

# CEA Bulletin

## Home Theater Recommended Practice: Audio Design

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## Foreword

This guide outlines recommendations for the audio design of high performance home theaters. CEDIA and its certified Electronic Systems Contractors (ESCs) follow these practices, where applicable, to deliver high value to dedicated home theater environments, helping ensure full performance potential for the equipment and the room.

*Home Theater Audio Design* provides a baseline for the design and installation of residential spaces to be used for home theater or multi-channel music playback. While the focus of these two applications is home theater audio design, many of the practices are applicable to multi-purpose, two-channel and other acoustic spaces.

CEDIA recommendations are assembled from its ESCs' years of experience and cumulative wisdom. Industry standards, practices and recommendations published by other relevant bodies, as well as commonly accepted commercial practices now regarded as "de facto standards" in the audio industry, are also represented in this document.

Standards include those from:

- Society of Motion Picture and Television Engineers (SMPTE)
- Audio Engineering Society (AES)
- International Telecommunications Union (ITU)
- European Broadcasting Union (EBU)
- International Electrotechnical Commission (IEC)
- International Organization for Standardization (ISO)
- American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE)

Accepted commercial practices include those from:

- Dolby Laboratories, Inc.
- THX, Ltd. (THX)
- Imaging Sciences Foundation (ISF)

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## Introduction

Home theater rooms are gathering spaces with one main purpose: watching movies. These rooms can also have other uses like listening to and performing music, entertaining, gaming, or simply lounging. It is important that the professionals who deliver the home theater experience be aware of the precise set of video and audio standards by which film content is created. *Home Theater Audio Design* outlines the various design parameters relevant to the proper design of a home theater that meets relevant industry guidelines. Additionally, these practices ensure that a home theater supports other media uses such as music, gaming, and broadcast TV.

Whether used as a dedicated space or a multi-purpose space, a properly executed home theater should be able to faithfully reproduce the picture and sound content. That's because the film director and the entire crew working alongside the director carefully craft the content to create an emotionally engaging story that can transport the audience to far away lands in far away times. The best way to ensure that an ESC's projects are successful and that customers are satisfied is simply adhering to movie technical production standards.

As is evident from the length of this document, when designing a home theater, many factors come into play. Several are interdependent and interactive, and the design process will invariably be iterative. This means that every step will need to be revisited and altered, continuing around the circle of decision points multiple times until the work is finished. Some compromises are inevitable. For example, the picture screen and front speakers will compete for space since they need to be in the same location. Of the several ways to deal with that issue, some yield better overall results than others. Ultimately, the best sounding and best looking home theater is the one with the most intelligent set of compromises!

## Performance Objectives for Audio

The most important performance objectives for the home theater audio design are:

- **No coloration** — Reproduced sound should not be audibly colored, and should be tonally similar from all loudspeakers in the system, fronts and surrounds.
- **A continuous, smooth sound stage** — The frontal sound stage should be continuous and smooth from the left to the center to the right speaker, and not biased to one side or the other.
- **Envelopment** — The playback system should be capable of providing a sense of envelopment—the impression of being immersed in non-directional sounds, as in the reverberation heard in large rooms, halls, and corridors, crowds in stadiums, environmental sounds and so on. Atmospheric and mood-setting music is another example. Ideally, all of this should be done without listeners localizing the surround loudspeakers except when sound effects are directed to a channel/loudspeaker for that deliberate effect.
- **Dialogue intelligibility** — The listening room should not degrade dialogue intelligibility.
- **No perceptible distortion** — The system should be able to play loud without audible (annoying) distortion.
- **Consistent performance** — Audio performance should be as consistent as possible over the seating area. Best performance is expected at the prime listening location.
- **Low-frequency accuracy** — Low frequency performance of the audio system should be capable of fully supporting all audio content, consistently from seat to seat, without sounding distorted or boomy.
- **No background noise** — Background noise levels should be low enough to either be inaudible, or at least not intrusive.
- **Isolation** — Under normal circumstances noise originating outside the theater should be inaudible inside the home theater. Similarly, noise originating inside the home theater should not be audible in sensitive adjacent spaces or loud enough to disrupt normal activities in any room in the house.

## A Procedure for Achieving the Performance Objectives

Several loudspeakers, several listeners and a room comprise a complicated system that cannot be completely separated into its parts. Achieving a satisfactory result might require some design iterations, a measure of trial and error. Before embarking on the project it may be useful to understand the underlying logic and issues as outlined in the guidelines that follow.

The details of room dimensions and seating locations are interactive. They should be determined together, with the result depending on how much flexibility the situation allows.

- **Prime listening location** – Industry guidelines for arranging front and surround loudspeakers are based on the position of the prime listening location. Under ideal circumstances, the prime listening location provides the optimum viewing angle for the video display. The prime listening location experience provides the basis for determining the number of surround channels to employ. Therefore, determining the prime listening location is fundamental; this will be an interactive decision process, driven by the physical, decorative and budgetary restrictions of the specific job.

- **Number of seats** – Two factors determine how many seats can be accommodated, and their arrangement:
  - Viewing angles and sightlines, and
  - Quality and seat-to-seat uniformity of bass.
- **Room size** – You should first reach agreement with the customer on the size of seats to be installed and the space required to provide access during a performance, including considerations whether extra space is needed. In an existing room, the room defines what seating arrangements are possible. In a new room design, the seating arrangement can help determine the room size and shape. In either case, it is much easier if the room has a rectangular shape.
- **Acoustical treatment** – Once the room dimensions, loudspeaker locations and seating have been decided, the interior acoustical treatment can be designed. The first requirement of that design is to ensure that dialogue intelligibility is not degraded by excessive reverberation and that tonal errors are not introduced by speaker/boundary interactions. Acoustical treatments can be designed to meet multiple purposes as required, including:
  - Assisting the front channels in providing a good soundstage
  - Providing localized sounds through the surround channels and
  - Providing immersion or envelopment.
- **Loudspeaker selection** – You can then select loudspeaker for front, surround and subwoofer applications capable of delivering high sound quality to all members of the audience, at the sound levels required for credible movie and music experiences.
- **Interior design and appearance** – Matters of interior design are of great importance, and there may be circumstances where appearance prevails over acoustical requirements. Flexibility is important, and it is good to understand what is needed and why so that trade-offs can be made intelligently. The guidelines here in *Home Theater Audio Design* are sufficiently detailed to insure that all such decisions are informed choices.

# Loudspeaker Layout

## Loudspeaker Layout Objectives

- Determine the multi-channel configuration to be used
- Identify the approximate loudspeaker locations

Once these two choices have been made, overall room design can progress. (Details of loudspeaker location and mounting will be discussed in “Audio System Component Location and Installation,” pg. 28.)

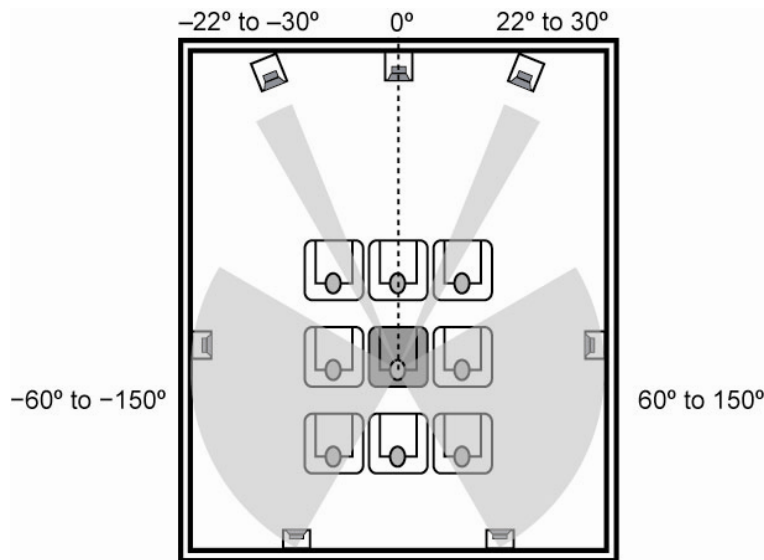


**Figure 1 –**

*A simple diagram showing the angular ranges within which loudspeakers should be located relative to the prime listening location.*

*The locations of the front loudspeakers follow guidance at [www.dolby.com](http://www.dolby.com). The angular range for surround loudspeakers is the recommendation in ITU-R BS.775-2 (2006)®.*

## Loudspeaker Layout Guidelines

- Loudspeaker layout is defined from the perspective of the prime listening location .

In the example in Figure 1, the prime listening location is in the center of the seating area; this is obviously not a requirement. If there is to be only one pair of surround loudspeakers, as in a 5.1-channel system, they should be placed within the angular range  $\pm 110^\circ$  to  $\pm 120^\circ$ . If there are four surround loudspeakers, as in a 7.1-channel system shown here, the side loudspeakers can be placed symmetrically within the angular range spanning  $\pm 60^\circ$  to about  $\pm 100^\circ$ , and the rear loudspeakers within the angular range spanning approximately  $\pm 135^\circ$  to  $\pm 150^\circ$ . A 6.1-channel system could obviously have a single center-rear loudspeaker, but it is recommended that the signal be split between two rear loudspeakers.

- Use additional surround loudspeakers for large audience areas and in large rooms.

Loudspeakers should be spaced by equal angles within the angular range shown in Figure 1.

# Seating Layout

## Seating Layout Objectives

- **There should be at least one prime listening location**

Rooms engineered for high quality presentation should always have at least one prime listening location where the minimum possible design compromises are made.

- **Replication of the prime listening location**

Other seats should recreate the prime listening location experience as closely as possible. It should be noted that many of the performance objectives listed above can be substantially met by proper configuration of the seats with respect to the room and to the installed loudspeakers.

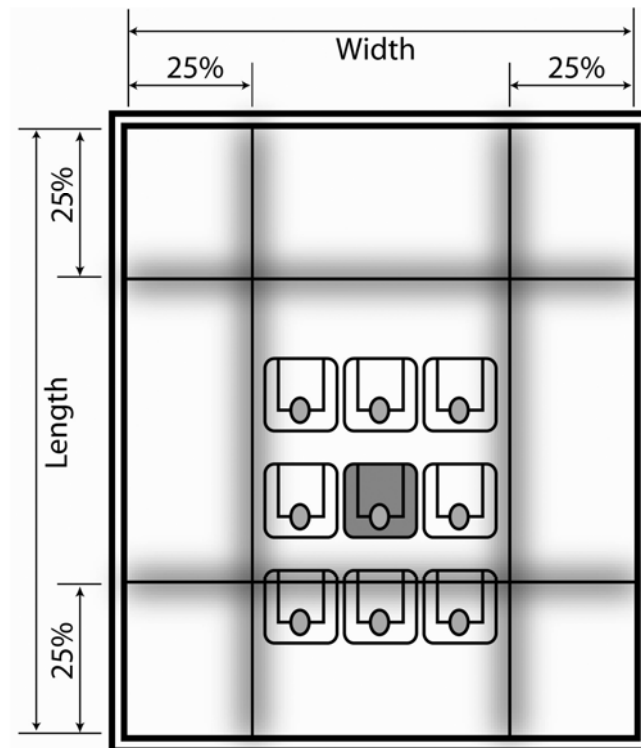


**Figure 2** – This floor plan shows locations of the pairs of nulls for the 2nd order axial (width and length) room modes. The shaded areas indicate that the designer should locate chairs such that listener's ears are more than 18" away from the nulls. Unshaded areas show acceptable locations for seats.

## Seating Layout Guidelines

Seating layout guidelines assume the room is rectangular and that wall constructions are reasonably uniform. Seat locations should meet requirements for image projection.

- **A central prime listening location**

In a rectangular room layout with reasonably uniform wall construction, the prime listening location should be at the geometric center of the loudspeaker array, as shown in Figure 1. Other excellent seating locations are on the central front-to-back axis.

- **Centerline seating**

Avoid aisles in the center of the room. Keep the centerline location free for seats between the left and right loudspeakers. The use of multiple subwoofers eliminates the odd-order room modes that otherwise would be problematic at these locations.

- **Maintain seat distance from speakers**

Avoid putting seats too close to any one loudspeaker, as this will result in an unbalanced sound stage, loss of envelopment, and distracting localization to the nearby loudspeaker.

- **Avoid null points**

Avoid putting listener's heads at or near the null points of the low-order (1st, 2nd and 3rd order) axial length and width standing waves (also called room modes). Listeners at these locations will not hear certain bass frequencies. The 1st order modes are particularly bothersome because they cut through the prime listening area.

Appendix 1 explains that certain arrangements of two or four subwoofers reduce the problem to the 25% null lines shown in Figure 2. If these subwoofer configurations are used, seats should be arranged to place the heads not less than about 18 inches (50cm) from these null lines.

## Low Frequency Room Optimization

Obviously it matters greatly if you are working within fixed room dimensions or with room dimensions that you are able to choose. If those dimensions describe a rectangular room, it may be possible to find a seating layout that provides good bass for multiple listeners. At the very least, these procedures make it possible to identify which seats are likely to be good, and which are likely to be less good.

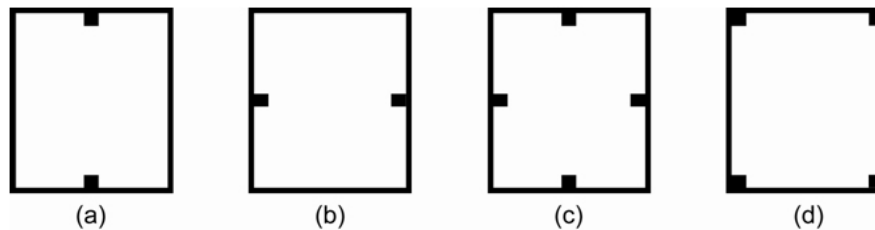


**Figure 3** – Arrangements of two or four identical subwoofers, driven by the same signal, that simplify the standing-wave patterns in a rectangular room to the one shown in Figure 2. This allows seating locations or room dimensions to be adjusted to avoid problems, or to identify those seats that have less than ideal performance. Note that arrangement (c) is significantly less acoustically efficient than the other options (requiring larger/more subwoofers and amplifier power for similar sound levels). Arrangements (a) and (b) require double subwoofers at each location to equal the sound levels of (d).

### Low Frequency Room Optimization Objective

- **Consistent bass across all seats**

The spectral content and overall level of bass should be consistent across all seats, with no audible resonances.

### Low Frequency Room Optimization Guidelines

- **Minimize seat-to-seat differences**

Because of standing waves no two seats are likely to experience the same bass response. Equalization can improve the sound quality, but the seat-to-seat differences remain unless multiple subwoofers are employed in a manner that simplifies the standing-wave patterns in a room.

- **Optimize bass through room management**

The use of full-range loudspeakers at the front- and surround-channel locations cannot deliver optimum bass to multiple listeners. Neither can a single subwoofer or LFE channel. Optimum bass is possible only when all low frequencies are combined through bass management and then delivered to multiple subwoofers arranged in specific patterns.

Figure 3 shows arrangements of subwoofers in a rectangular room. Of these, arrangements (a), (b) and (d) are preferred because they result in higher overall system efficiency, with only slightly

decreased seat-to-seat uniformity. Double subwoofers at the mid-wall positions in (a) and (b) result in acoustical output comparable to that of arrangement (d). The subwoofers should be identical, mounted similarly with respect to the room boundaries, connected in the same polarity and set to the same output levels.

## Alternative Methods for Low Frequency Room Optimization

One alternative low frequency room optimization method requires no specific room shape, subwoofer, or listener locations. It does, however, require specific acoustical measurements and signal processing. Similarly, yet another method is discussed in Appendix 1. It also assumes that the room is rectangular, but requires that the seating area be reasonably centered in the room. For each of several subwoofer arrangements, the alternative methods allow users to identify the room dimensions that minimize seat-to-seat variations in bass. These two methods can be used separately or in conjunction with each other.

### A SUMMARY OF THE PROCESS

#### 1. Select optimal combination of subwoofer layout and room dimensions.

If room dimensions are fixed, select optimal subwoofer layout for that set of dimensions. Refer to Figures 2 and 3, and Appendix 1.

#### 2. Use at least two subwoofers at different locations.

In rectangular rooms, the arrangements of Figure 3 are preferred.

#### 3. Damping of low-frequency room resonances is always desirable

This may be achieved by using certain forms of wall construction, but only if it does not interfere with requirements for sound isolation. Techniques that result in high sound transmission loss also tend to result in massive and stiff inner wall surfaces. In those cases, it will be necessary to use specially-constructed low-frequency absorbers. In general these will be of the diaphragmatic, membrane or panel type, and they should be located in high-pressure regions of the standing waves—corners are ideal locations.

#### 4. Choose designs which allow further optimization during calibration

Designs which allow control of individual subwoofer level and delay are particularly helpful in optimizing non-rectangular or otherwise non-trivial room designs. Judicious variation of levels and delays between multiple subwoofers can reduce audibility of resonances.

#### 5. Include a high-resolution parametric equalizer in the design, dedicated to the subwoofer

The equalizer should be able to place the filter's center frequency with a resolution of 2 Hz or better, and have at least 6 independently adjustable filters. Separate equalization channels for each subwoofer can be useful as well. *Final equalization should be made at the prime listening location with all subwoofers operating simultaneously.*

Additional analysis using modal calculators is possible, for example the method available at <http://www.harman.com/xls/Room/Mode/Calculator.xls>. The objective is to place the subwoofers so that they do not couple excessively into any mode which causes variation in sound levels in the seating area, and/or place the