Document: How to set up a Home Theater Sound System

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# How to set up a Home Theater Sound System

## The Theater Sound Experience

*"The giant door screeches as it is moving, finally closing with a ponderous thud that shocks through your body - you could swear the door was actually in your room, right there beside you. And all the subtle sound details that adds atmosphere to the illusion of being inside the adventure of your movie, the crystal clear voices from characters moving around as if they were for real."*

It is the sound that really immerses you in to the scene, when done right it will be so realistic that the fact you are looking at a screen is the only clue you are still sitting in a room, watching a movie. A good, properly configured sound system will make *the* difference for movies, but even watching an ordinary documentary is something that will make you regret not having done this a long time ago.

So, you are about to install a sound system for your home theater or media room. Or, perhaps wondering if your current system could actually sound better. This article presents basic information for setting up a typical sound system.

What equipment is needed, where to place speakers, and how to get the best sound.

# Contents

# Requirements

## How do you want it

First, find out what you want to achieve. Not only by deciding what kind of sound you want, but also keep attention to the intended purpose of the room, as this will affect choices for gear and placement.

If you have never experienced movie sound other than from an ordinary cinema, it would be wise to demo a really capable system, this can give you some clues about what you should prioritize in your own set-up. Remember, something that has not been experienced will not be missed, and this is especially true with movie sound.

You will have to make decisions and compromises to suit the needs of your room and your budget. Interior styling preferences and practicality will also set limits.

## Priorities

Consider to prioritize what you believe is important for your theater:

- How loud?
- Clean sound most important?
- Surround sound from as many speakers as possible?
- Subwoofer capacity - only subtle or tear-down-the-house?
- Sound coverage across all seats?
- More than one or two viewers - then a center channel will be very much desired

These parameters, along with room size and visual appearance considerations, is the foundation for the requirements of the sound equipment.

Room size is important because it takes more sound energy to fill a larger space, which will affect requirements for speakers.

## Reference Level

The defined sound pressure level for calibration is called “Reference level”; 85dB at -20dB signal, or 105dB peak for each main front channel at 0dB, 115dB peak for the LFE channel. This does not mean movie sound is always 105dB, it is just a reference level for calibration. Typical sound pressure levels for a movie played at reference level, or 0dB, can be 70 - 90dB - lower for quiet scenes and louder for heavy action.

The purpose is to ensure playback level is known compared to what was intended when the movie was made.

When your system is properly calibrated, sound will play at reference level when the master volume display on the receiver says “0dB”. Many will find this quite loud. It is perfectly valid to choose a different level, that is what the volume control is for, and the calibration also ensures that a -20dB setting is equal to a -20dB setting in another setup.

Often, reference sounds “loud” because the sound is distorted and compressed. This happens if the speakers and the amplifiers are not capable of delivering sufficient sound pressure level, and thus will distort the sound. And this will be the case for most “ordinary” hifi-style speakers - they simply do not have enough sound pressure capacity.

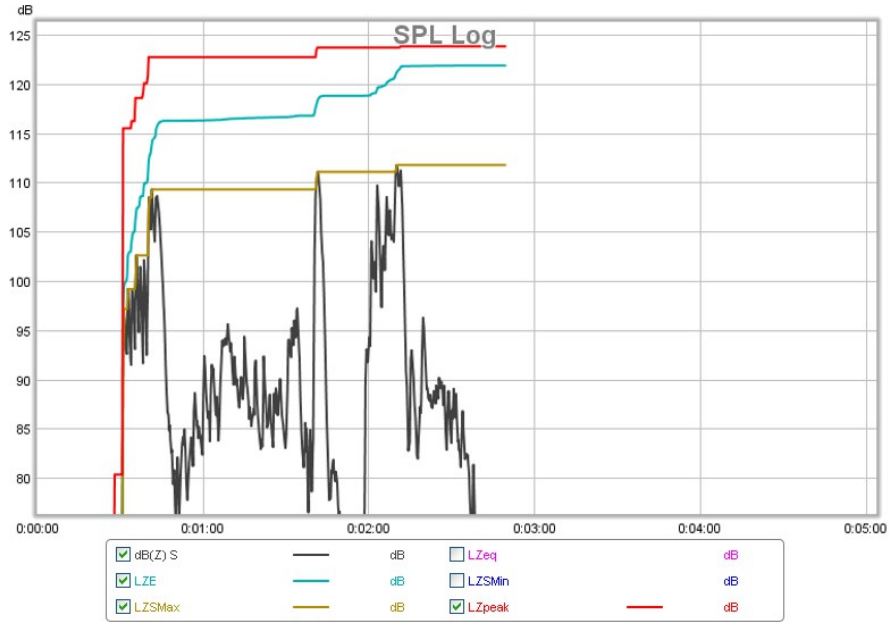
Room acoustics will also affect perceived loudness. A room with insufficient damping will sound louder, because it actually is, with the same volume setting. Smaller rooms also tend to be louder, because they have more early reflections.

To be able to reproduce sound at reference level is often used as a requirement for theater sound. But at home you are in charge of the volume, and a good system will sound better also at lower loudness levels – dialogue will still be crisp and clear and intelligible, and you will have the sense of powerful bass even if the house is not shaking apart.

| **Typical movie playback at reference sound pressure levels** | | |
|---|---|---|
| | **Sound exposure (dB SPL-C)** | **Max peak (dB SPL-Z peak)** |
| Dialogue scene | 65dB | 85dB |
| Quiet scene | < 55dB | -- |
| Massive action scene with cannons | 90dB | 120dB (LFE)<br>110dB (>120Hz) |

| **Theoretical max sound pressure levels** | | |
|---|---|---|
| | **Max SPL (dB RMS)** | **Max peak (dB SPL peak)** |
| All channels 0dB, diffuse sum | 117dB | |
| All front channels L/C/R 0dB no LFE, in-phase sum | 114dB | |
| All channels 0dB, in-phase sum (possible at low frequencies only) | 125dB | 128dB |

*Sound pressure levels logged from listening position, scene from the movie Master & Commander. Red line is peak level - this defines capacity requirements, black line is dB(Z) - this is the perceived loudness*



## Subwoofers

The subwoofers are responsible for reproduction of the lowest frequencies, the low sound you can barely hear but feel. In movies these low tones are important for the experience as it is the lowest frequencies that gives realism and physical dimension to the scenes playing.

In most home theater installations subwoofers are not properly dimensioned, and can not give a realistic reproduction of low frequency effects, due to lack of extension and insufficient sound pressure level. Too small subwoofers can not reach down below 20Hz with enough impact to give a real physical effect.

As a minimum extension should reach down to below 20Hz flat, and level should be matched to your listening level.

If level is specified as reference 0dB, that equals 125dB capacity for subwoofers when low frequencies are rerouted from front and surround channels. This is not easy to achieve, and will require several large cabinets. However, if one can get by with a little less, it is much easier to meet the requirement. LFE alone is only 115dB at 0dB, and it is rarely likely that all other channels have full 0db content at the lowest frequencies - in fact, this is impossible if there are other sounds at higher frequencies playing simultaneously.

The general rule is, it is not possible to get too much subwoofer capacity, and the more the better - it will sound cleaner, more dynamic, more realistic.

## Sound quality

No distortion or bad sounds, voices and instruments appear separated and clear, everything from the very deep bass up to the highest treble is reproduced, and transients and impulses sound powerful and clean.

This is achieved when you have a smooth frequency response, no early reflections, controlled decay, no audible distortion from amplifiers or speakers.

Contrary to what the audiophile "high-end" myths will try to tell you, achieving this does not require magic, it is all about science and engineering. You do it by speaker selection, room acoustics, calibration.

If you follow the advice given in this guide, you will end up with a system with very good sound quality.

## Sound character

Does it sound smooth and nice, or is it open and direct, perhaps leaning towards more hard and dynamic. But can you have it all - smooth and nice - and open and dynamic, at the same time.

Depends. Most traditional hi-fi speakers sound more smooth and nice than accurate and realistic. Many professional-style speakers with horn loaded high-frequency drivers can give you better dynamics, but some times at the cost of a more hard and forward sound character. But the best speakers can give you more of everything - smooth and dynamic at the same time. Key parameters are capacity and controlled directivity.

This character of sound will be determined by the speakers, but you will also be able to make adjustments with calibration and set-up.

If you are on a budget, some compromise may be necessary, but certainly it is possible to have it all, and even better. A system with full dynamic capacity and high resolution may at first sound unfamiliar, because it does not quite sound like "speakers" anymore, and that is exactly the point - it sounds realistic.

If you follow the guidelines from this article, you will end up with open, realistic and dynamic sound, more forward than laid-back and nice. A sound character I find very addictive for both movies and music.

## Requirements

| Requirements for home theater and media room sound reproduction | | | |
|---|---|---|---|
| **#** | **Requirement** | **Specification (Suggested alternatives)** | **How to achieve** |
| 1 | How loud | Reference | Speakers and amplifiers must meet SPL requirement |
| 2 | Speaker configuration | 7.1 / 6.1 / 5.1 / 4.1 / 2.1 , x.x.4 / x.x.2 | Add speakers according to chosen configuration |
| 3 | Clean sound | Yes? | Fulfilled when #1 is satisfied |
| 4 | Subwoofers | Max SPL +10dB / Reference / -10dB, extension below 20Hz | Add subwoofers with sufficient capacity |
| 5 | Sound coverage | Similar sound across all seats | Speakers with linear response across whole seating area |

# Equipment

## Overview

You need a source, to play your movies from, an AV-Receiver to process and amplify the sound, and speakers. Of course you also need some sort of screen for the picture as well, but that is not covered here.

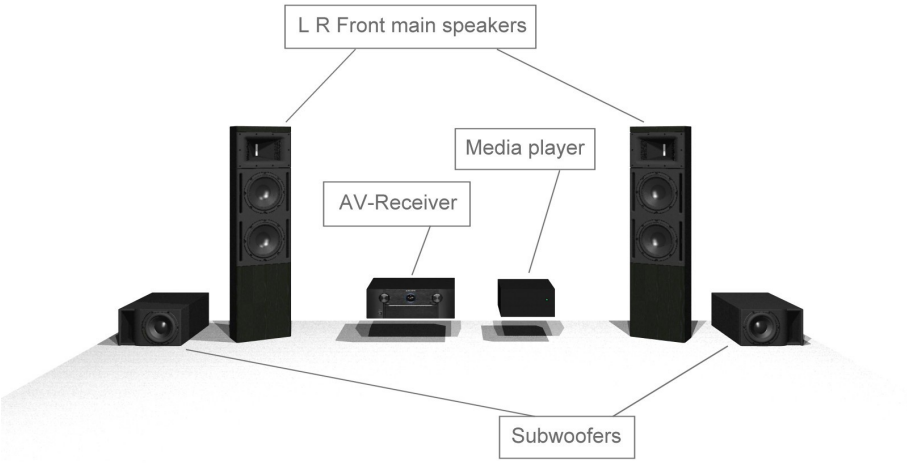
The speakers are the most important and demanding to choose. Also, there are so many of them in a full 7.1 system, budget-wise they will be the most expensive parts by far.

You can choose to start with a minimum system, and add more speakers later. Center speaker and surround back speakers are good candidates for future upgrades.

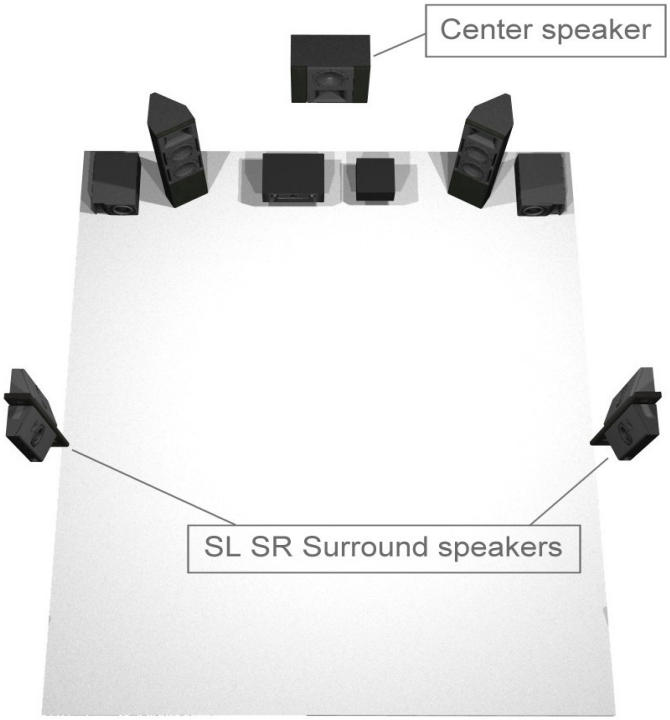
| **Equipment Overview** | | |
|---|---|---|
| **Item** | **What it does** | **How it affects sound** |
| Source: Some sort of player or computer | Play movies and other content | Only important for functionality |
| AV-Receiver | Processes the sound and drives the speakers | Set-up options and amplifier quality will affect sound |
| Option: Power amplifiers | Drives the speakers | Amplifier quality will affect sound |
| Loudspeakers | Makes the sound | The most important for sound quality |

| **Loudspeakers in the home theater** | |
|---|---|
| **Notation** | **Speaker** |
| L | Front left main speaker. |
| R | Front right main speaker. |
| C | Center speaker. |
| SL | Surround left speaker. |
| SR | Surround right speaker. |
| SBL | Surround back left speaker. |
| SBR | Surround back right speaker. |
| LTF, RTF, LTR, RTR | Ceiling speakers left top front, right top front, left top rear, right top rear |
| Sub | Subwoofer, one or several, plays the lowest frequencies that gives the sound weight and impact. |

*Sound equipment for 2-channel system - only front speakers and no surround sound, great solution if music is a priority and placement options for surround speakers are limited*




*Adding more speakers - 5.1 surround system, better sound for movies*



*A full 7.1 system - still great for 2-channel music, and full surround for movies*


## Source

The simplest and least expensive is to use a Blu-ray player to play your movies. The Blu-ray player will not affect the sound quality, it only reads the disc and sends an untouched digital data stream to the AV-receiver.

If you have some knowledge of computers, you can build a HTPC - a media-player computer, capable of playing Blu-ray discs, movies from a hard drive and also stream content from the net. The HTPC also has no influence on sound quality, as it just passes the digital signal to the AV-receiver, provided the sound-card has HD-audio pass-through on HDMI.

The HTPC is superior to the Blu-ray player when it comes to versatility and functionality.

Regardless what you choose, the source should not have any significance for the sound. Provided your player or computer works properly.

Other sources, such as media streamers and old-fashioned tv can also be connected to the AV-Receiver, so you can watch tv-shows and other content with high quality sound. Some streaming services now provide HD-quality.

As the format of media content is constantly changing, this is a part of your system that is likely to need replacement later on.

## AV-Receiver

The AV-Receiver controls the sound. It takes the signal from the source player and processes it to finally put out sound in all individual speakers.

A typical AV-Receiver has 5 or 7 power amplifiers for speakers, processing capability for all digital sound formats including Dolby True-HD and DTS HD-MA, and automatic calibration and room correction setup.

Receivers from the major brands all get you a lot for the money, and even the smaller budget-models will give good performance. The differences among brands and price range will be functionality, amplifier power, room correction capability, and connections.

Budget AVR for media room:

- 5.1 will be sufficient for 5.1 speaker system
- Typical 50-100W/channel
- HDMI input and output
- Look for ability to set individual crossover for front and surround

AVR for the enthusiast:

- 7.1 (or more), consider new formats like Dolby Atmos, Auro3D, DTS:X
- Typical 100-150W/channel
- HDMI input and output
- Look for ability to set individual crossover for front and surround
- Pre-out connectors for option to add external amplifiers

## Immersive sound and object based audio

In 2014 new sound formats promising a more immersive sound experience were announced form several vendors. Receivers with Dolby Atmos decoding was released late 2014, Auro3D is available, and DTS has announced their DTS:X.

The introduction of ceiling speakers and new sound formats capable of rendering the sound for the actual speaker layout in use during playback promises a better and more immersive sound experience, where sound sources appear to have exact position not only left-right, fore-aft, but also in height.

This requires adding speakers in the ceiling, and even though you choose not to mount them right now, it could be wise to prepare for later installation by having wires threaded and mounting brackets in place.

Object-based audio means that individual sound objects can be placed anywhere in a 3-dimensional space surrounding the listeners. This makes it much faster and easier to create sound effects that fly around from different locations, the sound designer need only to consider the location of the sound, independent of sound channels and speaker layout.

When the object-based soundtrack is finished, it is then rendered according to the actual speaker configuration, such as 7.1. Many soundtracks for later film releases are made this way, and they often excel with a rich, immersive surround sound-field.

The new thing about new formats like Dolby Atmos is that the rendering from sound object to speaker channels is done during playback, according to the exact speaker configuration in use, making it much more adaptable and flexible.

Those new formats can give improved surround sound-field presentation, due to the added speakers and more information in the soundtrack. But still it is the overall performance of the sound system that is important for the sound experience, and a properly calibrated and set-up system with proper room acoustics and good speakers is the foundation for good sound. A good 7.1 system can already provide a very immersive sound experience.

## Amplifiers

External power amplifiers for main and surround speakers are only necessary if your AV-receiver has insufficient power. If requirements estimate that more than around 50W on main front channels are needed, it may be worth looking for external amplifiers, to make sure there is enough headroom. Reliability may also be an issue – the typical receiver will quickly run very hot if pushed to the limit, which will increase risk of failure significantly.

Many higher performance subwoofers does not have the amplifier built-in. Typical power requirements are high, 500W-2000W, which means a professional style PA-amplifier is what to get. They are often noisy due to fans used for cooling, so it might be a good idea to place those amplifiers in a different room.

Professional amplifiers is a good alternative for main speakers as well, if more power than around 100W is needed.

## Main speakers

The main speakers are the most important for good sound in the theater. The midrange is especially important, for the best reproduction of dialogue.

Dynamics must meet sound pressure requirements, while bass extension below 60 or 80Hz is not needed, because the lower bass is handled by the subwoofers.

Woofer size is a very good indicator for sound pressure capability of a speaker. This is because the output will be displacement limited at the lowest frequencies, 60 – 100Hz, it does not matter what sensitivity and power handling a speaker has if there is not enough capacity to move air, the sound will be compressed and distorted.

Rule-of-thumb for woofer size and output requirements:

| Woofer size | Recommended use |
|---|---|
| 6” | 6” or smaller are really out of fashion.. |
| 8” | Small theater >80Hz |
| 12”, 2x8” | Small theater >60Hz and medium theater >80Hz |
| 15”, 2x12”, or even more.. | Medium theater >60Hz and small theater with high fun-factor |

Also note that there are no miracle speakers out there that magically delivers more, because all speakers have to follow the same physical laws. Actually, this table is valid for very good speakers designed with limited low frequency extension (>60Hz), good displacement linearity and powerful, efficient motor system.

Directivity – how the speaker radiates sound in the 3-dimensional space – should cover all seats, so that all listeners get the same sound, but at the same time limit sound radiated into walls and other boundaries as much as possible.

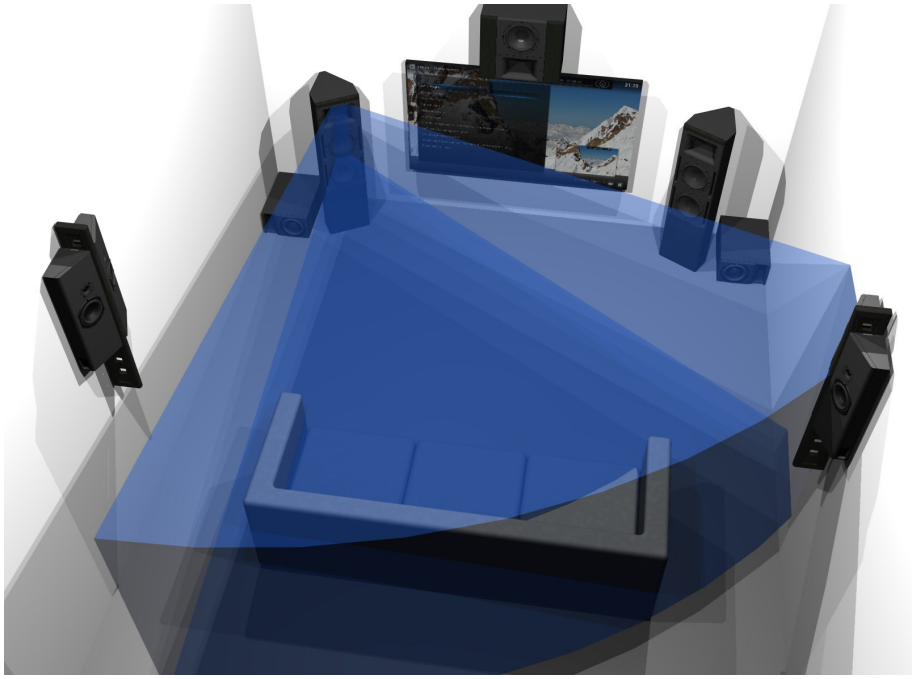
You should avoid the old-fashioned hi-fi speaker with dome tweeter and small woofers. The dome tweeter has no directivity control, and does not have the required dynamic capacity. Two small 6.5" woofers in a box designed to have bass down to 30 to 40Hz will never have the capacity required for realistic lower midrange reproduction.

Reasonably high efficiency is required to reproduce the full dynamics of a movie soundtrack at reference levels. Sensitivity is specified as dB/1m/2.83V, or dB/1m/1W. Higher value for higher efficiency, typical hi-fi speakers are in the 84-88dB range, and can never play loud even with unlimited power put into them because they will reach power compression or simply burn out. Typical usable speakers have sensitivity from 90dB and up, some full-range horn loaded systems more than 100dB.

A sensitivity difference of 6dB means four times power difference – a 90dB speaker requires 400W to play equally loud as a 96dB sensitive speaker with 100W.

*Speaker radiation should ideally cover all seats and not send sound in to walls*



Recommendation for main loudspeakers specification:

| **Media room or small dedicated cinema main front speaker requirements** | |
|---|---|
| Frequency range | 80Hz-20KHz |
| Sensitivity | 94dB/2.83V/1m |
| Woofer size | Minimum 2x 8”/ 1x 12” |
| Directivity | 60 degrees (+-30) degrees coverage with linear frequency response |

Speakers can be compared by looking at frequency response and polar charts, and sensitivity. A smooth frequency response in the required range 80Hz - 20KHz is desired. Polar plots show off-axis response, this should be smooth and not fall off at high frequencies inside the angle of the seating area. If the manufacturer can not provide this information, then go elsewhere.

For larger and medium sized rooms it is recommended to add dedicated mid-bass speakers to get more headroom in the important mid-bass and upper bass range, this is where much of the impact and energy will be in both music and movies. Such speakers are typically bass reflex enclosures equipped with one or two 15” or 18” bass drivers.

## Subwoofers

As already mentioned, subwoofers are very important for the theater sound experience. Frequency response should extend to below 20Hz, and output level must match requirements for chosen listening level in your room.

You need to ensure there is enough output capacity, and have a reasonably flat frequency response.

Practical incarnations of subwoofers tend to have different sound characteristics, due to different priorities in each design, here is an attempt to describe briefly the typical consequences of different approaches:

| **Subwoofer type** | **+** | **-** |
|---|---|---|
| Small sealed low-cost | Cheap. | Boomy, no impact and punch. Best to turn it off, as it will not contribute in any positive way to the overall sound experience. |
| Sealed with long-excursion driver | The best for very low frequency extension, small size, easy to design. | Lacking in dynamics and impact, often sounds kind of soft and rounded. |
| Ported with large motor driver | More output capacity, more impact and punch. | Port compression limits low frequency output, larger than sealed. |
| Horn | Great impact and punch, dry and powerful bass, high output capacity. | Limited usable bandwidth, very large, can be affected by resonances. |
| Compact Horn Subwoofer | Great impact and punch, dry and powerful bass, small compared to performance. | Difficult and advanced to design, expensive to build. |

Location of subwoofers significantly affects the response. By placing several subwoofers at different locations it is usually possible to get a reasonably smooth frequency response, across most of the room. Most subwoofers also employ some sort of DSP with equalizer, with manual or in some cases automatic setup.

Two or more subwoofers should be used, and the largest improvements can be seen going from one up to around four – adding even more does not necessarily give improvements comparable to the extra effort.

Relevant subwoofer specifications can be difficult to find, as most hi-fi and home-theater subwoofers are unspecified – it is not possible to see the output capability from the data provided. However, there is often a good correlation between subwoofer size, design type, and output:

| **Subwoofer typical performance** | | |
|---|---|---|
| **Type and size** | **Typical max output at 20Hz (1m/2π)** | **Suitable for** |
| Sealed with 12” driver | 100 dB | 2 for up to small room with reduced maximum spl (-10dB) |
| Sealed with 18” driver | 110 dB | 2 for up to small sized room |
| Reflex box with 12” driver | 103 dB | 2 for up to small sized room |
| Large (200l) reflex box with 18” driver | 116 dB | 2 for up to medium sized room, 4 of these will be great |
| Horn 500l | 124+ dB | 1 or 2 for any room, 2 of these will be great |

## Surround speakers

Requirements for surround speakers are less strict:

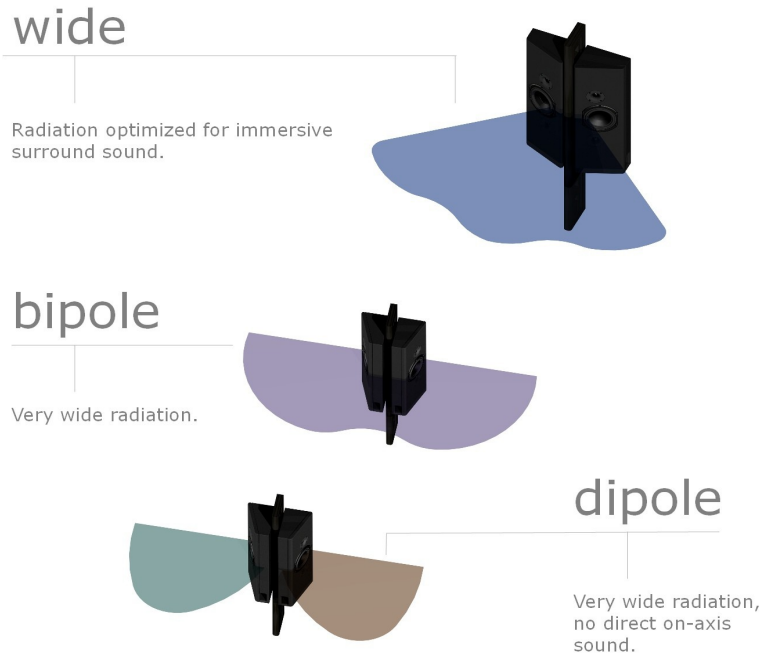
- Lower spl requirements (usually located closer to listeners)
- Hearing is less sensitive to faults in frequency response balance for sources from behind
- Mostly ambient and some sound effects comes from the surround channels

In a typical small room the surround speakers tend to be located very close to the listeners, and this causes some problems with speaker localization cues – instead of hearing birds in the wood you hear a bird in the speaker right next to your head. The solution to this is to have speakers with a more diffuse sound radiation pattern - wider dispersion, bipole or dipole speakers:

- Normal speaker: Speaker localization worst, less immersive sound image
- Wide: Speaker with wider than usual dispersion, more immersive sound image
- Bipole: Speaker radiating sound forward and backwards, very wide dispersion, diffuse sound image
- Dipole: Radiates sound forward and backward in opposite phase, little or no sound radiates directly to the listener, very diffuse sound with little localization cues

Many surround speakers have selectable configuration for bipole or dipole.

*Surround speaker radiation patterns*




When deciding between a 7.1 or a 5.1 setup, consider placement limitations due to room design.

Recommendation for surround loudspeaker specification:

| **Media room or small dedicated cinema surround speaker requirements** | |
|---|---|
| Frequency range | 80Hz-20KHz |
| Sensitivity | Min 92dB/2.83V/1m |
| Woofer size | 2x 6” or 1x 8” |
| Directivity | Configurable/Wide dispersion |

## Center speaker

The considerations for main speakers are mostly valid for the center as well, though there are some differences:

- For placement under or above screen/TV size limitations can have serious impact on sound
- Wider horizontal dispersion coverage needed to cover wide seating arrangement
- Optionally leave it out and run phantom center

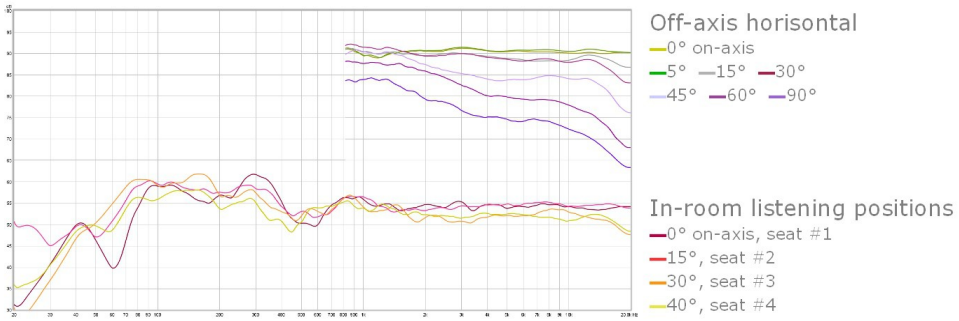
The center speaker will play most of the dialogue on movies and give the impression that the voices comes from the center of the screen, even for those viewers seated to one of the sides.

Phantom center means to leave out the center speaker and route the center channel sound to left and right main speakers. This works very well if you sit in the sweet-spot right in front of the screen, in the middle between the speakers. Obviously this is not possible if more than one person is watching. When seated off-center towards one of the speakers, the center image tends to collapse to the nearest speaker, so that the dialogue seems to come from that speaker only.

Improved phantom image off-axis can be achieved using main speakers with constant directivity – speakers with waveguide or horns. The theory behind this is time - level trading, our hearing uses both sound intensity and time to determine location. The closer speaker will have lower level due to the reduced sound slightly off-axis, causing the farther speaker to be louder, and this compensates for the distance being closer to the nearest speaker. However, this will not create a center image as good as a center speaker. Speakers of reasonable size and construction does not have directivity control across the whole frequency range, and in the lower midrange the time - level trading does not work that well, because the ears use phase and time information to determine where the sound comes from in the midrange.

Many center speakers with horizontal arrangement of the drivers are designed with severely non-linear horizontal off-axis response. Such designs should be avoided. To ensure the center is creating a seamless sound image across all seats, the horizontal dispersion should be reasonably linear, and this can be determined from off-axis frequency response charts, or polar plots.

*A center channel with carefully designed radiation pattern: Off-axis and in-room listening position measurements show smooth and very similar response across whole listening area, while sound drops fast further off-axis for reduced interference from early reflections*




## Ceiling speakers

Use the same spl requirements as for other surround speakers, wide radiation pattern is desired.

# Room Acoustics

The acoustics of your room is very important for the sound, some will say the most significant factor.

Reasonably good sound can not be achieved without taking care of acoustics, this is not something you can choose to ignore.

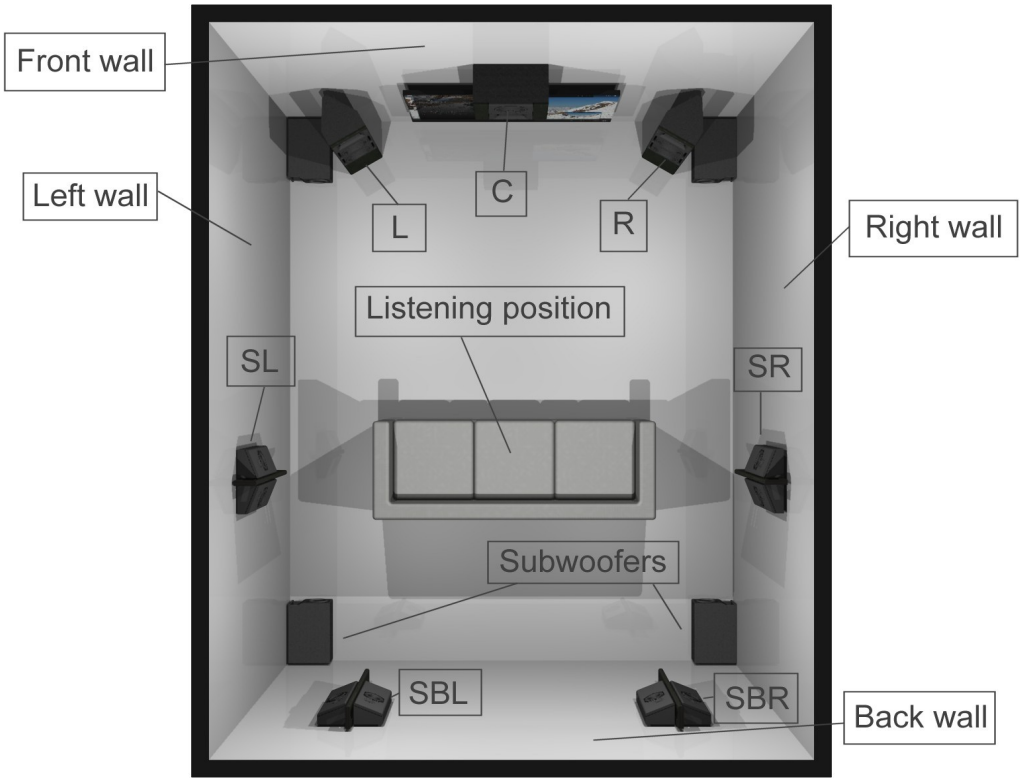
Good room acoustics means reasonably low reverberation and control of reflections. We know how an empty concrete-wall hall sound like – lots of echo, and it may be difficult to understand what a person says. Not the sound we want in our home theater.

There are products available today that can fix room acoustics, such as absorbers and diffusors. However, they tend to be expensive, large and visually obtrusive. Especially if the theater-media room also functions as a normal living room, there are esthetic concerns that will limit placement of such items.

I will describe acoustic treatment as a 3-stage process:

1. Reverberation control - Placing sufficient absorption material inside the room.
2. Remove early reflections - Reflected sound, from walls, ceiling, floor, should be removed.
3. Remove room mode resonances and boundary interference - Affects lower frequencies, difficult to remove.

*Walls and definitions in the home theater room*



## Reduce reverberation

Reverberation should be around 0.2 to 0.4 seconds, depending on size of the room – less reverb in smaller rooms. This is achieved by placing absorbent material in the room, such as furniture, and acoustic absorbers.

One relatively inexpensive and aesthetically good way to achieve this is to use absorbent panels in the ceiling. Use fiberglass or rock-wool panels intended for this purpose. Cover the ceiling with 120cm x 60cm, 50mm thick panels, and if possible mount them suspended at 30-60mm below the ceiling surface.

Acoustic panels can also be mounted hanging down suspended at a small distance from the ceiling, with distance in between the panels. It will be very effective, as the tiles will absorb sound both from the room directly and from the ceiling, reflected.

*Suspended acoustic ceiling panels and surround loudspeakers*

## Remove reflections

Reflections from surfaces such as walls will cause the sound to be less clear, and sometimes attain a hard character. Speech intelligibility will be compromised, and individual sound sources does not appear with the proper sense of physical dimension and lacks precise location in the sound field.

Reflecting surfaces are where you can trace a reflective path from your listening position back to a speaker, either through single reflection – typically sidewall, or multiple, such as sidewall-back-front. Sound reflects like light – entry and exit angle on reflecting surface is the same.

*First reflection points are where you can see the reflection of the speaker from the listening position*


*But we need to consider radiation pattern. Front left speaker, seen from listening position, radiation in blue - for high frequencies the sidewall, floor or ceiling does not exist*

*We turn around and see that there is a first reflection point on the back wall. From above, we see the speaker radiates high frequency sound into back wall and part of the right sidewall.*


*At lower frequencies the speaker becomes increasingly omnidirectional, now there are reflections on the left wall and floor for midrange frequencies.*

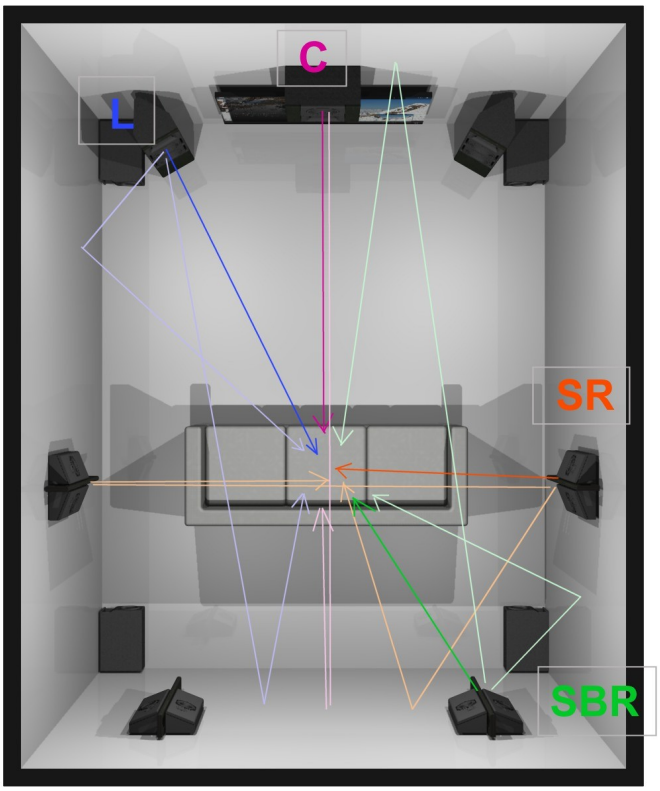

Since you now have chosen speakers with good directivity control, it may not be necessary to do much with the side walls, but the back wall should be damped, and this is more important if the back wall is close to the listening area.

This is the reflection pattern for one speaker - left main front. All other speakers will also have reflections, but focus on the front L-C-R speakers first, and then worry about the surrounds later. This is where a surround system is very different from 2-channel stereo - there are more speakers and many more reflections.

For best surround sound all reflections from all speakers should be treated, but using absorption only will make the room too dead. The solution is to use diffusion instead - spreading the reflection back into the room in a wide angled pattern. It is also desirable to treat all reflection points similarly, to achieve a homogeneous sound field. In practical situations some compromises are inevitable, especially if the room is multi-purpose, having acoustic absorbers and diffusors covering all walls is usually not an option in a normal living room.

*Direct sound and 1. reflections from walls for L, C, SR, SBR speakers*




Subwoofers work at low frequencies only, they have boundary interference with all surfaces inside the room, but no reflections that can be easily removed by using a thin panel.

Acoustic panels are good for reflection control. 50mm thick panels on a reflective surface will absorb sound from midrange and up. For better, wider frequency range absorption rock-wool or fiber glass standard building insulation in 20cm thickness will work better.

Reflection points on walls and ceiling can be treated with such absorption. Thickness and size determines frequency range for which the absorption is efficient, and as we see from the speaker radiation pictures there is no point in adding thin high-frequency absorption to the sidewalls or front wall, thicker and larger is needed to work at lower frequencies.

Usually the floor reflection is left untreated, it is not practical to place acoustic damping on the floor where people are walking.

It is not desirable to remove all reflections, if you use too much damping it will sound unnatural and dull. Leave some space untreated, and consider using acoustic diffusors which spread the sound reflection evenly back in to the room.

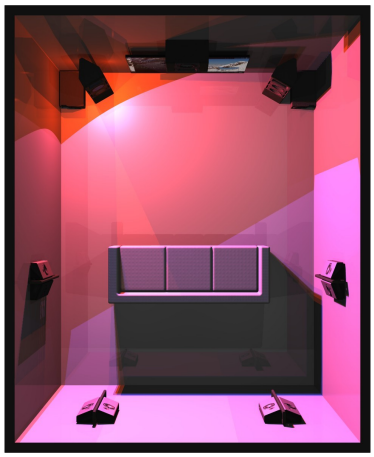
*Back wall with acoustic absorption panels and S1.2 surround loudspeakers*

## Room modes and boundary interference

At lower frequencies, typically around 200Hz and below, the response will be dominated by boundary interference – reflections from the surfaces around the speakers and reflections around the listener. Boundary interference is what causes most of the irregularities and deep cancellations on the frequency response.

Room modes can also be troublesome in many rooms - waves that resonates between the rooms acoustic boundaries – between walls, between floor and ceiling, there are also circular modes. These resonances are worse if the walls are very rigid, such as concrete walls.

*At lower frequencies there are also reflections from the front wall and ceiling, wavelengths are large and we call them boundary interference*

It is possible to fix this even in smaller rooms, but large constructions covering whole walls are required. This may not be practical in your room, or you simply will not put in the required effort.

A proper subwoofer system with several subwoofers will make a huge improvement in the lower bass range. Multiple sound sources will even out the response. Most subwoofers also has some kind of equalizer or digital sound processor, so that it is possible to adjust the frequency response and level out peaks.

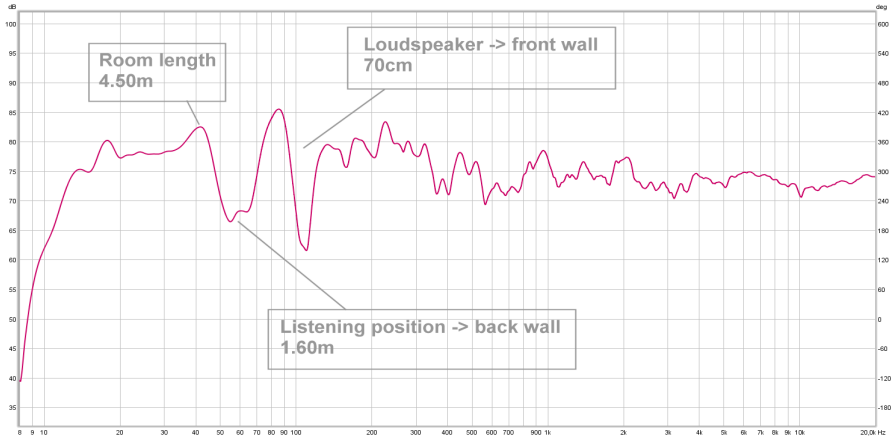
A better solution is to have proper 40cm acoustic absorption on the back wall, and place all subwoofers on the front wall. This will solve all major bass problems if the subwoofer system is large enough to act like a large sound source from floor to ceiling.

Signal processing room correction software can reduce the effects of boundary interference close to the speaker. This is achieved using time corrective filters, and must not be confused with equalizing, which only corrects the frequency response.

How to deal with boundary interference:

- Move speakers
- Move listening position
- Use multiple subwoofers
- Use equalizer
- Large acoustic damping constructions
- Use time-domain corrective room correction.

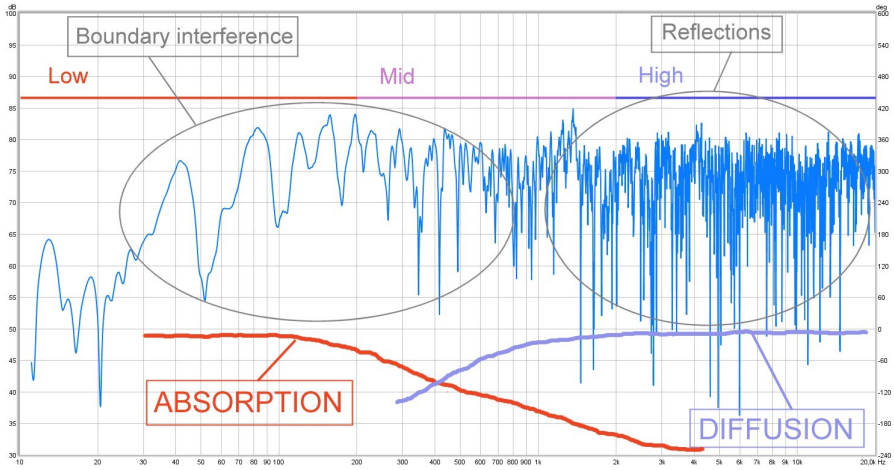
*Boundary interference from front wall and back wall causes huge dips in the frequency response*




In a small room the acoustic behavior changes with frequency. At low frequencies discrete boundary interference reflections causes dips and peaks affecting larger parts of the frequency curve, at high frequencies the reflections appear diffuse.

Since absorption at low frequencies requires very much damping - thick and covering whole surfaces, the result is too much high frequency damping, and the room will sound very dull. By using more diffusion at higher frequencies, it is possible to achieve a much more balanced sound. In a small room it is a good approach to try to get as much low frequency absorption as possible, and as much diffusion as possible at higher frequencies.

*Acoustic behavior changes with frequency*




## Don't forget the seats

If your seating is leather, then put some blankets over the backs and pillows on seats not in use, because the leather surface will cause early reflections due to the relatively close distance to the listeners ears.

Also, avoid seating with very high back-rests, as they will obstruct the sound from side and back channels.

## Soundproofing

Acoustic treatment inside the room has no effect on the sound level outside of the theater. To significantly reduce the sound level outside, very extensive construction work has to be done.

Some improvement can be achieved by covering walls and ceiling with an extra layer of drywall panel, but this will not enable you to watch movies at reference while others are sleeping in a nearby room.

## Loudspeaker radiation matters

Better speakers with controlled directivity will be less affected by room acoustic properties, and can give reasonably good results with less acoustic treatment. This makes it easier to get a nice esthetic appeal, and will also lower the total cost.

## Effects of furniture

All items placed inside a room affects its acoustic properties. Sofas, chairs, bookshelves, curtains, carpets will contribute to lower the reverberation by absorption, change reflections and change boundary conditions.

*A puff in front of the speaker functions as an acoustic absorber, and fits nicely in as part of the interior*

## Tactile response and floor construction - build a riser

At very low frequencies below 20Hz it turns out that tactile response - feeling the sound physically on your body - is greatly affected by the resonant behavior of the floor. A wooden floor will move and add physical tactile feel, while a solid concrete floor in the basement may not move at all.

Building a riser platform to place the seating on will greatly enhance this tactile motion, especially if you have that concrete floor. It does not need to be high, but the sides should be sealed so that the space between the floor and riser platform forms an airtight volume, and it must be able to flex or rest on some kind of flexible suspension like rubber feet to allow movement.

## Tactile response and bass

A reason for turning up the volume louder once you reach a level where dialogue and details can be easily heard is the tactile feel of the sound acting on your body - this sense of powerful sound.

Tactile feel is determined by sound field properties - not only sound pressure, but also particle velocity and sound intensity.

Tactile properties affects how the bass is perceived, a system with proper tactile response will also sound better at reasonable listening levels.

The sound source affects tactile feel - a larger source is better. This is one of the reasons you can experience nice punch on a live concert - the loudspeaker system is physically large. Horns tend to have better tactile feel than small sealed subwoofers.

Room boundary reflections destroy tactile feel, this is the other reason you experience much better punch in the bass at an outdoor live concert - there are no significant reflections at low frequencies.

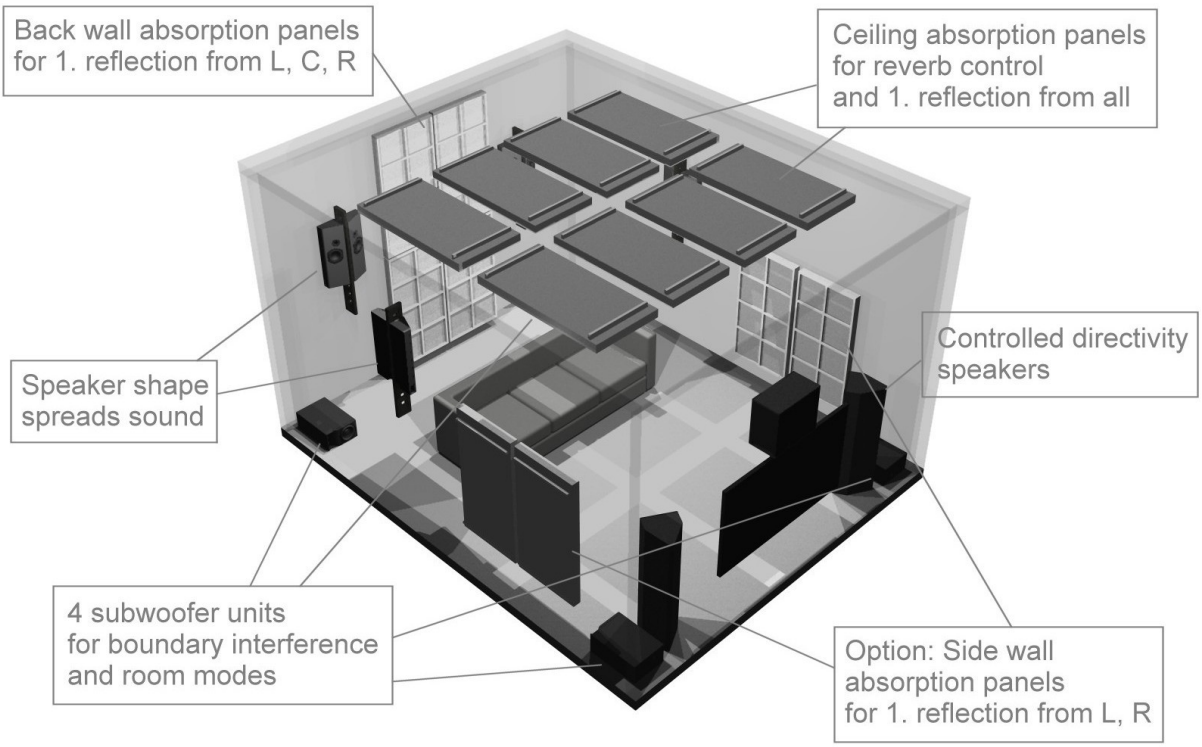
To preserve as much tactile feel as possible in a small room it is necessary to consider both the sound source and acoustics. Larger subwoofers systems and good acoustic damping works better. When setting up a multiple subwoofer system it is important to account for sound field properties, in a bad case it is possible to end up removing all tactile feel if you use only sound pressure measurement for adjustments.

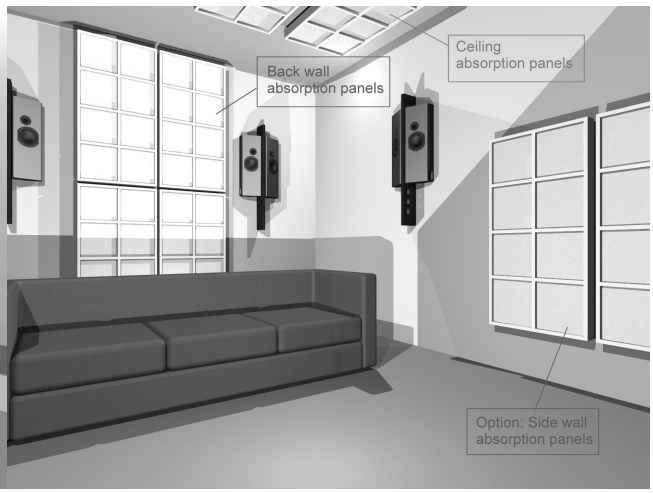
## Acoustics plan for home theater in the living room

- Suspended acoustic ceiling panels or ceiling absorber cloud - or:
- Replace the ordinary ceiling with acoustic ceiling panels
- Consider acoustic panels on side walls if reasonable due to interior design considerations
- Acoustic panels on most of the back wall surface
- Multiple subwoofers properly set up with DSP to deal with low bass resonances and modes
- Consider acoustic properties when choosing seating – no high backs, leather must be covered with blankets.
- Dining table? Consider decorative objects placed on the table to break up and absorb the reflection from the center channel

*Acoustic treatment without doing extensive construction work*



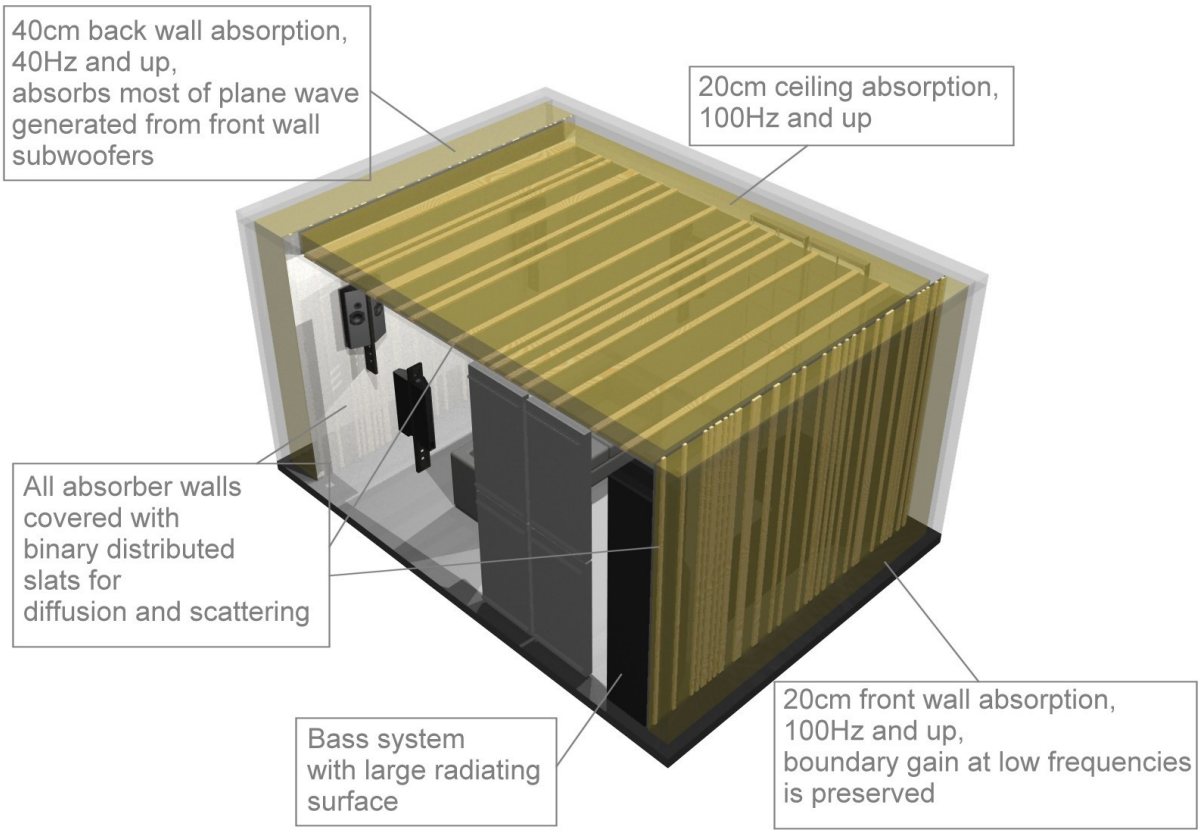




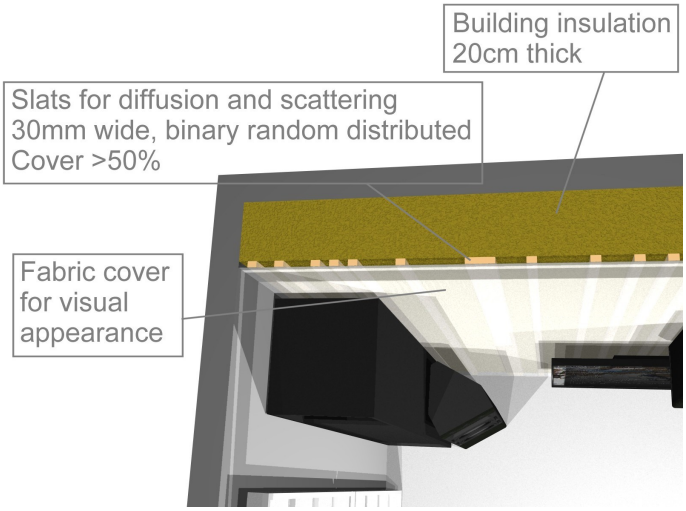
## Acoustics plan for dedicated home theater / media room

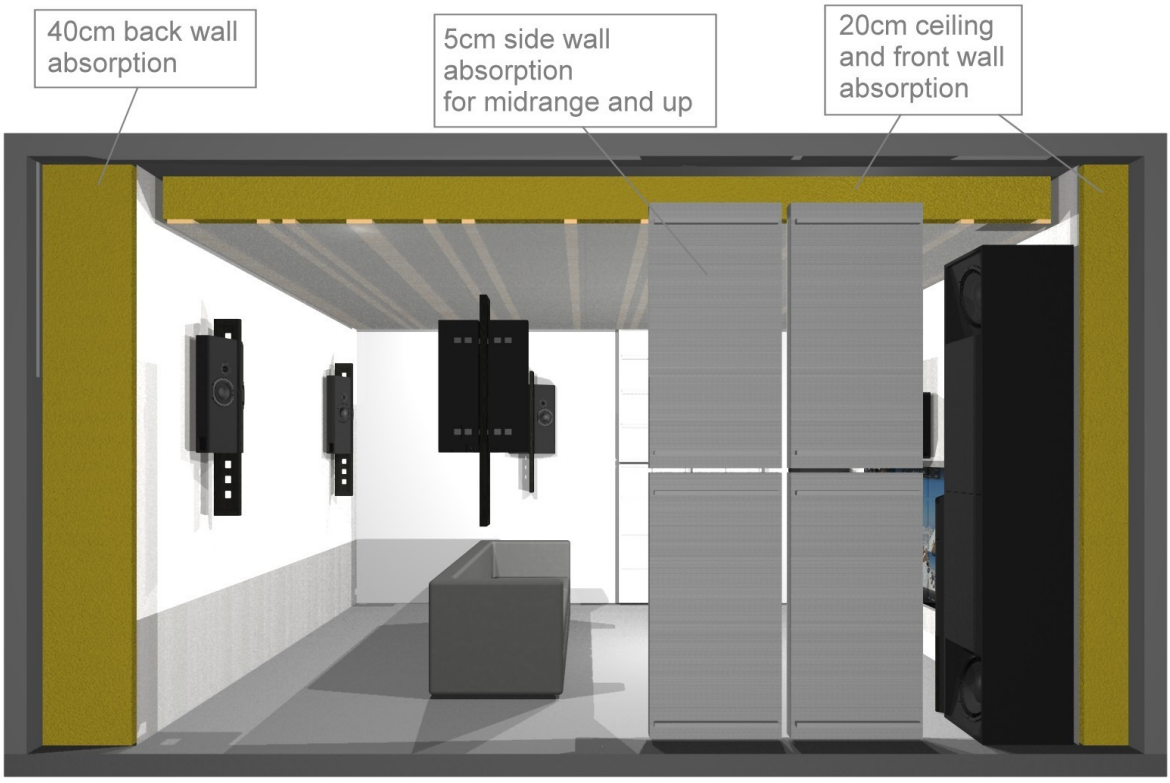
- 20cm damping with slats on ceiling
- 40cm damping with slats on back wall
- 20cm damping with slats on front wall
- Subwoofer system on front wall, large to create plane wave
- Consider 20cm damping with slats on side walls
- Consider acoustic diffusors for more and proper diffusion
- Consider acoustic properties when choosing seating – no high backs, leather must be covered with blankets.
- Build a riser

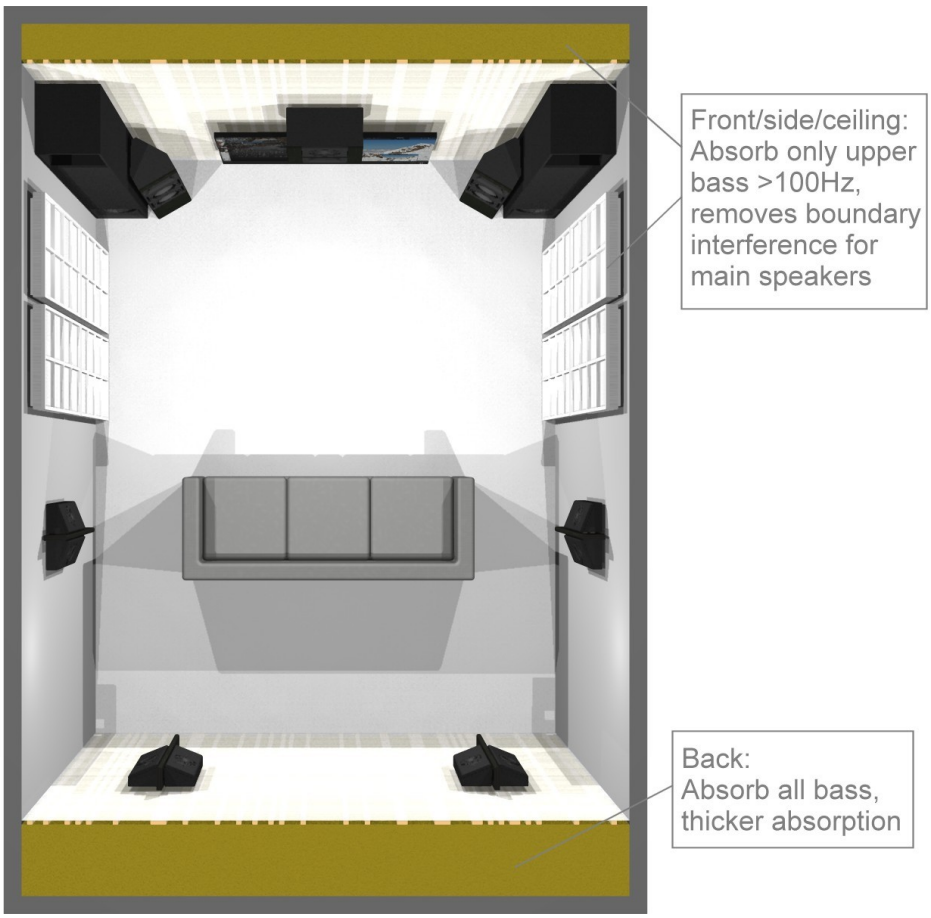
*Building a room from scratch - use the opportunity to fix acoustics properly*



*Acoustic treatment built into the wall - absorption at low frequencies, diffusion and scattering at high frequencies*




Front/side/ceiling:
Absorb only upper bass >100Hz, removes boundary interference for main speakers
Back:
Absorb all bass, thicker absorption


Speaker shape spreads sound
Absorbers with slats covered with fabric looks like clean wall
Controlled directivity speakers
Bass system with stacked units for large radiating source eliminates boundary interference

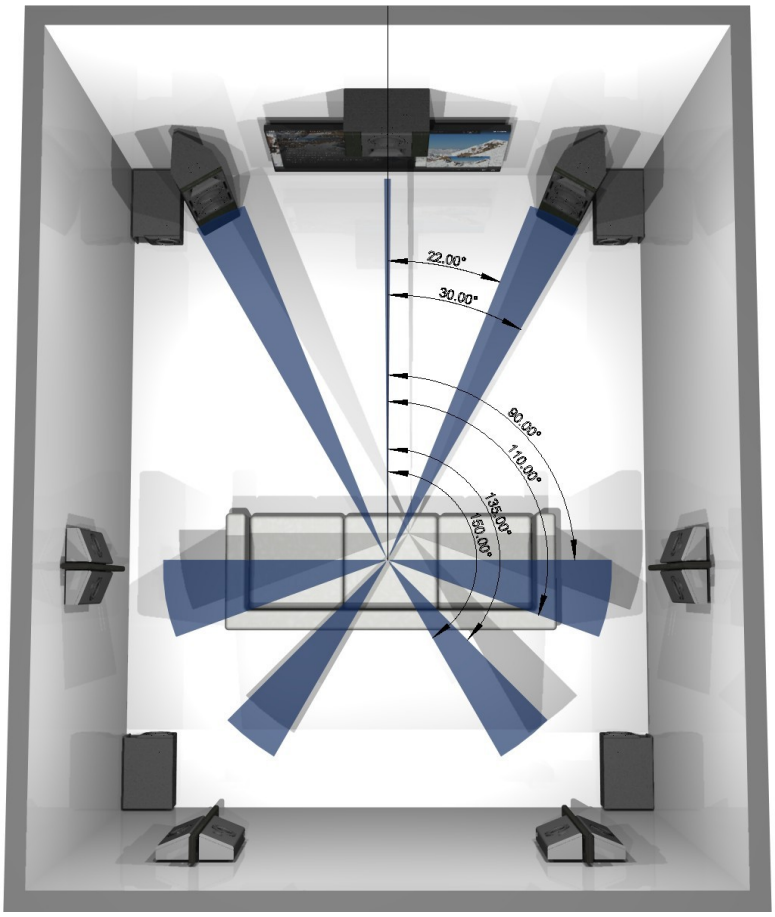
# Placing speakers and seats

## Screen - seating - speakers

In a home theater or media room the options for speakers and seating placement are limited by the fact that when the screen is placed, all other items just have to follow.

Also, there may be interior design and practicality issues limiting the choices, and this is not wrong – the ideal home theater sound system is the one that suits the needs on that particular room, even if that means some compromises.

*7.1 speaker placement guide*




The Dolby/THX specification for speaker locations can be used as initial guideline for placement.

Start by placing the screen on one of the shortest walls, and not too high up. Then the locations of the main speakers are also determined – they go besides the screen, one on each side.

Next place the seats. If possible try to avoid the middle of the room or close to the back wall – these locations tend to have the worst uneven bass response. The worst place is close to the back wall – the reflections from the very close wall are bad for sound, and back surround speakers will have to be above listeners head.

If you have a center it goes above or below the screen. With the screen placed low it will be more relaxing to watch and there is plenty room above for the center speaker. Avoid placing the center low close to the floor, especially if there is a table or other furniture that comes close to or even blocks the direct path for sound from the center speaker.

If you have an acoustically transparent screen then all front speakers – left, center, right – obviously can be located independent from the screen, and the positions for best sound can be chosen. The center can then be of same type as the L/R, or at least it can be mounted with HF horn section at same height as L/R speakers.

Distance between L/R main speakers is recommended to form a 45 to 60 degrees angle for home theater. For music many will prefer a little wider soundstage, and that is perfectly good, space them a little further apart, and you will find that music sounds better and it does not have a huge impact on movie sound, the front stage just seems a bit larger and wider.

Surround speakers goes along the side and back walls, as shown in the picture "7.1 speaker placement guide". Height above listeners heads, or slightly lower if you are doing a complete Atmos system with ceiling speakers.

What happens if you do not sit in the middle between the main front speakers? Imaging will be compromised, so that the virtual location of sounds tends to be imprecise and move towards the nearest speaker.

In an old-fashioned audiophile set-up the listening position is precisely located on the center-line between the main speakers, because this location is where it is possible to experience the magic three-dimensional sound stage. In a theater, however, we also want to create the best possible experience for more than one listener, and obviously only one person at a time can be seated in the ideal position. As described in the chapter about main speakers, better speakers with controlled directivity is the clue to get better sound for all seats, in combination with a good center channel. And then you can still have good sound if you prefer to lie down on the sofa and need not worry that your ears now are slightly off center.

## Subwoofer placement

Subwoofer location affects the low frequency response, and the actual response is a result of room dimensions but also wall flex and damping, and any windows and openings. The best placement depends on room acoustic properties, practical and interior considerations, number of subwoofers available and subwoofer size.

One subwoofer is rather hopeless, but if that's what is available, try placing it somewhere between the front speakers along the front wall, asymmetric.

If you have followed the advice in this guide, you have at least two subwoofers. If you have good bass absorption on the back wall it may work well to place them in the front left and right corners. Often it is possible to get a better response by moving them away from the corners, somewhere in between the front speakers. If practical due to interior issues, a placement further back along the side walls towards the back wall can also give better results.

If you have 4 subwoofers, place them in the corners, two up front and two at the back. The idea is to place subwoofers on opposite locations from boundaries, to be able to fill in nulls, or holes, in the frequency response.

If you want to experiment with alternative locations for subwoofers this should be determined by acoustic measurements, with focus on placement to fill in the nulls – holes in the frequency response – as those can not be equalized.

# Calibration

Calibration means to adjust all settings for speakers and sound so that level, distance and frequency range is reasonably correct for all speakers. The goal is to achieve a smooth frequency response and proper sound level across all seats, from all speakers, so that the movie will sound similar to as it did when the soundtrack was produced. Proper level means that the master volume on your receiver now will adjust the volume according to reference level, so that a given setting on your system always relates to a specific sound loudness.

The settings are adjusted on the receiver. Most receivers will have an automatic setup procedure, which at least will get you started with some reasonable initial settings.

| Setting | Affects | How to adjust |
|---|---|---|
| Speaker distance | Perceived location of sounds | Distance adjustment on receiver |
| Speaker level | Balance between speakers, playback sound level calibration | Trim level adjustment on receiver |
| Frequency response | Tonal balance, perceived sound quality | Equalizer in receiver, DSP with equalizer, equalizer and crossover frequency on subwoofers, speaker selection, speaker location, room acoustics |
| Crossover frequencies and distance for subwoofer | Subwoofer integration, punch and clarity in bass | Crossover frequency and distance settings on receiver |

## Target frequency response

A correct frequency response of the system is required for good and balanced sound. Decades of experience with sound reproduction have learned us how the response should be to give a perceptually neutral and good sounding balance to the sound; a tilted in-room response so that bass is louder and higher tones are softer.

Flat anechoic on-axis response from the speakers means that the direct sound – the sound from the speakers without room contribution – is flat. The room contribution will add more at lower frequencies and less at higher, so that the overall response measured at the listening position will be tilted downwards. How large the tilt is, depends on room acoustics, size of the room and loudspeaker radiation pattern.

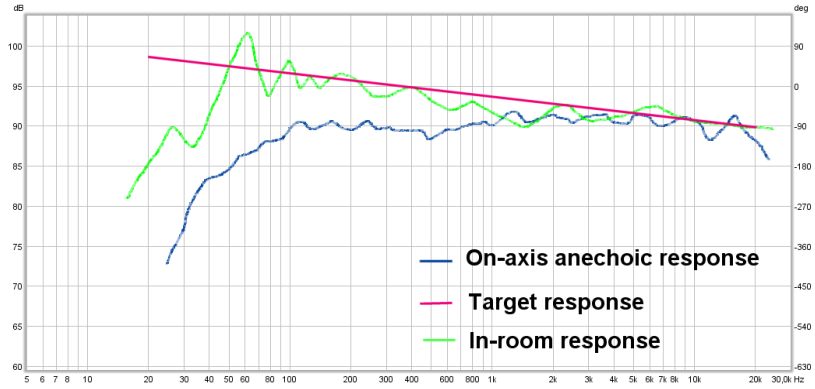
Generally, smaller rooms have a larger tilt, more damped rooms have less tilt.

It is important to note that this tilted response is not a result of personal preference to make it sound “better but not neutral” - the tilted curve *is* the neutral sound.

There should be no large holes or peaks on the response, this would indicate a problem with speakers or room acoustics. Generally, the smoother the better, part from the desired tilt.

The reasons behind the tilted response lies in how we perceive sound. The balance will mainly be judged from the direct sound from the speaker – before any room contribution is added. The human hearing operates in both time and frequency, something that is very easy to forget when working with frequency response measurements.

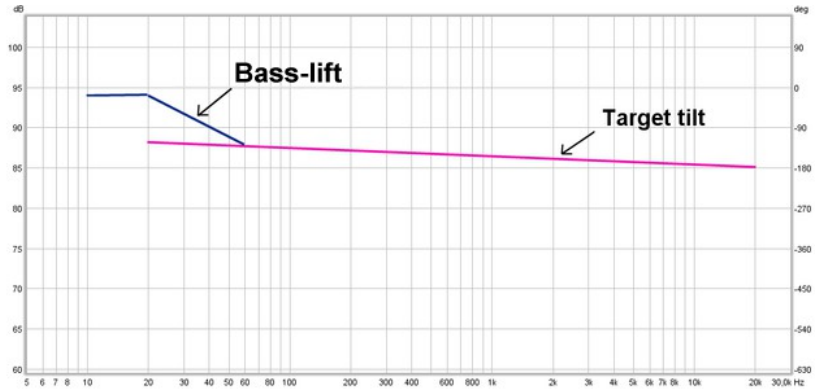
*Example typical frequency response with tilt*




Bass-lift means to add a little lift in the very lowest bass, to give sound effects more weight and impact. This is a customization from a strictly neutral response, and is chosen according to personal preference – some like no lift, some like much. The important thing is how the lift curve looks – it should only amplify the lowest frequencies, so that full level is attained at around 20Hz and below, while gradually sloping down in level up to around 50-100Hz.

The combined target correction curve is often referred to as House-curve.

*Target correction curve with 6dB bass-lift*

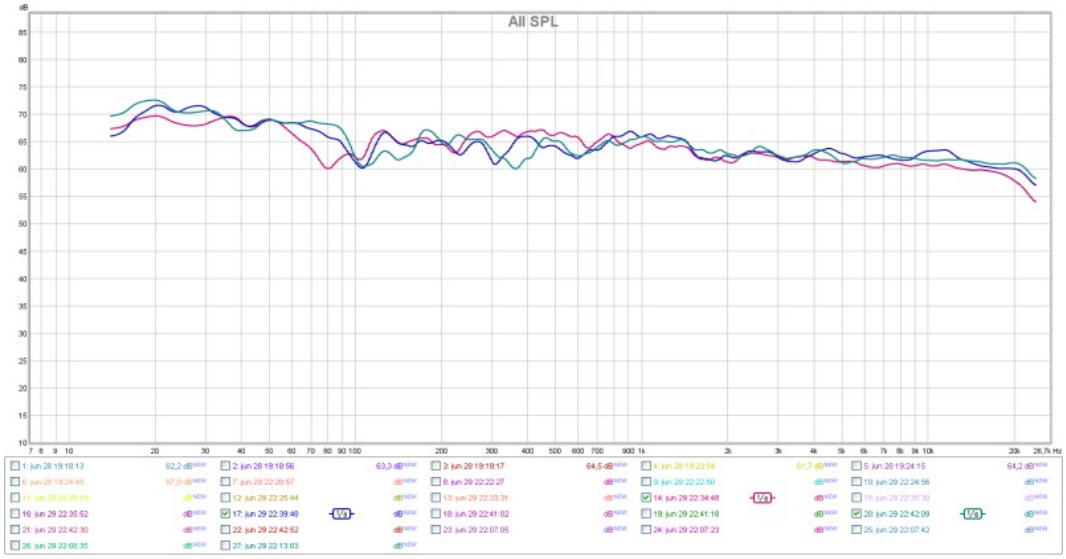



*In-room smoothed response with tilt and bass-lift*

Tweaking the frequency response requires acoustic measurement equipment and a proper equalizer. Some room correction systems can improve the response by automatic adjustment, but if the correction is not optimized for a tilted response that matches your room and speakers, the result will not be good.

Luckily, it turns out that good, reasonably linear speakers in a reasonably good room will give a decent frequency response, with flat on-axis direct sound, and tilted in-room total response. Then the only adjustment required is the bass-lift which is done on the subwoofers.

*Checking L, R speakers calibration for 3 seats using pink noise. Frequency response is smooth and shows the desired gradual tilt, approx. 10dB down at 20KHz from 20Hz. All 3 seats show very good consistency. No eq, no room correction, just decent speakers in a decent room.*




## Level calibration

The receiver automatic set-up will usually find usable values for speaker trim levels, so that main speakers and surrounds are balanced, and reference level is reasonably correct.

Most important is the balance between front main and surround speakers, so that surround sounds and front sounds have correct relative levels.

The reference level calibration is not very critical, as you will of course adjust the master volume setting to your preference when watching a movie, regardless of what the master volume setting displays.

Currently it seems the most widely used method for level calibration is to use the Dolby -20dB RMS Pink Noise signal. The adjustment is done by playing the pink noise signal and adjusting the level of speakers using a RMS sound pressure level meter. This method ensures your system will be calibrated to the same standard as all others using the Dolby signal as reference. This signal has full frequency range and will result in a much more accurate calibration than a typical receiver which uses narrow-band noise.

| Dolby Pink Noise -20dB RMS calibration | | |
|---|---|---|
| **Loudspeaker** | **Receiver master volume setting** | **Adjust trim level to measured SPL** |
| Main L/R/C | 0dB | 85dBC |
| Surround | 0dB | 85dBC / 82dBC (*) |
| .. | | |
| Main L/R/C | -10dB | 75dBC |
| Surround | -10dB | 75dBC / 72dBC (*) |

**: Home theater is calibrated to 85dB, cinemas use 82dB.*

The calibration can be done at lower level as well, just subtract the master volume setting from the measured level, master at -10dB means 75dB on the measured SPL.

If you have calibrated measurement equipment with a real-time spectrum analyzer you can verify the level and also check the frequency response at the same time.

Note that the Dolby pink noise signal does not have a RMS value of -20dB, it is closer to -18dB. The standard calibration in AV-receivers use a narrow-band -20dB RMS signal, which means an AV-receiver calibration will usually end up around 2dB hot compared to using the Dolby signal.

## Room correction

Most modern receivers have some kind of room correction – a digital processing filter making adjustments to the sound trying to minimize effects of room acoustics and speaker response.

The result of an automatic room correction will depend on how the correction system is implemented, speakers radiation pattern and frequency response, and room acoustics. If the correction equalizes to a flat target frequency response, the end result will most likely be too bright sounding.

If you find it difficult to achieve a perceived neutral frequency balance with the room correction, it is always possible to turn it off.

I recommend getting a better room correction system if this is something you desire very much. Such a system should let you customize the target frequency response and how corrections for reflections are done. Note that using an equalizer, whether manually set or automatic, is not the same as time corrective room correction.

## Manual setup

If you decide to not use the receivers built-in room correction, you can now do manual adjustments to get the best sound.

After running the automatic set-up on the receiver, I recommend checking and tweaking the settings:

- Set level and distance for L, R to same
- Set level and distance for SL, SR to same
- Set level and distance for SBL, SBR to same
- Set subwoofer crossover frequency to suitable values for all speakers
- Set subwoofer distance for best impulse response combined with L, R
- Disable room correction

Verify and adjust the trim levels if necessary, as described above in 'Level calibration'.

Note that if you change level or distance settings this will render the room correction configuration faulty, as the calculated filters were made using the automatically configured values.

If your speakers have a reasonably flat anechoic on-axis frequency response, and your room has reasonable acoustics, the system may now have a good frequency response – one with flat direct sound from the speakers, and a total in-room response slightly tilted downward with increasing frequency.

Some crude adjustments on frequency response can be done if the receiver has a graphic equalizer. On many receivers this equalizer can only be used when room correction is disabled. Measurements are required to make useful adjustments, as it is difficult and unreliable to do it without actually seeing the effects.

## Subwoofer calibration

Proper calibration of the subwoofer system is required for good seamlessly integrated sound in the lower frequencies, from lower midrange and down.

The receiver usually has an additional subwoofer trim level that can be used to set different bass level for different sources, or to change the level if a movie has too soft or too much bass. For this to work properly, the subwoofer system has to be set up with the right frequency response, so that the overall response is reasonably smooth for different subwoofer level settings.

The bass-lift is added to the target frequency response. Even with no bass-lift it will usually be better to set the target to a downwards tilt with increasing frequency, so that the lowest frequencies are louder than the higher up to the crossover. Generally, a target curve with no additional bass-lift will be perceived as more balanced on a system with a good bass system.

It is recommended to use acoustic measurements as an aid in the set-up process, it is very difficult to get it right without seeing the actual response and effects of adjustments. But ordinary acoustic measurements do not show a complete picture of how sound is perceived at bass frequencies, so listening evaluation is still necessary.

When using a DSP with parametric equalizer, be careful not to add much gain at holes in the response, focus on taking down peaks by adjusting q, center frequency and gain on filters.

Subwoofer calibration steps:

1. Place subwoofers in the four corners of the room, if you have proper 40cm damping on the back wall place subwoofers along front wall
2. Adjust DSP equalizer, delay, phase so that frequency response of subwoofers alone is reasonably smooth.
3. Never time-align 4 corner-placed subwoofers to the listening position, try adding 2ms delay on the front right and back right units.
4. Choose crossover frequency - often higher than usually recommended - try 120Hz, do not run mains as "large"/ full-frequency range.
5. Time align subwoofers and main speakers by setting Subwoofer Distance, remember to add delay of DSP and additional acoustic group delay in subwoofers and low pass filters - in total this may end up being several meters more than the physical distance to the subwoofers.

## Measurements

To be able to do a proper calibration where you check the frequency response it is necessary to measure using a microphone and acoustic measurement software.

I recommend a calibrated acoustic measurement microphone, a professional USB I/O device, and REW room acoustic measurement software, you run it on a standard laptop computer.

With measurement capability in place, you can now see the effects of tweaking the configuration settings and changes in room acoustics.

Getting the subwoofer system properly integrated is now possible, as you can see what is happening with the combined response when you make adjustments.

If you do not want to put in the required effort to find out how this works, you can try to find a friend or enthusiast in the neighborhood to help you out with some basic measurements. A competent dealer may also be able to help, but be prepared to pay for the service.

*Microphone placed at main listening position, ready for measurement*

# Further improvements

## Learning more

This article covers basic principles for getting the best sound, it does not go in to detail on technical terms and theory. A place to start for more information and to learn more, can be to search the net for terms and subjects mentioned.

Good places for information and discussions on anything about home theaters and sound:
www.data-bass.com

The Audio Calculator for speaker sensitivity and power requirements:
www.kvalsvoll.com/Articles/AudioCalculators.htm

My audio blog on everything sound related:
kvalsvoll.blogspot.com

Kvålsvoll Design web pages has informative articles and product presentations:
www.kvalsvoll.com

## Better sound

Improvements to sound can be done by doing changes to your system:

1. Calibration and setup
2. Room acoustics and placement
3. Loudspeakers
4. Amplifiers

How to proceed depends on what you want to improve.

Louder and cleaner at high sound pressure levels:

- Better loudspeakers with increased sensitivity
- Improving room acoustics will make it sound cleaner and more dynamic
- Install more powerful external amplifiers for front speakers

Cleaner, more defined sound:

- Improve room acoustics
- Better loudspeakers in front
- Work on calibration and setup

More impact and punch on low frequency effects, less boom:

- Install capable subwoofers
- Work on calibration to get more even response and perhaps lift the low end quite a bit
- Relocate subwoofers to get more impact

# About the Author

I run  the Norwegian registered company Kvålsvoll Design AS.

I like to create things, I like to work on engineering challenges as well as shape and visual appearance. I also enjoy working on abstractions like systems and concepts. This forms the foundation of Kvålsvoll Design.

I am an engineer in cybernetics and electronics. I have started several companies, and I have designed, built and tested complex cybernetic systems involving advanced dynamic control algorithms.

I designed and built my first speakers around age 14, and continued exploring and building audio speakers and amplifiers as a hobby throughout the years, learning more and applying what I learned in school about electronics, system theory and mathematics.

In 2012-2013 I started designing loudspeaker systems for home entertainment. Development is based on my expertise on simulation and dynamic systems. I have also learned a lot about how we perceive sound, which is of vital importance for defining proper requirements for sound system design.

The development of audio solutions in Kvålsvoll Design has lead to several new technologies for sound reproduction, such as the Compact Horn subwoofers, controlled directivity waveguide horns, very-high-slope crossover networks.

Acknowledging the importance of set-up and calibration, a new method for subwoofer calibration has been developed, which accounts for sound-field intensity for better tactile feel. This is new, and Kvålsvoll Design is so far the only company using this method.

Thank you for reading,

Øyvind Kvålsvoll