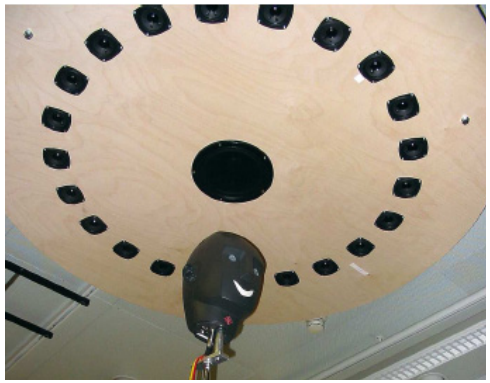
The Binaural Sky /[1]

Helmut Wittek, Schoeps Mikrofone GmbH, Karlsruhe, Germany,
Daniel Menzel, TU München, Arbeitsgruppe Technische Akustik, Germany
Günther Theile, Institut für Rundfunktechnik, München, Germany



The **Binaural Sky** is a novel system for the reproduction of virtual acoustics. It generates stable 3-D sound without the need for headphones. The array can be mounted above the listener so that no loudspeaker is in the listener's field of vision. The system combines Wave Field Synthesis, binaural and transaural audio. It applies head-tracking to ensure optimal localization and sound color reproduction. The listeners are allowed to turn around and move their heads. The function is successfully evaluated in simulations and practical experiments.

The **Binaural Sky** comprises different systems and technologies in order to create 3-D sound without headphones.

The main technique applied is transaural reproduction, i.e. rendering of ear input signals rid of HRTFs (Head Related Transfer Functions) by means of "crosstalk cancellation" (inverse HRTF pre-filtering). The disadvantages of transaural audio, however, are consequently avoided. Usually transaural techniques suffer from even small head movements and rotations due to radical changes of the HRTFs at the high frequency end. In theory, it would be required that the loudspeakers remain at the same relative position when the listener turns his head (Figure 1).

[1] *Patent pending IRT 2005*

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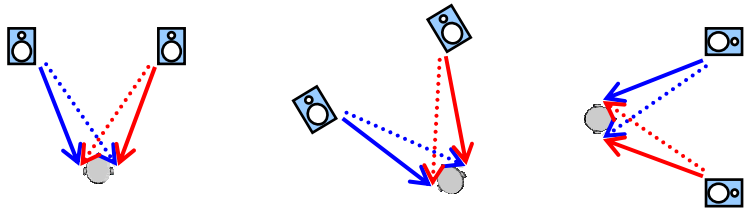

Figure 1: Ideal Case: the loudspeakers follow your head rotation

This is realized by the **Binaural Sky**. WFS focused sources are rendered close to listener's ears and used for transaural signal reproduction ("transaural sources"). Their locations are constant relative to the ears for every head direction by means of head tracking data. Hence, there is no need to change the inverse HRTF ("crosstalk canceling") filters due to head rotations, which could create audible artefacts and instabilities. The system is sufficiently stable allowing for loudspeaker array installations above the listener. Figure 2 shows the chosen geometry of the array and the transaural source locations.

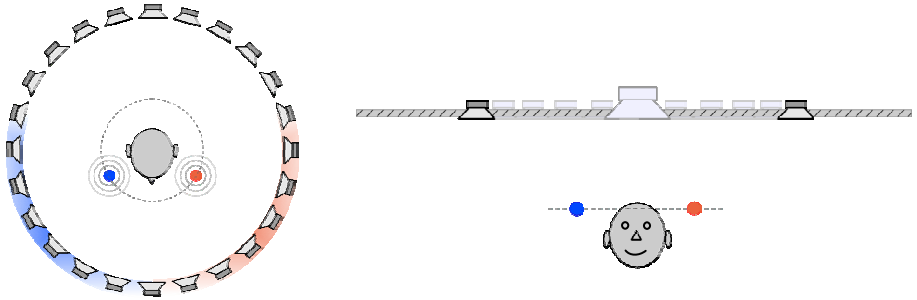

Figure 2: View of the array from above (left picture) and from the front (right picture)

Thus, head rotations are allowed providing a natural listening experience. This is achieved by applying Wave Field Synthesis (WFS) which enables headtracking controlled focused sources at a high sound quality between array and listener.

By this procedure, a **"virtual headphone"** is created by which either usual stereophonic signals ("in-head-localization") or, more importantly, binaural signals can be reproduced. The binaural data could include head-tracking as well. The corresponding transfer functions stored in the database can easily combined with the transaural WFS reproduction functions.

Wittek, Theile, Menzel 2005 for IRT

As a result, high-quality binaural reproduction (**BRS, "Binaural Room Synthesis"**, another IRT key-technique) can be enjoyed without wearing headphones and even without loudspeakers in the listener's field of vision.

Subjective Evaluation

In experiments the localization accuracy and sound color stability of the complete system were evaluated (BRS plus virtual headphone reproduction). In the tests real and virtual sources were presented in different directions in random order. The real sources (small loudspeakers) were hidden behind an acoustically transparent curtain. - The results show that **Binaural Sky** accurately can reproduce the sources in correct directions without generally having a significant increase of the mean standard deviation of the collected results (Figure 3). According to known experience with dummy head techniques the reproduction of elevation of a virtual source is possible with some constraints, and reproduction of virtual sources below ear level is not possible.

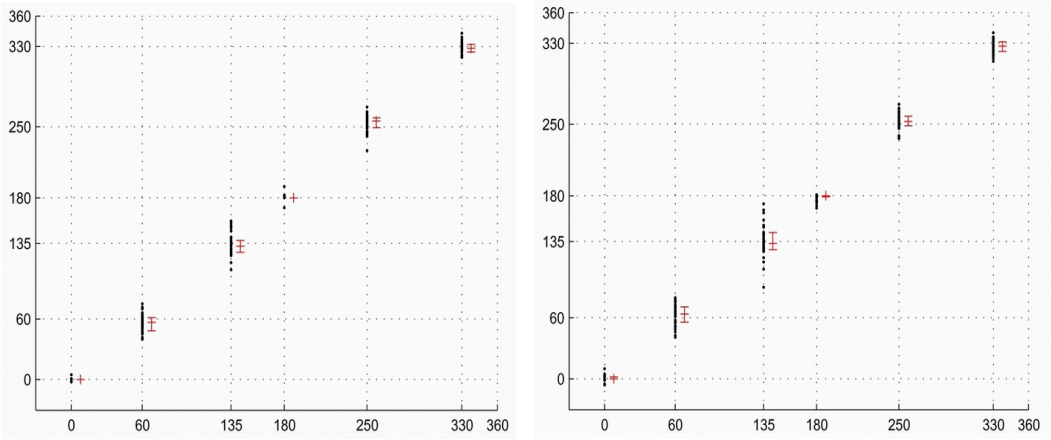

*Figure 3: Experimental results: Localization of **Binaural Sky** sources (right picture) is not inferior to localization of real sources (left picture). The perceived source directions are plotted vs. the actual source directions (x-axis)*

Further experiments show that the change of the sound color between virtual sources in different directions is not higher than it is with the BRS headphone system, thus showing that the transaural process works without audible artifacts.

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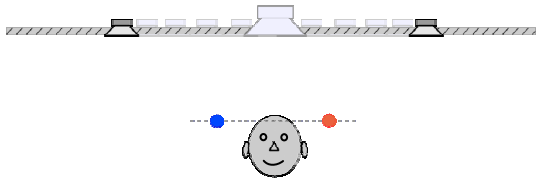

*Figure 4: The **Binaural Sky** enables the perception of distant sources without visible loudspeakers*

Summary

The "Binaural Sky" is a new concept of immersive virtual audio, combining wave field synthesis, binaural techniques, transaural audio and headtracking. Stable room related localisation of virtual sources is achieved for listeners that are allowed to turn around and move their heads.

WFS focused sources are rendered close to listener's ears and used for transaural signal reproduction ("transaural sources"). Their locations are constant relative to the ears for every head direction by means of head tracking data. Hence, there is no need to change the inverse HRTF ("crosstalk canceling") filters due to head rotations, which could create audible artefacts and instabilities and impair the virtual headphone quality. The system is sufficiently stable allowing for loudspeaker array installations above the listener. As a result, binaural (e.g. BRS) reproduction can be enjoyed without wearing a headphone and without loudspeakers in listener's field of vision (Figure 4).

Further optimizations of the virtual headphone are possible with regard to the geometry of the transaural sources and the size of the sweet spot. Future realizations could well include tracking of the head position rather than only head rotation (azimuth). This would enable a further degree of freedom of movement for the listener without loosing accurate rendering of the virtual headphone, offering immersive perception in a virtual spatial sound scenario.

Contact:

Institut für Rundfunktechnik IRT GmbH
Floriansmühlstr.60 - 80939 München

Helmut Wittek, wittek@schoeps.de
Günther Theile, theile@irt.de
Daniel Menzel, danielmenzel@gmail.com

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