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TESTING A NEW LISTENING-ROOM

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New listening-rooms purposely designed and built are relatively seldom described in the literature, nevertheless problems arise especially when assessing their acoustic quality. Such problems are considered on the example of a new listening-room of the Acoustic Laboratory at the Aalborg University in Denmark. Results of the measurements and testing are discussed and some more general conclusions presented.

Nowe pomieszczenia odsłuchowe są stosunkowo rzadko opisywane w literaturze. Problemy związane z oceną ich jakości akustycznej rozpatrzono na przykładzie nowego pomieszczenia odsłuchowego Laboratorium Akustyki na Uniwersytecie w Aalborgu, w Danii. Przedyskutowano wyniki pomiarów i badań testowych oraz przedstawiono bardziej ogólne wnioski.

1. Introduction

Necessity of a high quality listening-room for all professional recording activities is still not sufficiently understood. Sound-engineers mostly listen to their recordings in their control-rooms only. However, many control-rooms in existing studios are either too small in volume or otherwise acoustically defective so that a rigorous assessment of the recordings quality can not be attained therewith. Moreover such an assessment ought very often to be performed by several people simultaneously, among them e.g. a composer, an arranger, a conductor, a producer, a sound-engineer

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etc., while usual control-room can not afford so many seats appropriately situated acoustically.

So, purposely built and equipped listening-room became an unavoidable facility in every bigger professional recording centre, first of all at productional broadcasting-studios. Similar facilities are also needed for other purposes e.g. for psycho-physiological research, for various kinds of subjective aural testing etc., as well as for didactic aims.

However, with growing number of nowly built and rebuilt control- or listening-rooms, an important question arises how to test the quality of such rooms. The question will be here partially answered on example of testing a listening-room at the newly built Acoustic Laboratory in the Institute of Electronic Systems of the Aalborg University Centre in North Jutland, Denmark.

The listening-room has been acoustically designed by JORGEN PEDERSEN from the Scandinavisk Lydteknik, Aalborg [11], together with other special rooms of the Acoustic Laboratory, such as an anechoic-room, a reverberant-chamber, an audiometric-room, an infrasound-booth, etc. subsided by several appropriate control-rooms. The designs were based on assumptions prepared by scientific staff of the Laboratory, in accordance to recommendations mentioned beneath.

2. Objective criteria of the listening-room quality

The objective criteria, selected among more general ones concerning acoustical quality of rooms, are, first of all, contained in various recommendations edited by appropriate national or international bodies, e.g. the Scandinavian Broadcasting Corporations [20, 21], the International Electrotechnical Commission [19], Organisation Internationale de la Radio et Télévision [16, 17], Deutsche Industrie Normen [18], etc. The recommendations quote typical parameters relevant for the listening-room quality, show desirable ranges of those parameters values, and formulate some additional requirements. The particular parameters values being generally well known they will be not repeated here. Besides they were broadly discussed in many earlier [21, 25] and recent publications [3, 10, 12].

On the other hand, it might be argued that the notion of acoustical quality has not been, so far, defined and that it is frequently employed in discrepant meanings. However, such considerations are beyond the scope of this article.

The mentioned parameters and requirement neither exhaust all possible variations of the conceptual design of listening-rooms, nor preconize any important details influencing their acoustical quality. Besides, as design rules for listening-rooms are far from being stable, so variable trends may be observed actually [7, 9] and more so, when many aspects of acoustical quality of rooms are being revised and discussed again [13, 14, 15].

At any rate some of the objective criteria are unquestionable and thus the

following general requirements ought to be fulfilled for any high quality listening-room:

1) Sufficient volume of the room.
2) Appropriate shape and dimensions.
3) Optimum reverberation time characteristics.
4) Necessary outfitting.

Ad 1) The preferred volume is to be about 80 cu.m [18]. However, lower values, starting from 43 cu.m, are also recommended [5, 12, 19], while much higher ones are mostly required [16, 17, 21], going up to 150 cu.m.

Ad 2) Although irregular shapes are not excluded, the main concept remains to be a parallelepipedly shaped room.

Its length to height and width to height ratios should be different and far from integer values. Recommended ratios are [17, 21]: length/height < 1.9 or $2.1 <$ $<$ length/height and width/height $= 1.25$ to 1.45. Elsewhere, recommended dimensions are given directly [12, 19]: length $= 6.7$ m, width $= 4.2$ m, height $= 2.8$ m.

Ad 3) Recommended values of reverberation time versus frequency are fairly discrepant which is depicted in Fig. 1.

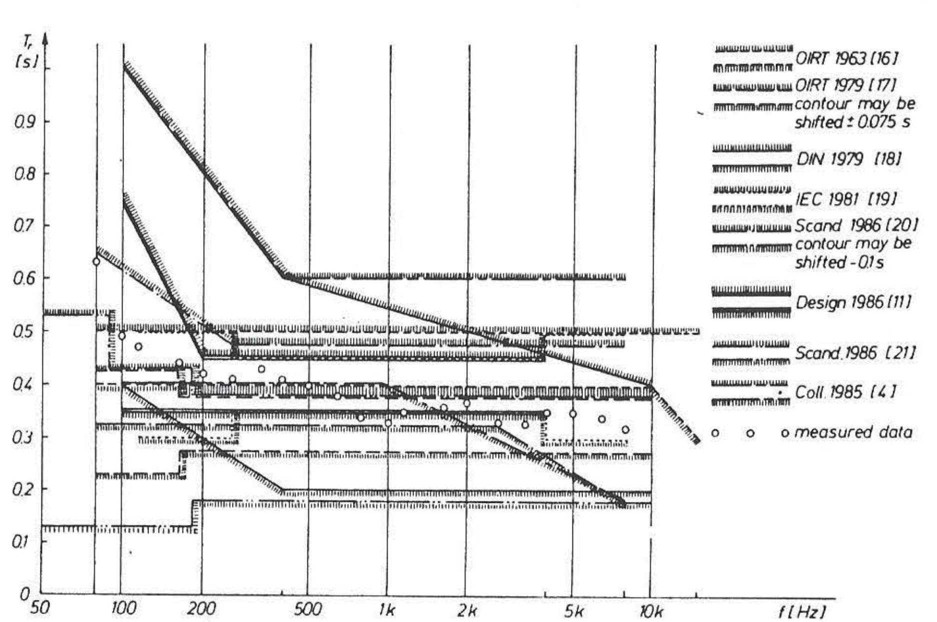


FIG. 1. Comparison of tolerances for optimum reverberation characteristics, drawn along various recommendations; the values measured in the tested room are superimposed, marked with circles. NB: The diagram seems to be unintelligible at a first glance; however, it shows how the recommendations disagree or contradict

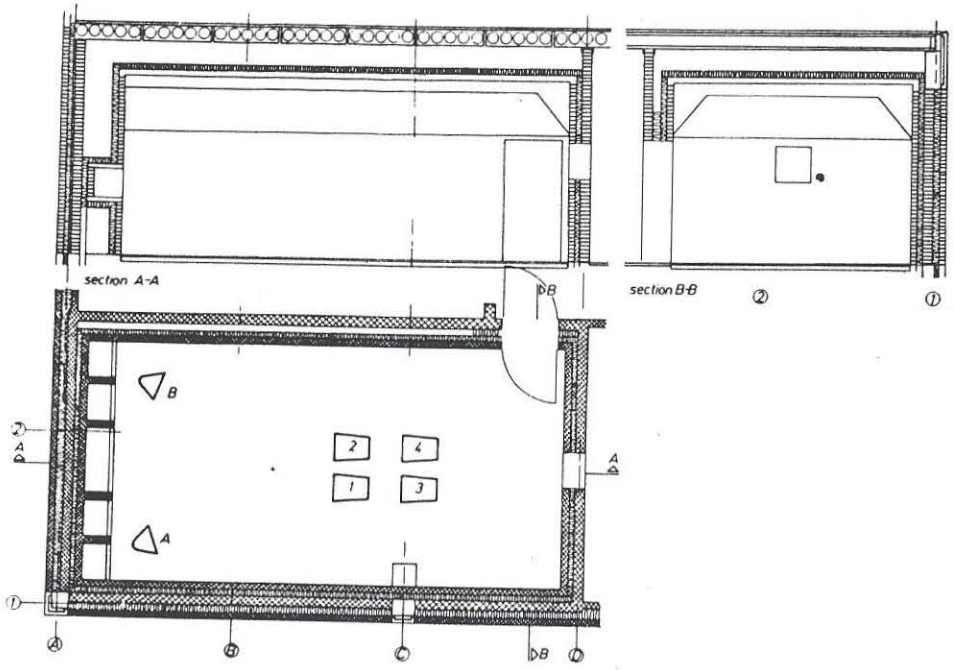


FIG. 2. Listening-room shape and dimensions. Superimposed are loudspeaker positions A and B, and seat positions No. 1, 2, 3, and 4

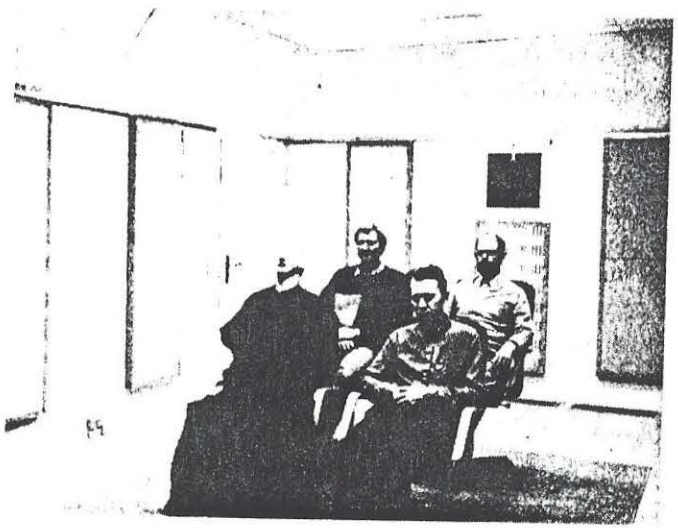


FIG. 3. Listening-room as seen from the left loudspeaker position. The seat No. 2 is occupied by a B and K artificial head- and torso-simulator in a dressing

Taking into account the angle-cut-volume between the ceiling and three walls, which has to be subtracted from the brutto volume, it makes the real volume of the room equal to 85,5 cubic metres. The relative dimension ratios are:

$$\text{lenght/height} = 7.80/2.77 = 2.8 \quad > 2.1$$
$$\text{width/height} = 4.12/2.77 = 1.49 > 1.45(!).$$

The above ratios exceed the majority of recommended ones (see Section 2). However, augmenting the room volume by increasing its height was impossible due to architectural limitation. From the three-meter standard height of the room the 23 cm were to be devoted to a false ceiling construction necessary to improve sound insulation, mainly against impact noise coming from the rooms above.

It may be added here that other recommendations advise for medium size rooms, i.e. of about 80 cu.m volume, the higher ratios: the length/height = 2.5 and width/height ≐ 1.6 [4] being closer to the measured above.

The angle-cut-volume, visible on Fig. 2 and 3, causes not only additional reflecting surfaces but, being separed from the room with elastic partition-panels, it acts as low-frequency absorber, which diminishes low-frequency reverberation time. This influence is mentioned beneath.

4.2. Objective results

The following parameter values were obtained from measurements:

Mean reverberation time T60 = 0.47 s;
Mean reverberation time T30 = 0.35 s;
Mean early-decay-time T10 = 0.34 s;

The frequency characteristics showing the results of reverberation measurements is depicted in Fig. 1, where it is superimposed on various contours of tolerances concerning such characteristics. The measured results can not satisfy all requirements at the same time because they are contradictory to each other. However, the measured curve fits rather well to the designed one [11], except few points in the vicinity of 1 and 3 kHz (see Sect. 5), and is in good agreement with recent recommendations [18, 20]. The presented measurements have been done with the use of B and K Precision Sound Level Meter, type 2231+1625+BZ 7104. The results, however, turned out to be strongly dependent on measurement conditions and methods, which is discussed in Sect. 5 in context of various additional measurements executed in the listening-room.

The further parameters values were processed with the use of a personal computer with appropriate software program, basing on a recorded sound impulse described above. The following parameters were evaluated:

Distinctness "Deutlichkeitsgrad" D = 85%;
"Schwerpunktzeit" t = 30 ms;
Clarity ("Klarheitmass") C80 = 14 dB;

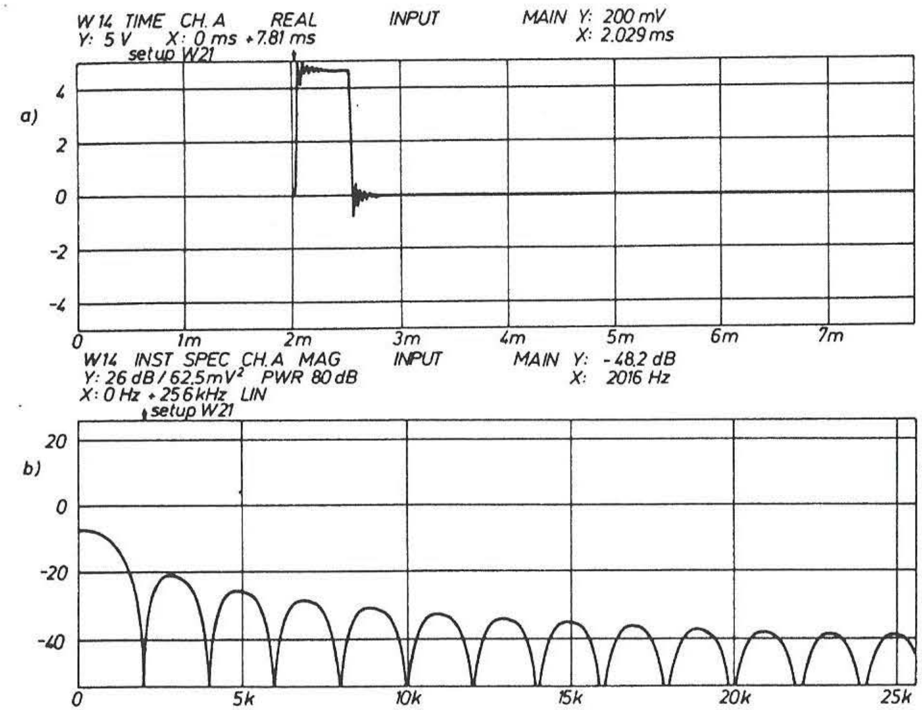


FIG. 4. An electrical excitation impulse measured at the generator output: a) time function, b) its spectrum

Furthermore, time-characteristics or reflectograms of the room were measured by means of an artificial head B and K type 4128 + 2812 (Head- and Torso-Simulator) and a two-channel digital analyzer B and K 2032, with a Hewlett Packard 7475A Plotter. The room was excited by triggered impulses produced by a digital generator Philips type PM 5193. Impulse duration was 0.6 ms, see Fig. 4. Those impulses were fed through a B and K power-amplifier to the pair of VIFA dynamic loudspeakers, type MD 10-39. A sound impulse radiated from such loudspeaker and recorded in an anechoic room is depicted in Fig. 5. The impulse shape and its spectrum show that the room was adequately excited. An example of reflectogram taken in the listening-room is shown in Fig. 6. Such reflectograms were made for four positions of the artificial head at each of the four seats within the room, visible in Fig. 2 and 3. A study of those reflectograms permits to appreciate the share of delay-specified groups of reflections on the envelope of perceived sound, depending on the listeners' seats. It allows also to observe the influence of minor changes in positioning of loudspeakers or listeners' seats, the result of an introduction of some reflecting surfaces within the listening-room etc.

FIG. 6. A reflectogram (echogram) of a sound impulse from the left loudspeaker (A), received by a B and K artificial head situated in the seat No. 1

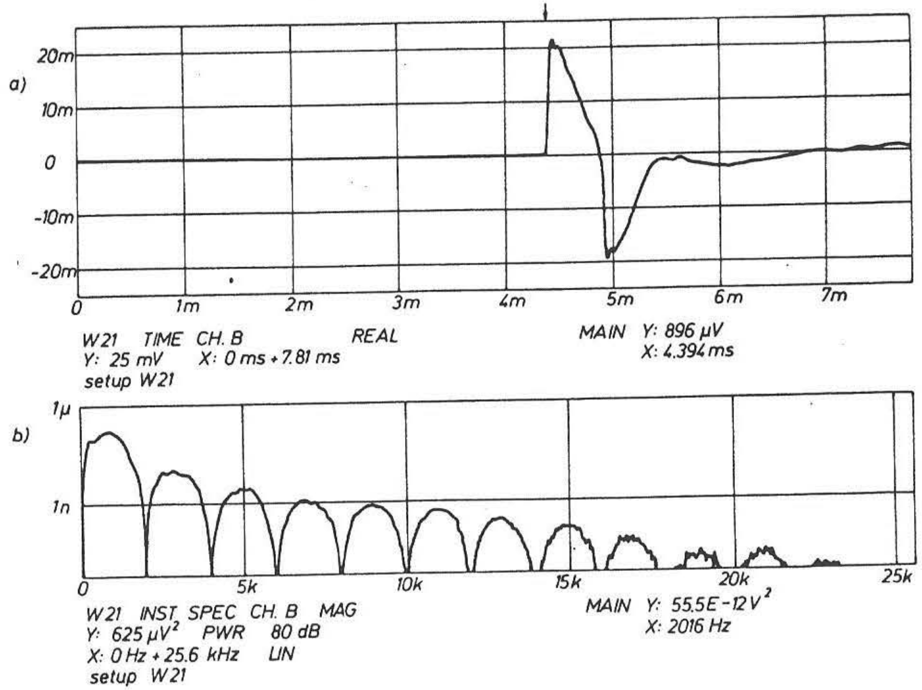
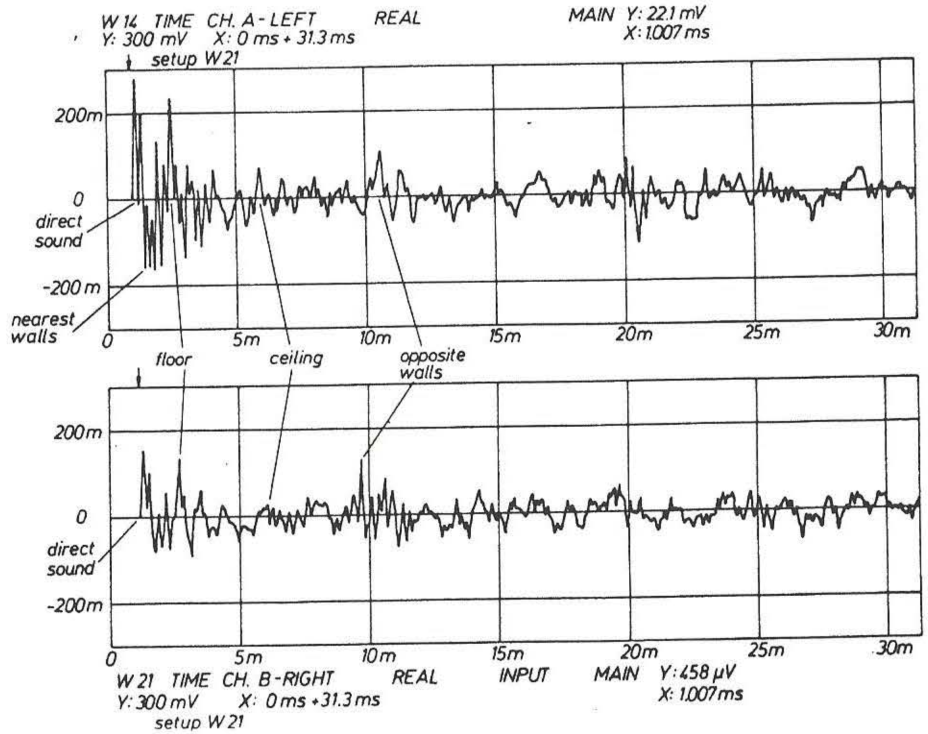


FIG. 5. A sound impulse radiated from the employed loudspeaker, measured in an anechoic-room: a) time function b) its spectrum. NB: The choice of loudspeaker type influences the degree of correspondence of the functions shown in Fig. 4 and Fig. 5, a) and b) respectively



4.3. Subjective tests

In contrast to the objective measurements, where closed VIFA boxes containing a single dynamic driver MD 10-39 were used, a pair of high quality KEF – Reference Model 107 – three-way loudspeakers has been installed for the subjctive tests. Cabinets were positioned so, as it is shown in Fig. 7, according to appropriate

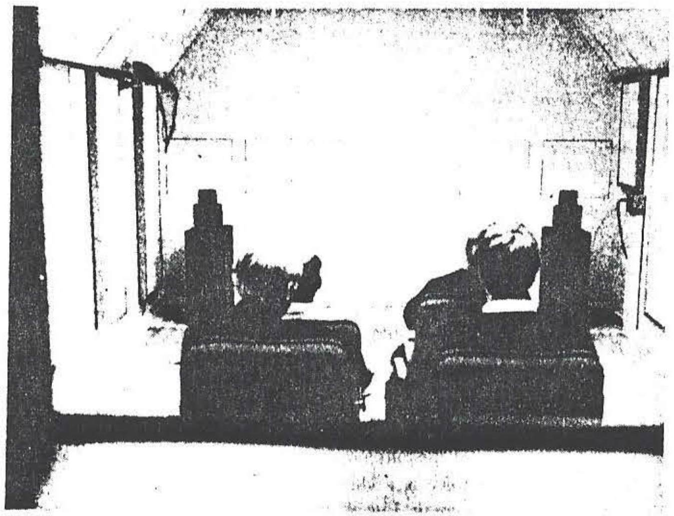


FIG. 7. The listening-room as seen from the control-room through the control-window

recommendations, i.e. spaced 0.7 m from side-walls and 0.8 m from the rear wall, with main acoustical axis elevated 1.25 m above floor and directed to the centre of listeners' seats.

The group of test-persons composed of twelve acousticians included eight persons from the Acoustics Laboratory of the Aalborg University and four persons from the Sound Engineering Department of Gdańsk Technical University.

The test program has been selected among available CD-discs containing various kinds of music. Five examples have been chosen, each lasting about two minutes. The selected examples are specified (see **Appendix**).

A special technique of answering during tests was introduced. A slide potentiometer with stepless linear scale was installed at every listener's seat, what allowed to the listener to express his mark concerning the tested example. As all potentiometers were branched in series so direct readings made with an ohmmeter represented mean assessments of the listeners' group for every consecutive part of the test. The ohmmeter scale may be divided for any number of steps suitable to employed marks. For the reported test a four mark scale was applied (very good, good, sufficient, unsufficient).

The described technique fits well for cases of small groups of listeners, treated as experts, where all answers are equally meaningful and where statistical averaging of individual answers is dispensable. Main advantages of the technique are: immediate test answers needing no written forms, and steplessness of the scale, which may be arbitrally divided. Necessity of a short period of listeners' entrainment to that technique may be considered as a certain disadvantage.

Performed tests showed that the high quality of employed digital recordings and reproduction chain rendered irrelevant test questions concerning linear and non-linear distortions, interfering extraneous noise etc. The salient point of an assessment depends on the properties of a recording such as its clarity, transparency, frequency balance, spaciousness, possibility of localization of sound sources in the whole frequency range, etc. Distinguishing of such properties can be achieved only in an excellent or a very good listening-room.

Test question concerning e.g. the spaciousness of the tested program was answered with highest mark for the item No. 3 – Opera Chorus (see **Appendix**), while the highest localization of sources was attributed to the item 1 – Symphony Orchestra. No significant faults of the listening-room have been observed during the described test sessions.

4.4 Subsidiary features

Among additional advantages of the examined room its efficient connections to neighbouring control-rooms should be emphasized. First of all, a good direct insight from the control-room is allowed due to a control-window, see Fig. 7. Other kind of visual control is permitted due to a CCTV link composed of a camera, visible in the left front corner of the room, and a monitor in the control-room, see Fig. 8. The

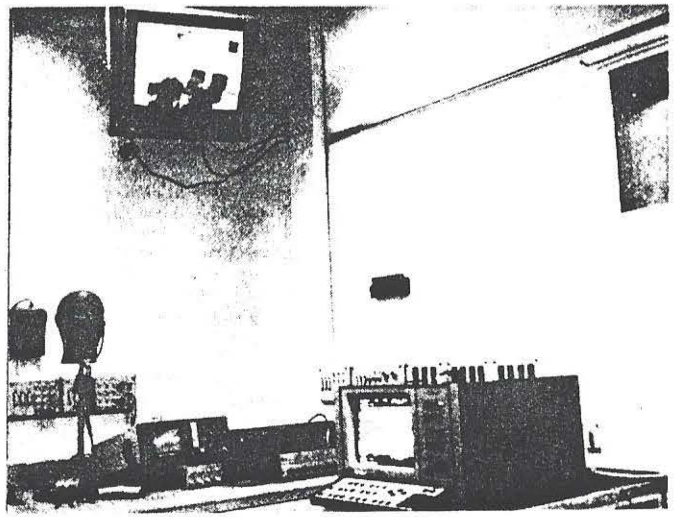


FIG. 8. Measuring equipment in the control-room

overview on the monitor, see Fig. 9, showing listeners' faces, facilitates and accelerates the execution of tests.

Additional outfittings such as a curtain and carpets on floors are visible in Fig. 10.

Subjective opinions on the listening-room general quality were very high.

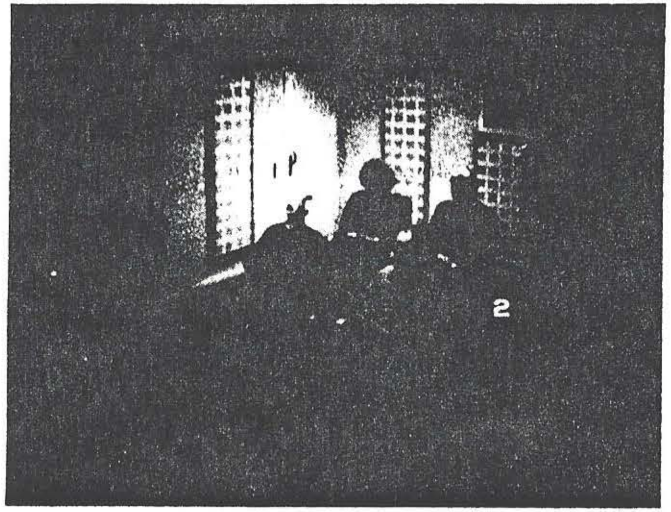


FIG. 9. The listeners observed on CCTV-monitor from the control-room

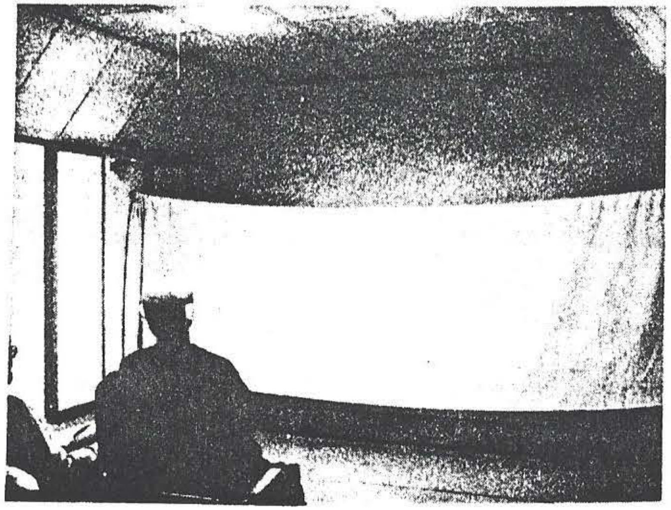


FIG. 10. Auxiliary outfitting of the listening-room: an opaque curtain, carpeted floor, markers from above showing exact listening positions, etc.

5. Discussion

As mentioned in Section 4.2, some of the objective results require further examination. First of all, the repeatibility of reverberation measurements and their dependence on employed equipment and measuring method. Besides of the results shown in Fig. 1, several other measurements have been done in the listening-room at the same or slightly altered conditions. All results are presented in Fig. 11. The

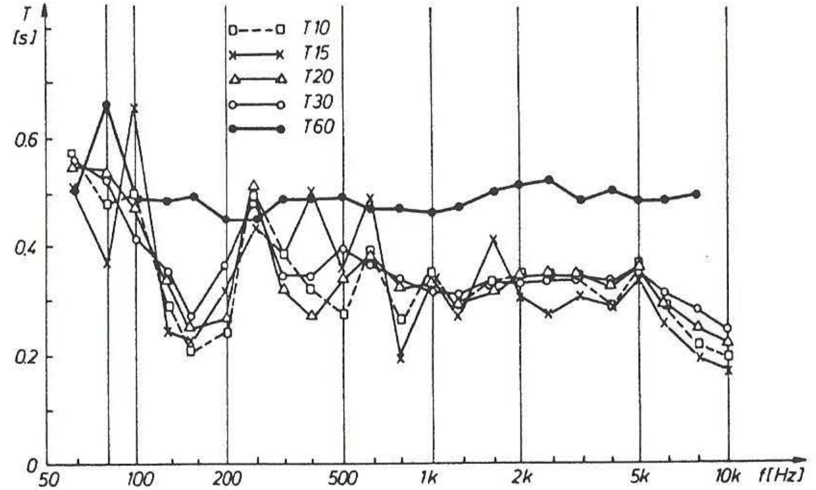


FIG. 11. Comparison of various reverberation characteristics of the listening-room

reverberation time values are processed in dependence on the analyzed portion of the sound-decays relative to 10, 15, 20 or 30 dB. An additional series of measurements has been done using a traditional evaluation of recorded decay-slopes within the 60 dB dynamic range, however, at pistol-shot room excitation.

An inspection of Fig. 11 permits to conclude that the measuring points for EDT marked T10, T15, T20 and even T30 curves are less smooth than the T60 reverberation curve. Most probably resonances within the excited room favour short lasting oscillations, which die quickly enough not to disturb the general rate of decays observed at T60 evaluation. It seems to argue for the use of T60 values rather than T30 as a characteristic parameter of the listening-room reverberation time.

For the lowest one-third octave bands of measurements i.e. 50 and 63 Hz ranges, the results are either inessential or dubious, because of stronger room resonances at lower frequencies. This observation is corroborated by subjective impressions at the listening of music tests. Some very low-pitch sound-sources, e.g. double-basses or kettle-drums seemed unlocalizable, their resonating sound as if filling the entire room volume uniformly.

It was already noticed that some points of the measured reverberation characteristics shown in Fig. 1, especially in the vicinity of 1 and 3 kHz, did not fulfill the requirements of the design. However, in the light of above discussion such small departures of the prescribed curve seem to be unimportant. Besides, some changes in the room outfitting are foreseen, among other connected with the installation of an additional pair of flush-mounted loudspeakers, which will permit to broaden the base-width for stereophonic reproduction and reduce the amount of very early reflected sounds. The booths provided for such loudspeakers are visible on the front wall of the room (see Fig. 2 and 7). Other minor corrections may also be undertaken, e.g. eventual repositioning of sound-absorbing and sound-reflecting panels visible on side- and rear-wall (see Fig. 3 and 7), based on detailed observation of impulse delays on appropriate reflectograms (cf. Fig. 6).

6. Conclusions

The acoustical quality of a listening-room as a link in a widely understood reproduction chain presents important yet underestimated problems concerning the proper designing and efficient testing of such rooms. Many recommendations intended to facilitate solutions of those problems have been issued so far, however, most of the problems remain open. Comparison of the recommendations shows some discrepancies and even contradictions in their subject-matter, especially concerning the demanded reverberation characteristics. The discrepancies stem from different subjective preferences dependent, first of all, on style of listened music. As only in some highly specialized production-studios and in attached listening-rooms a given style of music may exclusively be recorded and listened to, so, for all other listening-rooms, a reasonable compromise between extreme demands should be accepted. The investigated listening-room of the Aalborg University Centre may serve as a good example of the fulfillment of acceptable compromise demands.

A sensitive dependence of subjective reverberation measurements on an employed measuring method and a minor changes in position of a measuring microphone, as well as of objects within the room, has been demonstrated in practice. It emphasizes the need for a precise specification of requirements to examine the acoustical properties of small rooms, in contrast to medium and large rooms, where only averaged characteristics are taken into considerations.

The properties of a listening-room referred to a specified place within the room may be precisely described due to reflectograms obtained by the use of impulse measurements aided by the technique of two-channel digital analysis. This technique experimented on the investigated example may be, and should be developed in similar future investigations. It may be especially useful for creating conditions of repeatible listening situations for assessments of stereophonic sound images.

The method of reflectograms may be generally applied to proper positioning of loudspeakers and listeners' seats, as well as reflecting or absorbing panels within a room. Such panels existing within the examined listening-room might be optimally positioned depending on concurrently measured reflectograms. Some method facilitating the time-consuming trial-and-error searching for optimal position of every panel should be invented before. Referring to the necessity of precise positioning of the listeners' seats, some method of marking their localization in the room should be applied.

The comparison of results of various reverberation measurements, discussed in section 5, underlines the need of precise standards for such measurements. On the other hand, it may be commented as an argument against tendency to overall use of the extrapolated EDT and T30 values instead of traditional T60 values measured in full dynamic range. While the former are most often in good agreement with subjective assessments of reverberation, masked usually in its late decay portion by ambient noise, the latter seem to be more realistic, especially in cases of high quality listening-rooms, where no masking ambient noise exists. The difference in defining reverberation-time values should be considered when preparing future recommendations for the measurements of listening-rooms properties.

The presented results convince that the new listening-room at the AUC is a well designed facility, ready to satisfy all demands concerning subjective assessments of sound quality, and thus, together with modern equipment for objective measuring of sound properties, will serve as an efficient tool for any analytical investigation on sound quality. Authors hope that this contribution will suit as a useful reference for acoustical designers or consultants, as well as for sound-engineers dealing in practice with listening-rooms problems.

7. Acknowledgement

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Authors gratefully appreciate participation of their colleagues of the Aalborg University Centre as well as colleagues from Gdańsk Technical University visiting Aalborg, who helped in the measurements and at preparing materials necessary for the presentation of results.

Appendix: List of recordings used as subjective test

1. G. MAHLER: *Symphony No. 7, Introduction* (*executed* by Frankfurt Symphony Orchestra, conduct. by E. Inbal) CD Denon Digital, No. 1553, 1986.
2. Fr. CHOPIN-MILSTEIN: *Nocturne C sharp minor* (played by Kyung Wha Chung, acc. by Ph. Moll) CD Decca, 1987.

3. C. M. v. WEBER: "*Viktoria, Viktoria*" (Opera Chorus) Deutsche Grammophon, Digital Recording, 1985.
4. J. BRAHMS: *Prelude from Op. 122* (played by Kurt Rapf on the Hammer Organ of the Jesus Christ Church in Berlin–Dahlem) Intercord, Digital Recording, 1985.
5. E. GARDNER: "*Misty*" Jazz – Verve Records, AAD.

(Every item, eventually faded out, lasted about 2 min.; the whole test was rerecorded on tape, using a noise reduction system Dolby C).

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PROBLEM OF ACOUSTICAL RELAXATION OF LUTIDINE 3–4

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In this paper the results of acoustical absorption measurements in frequency range from 300 kHz to 9 GHz for lutidine 3–4 are presented. An acoustical relaxation process in the low frequency range between 0.3–10 MHz was observed. The relaxation process which has been noticed can be explain as a phenomenon of association and dislocation of sandwich molecules.

W pracy przedstawiono wyniki pomiarów absorpcji akustycznej w 3–4 lutydynie w zakresie częstotliwości od 300 kHz do 9 GHz. Obserwowano proces relaksacji akustycznej w zakresie niskich częstotliwości od 0,3 do 10 MHz. Proces ten można wytłumaczyć jako zjawisko asocjacji i dysocjacji cząsteczek sandwiczowych.

1. Introduction and experimental setup

The ultrasound investigations in many organic liquids indicate that it is necessary to use a set-up which gives a possibility of acoustical absorption measurements in very wide frequency range to obtain the complete information about relaxation processes in such liquids. Usually it is rather difficult.

In this paper we present the ultrasound measurements performed by four different methods. They allowed to cover five decades of frequencies. The frequency range was divided into four intervals and the following methods were applied: 0.3 MHz-3 MHz – the statistical reverberation method [4], 10–180 MHz – the pulse method [10], 0.4–1.3 GHz – the pulse method using the lithium niobate crystal