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PSYCHOACOUSTIC INVESTIGATION OF LISTENING WITH QUADROPHONIC EARPHONES

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Despite the existence of a variety of designs of quadrophonic earphones, there have been no papers concerned with the psychoacoustic phenomena accompanying quadrophonic earphone projection. The present paper presents the results of seven experiments in the field of the psychoacoustics of hearing under conditions of earphone projection involving the use of four transducers, and also presents the technical principles of the formation of binaural images. The results obtained permit the conclusion to be drawn that quadrophonic or even stereophonic earphone projection involving four transducers enables the sound sources to be located outside the listener's head. It seems interesting that the listening to stereophonic signals with four transducers gives effects incomparably better than those for the projection with two transducers and is of a quality comparable with the monitoring of quadrophonic signals.

1. Introduction

The development of phonic techniques, permitting the multichannel recording of sound has caused an increasing interest in multichannel systems of sound projection which permit the formation of complex spatial images with the signals emitted from many electroacoustic sources placed in a given space. The best known of systems of this type is that of quadrophonic projection consisting of sound emission from four sources located around the listener and controlled by the signals: *LF* (left front), *RF* (right front), *LR* (left rear), and *RR* (right rear). Various multichannel systems of sound projection are met at present in shows and cinema halls, in the outdoor spectacles of the "Son et Lumière" type, in variety shows, and even in apartments. In all cases the sound is emitted from sets or columns of loudspeakers.

The spreading of multichannel techniques of sound projection caused the first multichannel earphones, the so called quadrophonic earphones, to appear in the early 1970's. Typical quadrophonic earphones are equipped with four transducers — placed in pairs in enclosures around the ears — permitting

independent emission to the listener's ears of signals from the front (F) and rear (R) channels. The idea of quadrophonic earphones — permitting the formation of spatial sound impressions similar to the impressions caused by multichannel systems of loudspeaker projection, and at the same time permitting the technical requirements to be simplified and the cost to be lowered considerably — has long fascinated designers, while at same time raising many doubts. The difficulties in the evaluation of the possibility of building coherent three-dimensional spatial impressions with earphone projection were due primarily to the lack of fundamental research in the field of multichannel audio monitoring. The possiblity of the listener being able to separate and locate the signals from the front and rear channels seemed the most controversial question. In general, there is a lack of papers concerning, for example, the influence of the ear lobe on the sound impressions produced under conditions of earphone projection.

The investigations reported here were aimed at the evaluation of the resolution of signals radiated by the front and rear transducers under different projection conditions and the qualitative comparative evaluation of quadrophonic earphones in the stereo and quadrophonic projection of test signals. The investigations were performed on three models (A, B, C) of quadrophonic earphones designed in KAM-PWSM (Department of Musical Acoustics, State Higher Musical School) [6]. Each of the models was equipped with four Tonsil SN 60 transducers placed in pairs in the right and left earphone enclosures. All the transducers were in the same horizontal plane, producing a system which was symmetrical with respect to the plane which included the centres of the listener's ears. In models A and B, the individual pairs of transducers were placed parallel to each other (side by side) at distances of 30 and 45 mm, respectively. In model C the distance between the transducers was $l = 45$ mm, as in model B, but the planes of the transducer membranes were at an angle of 135° to each other. Model C was designed in two versions (C-1 and C-2) differing only in the form of the earphone pads. The C-2 version, which was equipped with deeper and more elastic pads, was investigated in the later phase of the experiments.

In addition, three standard foreign-made earphones were included in the investigations: DT 204 of Beyer, DH 32Q of Hosiden, and 5844 of JVC Nivico.

Also, in the comparative evaluation phase the investigations included a pair of broadband stereophonic ZWG Tonsil SN 60 earphones.

The audio monitoring group consisted of 15 persons chosen from among the staff and students of the Sound Recording Department of State Higher Musical School in Warsaw. All the tests were made on each participant individually.

The experimental investigations performed consisted of 7 tests. The tests were concerned with:

(a) the recognition of signals radiated by individually activated front and rear transducers;

(*b*) the discrimination between mono and stereophonic projections from a set of transducers operating in a common casing;

(*c*) the discrimination between stereophonic signals radiated by the front and rear pairs of transducers;

(*d*) the discrimination between two-transducer and four-transducer stereophonic projections by quadrophonic earphones;

(*e*) the discrimination between mono, stereo and quadrophonic projections;

(*f*) a comparative evaluation of the quality of quadrophonic earphones;

(*g*) a comparison of the properties of quadrophonic monitoring with earphones and with loudspeakers.

2. Recognition of signals radiated by individually activated transducers

The aim of this phase of the investigations was the determination of the possibility of the listener recognition of the signals emitted by the individual transducers. The earphones were activated individually with a tone at a frequency of 1000 Hz or with white noise. The test signals were reproduced from a tape recorder through a switch system permitting the selection of one of eight possibilities: *FR*-tone, *FR*-noise, *LF*-tone, *LF*-noise, *RR*-tone, *RR*-noise, *LR*-tone, and *LR*-noise.

A single test consisted of 16 tasks (two tasks of each type) in random succession. The duration of the test tasks was 5 s, with pauses for the listener's answer lasting about 3 s. The duration of the test for one earphone was about 2 min, with the duration of the test for all the earphones being about 20 min. The task of the experts was to determine the direction of the signal received: *RF*, *LF*, *RR*, or *LR*.

The results obtained for the different signals are shown in Table 1.

Table 1. Recognition of signals radiated by individually activated front and rear transducers

Kind of signal	Percentage of correct answers P				
	A	*B*	*C* – 1	DT 204	DH 320
Tone 1000 Hz	57	87.5	68.1	78.8	58.8
White noise	98.8	98.8	100	100	97.6

The results obtained show that with the earphones having four transducers, in addition to the obvious possibility of "left-right" direction differentiation, it is possible also to differentiate between transducers in the "front-rear" configuration. The resolution of the transducers is closely correlated with the spectral structure of the signal emitted. In the testing of the individual transducers with a signal having a wide spectrum (white noise), the sample investi-

gation showed nearly 100 percent agreement between the responses and the real projection conditions. However, for the emission of a sinusoidal signal, the number of correct answers decreased to between 60 and 90 %, depending on the specific design of the earphone (the possibility of identification is represented by $P \geqslant 75\,\%$). In the interpretation of the results obtained it should be stressed that the possibility of identifying the transducers is not equivalent to the specific directional location of the sound impressions received. The basic criterion permitting the resolution of the signals emitted by the front and rear transducers was the difference in the timbre of the impressions received, resulting from the transformation of the spectrum of the signals received, due to the influence of the ear lobes and hearing channels of the observer. In the case of broadband signals, a characteristic distortion of timbre occurring on the signals emitted in the rear channels (a decreased content of higher frequency components) enabled the evaluators to perform the test tasks correctly. However, at the same time — apart from whether the front or rear transducer was operating — the listeners retained the impression that the sound source was located directly in the excited ear.

In case of narrowband signals when the screening effect of the ear lobe was evidenced only by slight changes of the loudness of the signal emitted by the front or rear transducer, the discrimination between the projection conditions was considerably worse.

The above observations permit the conclusion to be drawn that in quadrophonic earphone projection, the amount of directional information on the location of the sources in the lateral spaces is very limited. The situation is analogous to the uniaural reception od signals reaching the listener as a result of quadrophonic loudspeaker projection [2]. In both cases the decrease in the amount of information on the spatial distribution of the sources results from the lack of binaural perception of the signals carrying the information.

3. Discrimination between mono- and stereophonic projection for a set of transducers working in a common casing

The aim of the investigation was to determine the possibility of listener discrimination between mono and stereophonic projection of signals to one ear. The sound material of the test was a stereophonic tape recording of the song "Aquarius" from the musical "Hair". A sound signal was transmitted to a pair of transducers placed in a common encasing and reproduced mono- or stereo-phonically in ten-second fragments with a one-second pause between successive tasks. Altogether, the test contained eight tasks in random order. Each test was preceded by four examples demonstrating mono and stereophonic projections in a *M-S-M-S* regime (4×5 s). The duration of the test for one earphone was about 2 min. and it took about 10 min. to test all the earphones. The task of

the experts was to determine whether the fragment of the song presented was reproduced mono-or stereophonically.

The results obtained are shown in Table 2.

Table 2. Results of the discrimination between mono- and stereophonic projections for one ear

Earphone	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	$\bar{x}$	σ	*P*[%]
KAM/*A*	4	4	3	5	5	3	4	4	6	5	4.3	0.95	53.8
KAM/*B*	7	7	8	4	7	7	6	6	7	6	6.5	1.08	81.2
KAM/*C* – 1	7	8	3	8	5	5	6	5	6	7	6.0	1.56	75.0
DT 204	6	4	6	8	5	7	8	4	6	7	6.4	1.43	80.0
DH 32 *Q*	5	4	6	8	5	8	3	8	6	7	5.7	1.70	71.2

$\bar{x}$ – arithmetic mean of results obtained for 10 listeners
σ – standard deviation of results
P – percentage of correct answers

The results obtained show that with two-transducer emission of signals to one ear it is possible to distinguish a monophonic projection from a stereophonic one ($P \geqslant 75\,\%$). The criteria permitting such a distinction are not, however, unambiguous, since none of the earphones investigated gave a 100 percent correct response and none of the experts avoided mistakes in the solution of the test tasks.

The results of the experiment performed show a significant correlation with some of the results obtained in the first experiment (see Table 1 under a continuous tone test signal at 1000 Hz). Classifying the earphones tested in terms of the percentage of correct answers, both tests gave the same rank order: KAM, DT 204, KAM $C-1$, DH 32Q, KAM/A. The results of the Students t – test showed that, in addition, the differences between the first four earphones of the above series were statistically insignificant. However, the differentiation of the type of projection for earphone KAM/A was significantly worse (at a level of $\alpha = 0.05$). In the interpretation of the above results it should also be observed that the first three earphone designs are among those with a relatively long distance between transducer centres ($l = 45$ mm), while in model KAM/A the centre spacing was considerably shorter ($l = 30$ mm). The design of the DH 32Q earphones is essentially different from the other designs. Three transducers (two high-tone and one low-tone) are placed in each enclosure of the earphones, with the signals from both F and R channels being supplied – through electrical switches – to a common low-tone transducer in the central position facing the inlet of the ear channel, and to two high-tone transducers deeper placed inside the enclosure, with their radiation axes facing each other. As a result, for both mono and stereo emissions the low-tone signals retain the central location, and the signals emitted by high-tone transducers mix in the common part of the inner earphone chamber; thus the directional information contained in these signals becomes less distinct.

4. Discrimination between stereophonic signals radiated by the front and rear pairs of transducer

As before, the sound material used in the experiment was a stereophonic recording of the song "Aquarius" from the musical "Hair". The sound signal was supplied to the front and rear pairs of transducers in ten-second fragments divided by one-second pauses. The test consisted of eight sound tasks presented in random order, preceded by four examples demonstrating the projection by the front and rear pairs of transducers — in the regime $F-R-F-R$ (4×5 s). The duration of the test was about 2 min. for one earphone. The task of the experts was to determine which pair of the transducers was reproducing the song fragment heard.

The results obtained are shown in Table 3.

Table 3. Results of discrimination between of stereophonic signals radiated by the front and rear pairs of transducers

Expert / Earphone	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	$\bar{x}$	σ	*P*%
KAM/*A*	7	8	5	4	6	6	7	8	8	8	6.7	1.42	83.75
KAM/*B*	8	7	8	7	8	8	8	8	8	8	7.8	0.42	97.5
KAM/*C* − 1	8	8	6	7	8	7	6	8	8	8	7.4	0.84	92.5
DT 204	8	8	7	8	8	8	8	8	8	8	7.9	0.32	98.75
DH 32*Q*	6	7	6	7	6	7	7	4	6	4	6.0	1.15	75

$\bar{x}$ — arithmetic mean of results obtained for 10 listeners
σ — standard deviation of results
P — percentage of correct answers

The results of the experiment performed show the possibility of resolving the projection of stereophonic signals emitted from the front and rear pairs of the transducers of quadrophonic earphones ($P \geqslant 75\,\%$). The very high mean values for the percentage of correct answers for most of the earphones tested, show that the correct solution of the test tasks was not difficult for the participants in the experiments. The imposing evaluation criterion was a different sound perspective for the work of the front and the rear channels. Changes of the spectrum of the signals radiated by the rear transducers, resulting from the screening effect of the ear lobes, were interpreted by the monitoring group as fading and flattening of the subjective space of the sound events. The effect was greatest for the earphones with a long distance between the transducer centres (*DT* 204, KAM/*B*, KAM/*C* − 1), and was less noticeable for earphones KAM/*A*, and, in particular, for DH 32*Q* (a difference significant at a level of $\alpha = 0.02$).

5. Discrimination between two-transducer and four-transducer stereophonic projections by quadrophonic earphones

The aim of the following experiments was to establish subjective criteria which would permit the listeners to distinguish between two-transducer and four-transducer stereophonic projections (the possibility of such a distinction was shown indirectly in the investigations discussed above).

The investigations were performed on the three pairs of earphones, which in the previous experiments showed the highest resolution of the signals emitted by the individual transducers, i.e. *DT* 204, KAM/*B*, KAM/*C*−1, also on KAM/*C*−2 (a model similar in design to KAM/*C*−1, but equipped with different ear-pads) and on JVC 5844 (of Nivico). The JVC 5844 earphone represented in terms of design a type similar to the KAM/*C* models, with transducers inclined at an angle, of centre-spacing $l = 50$ mm, placed in spacious, deep, earphone enclosures.

Two experiments were made within the framework of the evaluation. In the first experiment a stereophonic recording of popular music was switched by the operator to the transmission channels *LF* and *RF*, or *LF* + *LR* and *RF* + + *RR*, respectively. The test contained 10 tasks presented in random order (five tasks for each projection variation), preceded by four examples demonstrating two-transducer and four-transducer projection. The duration of each task was 10 s., the duration of the pause between successive tasks was 1 s. In view of the higher pressure level produced by the earphones in four-transducer emission, and also because of the varying efficiency of the earphones tested, the investigations were preceded by a regulation of the testing levels so that during the evaluation, the listeners had the impression that the individual signals were of the same loudness.

Five experts participated in the audio monitorings. The task they were given was to determine whether the signal they heard was emitted from two or four transducers. As was expected, the results of the evaluation showed 10 percentage agreement between the answers and the real projection conditions.

The same group of listeners participated in the second part of the experiment. The experts' task was to compare the features of the projection discussed for all the earphones investigated, and subsequently to formulate observations on the variation in the sound timbre, directional location and spatial character of each of the projection variants. The monitoring was performed according to the principles of free rate of testing and free selection [5].

The experimental material permitted the following hypotheses to be formulated, concerning esthetic criteria for differentiating between two-transducer and four-transducer stereophonic conditions.

The essential differences, as stressed by all the evaluators, concern the imaginative space of the sound impressions received. In the case of two-transducer projection the sources of the sound image were located, in the listeners' opinion, inside the head, along a line in the form of a flat arc connecting the

ears. With four-transducer projection the sources of the sound image were lowered or retreated, forming a space of sound action which expanded behind the listener's head, with decreasing resolution of the sound impressions obtained.

The fascination with spatial effects — unobtainable in the two-transducer transmission — caused the listeners' attention to concentrate to a lesser degree on the timbre of the sound. Nevertheless, the impressions obtained in four-transducer projection were found to be more natural, and closer to the subjective standards established in the direct listening.

In the general evaluation of the quality of the monitoring the experts' preference was the same: the four-transducer projection was considered to be decisively better.

An attempt at relating the regularities observed to the objective transmission conditions occurring in two-transducer and four-transducer projection of the signals leads to the observation that the basic cause of the difference in the sound impressions for the two-transducer and four-transducer stereophonic transmission is the asymmetry of the outer ear, which introduces different spectral transformations of the signals from the front and rear transducers.

The present asymmetry — apart from the modification of the transmission characteristics for the individual channels — also introduces time delays between the signals reaching the inlet of the ear channel from the front and the rear transducers. The combined influence of the factors mentioned above causes the four-transducer stereophonic projection to give a stronger impression (with respect to the conventional two-transducer projection) of the deepening of the sense of space of the sound image and the location of the sound sources outside the listener's head.

It is worth noting that in stereophonic earphone projection the time delays between the signals reaching the listener's ears are the basic cause of the effect of the sound sources being located outside the head. The time delays can have a twofold character

(a) as a delay in the time arrival of the same signal from one ear to the other,

(b) ambiphonic delays in signals reaching the same ear. In the case of four-transducer stereophonic projection the second factor plays an essential role. The time delay between the ears for the same signal (immitating the monitoring conditions occurring with loudspeaker projection) can also lead to the location of the sound sources outside the listener's head; however, at present there is a lack of adequate data concerning the conditions necessary to obtain a natural spatial effect in this manner.

6. Discrimination between four-transducer mono, stereo and quadrophonic projections

The aim of the present investigation was to determine the possibility of the listeners differentiating between the mono, stereo and quadrophonic projection of signals by quadrophonic earphones. The investigations were performed for five types of quadrophonic earphones, i.e. DT 204, JVC 5844, KAM/*B*,

KAM/$C-1$ and KAM/$C-2$. The sound material used consisted of quadrophonic recordings of popular and symphonic music from the demonstration tape of the SANSUI firm, reproduced on a quadrophonic tape recorder *M* 2406 *QD*. Signals from the tape-recorder were supplied to the earphones through a mono-stereo-quadro switch permitting the combination of signals in accordance with the desired projection conditions.

Ten experts participated in the evaluation, each performing 45 test tasks (9 tasks for each earphone). Test tasks for each earphone were randomly ordered. The duration of each test task was 10 s., with a one-second pause between successive tasks. Each monitoring series was preceded by three examples: of mono, stereo and quadrophonic projections, respectively.

The results obtained are shown in Table 4.

Table 4. Discrimination between mono-, stereo-, and quadrophonic projections by quadrophonic earphones

Projection conditions	*M*	*S*	*Q*	*P*[%]
M	147	3	0	98
S	1	86	63	57.3
Q	0	67	83	55,3

The results of the investigation show, under the conditions of the experiments performed, that the essential qualitative difference permitting a correct identification of the variants of the projection presented occurred for the comparison of "mono" and "stereo" monitorings; while "stereo" and "quadro" projections were, in general, indistinguishable.

The results of the investigations complement the conclusions drawn earlier that stereophonic transmission through quadrophonic earphones leads to a considerable increase in the quality of the monitoring compared to conventional monitoring involving two transducers. As has been shown by the present investigations, the use of four independent transmission channels does not — under earphone conditions — appear to make the listener's sound impressions any more attractive.

On the basis of the conclusions and observations made during the investigations performed a general classification can be established of earphone systems of sound projection, in terms of the possibility of forming an imaginary space for the sound events (Table 5).

7. Qualitative evaluation of earphones with quadrophonic projection

The evaluation of the quadrophonic monitoring was made for all the seven pairs of quadrophonic earphones used in the previous experiments. A stereophonic pair SN 60 was also included in the investigations, its transducers being supplied with signals *LF* and *RF*, respectively.

Table 5. Earphone projection classification

No	Signal	Projection system	Observations
1	Monophonic	One-, two-transducer to one ear	Location of sound directly in the stimulated ear
2	Monophonic	Two-, four-transducer to both ears	Location of sound "in the middle" of the listener's head
3	Stereophonic	Two-transducer to both ears	Location of sound "inside" the head on a line between the ears
4	Stereophonic Quadrophonic	Four-transducer to both ears	Location of sound "outside" the listener's head*

* The effect of the location of the sound outside the listener's head can also be achieved during conventional binaural two-transducer projection. However, it involves the use of specialised recording or reproduction conditions for the sound signals, including the "artificial head" technique [3], two-channel projection of coded signals of a matrix of quadrophonic signals [1], or the technique of electronic mixing and mutual delaying of the L- and R-signals [7].

The evaluation was made, based on the method of ordering the earphones, with each of the 10 experts giving 7 points to the earphones he found best, while the other earphones were assigned 6, 5, 4, 3, 2, 1 and 0 points. The timbre of sound, sense of space, location of the sources and listening comfort were taken as the basic parameters giving jointly a general qualitative evaluation of the earphones compared.

Before the monitoring the levels of signals controlling the individual earphones were individually adjusted. A quadrophonic test recording of popular music by Polish Radio and Television was used as the sound material. The monitoring was performed at the listeners' own rate and with free selection. The total duration of the listening was about 30 min. for each listener.

The results obtained are shown in Table 6.

Table 6. Results of general evaluation of the quality of the earphones during quadrophonic projection

Earphone	A	B	C	D	E	F	G	H	J	K	Σ	$\bar{x}$	σ
KAM/A	2	3	1	4	3	3	5	1	4	2	28	2.8	1.31
KAM/B	3	5	3	6	6	6	7	6	7	6	55	5.5	1.43
KAM/$C-1$	5	4	5	3	2	2	1	3	2	4	31	3.1	1.37
KAM/$C-2$	6	5	2	7	4	4	4	4	5	5	46	4.6	1.35
DT 204	7	0	6	2	7	7	6	5	3	3	46	4.6	2.46
JVC 5844	4	7	7	5	5	5	3	7	6	7	56	5.6	1.43
DH 32 Q	0	1	4	0	0	1	2	2	0	0	10	1.0	1.34
SN 60	1	2	0	1	1	0	0	0	1	1	7	0.7	0.68

The results obtained show a lack of conformity of opinion among the experts participating in the monitoring. Two earphones were outstanding in the general evaluation: JVC 5844 and KAM/*B*. The second group – from the point of view of the preferences recorded – included earphones KAM/*C*–2 and DT 204, another group included KAM/*C*–1 and KAM/*A*, while DH 32*Q* earphones and the stereophonic earphones SN–60 were found to be the worst. The existence of significant differences was determined, using the Students t–test at a level $\alpha = 0.05$, between the first and the third groups and between the fourth and the first three groups, respectively.

A random examination of the listeners' opinions showed that earphones JVC 5844 and KAM/*B* were found to be best from the point of view of timbre, JVC 5844 and KAM/*C*–2 were found best from the point of view of the sense of sound space, and earphones KAM/*B* and JVC 5844 were found best from the point of view of the spatial location of the sources. These opinions are confirmed by the objective properties of the earphones discussed [6]. Earphones JVC 5844 and KAM/*B* showed the flattest frequency transmission characteristics of the transducers as measured by the *B*–*K* type 4133 "artificial head" method. At the same time these earphones, for the group under investigation reproduced high tones best, and were thus ranked highly from the point of view of the differences in the locations of sound sources. In turn, earphones JVC–5844 and KAM/*C*–2, the designs with the deepest earphone chambers and with the planes of the transducers inclined at an angle, gave the best impression of the sound space [6].

The very low ranking of the SN–60 stereophonic earphone (which was found worst in the group) confirmed an earlier thesis that four-transducer earphone monitoring is decisively better than two-transducer monitoring.

8. Comparison of the properties of quadrophonic monitoring by earphones with loudspeaker monitoring

A comparative evaluation of quadrophonic monitoring by earphones and by loudspeakers was performed using the following criteria: a general evaluation, the sense of the sound space, the quality in differentiating the phantom sources, sound quality and naturalness of the phantom sources located at the back, and the distinctness of the sound impression. A quadrophonic JVC 5844 earphone and four cased matched loudspeaker sets *GK*–132 (from "Fonia") were selected for the investigations.

The comparison was performed in the audio monitoring room of the State Higher Musical School in Warsaw. A test recording of popular music by Polish Radio and Television was used as the sound material. Fifteen experts participated in the investigations. They compared – individually – the two variants of quadrophonic sound projection.

The results of the experiment showed considerable differences of opinion

from all the participants in the monitoring. Some experts, considering the presented projection variants as incomparable, declined to give their opinions in terms of the qualitative criteria suggested. The preferences of the remaining listeners presented a very indistinct picture of the relation between the two systems of quadrophonic sound projection compared (Table 7).

Table 7. Results of quality evaluation of quadrophonic monitoring by loudspeakers and by earphones

Criterion	Preferred monitoring system			No. opinion
	Loudspeakers	Earphones	Comparable quality	
General evaluation	9	5	—	1
Sense of space	6	2	2	5
Spatial stability	1	3	—	11
Quality in differentiating the phantom sources	2	2	3	8
Naturalness of the sources behind the listener's head	3	1	—	11
Distinctness of sound impression	2	4	2	7

The results obtained show that the sound impressions occurring under quadrophonic sound projection by loudspeakers and by earphones belong to essentially different aesthetic categories, the preference of one of the two projection variants depending primarily on the predispositions and likings of the individual listeners.

9. Conclusions

(1) With two-transducer emission of signals into one ear, the listener is able to recognize the projection conditions when only one transducer is being operated, and to distinguish mono from stereophonic projection during the simultaneous operation of the transducers. The degree of recognition of the projection conditions is closely related to the spectral structure of the signals emitted (the wider the bandwidth of the signal, the better the recognition of the projection conditions becomes).

(2) Four-transducer earphones assure the posibility of distinguishing between signals coming from the front and the rear pairs of transducers.

(3) It follows from the experiments performed that differences in timbre and the mutual time delays of the signals coming from the front and rear transducer pairs determine the directional and spatial impressions during four-transducer earphone monitoring.

(4) Four-transducer earphones permit monitoring of quadrophonic signals and also of stereophonic signals emitted by two-and four-transducer systems.

(5) Quadrophonic earphone monitoring permits location of the sound sources outside the head and considerable deepening of the spatial sense of the sound image. However, the possibility of locating directions over the whole range of space angles is not to be expected.

(6) Four-transducer two-channel monitoring represents a very great improvement in quality with respect to traditional two-transducer monitoring (considerably greater than the step between the four-transducer two-channel monitoring and quadrophonic monitoring).

(7) Four-transducer projection of stereophonic signals permits location of the sound outside the listener's head and compared to other, special techniques of earphone projection which give the effect mentioned above, seems to be the most natural and at the same time the most attractive from the economic point of view.

(8) The quality of the sound image and the listening comfort achieved under conditions of four-transducer binaural projection depend primarily on:

(a) the quality of the earphone transducers used,

(b) sufficiently large earphone enclosures,

(c) the distance between the transducers in a pair, and their position relative to the ear lobe,

(d) the quality of contact between the earphones and the listener's head.

(9) In comparing quadrophonic earphone monitoring with quadrophonic loudspeaker monitoring it should be noted that the sound impressions occurring under the two monitoring conditions belong to basically different aesthetic categories, preference towards one or other of the two sound projection variants depending primarily on the individual predispositions and likings of the listeners.

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