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# ACOUSTIC STANDARDS FOR LISTENING ROOMS AND CONTROL ROOMS

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## 1. INTRODUCTION

The European Broadcasting Union (EBU) has, for many years, issued recommendations for the listening conditions appropriate for critical listening to audio material[1]. The main motivation and emphasis for the EBU has been the control of variation in listening conditions in order to facilitate programme exchange between members.

The International Telecommunications Union (ITU-R) (formerly CCIR) have also been involved for many years in the recommendation of high-quality listening conditions. It has recently become concerned with the assessment of new methods of sound coding and in the selection of a preferred system of sound coding. Such systems are, in principle, virtually transparent and require the most careful tests and data analysis to select what might be a world-wide standard for many years.

In the former eastern European countries, the OIRT had similar sets of standards. It has been part of the tasks of the EBU and the ITU groups to integrate these into the new recommendations.

The Audio Engineering Society (AES) and the International Electrotechnical Committtee (IEC) have also made recommendations or set standards for listening conditions. In both of these cases, the emphasis has been more on the assessment of equipment intended for domestic use. As a result, those requirements are much more like an idealised domestic room than are the EBU and the ITU recommendations.

This paper presents some of the arguments leading to various aspects of these standards and compares some of the parameters and their values.

## 2. THE NEED FOR STANDARDISATION

### 2.1 EBU

Programme makers within the EBU group frequently exchange material, either whole programmes or contributions. Disagreements over technical quality are also exchanged from time to time. Especially in the present more competitive commercial market-place, these disagreements may have financial implications. The need for agreed assessment standards is self-evident. By recommending standard conditions for the creation and evaluation of programmes, it is also hoped that the actual differences may be reduced and a more consistent view established of what constitute programme defects*.

*The EBU G1/LIST group is preparing demonstration material illustrating acoustic defects of various types. The recordings will probably become available in late 1994 or early 1995

## 2.2 ITU.

The ITU is more concerned with setting standards for technical equipment than the subjective assessment of individual recordings. In recent years, the advent of digital signal processing, especially low bitrate audio coding, has underlined the need for good control of many aspects of the assessment methodology.

A number of alternative bitrate reduction schemes have been proposed in the last few years. Each one of these is intended to be near-transparent, that is, to be virtually undetectable in use. Each one applies different coding schemes and produces different artifacts, at levels which are (in principle) almost undetectable. In order to choose the 'best' coding system, it is necessary to control as many aspects of the tests as possible. The acoustic environment of the listening room and the performance of the ancillary technical equipment, for example loudspeakers, can introduce variability which is orders of magnitude greater than the artifacts being assessed, although usually of a quite different character.

## 2.3 AES/IEC.

The AES and the IEC are also both concerned with the assessment of sound quality, at the limits of high quality audio engineering. However, with the emphasis on the assessment of commercial reproduction equipment, the optimum listening room has to represent a domestic environment, even if somewhat idealised. The same arguments for consistency still apply, because of the large acoustic artifacts introduced by any room.

The fields of application of the AES and IEC standards are so close that the two may be considered together. The two bodies are actively discussing the harmonisation of their standards, and have held joint meetings.

# 3. BASIC CONTROLLED PROPERTIES.

The subjective acoustic impression created by a programme or recording is more affected by the loudspeakers and the environment in which the listening is taking place than any other aspect, except, of course, the acoustic environment in which it was made. For the acoustic and the electro-acoustic aspects of the listening environment, the scope for the introduction of defects and artifacts is significant. Variations in some parameters, because of the room acoustics or the loudspeakers, may be several orders of magnitude greater than those which occur in purely electronic systems.

Unlike other technical aspects of a programme, which might be measured objectively by instrumentation of reasonably determinate accuracy, many of the technical aspects of the sound quality are also largely subjective. In the limit, the only valid measure of sound quality is the subjective assessement in the listening environment.

In the present state of the art, it is not expected that specifying and controlling such parameters that can be specified will lead to identical rooms and listening conditions. Rather, the intention of all of the standards' bodies is to reduce the total variability to the point at which it ceases to be such a dominant factor.

### 3.1 Low frequencies.

Most control rooms, listening rooms and small studios have dimensions that will become comparable with the wavelength of the sound at some frequency within the normally accepted audio range. The effects on the perceived frequency response of the modal behaviour of the sound within the room are well documented [2,3,4,5,6,7].

The overall response will be characterised by large peaks at frequencies close to the modal frequencies, with significant dips between. It will also be a strong function of position of both the listener and the sound source; both the coupling of the source to the room modes and the magnitude of the listener's perception of the mode will depend on the positions relative to the standing wave pressure distribution.

The irregularities are increased if the room proportions tend to cause the modes to cluster together. Rooms with the three principal dimensions related by simple integers are especially poor. It is, therefore, desirable to find room shapes that minimise any such groupings. Several so-called 'optimum' dimension ratios have been suggested in the past and are in fairly common use. In general, however, it is not possible to constrain room designs to a small set of preferred proportions because they are almost always unsuitable in other respects, for example in having insufficient floor area for the given height. It is also not practical to mandate the construction of new rooms to satisfy a particular standard.

### 3.2 Room reverberation time.

It is reasonably self-evident that the room reverberation time should be controlled. It is one acoustic parameter about which there is almost total concensus. Satisfactory rooms for any purpose are most unlikely to have reverberation times which differ too much from the common expectation. For critical listening and programme production the usual reverberation time is rather shorter than an average domestic room.

### 3.3 Loudspeakers - intrinsic performance.

Loudspeakers have a profound effect on the perception of sound quality. This is largely because loudspeakers depart from the ideal electro-acoustic performance by larger margins than any other part of the reproduction chain, except for the listening room itself. Restrictions of and irregularities in frequency response, high levels of distortion and erratic directionality characteristics are at least quantifiable. Colorations and resonances occur in significant proportion and are, essentially, purely subjective. There is little expectation that specifying objective parameters will result in a 'standard' loudspeaker.

### 3.4 Loudspeakers - in-situ responses.

When imperfect loudspeakers are placed in an imperfect room, the combination usually proves to be even more imperfect. Objectively, measurements can be carried out in the frequency domain or in the time domain or both and specifications can be set for the overall response. Because such responses are significantly position dependent, it is only practicable to apply the specification to relatively small listening zones.

### 3.5 Early reflections.

In any enclosed space, sound energy will be reflected from objects and surfaces to reach the listener by indirect routes. The disturbing effects of early reflections, that is those reaching the listener within about 20ms after the arrival of the direct sound, are well-known. Changes in timbre[8] and in image localisation[9] have been investigated.

### 3.6 Sound field control.

The principle of the approach to standardisation by the EBU and the ITU was to eliminate (as far as possible) specifications for the room itself. The majority of conditions refer to the properties of the sound field in the vicinity of the listener. Inevitably, some of the properties of the room have a direct bearing on that sound field.

### 3.7 Background noise level.

The need for control of the continuous background noise level is self-evident. Especially with the wide dynamic range possible with modern recording systems, low-level sounds and system artifacts could be masked by excessive incidental noise. However, the provision of very low acoustic noise levels from ventilation systems and technical equipment is expensive. It is also unnecessary to reduce noise levels to levels much below those created by the room occupants.

### 3.8 Listening level.

It is widely recognised that the absolute level of sound reproduction significantly affects the subjective impression and can also reveal (if excessively high) or hide (if too low) system artifacts. It was considered important, especially for the ITU equipment test methodology, that some absolute level reference was provided, even if the tests themselves permitted variations. Then, at least, the variations could be recorded as a known variable factor.

## 4. EBU/ITU RECOMMENDATIONS

Close liason, and a significant common membership on the drafting groups led to the EBU and the ITU harmonizing their recommendations almost completely.

## 4.1 Sound field parameters.

The principle controlled parameters, as far as possible, relate to the properties of the sound field in the vicinity of the listener. The main reason for this was an attempt to separate the factors affecting the sound quality directly from those arising from physical aspects of the room and so to avoid the specification of a standard room, which would be unnecessarily restrictive.

4.1.1 Direct sound. The quality of the direct sound arises purely from the on-axis response of the loudspeakers, without significant interference from the listening environment.

4.1.2 Early reflections. The audibility of isolated early reflections has been studied for many years. However, because of the complexity (multi-dimensionality) of the problem, little study of the effects of multiple reflections has been carried out. Some recent work[8, 10, 11] suggest that a time range of 15-20ms and relative levels of −10 to −20dB are adequate to make the effects of early reflections reasonably insignificant. A specification of −10dB/15ms was selected as reasonably representative figures. This means that sound travelling by an indirect path which has a relative time of arrival within 15ms of the direct sound should be at a level below −10dB relative to the level of the direct sound. The measurement method is not specified, but it is implicitly wideband. The difficulties (not to say the questionable meaning) of such measurements at lower frequencies is recognised.

4.1.3 Reverberant field. The reverberation time requirement is based on common practice, as represented by many of the members' organisations. A overall average figure of 0.2s to 0.4s is based on a room of $100m^3$, with allowances for different room volumes as:

$$T_m \approx 0.3\,(V/V_0)^{1/3}\ \ \mathrm{s}$$

where $T_m$ is the mean reverberation time, $V$ is the room volume and $V_0$ the reference room volume ($100m^3$)

The frequency-dependency of the reverberation time characteristic, measured in 1/3rd octave bands, should fall within the limits indicated in Fig. 1. In the middle frequency range (200Hz to 4000Hz) the permitted irregularities are ±0.05s. A progressive bass rise is permitted, as is a high-frequency fall.

4.1.4 Operational room response curve. The most important parameter affecting the tonal balance is the effective frequency response of the loudspeaker in the room, as perceived at the listening position. Some recent work[12] identified strong correlations between parts of the frequency spectrum and the perceived sound quality. This frequency response, as measured in 1/3rd octave bands, should meet the specification shown in Fig. 2. $L_m$ is the average value of the bands with centre frequencies from 200Hz to 16kHz (inclusive). It is recognised that the response may be difficult to achieve at low frequencies and that electrical equalisation might be needed, as a last resort.

4.1.5 Listening level. The reference listening level has been set at 85dBA, using pink noise as a test signal. This should be set for an input signal level equal to the "Alignment Signal Level" [13, 14]. For $n$ multiple loudspeakers, the reference level is reduced by $10\log(n)$ dB. The reference level is used only as a means to set the reference system gain and does not mean that all programme maximum levels are limited to 85dBA. It does mean that the intended listening level can be specified or adjusted by a known amount.

4.1.6 Background noise level. The need for a background noise level specification representing a compromise between cost and what is technically feasible is self-evident. Noise levels close to the threshold of hearing are desirable. Levels around 20dBA or NR 10 are usually economically justifiable in special facilities or in the highest quality control rooms. A specification given as a frequency spectrum offers closer control, although a single figure measurement is easier to make. Overall, both ITU and EBU committees had a preference for a spectral definition. With the withdrawal of the Noise Rating curves by ISO*, ITU TG10/3 took the decision to redefine those curves. The recommendations are for NR10. The ITU recommendation permits levels up to NR15 as a maximum.

4.2 Appendices.
Some of the parameters cannot be specified in terms of the sound field in the vicinity of the listener. These are physical properties of the room and are given as a guide to achieving the sound field parameters or are secondary controlled parameters.

4.2.1 Room geometry and loudspeaker arrangement. The creation and reproduction of multi-channel stereophonic programmes are based on predetermined geometrical layouts of the loudspeaker and listener positions. The recommendations set out reference listening arrangements, based on the usual triangular baseline for the two main front loudspeakers and the listening position.

4.2.2 Room dimensions. In order to accomodate a number of listeners and to ensure that loudspeakers and listeners are not too close to the walls, a listening room has to be reasonably large. Much greater difficulties are also encountered with low-frequency response irregularities in small rooms. The EBU-recommended minimum floor areas for reference listening rooms and high-quality sound control rooms are 40m$^2$ and 30m$^2$ respectively. The ITU recommendations are:

| | |
|---|---|
| 20 - 60 m$^2$ | for monophonic or two-channel stereophonic reproduction |
| 30 - 70 m$^2$ | for multi-channel stereophonic reproduction |

4.2.3 Room proportions. Simple, so-called "golden ratios" were considered too restrictive for the construction (or conversion) of rooms by a number of organisations. A study[13] was carried out which showed that, on average, a wide range of room proportions could give similar overall room

*The ISO NR curves officially ceased to exist with the 1982 revision of ISO-R1996.

mode distributions. The principle room dimensions should fall within the limits:

$$1.1\, l / w \quad \le \quad l / h \quad \le \quad 4.5\, w / h - 4$$

where $l$ and $w$ are the principle plan dimensions and $h$ is the room height.

This, however, is only a guide and it is still advisable that each room is considered individually for clustering of low-frequency room modes. The final response is also very dependent on the positions of sources and listener positions.

4.2.4 **Loudspeaker frequency response.** The loudspeaker, measured in an anechoic environment, should have reasonable characteristics. These are not principle requirements, but are given as guidance to the achievement of the main sound field characteristics without undue corrections having to be applied. It is recommended that the on-axis response of the loudspeakers, when measured in 1/3rd octave bands using pink noise, should fall within a 4dB tolerance band from 40Hz to 16kHz. Additional tolerances of ±3dB at ±10° and ±4 dB at ±30° are also recommended (±30° in the horizontal plane only).

4.2.5 **Loudspeaker directivity.** Loudspeaker directivity has a controlling effect on the ratio between the direct sound and the reverberant field. There is very little information on the effects of loudspeaker directivity on the perceived sound quality but it is reasonably clear that excessive directionality should be avoided. It is recommended that, over the frequency range 250Hz to 16kHz, the loudspeaker directivity, $D$, should fall within the limits

$$0 \le D \le 12 \text{ dB.}$$

The method of measurement is not specified.

4.2.6 **Loudspeaker distortion.** Loudspeaker distortion is stated in terms of the generation of harmonic frequencies. Other bases, such as intermodulation are still under consideration. Relative to an average sound pressure level of 90dBA, the harmonic components should not exceed

$$-30\text{dB } (3\%) \text{ for } 40\text{Hz} < f < 250\text{Hz}$$
$$-40\text{dB } (1\%) \text{ for } 250\text{Hz} < f < 16\text{kHz}$$

4.2.7 **Loudspeaker transient response.** Loudspeakers with in-built resonant systems, for example the port in a vented cabinet, may resonate for relatively long periods, causing audible transient effects. It is recommended that the decay time should be limited to

$$t_s \le 2.5 / f \qquad \text{(EBU)}$$
$$t_s \le 5 / f \qquad \text{(ITU)}$$

The decay time, $t_s$, is define as the time taken for the output to decay to $1/e$ (≈0.37) of its original value. (These are approximately equivalent to 'reverberation times' of $17/f$ and $35/f$ respectively.)

4.2.8 Loudspeaker dynamic range. The highest sound level which can be reproduced by a loudspeaker without damage, for a minimum of 10 minutes, is recommended to be at least 108dB. This should be assessed using simulated programme signal[16]. The measurement should be carried out at a distance of 1m using a sound level meter set to flat response, RMS (slow).

Under the same conditions, but without the test signal and with an A-weighted frequency response, the output noise level, due to electronic self generated noise, should be less than 10dBA.

4.2.9 Headphones. For headphone monitoring, the acoustic qualities of the room are almost irrelevant. For the headphones, the frequency response should meet the requirements of ITU-R Recommendation BS.708[17]. All other characteristics should meet the requirements of IEC-581, Part 10[18]

## 5. AES RECOMMENDED PRACTICE FOR SUBJECTIVE EVALUATION OF LOUDSPEAKERS.

The AES (draft) standard for loudspeaker evaluation is just that — it applies only to the subjective evaluation of loudspeakers. It therefore contains only specifications relating to the listening environment. Many of these are expressed in general, descriptive terms rather than as definite requirements.

### 5.1 Room size and shape.

The room "working area" must be more than $20m^2$. It is not clear whether this refers to the space available as a listening zone or the whole usable floor area.

### 5.2 Reverberation time.

The mid-band reverberation time must be $0.45 \pm 0.15$ s. A bass rise and a high frequency fall are permitted, as is a degree of dependency on room volume. All of these additional factors are unquantified.

### 5.3 Room modes.

No requirements for the distribution of low-frequency room modes are made. Instead, it is required that each room and loudspeaker arrangement is considered individually — a method is recommended for objectively obtaining the most regular response possible.

### 5.5 Background noise level.

The background noise level must not exceed 35 dBA.

### 5.6 Listening arrangement.

Reference listening arrangements, based on the usual triangular baseline for the main front loudspeakers and listening area are specified. Loudspeaker locations at least 1.0m from the room boundaries should be available, if the loudspeaker design requires the units to be positioned away from the boundaries.

## 6. REVISION OF IEC 268, Part 13: LISTENING TESTS ON LOUDSPEAKERS

### 6.1 Room dimensions.

Ranges are given for each of the principle room dimensions independently, with no proportions:

| | | | |
|---|---|---|---|
| Height | 2.80 | - | 3.00 m |
| Width | 4.20 | - | 4.70 m |
| Length | 6.70 | - | 7.45 m |
| Volume | 80 | - | 105 $m^3$ |

### 6.2 Reverberation time.

The average reverberation time over the frequency range 250Hz to 4000Hz must be 0.3 to 0.6s. Outside that frequency range, the reverberation time must not differ by more than 25% from the average value and should not exceed 0.8s at frequencies below 250Hz. No 1/3rd octave band value must differ from the adjacent bands by more than 10%. It is preferable to restrict the mid-band average to 0.35 to 0.4s.

Detailed recommendations are given on the disposition of the acoustic treatment on the room surfaces.

### 6.4 Loudspeaker position and orientation.

Recommendations are made for the placement of loudspeakers more than 1.0m from the side walls and within 0.2m of the front wall. This is intended to represent common domestic practice.

### 6.5 Listening levels.

The specified listening level is the "preferred level for the average listener". As a guide, this is stated to be close to the level which would have occurred at a typical listener position in a live performance.

## 7. COMPARISON OF STANDARDS.

### 7.1 Overall

The four recommendations/standards fall clearly into two groups. The EBU and the ITU are primarily concerned with the assessment of the sound itself, either as programme material or as tests on signal processing equipment. Thus, much of the reproduction equipment and especially the loudspeakers, are incidental to the main purpose. Criteria for them have to be included in the recommendations in order to reduce the number of uncontrolled variables.

In the case of the AES and the IEC standards, the loudspeakers are the subjects of the assessments. Thus, only the environment needs to be specified and controlled.

Even with that distinction there remain significant differences between the two groups of standards. These relate to the need, in the case of the EBU and the ITU, to provide highly analytical conditions in which many aspects of the sound quality can be assessed. In the case of the AES and the IEC, the objective is to assess the loudspeakers; the listening conditions need to be 'representative' of those in which the products might be used.

### 7.2 Harmonisation

A significant degree of harmonisation has already or is, at the time of writing, taking place between the EBU/ITU as one group and the IEC/AES as the second group. Because of the fundamentally different objectives, there is little prospect of harmonisation between all four groups. The EBU and the ITU recommendations are almost entirely harmonised, with one or two minor numerical differences.

For the AES and the IEC standards, the language used is significantly different. The AES draft, although presented as a standard, with words such as "shall" and "must" (and despite the use of the words "recommended practice" in the title), is largely descriptive. Very few definite values are given for the parameters. It is difficult (for this author) to see how significant harmonisation with the IEC draft could be achieved. This may, however, be a problem of the relatively early drafting stage.

## 8. CONCLUSIONS

A brief overview has been presented of four draft recommendations/standards relating to the acoustic design of listening rooms or sound control rooms. These can be divided into two groups — one relating to the assessment of overall sound quality of programmes, recordings or technical equipment and another relating to the assessment of the loudspeakers themselves.

Because of this division, the basic requirements of the two groups of recommendations/standards differ.

Between the individual members of the groups significant harmonisation has taken or is taking place.

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## ACOUSTIC STANDARDS FOR LISTENING ROOMS AND CONTROL ROOMS

### FOOTNOTE

The author has been involved with EBU drafting groups since 1982, working on successive versions of Recommendation R22. He is also a member of the ITU-R Task Group 10/3 (formerly CCIR TG10/3), working on the specification of listening conditions for the evaluation of systems with small impairments.

The views expressed in this Paper are those of the author only, as gathered from numerous meetings. They do not necessarily represent the views of every member of the Working Groups of the EBU, ITU, AES and IEC engaged in drafting recommendations and standards. Indeed, many of the members of those groups do not agree entirely with each other. The final recommendations are, inevitably, a concensus view.

The details given in this paper are not complete expressions of the respective recommendations and standards. Except for the EBU Recommendations, none of the proposals is, at the time of writing, formally ratified and all are still subject to changes. This is especially true of the AES and the IEC standards, which are still the subject of detailed drafting. The EBU proposal was ratified in August 1994 as Recommendation R22-1994. The accompanying Technical Document Tech. 3276 gives the details of the recommendations.

### ACKNOWLEDGMENT

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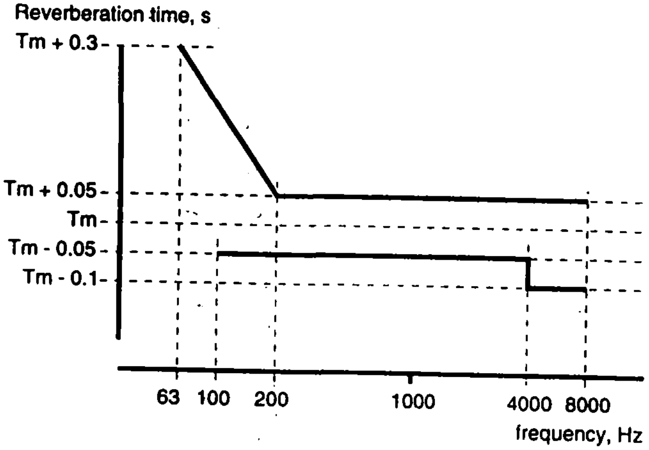
Fig. 1 EBU/ITU Tolerances for reverberation time ($T_m$ is the mean reverberation time over the frequency range 200Hz to 4000Hz).



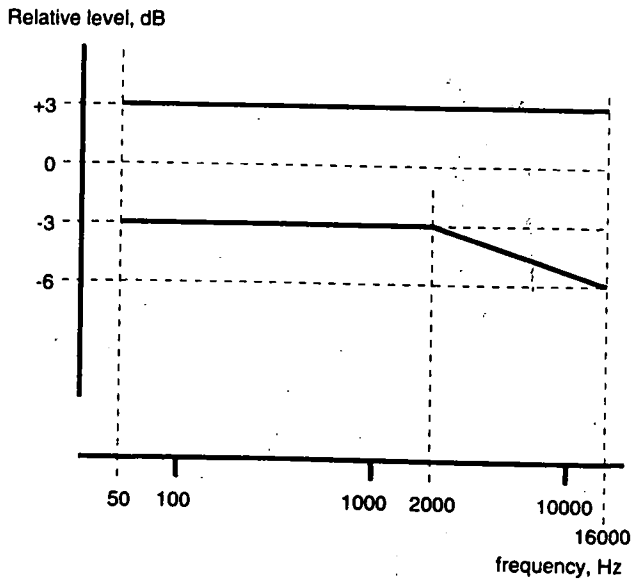




Fig. 2. EBU/ITU tolerances for operation room response curve. (The reference level is the mean level over the frequency range 200Hz to 16kHz.)