Subjective assessment of audio quality – the means and methods within the EBU

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This article presents a number of useful means and methods for the subjective quality assessment of audio programme material in radio and television, developed and verified by EBU Project Group, P/LIST.

The methods defined in several new EBU Recommendations and Technical Documents are suitable for both operational and training purposes in broadcasting organizations.

1. Introduction

The existing EBU Recommendation, R22 [1], states that *"the amount of sound programme material which is exchanged between EBU Members, and between EBU Members and other production organizations, continues to increase"* and that *"the only sufficient method of assessing the balance of features which contribute to the quality of the sound in a programme is by listening to it."*

Therefore, "listening" is an integral part of all sound and television programme-making operations. Despite the very significant advances of modern sound monitoring and measurement technology, these essentially objective solutions remain unable to tell us what the programme will really sound like to the listener at home. The human ear alone is able to judge the aesthetic or artistic quality of programme material and, indeed, certain aspects of the technical quality as well.

An essential prerequisite for ensuring a uniform high quality of sound programmes is to standardize the means and methods required for their assessment. The subjective assessment of sound quality has for a long time been carried out by international organizations such as the (former) OIRT [2][3][4], the (former) CCIR (now ITU-R) [5] and the Member organizations of the EBU itself. It became increasingly important that common rules for subjective sound assessment should be specified and, consequently, the EBU set up Project Group P/LIST to develop tools for the subjective assessment of sound programme quality. These tools are described in several EBU Recom-

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mendations, Technical documents and other printed material.

2. Listing conditions

2.1. General

Typically, the monitoring of programme material in sound production and broadcasting is done by listening in a certain room using loudspeaker presentation. (Listening by headphones is also used in certain cases, but is not covered in this article.)

It is self-evident that both the acoustics environment and the electro-acoustic properties of the loudspeakers must be controlled, in order to allow consistent subjective assessments to be made.

The main components of the reproduced sound field are the *direct sound*, the *early reflections* and the *later reflections* which form the reverberant field. All these components are time- and frequency-dependent.

The following is a brief summary of the parameters and other requirements for loudspeaker presentation, as specified in EBU document Tech. 3276 [6]. They also largely meet the requirements given in ITU-R Recommendation BS.1116 [7].

2.2. Requirements of the reference sound field.

Direct sound

The quality of the direct sound is mainly determined by the relevant loudspeaker parameters, as measured in anechoic conditions (see *Section 2.3.*).

Early reflections

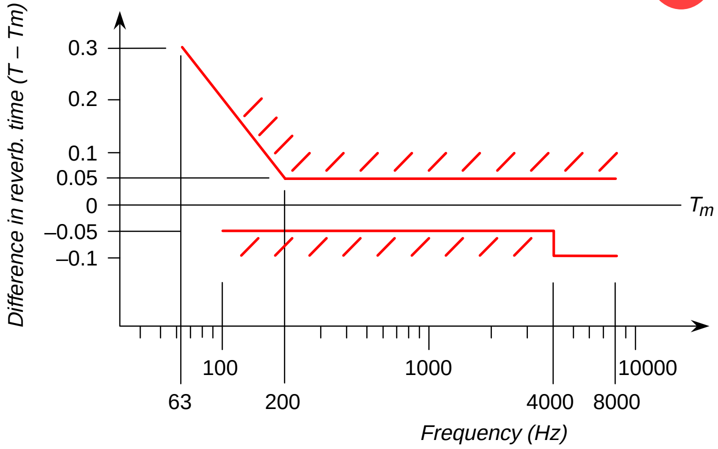
The levels of reflections earlier than 15 ms relative to the direct sound should be at least 10 dB below the level of the direct sound for all frequencies in the range 1 kHz to 8 kHz.

Reverberation field

The reverberation field should be sufficiently diffuse over the listening area to avoid perceptible acoustical effects such as flutter echoes.

The *nominal reverberation time* (T_m) for the $^1/_3$-octave bands from 200 Hz to 4 kHz is found as follows:

$$T_m = 0.25(Roomvolume/Ref.volume(100))^{\frac{1}{3}}$$



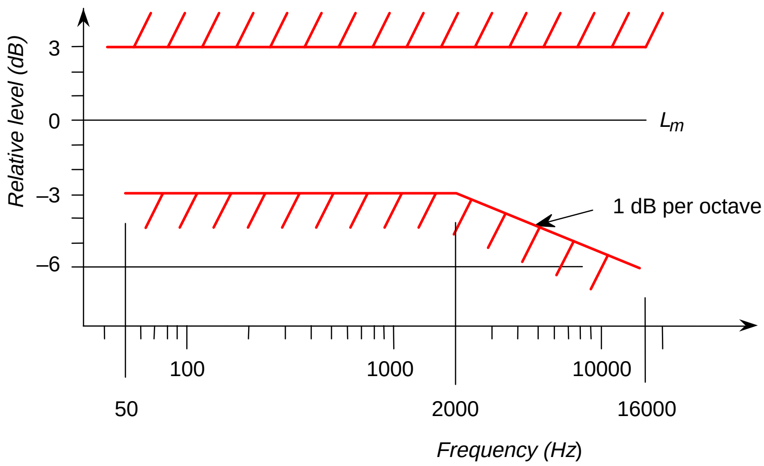


Figure 1 *(upper)*
Tolerance limits for the reverberation time.

Figure 2 *(lower)*
Tolerance limits of the operational room response curve.

T_m should lie in the range: $0.2 < T_m < 0.4$ s

As a function of frequency, the *reverberation time* (T) should conform to the tolerances shown in *Fig. 1*.

Operational room response curve

The tolerance limits for the operational response curves, measured at any point in the listening room, are given in *Fig. 2*. L_m is the mean value of the $^1/_3$-octave bands from 200 Hz to 4 kHz. The tolerances should be met for each channel separately. For stereophonic reproduction, the close matching of the room response of each channel is important.

Listening level

For pink noise at the "alignment signal level", the gain of each loudspeaker channel is adjusted so that the sound pressure level at the reference listening point is:

$$L_{LISTref} = 85 - 10\log(n) \quad \text{dB(A)}$$

where: n = number of reproduction channels in the total configuration.

The measurement signal is available from the EBU tape of R-DAT Levels [8].

Background noise

The sound pressure level (SPL) of the continuous background noise should not exceed the ISO Noise Rating Curve, NR 15, and should preferably not exceed NR 10. It should not be perceptibly impulsive, cyclical or tonal in nature.

2.3. Geometrical conditions for the listening arrangement

Positioning of sound sources and listeners

The height of the acoustical centre of the loudspeaker monitor should be at least 1.2 m above floor level and the inclination angle of its reference axis in relation to the horizontal plane should not exceed 10°. The monitor's reference axis should intersect the reference listening point at the height of the ears of a seated person.

If the loudspeaker monitor is not installed into the wall, the distance of its acoustical centre from the surrounding walls should be at least 1 m. All listening positions should be situated at least 1.5 m from the side walls and the back wall of the room.

Stereo listening

Two loudspeaker monitors should be placed in the listening room for two-channel stereophonic reproduction according to the layout given in *Fig. 3*. The base width, *b*, should be within the range 2 to 4 m.

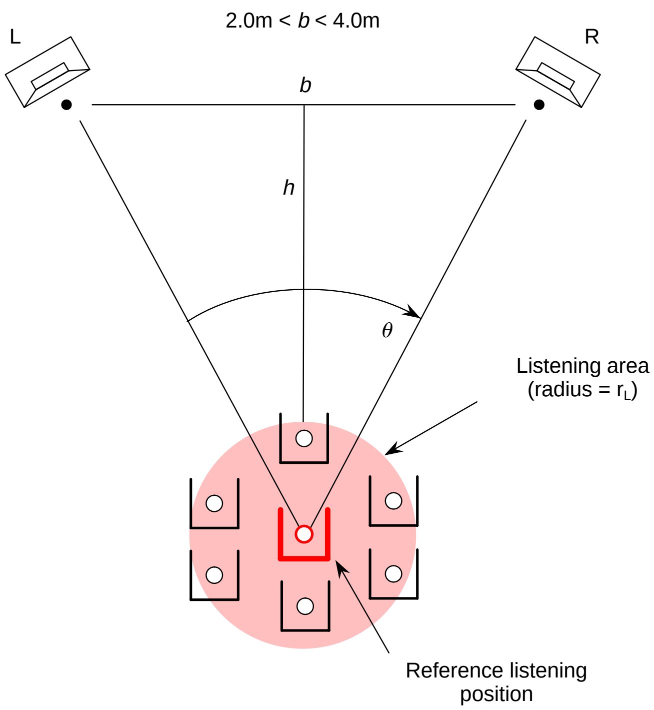


Figure 3
Typical layout of a stereo listening arrangement.

Separate bass loudspeakers

If separate bass loudspeakers are used, the optimum cross-over frequency between the bass and the main loudspeakers depends on many factors, including the positions of the loudspeakers in the room, the room acoustics and the desired overall frequency response. To prevent the separate bass source locations from becoming perceptible, lower cross-over frequencies (between 80 and 160 Hz) will be required for bass loudspeaker positions which are located further from the main loudspeakers (for more details, see [6]).

Room dimensions

The minimum *floor area* should be:

– 40 m^2 for a reference listening room;

– 30 m^2 for a high-quality sound control room.

The *volume* should not exceed 300 m^3.

The following limits for the length-to-height and the width-to-height ratios should be observed:

$$1.1w/h \le l/h \le 4.5w/(h-4)$$

$$l < 3h$$

$$w < 3h$$

where: l = larger dimension of floor plan, irrespective of orientation;
w = shorter dimension of floor plan, irrespective of orientation;
h = height.

Ratios of *l*, *w* and *h* which are within ± 5% of integer values should be avoided.

Careful design and good workmanship in the construction of listening rooms can greatly enhance the acoustic environment. Additional design considerations are given in [6].

2.4. Requirements of the monitoring loudspeakers

Frequency response curve

The frequency response curve is measured in $^1/_3$-octave bands with a pink noise test signal. The measurements are taken on the main axis and the curve should fall within a tolerance band of 4 dB over the frequency range from 40 to 16 kHz.

Directivity index, D

250 Hz to 16 kHz: $4 \leq D \leq 12$ dB.

Harmonic distortion (sinusoidal test signals)

40 Hz < f < 250 Hz –30 dB (3%)
250 Hz < f < 16 kHz –40 dB (1%).

Decay time

The decay time, t_s, using a sinusoidal tone burst shall not exceed the following limit:

$t_s \leq 2.5 / f$ where f is the frequency.

Time delay of loudspeaker system

The time delay of the loudspeaker system should not cause the relative delay of the sound and vision components at the listening position to exceed that defined in EBU Recommendation R37 [9].

Operational SPL

The maximum operational sound pressure level which the loudspeaker monitor can produce for a period of at least 10 minutes without thermal or mechanical damage and without overload circuits being activated is:

$$L_{eff\text{-}max} \geq 108 \text{ dB.}$$

Self-generated noise level

The maximum allowable self-generated noise level is:

$$L_{noise} \leq 10 \text{ dB(A)}$$

2.5. Measurement results of existing listening rooms

In order to verify the requirements given in [6], and to show that listening rooms which meet those requirements are already available in several organizations, a number of detailed acoustics measurements have been carried out by members of P/LIST at the following places:

– BBC Research & Development, Surrey, UK;

– Deutsche Telekom Berkom, Berlin, Germany;

– IRT/ARD/ZDF, Munich, Germany;

– Magyar Radio (MR), Budapest, Hungary;

– YLE, Helsinki, Finland.

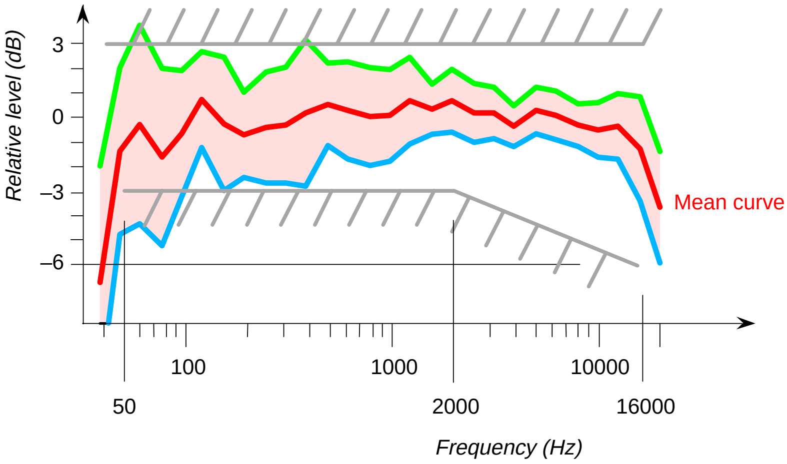


Figure 4
Measured room response curves in different listening rooms: mean values and standard deviations in relation to frequency.

The measurement results have been collected as an internal report of the EBU. They mainly meet the requirements and show that the listening conditions specified in [6] are quite realistic and could be reached by several existing listening rooms (see *Fig. 4*).

3. Subjective assessment methods

3.1. General

The method described below has been developed to assess the quality of “classical music” programmes: symphonic music, orchestral music, choral music, opera, chamber music and solo performances. The method may also be applied to other types of “acoustic” music.

Classical music programmes are among the most expensive produced by the broadcasters. Consequently, programme managers have a vital interest in obtaining and maintaining the highest possible quality.

The technical and production quality of sound programme material can only be monitored by subjective assessment in controlled conditions, and this is what is briefly described in the following sections. For more details, see EBU document Tech. 3286 [10].

EBU project group P/MCA has just been formed to expand the method described here to cover multichannel audio, with and without pictures – a subject which is rather “hot” at the present.

3.2. *Subjective parameters*

A set of subjective main parameters has been defined to cover the technical quality of "acoustic music":

- spatial impression;
- stereo impression;
- transparency;
- sound balance;
- timbre;
- freedom from noise and distortions;
- main impression.

Each of the first 6 main parameters consists of a number of sub-parameters (see *Table 1*)

The sub-parameters can be regarded as a detailed description of the main parameters. There is a close connection between the sub-parameters, the actual production technique and the acoustical properties of the originating room.

Using these sub-parameters to describe the quality of a given recording can give a useful feedback to the producer/engineer involved, as this information is fairly easy to relate to specific actions.

Table 1
Parameters and examples of common descriptive terms (taken from EBU doc. Tech. 3286 [10]).

Main parameter	Sub-parameters	Examples of common descriptive terms
1. Spatial impression		
The performance appears to take place in an appropriate spatial environment	– Homogeneity of spatial sound – Reverberance – Acoustical balance – Apparent room size – Depth perspective – Sound colour of reverberation	Room reverberant / dry; Direct / indirect; Large room / small room
2. Stereo impression		
The sound image appears to have the correct and appropriate directional distribution of sound sources	– Directional balance – Stability – Sound image width – Location accuracy	Wide / narrow; Precise / imprecise
3. Transparency		
All details of the performance can be clearly perceived	– Sound source definition – Time definition – Intelligibility	Clear / muddy
4. Sound balance		
The individual sound sources appear to be properly balanced in the general sound image	– Loudness balance – Dynamic range	Sound source too loud / too weak; Sound compressed / natural
5. Timbre		
Accurate portrayal of the different sound characteristics of the sound source(s)	– Sound colour – Sound attack	Boomy / sharp; Dark / light; Warm / cold
6. Freedom from noise and distortions		
Absence of various disturbing phenomena such as electrical noise, acoustical noise, public noise, bit errors, distortions, etc.		Perceptible / imperceptible disturbances
7. Main impression		
A subjective weighted average value of the previous six parameters taking into account the integrity* of the total sound image and the interaction of the various parameters.		

* Integrity: A sound image which is appropriate to the performance so that the two appear as an integrated whole.

For example:

Evaluation: Sound image too narrow.

Possible action: Increase the spacing of the A/B main mic (if used).

During the quality evaluations, the listening panel members are asked to grade their subjective impression of the defects in the first 6 main parameters, taking into account the sub-parameters. The panel members use the 6-point impairment scale shown in *Table 2* for this purpose.

Grade	Impairment
1	Very annoying defects.
2	Too many annoying defects.
3	A number of annoying defects.
4	Some slightly annoying defects.
5	Some perceptible but not annoying defects.
6	No perceptible defects,

Table 2: Impairment grades.

Having analyzed the six main parameters of the recording in this manner, each panel member is then asked to give his/her *main impression* of the material under test, using the 6-point quality scale shown in *Table 3*. This final assessment of the overall quality is meant to be a subjectively-weighted (not arithmetically-weighted) average value of the grades awarded to the first six parameters, taking into account the integrity of the total sound image and the interaction of the various parameters. This means that the sound image is appropriate to the performance so that the two appear as an integrated whole.

Grade	Quality
1	**Bad** Substantial technical defects. Unsuitable for transmission.
2	**Poor** Should be used for transmission only in exceptional cases. Only of documentary value.
3	**Fair**
4	**Good**
5	**Very good**
6	**Excellent**

Table 3: Quality grades.

– – –	– –	–	+	+ +	+ + +
1	2	3	4	5	6

Figure 5
Ranking scale.

3.3. Evaluation scale

As mentioned above, the evaluation scale is divided into 6 different rankings, also shown in *Fig. 5*. It has been designed to have equal positive and negative parts, forcing the listeners to evaluate in either a positive or a negative direction.

It is stressed that this scale is to be looked upon as an ordinal scale, that is a scale of quality rankings. No attempt should be made to use fractional values or to interpolate between the rankings.

3.4. The EBU demonstration CD "PEQS"

To increase the reliability of the listening tests, it is recommended that a training period is arranged for the panel members in advance of the actual listening tests. This training period is organized to demonstrate the exact meaning of the sub-parameters in order to minimize any correlation (overlapping) between the subjective main parameters.

For use during this training period, the EBU has prepared a specially-designed CD called "PEQS" (**P**arameters for the subjective **E**valuation of the **Q**uality of **S**ound programme material – Music) which demonstrates both positive and negative examples of all the parameters shown in *Table 1*. This new CD contains 63 music examples in total, produced by several EBU member organizations using different origination and/or mixing conditions. An excerpt from its list of contents is shown in *Table 4*. Similar in format to the well-known EBU compact disc called "SQAM" (Subjective Quality Assessment Material) [11], the "PEQS" CD [12] contains a printed insert in the form of a miniature EBU Technical Document.

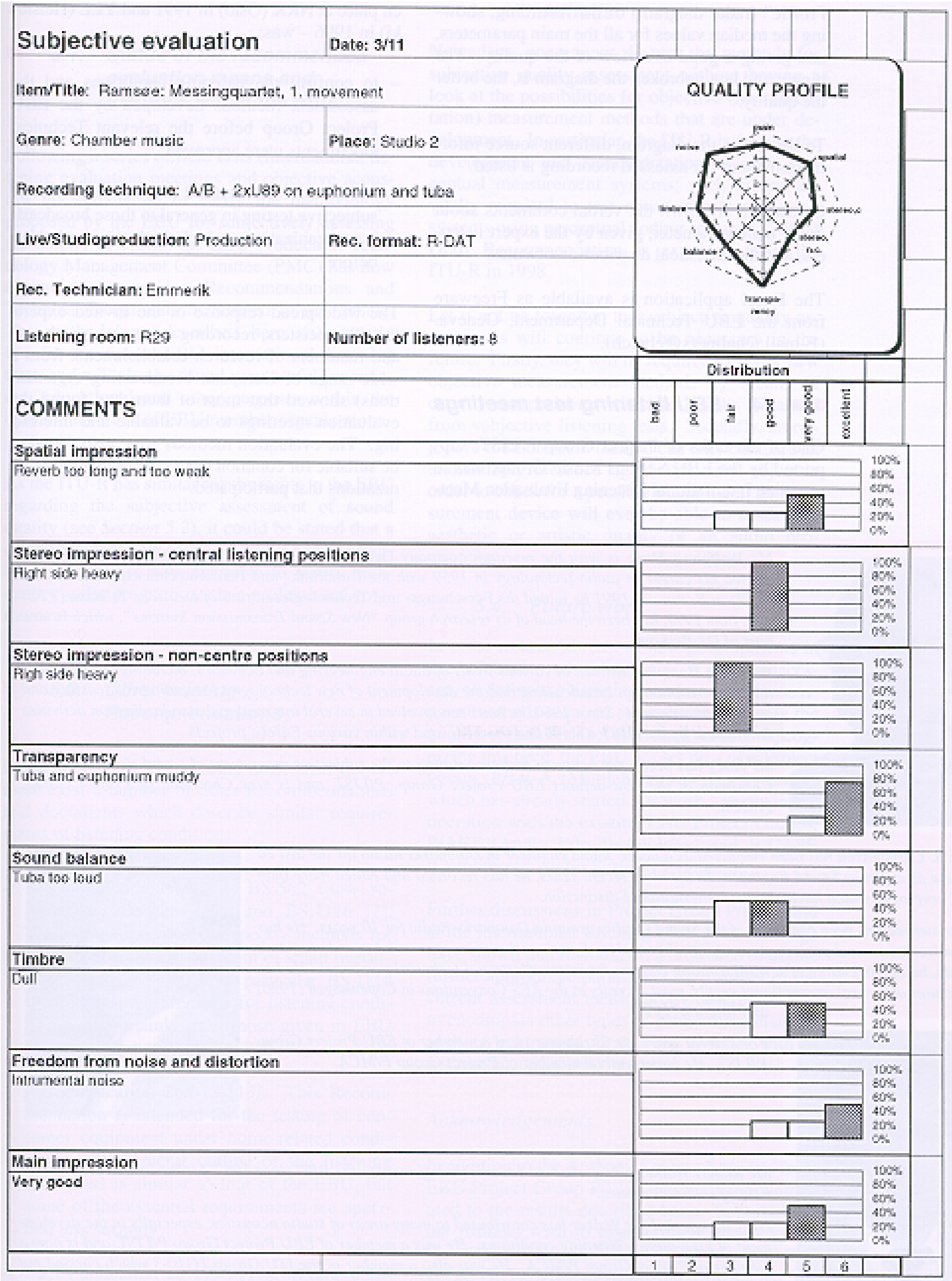
In addition to the training of expert listeners, the "PEQS" CD will also be well suited for training the technical and artistic staff in the production areas of recording companies and broadcasting organizations, and for use by students training to be Tonmeisters or recording engineers.

3.5. Presentation of results

After completing a listening test, using the special score forms as specified in EBU document Tech. 3286 [10], the data is transferred to a specially-developed Microsoft Excel application. The outcome of the test (in Excel) could take the form shown in *Fig. 6*.

Track No.	Description	Level dBFS	Duration min:sec
I.	3 level test signal according to Rec. ITU-R BS.661 Frequency 1 kHz	–30 –18 –9	01:46
II.	Alignment leader according to EBU Recommendation R49 Frequency 1 kHz	–18	01:00
III.	Pink Noise, non-coherent Frequency 1 kHz	–9	05:00
...	....		
IV.	**Homogeneity of spatial sound: *Uneven*** Puccini: O mio babbo caro Song/Piano (NRK–studio)	–9	01:05
V.	**Homogeneity of spatial sound: *Even*** Puccini: O mio babbo caro (same source as track IV)	–9	01:05
VI.	**Reverberance: *Too dry*** Planicky: Opella Ecclesiastica Chamber orchestra (Atrium Hall, Prague) Recorded with 3 A/B pairs (mic–type: U87)	–9	00:24
VII.	**Reverberance: *Too reverberant*** Planicky: Opella Ecclesiastica (same source as track VI; added reverb from Lexicon 300)	–9	00:24
VIII.	**Reverberance: *Appropriate reverberant*** Planicky: Opella Ecclesiastica (same source as track VII)	–9	00:24
IX.	**Acoustical balance: *Too direct*** Prokofiev: Romeo and Juliet Piano solo (BBC studio) Recorded with a pair of AKG 414 mics	–9	00:41
X.	**Acoustical balance: *Too indirect*** Prokofiev: Romeo and Juliet (same source as track IX)	–9	00:41
XI.	**Acoustical balance: *Well balanced*** Prokofiev: Romeo and Juliet (same source as track IX)	–9	00:41
XII.	**Acoustical balance: *Too direct*** Bruckner: Symphony no. 3 Slovenia Philharmonic Orchestra/Gyorgy Gyorivanyi (Lubljana, Gallus Hall) Recorded with an A/B pair of B&K 4006 (10 m height), Stereo Comp C426 (4 m height, position at the conductor), 12 spot mics for strings and woodwinds (AKG414), spot mic for percussion (KM84)	0	00:45
XIII.	**Acoustical balance: *Too indirect*** Bruckner: Symphony no. 3 (same source as track XII)	0	00:47
XIV.	**Acoustical balance: *Well balanced*** Bruckner: Symphony no. 3 (same source as track XII)	0	00:47
...	....		

Table 4
Excerpt from the table of contents of the EBU "PEQS" CD: *subjective parameters, positive and negative values*.


Subjective evaluation

Date: 3/11

Item/Title: Ramsøe: Messingquartet, 1. movement

Genre: Chamber music

Place: Studio 2

Recording technique: A/B + 2xU89 on euphonium and tuba

Live/Studioproduction: Production

Rec. format: R-DAT

Rec. Technician: Emmerik

Listening room: R29

Number of listeners: 8

QUALITY PROFILE

Distribution

bad | poor | fair | good | very good | excellent

COMMENTS

Spatial impression

Reverb too long and too weak

Stereo impression - central listening positions

Right side heavy

Stereo impression - non-centre positions

Righ side heavy

Transparency

Tuba and euphonium muddy

Sound balance

Tuba too loud

Timbre

Dull

Freedom from noise and distortion

Intrumental noise

Main impression

Very good

100% 80% 60% 40% 20% 0%

1 2 3 4 5 6

Figure 6: Sample outcome of a subjective listening test.

At the upper right corner is shown a "Quality Profile" (radar diagram) of the recording, showing the median values for all the main parameters, and giving a good overview of the quality. The bigger and less unbroken the diagram is, the better the quality.

To the left to the diagram, different source information about the assessed recording is listed.

Below that is shown the verbal comments about every main parameter, given by the expert listeners, and the statistical distribution of votes.

The Excel application is available as Freeware from the EBU Technical Department, Geneva. (E-mail: chalmers@ebu.ch).

4. EBU listening test meetings

One of the tasks of Project Group P/LIST, supported by the EBU Serious Music Group, was to organize International Listening Evaluation Meetings. The aim of those meetings – which have taken place at NRK (Oslo) in 1991 and YLE (Helsinki) in 1996 – was:

– to confirm the listening conditions and the assessment methods developed by the EBU Project Group before the relevant Technical Documents were approved;

– to introduce the method and the principles of subjective testing in general to those broadcasting organizations which had not used them before.

The widespread response of the invited experts (i.e. Tonmeisters, recording engineers, producers and members of research establishments from a wide range of European broadcasting organizations) showed that most of them had found the evaluation meetings to be valuable and interesting. The evaluation methods were also found to be suitable for common use in the individual organizations that participated.

Mr Wolfgang Hoeg *is with the research company* Deutsche Telekom Berkom*, Berlin, Germany. He started his career in audio technology in 1959 with the* Rundfunk- und Fernsehtechnisches Zentralamt *(RFZ) in Berlin. In 1991 he joined the* Forschungs- und Technologiezentrum *of Deutsche Telekom (FTZ) and, from 1995, has been the head of its research group "New Sound Transmission Systems", which is now part of DT Berkom.*

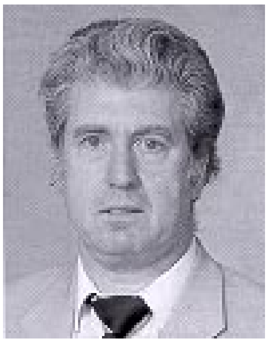
Wolfgang Hoeg has worked in various fields of audio engineering and acoustics, including the introduction of stereophony in broadcasting and the development of new technologies for audio broadcasting and sound reinforcement. Since 1960, he has been involved in several international standardization activities carried out by the OIRT, ITU-R and the EBU, and within various Eureka projects.

Mr Hoeg has been very active in matters relating to the subjective assessment of sound quality. He was Chairman of the now-defunct EBU Project Group, P/LIST, and is now Chairman of Project Group, P/MCA.

Mr Lars S. Christensen *has been employed as a music sound engineer in Danmarks Radio for the last 20 years, now as a Senior Sound Engineer. In the most recent years, he has recorded and edited more than 50 CDs, several of which have obtained international distinction.*

Lars Christensen has been chairman of the Sound Quality group in Danmarks-Radio for 10 years. He has been involved in several project groups (digital consoles, digital workstations, surround sound etc.) and, additionly, he was in charge of several training courses for internal/external technical personnel. He has given lectures at several international events, most recently at the AES Conventions in Copenhagen (1996) and Munich (1997).

For several years Mr Christensen was a member of EBU Project Group P/LIST. He is currently a member of Project Group P/MCA.



Mr Robert Walker *has worked as a research engineer for the BBC since 1967, for the last 20 years in the field of studio acoustics.*

Over that period Mr Walker has contributed to many areas of studio acoustics, especially in the development of high-quality listening conditions. He was a member of EBU Project Group P/LIST, and is now a member of Project Group P/MCA. He was also a member of the ITU Group TG10-3 which carried out studies on sound-quality assessment conditions.

5. Conclusions

5.1. Status of the recommended evaluation means and methods within the EBU

Following a series of field tests (international listening evaluation meetings and objective acoustics measurements) to verify the methodology proposed by the EBU for subjectively assessing the quality of sound, the EBU Production Technology Management Committee (PMC) has now approved the various Recommendations and Technical Documents mentioned in this article. The methodology described here will greatly benefit the future EBU international listening tests, and will also be found very useful for training, educational and other purposes within the operational areas of EBU member organizations.

As the ITU-R has similar requirements to the EBU regarding the subjective assessment of sound quality (see *Section 5.2*), it could be stated that a de facto world-wide Standard on reference listening conditions is now available to assess high-quality audio programmes in a professional environment.

5.2. Other existing Recommendations

Besides the EBU documents dealt with above, there exist a number of other Recommendations and documents which describe similar requirements of listening conditions:

– ITU-R Recommendations BS.562 (now replaced by BS.1284 [5]) and BS.1116 [7]. These Recommendations specify methods for critical subjective assessment of small impairments of sound systems. In particular, BS.1116 specifies the requirements for listening conditions which mainly meet those given in EBU Recommendation R22.

– IEC Publication 268-13 [13]. This Recommendation is intended for the testing of consumer equipment under home-related conditions. The general outline of the listening conditions is similar to that of the EBU, but some of the essential requirements are specified less strongly.

– AES Publication 20-1996 [14]. (Same comments as apply to the IEC document.)

5.3. Objective measurement methods

Nowadays, one cannot discuss the methods for subjective quality assessment without having a look at the possibilities for objective (instrumentation) measurement methods that are under development. In particular, the ITU-R is forcing the development and standardization of new perceptual measurement systems; such means are vitally required to test new audio transmission systems using perceptual coding schemes. A first Draft Recommendation is expected from the ITU-R in 1998.

Let it not be forgotten that subjective quality assessments will continue to be necessary in the future. Firstly, they will be required to verify new objective measurement methods by means of careful comparisons with the results obtained from subjective listening tests. Secondly, an objective measurement method can only compare an undisturbed reference signal with a test object in order to check for a possible impairment: no measurement device will ever be able to assess the aesthetic or artistic quality of an audio programme.

5.4. Future work

In order to keep abreast of new developments in audio formats and technologies, it will be necessary to define the listening conditions and assessment methods required to assess subjectively the quality of multichannel (surround) sound. Recognizing this need, the EBU has set up a new Project Group, P/MCA (Multichannel Audio Systems), which has already started this work – partly in co-operation with the existing EBU Project Groups, P/AFT (Audio File Technology) and B/CASE (Compressed Audio Systems Evaluation).

Further discussions in Project Group P/LIST and at the international listening evaluation meetings have shown that it would be worthwhile to define further appropriate parameters, as a subset of the current assessment methodology described here, to encompass other types of programme material such as light music, drama etc. – either with or without accompanying pictures.

Acknowledgements

In addition to the Authors, a team of experts from EBU Project Group P/LIST has actively contributed to the results described here. In particular, the Authors wish to express their thanks to Mr Kurt Huhn (Deutsche Telekom), Mr Gerhard Spikofski (IRT), Ms Eva Arato-Borsi (MR), Mr Tor Vidar Fosse (NRK), Mr Juhani Borenius and Mr

Olli Salmensaari (YLE) and, last but not least, Mr Richard Chalmers (EBU Technical Department).

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