Key to Ambiophonic crosstalk cancellation – ITD_{spkr}

inter-aural time difference from a positioned loudspeaker

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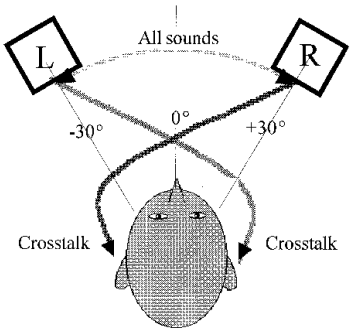
Crosstalk cancellation (XTC), by which speakers can act like headphones to reproduce life-like binaural audio, is used for Ambiophonics as well as *transaural* and other methods. The difference with Ambiophonics is that, rather than angling speakers 60° as with stereo, the speakers are together in front, angled 10~20°. For important central sounds, this move obviates stereo's problems of comb filtering (alters tone color, or timbre) and pinna confusion (alters localization). It eliminates stereo's shifting images toward the speakers that create the *hole-in-the-middle.* Correcting stereo replay with Ambiophonics works because sound from the speakers comes from where the central images are.[1]



Stereo (2/0)

Crosstalk is inevitable using speakers. Delay artifacts (when sounds travel farther to the opposite ear) reduce clarity and distort center voice timbre with comb-filtering.

In any XTC method, the signal of one channel is delayed, attenuated, inverted, and mixed with the other speaker's signal so that it arrives at its ear in time for the crosstalk from the first speaker. For one or two listeners on the median line bisecting the speakers, this XTC signal cancels the crosstalk acoustically, leaving each ear to hear only the speaker on the same side, i.e. with no crosstalk. (It is the equivalent of acoustically isolating each speaker to its ear, such as with a barrier.)

Various methods have been used over the years to generate XTC signals, ranging from building into each speaker a second driver recessed and fed the opposite channel, to DSP that convolves the inverse of crosstalk impulse responses, to RACE (Recursive Ambiophonic Crosstalk Elimination), which performs the requisite delay, attenuation, inversion, and mixing recursively within PC audio host software (see DIY tools at www.ambiophonics.org), in VST plug-ins, or in firmware within audio hardware, such as manufactured by TacT.

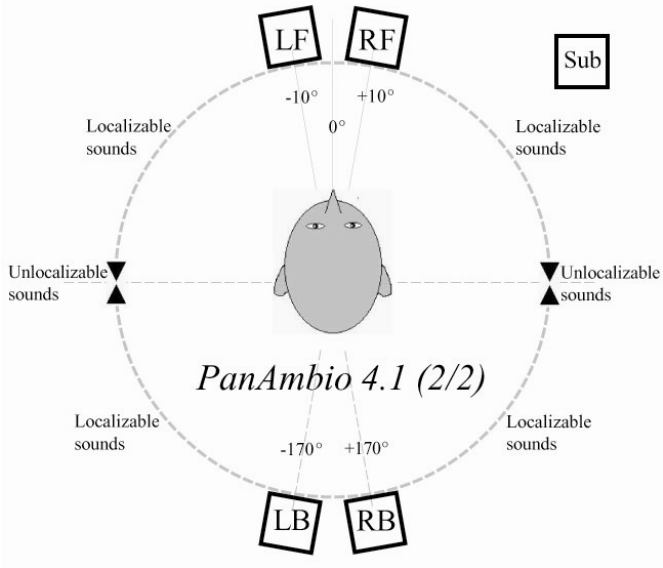
Key to XTC is the delay that occurs when sound from speaker L rounds the head to ear R, and vv. This inter-aural transit time difference varies with the angle between speakers as positioned. The four variables are: speed of sound (c, varies with temperature & humidity), ear separation (inter-aural distance IAD, varies by individual), speaker distance, and speaker separation. The last two form an equilateral triangle for conventional 60° stereo, but the angle is smaller for PC or TV speakers, or an "Ambiodipole" speaker pair.

As an example, for 68°F room temperature and 50% relative humidity, c=344.6 m/s. The equivalent average spacing between a listener's ears (inter-aural distance IAD) was established by Blauert as 0.175m, the diameter D of a head-equivalent sphere. Under these conditions, conventional stereo crosstalk for speakers angled 60° (e.g. separated 1.80m, positioned 1.80m from the listening position) results in ITD_{spkr} of 260µs – the delay inherent in all crosstalk signals. For a center phantom (including important soloists or dialogue), this time lag produces nearly identical but 260µs-delayed signals that mix acoustically at each ear, causing comb filtering (raspy dips in frequency response beginning about 2kHz and up) and smearing transient details (reduces clarity). The brain interprets these duplicates as extra *early reflections* that come from the speakers, not anything recorded. Sounds that are just off-center are "relocated" toward the speakers, creating the *hole-in-the-middle.* Prior XTC methods such as transaural retain this 60° geometry, along with similar distortions for important central voices.

Ambiophonics on the other hand locates speakers close together, for example separated 0.5m at the same 1.80m distance from the listener (a resulting angle of 16.0°) with an ITD_{spkr} of 71µs. Setting this delay using RACE XTC in DSP or a VST plug-in, the listener will experience with most stereo recordings no center image problems, a very wide 120° stage – perceived *outside* the speakers – and linear imaging side-to-side. (Compare this with stereo's limitation of the 60° width

[1] Solving stereo's center problems is the purpose of the C speaker of multi-channel 5.1, although similar problems persist around the rest of its 360°.

between speakers). The downside of Ambiophonics is that with an imprecise layout, or listening off-axis, RACE XTC signals will not cancel at the ears, and artifacts will be heard.[2]



Ambiophonics positions two speakers closely in front and uses crosstalk-cancellation DSP. *PanAmbio* adds a second pair in back for 360° surround (5.1-compatible).

Dimensions in the example above are illustrated in the media room/speaker plan in the Appendix. For geometries differing from the example, the following formula may be pasted in a spreadsheet with XTC's four values in cells as below. Calculated ITD_{spkr} is:

=1000000*H3/2*(ASIN((F7/2)/D7)+((F7/2)/D7))/D3

where: D7 is distance from listener to speakers, in m;

F7 is the separation between speakers, in m;

D3 is the speed of sound, in m/s (typ. 344.6);

H3 is the ear spacing, in m (avg. 0.175).

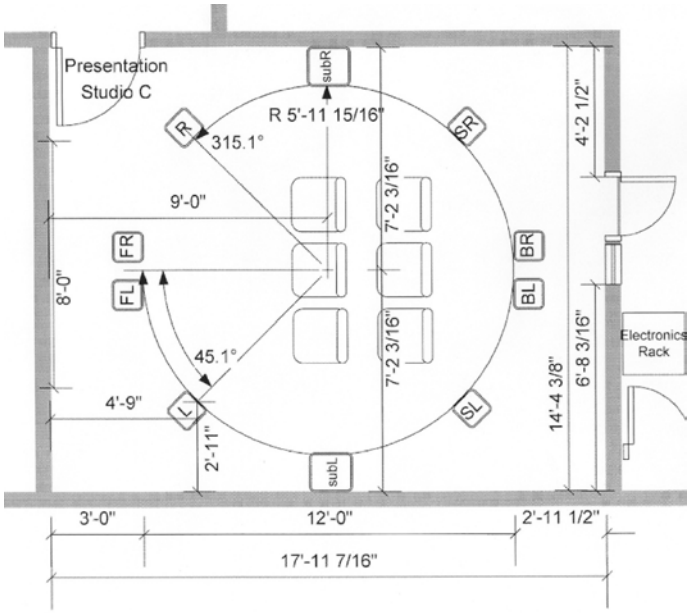
Calculated ITD_{spkr} for typical media room layouts will range between 40~179µs (185µs for typical PC/gaming speakers, 114µs a typical laptop). Furthermore, the angle between speakers measured from the center of the listener's head will be =2*57.3*ASIN((F7/2)/D7), ranging 9~41° (42° for PC speakers, 26° for a laptop).

Appendix- multi-mode Media Room plan

In the plan below speakers located on a 1.80m radius circle with speaker switching can be used in a home media room or content production studio for a multi-purpose layout for conventional stereo, Ambiophonic 2-channel (stereo-compatible), PanAmbio 4-channel surround (5.1-compatible), and multi-channel 5.1/6.1/7.1 surround (feeding C to the front speakers in parallel). Minimum room size of 18x14ft allows eight speakers shown, with none within one meter of a wall for clarity (per Toole), plus two subwoofers.

Stereo dipoles front & back separated 0.5m for critical listening (music, games) in Ambiophonic 2.0/PanAmbio 4.0 accommodate two persons (in middle seats). Switching to 5.1 for movies viewed on the 8ft screen on front wall shown at left accommodates six, with the back middle seat meeting ITU-R775 standard for home theater. Dimensions are ft/in.

This plan is implemented at Filmaker Technology for demonstrating comparisons of the various modes, plus full-sphere 3D with speakers above and below (not shown).



An internationally recognized engineering consultant and Peabody award-winning film producer, ***Robin Miller*** *has presented advanced 2D and 3D audio solutions worldwide to the Audio Engineering Society, Society of Motion Picture & Television Engineers, Acoustical Society of America, Canadian Acoustical Association, and German Tonmeisters. As an invited panelist at the AES 2007 Italia conference in Parma, he demonstrated using original recordings Ambiophonics, 5.1-compatible PanAmbio 2D surround, and full-sphere 3D. His company, Filmaker Technology, engages in applied research, systems design & integration, and has a patent for a system of full-sphere 3D recording & reproduction. See www.filmaker.com.*

Angelo Farina (left) introduces invited panelist Robin Miller (third from left) at AES2007 Italia, Parma.

[2] Also, side sounds can create *pinna confusion* because they come from the front, but side images are usually more diffuse, so a compromise favoring correct central timbre is the preferred choice.