The reproduction revolution: taming three-dimensional audio

The room/loudspeaker 'system' has long been identified as critical in the reproduction of faithful audio. CURTIS HOYT of Trinnov Audio explains how advances in research have resulted in an innovative solution to the requirement for 'universally consistent' audio.

AUDIO HAS GONE through many evolutionary changes over the years — tubes, transistors, ICs, DSP and now the current trend is on improving the acoustical reproduction elements with DSP tools: the combined loudspeaker/room system for studios and homes. We are quickly arriving at the point where sound can be spatially reproduced in the home as in the studio without elaborate physical constraints. This article will consider the obstructions in the way of consistent sound reproduction and will introduce a set of revolutionary tools created by Trinnov Audio, a Paris based acoustics/DSP research and development firm.

The need for improvement in the loudspeaker/room 'acoustic system' has long been documented. On the loudspeaker side, speakers are the weak link in the reproduction chain, generally adding many forms of distortion — frequency response, irregular dispersion, phase or group delay, and so on. Adding to the speaker's distortion is the 'room', which can provide uneven power response, dramatic tonal changes based on speaker placement, early reflections, reverberation and absorption, low frequency room modes, and so on. Matters are further complicated when using more than one speaker, i.e. stereo, where phantom images rely on consistent performance from both loudspeakers over a wide frequency range. Throw surround sound into the mix – 3, 4, 5, 7 or more loudspeakers — and the situation becomes literally out of control for any but the most meticulously setup speaker/room playback system.

It is no wonder that audiophiles focus on stereo and, for the most part, completely ignore surround. It's hard enough to get two speakers working right — symmetry with the room and the relative listening position are an absolute must for correct spatiality. For surround, the extra channels make matters more complicated. To get surround right is practically physically impossible without a dedicated room, along with the proper orientation.

Surround speaker placement (based on the ITU standard) calls for five equal distant loudspeakers placed at degrees of 0, +/-30, and +/-110. To get effective use of a listening space, you must use a 'wide wall' front orientation. With just this one consideration, rotating the system to a lengthwise orientation will dramatically reduce the useful space.

And when we examine the professional audio production environment, it doesn't get much better. Often mixes travel to various professional and home studios that can be dramatically different, and all will play havoc with the creative process and will call on trained ears to remember not only their space, but also those of their co-creators. Everyone's formula for what works is different, but it is no wonder that at the end of the day, a good mastering room/engineer is a must to get consistently good results. It's their job to fix the many 'playback system' errors up to that point.

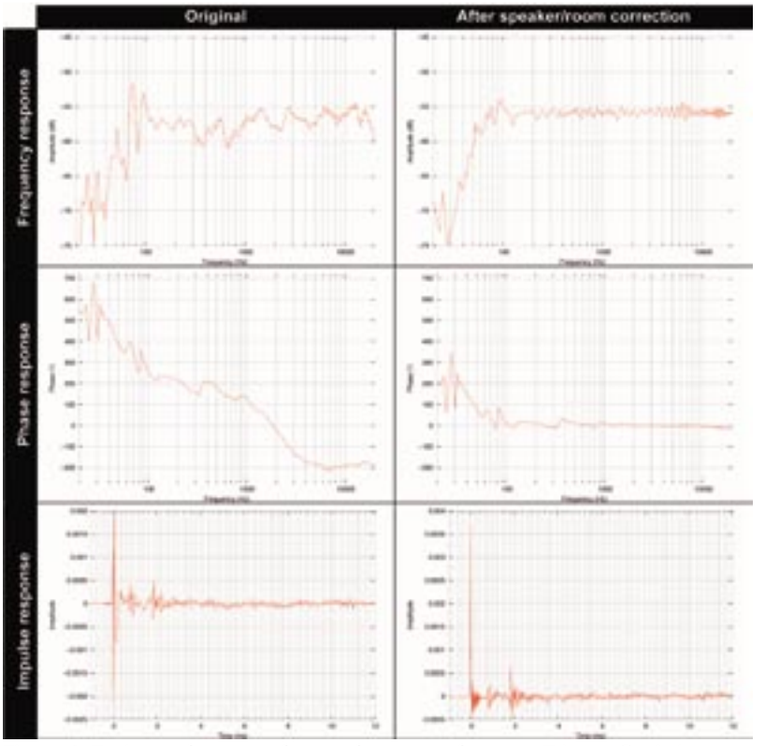

Figure 1. Typical before and after performances from the Trinnov Optimizer.

Let us consider what would be required in the ideal acoustical reproduction system. While the underlying acoustical concepts are quite complex, we can use basic criteria to describe what we consider necessary:

the ideal system would provide a consistent listening experience for the listener throughout the professional and consumer audio listening environments. For this, a minimum of two conditions would have to be met. First, the loudspeaker/room system must voice the same, and second spatiality must be maintained through consistent, standardised loudspeaker angular placement relative to the listener.

LOUDSPEAKER/ROOM VOICING — Why is loudspeaker voicing so important? On the pro audio production side, critical mixing relies on hearing a reference. When more than one room or facility is used, the reference is lost, even if the same model of speaker is used. Frequency response at the listening position varies dramatically with placement and room acoustics, the resultant being the 'power response'. Is it enough to get a well-known brand of pro speakers and mix? Of course not — you must take into consideration how the placement of the speakers within the room will colour the sound. Here is a list of considerations for consistent voicing:

- Loudspeaker frequency response
- Loudspeaker phase/group delay
- Loudspeaker enclosure diffraction
- Loudspeaker placement
- Loudspeaker/Subwoofer integration — bass management
- Room volume and geometry (cubic space)
- Room early reflections
- Room late reverberation decay
- Room modes — low frequency
- Room heating, ventillation and AC.

The curves in Figure 1 point out typical improvements obtained with advanced loudspeaker/room correction.

PLAYBACK SPATIALITY — Playback spatiality is what gives us the sense of localisation and depth in recordings. Spatiality is the degree to which a listener can distinguish placement of a sound within an environment. Done right, images will have a sense of three dimensionality. Historically, the only way this has been accomplished in sound reproduction is through standardised, critical placement of loudspeakers relative to the listener's position. Further, for accurate phantom imaging between loudspeakers, voicing must be consistent for all loudspeakers within a given loudspeaker/room system. This is an often overlooked criterion, perhaps because it is difficult to achieve from room to room, so it's wise for us to pause on this point now.

Let's identify each element that will affect the listening outcome for two conditions first within a system and second between systems:

1. Loudspeaker to loudspeaker matching
2. Room to loudspeaker matching
3. Loudspeaker angular placement (azimuth and elevation) to the listener.

Predicted results of a combined Voicing/Spatiality Matrix looks like those in Figure 2.

We can see from the above matrix that the key to universally consistent sound is in providing matched speakers to matched rooms with a standardised placement. Big job, no wonder it's seldom right and audiophiles have a tough time with stereo and look the other way when it comes to surround. Let's now take a look at an elegant solution, based in part on mathematics that date back to 1870…

			Result			
			within a System		between Rooms/Systems	
Speakers	Room Acoustics	Placement	Voicing	Spatiality	Voicing	Spatiality
Unmatched	un-symmetrical	Random	Inconsistent, unbalanced	Inconsistent	Inconsistent, unbalanced	Inconsistent
Matched systems for different room to room	un-symmetrical	Standardized	Inconsistent	Inconsistent	Inconsistent, unbalanced	Inconsistent
	symmetrical but not identical room to room	Random	Inconsistent	Inconsistent	Inconsistent, unbalanced	Inconsistent
		Standardized	Consistent	Consistent	Inconsistent, unbalanced	Inconsistent
	symmetrical and identical room to room	Random	Consistent	Inconsistent	Consistent	Inconsistent
		Standardized	Consistent	Consistent	Consistent	Consistent
Universally matched	un-symmetrical	Standardized	Inconsistent	Inconsistent	Inconsistent, unbalanced	Inconsistent
	symmetrical but not identical room to room	Random	Inconsistent	Inconsistent	Inconsistent, unbalanced	Inconsistent
		Standardized	Consistent	Consistent	Inconsistent, unbalanced	Inconsistent
	symmetrical and identical room to room	Random	Universally Consistent	Inconsistent	Universally Consistent	Inconsistent
		Standardized	Universally Consistent	Universally Consistent	Universally Consistent	Universally Consistent

Figure 2: Reproduction Voicing-Spatiality Matrix.

THE NEW FRONTIER — three dimensional manipulation of audio leads to universally consistent reproduction. Acousticians and mathematicians have been working for years to find ways to bring more flexibility to acquisition and reproduction. For years, sound could only be manipulated in a one dimensional way — frequency and amplitude. Early computers afforded folks like Richard C. Heyser to apply a second dimension — time. We know it today through extensive use of Time Delay Spectrometry and Fourier transforms, which allow us to analyse and manipulate both time and frequency. This is the current reality of audio and the basis for all DSP processing prevalent today in live performance, recording, and reproduction. It's gone a long way to solving the loudspeaker/room voicing puzzle and has trickled down to the most basic of consumer audio gear.

Now we are facing a new paradigm in audio

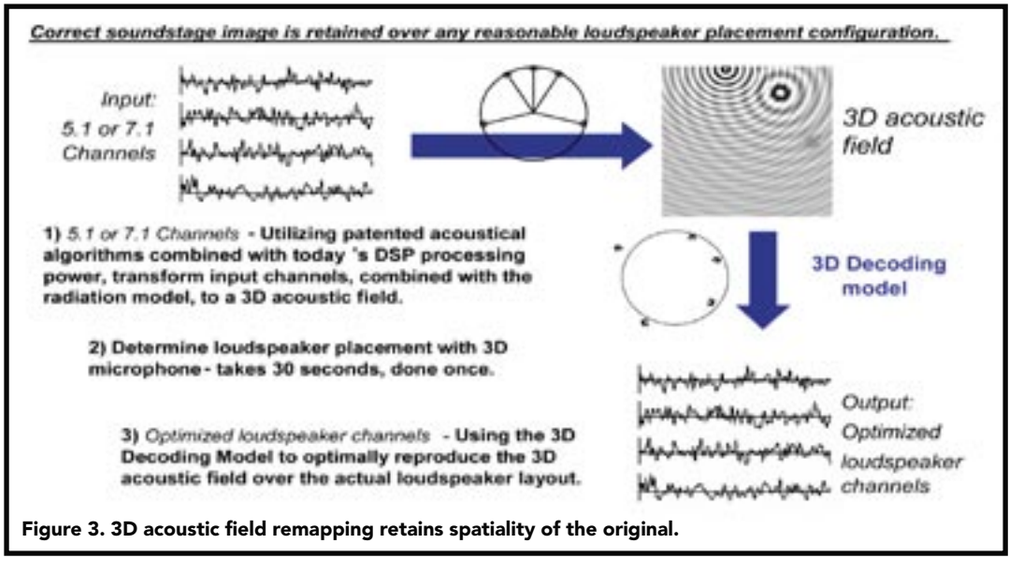

Figure 3. 3D acoustic field remapping retains spatiality of the original.

where sound can be described and manipulated in a three-dimensional way using advanced mathematics — Fourier Bessel transforms. The transforms allow for the mathematical representation of an acoustic field and are quite powerful, as they allow the transformation of an acoustic field from one space (or room) to another. (See Figure 3.)

Trinnov Audio has done pioneering research in this area and is now bringing solutions to the audio industry through various professional and consumer audio products. Let's consider the Trinnov Optimizer here.

The Optimizer solves the dilemma of reproduction: it has the learning capability to automatically gather information relating to over 30 variables regarding the loudspeaker and room with a single point, four-capsule microphone routed to a dedicated, high performance PC-based DSP engine. Information gathered during the calibration phase includes the domains of frequency, time, and direction. It learns the placement of the loudspeaker within 2 degrees elevation and azimuth, and distance within 1cm. This takes approximately one minute for a 5.1 surround system, and works equally well in a small room or a 200-seat theatre.

Figure 4: 3D calibration probe

The Optimizer then uses the calibration information to voice and spatialise the loudspeaker/room system to a user preset standard. It sounds remarkable and it is revolutionary. Within reason (read within the constraints of the laws of physics), the system can make different speakers voice the same and retain spatiality of the original recording even if the loudspeakers aren't placed anywhere near their ideal location. While the concepts for solving the problem are complex, the user interface and solution is rather simple and elegant. The day is coming where we can finally copy an original acoustic field and superimpose it on another space. The result is no longer constrained by the aforementioned matrix and sound becomes 'universally consistent'.

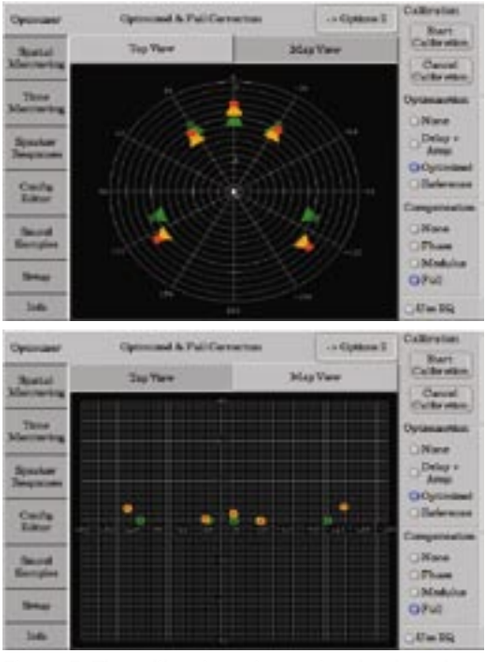

Figure 5. The calibration mic acquires loudspeaker location relative to listener: distance, elevation and azimuth. Shown are a Top View and Map View in degrees.

The Optimizer Pro is dedicated to advanced audio applications and has been used in a variety of acoustic spaces over the past year including music studios, television and radio broadcast facilities, film and homes.

The Optimizer Pro's interface allows for digital and analogue input and output thanks to optional internal or external conversion modules. The device receives multichannel or stereo signals, for example the outputs of mixing desk or a player/decoder. The outputs of the Optimizer are routed to the amplifiers, without taking care of the order or even the phase of the cabling. The system will measure the best feed for each loudspeaker and compensate for the imperfections of each loudspeaker/room couple.

The setting of the device consists of choosing the input format and the number of loudspeaker and placing the 3D acoustic probe at the listening position. About one minute after having pushed the 'start calibration' button on the touchscreen, the installation has been measured and the compensation processing is running, transforming the input signals into signals that are specifically optimised for the installation. ■

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