lack of laboratory grade figure-eight microphones with flat frequency responses. A simple method to equalize the frequency response of the bidirectional microphone by convolution with a FIR filter has been presented.

A method is proposed to minimize the uncertainties related to the microphones consisting in measuring sequentially with a reference microphone [17]WS2F and a figure-8 microphone using the same channel and the swept-sine method. The dipole impulse response will be corrected afterwards by convolution with an adequate FIR filter to match the free-field responses of both microphones in the range of interest.

Directivity in omnidirectional pattern is far from ideal so it seems better to use a small laboratory grade omnidirectional microphone and a figure-8 small microphone such as the Sennheiser MKH 30-P48 rather than using a variable pattern microphone.

It can be argued that smaller microphones with adequate corrections or modern techniques using microphone arrays can enable the measurement of LF at higher frequencies that are important to the subjective impression of spaciousness.

6. REFERENCES

1. ISO. ISO 3382-1 Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces. In: ; 2009.
2. Kleiner M. A new way of measuring the lateral energy fraction. *Appl Acoust*. 1989;27(4):321-327. doi:10.1016/0003-682X(89)90037-6
3. Barron M. The subjective effects of first reflections in concert halls-The need for lateral reflections. *J Sound Vib*. 1971;15(4):475-494. doi:10.1016/0022-460X(71)90406-8
4. Olive SE, Toole FE. The Detection of Reflections in Typical Rooms. November 1988. http://www.aes.org/e-lib/browse.cfm?elib=4725.
5. Behler M. Uncertainties of measured parameters in room acoustics caused by the directivity of source and/or receiver. http://webistem.com/acoustics2008/acoustics2008/cd1/data/fa2002-sevilla/forumacusticum/archivos/rba02008.pdf. Accessed November 27, 2018.
6. Dick DA, Vigeant MC. A comparison of late lateral energy (GLL) and lateral energy fraction (LF) measurements using a spherical microphone array and conventional methods. https://depositonce.tu-berlin.de/bitstream/11303/162/1/4.pdf. Accessed November 26, 2018.
7. Protheroe D, Day ; Christopher. Validation of Lateral Fraction results in room acoustics. https://www.marshallday.com/media/1349/validation-of-lateral-fraction-results-in-room-acoustic-measurements.pdf.
8. Knüttel T, Witew IB, Vorländer M. Influence of “omnidirectional” loudspeaker directivity on measured room impulse responses. *J Acoust Soc Am*. 2013;134(5):3654-3662. doi:10.1121/1.4824334
9. Farina A. Advancements in impulse response measurements by sine sweeps. *Proc 122nd AES Conv*. 2007. doi:10.13140/2.1.1598.6882
10. Barron M. Measured early lateral energy fractions in concert halls and opera houses. *J Sound Vib*. 2000;232(1):79-100. doi:10.1006/jsvi.1999.2686
11. Barron M. Using the standard on objective measures for concert auditoria, ISO 3382, to give reliable results. *Acoust Sci Tech*. 2004;26. doi:10.1250/ast.26.162
12. AKG acoustics. C414EB User Instructions. https://www.barryrudolph.com/recall/manuals/akg414eb.pdf.
13. Chris Townsend. The Many Faces of the 414 - Townsend Labs. https://townsendlabs.com/many-faces-414/. Accessed November 29, 2018.

14. Farina A, Capra A, Chiesi L. A spherical microphone array for synthesizing virtual directive microphones in live broadcasting and in post production. doi:10.1007/s00766-009-0078-8
15. Farina A, Capra A, Conti L, Matignon P, Fazi F. Measuring Spatial Impulse Responses in Concert Halls and Opera Houses Employing a Spherical Microphone Array. *19th Int Congr Acoust*. 2007;(September):2-7.
16. Room EQ Wizard. www.roomeqwizard.com.
17. IEC 61094-4: I 1995. Measurement microphones — Part 4: Specifications for working standard microphones. 1995. doi:10.3397/1.2832075