Letter to the Editor

Response to "Comments on Reverberation Radius in Real Rooms"

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IN his Letter to the Editor [1] P. Jafari Shalkouhi makes remarks on the results presented in the paper "Reverberation Radius in Real Rooms" [2]. He suggests there might be some inaccuracy in the method of reverberation radius measurement introduced in the paper. The remarks are based on the assumption that critical distance in a room should be inversely proportional to the reverberation time.

This is true concerning the statistical model of a sound field in room, that is, in the case of an ideally diffuse and homogenous sound field. In such circumstances reflected sound energy shows exponential decay and is equally distributed across the room, while its total value is proportional to the reverberation time. Critical distance and reverberation time are then related by the Equation (1) given in the paper [2]:

$$r_c = 0.057\sqrt{\frac{\gamma V}{T}} \qquad (1)$$

where r_c is critical distance in (m), V is room volume in (m^3), T is reverberation time in (s) and γ is directivity factor of the sound source. The Equation (1) is valid along the axis of the source (i.e. the loudspeaker), where it produces maximum intensity.

The energy of direct sound does not depend on the room acoustic properties, and direct-to-reflected sound energy ratio (D/R) is inversely proportional to the reverberation time. Consequently, the increase of reverberation time will cause the decrease of critical distance, since more direct sound energy is needed to keep the D/R ratio equal to 1.

However, in the case of a non-diffuse and non-homogenous sound field, as in real rooms, the relation between the critical distance and the reverberation time is more complex. In such circumstances reflected sound energy is not directly proportional to reverberation time. It can highly depend on the source and receiver positions, macro and micro geometry of the room [3] and the spatial distribution of absorption in it. The paper on which P. Jafari Shalkouhi has made the comments is particularly concerned with such non ideal circumstances in real rooms. The measurements presented in it were organized to reveal the possible range of differences between the critical distance values obtained by simplified theory and in reality.

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In real rooms appearance of strong early reflections can highly influence the total reflected sound energy, while keeping more or less the same the value of reverberation time. Since reverberation time quantifies only the rate of sound energy decay in the room, one isolated early reflection may not change its value noticeably, but can make a considerable contribution to reflected sound energy and thus influence the critical distance. This is demonstrated in Fig. 1.

Fig. 1a presents a theoretical example of impulse response consisting only of the direct sound and one delayed reflection, which is its exact replica. Since the reverberation time quantifies the slope of sound energy decay curve (standardized from –5 dB to –35 dB), in this theoretical case it would take extremely low value, close to zero. On the other hand, direct and reflected sound energy values are equal, so the measurement point is at the critical distance from the sound source. This theoretical example of impulse response clearly indicates that a lower value of reverberation time does not necessarily mean a larger critical distance.

In more realistic cases, reflected sound energy does not decay exponentially and contains strong isolated early reflections in the initial part of impulse response. This is the situation when a sound field in the room is not diffuse and homogenous. Fig. 1b and Fig. 1c show two impulse responses recorded in room 3 (used in the analysis presented in paper [2]) at the distances of 1 m and 4 m from the sound source. Major differences between them are in the direct sound energy (due to different distances from the source) and presence of some strong early reflections. The reflected sound energy decay rate is more or less the same and so is the reverberation time, but the direct-to-reflected sound ratio is different. One can conclude that in real rooms the D/R ratio and, consequently, the critical distance, do not necessarily depend only on the reverberation time, but on the time distribution of reflected sound energy as well.

In rooms with a non-homogenous sound field strong early reflections can occur in some limited areas, shifting the critical distance towards lower or higher values, depending on the receiver position. Such differences in the structure of strong early reflections in the room impulse response can be influenced by the variation of spatial distribution of the same absorptive and reflective surfaces, as well as by changing the positions of source and receiver, while the value of reverberation time remains the same.

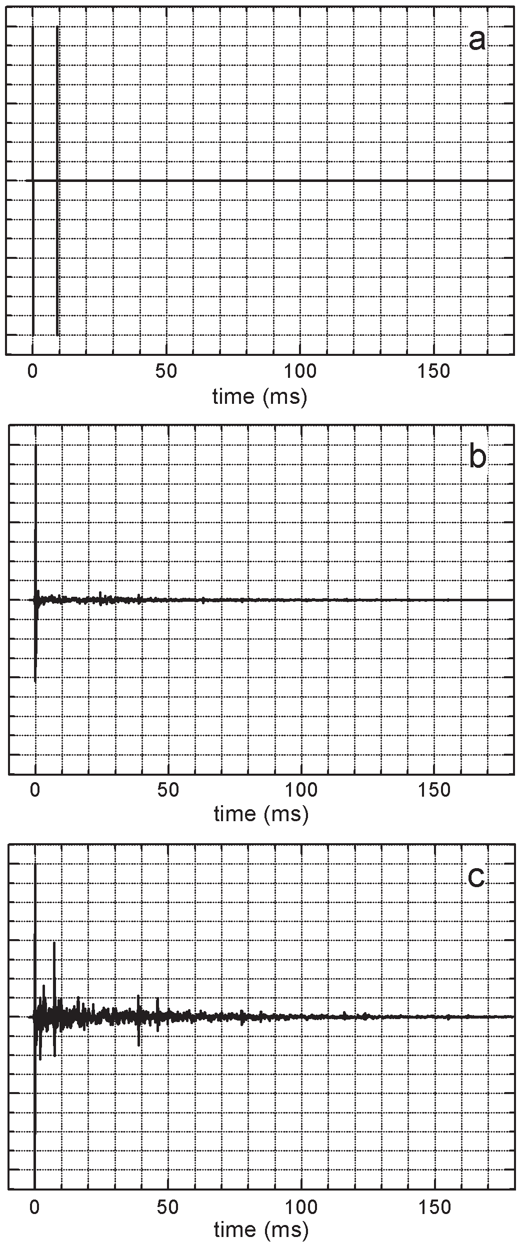

Fig. 1. Examples of impulse responses: (a) theoretical case with direct sound and its delayed replica, (b) room 3 at the distance of 1 m from the source and (c) room 3 at the distance of 4 m from the source.

Rooms in which a sound field tends to be non-homogenous are most often highly damped, acoustically treated rooms with a low reverberation time. That is the case in various kinds of studios and audio control rooms. Such were rooms 2 and 3 used in the analysis described in paper [2]. Non ideal acoustic design of such rooms means that all strong early reflections are not suppressed sufficiently. Very often strong early reflections from the hard floor or walls (such is the case with room 2) or the equipment and furniture (in room 3) are easily noticeable when most of the other reflections are attenuated. In addition, strong early reflections can occur only in limited zones of the room, depending on their paths. Such reflections can also have spectral content different from the direct sound, depending on the absorption and scattering properties of the reflective surfaces in the room. Therefore, their contribution to the reflected sound energy can vary with frequency, changing the critical distance either way (towards lower of higher values), while the average value of the reverberation time in the room stays unchanged, depending on the overall absorption in the room. In the rooms 2 and 3 strong reflections most probably occurred, influencing the total amount of reflected energy at the receiver location. The surfaces these reflections hit might have been more absorptive (or diffuse) at higher frequencies and thus attenuated (or scattered) them more efficiently in those parts of the spectrum, increasing the critical distance at the same time. On the other hand, the areas of the same surfaces might have been too small in comparison to the total area of the surfaces in the room to influence the global reverberation time noticeably.

As opposite to the previous cases, large rectangular rooms with hard walls should obey the principles of statistical theory, at least in the middle and high frequency bands. In such circumstances it is reasonable to expect the reverberation time to decrease towards high frequencies and critical distance to increase, not only due to usually higher value of absorption in the room at higher frequencies, but also to the directivity of the sound source. This is generally observable in both rooms 1 and 4. Unfortunately, there are some exceptions in the lowest two octave bands, probably due to insufficient signal-to-noise ratio, especially in the reverberation time values. That fact confirms the difficulties appeared in impulse response measurements at low frequencies. Other observable variations of the reverberation time values at higher frequencies in room 4 are below 10%.

In the end of his comments P. Jafari Shalkouhi also suggests more measurement positions in small rooms with the sound fields strongly influenced by the eigenmodes occurrence. Naturally, increasing the number of measurements in the room will lower the measurement uncertainty, but also is more time consuming. The number of measurement locations given in the paper was considered as a good compromise between the measurement accuracy and its complexity. It also enabled fitting the D/R curve in each room with sufficient accuracy, which was the basis for critical distance determination.

We appreciate the diligence of P. Jafari Shalkouhi. However, we cannot agree with the conclusion that “the comparison of critical distance measurement results with reverberation time measurement results will show the accuracy of critical distance measurement”. Furthermore, the value of critical distance in real rooms is not unique for all the combinations of source and receiver. The intention of the paper “Reverberation Radius in Real Rooms” was to reveal the average range of its variation.

References

[1] P. Jafari Shalkouhi “Comments on "Reverberation Radius in Real Rooms”.

[2] M. Mijić and D. Mašović, “Reverberation Radius in Real Rooms,” *Telfor Journal* 2, no. 2, pp. 86-91, 2010.

[3] D. Šumarac-Pavlović and M. Mijić, “An insight into the influence of geometrical features of rooms on their acoustic response based on free path length distribution,” Acta Acustica, vol. 92, no. 6, pp. 1012-1026, 2007.