ARCHIVES OF ACOUSTICS
36, 2, 333–345 (2011)

DOI: 10.2478/v10168-011-0025-9

Comparison of Sound Attributes of Multichannel and Mixed-Down Stereo Recordings

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(*received February 10, 2011; accepted April 15, 2011*)

The work presents a comparison of some sound attributes perceived at a multichannel and stereo playback of musical recordings. The width of the virtual source, coherence impression, total size of sound scene, general quality and balance were the subjects of interest after the format reduction in accordance with the ITU recommendation. The results showed that evaluation of these attributes depends on the way the original audiosphere has been created in the surround system, for example, for a narrow virtual source the mix-down process causes only a small change in its size but for a broad source the observed degradation is significant. In addition, different ways of conversion from the multichannel to stereo format have been tested for compatibility.

Keywords: sound quality, recording formats, art of mixing.

1. Introduction

In spite of the fact that surround playback systems have become deeply rooted into the audio area, the classical stereo recordings remain the most important branch of the audio industry, particularly in the musical domain. It is a result of many advantages of two-channel stereo systems such as the use and placement of only two loudspeaker systems and fulfilling non-critical requirements for the listening room in comparison to listening conditions for a surround playback system. Of course, the optimal impressions of the sound image can be perceived only in a narrow listening area called “sweet point”, nevertheless, many listeners' opinion is that “well-made stereo sounds everywhere”.

There are many recordings in 5.1 surround format which can be played as a two-channel stereo, for example, headphone listening, only as a result of reducing the number of channels, a so-called mix-down process. One way of the mixing-down operation is recommended by the International Telecommunication Union – ITU-RBS 775-1 (1994). The other way is to playback an additional DVD stereo track which has been previously prepared as an independent mix from the same material as the one used for the surround recording but differently mixed. A dummy head is sometimes used for recording for improvement of the spatial impression quality via headphone listening when musical material is reproduced with a surround system (Deschamps *et al.*, 2003).

Achieving the same (or similar) hearing impressions when both stereo and multichannel recordings are presented, which is the essence of recording compatibility highly desirable to obtain by many producers and recording engineers, is a very important aspect. The work presents a comparison of some sound attributes during a multichannel and stereo playback. The width of the virtual source, coherence impression, total size of the frontal sound scene and clarity of the sound image were the subjects of interest when the format was reduced in accordance with the ITU recommendation. The subjective tests have been provided for various means of recordings prepared in 5.1 format and then mixed-down to the two-channel stereo. Changes of particular attributes during a stereo presentation were observed and compared to the original ones in a higher format.

2. Mix-down versus stereo in compatibility aspects

Suggested by the ITU recommendation (1994) the algorithm for stereo preparation from 5.1 format is based on the following formulas:

$$\mathrm{L} = \mathrm{LF} + 0.7\mathrm{C} + k\mathrm{LS} \quad \text{and} \quad \mathrm{R} = \mathrm{RF} + 0.7\mathrm{C} + k\mathrm{RS},$$

where L, R are stereo channels, left and right respectively, LF, RF are front channels of 5.1 format, left and right respectively, C is the central channel of 5.1 format, LS, RS are surround (rear) channels of 5.1 format, left and right respectively, and k is the coefficient of importance ($k = 0, \ldots, 1$).

The main interest of recording compatibility is that most attributes have to be the same (or similar) when subjects listen to a stereo recording as a result of mix-down process and recording in its original 5.1 format. According to this recommendation, it seems to be obvious that the most significant factor that influences the coherence of both the surround and stereo impressions is a distribution of the signals for the specific five channels. When some important sources are given to the rear channels it must cause the k value of 1. On the other hand, that level of importance might not be achieved in the stereo format, when the mix-down process is done with a lower value of k and as a result one obtains a low-quality recording with a wrong balance. In the classical music the method called "in front of the band" is often applied, i.e., the rear channels are usually used to create an ambience or space impression or special musical effects, while the proper musical action takes place in front of the listeners, being reproduced by the three front channels. In the popular and jazz music the situation can be different when the method called "inside of the band" is applied, i.e., the listener is as one of the band members and the sound from various instruments surrounds him/her, which involves k value as equal to 1. Of course, in the second method of the sound scene creation it is impossible to achieve the original sound source localization, so it is highly recommended to create an additional, two-channel stereo track with a proper mix done by the producer. Except for a proper balance, almost all important sound attributes can be achieved in a good agreement with an originally applied intention meant for the surround format, whereas creation of the sound scene in 5.1 system involves some roles and facts of signal processing and its reflection in the process of hearing.

From the compatibility point of view the act of space creation in a higher format cannot be restricted by the limitations of a lower format when the differences in kinds of audiosphere being possible to obtain are assumed (Bartlett, 2007). For example, when a specific sound scene ranges from left to right and it results from use of the three front channels to which the direct signals are fed, while the rear channels reproduce only the indirect signal of space impression information, after mix-down operation the space information might be found in front of the listener but important semantic signals will remain untouched. Thus, a general impression about the only difference between such a recording and its original is that the ambience has changed its position without any significant influence on the other sound attributes (Bregman, 1990) making the multichannel and stereo impressions comparable.

The central channel might be used in two ways in surround systems, i.e., as a sound source for reproducing the direct signals or as a means of creation of a sound perspective by the way of using the indirect parts of the signals being reproduced by the other two front channels. The change of the balance between the direct and indirect sounds reproduced by the central channel may influence the stability of specific virtual sources in the frontal plane, i.e., a higher amount of the direct signal makes these sources more stable. When the mixing-down process takes place the source positions would be unchanged making the whole front part of the sound scene similar to a multichannel one.

3. Experiment

In order to find the relations between the way of preparing 5.1 surround mix and impressions before and after the mixing-down process the listening tests have been carried out. The musical material containing four pieces of popular music had been recorded and mixed in the surround format in a way that would bring into relief the specific tested sound attribute, then mixed-down to a two-channel stereo, which allows to obtain two samples in 5.1 and stereo formats, respectively. The Magix Samplitude was used for the preparation as well as for the playback. The listeners' task was to compare the tested specific attributes presented in pairs which consisted of recordings of both formats, to assess the second sample in reference to the first one, and to estimate the investigated sound attribute in the range from -3 to 3. The two 30-second samples with a 5-second pause between them were presented in a random order. The listeners were informed which attribute was being tested but the values of some parameters of the sound image were unknown. The samples were reproduced from a computer as one specific arrangement of five variants which differed in order of the samples and their features. In one arrangement the particular value of the investigated attribute was presented three times. The answers were noted in test charts and the listener marked the number of the presented arrangements. Ten people with normal, good hearing (with hearing loss no greater than 5 dB that had been confirmed in audiometric tests with Maico M53 Audiometer) participated in the experiment. All of them were experienced in sound mixing and listening experiments. As a result, for each value of every attribute 30 answers per measurement point have been collected. With regard to the sweet point, tests were provided individually for each listener. A duration of one listening session did not exceed the recommended values (EBU, 1999a). The results have been taken to the statistical treatment with Wilcoxon test (Koronacki *et al.*, 2001), where the lower tail value for this experimental condition is $S_\alpha = 138$, while the upper tail value is $S_\alpha = 327$. On the basis of the analysis of the variance (Greń, 1978) it was found that for all tested attributes and particular parameters there was a good convergence between all the subjects' notes, and evaluation did not depend on the listener in all cases at the 95% of confidence ($F < F_\alpha = 2.39$, where F, F_α are the calculated and critical values of the F-Snedecor test, respectively). This fact allowed to average all of the obtained notes for the specific sound attribute and create the degree indicating the difference (D) between the evaluated, averaged values for the surround (A) and stereo (B) systems. The positive or negative values indicate that a specific attribute is perceived as better for the surround or stereo playback, respectively. For the two-channel stereo exposure, the front

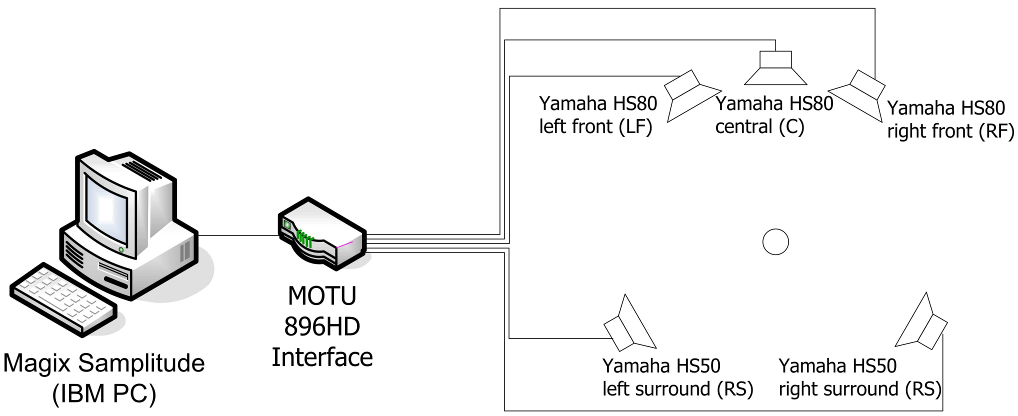

Fig. 1. Scenery of the experiments. The RF and LF were used for 2.0 exposure.

loudspeaker systems, left and right, were used with the other channels muted (of course, in the surround exposure all the channels were applied).

The tests have been done in the control room of the recording studio at the Institute of Telecommunications, Teleinformatics and Acoustics, Wroclaw University of Technology, which features the acoustical conditions recommended for such an application (Bolejko *et al.*, 2003; EBU, 1999a). The set of Yamaha HS 80 and HS 50 was used as the loudspeaker system after a calibrating procedure.

4. Results

The results of the subjective tests examining some sound attributes perceived in both the surround and stereo formats are presented in the following figures. They are expressed as subjectively perceived impressions of the two formats playback. These values have been averaged over all the ten listeners. In the following figures the standard deviation values are presented as vertical lines on the tops of the bars. The interpretations of these results are given in the following subchapters.

4.1. Width of the virtual source

In order to find out how the initially prepared width of the virtual source can change after a mix-down a recording of the popular instrumental music had been prepared in which one of the instruments (the piano) had the narrow (±30 degrees) or broad (±60 degrees) size in the frontal plane in 5.1 system. The rest of the instruments, i.e., the drums, guitar, bass guitar and tenor saxophone, remained unchanged. The size was controlled by the panning of two microphones used for the piano recording in the frontal plane of LF and RF channels while recording this sample. The results of the listening test are presented in Fig. 2

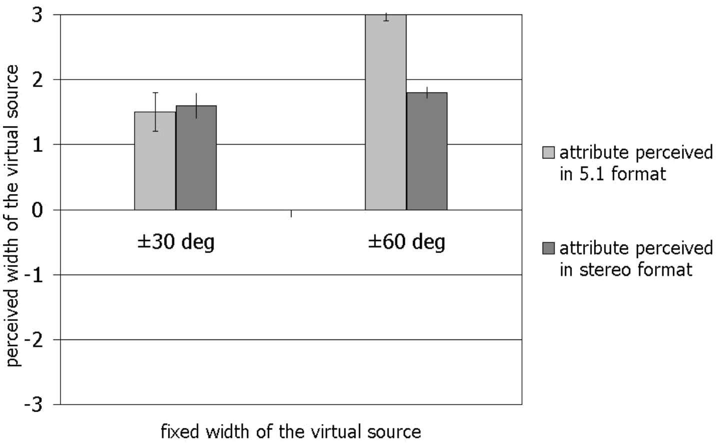

Fig. 2. Perceived changes of the width of the virtual source. The reference value is +3 as the width of the source of ±60 degrees size.

and the standard deviation values are presented as vertical lines on the bars. The reference value is +3 and it is the perceived width of the wider source of ±60 degree size in 5.1 format. It turned out that the narrow virtual sound source preserved its width (the difference equaled to D = 0.1) when a mix-down process was applied according to the ITU recommendation, and no one could indicate which sample (surround or stereo) is better in the total context ($S = 144 > S_\alpha = 138$, where S, S_α are the calculated and critical values of Wilcoxon test for $\alpha = 0.05$, respectively). When the width of a source is broad (±60 degrees) the difference changes and it may indicate that better results have been noted for the surround sample (D = 1.2, $S = 87 < S_\alpha$) but this could come from the total context of the surround scene, where other virtual sources are perceived as wider.

4.2. Overall size of the frontal sound scene

Three versions of an instrumental piece of pop music were investigated. One of them included a broad panoramic frontal scene exceeding the stereo base between LF and RF, and the other two versions had a narrower panoramic one (about half of the base and the whole base, respectively). The ensemble consisted of drums, an acoustic bass, electric and acoustic guitars and keyboards. These versions of the tune have been created by the means of panning with the addition of a phase shift (for the scene wider than the base), and panning alone (for the other two versions).

The results of the subjective research (see Fig. 3) showed that the size of the frontal sound scene does not change with the playback format when the originally created width of the sound scene does not exceed the base between LF and RF (D = 0.1 for half of the base, at $S = 173 > S_\alpha$, and D = 0.13 for the whole size, at $S = 154 > S_\alpha$). Exceeding the base in the surround format causes the worst results in evaluation of the size of the frontal scene after a mix-

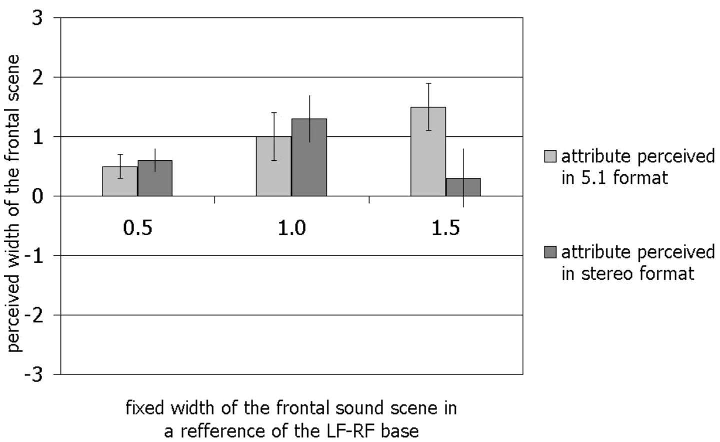

Fig. 3. Perceived size of the frontal scene.

down process (D = −1.2, $S = 39 < S_{\alpha}$). It should be noted on the basis of the standard deviation values presented as vertical lines on the tops of the bars that the change in the size of the sound scene (with a format reduction) influences the accuracy of the sound sources localization because of a finite ability to discern sources by the human hearing system: more sources exist in the narrower space making it impossible to separate some particular source from the complex sound image (BLAUERT, 2005).

4.3. Coherence impression of the sound scene

Surround recordings have been prepared in the following way: for creating the frontal scene the central channel was fed by various amounts of the direct signal from one instrument, tenor saxophone in this case, while the band consisted of the drums, electric bass and acoustic guitar. The higher value of the signal was sent to the center, the lower amount was given to the other two frontal (LF and RF), so the total loudness of this instrument remained the same. The famous jazz standard *My Funny Valentine* was used for this recording.

It turned out that the coherence impression of the frontal scene worsens significantly after mixing-down, while a greater amount of the signal is fed to the central channel, which can be seen in Fig. 4. However, the standard deviation values presented in this figure as vertical lines on the tops of the bars indicate that the accuracy of the perceived coherence impression does not change with the degree of the direct signal distributed to channel C. For the change from 0% to 100% of the signal contents of the central channel the coherence impression after the mix-down decreases from D = −0.2 to D = −2.3 ($S < S_{\alpha} = 138$ for all cases). It should be noted that the coherence impression of the frontal scene in the surround system can be controlled by the degree of direct signals fed to channel C, which is a specific bridge between LF and RF only in a situation when

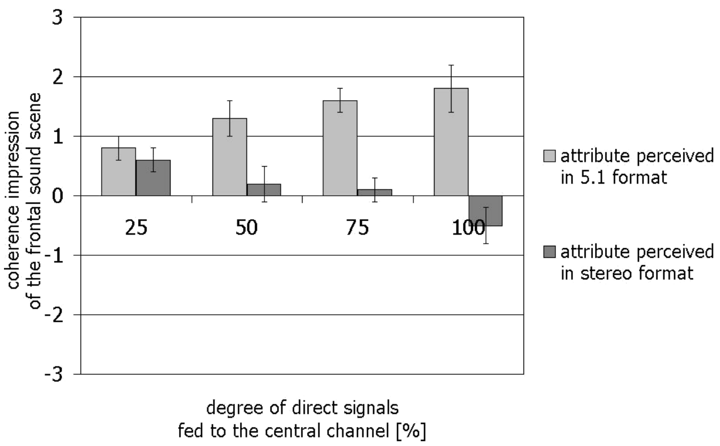

Fig. 4. Coherence impression of the frontal sound scene in dependency to the direct signal fed to the central channel.

the signals given to C are semantically important. The coherence impression of the surround recording gets higher when more direct signal is fed to channel C (from D = 0.1 to D = 1.8). In the case of a mixed-down stereo comes from that channel C the opposite character of the change is with the factor 0.7, independently of the kind and the amount of contents. This phenomenon is based on the integration process of acoustical events which takes place in the human hearing system, i.e., it is easier for the auditory system to add some acoustical events from three sources (in this case, the loudspeakers) than from two sources with a phantom source in-between (Blauert, 2005).

4.4. Clarity of the sound image

Test samples had been prepared from the same recording as in Subsec. 4.2 with the frontal scene wide as the left-to-right base. It should be noted that the spaciousness of the sound image is very often a contradicting clarity, so it is a difficult subject of art to make a proper balance or to find such critical point when recording is clear and spacious. Our research pointed out that when the surround recording has its spatial character due to ambient signals given to the rear channels only the clarity depends mainly on the auditory scene in front of the listener as presented in Fig. 5.

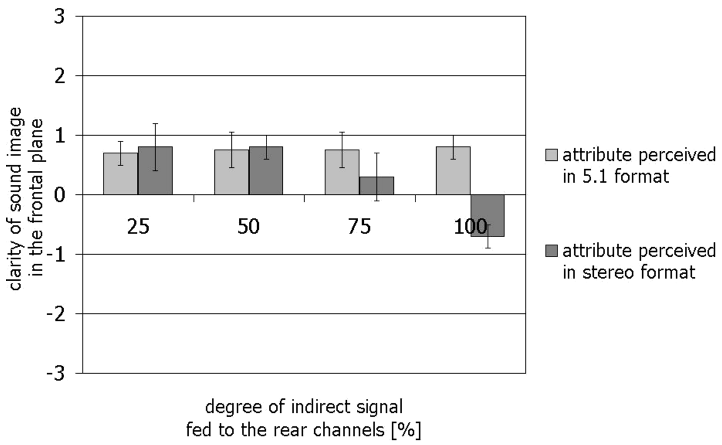

Fig. 5. Perceived clarity of the sound image in dependency to the degree of the indirect signals fed to the rear channels (LS and RS). The standard deviation values are presented as vertical lines on the tops of the bars.

After a mix-down to stereo format the overall clarity may become significantly worse ($D = -1.5$, $S = 17 < S_\alpha$) if k-coefficient is high (near 1). The mix-down operation will assure a spatial character as well as a good clarity when the surround image contains ambient signals in the LF and RF frontal channels only (D $= 0.1, \ldots, 0.3$, at $S = 254 > S_\alpha$), although the original surround mix has no such spacious impression as a recording with a great amount of ambience in the rear (LS and RS) channels only.

5. Research on different methods of the multichannel to stereo conversion

In order to find out the way the stereo track preparation influences some spatial sound attributes a subjective research of different methods of the multichannel to stereo conversion for headphone listening has been done. An auditory scene stability, a perspective of the sound scene, and a surround impression were the subjects of interest. Samples created in accordance with the ITU recommendation (1994), dummy head recordings of a multi-channel playback (DH), and a PCM stereo signal at the output of a DVD player (PCM) were recorded on the computer with Samplitude edition system, then presented to the listeners individually via AKG K-141 headphones. The exposure level for Dummy-Head recording was set at the typical level of approximately 70-90 dB (EBU, 1998, 1999a). Neumann's KU 100 Dummy-Head was set in a sweet point of the listening area. The test signals contained twelve fragments with duration of 30 sec. taken from four commercially issued DVDs representing jazz-rock (*Legends of Jazz*, LRSmedia), jazz (*Diana Krall, Live in Paris,* Eagle Rock Entertainment, EREDV250), classical music (E.W. Korngold *Die Tote Stadt*, Arthaus Music, 100 342), and spatial sound effects (*The Ultimate DVD Surround Sampler & 5.1 Set-Up Disc*, Chesky Records, CHDVD221). The Pioneer DVD DV 575 player was used in an environment described in Sec. 3. The test signals were presented in pairs, so a comparison of each combination was possible. The listening crew was the same as in the previously described tests (see Sec. 3). The listeners' task was to compare these specific attributes presented in pairs which consisted of the recordings of all three ways of conversion with all possible combinations, to assess the second sample in reference to the first one, and to estimate the investigated sound attribute in the range from -3 to 3. The order of the 30-second samples was randomized but each pair contained the same piece of the musical material with different ways of conversion. Each combination of the signals was repeated three times during the trial. The procedure was repeated twice in a period of two days, so 60 answers have been collected for each measured pair. The answer notes have been averaged over all the ten listeners and their notes due to the high convergence in all cases at the 95% of confidence ($F < F_\alpha = 2.07$, where F, F_α are the calculated and critical values of the F-Snedecor test, respectively). The structure index test (Greń, 1978) as a statistical treatment was applied to the series which reflects the listeners' preference of the tested attributes with $u_\alpha = 1.96$ at $\alpha = 0.05$. Table 1 contains the results of the comparison of all the three methods of the surround-to-stereo conversion.

It turned out that an influence of the conversion method on the sound perspective impression does not exist, i.e., for the each of the three methods the

Table 1. Spatial attributes assessment after the surround-to-stereo conversion in dependency to the way of the mix-down operation.

way of mix-down operation	sound perspective	stability of auditory scene	listener's envelopment impression
ITU	1.0	1.8	0.8
DH	0.9	2.3	2.0
PCM	0.9	0.1	0.8

results have become inessential statistically ($|u| \leq u_\alpha$). The auditory scene stability, taken into consideration as an impression that all the sound sources are fixed in their places and do not change their positions in spite of the context, is perceived in dependency to the conversion method. The best stability has been found for the dummy head recording ($|u| = 4.30$), while the worst one was detected for the PCM stereo signal at the DVD player's output ($|u| = 2.37$). It has also been found that there is a significant influence of the conversion method on the listener's envelopment impression, although with a small exception, unlike for the previously mentioned attribute, i.e., the best impression was found for the dummy head recording ($|u| = 3.75$) but the difference between the ITU-based method and the PCM stereo output signal is inessential from the statistical point of view ($|u| = 1.38$). These facts suggest that the best way for the stereo signal preparation from 5.1 format for the headphone exposure is applying the dummy head for recording the spatial exposition. This is in a good agreement with the typical stereo recording method with the dummy head placed in the field of the sound. Although, the main disadvantage of this is a fact that control rooms, or other places where this kind of operations is performed, must meet very high acoustic standards set in the EBU recommendation (1999b), and a good sound isolation from the outer noise should be arranged.

6. Discussion

In the case of stereo and mono recordings, a full compatibility during the format reduction process is possible when the techniques and tricks based on the intensity difference are applied for the stereo image production. Thus, the mono format preserves such features of the sound image as its clarity, proper balance and depth. The results presented in the paper may point out the directions in the surround sound image production which will make it compatible to the stereo format after a mix-down process. The reduction of the formats (from the surround to stereo) in the accordance with the ITU recommendation changes neither the width of the virtual sound source nor an overall size of the frontal sound scene when both elements are created as not too broad in their original, surround format. This means that the use of the intensity techniques alone does not cause any distortion in the format change. However, the change in the size of the sound scene influences the accuracy of localization of the sound sources due to the human hearing properties, i.e., this accuracy worsens twice for the sound scene exceeding the stereo base. A coherence impression of the frontal scene depends on the contents of the direct signal fed to the central channel in the surround system, i.e., a higher amount of the direct signal of channel C causes a decrease of coherence impression after the mix-down process, while in the case of the surround image an increase of this impression has been observed when more direct signal is fed to the central channel. When the surround scene is needed to exceed the base of the LF and RF loudspeakers, a special trick can be done, i.e., the virtual sound sources have to be placed in the two so-called semi-bases marked by LF and C and RF and C, respectively. As a result of this, the surround sound image would be stable and coherent and it allows perceiving even small changes in the virtual source position. Moreover, this trick is not sensitive to further processing, according to the ITU directions. This situation is similar to a microphone set for very large sources (choirs, orchestras) based on two XY-systems (Deschamps *et al.*, 2003). It should be said that this trick is possible to realize only in the frontal plane of 5.1 format and this does not work on the sides or behind the listener because of the lack of an additional channel which could work as a bridge and divide the proper plane into two semi-planes.

The research on clarity of the sound image shows that when the surround recording has its spatial character due to ambient signals given to the rear channels only, the clarity depends mainly on the auditory scene in front of the listener. After a mix-down to the stereo format the overall clarity may become worse if the more indirect, ambient signals have been supplied to the front channels. The mix-down operation will assure a spatial character and a good clarity when the original surround image contains ambient signals in the LF and RF frontal channels only but the rear channels are used for changing the distance impression between the listener and the virtual frontal scene. It can be noted that the total information of the sound scene including its depth may be contained in a combination of the three frontal channels, which in the light of the ITU recommendation is insensitive to further processing. Of course, the full compatibility between the formats is possible only in some specific situations which can limit advantages of the surround system in exchange for the stereo signal which is free of the comb-filtering effect, stable in space and not equalized after a mixing-down operation according to the ITU directions. Nevertheless, these facts may be useful in mix-up operations (from the stereo to surround format), i.e., sound designers will be sure that their activities do not produce some unwanted artifacts in the case of the surround playback (Hen *et al.*, 2008). If some virtual sources appear in the rear plane, they will appear in the frontal plane with a k-weighted value (from 0 to 1) after the format reduction, but this fact induces sound producers not to utilize all possibilities of the higher-order format (surround in this case) due to the preservation of impressions possible to obtain in a stereo playback.

In reference to the methods of the multichannel to stereo conversion for headphone listening, it can be said that stereo signals obtained by the three investigated methods, i.e., with a dummy head, being in accordance with the ITU recommendation, and based on the stereo signal at the output of DVD player, are perceived as different. However, there is no influence of the conversion method on one attribute, namely, the sound perspective impression. The main feature which distinguishes these methods is the stability of the sound scene, i.e., a conversion based on the dummy head recording preserves the best stability, while the PCM stereo signal is the worst. The third investigated attribute, i.e., the listeners' envelopment impression, can be achieved with the best results by the dummy head recording, and the two remaining methods – the ITU-based method and the PCM stereo output signal – were evaluated as worse but the difference between them is inessential from the statistical point of view. It means that the method involving the dummy head recording has been found to be the best for this operation. It is in a logical consequence of the fact that some producers recommend the dummy head only for the headphone exposure (Bartlet *et al.*, 2007), some of them suggest using this device in a combination with other microphone systems in order to obtain a proper impression of the auditory scene.

7. Conclusions

The results of the experiments have indicated that the reduction of the formats – from the surround to stereo – carried out in the accordance with the ITU recommendation does not influence such sound attributes as its width or the overall size of the frontal sound scene, if the applied operations for the scene creation are based only on the intensity techniques. The use of some phase-shift-based means to make the source or the scene wider may cause changes of the perceived attributes similar to the stereo to mono mix-down operation.

The distribution of the signals can influence subjective impressions in such a way that when the central channel is fed by a big amount of the direct signal, the coherence impression gets worse in the stereo image even if it has been assessed as very high in the surround playback. The clarity impression of the frontal sound image may be changed when the whole contents of the indirect sound and ambience, originally designed for the playback by the rear channels only, is given to the frontal stereo loudspeakers. It suggests that the rear channels can be used for changing the distance impression between the listener and the virtual frontal scene, and after a mix-down operation the clarity of the frontal sound image will not be changed.

Finally, it has been found that the recording with a dummy head of the multichannel playback is the best tool for the surround to stereo format reduction, although the application could be done only in rooms that fulfill the specific acoustical requirements.

Acknowledgments

The authors would like to express their gratitude for two anonymous reviewers for their helpful comments.

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