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Enlarging of the Listening Area by Increasing the Number of Loudspeakers

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Abstract:

Future multichannel sound systems, especially suited to accompany HDTV and EDTV systems, should provide a stable localisation of stereophonic images in a sufficient listening area. Arrangements with two, three or four loudspeakers in the frontal area have been compared with respect to the directional stability of auditory events for different listening positions. It is concluded, that four loudspeakers are necessary to obtain the same localisation curves for all listening positions within an area as wide as a large HDTV screen. This is important for a directional congruence between visual and sound images.

Introduction

The future HDTV systems will offer an improved television picture with a high resolution of 1250 lines (PAL: 650 lines) and a different aspect ratio of 16 : 9 (PAL : 4:3). This might change the visual and auditive reproduce situation in some aspects. As a consequence of the high resolution, the use of larger picture screens and auditoriums are reasonable.

Some studies about accompanying sound systems have indicated, that a two channel stereo system is not sufficient for HDTV. The following requirements should be considered for a sound system suitable for HDTV applications /1/:

— downward compatibility to more simple reproduction standards (mono, stereo),

— system compatibilty to the present reproduction standards of the various cinema sound systems,

— stable localisation of directional sound events in a large listening area,

— imaging capacity of auditory ambience of the scene (eg. supporting sound effects, off-picture sound sources, atmospheric sounds, music, etc.),

— transmitting capacity for a multichoice language program,

— maximal economy in all respects,

This report is ment to work especially on the requirement of stable localisation and tries to optimize the auditory conditions with respect to the enlargement of the listening area.

Auditory conditions

Figure 1 illustrates the two spatial situations given by the conventional TV system and a future HDTV system. In both cases a stereo standard arrangement of two loudspeakers with a listening angle of ± 30° is added for comparision:

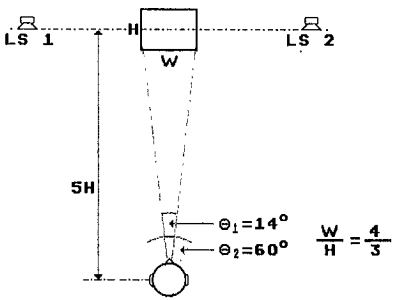

Fig. 1 a: PAL
normal TV set

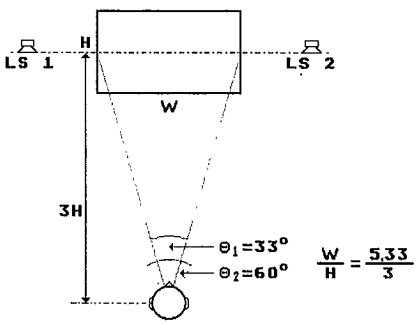

Fig. 1 b: HDTV
large screen

The viewing angle will change from 14° (distance 5 x height, aspect ratio 4: 3) to at least 33° (distance 3 x height, aspect ratio 16 : 9). This new situation is more comparable to a cinema situation, and a listening area for a larger auditory is desired. Within a suitable listening area, proper image localisation should be possible, providing sufficient sharpness and directional fidelity. Stability of perceived directions with respect to the listening position has to be ensured.

Fundamental experiments on the directional localisation of phantom sound sources

Figure 2 shows the result of a listening experiment concerning intensity difference stereophony with ΔL: 1...13 dB. This experiment had been carried out in a low reflection studio rooom at the IRT with 14 trained listeners, using gauss-modulated pink noise bursts (for details see /2/).

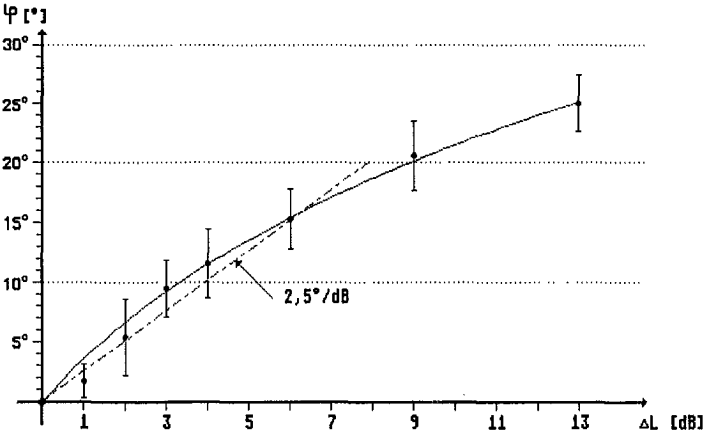

Fig. 2: Perceived phantom sound source directions, means and variations, subjects on the ideal listenig position in a standard stereo arrangement

This localisation curve shows the typical progressive form as known from other publications / eg. 3, 4 / with a ratio of aprox. **2,5° / dB** in the section $\varphi \leq 20°$. The application of a nonlinear x-axis for the intensity differences, as shown in Figure 3, leads to a linear localisation curve:

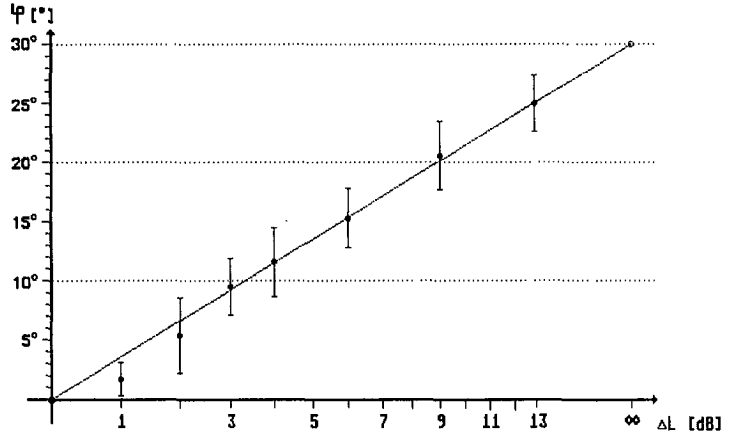

Fig. 3: Perceived phantom sound source directions, linearised localisation curve

The measurement point corresponding with the infinity mark on the x-axis represents the real sound source direction of the loudspeaker located at the 30° position.

In principle, the equivalent localisation curve can be found as well by using time differences (4°/100μs). However, as found in /2/, the sharpness of the localisation gets reduced at time differences with more than aprox. 200 μs. Therefore, and for practical considerations, this study has been made by using only level differences.

Split-up of the entire imaging area into "stereophonic subareas"

In a concept for a multichannel sound system it has been proposed, to enlarge the listening area by subdividing the frontal area into "stereophonic subareas" /5/. Calculations led to the conclusion, that the extension of the listening area grows out of proportion to the number of subareas. It is estimated, that 3 subareas (i.e. 4 loudspeakers) could provide a sufficient stability of localisation within a suitable listening area .

As a mean matter in this study, localisation curves depending on the number of subareas and different listening positions should be worked out as the result of listening tests. Figure 4 shows the design of the listening arrangement. The details about width **W** and height **H** are corresponding with a virtual HDTV screen in the frontal area.

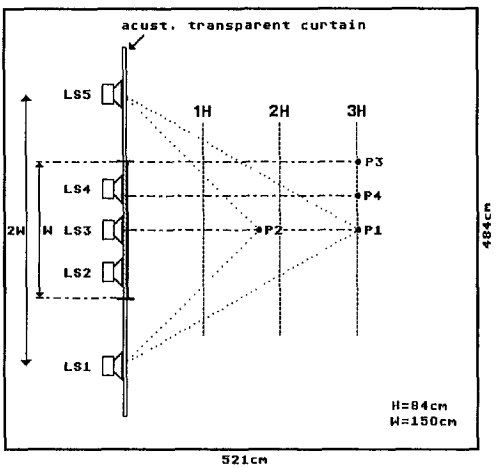

Fig. 4: Loudspeaker arrangements: 1) LS 1 and LS 5
2) LS 1, LS 3 and LS 5
3) LS 1, LS 2, LS 4 and LS 5,
Listening positions: P 1, P 2, P 3 and P 4

The position **P 1** represents the ideal listening position of a stereo standard arrangement formed by an equilateral triangle. **P 2** is located in the distance as wide as the picture screen in the middle of the imaging area. **P 3** has the same distance 3 H as P 1, but this position is shifted to the right border of the virtual HDTV screen. **P 4** lies inbetween P 1 and P 3.

The line up of the loudspeakers makes it necessary to put in a time delay for the loudspeaker signals of LS 2, LS 3 and LS 4. As a result of calculations with regard to the ideal listening position P 1, a time correction of $\Delta t = 1{,}0$ ms for LS 3 and $\Delta t = 1{,}2$ ms for LS 2 and LS 4 was applied.

To rule out a visual influence, the loudspeakers were covered with an acoustical transparent curtain.

Three different loudspeaker arrangements were tested. **LS 1** and **LS 5** represent the two loudspeaker arrangement as known from the traditional stereo setting, the entire imaging area is defined as **SA 1.**

LS 1, **LS 3** and **LS 5** split up the imaging area into the two subareas **SA 2** and **SA 3.**

The 4-loudspeaker-arrangement **LS 1**, **LS 2**, **LS 4** and **LS 5** destines the subareas **SA 4**, **SA 5** and **SA 6.**

The listening tests were carried out with the same testsignal (gauss-modulated pink noise) and nearly the same test subjects as in the fundamental experiments above.

Results of the listening experiments

The next figures show the perceived image directions dependent on the listening position and the loudspeaker arrangement, in the form of means and variations. The statistical variation can give evidence about the sharpnes of a localisation. As a modification of the localisation diagramms shown in Figures 2 and 3, the y-axis representing the perceived directions is changed to a percentage scale to allow comparable results independent of the listening position. The entire imaging area of ± 50 % is plotted, because the listening positions P 3 and P 4 represent a non-symmetrical situation.

To evaluate the results, the figures show four diagonal lines, which mark the boundaries of two thresholds. Their positions and sizes are marked in Fig. 7.

The two inner lines represent the threshold value of the **just-noticeable difference** $\mathbf{TH_{aud}}$ between the directions of sound and video images. As found in /6/ a discrepancy of less than **± 4°** or **± 6,6 %** (referring to an image area of ±30°) is not perceptible.

The two outer lines mark the boundary of the threshold value concerning the **acceptable extent of discrepancy** $\mathbf{TH_{accept}}$. In a study on this matter /7/ it has been found, that a deviation of **± 11°** or **± 18,3 %** (referring to an image area of ± 30°) is the acceptable limit of discrepancy between the directions of sound and picture images.

Localisation diagrams

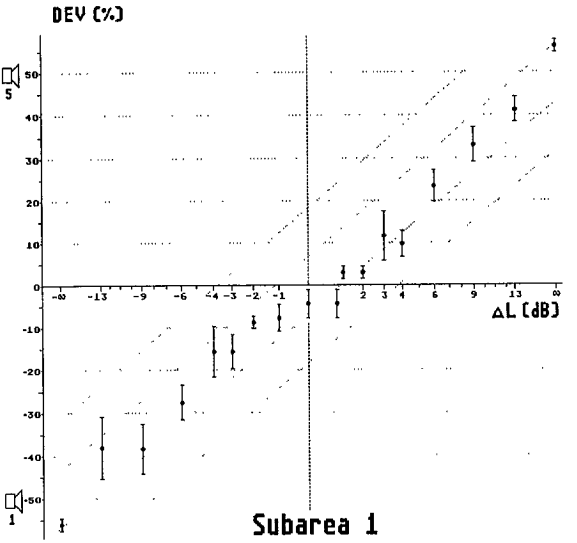

Fig. 5: 2-loudspeaker arrangement, listening position P 1

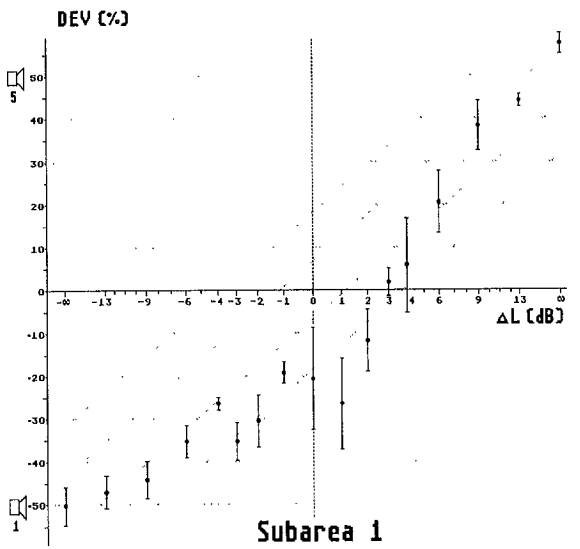

Fig. 6: 2-loudspeaker arrangement, listening position P 2

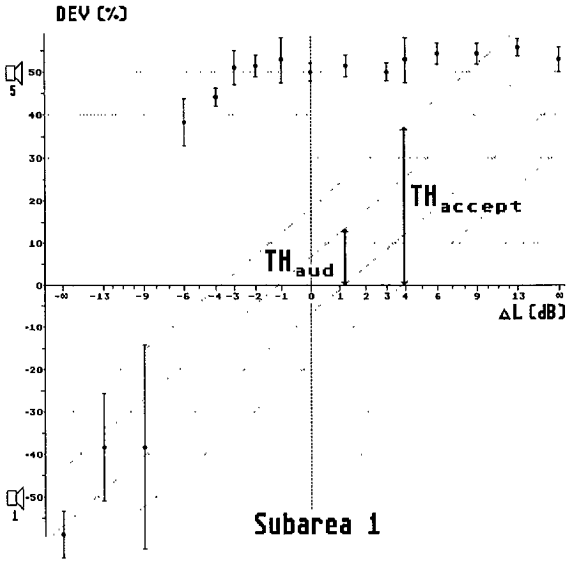

Fig. 7: 2-loudspeaker arrangement, listening position P 3

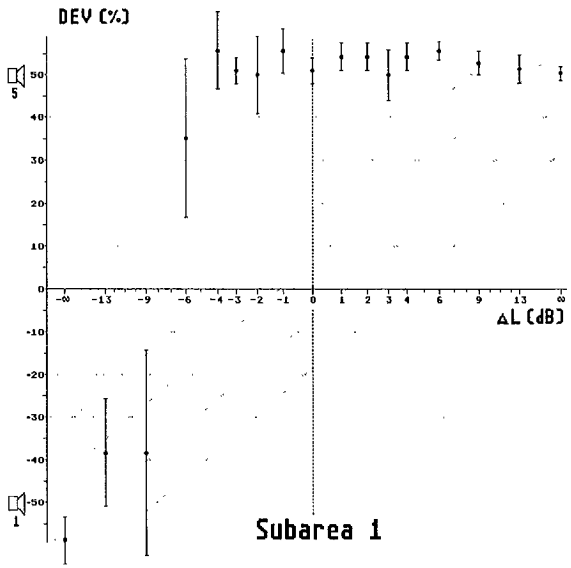

Fig. 8: 2-loudspeaker arrangement, listening position P 4

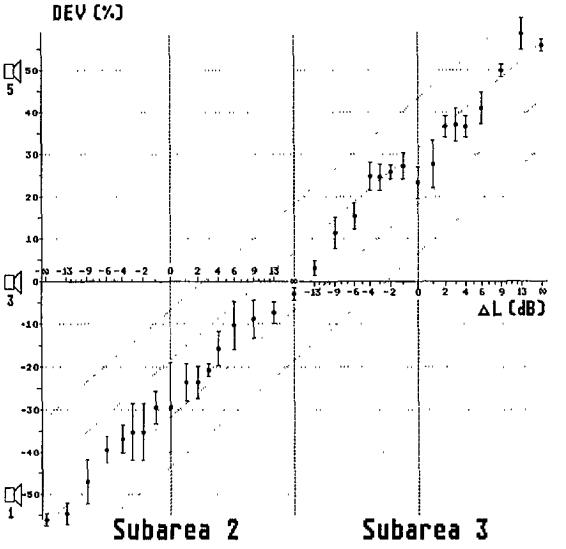

Fig. 9: 3-loudspeaker arrangement, listening position P 1

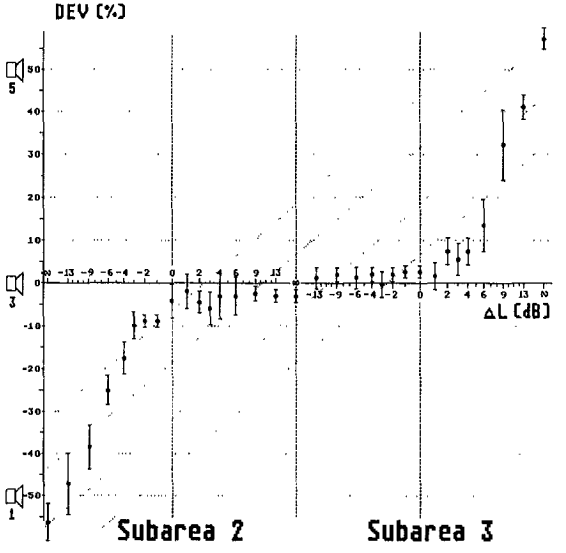

Fig. 10: 3-loudspeaker arrangement, listening position P 2

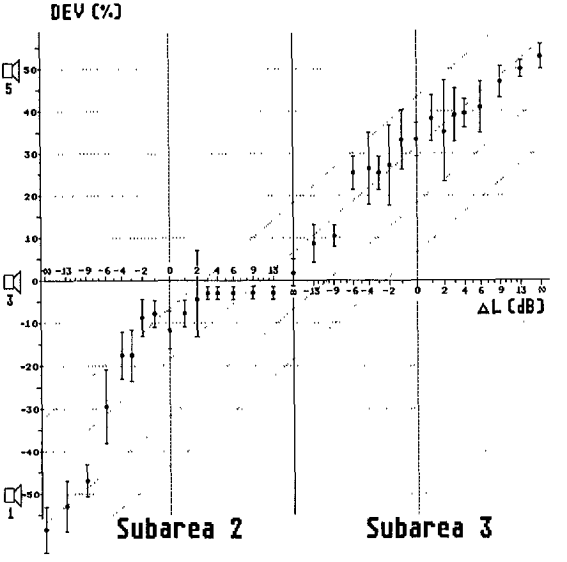

Fig. 11: 3-loudspeaker arrangement, listening position P 3

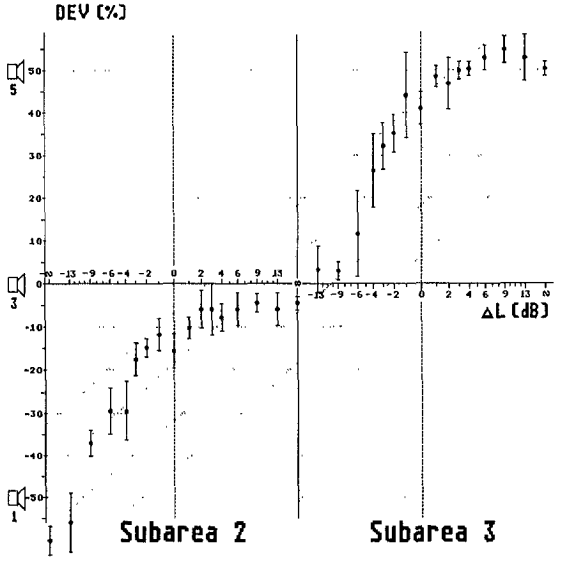

Fig. 12: 3-loudspeaker arrangement, listening position P 4

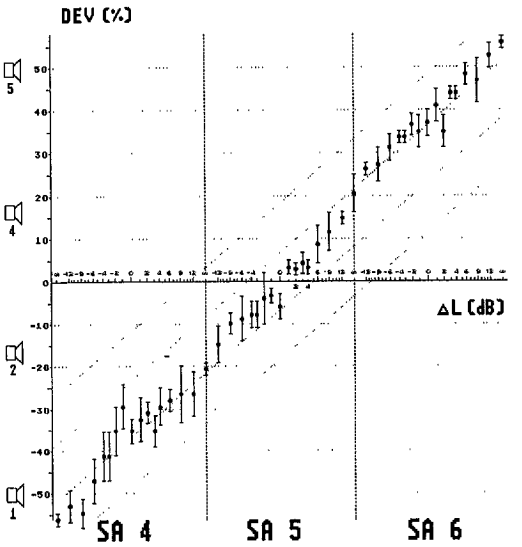

Fig. 13: 4-loudspeaker arrangement, listening position P 1

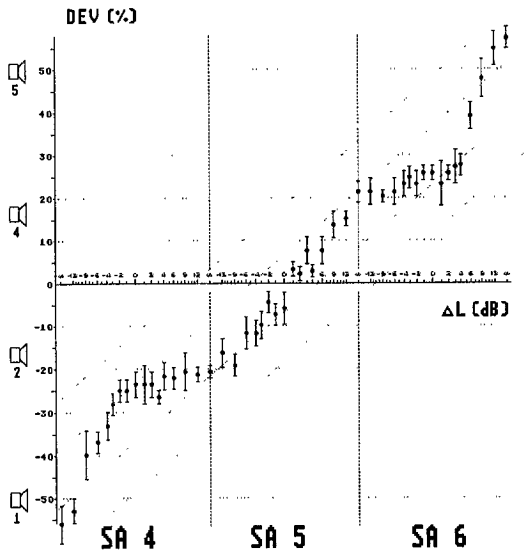

Fig. 14: 4-loudspeaker arrangement, listening position P 2

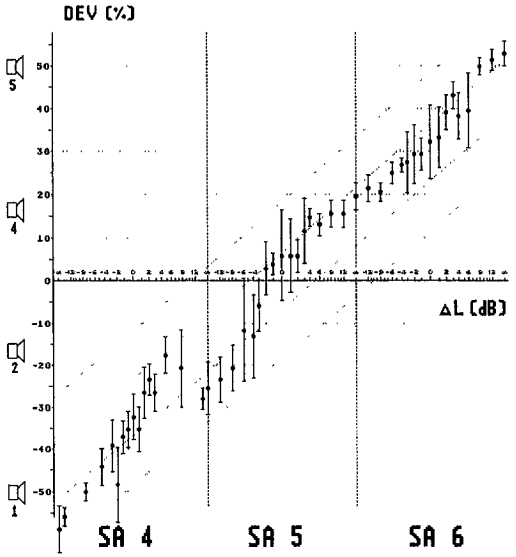

Fig. 15: 4-loudspeaker arrangement, listening position P 3

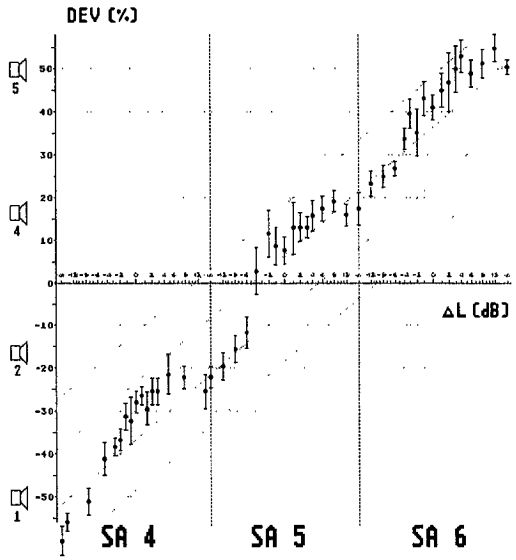

Fig. 16: 4-loudspeaker arrangement, listening position P 4

Analysis

2-Loudspeaker arrangement

On the ideal listening position **P 1** the result was a very linear and symmetric course of the localisation curve, even inbetween the $\mathbf{TH_{aud}}$ with a constant and small variation (Fig. 5).

On the position **P 2** the phantom sound sources, especially caused by small intensity differences, were located with a low sharpness, in this "middle section" about ± 4 dB the perceived directions lay beyond the threshold $\mathbf{TH_{accept}}$ (Fig. 6).

A continous and symmetric course of the localisation curve on the listening positions **P 3** and **P 4** was not able to be reached. Over a wide range of intensity differences, the phantom sound sources seemed to stay at the place of the nearer loudspeaker LS 5. On each of both positions only five of seventeen located directions were placed within the threshold $\mathbf{TH_{accept}}$ (Fig. 7 and 8). For these listening positions a sufficient congruence between visual and sound images could not be guaranteed.

3-Loudspeaker arrangement

The localisation curve on position **P 1** has nearly the same symmetric and linear course as in the case of the 2-loudspeaker arrangement (Fig. 9).

The use of an additional Loudspeaker in the middle of the imaging area (LS 3) decreases the localisation conditions on the position **P 2**. Over a wide range of intensity differences, the directions of the phantom sound sources seemed to have "stuck" to the middle (Fig. 10). The reason for this is the incorrect time delay correction of the loudspeaker LS 3 for the Position P 2. As mentioned above, it was calculated for the ideal position P 1.

The split up of the entire imaging area into the two subareas SA 2 and SA 3 offers a considerably optimized localisation curve on the positions **P 3** and **P 4** (Fig. 11 and 12), however a general slight displacement towards the two listening positiones P 3 and P 4 was recognizable.

4-Loudspeaker arrangement

For **all listening positions** the use of a 4-Loudspeaker arrangement led to the best results of linear and symmetric localisation curves with a small variation on average (Fig. 13 - 16). In less than a third of all located directions, the results fell slightly into the range of the acceptable extent of discrepancy TH_{accept}, i.e. a directional discrepancy between visual and sound events could have been noticed, but not with an annoying effect.
As a result, a 4-Loudspeaker arrangement, splitting-up the entire frontal imaging area into three subareas, would be desirable for a future HDTV sound system. In a large auditory it will be able to support even critical viewing positions, eg. close to the picture screen, with directional congruence between visual and sound images. The use of small auditories, eg. home application, may allow to use a sound system with less effort.

References

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