LEV and the "Money Seat" of Surround Sound

Spatiality research models listener preference

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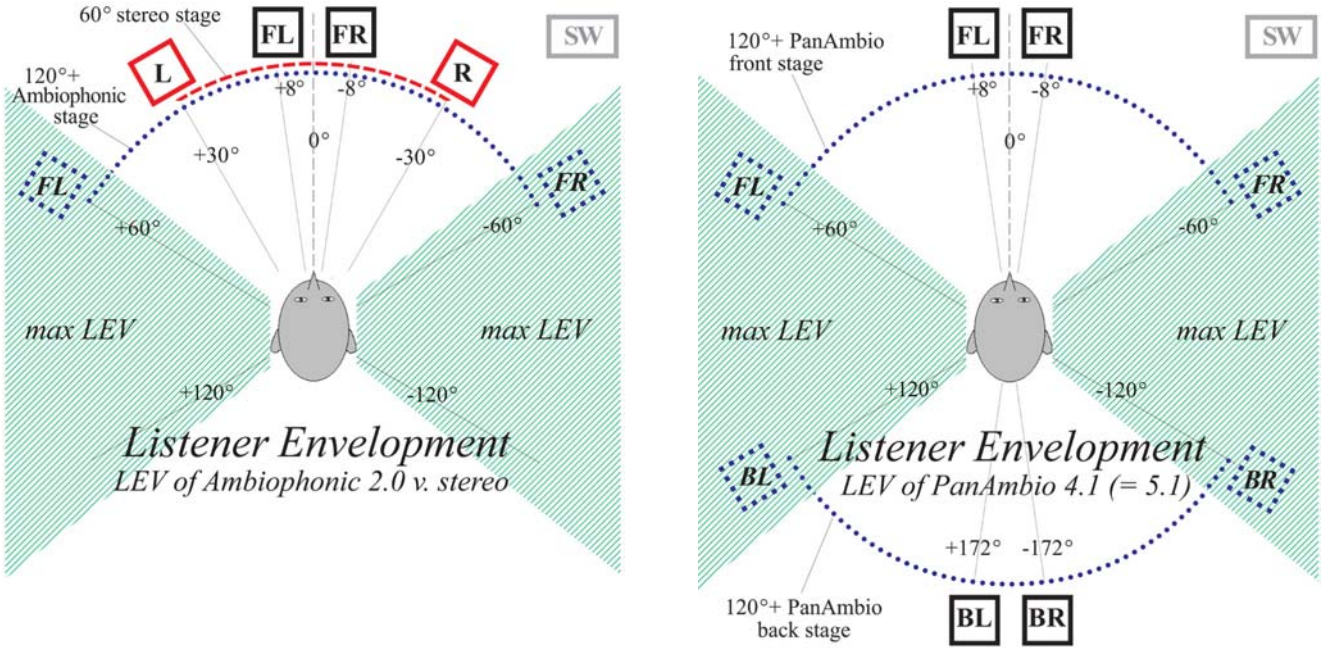

Studies of inter-aural cross-correlation (IACC) explain why stereo has poor listener envelopment (LEV), and why we standardized 5.1 surround. They also show how ***Ambiophonics*** speakers FL & FR in front convey LEV from stereo recordings. Left, stereo/5.1 speakers L & R image too far from ear signal difference-producing regions of maximum LEV, but Ambiophonic imaging reaches within them as virtual speakers *FL* & *FR*. Right, **PanAmbio 4.0 surround** exceeds 5.1's envelopment, adding back speakers BL & BR, imaging as *BL* & *BR* – four "speakers" within LEV regions.

Along with faithful recreation of *tone color (timbre)* and accurate *localization*, "listener envelopment" (LEV) is sought by audiophiles in recordings and playback systems, just as it is prized when heard live by concert-goers in fine halls. Or by movie viewers or gamers who crave immersion. LEV is the reason for "surround" speakers – to recreate life-like *spatiality*. But "How many (few) are required?" and "Where should they be located?" And "What benefit/interference does the listening room contribute?" Decades of research are behind the answers.

Human preference for spatial envelopment

With eyes closed, humans need only hear another's voice, or clap their hands, to visualize the space they're hearing – a large hall, bathroom, cave, etc. Characteristics of our head, outer ears, and torso guide perception of any space we're immersed within, based on familiar environs, learned since childhood. But how we are able to do this depends on reflected *after-sounds* – the acoustic response to the original *direct* sound. More important, what otherwise would be sound emanated only in a direct line to our ears, as is an anechoic test chamber or a snow-covered field, this augmentation contributed by room acoustics adds life and enjoyment to live performances, and therefore to well recorded music, movies, and games.

Whether hearing live or recorded sounds, our ear-brain system is sensitive to sounds arriving later in time and from different directions from the direct sound of a source, whether a live voice/instrument, or a speaker during reproduction. Researchers (Haas and others since) measured a tradeoff in human detection of reflections, calling the effect *precedence,* which refers to the favor we bestow on sounds that arrive before others – the direct sounds preceding their reflections, delayed as these are by the trip they make via a wall, floor, or ceiling to the ear. Within the shortest interval, a reflection is perceived as fused with the direct sound (even when in experiments the later sound has been made artificially louder). With longer delay, we increasingly detect reflective boundaries and unconsciously form an impression of the enclosure we and the source of sound are in. Not only its size, we piece together its shape, because all sonic arrivals are colored as to direction by our personal head-related transfer function (HRTF). Our *preference* for reflection-based spatial cues translates to adding life to a concert, or to its reproduction, by creating or preserving envelopment – LEV.[1]

Hearing "through the listening room"

Reflections due to the home theater/media room itself are delayed too short to cause envelopment – *therefore the signals needed to convey a sense of envelopment must be recorded in a larger space, or simulated.* The enveloping reflections and diffuse reverberation of large rooms are not possible in small

[1] "Envelopment" in two-dimensional (2D) surround sound means being encircled. However, in natural hearing we also perceive sounds elevated above and below horizontal – "immersion" in a 3D sphere.

ones. Furthermore, multiple loudspeakers, especially surround speakers, provide the diversity of angles that enable recorded envelopment signals to be differentiated naturally from recorded direct sounds. So LEV is a product of 1) signals presented in multi-channel recordings and 2) surround sound reproduction involving four or more speakers positioned around the listener.

Attenuated by wall absorption, media room reflections usually fail, at such short delay times, to be strong enough to cross the threshold of the precedence curve. However, recorded, longer-delayed reflections fall on the precedence curve where the ear-brain is increasingly sensitive. Therefore re LEV, most listening room's acoustics are far less effective than recorded ones, and tend to be ignored. Human adaptation is also at play, so in short order the listener is focused on cues in the recording in spite of many, possibly deleterious, acoustic characteristics of the media room. (More damaging acoustic conditions need be addressed and, if possible, fixed.) This ability of humans to ignore and, within a matter of minutes, adapt is sometimes called "listening *through* the room" – i.e. perceiving cues in the recording in the presence of mostly ineffective cues added by the listening acoustics.[2]

Therefore, conveying spatiality, along with faithful *tone color (timbre)* and accurate *localization*, involves fine recording technique to capture LEV, reasonably good listening room design/execution to avoid big acoustics issues and preserve LEV, recognizing listener adaptation to mild conditions, and simply ignoring effects that prove negligible. Still, the money seat is where you've paid to be. But this "sweet spot" also depends on choosing and placing loudspeakers…

Speaker layouts for good listener envelopment (LEV)

Wavefield Synthesis (WFS) recreates impressive two-dimensional surround sound, but it requires the resources implied by 48~96 speakers. For home use, most people would shy from 24 or even 12 speakers. But what is the justification for choosing a layout with only from 4 to 7 loudspeakers, plus subwoofer(s)? One such layout is standardized internationally as "5.1" (and related 6.1 and 7.1) surround sound systems and content. Is 5.1 the best we can do? Or is there knowledge indicating what is better, or next in the evolution in audio?

As in generating original LEV live in the more successful concert halls, some audio reproduction speaker layouts are more effective than others in enabling recorded spatiality to reach the listener. Researchers over many decades have investigated and agree generally about the degree to which speaker layout is important. Their results explain why two-channel stereo does not convey much envelopment, why quad was unsuccessful, and how the industry came to standardize on 5.1 surround sound.

The degree of LEV is related to the *sameness* of signals at the two ears, termed inter-aural cross-correlation (IACC). The more different the ear signals are, the more envelopment is perceived. The most effective range of angles for arriving envelopment-producing signals is between 30° and 120° on either side of straight ahead, with the highest sensitivity at ±60° (see illustrations above). Demonstrate this range for yourself by extending and swinging each arm within its most comfortable range, from two-thirds forward through slightly behind. Spanning typically 45 to 60° in front, conventional two-channel stereo speakers lie at the edge or outside this envelopment-producing range. This explains why stereo, and 5.1's front stage alone, are limited in their contribution to life-like LEV.

Adding speakers in back as did *quadraphonics* (and the rear-most speakers of 7.1), sounds intended to convey hall ambience are even more outside the back-most range for LEV, behind ±120° – well beyond comfortable pointing range. So *quad* did not satisfy as a method of two-dimensional surround.

However, adding speakers and appropriate recorded signals between 60° to 120° – within comfortable pointing range on both sides – maximizes LEV. In fact in controlled experiments, four speakers placed optimally is almost as good as 12! Indeed "4.1" (5.1 with no C signal) is preferred by some content producers for instrumental music, where, compared to quad, the two surround speakers are spaced widely, and therefore are more effective in conveying LEV. Completing the circle with a center speaker to anchor on-screen dialog or solo voices, and we have international standard ITU-R775 for "5.1" surround. (Note that 7.1 still has only the two side-most speakers in LEV regions, explaining its marginal improvement over 5.1, although it is useful for increasing seating.)

Referring to the figures and caption above, using crosstalk cancellation and a pair of speakers in front alone in order to reproduce two-channel recordings, or using two pairs front and back to reproduce multi-channel surround, spatiality is life-like because both stages, between ±60° in front and ±120° around back, reach within the prime LEV regions. These are layouts of *Ambiophonics* for playing stereo recordings and *PanAmbio* for surround . (Note: Play 5.1 in PanAmbio by setting the player to "no center" to mix the C channel to the front speaker pair.) Listening on the median plane where ear signals are equivalent to virtual speaker positions shown, all "speakers" are perceived to reach well within the maximum LEV regions. PanAmbio has double 5.1/7.1's two surround speakers within LEV regions.

Speaker models are a trade-off of price-performance: price can buy status if not real performance; cheap may be a wasted investment, advertised as too good to be true. Believable performance, clearly specified, should outweigh mere looks – there are choices to be had that both perform well and look fine. As important as power-handling and smooth, flat frequency response on-axis, problems will occur if *dispersion* (off-axis response) is poor at the wide angles that are mirrored at the room walls, producing reflections that might not be ignored if much altered in timbre from direct sound that arrives on-axis.

The science above is the work of many researchers, and is nicely reported in Toole's *Sound Reproduction: Loudspeakers and Rooms,* see pp.99~126 and 292~305; Ambiophonics is discussed on p.277. For more info, see www.ambiophonics.org.

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[2] Sensitized with practice, professionals in control rooms need a more critical approach.