New Reference Listening Room for Two-Channel and Multichannel Stereophonic

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ABSTRACT

The paper describes the design, modeling method and measurement results of a new reference listening room. The results are compared with the current listening room standards. The conclusion of the subjective assessment taken in the room is presented. The authors present some parameters for room acoustical evaluation of listening rooms based on M factor, middle time and clarity.

0 INTRODUCTION

In sound recording and broadcasting the need to test the different techniques by listening tests calls for the improvement of the listening conditions. The demand to achieve special environment for listening conditions led to the design of a new reference listening room in the Hungarian Radio.

Assuming that the necessary information has been encoded in the recording in a proper way, the replication can be successful only to the extent that the listening room is capable of conveying the sound to the ears of listeners without coloration.

In the design of the listening room the aim was to achieve the requirements given by the standards first of all for two-channel stereophonic and then for multichannel stereophonic too.

Extensive measurements have been carried out and the results have been compared with the current listening room standards.

The results of subjective tests show that searching for relationships between the subjective aspects and sound field properties needs more experimental efforts. The experiences of the tests stimulate us to find new objective parameters corresponding with the subjective ones. Because the state of the knowledge does not allow yet the description of he reference sound field completely, in the standards only some geometric and room acoustic requirements are given for reference listening rooms.

Although the perception of sound in rooms has been of interest to consultants in acoustics for many years, the interaction between a loudspeaker, the listening room and the listener is still not well understood. In this paper the authors present some parameters for room acoustical evaluation of small rooms - like listening rooms - based on M factor, middle time and clarity.

One issue is that what sort of objective parameters can characterize for multichannel reproduction. Is it possible to specify them with the same characteristics of the listening rooms for both two-channel and multichannel stereophonic? To find the answer, measurements were carried out for two-channel and multichannel arrangement too in the new reference listening room.

As the description of the reference sound field completely and uniquely is not possible, a computer model has been created. On the basis of the simulation, the low and high frequency properties of he room were investigated with combination of the different methods.

The results of the simulation and measurement are compared: the reverberation time and decay curves and transfer functions from the impulse response of the room. By the 3-dimensional ETF measurements the time and frequency responses of reflected energy can be obtained. As to predict the quality of the sound produced by a loudspeaker in a specific environment is very difficult the results of the comparison are useful.

1 DESIGN CONSIDERATION

In the design of the listening room the task was to achieve consistent results with the EBU recommendation EBU Tech 3276 "Listening conditions for the assessment of sound programme material: monophonic and two-channel stereophonic".

The room geometry, boundaries, placement of the loudspeakers and listening points were determined with this end in view.

The room shape originally was given, as the listening room had to be designed into an existing room. For practical reasons the room is used not only for listening purposes but as a talk studio too.

The floor plan and the 3-dimensional view of the listening room can be find from Fig.1. In the EBU document there are proposals for minimum floor area, maximum volume and room ratios.

To ensure a reasonably uniform distribution of the low-frequency eigentones, the proportions of the room must lie within controlled limits [1]. The minimum floor area for reference listening room is, 40 m^2, the volume should not exceed 300m^3.

The proposal for the length to height and width to height ratios:

$$\frac{1.1 \cdot w}{h} \le \frac{l}{h} \le \frac{4.5 \cdot w}{h} - 4$$

$$l < 3 \cdot h$$

and $$w < 3 \cdot h \,.$$

The dimensions of the listening room are:

length	7.8	m
width	7.05	m
height	4.85	m
area	55	m^2
volume	267	m^3

Although all dimension suit the recommendation, these are based on calculation assuming perfectly rigid walls and a rectangular room. Hence for investigating the low frequency behavior of the listening room, a finite element model was created. The mesh was analyzed using SYSNOISE. On Fig.2. some example are presented from the modal analysis results.

On the basis of calculations different materials and constructions were chosen to cover the interior surfaces of the room. The placement of acoustic elements are shown on Fig.3.

2 THE MEASURED SOUND FIELD PARAMETERS

Since the human hearing system could be thought of as a complicated signal processing system, it is very difficult to investigate the influence of effects creating the stereophonic audio illusion. In this context to specify the characteristics of listening room for multichannel stereophonic is a new field of research. What sort of objective parameters can be the same for two-channel and for multichannel stereophonic? What type of acoustical measurements have to be done?

The quality of the listening environment is determined by the properties of the sound field produced by the loudspeakers in the listening area, at the height of the listeners ears [5]. In our measurements the parameters recommended by the EBU were calculated first. The specified sound field parameters are :

- Direct sound
- Early reflections
- Reverberation field
- Operational room response curve
- Background noise

For the measurement an MLSSA analyzer of DRA Laboratories was used. The measuring reference point is shown on Fig.1., the loudspeakers used are 1038A (FL, FC, FR - front) and 1032A (SL, SR - surround) from Genelec.

2.1 DIRECT SOUND

The direct sound is defined as the sound field which would be measured, using the same loudspeakers, under anechoic conditions. The quality of the direct sound is determined by the loudspeakers. The Genelec 1038A and Genelec 1032A suit the specifications given for reference monitor loudspeakers.

2.2 EARLY REFLECTIONS

On the basis of extensive researches the acceptable level of early reflections was determined in [2] [3]. As reflections after the direct sound up to about 15-20 msec disturb the subjective stereophonic imaging process and cause coloration in the perceived sound, the object was to reduce the level of the early reflections under -10dB relative to the direct sound using combination of absorbing and re-reflecting surfaces with certain angles in the reference point.

On Fig.4. the ETF (Waterfall) show the Energy-Time-Frequency response at the reference point. Sound sources are the front left and right loudspeakers. Only in the period of up to 5msec are reflections integrated with the direct sound, coming from the floor and the table, other strong reflections are not coming to the reference point up to 20msec.

To investigate the influence of the early reflections in the multichannel arrangement further measurements were necessary.

Although it is well known that the spatial information about the surrounding space is mostly in the sound after 20msec, it can't be presumed that the early reflections around the surround loudspeakers have no disturbing effect.

In our work the design objective was to avoid the strong early reflections for every channel at the same time not to damp the room too much. The subjective investigations showed that in the two channel situation the energy coming after 70-80msec is very important, the sound must become reverberant. As in small rooms, normally, the reverberant sound field rarely appears above the ambient noise level. To sustain energy after 80msec for the front channel, diffusors are used. These also scatter the early reflections for the back channels.

2.3 REVERBERANT FIELD

The reverberation time is an important representative of the reverberant field. In the recommendation the nominal value of he reverberation time is proposed to be:

$$0.2 < T_m < 0.4\,\text{sec.}$$

To ensure that the acoustic field remains "natural", the value of nominal reverberation time is given in this way:

$$T_m = 0.25 \cdot \left(V / V_0 \right) [\text{sec}].$$

The measured reverberation time is showed on the Fig.5.

2.4 OPERATIONAL ROOM RESPONSE CURVE

The operational room response curve is defined as the frequency response of the sound pressure level produced by the loudspeakers at the reference point. This parameter is an important criterion in the evaluation of the influence of the acoustical environment.

The measured operational room response curves are on Fig.6-7.

2.5 OBJECTIV CALCULATED PARAMETERS

Also there are several specified objective parameters corresponding to the subjective evaluation. The experiences verify that new parameters are needed to evaluate the acoustical behavior of small rooms.

To work with new objective parameters an evaluation program has been developed (Fig.8.). With the program new factors are calculated on the basis of energy time domain integrals, such C_{50}, $C_{20\text{-}80}$, t_s and M-factor [4]. An important question using time integrals is the exact determination of the beginning and the end of the impulse responses. Without these information only the noise and the distortion may be measured. In the forms the ∞ means the calculated end of the responses.

The position of the end point depends on the energy integration. The used impulse response length must contain the 99,5% of the whole calculated energy. It is important working with t_s:

$$t_s = \int_0^{\infty} t \cdot p^2(t)\,dt$$

The formulas for the calculation processes are:

$$C_{50} = \frac{\int_0^{50\,\text{ms}} p^2(t)\,dt}{\int_0^{\infty} p^2(t)\,dt}, \quad C_{20-80} = \frac{\int_0^{20\,\text{ms}} p^2(t)\,dt}{\int_{20\,\text{ms}}^{80\,\text{ms}} p^2(t)\,dt},$$

$$M = 10 \cdot \log_{10} \frac{k_2^{(20\,\text{ms})}}{k_2^{(2\,\text{ms})}}, \quad \text{where} \quad k_2^t = \frac{\int_0^{t} p^2(t)\,dt}{\int_t^{\infty} p^2(t)\,dt}.$$

The calculation are based on psycho-acoustical experiences. The important parts of the impulse responses are the direct sound, the first 20msec, and the 20-200msec range. The direct sound refers to the sound sources. The first 20msec after the direct sound is the interval to examine the time process of the sound actions. In the next interval, 20msec to 200msec, mainly the loudness, the spatial characteristic and the timbre are important. The calculated results are in the Table I.

3. MODELING OF SMALL ROOMS

There are several methods for computer aided modeling of closed acoustic spaces (for a short summary see e.g. [6]). Most of the methods used in available room acoustics modeling systems utilize the simplifications of geometrical acoustics, where reflections are supposed to be principally specular. This simple approach allows image-source (ISM), ray-tracing (RTM) or their hybrid methods to be used.

Purely geometrical acoustics is a good approximation only if the wavelengths of the modeled frequency range are small compared to the size of obstacles and reflectors. The lower frequency limit could be determined as the ratio of the linear size and the wavelength. Considering the probability distribution of surface areas of a given room geometry and source-receiver configuration the ratio of $\sqrt{2}$ could be a usable rule of thumb [7]. Even the extreme case of a car interior modeling and measurement showed that the 350Hz is a lower frequency limit still usable [8].

Modeling wave propagation features like diffuse reflection, diffraction or refraction need special approaches (e.g. the modeling possibilities of diffuse reflections are discussed in [9]).

In contrast to geometrical acoustics the finite or boundary element methods and finite difference methods are approximations of the wave equations, where the upper frequency limit is given by the size of the element or the step size. These models describe accurately all wave phenomenon, but as we reduce the element sizes to reach higher frequency limit, the computational effort becomes prohibitive.

Modeling the acoustics of listening and control rooms is a special challenge, because they are typically small, the influence of the furniture is not negligible and walls are made of special materials. In the following the modeling methods and results of the listening room described above are detailed.

3.1 LOW FREQUENCY MODELING

The mesh for finite element modeling of the listening room consists of 2385 cubic elements. The largest size of the elements is smaller than 0.57m, the walls carrying the front loudspeakers were supposed to be perfectly rigid. The mesh was analyzed using SYSNOISE. Some results of the modal analysis are shown in Fig.2.

Using the results, peaks in the measured transfer functions could be explained posteriorly, also the importance of proper strutting of the walls around the front speakers can be seen.

3.2 HIGH FREQUENCY MODELING

For the high frequency range a model based on geometrical acoustics was used. The older version of the system under development uses a beam-tracing method, where the rays have finite dimensions to have an exact intersection with the point-like receivers.

This finite dimension represents also a kind of uncertainty in detecting the precise direction of incoming beams. Using this uncertainty we may get a coarse model of diffuse reflection if the solid angles of the beam change according to the diffusing properties of the reflecting surface.

The model is not limited to only plane surfaces, and is capable to follow the distortions of the beam surface in this case, although the room here doesn't have any curved surface.

Modeling of diffraction is not implemented in this version. For modeling the properties of the wave propagation at lower frequencies a kind of sampling was introduced in the detection of reflections, where a ray doesn't reflect from an obstacle if it is much smaller than the wavelength of the highest frequency examined. Also in the older version this sampling causes the time resolution to be worsen in echograms.

3.3 PROCESSING, PREDICTIONS VS. MEASUREMENTS

The high frequency model gives the impulse responses of a given source-receiver configuration. From the impulse responses the desired parameters may be calculated. The model also enables the visualization of wave propagation (Fig.9.). This feature makes easy to understand the development of reflection patterns, and to identify given reflections.

Figure 10 and Fig.11 shows some classic results of predictions and their corresponding measurement result.

Differences of the measured and modeled functions are explicable and are obviously due to the small number of beams used, the lack of correct modeling of diffuse reflection and diffraction, finally the imprecise parameters of materials. Also the narrow frequency range of the available measured material parameters could be mentioned here as a potential error in predicting broad band parameters.

4 CONCLUSIONS

Our examinations show that looking for objective parameters describing the subjective quality of two-channel and multichannel configurations could differ. To find the appropriate parameters and measurement conditions, further investigations have to be made in other reference listening rooms too. The answer could be found most likely in extensive subjective tests.

Using acoustic models, calculated parameters of the developing acoustic spaces may be used not just for a given source-receiver configuration, so a number of other measurement methods could be developed that are not available in practice.

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Fig.1. The floor plan and the 3-dimensional view of the listening room with the place of soundsources and reference listening point.

Fig.2. Some example of the calculated room modes with help of FEM (Sysnoise).

Fig.3. View of the péacement of the different acoustical elements.
a. Low frequency absorbers
b. Diffusors
c. Wide-band absorbers?

Fig.4.. Energy-Time-Responses at he reference point
a. Fornt Left, b. Front Right, c. Center, d. Surround Left,e. Surround Right

Fig.5. Reverberation time

Fig.6-7. Measured operational room response curves

Fig.8. Main screen of the evaluation program

TÁBLÁZAT!Table

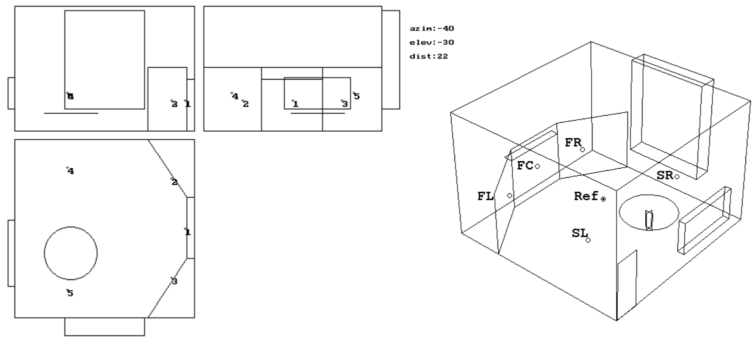


Fig.1. The floor plan and the 3-dimensional view of the listening room with the place of sound sources and the reference listening point. (FL - Front Left, FC - Front Center, FR - Front Right: Genelec 1038A;SL - Surround Left, SR - Surround Right: Genelec 1032A).

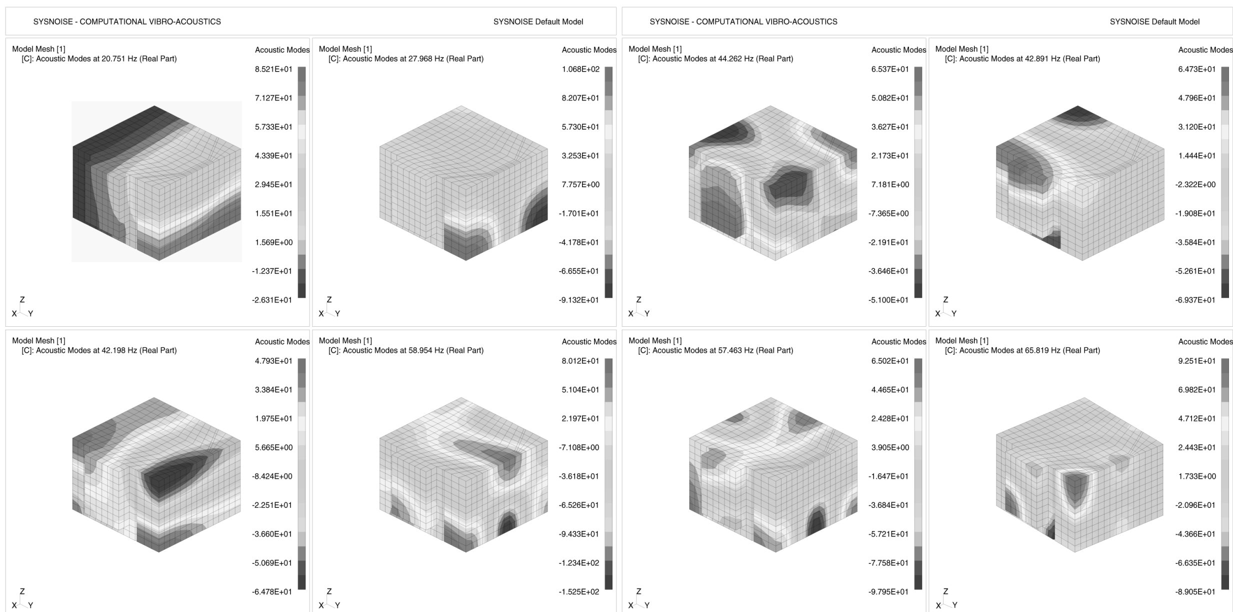
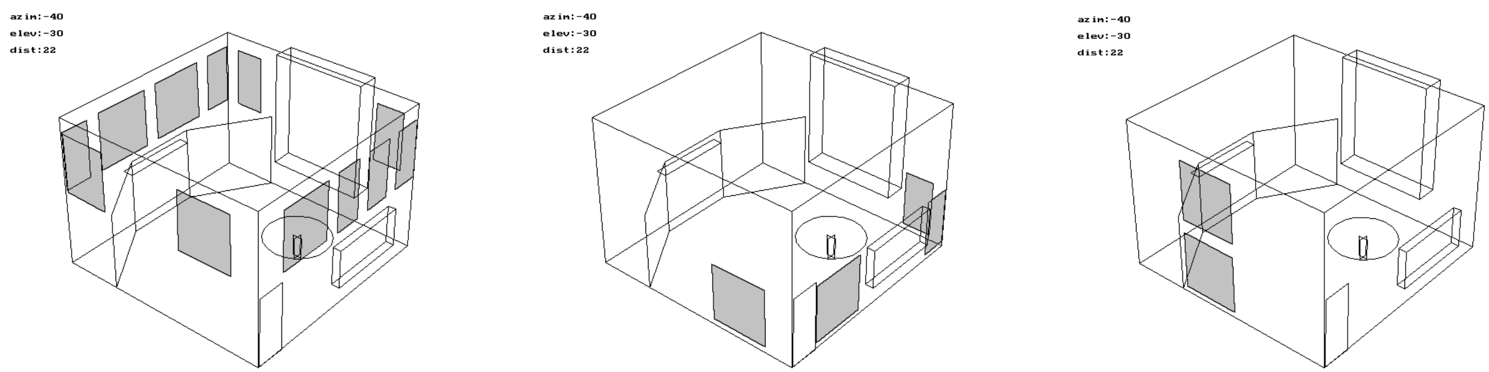
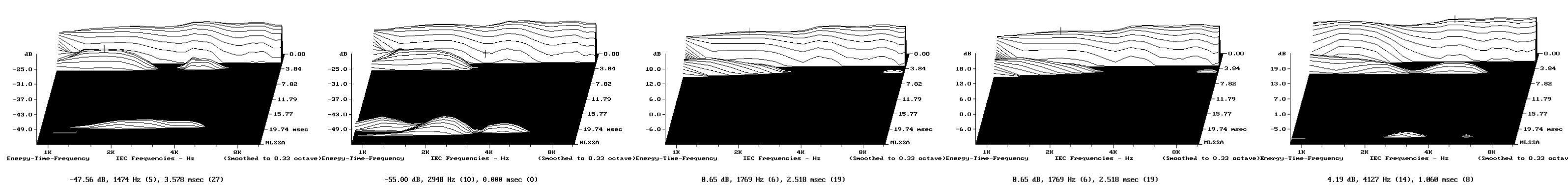


Fig.2. Examples of calculated room modes with FEM modeling (SYSNOISE).



a) b) c)

Fig.3. View of the placement of the different acoustical elements.
a) Low frequency absorbers, b) Diffusors, c) Wide-band absorbers



a) b) c) d) e)

Fig.4. Energy-Time-Responses at the reference point
a) Fornt Left, b) Front Right, c) Center, d) Surround Left, e) Surround Right

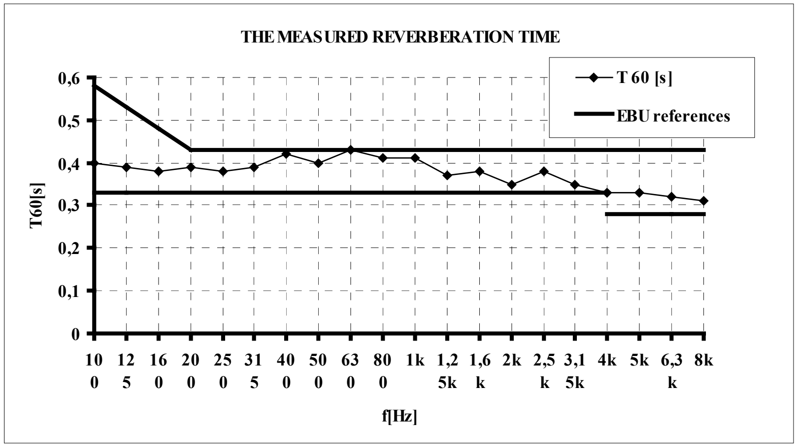


Fig.5. Reverberation time

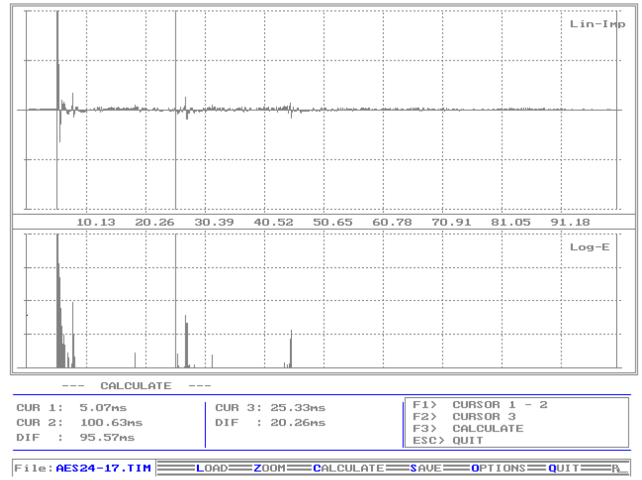


Fig.8. Main screen of the evaluation program

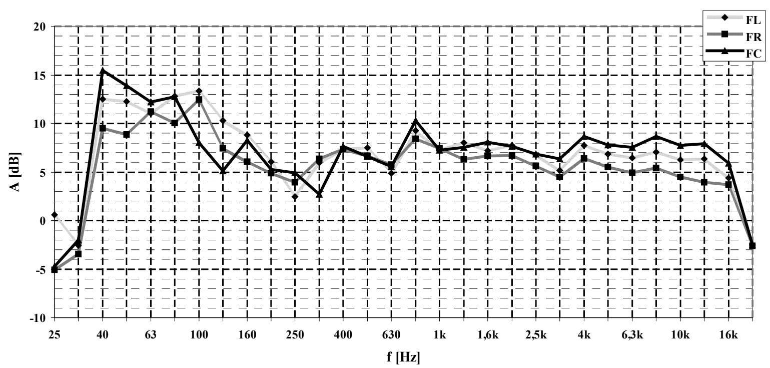


Fig.6. Measured operational room response curves (front channels)

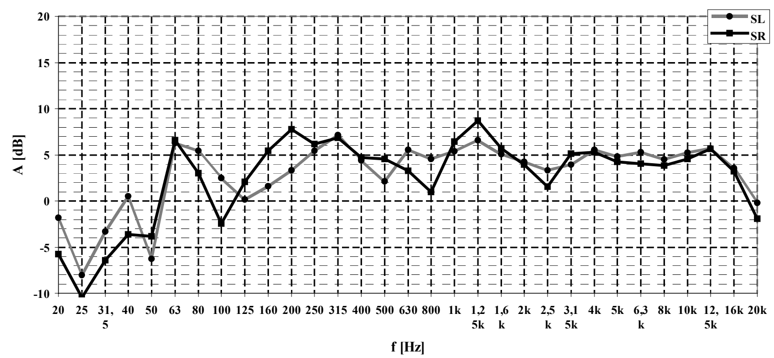


Fig.7. Measured operational room response curves (surround channels)

	FL	FR	FC	SL	SR
C_{50}	0.942	0.903	0.914	0.939	0.923
$C_{50,}$ [dB]	-0.26	-0.44	-0.39	-0.27	-0.35
$C_{20\text{-}80}$	17.388	9.786	11.21	20.83	19.125
$C_{20\text{-}80}$ [dB]	12.4	9.9	10.5	13.2	12.8
t_S [msec]	4.07	5.26	12.83	9.67	10.22
M-factor [dB]	0.4	0.262	0.241	0.343	0.334

Table I. Calculated parameters

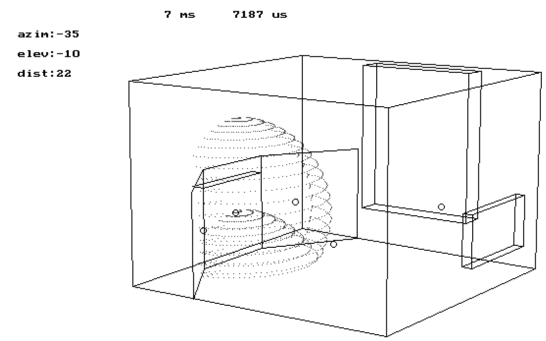


Fig.9. Visualization of wave propagation

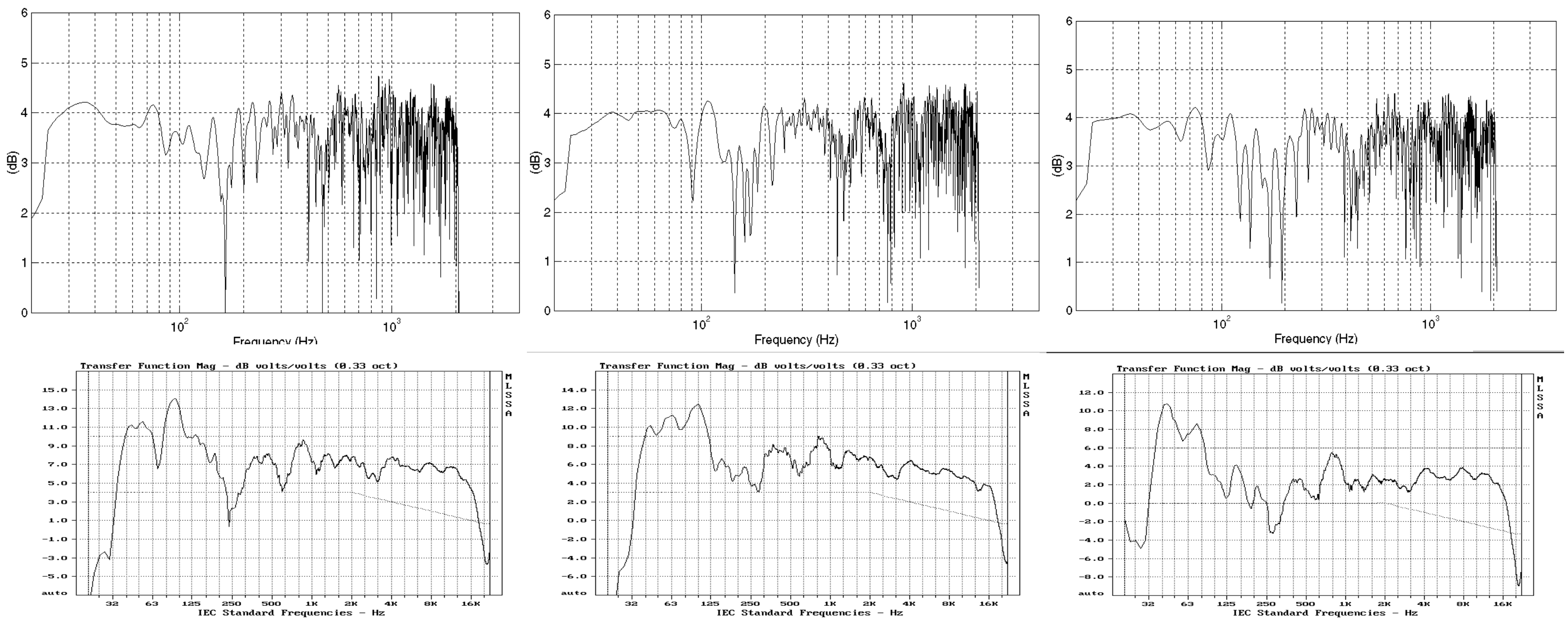


Fig.10. Measured and predicted transfer functions (FL, FC, FR)

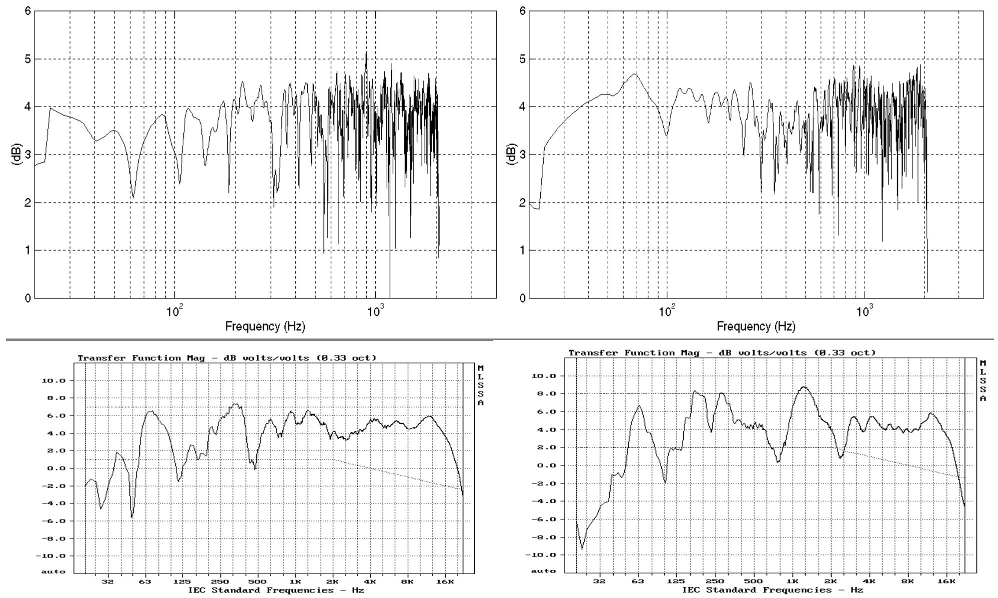


Fig.10. cont'd Measured and predicted transfer functions (SL, SR)

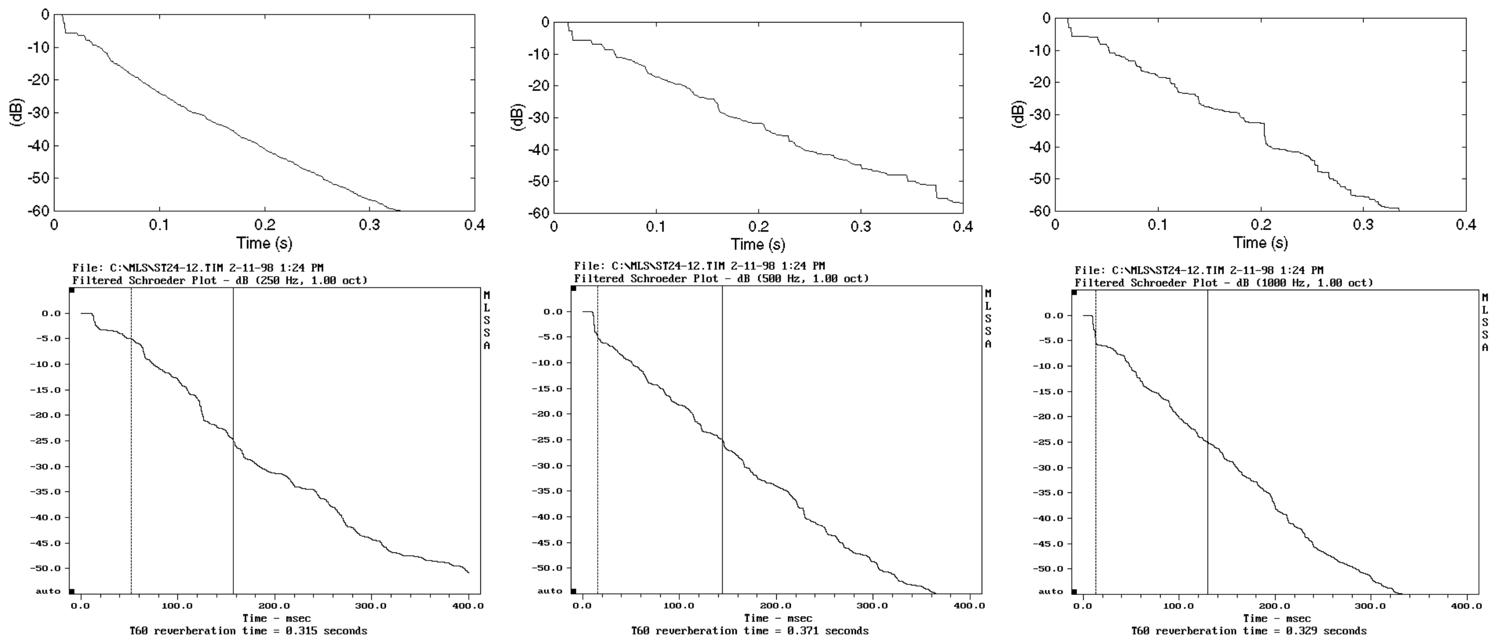


Fig.11. Measured and predicted Shroeder-plots (250Hz, 500Hz, 1kHz)