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Reverberation time measuring methods

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In this paper different well-established methods of reverberation time measurement are compared. Furthermore, the results obtained using these methods are compared to the results provided by some additional methods which could serve as an in situ tool if, for any reason, the reverberation time measurements cannot be carried out using the standardized methods. The methods compared in this paper include the standardized methods (EN ISO 3382:2000), namely the impulse response measured with pink noise, exponential sweep, MLS, but also pistol shots of different calibers, balloon bursts, gated external pink noise, and the B&K filtered burst method. In order to make the comparison, the measurements were performed in four acoustically very different spaces - a rather small and well-damped listening room, a much bigger damped drama theatre, a rather reverberant atrium, and a large and very reverberant shoebox-shaped room. The results were evaluated taking into account to signal-to-noise ratio criterion and special attention has been given to the influence of room modes on measurement results.

1 Introduction

Over the years, a large number of parameters have been defined in order to describe and evaluate acoustical properties of a certain space. Nevertheless, the reverberation time has always been the basic indicator of acoustical behavior [1]. In the professional work of an acoustician, it is often required to measure the reverberation time in spaces with very different sizes, shapes and intended purposes. As a part of this large-scale research on the measurements of reverberation time, an attempt was made to determine the best possible measurement setup to be used in reverberation time measurements which will provide the most reliable results.

Over the years, a number of different methods for measuring the reverberation time has been developed and implemented, the most common being: the interrupted noise method, the integrated impulse response method, the method of recording the room response to an impulsive source, the burst method. Earlier research [2] has suggested that the integrated impulse response method and the method of recording the room response to an impulsive source could be the most suitable ones to be used in field measurements, so the emphasis in this paper has been made on these particular methods.

In order to remove a degree of uncertainty, most measurements were made using the same sound source, except when an impulsive source was used instead (balloons and pistol shots), and when the effect of directivity of a loudspeaker on reverberation time measurement was investigated. Furthermore, all responses were recorded with the same microphone.

The measurements were taken in four acoustically very different spaces. The future research shall include the measurements in spaces with variable acoustic finishing throughout the space itself (e.g. one side very reflective, the other very absorptive), which were not available at the time the measurements were conducted.

2 Requirements in reverberation time measurements

The requirements that have to be met when performing a reverberation time measurement are stated in [1] and can be summarized as:

- the source, either a loudspeaker or, if nothing else is available, an impulsive source of some kind, should have an omni-directional radiation pattern (or as close to it as possible)
- the sound pressure level must be high enough to provide a minimum required dynamic range to perform a reverberation time measurement, to be more precise, at least 45 dB for methods that do not apply synchronous averaging

It is quite clear that an omni-directional source has to be used in order to excite the measured space uniformly in all directions. All our measurements have been performed using the omni-directional loudspeaker or impulsive sources, for both of which it was assumed that their radiation pattern approaches the ideal one, thereby fulfilling the requirement on omni-directivity. Nevertheless, a small number of measurements were made using directional loudspeaker in order to examine the influence of the directional properties of the source on measurement results.

Several parameters [1] can actually be measured and calculated from the energy decay curve obtained from reverberation time measurements. The RT30 parameter is considered to be the most accurate and the goal is to be able to measure it whenever possible. If this is not the case, the RT20 parameter is used as the indicator of reverberation time. The EDT is only used when all else fails, however, it should be noted that it is not a true measure of reverberation time because it can and often does differ a lot from RT20 and RT30.

3 Methods of measurement

As already stated in the introduction, the following methods were investigated in this paper:

- the integrated impulse response method
- the interrupted noise method
- the method of recording the room response to an impulsive source
- the filtered burst method implemented by Bruel&Kjaer

The integrated impulse response method has been implemented in a number of computer applications. The application of choice for our measurements is the ARTA Software [3], designed for audio measurements and analysis in acoustical and communication systems. The available test signals in ARTA for impulse response measurements are pink noise, swept sine and MLS and the decision has been made to investigate all of them to determine the best one to be used in reverberation time measurements. This method has the inherent advantages of a) ensuring the repeatability of the measurements and b) allowing for synchronous averaging, thereby increasing the dynamic range and lowering the demands on the sound source at the same time.

The interrupted noise method basically uses a portion of pink noise with a duration of several seconds which ends abruptly. The response of the room to this noise signal, i.e. the reverberation, is recorded as a wav file and then imported in ARTA for further analysis. This method is used by our students as a standard laboratory exercise in one of the courses, so the desire was to examine its usefulness in real field conditions.

The method which utilizes an impulsive source of some kind by recording the response of the room to it is actually quite similar to the interrupted noise method. The procedure is described above, while the only difference is the source of excitation. Unlike the interrupted noise method, which uses a loudspeaker, this method allows for a wide variety of impulsive-like sources [4], like air-filled balloons, firecrackers, pistol shots, hand clap, two pieces of board clapped together, etc. Unfortunately, most of the sources mentioned above (with the exception of large-sized balloons) have a very poor spectral content at low frequencies. They are, therefore, not suitable for reverberation time measurements at low frequencies because they usually cannot provide the required dynamic range, even in small spaces.

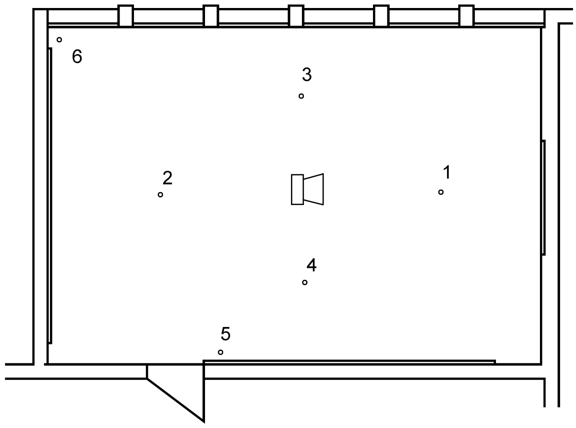
Since we acquired a Bruel&Kjaer 2231 Sound Level Meter with the Reverberation Processor module, the filtered burst method of measuring the reverberation time implemented in this module was also used. The B&K 2231 Sound Level Meter equipped with the Reverberation Processor module acts as a self-sufficient measurement system, requiring only a power amplifier and a loudspeaker to be complete. A number of bandwidth-limited bursts are used in the frequency range of choice in order to measure the reverberation time.

4 Measurement setup and measured spaces

As one of the goals of this research is to perform measurements in spaces with different acoustical properties, given their size, shape and acoustic treatment, four such rooms have been chosen.

.Fig.1 The interior of room 1.

The first room is actually a listening room located at the Department of Electroacoustics of the Faculty of EE and Computing in Zagreb. The room itself is 10.2 m long, 7.1 m wide and 3.2 m high and has a room volume of 230 m^3. Since all the acoustic elements used for acoustic treatment can easily be removed from the walls and put back on (a concept of changeable acoustics), the room acts as a constant test room for different acoustic setups. The current one brings the room very close to a good listening room. The current interior of the room is shown in Fig.1 and the floor plan of the room with indicated source and microphone positions is shown in Fig.2.

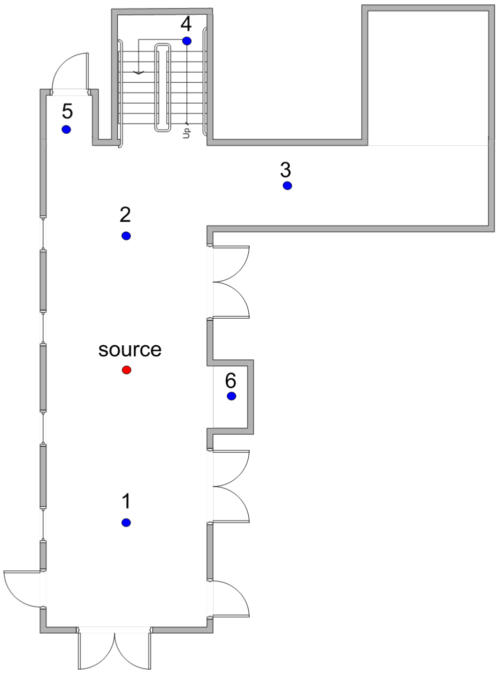


.Fig.2 The floor plan of room 1.

The second room is a rather reverberant hallway also located in one of the buildings of the Faculty of EE and computing. The room acts as a multipurpose space with the primary function of providing access to several lecture halls, but it also serves as an art gallery and sometimes as a bar, if required. It is an elongated, rather tight L-shaped space with a staircase leading to a lower level hall, thereby forming a coupled room system. The room itself was chosen because of its availability and proximity. Furthermore, its room volume of approximately 800 m^3 is not significantly larger than the volume of the first room, but the acoustic finishing differs a lot, consisting mostly of marble. The interior of the room is shown in Fig.3 and the floor plan with indicated source and microphone positions is shown in Fig.4.

.Fig.3 The interior of room 2.

The third room is a high voltage laboratory also located at the Faculty of EE and Computing in Zagreb. It has an ordinary shoe box shape with the exception of a gallery built at half the height of the room, intended for observing the experiments going on in the laboratory. The room volume is approximately 2000 m^3 and all surfaces are made of concrete with no acoustic treatment whatsoever. The interior of the room is shown in Fig. 5 and the floor plan indicating the source and microphone positions is shown in Fig. 6.



,Fig.4 The floor plan of room 2.

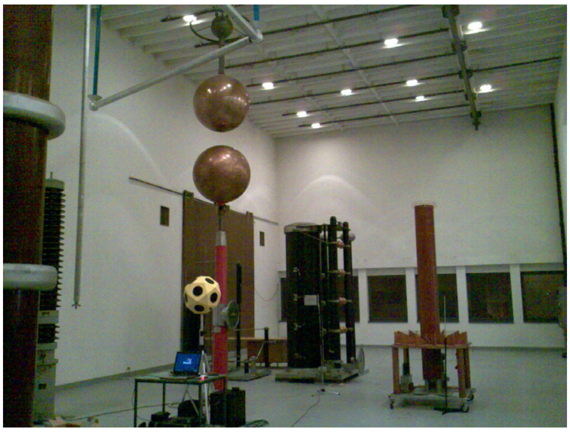
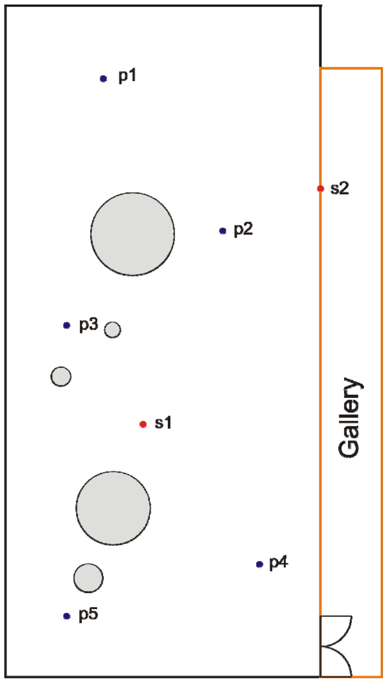


Fig.5 The interior of room 3.

The photograph of the third room shows the equipment specific for high-voltage experiments. From the acoustic point of view, these cylindrical and spherical shapes represent acoustic elements that introduce additional diffusion into the already diffuse sound field that forms in the room.

Finally, the fourth room is a recently adapted drama theatre located in Zagreb. It is about 23.3 m long, 15.6 m wide and has a volume of about 3130 m^3; its interior is shown in Fig. 7. As shown on the floor plan in Fig. 8, the theatre has only 218 seats due to the fact that this drama theatre used to be a cinema. The theatre is acoustically treated in order to control the sound pressure level and distribution in the audience area and to enhance the speech intelligibility.

In order to provide equal conditions for all investigated methods that require a loudspeaker as a source, namely, the integrated impulse response, the interrupted pink noise and the B&K filtered burst method, measurements were done using the same omni-directional loudspeaker of our own design, shown in Fig.3 and 5, powered with TOA P300D power amplifier. The source of the test signal was either a laptop computer connected to the power amplifier via TASCAM US-144 audio interface or the B&K 2231 Sound Level Meter with the Reverberation Processor module acting as a self-sufficient system.



,Fig.6 The floor plan of room 3.

Fig.7 The interior of room 4.

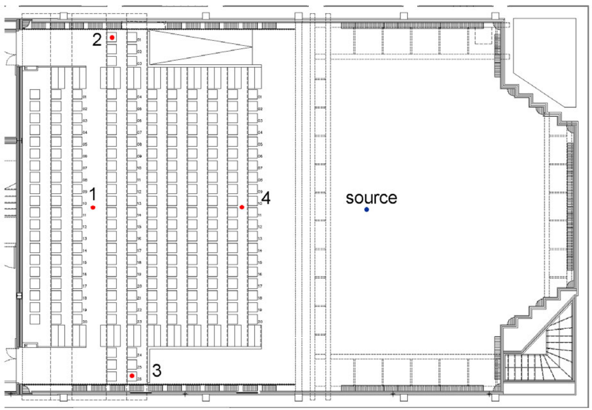


Fig.8 The floor plan of room 4.

In the investigation of the method of recording the room response to an impulsive source, balloons of 80, 120 and 160 cm in circumference were used as the sources of excitation, as well as pistol blanks of 6 and 8 mm caliber. Furthermore, a Behringer ECM-8000 omni-directional microphone was used in all the measurements except the ones conducted with B&K equipment, which used its own microphone. The analysis of measurement results was done in octave bands with center frequencies from 63 Hz to 8 kHz.

5 Measurement results

The first issue that has to be analyzed is the question of available dynamic range each method is able to provide, given that the measurement setup is always the same. The energy decay curves indicate that the integrated impulse response measured using the swept sine signal and a balloon burst provide by far the greatest available dynamic range, thereby ensuring the maximum commodity in the process of calculation of reverberation time. On the other hand, the integrated impulse response measured using the pink noise and the MLS signal are not able to provide the required dynamic range, but they can still be utilized if certain precautions are taken. Finally, the interrupted noise method provides a dynamic range so small, compared to other methods, that the results obtained from it cannot be considered as reliable.

Figs.9 and 10 show that in room 1 all methods provide results that are in very good agreement, unlike in room 2, as shown in Figs.11 and 12. One explanation could be the very acoustical properties of both rooms. On one hand, room 1 is acoustically dampened space of an ordinary shape, while room 2 is quite the opposite, a space with highly reflective surfaces and an exceptionally irregular shape. The results also show the best agreement at high frequency octave bands, while the dispersion of results becomes evident as the frequency decreases. At low octave bands, however, the decay curve loses its smoothness because of room modes and usually has more than one slope, so it can be difficult to determine the right one.

In room 3 the omni-directional source and the balloon were positioned at position S1 indicated on the floor plan of the room, while the small loudspeaker, being a part of a permanent sound reinforcement system installed in the room, is placed at position S2. The resulting reverberation times are shown for position 1 in Figs.13 and 14. The measurements performed using the integrated impulse response method utilized the sine sweep as the excitation signal, while the method of recording the room response to an impulsive source used balloons as the source of excitation. The comparison of results shown in Figs.11 and 14 reveal that the choice of the sound source is much more critical in smaller rooms where the sound field is never truly diffuse. The differences become larger at lower frequencies due to the smaller room dimensions and more emphasized room modes.

Furthermore, these results suggest that the choice of measurement method is not critical in room 3, whereas in room 2 it is important as the results obtained using different methods are significantly different. Other authors [5] suggest that the integrated impulse response method using the sine sweep is preferred due to the best S/N ratio and low sensitivity to harmonic distortion.

Fig.15 shows the measurement results in room 3 for all positions using the integrated impulse response method with the sine sweep as the excitation and the omni-directional sound source coupled with the subwoofer as the sound source. These measurement results are in much better agreement then the ones in room 2 because the shape and interior of room 3 do not allow the forming of standing waves. Furthermore, the size and non-existence of acoustic treatment in room 3 lead to a very small room radius. As a consequence, all microphone positions are deeply in the diffuse sound field.

Finally, Fig.16 shows the results of reverberation time measurements in room 4 at position 1. It is obvious that the results differ very much due to the difference in directivity of the sources, and the small dynamic range of pistol shots compared to the range obtained using the integrated impulse response method.

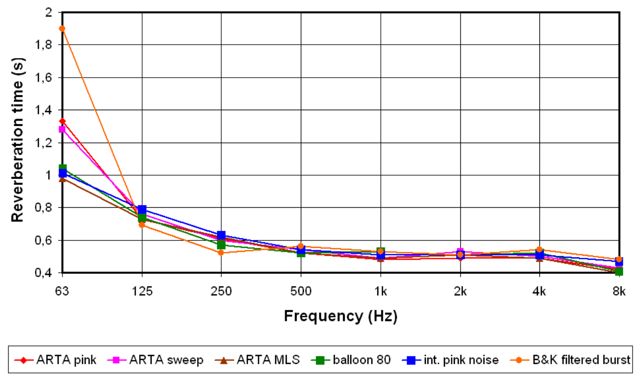


Fig.9 RT60 measured in room 1 at position 1.

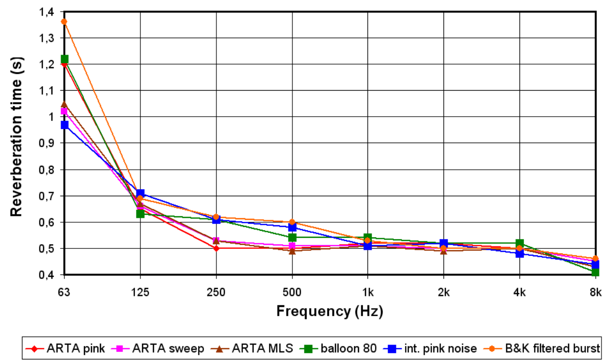


Fig.10 RT60 measured in room 1 at position 2.

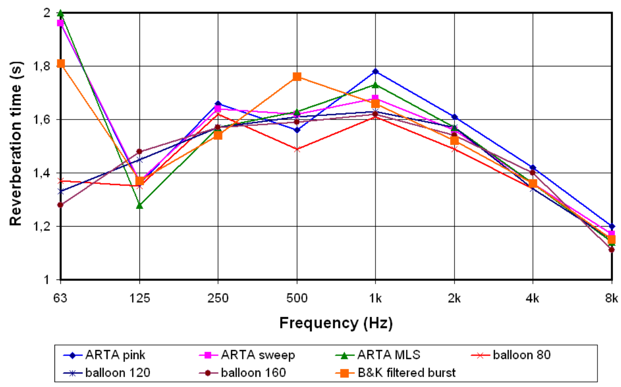


Fig.11 RT60 measured in room 2 at position 1.

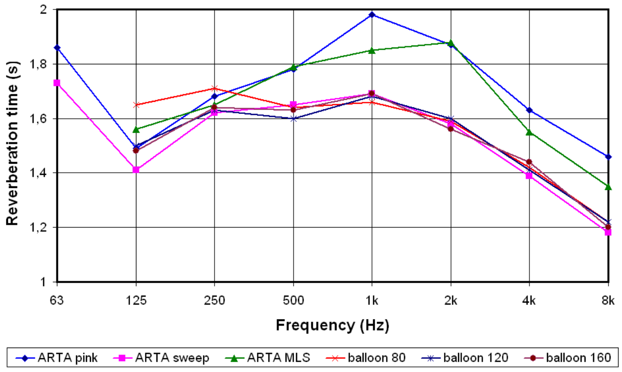


Fig.12 RT60 measured in room 2 at position 3.

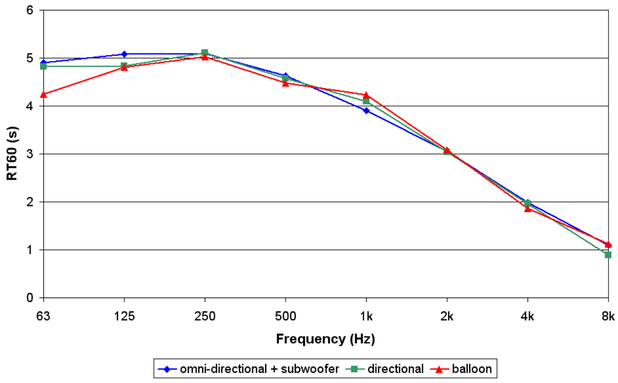


Fig.13 RT60 measured in room 3 at position 1 using different sound sources.

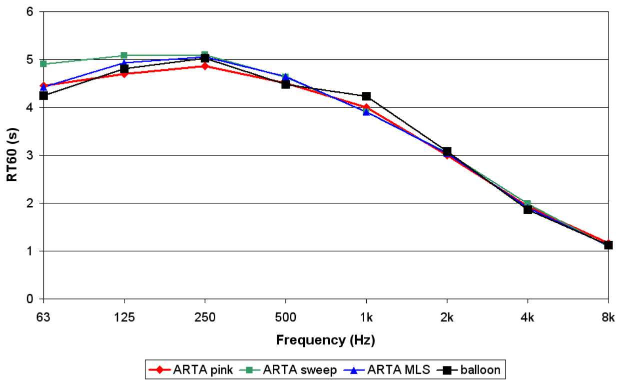


Fig.14 RT60 measured in room 3 at position 1 using different methods.

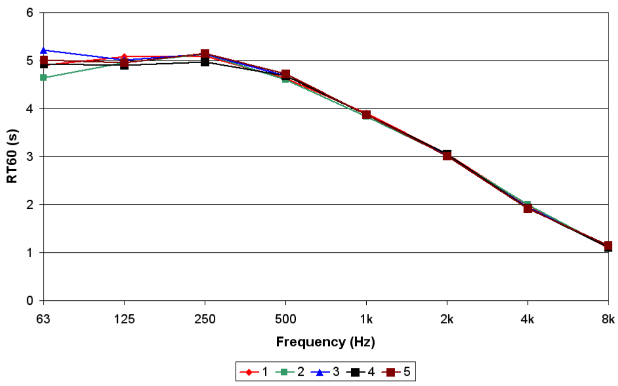


Fig.15 RT60 measured in room 3 at all positions.

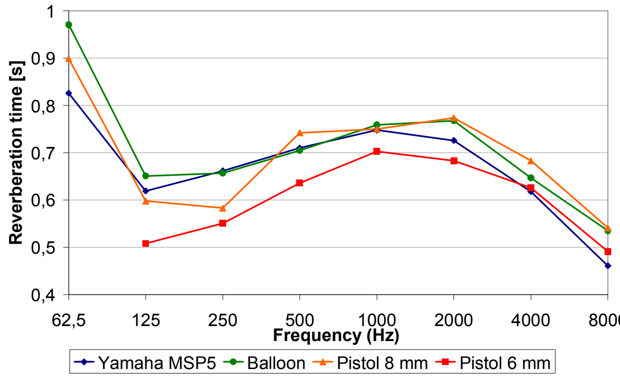


Fig.16 RT60 measured in room 4 at position 1.

5 Conclusion

The reverberation time was measured in two reverberant and two rather damped rooms of different size and shape. Although the reverberation time measurements are standardized demanding an omni-directional sound source and repeatable measurement method to be used, the shown results suggest that other types of sound sources and measurement methods can be used with almost no influence on the final result if the measured room is large and reverberant. However, this conclusion is valid if the sound field in the room is diffuse. The basic conditions that have to be met are that the room has no emphasized room modes in the frequency band of interest and that its shape and acoustic finishing leads to sufficiently long reverberation time. If the room is large enough, its dominant modes form at frequencies below the frequency range of interest.

On the other hand, if the room is of irregular shape and/or smaller size, much more attention should be paid to the choice of appropriate measurement method and excitation source. Furthermore, measurement positions and their number should be carefully chosen as the resulting reverberation time will be merely the average of the results measured at different positions.

References

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