THE HARDWARE-SOFTWARE COMPLEX FOR MEASURING SOUND FIELD CHARACTERISTICS IN A ROOM AT THE FINAL STAGE OF THE ACOUSTIC EXAMINATION

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Abstract: In the article, the authors describe the hardware and software complex that allows to measure objective parameters of the sound field in the room at the final stage of the acoustic examination of the room. The methods for measuring and analyzing the parameters of speech and musical clarity, the indicators of space, and reverberation time are described.

Key-Words: room acoustics, acoustic examination, hardware-software complex, sound field characteristics.

1. Introduction

In order to create the optimal acoustic conditions for listening to musical and speech material in the rooms of auditoriums and in specialized rooms (auditoriums, studio rooms, press centers, etc.), an acoustic examination of architectural and construction solutions is conducted. However, the tasks of the acoustic expertise are not only the development of the recommendations for optimizing the sound field on the basis of wave, statistical and geometric theories of sound propagation in the room, but also an assessment of the objective characteristics of the sound field after all the construction and finishing works [1].

To obtain the characteristics of the sound field in the room, the authors suggest the use of a hardware-software complex based on the EASERA 1.1.3 software product.

2. Main part

Acoustic properties of the room are determined by the following factors:

- the volume and the shape of the room;
- the number and the availability of the public;
- the sizes, shape, construction of the enclosing surfaces;
- materials used for finishing the surface of the room and distributing them on the surfaces of the room.

All listed acoustic properties, more-less, are interrelated with the objective and subjective criteria's of room acoustics, estimation such as: the early decay time; the standard reverberation time; the subjective time of reverberation, boisterousness-vitality; the spatiality; the distinctness, clarity of speech and musical material; the intelligibility of speech and musical material; the volume; the heat [1]. The measurements of the characteristics of the existing sound field are carried out using the hardware-software complex shown in Fig. 1.

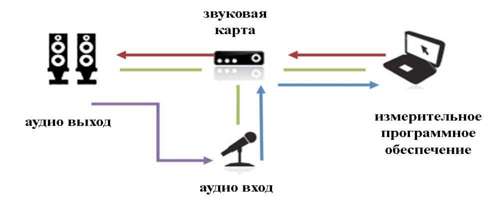


Fig. 1. Scheme of the hardware-software complex

The complex includes: a measuring software (EASERA 1.1.3), a sound card, an audio output and audio input. The audio signal, which is generated by EASERA 1.1.3, is fed to the audio output, in which the loudspeaker is used. The result of the room response is obtained using a measuring microphone and a sound card. The received signal is processed by EASERA 1.1.3.

The total measurement methodology includes several stages [2].

1. The preparatory stage. It includes the selection of measuring channels, the calibration (Fig. 2) of the inputs and outputs. This stage is carried out for the performance of the first work, if necessary, is repeated for other works. At the preparatory stage, the volume levels are also regulated to ensure safety when carrying out the work.

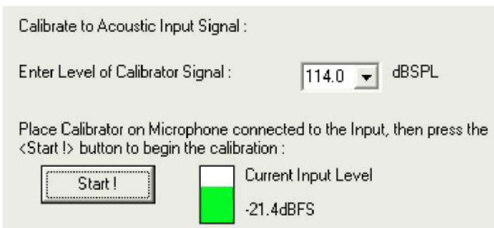


Fig. 2. Microphone Input Calibration Window

2. The measuring stage. This step is represented by the selection of the test signals for measurements. They include standard software signals, such as pink and white noises, frequency-modulated and sinusoidal signals. It is possible to use speech and music samples as a test signal. The measurement involves directly selecting the required parameter as the measured quantity, determining the number of test signals and the degree of averaging of the results (Fig. 3).

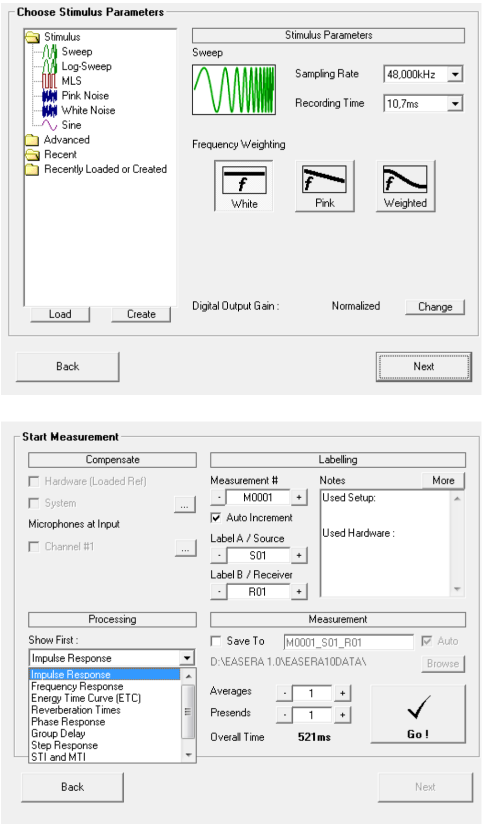


Fig. 3. The window for selecting the test signal and the measured parameters

3. The final stage. It consists of obtaining graphical dependencies of measured values, processing and analysis of the measurement results (Fig. 4).

The use of the hardware and software complex makes it possible to obtain the following quantitative characteristics of the sound field.

1. The reverberation time T_{10}, T_{20} and T_{30}, the early decay time EDT and the coefficient of BR.

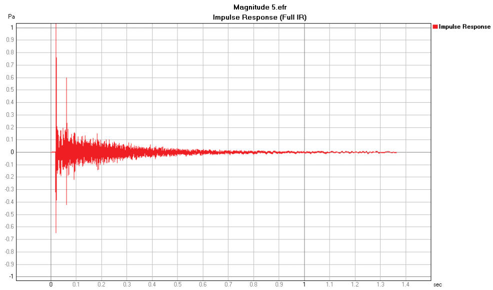


Fig. 4. Graphical representation of pulse impulse response measurement

To measure the EDT and the reverberation time, a response to the impulse in the room is used. Since it is difficult in real world conditions to reach the required dynamic range of 60 dB to obtain the standard reverberation time (T_{60}), the reverberation time is defined as the attenuation of the sound pressure level in the range from -5 dB to -35 dB and is called T_{30}. The initial reverberation time (IRT, T_{15}, between -5 dB and -20 dB) and the early decay time (EDT, T_{10}, between 0 dB and -10 dB) are more consistent with the subjective evaluation of the reverberation time, especially in low-volumes. EASERA calculates the reverberation time T_{10}, T_{20}, T_{30} in a frequency-weighted form.

A series of pulses is used as a test signal. According to the results of impulse response processing, a low tone coefficient (CST) the meaning of which is subjectively perceived as "warmth" or "sonority of basses" is calculated.

$$BR = \frac{T_{20,125} + T_{20,250}}{T_{20,500} + T_{20,1000}} = \frac{T_{20,НЧ}}{T_{20,СЧ}}, \qquad (1)$$

where $T_{20,x}$ - is the reverberation time T_{20} at the corresponding x-octave frequency.

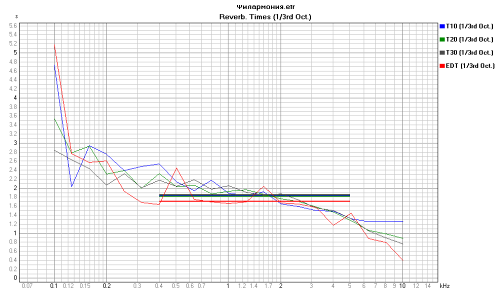
The results of general parameters of assessing the quality of the acoustics of the halls obtained by the hardware-software complex according to the developed method are shown in Fig.5.

2. According to the impulse response of the room, the values of musical (C_{80}) and speech clarity (C_{50}) are obtained, as well as the clarity of the direct sound (C_7).

The indicator C_7 is a criterion of the subjective perception of proximity or immediacy of sound sources (singers, orchestra, soloists).

$$C_7 = 10 \log_{10}\left(\frac{E_7}{E_\infty - E_7}\right) \qquad (2)$$

The C_{50} index estimates the clarity of the speech material.



Reverb. Times (1/3rd Oct.) Филармония.efr : Measures

	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	000 Hz	250 Hz	600 Hz	000 Hz	500 Hz	150 Hz	000 Hz	000 Hz	300 Hz	000 Hz	000 Hz	z-2kHz	z-4kHz
	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
EDT (1/3rd Oct.)	5,18	2,76	2,57	2,60	1,93	1,68	1,64	2,45	1,75	1,70	1,66	1,70	2,04	1,67	1,65	1,57	1,18	1,45	0,88	0,79	0,38	1,87	1,70
T10 (1/3rd Oct.)	4,73	2,03	2,94	2,75	2,39	2,47	2,53	2,14	1,95	2,18	1,89	1,84	1,91	1,65	1,59	1,50	1,49	1,32	1,25	1,25	1,26	2,11	1,83
T20 (1/3rd Oct.)	3,53	2,78	2,93	2,32	2,39	2,00	2,32	2,03	2,07	1,87	1,93	1,97	1,86	1,76	1,70	1,58	1,47	1,27	1,06	0,99	0,88	2,02	1,82
T30 (1/3rd Oct.)	2,84	2,63	2,43	2,06	2,32	2,01	2,17	2,04	2,18	1,97	2,05	1,90	1,83	1,87	1,74	1,56	1,50	1,32	1,05	0,89	0,76	2,01	1,85

Fig. 5. Measurement results EDT, T_{10}, T_{20}, T_{30}

$$C_{50} = 10 \log_{10}\left(\frac{E_{50}}{E_{\infty} - E_{50}}\right), \qquad (3)$$

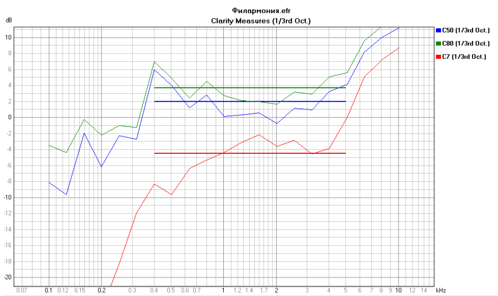
If the C_{50} is <-2 dB, it helps to avoid a decrease in the clarity of the syllable below 80%.

The clarity indicator C_{80} is important for assessing the clarity of musical works, especially for fast musical excerpts.

C_{80} is calculated

$$C_{80} = 10 \log_{10}\left(\frac{E_{80}}{E_{\infty} - E_{80}}\right). \qquad (4)$$

The example of the obtained measurement results is shown in Fig.6.



Clarity Measures (1/3rd Oct.) Филармония.efr : Measures

	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	000 Hz	250 Hz	600 Hz	000 Hz	500 Hz	150 Hz	000 Hz	000 Hz	300 Hz	000 Hz	000 Hz	z-2kHz	z-4kHz
	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB
C7 (1/3rd Oct.)	-30,6	-25,2	-25,3	-24,1	-18,3	-11,9	-8,3	-9,6	-6,4	-5,3	-4,3	-3,1	-2,2	-3,6	-2,8	-4,6	-3,9	0,0	5,1	7,2	8,8	-8,3	-4,5
C50 (1/3rd Oct.)	-8,1	-9,6	-1,9	-6,2	-2,3	-2,7	6,0	4,0	1,2	2,8	0,1	0,3	0,6	-0,8	1,2	0,9	3,2	4,2	8,2	10,0	11,3	0,4	2,0
C80 (1/3rd Oct.)	-3,5	-4,4	-0,3	-2,2	-1,0	-1,3	7,0	4,9	2,4	4,5	2,8	2,1	2,0	1,7	3,2	2,9	5,1	5,6	9,6	11,5	12,6	2,2	3,7

Fig. 6. Measurement results C_7, C_{50}, C_{80}

3. To assess intelligibility, the following criteria are obtained and analyzed: the articulation index - AI (articulation Index); the percentage of articulatory loss of consonants -% ALcons (percentage Articulation Loss of Consonants); the speech transmission index is STI (speech transmission index); the rapid speech transmission index - RASTI (rapid speech transmission index); the index of speech intelligibility - SII (speech intelligibility index).

In Easera, the measurement of intelligibility is based on obtaining a modulation transfer function. With this software package, you can get a graphical view of MTF, as well as numerical values of Alcons, STI, RaSTI. Alcons values are combined by a rating scale to assess the verbal speech clarity (Table 1).

Table 1. Distribution of the results of speech clarity

Al_{cons}	Evaluation of speech clarity
≤ 3%	ideal
= 3%	very good
= 8%	good
≥ 11% to 20%	bad
>20%	useless (limit value of 15%)

The limits change of STI to ensure good intelligibility, especially important for the audience, are 0.6 ... 1.0.

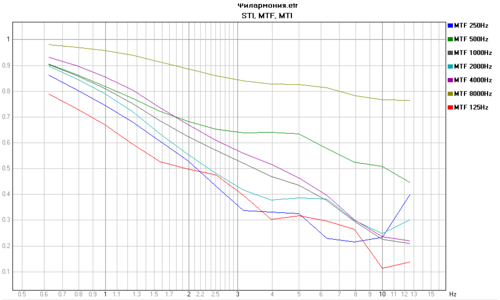
Based on a comparison of the results of the subjective experiments with the maximum possible clarity of syllables of 96%, the RASTI values are classified in subjective estimates for syllabic clarity according to Table 2.

Table 2. Correspondence of syllabic clarity to values RASTI

Syllable clarity	RASTI
poor	0-0.3
satisfactory	0.3-0.45
good	0.45-0.6
very good	0.6-0.75
excellent	0.75-1

The obtained measurement results are shown in Fig.7.

4. Spatiality, as a subjective criterion of room acoustics, consists of two components: "wrapping" sound (sinking) - LEV and "apparent widening of the source of a sound" - ASW. Wrapping is associated with the diffusion of the sound field after 80 ms, and the apparent expansion of the sound source - with the level of the early lateral reflections. To analyze the spatial components obtained by the hardware-software complex, measurements are made: the lateral efficiency LE (the ratio of lateral energy in the range from 25 to 80 ms to the sound energy coming from all sides in the range from 0 to 80 ms); the side lateral efficiency LEM, the proportion of lateral reflections



STI, MTF, MTI	Филармония.efr : Measures						
	MTF 125Hz	MTF 250Hz	MTF 500Hz	MTF 1000Hz	MTF 2000Hz	MTF 4000Hz	MTF 8000Hz
0,63 Hz	0,789	0,862	0,904	0,903	0,897	0,932	0,981
0,8 Hz	0,732	0,806	0,865	0,861	0,849	0,899	0,971
1 Hz	0,672	0,746	0,820	0,811	0,791	0,857	0,958
1,25 Hz	0,595	0,681	0,772	0,753	0,721	0,805	0,940
1,6 Hz	0,527	0,606	0,722	0,685	0,635	0,737	0,914
2 Hz	0,499	0,531	0,683	0,625	0,555	0,671	0,887
2,5 Hz	0,476	0,432	0,654	0,572	0,481	0,609	0,861
3,15 Hz	0,397	0,338	0,638	0,520	0,417	0,559	0,840
4 Hz	0,304	0,332	0,641	0,469	0,378	0,517	0,829
5 Hz	0,316	0,325	0,635	0,434	0,386	0,464	0,826
6,3 Hz	0,298	0,230	0,578	0,375	0,381	0,397	0,814
8 Hz	0,264	0,216	0,525	0,294	0,299	0,300	0,784
10 Hz	0,113	0,234	0,509	0,225	0,247	0,236	0,767
12,5 Hz	0,139	0,400	0,445	0,209	0,302	0,220	0,766
MTI	0,455	0,492	0,615	0,541	0,524	0,569	0,799
STI	0,569						
AlCons [%]	7,827						
STI (Male)	0,580						
STI (Female)	0,590						
RaSTI	0,569						
Equiv. STIPa (Male)	0,586						
Equiv. STIPa (Female)	0,599						

Fig. 7. Results of measurements of intelligibility

LF and the level of lateral reflections (LFM):

$$LF = \frac{E_{80\,Bl} - E_{5\,Bl}}{E_{80}}, \qquad (5)$$

where E_{xBl} – is the sound energy component measured by a bi-directional (in the form of 8-ki) microphone (a gradient microphone).

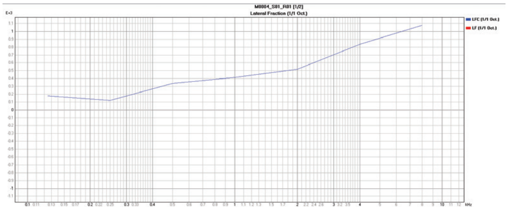
An example of the obtained measurement results is shown in Fig. 8.

The quantitative estimates of the sound field characteristics obtained with the help of the proposed complex make it possible to make a comparative analysis with the results of modeling the acoustic conditions in the room under study, obtained in the third stage of acoustic examination in the Ease 4.3 software package [3-5].

3.Conclusions

The authors consider the application of a hardware-software system for measuring the criteria for estimating the sound field in a room as the final stage of acoustic examination. The approbation of the measurement methodology was carried out on the basis of the project documentation for the already existing halls of Ukraine and the near abroad, for which the recommendations of the acoustic expertise were taken into account when carrying out construction and finishing works.

Currently, the authors are developing a methodology for conducting the measurements using the



Lateral Fraction (1/1 Oct.)	M0004_S01_R01 [1/2] : Measures						
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
LF (1/1 Oct.)	99370,7	36895,3	255981	461066	631718	1776431	3113456
IACC Late (1/1 Oct.)	0,206	0,799	0,996	0,997	0,998	0,999	0,999
IACC Full (1/1 Oct.)	0,208	0,800	0,996	0,997	0,998	0,999	0,999
IACC Early (1/1 Oct.)	0,411	0,865	0,997	0,998	0,998	0,998	0,999
Average	24842,9	9224,44	63996,1	115267	157930	444108	778365
Std. Dev.	43028,7	15975,8	110843	199647	273542	769217	1348165
Maximum	99370,7	36895,3	255981	461066	631718	1776431	3113456
Minimum	0,206	0,799	0,996	0,997	0,998	0,998	0,999

Fig. 8. Results of measurements of the lateral share LF

complex to evaluate additional criteria for a room acoustics (obtaining and analyzing the structures of the reverberation process at the spectator place) and adjusting the sound reinforcement system.

4. References

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