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THE INVESTIGATION OF THE INFLUENCE OF AUDIO SIGNALS TRANSMISSION CHAIN CHARACTERISTICS ON THE SPATIAL PROPERTIES OF REPRODUCED SOUND

KOLTSOVA A.S., BORISOV V.V.

O.S. Popov Odessa national academy of telecommunications
1 Kovalska st., Odessa 65029, Ukraine
State enterprise "Ukrainian scientific research institute of radio and television"
31 Bunin st., Odessa 65026, Ukraine
tango@i.ua, vladborv@gmail.com

ДОСЛІДЖЕННЯ ВПЛИВУ ХАРАКТЕРИСТИК КАНАЛУ ПЕРЕДАВАННЯ АУДІОСИГНАЛІВ НА ПРОСТОРОВІ ВЛАСТИВОСТІ ВІДТВОРЕНОГО ЗВУКУ

КОЛЬЦОВА О.С., БОРИСОВ В.В.

Одеська національна академія зв'язку ім. О.С. Попова,
65029, Україна, м. Одеса, вул. Ковальська, 1.
Державне підприємство «Український науково-дослідний інститут радіо і телебачення»,
вул. Буніна, 3 , м. Одеса, 65026, Україна

tango@i.ua, vladborv@gmail.com

Abstract. *Contemporary methods of audio signals transmission should be aimed at ensuring the so-called immersive (spatial) sounding, wherein the listener could feel himself "as if present" in the original sound field. When developing such methods, it is necessary to take into account the properties of human auditory perception. From previous studies and practical experience of sound engineers, it is known, that changes of the signal levels in certain frequency domains of their spectrum can result in a change of the sensation of the spatial position of the sound source and other spatial characteristics, such as, for example, the experience of the size of sound source, or the depth of the sound image. Taking into account the importance of such line of research, the influence of changes in the frequency response of audio signals transmission chain in the domain of middle and upper frequencies of the audible bandwidth on the spatial properties of the reproduced sound is considered using different types of sound material: symphonic music, jazz and piano solo. During the investigation, the method of subjective assessment of the reproduced sound quality was applied with the invitation of non-professional experts in the room without a special acoustic adaptation, which comply with the situation of listening in typical living accommodation. Listeners were asked to answer the question about changes in the spatial characteristics of the reproduced sound when changing the frequency response at certain frequencies were made. On the basis of the survey results, it is determined for which types of audio material the change in the signal levels is most noticeable, as well as the way the frequency response of the audio signal transmission chain should be changed from the point of view of enhancement of the spatial properties of sounding. The assessment of the reliability of the result obtained is carried out within this proceeding also. Recommendations on the line of further research work on determining the optimal shape of the frequency response of the audio signal transmission chain are given.*

Key words**:** *frequency response, spatial parameters, subjective assessment, sound source*

Анотація. *Сучасні методи передавання аудіо сигналів мають бути орієнтовані на забезпечення так званого іммерсивного (просторового) звучання, за якого слухач міг би відчувати себе «ніби присутнім» у первинному звуковому полі. При розробці таких методів обов'язково слід враховувати властивості слухового сприйняття людини. З попередніх досліджень та практичного досвіду роботи звукорежисерів відомо, що змінення рівнів сигналів у певних частотних областях їх спектрів може призвести до відчуття змінення просторового положення джерела звуку та інших просторових характеристик, таких як, наприклад, відчуття розмірів джерела звуку, або глибини звукової сцени. Враховуючи актуальність такої дослідної тематики, в роботі досліджується вплив змінення АЧХ каналу передавання звукових сигналів в області середніх та верхніх частот звукового діапазону на просторові властивості відтвореного звуку при використанні різних типів звукового матеріалу: симфонічної музики, джазової та фортепіано соло. Під час проведення досліджень було застосовано методику суб'єктивного оцінювання якості відтворюваного звуку із запрошенням непрофесійних експертів у приміщенні без спеціальної акустичної обробки, що відповідає ситуації прослуховування у типових побутових приміщеннях. Слухачам пропонувалося при зміненні АЧХ на певних частотах відповісти на запитання щодо змін у просторових характеристиках відтвореного звуку. На основі результатів опитування*

визначено, для яких типів звукового матеріалу змінення співвідношення рівнів сигналів є найбільш помітним, а також, як має бути змінено форму АЧХ каналу передавання звукових сигналів з точки зору поліпшення просторових характеристик звучання. Також у роботі виконано оцінку достовірності отриманого результату. Надано рекомендації щодо напрямку подальших досліджень з визначення оптимальної форми АЧХ каналу передавання звукових сигналів.

Ключові слова: *АЧХ – просторові параметри – суб'єктивна оцінка – джерело звуку*

Аннотация. *Современные методы передачи аудиосигналов должны быть ориентированы на реализацию так называемого иммерсионного (пространственного) звучания, при котором слушатель мог бы ощущать себя "как бы присутствующим" в первичном звуковом поле. При разработке таких методов обязательно должны быть учтены свойства слухового восприятия человека. Из выполненных ранее исследований и практического опыта работы звукорежиссёров известно, что изменение уровня сигналов в определённых частотных областях их спектров может привести к ощущению изменения пространственного положения источника звука и других пространственных характеристик, таких как, например, ощущение размеров источника звука или глубины звуковой сцены.*

Учитывая актуальность такой исследовательской тематики, в работе исследуется влияние изменения АЧХ канала передачи звуковых сигналов в области средних и верхних частот звукового диапазона на пространственные свойства воспроизводимого звука при использовании разных типов звукового материала: симфонической музыки, джазовой и фортепиано соло.

Во время проведения исследований использовалась методика субъективного оценивания качества воспроизводимого звука с привлечением непрофессиональных экспертов в помещении без специальной акустической обработки, что соответствует ситуации прослушивания в типовых бытовых условиях. Слушателям было предложено при изменении АЧХ на определённых частотах ответить на вопросы относительно изменений пространственных характеристик воспроизводимого звука. На основе результатов опроса определялось, для каких типов звукового материала изменение соотношения уровней сигнала наиболее заметно, а также, как нужно изменить форму АЧХ канала передачи звуковых сигналов с точки зрения улучшения пространственных характеристик звучания.

Также в работе выполнена оценка достоверности полученного результата.

Приведены рекомендации относительно направления дальнейших исследований по определению оптимальной формы АЧХ канала передачи звуковых сигналов.

Ключевые слова: *АЧХ, пространственные параметры, субъективная оценка, источник звука.*

1 INTRODUCTION

Nowadays it can be seen an active development and enhancement of methods, means and the technologies of recording, processing, transmission and reproduction of audio information.

Over the past decade the advanced systems of multichannel sound transmission, which allowed to reproduce in place of listening the sound field that is much more similar to the sound field produced by the original sound source, have been introduced. However, the emergence of high-definition television systems and systems of VR led to the users requirements of greater enhancement of the quality of sound.

First of all, the audience tend to auditory sensation of themselves as "participants", i.e. to be inside the sound field. Therefore, the development of systems, providing the transmission and reproduction of the so-called ìmmersive (spatial) sound, or 3D sound is of current interest.

The research work of variety of the world's research organizations in the field of acoustic engineering is now dedicated to the solution of this task.

It should be noted, that all of these studies are performed with regard to the properties of human's auditory perception. Currently, the investigation and application of spatial hearing properties for sound transmission systems design is a quite relevant objective.

2 THE INVESTIGATION OF THE INFLUENCE OF THE CHANGES IN FREQUENCY RESPONSE OF AUDIO SIGNALS TRANSMISSION CHAIN ON SPATIAL PERCEPTION OF REPRODUCED SOUND IMAGE

2.1 Task description

According to the results of a number of studies, it was found that the boost of the frequency response in some frequency ranges of overall audible bandwidth and, consequently, changing the spectrum shape of a sound signal, can lead to the listener's experience of changing the spatial position of the sound source.

Changing in the experience of sound source direction is illustrated by fig. 1 [1]. On this figure, letters F, B, A indicate the domains of boost of frequency response, at which the effect of the sound coming from the front (F), behind (B), and above (A) is achieved. The value of the boost of the frequency response, enough to obtain a noticeable effect, is not less than 3 - 6 dB [1].

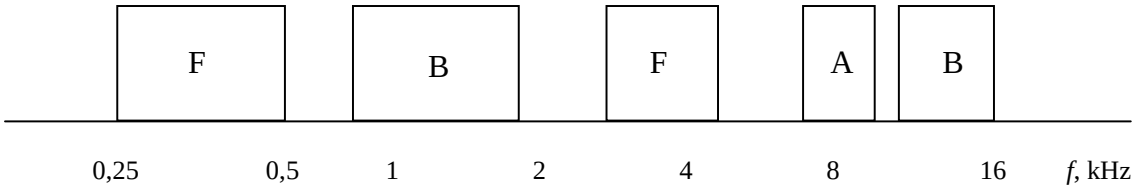

Figure 1 – The domains where the boost of the frequency response results in the effect of removing of the sound source

Such an effect is quite in line with the binaural properties of hearing, which stipulate that the listener is experiencing the nearing or remoteness of the sound object, when changing the signal spectrum shape in the high-frequency domain. However, the ability to estimate the size of sound object, and the overall spatial perspective of sound image is also of interest within the investigation.

Within the research work it was conducted an investigation concerning the impact of the boost of the frequency response of audio signals transmission chain at certain frequencies from a bandwidth of 3000 to 15000 Hz on various components of the spatial impression.

Since the spatial impression consists of different components, and not only reflects the position of the sound source with reference to the listener's position, during the research attention was paid to the following:

- possibility of localization of sound source ;
- estimation of the size of the sound source ;
- the width of the sound image ;
- transparency of sounding;
- general acoustic listening atmosphere.

Such components of spatial impression were chosen based on the recommendations of the European Broadcasting Union – EBU [2].

2.2 The experiment and the results

During the investigation, it was considered whether the boost of the frequency response at medium and high frequencies affects the perception of the mentioned above subjective parameters of sounding. It was also investigated what the value of this boost should be, that the listener could notice the change in the spatial properties of the sounding.

Such investigations are often performed by conducting subjective assessments of sound quality.

For the reference of sound quality should be used the recording of the natural sound of an orchestra, chorus, solo performances, sounding of individual instruments, etc. This reference, common

to all expert listeners, serves as the basis for conducting subjective assessment of sound quality.

While test procedure the experts were surveyed in order to gather information about that types of audio musical signals, for which the change of signal levels at different frequencies (in terms of spatial perception) are most noticeable. Using the digital audio editor Sound Forge the signal levels were changed at the following frequencies: 3,6 kHz; 5,1 kHz; 7,2 kHz; 10 kHz; that allowed to simulate the frequency response shape of the audio signals transmission chain. The increase of signal levels was carried out in the range of 3 to 10 dB. The survey was attended by three groups of listeners with a total of 25 experts.

The expert group was located inside the room without a special acoustic adaptation, which comply with the situation of listening in typical living accommodation. Linear dimensions of the room in the plan view are following: length l = 8 m, width b = 5,9 m. The optimal location of the speaker acoustic systems in the room is shown in Fig. 2. It was determined using the on-line calculator provided on the site acoustic.ua [3]. The height of the position of the acoustic systems is in accordance with the ITU-R Recommendation concerning the systems of stereo and multichannel sound reproduction [4].

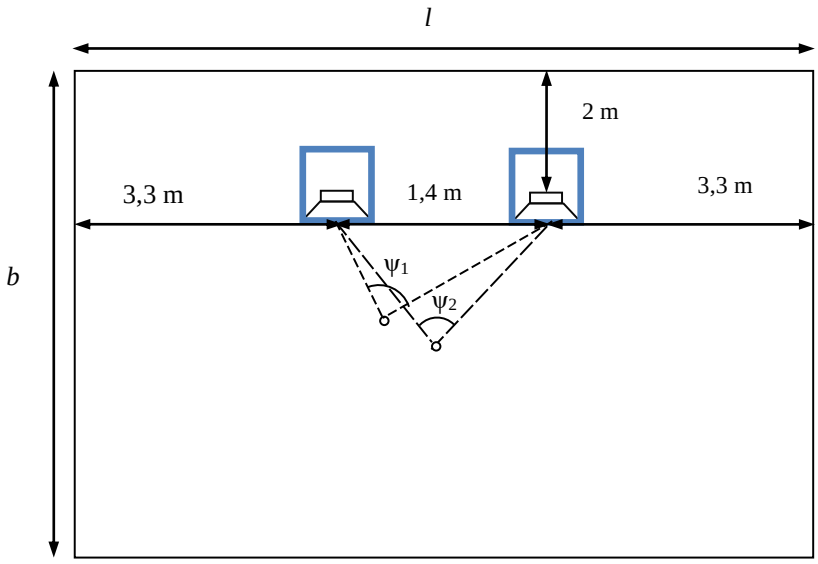

Figure 2 – The dimensions of the listening room in the plan view and location of the acoustic systems used for sound reproduction during the listening tests

It is also important to keep the correct placement of experts in the listening room. It is known that there is a significantly pronounced dependence of the quality of the perceived sound image from the location position of the listener [5, 6]. An undistorted perception of a stereo program, created by a sound producer while recording, will only exist if the listeners are situated in the so-called stereo effect area. According to the results of investigation [6], the limits of the maximum possible area of the stereo effect are determined by the conditions:

$$(12^{\circ}–16^{\circ}) \le \psi \le (90^{\circ}–120^{\circ}), \quad (1)$$

where ψ – the angle, formed by the locations of the loudspeaker monitors and the listener (loudspeaker monitor 1 – listener – loudspeaker monitor 2) (Fig. 2).

For the test purposes a placement was proposed to the listeners, where the condition (1) was fulfilled.

During the listening tests, the following types of audio signals fragments were used:

– symphonic music (L. Beethoven, symphony No. 5),
– jazz music (saxophone) (B. Webster),
– piano.

The special form, having been given to every expert, contained questions about the five

parameters of spatial sounding listed above. During the test, the experts were asked to give a brief answer, whether they noticed some changes regarding the parameters of spatial sound after the boost of the frequency response at certain frequencies for a certain value (unknown for listeners), and whether these changes were towards enhancing the sound quality.

It is considered that changing of the parameters can be characterized as noticeable if more than 50% of the listeners gave a positive answer.

It is also reasonable to assume that, due to the different frequency component in the signal spectrums, the noticeability of changes in spatial properties of sounding as a result of changing the shape of the frequency response will be different for different types of audio signal (different genres).

Based on the processing of the results of the survey, recommendations were made concerning the changing the shape of the frequency response of audio signals transmission chain at the medium and high frequencies domain in terms of improving the spatial properties of reproduced sound.

The result is executed in the form of graphs, given at fig. 3. By ΔN is denoted the boost of the signal level with reference to its initial value.

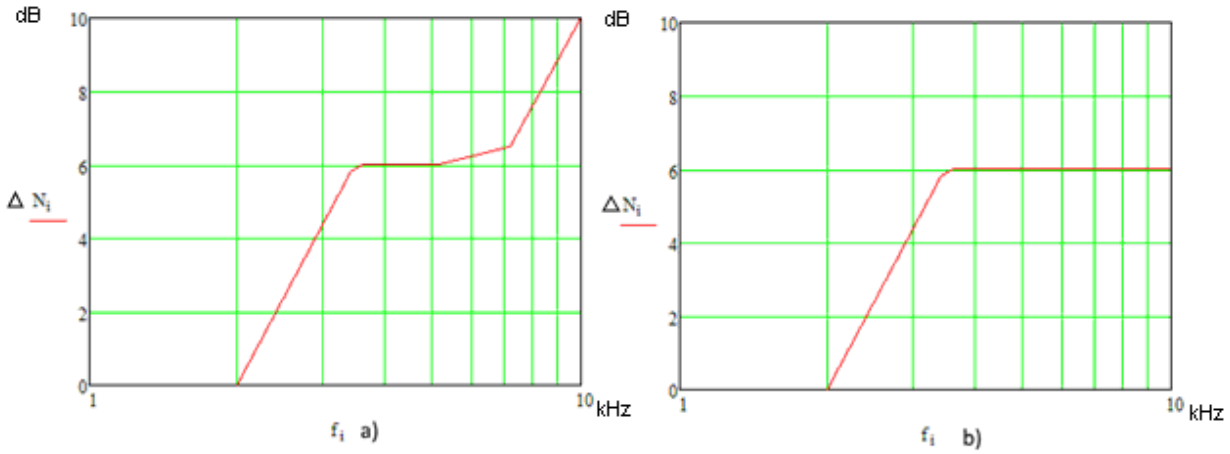

Figure 3 – Dependency graphs of the boost of the signal level from the frequency to achieve enhanced spatial properties of sounding: a) piano; b) saxophone and symphonic music

As can be seen from the graphs, the 6 dB signal boost at medium and high frequencies for the analyzed signal types already leads to the fact that most of listeners noticed some changes in the spatial impression of the reproduced sound and characterize them in such a way that they improve the overall impression of listening. For piano music at frequencies closer to the upper boundary of the audible frequency bandwidth, a gain of the output level of the signal by 6 dB did not lead to a noticeable change in the sounding, such change becomes noticeable when approaching the boost level to 10 dB.

However, at the same time, it should be noted that at some frequencies boost of the signal level will enhance the localization ability and experience of the source size, but the overall sound will be somewhat “non-natural”, and thus unpleasant for some part of the audience. Therefore, it is unreasonable to recommend the significant boost of the signal level at high frequencies, and hence, it is worthwhile to continue research in order to find the optimal shape of the frequency response of audio signals transmission chain in terms of the best balance of “spatiality/naturalness”.

We will add that non-professional experts – students and staff of the department participated in the listening tests, but among the overall listening audience of broadcasting programmes in general, professional musicians, sound producers and sound engineers are substantially less than “untrained” listeners, so the results of the experiment can be considered as indicative.

2.3 Assessment of the reliability of the obtained results

Assume the probability that the change of sounding is noticeable for most listeners is equal to 0,853.

Let's find such error value of the results, for which

$$P\left|\frac{x}{n}-p\right|\le\varepsilon=0{,}853, \tag{2}$$

$\frac{x}{n}$ – relative frequency of the event,

p – probability of an event,

n – number of tests.

For approximate calculation of probability, the following formula can be used [7]:

$$P\left(\left|\frac{x-np}{\sqrt{npq}}\right|<t\right)\approx\Phi(t) \tag{3}$$

In relation to our task, inequality $\left|\frac{x}{n}-p\right|\le\varepsilon$ can be reduced to

$$\left|\frac{x-np}{\sqrt{npq}}\right|<\frac{n\varepsilon}{\sqrt{npq}}=\varepsilon\sqrt{\frac{n}{pq}}=t \tag{4}$$

and, consequently

$$P\left(\left(\left|\frac{x}{n}-p\right|\le t\right)\cdot\sqrt{\frac{pq}{n}}\right)\approx\Phi(t). \tag{5}$$

For the confidence probability of 0,853, we find on the table the integral of probabilities [7] the value of t, whereby $\Phi(t)=0{,}853$:

$t=1{,}45$.

Calculate the estimation error: $\varepsilon=t\sqrt{\frac{pq}{n}}$,

$q=1-p$

$p=0{,}5$

With $n=25$ the value of $\varepsilon=0{,}145$.

Thus, for the available number of expert answers, the error of the result does not exceed 14,5% with the probability of 0,853.

To increase the reliability of the result more participants have to be involved in the subjective assessment tests, thus increasing the number of expert answers.

3 SUMMARY

There is a significant number of methods for improving the quality of sounding in terms of enhancement the spatial parameters of the reproduced sound image. Their review is not in the scope of this proceeding, which considered the interrelation of changing the shape of the frequency response of audio signals transmission chain and the spatial perception of the sound image. Such problem was considered because the correction of the frequency response is quite accessible method of the reproduced sound spatial characteristics harmonizing to the sound engineers while programme-making.

Known data on the influence of the boost of frequency response at certain frequencies on the subjective perception of the spatial properties of the reproduced sound are of a generalized character, without specifying the type of audio signals and conditions for which they were obtained. Within the described investigation, existing data were tested on different types of sound material involving a group of untrained listeners (without musical education and experience in assessment of sound quality), as well as most of the audience listening to the broadcasting service programmes.

The obtained results are presented in the form of graphs on fig. 3, which show the minimum values for the boost of the frequency response, wherein the listener evaluates the sounding as the best in terms of spatial properties. However, these data only take into account localization improvements, more accurate estimates of the source width and overall sound image width. Other characters of sound quality, which are usually drawn attention during subjective assessment of sound quality [2, 5], such as, first of all, the naturalness of timbre, were not taken into account. Therefore, it would be worthwhile to continue work concerning optimization the shape of the frequency response of audio signals transmission chain with regard to enhancement of the spatial impression of sounding while maintaining a high degree of its naturalness.

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