BACCH™ 3D Sound

What is the invention?

BACCH™ 3D Sound is a recent breakthrough in audio technology (licensed by Princeton University) that yields unprecedented spatial realism in loudspeaker-based audio playback allowing the listener to hear, through only two loudspeakers, a truly 3D reproduction of a recorded sound field with uncanny accuracy and detail, and with a level of high tonal and spatial fidelity that is simply unapproachable by even the most expensive and advanced existing audio systems.

How is it innovative?

BACCH™ 3D Sound is a vast improvement over Surround Sound. Surround Sound, which was originally conceived to make the sound of movies more spectacular, does not (and cannot) attempt to reproduce a 3D sound field and can only provide some degree of sound envelopment for the listener by surrounding the listener with five or seven loudspeakers.

The technology is completely compatible with all stereo recordings made since 1954, which become naturally 3D when played through the BACCH™ filter.

Applications

BACCH™ 3D Sound is ideal for many applications including home audio, car audio, 3D Movies, 3D TV, computer sound, gaming, teleconferencing, music recording, live broadcasting, sports, military, and medical (e.g. helping the hearing impaired).

It has received wide media coverage in CNET, The Atlantic magazine, BBC Radio, NPR and the Discovery Channel.

Implementation and Multiple Sweet Spots

• BACCH™ Filters can be designed for any pair of loudspeakers to give 3D Audio in a single but large sweet spot.

• BACCH™ is implemented as a digital filter that is used to process (in real-time or offline) digital audio on a DSP chip or computer.

• DynaSonix™ is a combination of Princeton’s BACCH™ 3D Sound technology with the unique phased array speaker technology developed by our strategic partner, Cambridge Mechanonics Ltd. (Cambridge, UK). It allows up to 8 listeners sitting anywhere in a room to get simultaneously a 3D audio image. The multiple sweet spots are adjusted dynamically by steering the 12 sound beams from the phased array to the ears of the listeners, located with a head tracking camera.

More info at: www.princeton.edu/3D3A

3D Imaging

3D Imaging (top panel) and 3D Audio through two loudspeakers (bottom panel) share the same stereo principles. In 3D Imaging (3D Audio) two lenses (microphones) of a camera (dummy head) separated by the human inter-ocular (inter-aural) distance are used to record two separate images (audio channels) intended for the left and right eyes (ears) separately. Such a stereoscopic recording contains the visual (aural) 3D cues needed to see (hear) in 3D.

3D Imaging

For viewing a 3D image the required right-eye suppression is done by placing a physical barrier (BACCH™ filter) in the front of the image. This can be performed using a crosstalk cancellation (XTC) filter that insures the left image (channel) is seen (heard) by the left eye (ear) only. The same applies for the other eye (ear). This cross-eyed (crosstalk) cancellation insures the proper transmission of the stereocoded cues to the brain leading the viewer (listener) to perceive a realistic 3D image (sound field).

Perfect XTC Filter:

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Perfect XTC Filter:

Crosstalk cancellation (XTC) filter is a digital filter that allows the signals $D_L$ and $D_R$ (see schematic below) on the Left and Right channels of a stereo (or binaural) recording to be manifested as air pressure signals $P_L$ and $P_R$ at the left and right ears respectively, so that the left (right) ear hears only what is on the left (right) channel. The XTC filter, which has been known for some time, consists of simply inverting the transfer matrix (shown schematically and symbolically) below for the idealized case of point sources in free space that describes the wave propagation from two loudspeakers to two ears.

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Perfect XTC Filter:

This perfect XTC filter yields infinite crosstalk cancellation (in a perfect world, with no reflections) at the ears of a perfectly aligned listener. It has the following intuitive time response, which shows how, for an impulsive signal to be perceived at the left ear only, positive and negative impulses are emitted from each speaker with the proper delay and attenuation to cancel out the crosstalk perfectly, so that only the first impulse is heard and only at the left ear.

Theory: Perfect XTC

Imperfection sounds better: The frequency response of the perfect XTC filter at the loudspeakers has very large peaks, typically exceeding 37 dB, (in order to compensate for destructive interference) as shown by the dotted curve in the plot below. While in a perfect world these peaks should not be audible at the sweet spot, in the real world the slightest head misalignment from the perfect head location will cause these peaks to be audible, resulting in severe and intolerable spectral (tonal) coloration to the sound.

To do away with this severe coloration, a frequency-dependent error is deliberately added in the inversion of the transfer function $C$. The error is calculated in a way to minimize the cost function that represents both the coloration and the crosstalk level, and to meet a psychoacoustic target frequency response.

This results in an optimal XTC filter with an arbitrarily low coloration level. (e.g. a maximum 7 dB as shown by the hard curve in the figure).

Such an optimal XTC filter is called BACCH™ for Band-Assembled Crosstalk Cancellation Hierarchy, because the optimization process theoretically requires splitting the audio spectrum in finite bands, applying a hierarchy of XTC filters, then reassembling the bands.

Theory: Introducing Imperfection

The invention is described in Sections 5.1 and 5.2 of this poster.

DynaSonix™ implemented on a phased array mounted on top of a laptop computer being tested in the anechoic chamber of the 3D3A Lab. Up to 6 simultaneous 3D audio sweet spots can be produced.

3D Audio and Applied Acoustics (3D3A) Lab

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