

# **Design considerations for an idealized domestic surround sound listening space**

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## **Abstract**

The author has actively involved himself in the production of music for surround sound systems since the late 1960s, including composition, production, recording (classical, multichannel pop and experimental), loudspeaker design and acoustical design. Based on his experiences, he will present some design principles (and constraints) for domestic (and public) surround sound playback spaces, possible loudspeaker configurations and topologies. He will also suggest a possible ideal domestic music playback space.

## **Surround Listening Space As Musical Instrument**

The evolution of loudspeaker music playback and performance over the past half century has been essentially an ad hoc collective attempt to bring the performance of music into a variety of private and personal spaces for individual or small-group enjoyment. At the same time, a genre of "loudspeaker music" has evolved, essentially without notice.

In addition to the production of recordings that attempt to mimic a live performance, music is now also being composed and produced directly for loudspeakers, to be played back by those loudspeakers in private domestic spaces as the primary performance. With the emergence of surround sound as a viable production medium, composers have begun to create music specifically for 5.1 (or related) arrays. This musical genre has specific and distinct characteristics.

In an earlier paper<sup>1</sup>, I noted the following distinctions between "live" traditional performance and "loudspeaker" performance:

- Live music is public and usually occurs in large, crowded venues, while loudspeaker music is generally performed in private and for only a few people.
- Live music is highly social and ritualized, while loudspeaker music is casual, ubiquitous and often extremely intimate.
- Live music has a strong emotional interaction between listeners and performers, while loudspeaker music has no such interaction.
- Live music is mostly limited by human capabilities for performance, while loudspeaker music is not constrained by human performance limitations.
- Live music is a one-time event not under the listener's control, while loudspeaker music is under the direct control of the listener, who can vary its spectrum and level at will. It can be played on demand, stopped, restarted and repeated exactly, ad infinitum.

It is now also appropriate to consider what reasonable expectations can be had by both composers and listeners for a an idealized domestic surround listening system and room as a viable musical instrument in its own right. There is a growing, diverse body of music being directly

created for this medium (as you can hear later in this convention). It is reasonable to specify criteria for such a space and system. Interestingly, the issue here is no longer the “accurate” reproduction of a recording made in a concert hall, but rather the creation of beautiful, moving and powerful music for individuals who listen to their music on loudspeakers.

## **The Surround Sound Playback/Performance Topology**

### **Mission**

The restated mission of an idealized Surround Sound system and environment might reasonably be: To provide a superb array of musical and audio experiences in a comfortable, ergonomically conducive and flexible domestic space, without particular regard to style, genre, or specific production preferences, but encompassing as broad a range of such experiences as possible while maintaining an acceptably high level of performance for all of them.

## **Criteria for a high-quality domestic listening environment**

### **Multiple uses**

It is not reasonable, given the investment involved and the similarity of architectural and hardware requirements, to devise separate and unique spaces for listening to original music, to reproduced music or for viewing film and/or video. I assume, therefore, a single, multi-use space. I have even envisaged the integration of live acoustic music performance as well, but that implementation remains beyond the scope of this paper. Some fascinating possibilities exist.

### **Acoustical levels and isolation**

The principles of acoustical isolation and the engineering requirements needed to achieve various values are well-known and understood. Suffice it to say that the noise floor, with all systems running, should be less than 40 dBA SPL Leq, and maximum levels should probably not exceed 115 dBC SPL (fast detection). Isolation of the listening space from its surroundings should probably be at least 40 dB, depending of course on the noise issues pertaining to those adjacent spaces.

### **Minimum and maximum dimensions**

Based on personal experience with numerous purpose-built and adapted home theatre and studio-type listening rooms, I suggest that the minimum size for a successful high-quality room might be 20' long, 15' wide and 8' high. At the other extreme, I have come to believe that no single dimension should be significantly greater than 50' and that the overall floor area should be not exceed approximately 1500 square feet, in order to constrain the onset of long-term reverberance in the playback space which may interfere with impulsive transient characteristics inherent in any given recording. Ceiling height, depending on topology, should probably be no greater than 20 feet, for a total volume of no more than 30,000 cubic feet. It should be noted that such a maximum volume will require significant absorption at all frequencies to obtain satisfactory performance.

### **Optimum Listening area/population size**

The question of the optimum listening position and area, as well as the number of people that can share that space, is a key concern that has serious implications for loudspeaker music. It is

widely accepted in stereophonic practice that the optimum listening position can exist only along the median plane (with a lateral tolerance of approximately six inches). Therefore, for “optimum” stereophonic listening, it has come to be accepted that listeners should be positioned in a single column placed along the median plane. In end-user practice, this constraint is usually set aside and listeners listen side-by-side in a “near-optimum area” within a few feet of the median plane, accepting the phantom-image distortions that occur without major complaint.

With a multi-channel array, however, we no longer have a median plane, but rather only a unique median point. Therefore, the number of people who can appropriately enjoy a music performance is severely constrained by this, and may be exacerbated by some of the philosophies and approaches of recordists who prepare highly correlated multi-channel music recordings. In the worst case (where phase coherence is required up to 1 kHz.), a single individual may be the maximum number that can enjoy a satisfactory performance at a single time.

However, if we assume reasonably conventional management of correlated signals among channels and traditional musical standards of rhythmic integrity, it seems to me that the upper limit of the optimum listening area is, in general, going to be limited by the amount of time error that is tolerable for rhythmic materials used in hockets “bouncing” between multiple speakers.

I estimate the threshold of audibility of that time error, based on my own production and testing experience, at approximately 6 ms. (at which point an error in consistent rhythm can be detected). A 20 ms. error results in a distinct “loping” rhythmic offset which I believe will be found unacceptable by most musicians. A 10 ms. error seems to me to be audible but generally not annoying. This suggests that the greatest error in distance between speakers should be no greater than approximately eleven feet, which in turn suggests an optimum listening area of approximately 11' in diameter (94 square feet). From this, we can posit that a group of up to twenty-five listeners of close acquaintance (thirteen would be better and nine would be best) might be a reasonable maximum. Consider the following graphics:

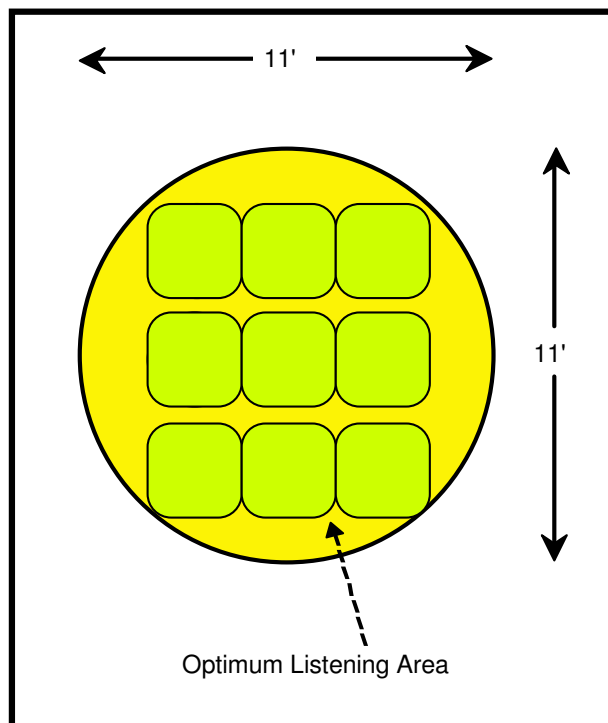


Figure 1. The optimum listening area for a surround sound system where the maximum time error between speakers in the array is 10 ms. Rhythmic (time) and amplitude degradation increase as listeners move outside of the optimum area. Nine listening positions (in close proximity) can fit entirely within the optimum listening area.

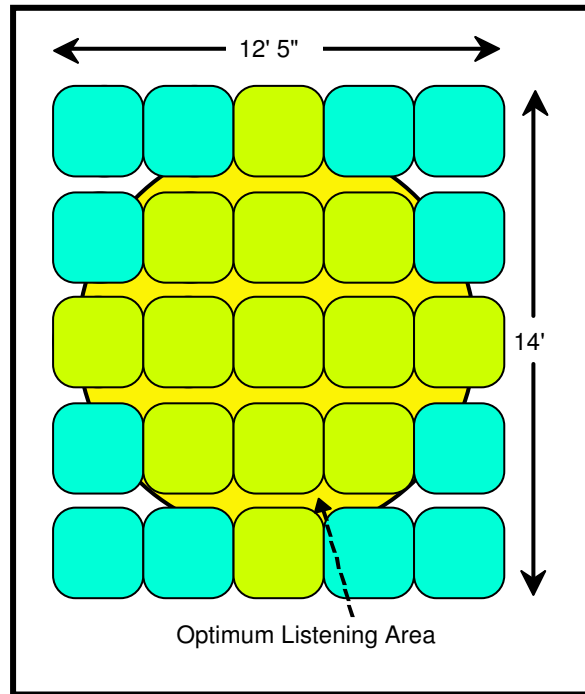


Figure 2. Thirteen listeners can fit “nearly” within the optimum listening area, while another twelve can fit “just outside.” This represents a reasonable maximum population that can listen to a high-quality surround sound performance at one time.

Therefore, it is clear that the population that can be musically well-served by a five-channel surround sound system similar to the one we are discussing is necessarily quite small. It is not possible, due to the errors that accumulate due to the propagation rate of sound in air, to present such music with high quality to large groups of people. Multichannel loudspeaker music is, therefore, by this primary physical constraint suitable ONLY for domestic use in small groups. It cannot be a viable public medium.

### Proposed room surface treatments and supporting criteria

#### Management of Early Reflections and Decay

Early reflections will begin to arrive at listeners in the optimum listening area approximately 10-15 ms. after their direct predecessors, and will build up over the next 40 ms. (the nature of that buildup is strongly affected, of course, by the room volume and absorptivity at frequency). It has been my experience that these early reflections (and particularly their high-frequency content) are extremely beneficial in generating strong phantom images, depth, reverberance and envelopment.

Some constraints apply:

- loudspeakers need to be at least 6' from the nearest wall or else installed in the wall;
- loudspeakers need to have broad and uniform lateral high frequency dispersion (and it is desirable to have constrained high frequency vertical dispersion);
- in general, the "front" wall (the wall behind the front loudspeakers) and the ceiling (at least the front part) need to be treated with broadband absorption;
- the side and rear walls need to be hard and reflective at all frequencies. It is desirable for the rear wall to include a large vertical cylindrical diffuser at the median plane in order to specularly reflect high frequencies laterally. Such a diffuser can also serve as a bass trap as needed.
- the floor needs to be carpeted to provide additional high-frequency absorption.

The goal here is to provide a rich, broadband array of lateral early reflections from the loudspeakers for at least 50 ms., but not much after that. Meanwhile, vertical early reflections are suppressed, which serves to support the asymmetrical behavior of our auditory localization mechanism. These behaviors permit the playback room to carry whatever phase-locked lateral early reflection and reverberant artifacts exist in the recorded music without significant interference.

### Management of Standing Waves and Room Modes

It is important to account for the room modes of the playback room. In general, in rooms with these dimensional limits, the widely spread lowest modes will be high enough in frequency to impose a significant tonal signature based on room dimensions.

The use of broadband absorption on at least two adjacent surfaces in the playback room will tend to absorb and dissipate most of the resonant room modes that are excited by the loudspeakers. Only the lateral axial mode will remain essentially unaffected, and it will tend to be comparatively unimportant to the loudspeaker/room/listener interaction. By designing the room so that side walls are not parallel, the lateral axial mode can be diffused as well.

### Lateral symmetry

It is desirable to make the playback room symmetrical along the front-to-back median plane (and, of course, to place the loudspeakers so that they use the same median plane for their Left/Right orientation). Such symmetry enhances the effectiveness of lateral early reflections in supporting phantom images, phantom reverberance and envelopment.

## Loudspeaker Topology

### Primary Multi-Use Assumptions

It is easy to envision a wide range of uses for such a space. They include, but are not limited to, the following:

#### Home Theater

Home theater uses a 5.1 loudspeaker array with a screen and video projection system, subject to an array of conventions. It may be possible to replace the subwoofer by using identical full-range

speakers and route the LFE channel to at least two of the full-range loudspeakers. At present, it is recommended to place speakers in a circle (or time-corrected polygon) at the following angles:

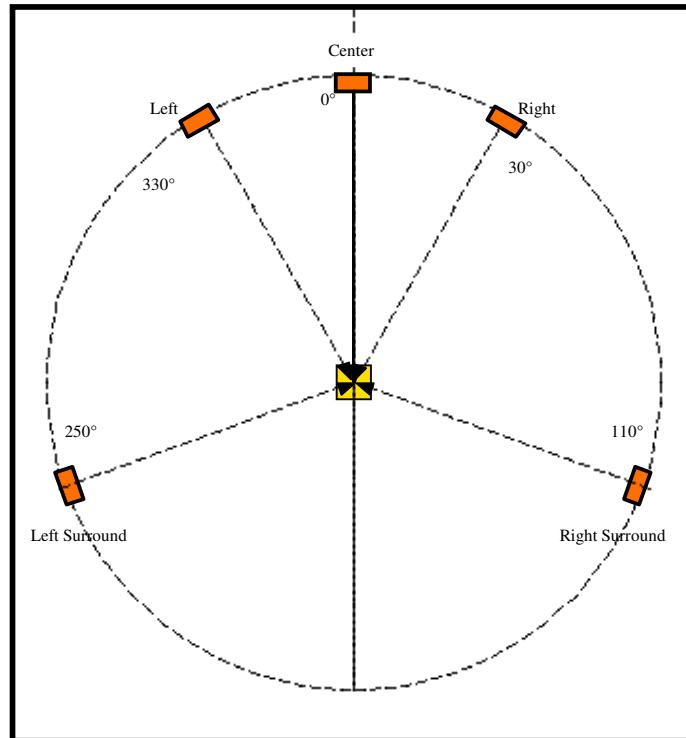


Figure 3. Recommended Home Theatre 5-channel array.

It has been my experience that these angles can be altered significantly without trouble, so long as lateral symmetry is maintained. This is particularly true when high-quality loudspeakers are used. Note also that the rear, surround angles are derived from movie theater practice and may not be optimum for either musical or home theater use.

#### Stereophonic Playback

The system should also permit high-quality two-channel stereophonic playback, which requires quite high quality loudspeakers, plus careful and symmetrical placement.

#### Multi-Channel Playback of traditional music

The system should permit high-quality multichannel playback of traditional “acoustic” recordings, supporting a variety of approaches to those recordings.

#### Multi-channel Playback of original Surround Sound Music

The system should permit high quality multichannel playback of dedicated “surround-sound” music composed specifically for a loudspeaker array. This means that no constraints to the playback system should be applied that are based on assumptions about “how” various channels will be used. It reinforces the call for all channels to be identical, high-quality full-range channels.

## **The 5.1 Channel Array**

The 5.1 channel array in current use evolved from film production and movie theater playback requirements and here we DO make assumptions about how the channels will be used. A center channel is needed for on-screen dialogue, left and right channels are used for stereophonic music and off-screen effects, the surround channels are used for reverberance and ambience as needed, plus rear-of-hall effects, while the LFE channel is used for low-frequency extension for dramatic effect as needed. These usages have evolved over fifty years and are well-known and understood by the film production community as well as accepted by audiences.

The application of this cinematic theater tradition to the home theater is less well-developed and implemented, due to manufacturers' urges to reduce system costs by reducing bandwidth of speakers and related economies. As a result, the performance of the speakers in home theaters has often been degraded on the assumption that the subwoofer can provide the low-frequency bandwidth (this assumption is not part of the movie theater experience, or planned for in film production). Surround speakers are often reduced in performance (and cost) on the assumption that they ONLY carry band-limited low-power reverberant information. The result has been a chaotic and often quite poor implementation of home theater for middle-class consumers, an implementation that is not really adequate for satisfying film viewing, much less musical playback.

Nonetheless, extremely high-quality installations can be obtained with existing technology and often are realized in purpose-built rooms in upper middle class homes. An entire niche industry has evolved to serve this market.

### **A proposed 6-channel Array**

For my own work, I have been using a six-channel array (five full-range channels in approximately the conventional home theater arrangement plus a sixth full-range channel mounted directly overhead).

The height channel is an extremely interesting one, whose virtues aren't particularly obvious at first, but whose impact is quite substantial. For original multitrack music, its availability as a source channel suggests a variety of musical gestures, meanings and spatial relationships that are simply not available in "horizontal" music.

In acoustic recordings, the overhead channel is usually captured by an upward facing hypercardioid microphone positioned somewhere behind the main front stereo array. The result of this ambient information is a sense of open "airiness," additional fullness and richness to the sound and a "coupling" of front and rear speaker arrays.

Because of the low-frequency extension of my BeoLab 5 loudspeakers, I simply send the LFE channel to Left and Right, which works entirely satisfactorily. I have been able to use this topology successfully for both stereophonic and surround production and mastering of both music and sound for film/video.

### **A possible pentagonal topology**

Noting the benefits Tomlinson Holman has derived from his 10.2 experimental playback system<sup>2</sup> for more solid "side phantom" images, I have experimented with a pentagonal horizontal array, as shown below:

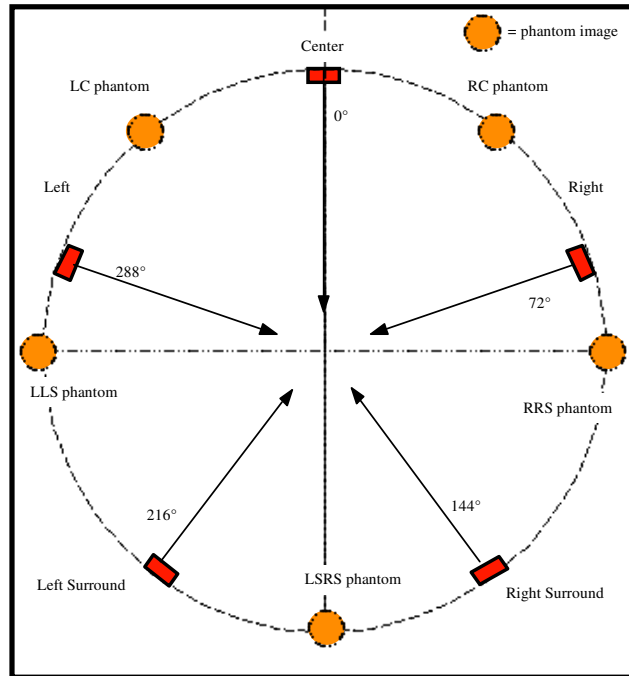


Figure 4: Pentagonal loudspeaker array, showing also the approximate locations of phantom images derived from individual pairs.

Such an array can be used successfully for all of the above applications, with some simple but interesting modifications. For surround music, the ability to have robust lateral images (there is a solid source at  $\pm 72^\circ$  and a L/Ls or R/Rs phantom at ca.  $90^\circ$ ) is quite attractive and significantly expands the compositional repertoire.

Meanwhile, really effective stereo (I find it more satisfying than conventional stereo) can be created by sending the mono LR sum to the Center speaker for 3-channel stereo. In the normal  $\pm 30^\circ$  stereo configuration, this causes the stereo image to collapse unacceptably around the center channel. However, because Left and Right are both at  $72^\circ$  from Center in the pentagonal array, Left/Center and Right/Center phantoms are generated at  $\pm 36^\circ$  and the result is an extremely satisfying stereo image with a solid Center image and phantom Left and Right images (as opposed to the conventional phantom Center image and solid Left and Right images). Meanwhile, the rear stereophonic field is much more stable with robust solid sources and phantom images and reverberance wrapping forward from  $180^\circ$  forward to  $90^\circ$  on each side.

It is my intention to return to this as my primary working topology by the end of 2006.

### Summary and Conclusions

- A genre of loudspeaker music has evolved without notice.
- That genre has a number of specific characteristics that strongly differentiate it, as a genre, from live music performance.
- Loudspeaker music takes place in private environs.

- High-quality multichannel sound playback systems support high-quality loudspeaker music.
- Music is now being composed directly for such systems/spaces, and there is a growing body of work. We can now think of the domestic playback system/space as a “musical instrument” in and of itself.

At the same time, a multi-channel surround sound listening environment can serve multiple purposes successfully. It is desirable to impose as few aesthetic, musical and production constraints on the installation as possible, and to make as few assumptions as possible about how each channel will be used.

Such an environment is by musical and acoustical necessity only suitable for a limited audience size (twenty-five listeners maximum) if performance quality is to be maintained.

I assume that such multichannel systems will be compatible with a conventional 5.1 loudspeaker topology, but suggest the following adaptations:

- the use of identical full-range loudspeakers for all channels;
- the elimination of the subwoofer, while routing the LFE channel to Left and Right;
- the addition of a sixth, overhead channel;
- the redeployment of the five floor speakers into a symmetrical pentagonal array, with appropriate upmix integration of the Center channel into the Left/Right stereophonic array.

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<sup>1</sup> Moulton, David, “Loudspeaker As Musical Instrument.” See below.

<sup>2</sup> Tomlinson Holman, The Number of Audio Channels, Part 2, Surround Professional magazine, Volume 2 #8, Dec. 1999, pp. 50-56

Related ASA papers available for download at [moultonlabs.com](http://moultonlabs.com)

The loudspeaker as musical instrument: an examination of the issues surrounding loudspeaker performance of music in typical rooms, by David Moulton, presented in Nashville, April, 2003. Available gratis as a PDF from the author at [www.moultonlabs.com](http://www.moultonlabs.com)

A new loudspeaker design: a case study of an effort to more fully integrate the loudspeaker into the playback room in a musical way, by David Moulton, presented in Nashville, April, 2003. Available gratis as a PDF from the author at [www.moultonlabs.com](http://www.moultonlabs.com).

Loudspeaker array as a musical composition genre, by David Moulton, presented in San Diego, November 2004. Available gratis as a PDF from the author at [www.moultonlabs.com](http://www.moultonlabs.com).

Power Chords, Polyphonic Trains and Plain Old Phase, by David Moulton, presented in Providence, June, 2006. Available gratis as a PDF from the author at [www.moultonlabs.com](http://www.moultonlabs.com).

For a fairly comprehensive history of the development process for the BeoLab 5 loudspeaker, see the Boston Audio Society Newsletter (The BAS Speaker), Volume 26, #3, available from the Boston Audio Society ([www.bostonaudiosociety.org](http://www.bostonaudiosociety.org))