From Conference Room to Listening Room

Stroud Audio Inc.

Perhaps you manufacture audio products that could be best displayed in a high-quality music listening room. Maybe you need a place to do development of audio equipment. And just possibly you have a conference room or other office area that will make a fine location for implementing your listening room design. If so, this paper will show you how you can best make that most useful conversion.

You will be using the same scientific methodology that SAI would use if we were there working beside you (and you can easily arrange this).

I. Site Analysis and Surveys

A. Room Shape Analysis

It is desirable to select a room with dimensions that distribute room modes (more later on room modes). Typically, this means finding a room with a length:width:height ratio of 2.6:2:1. A somewhat ideal IEC-60268-13 listening room is 7 m long x 5.3 m wide x 2.7 m high.

In reality, you don't need to worry all that much about room shape. Walls aren't rigid and may not be acoustically where you think they are. Also, room modes can be managed by speaker and listener placement, and further mitigated with bass absorption. More on all this later.

Having a floor area of more than 20 square meters is desirable for positioning and having enough space for people and reflection control.

B. Room Noise Survey

Very important among issues is a survey of noise, both in the proposed environment and also the environment which could be impacted by listening room use.

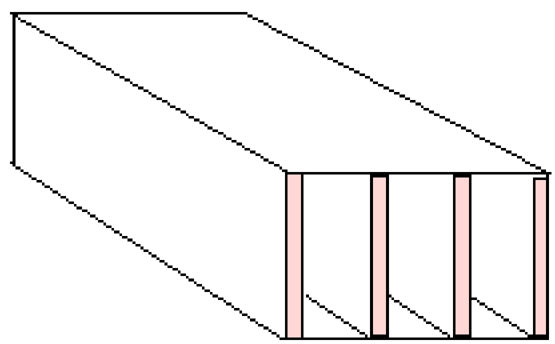
Is this a good place to start?

Using special construction methods can add costs, so finding a room with a quiet environment is best. Survey instruments such as spectrum analyzers are useful in room evaluation, but you can use an inexpensive Radio Shack 33-4050 or 33-2055 hand-held sound meter to determine if a candidate room is suitable.

For most purposes, listening room noise levels should measure less than 35 dBA, less than 50 dBC (use the slow settings). World-class rooms will measure less than 20 dBA, but most rooms don't achieve and don't require this level of performance.

Impulsive noises from nearby rooms will disturb your listening room's environment. Make sure that activities are happening during your survey, and that these sources will not generate intrusive noise.

Note that heating and air conditioning ducts are a major source of room noise, and they can be easily quieted by the use of isolators, special baffle duct silencers and curved duct routing.



Fiberglass Baffle Duct Silencer

C. External Environment Survey

The rooms adjacent to the four-to-six surfaces of your candidate room should be examined. If these rooms involve work that requires concentration, noise levels in these rooms should be high enough to mask noises coming from your new listening room.

To test this, place a full-range speaker system with a capable subwoofer in the candidate room. Using a pink-noise source, adjust the equipment to produce 100 dBC (wear headphones). Have someone turn the noise on and off as you tour the adjacent rooms. If these noises are audible and potentially disturbing, another candidate room, if available, should be evaluated.

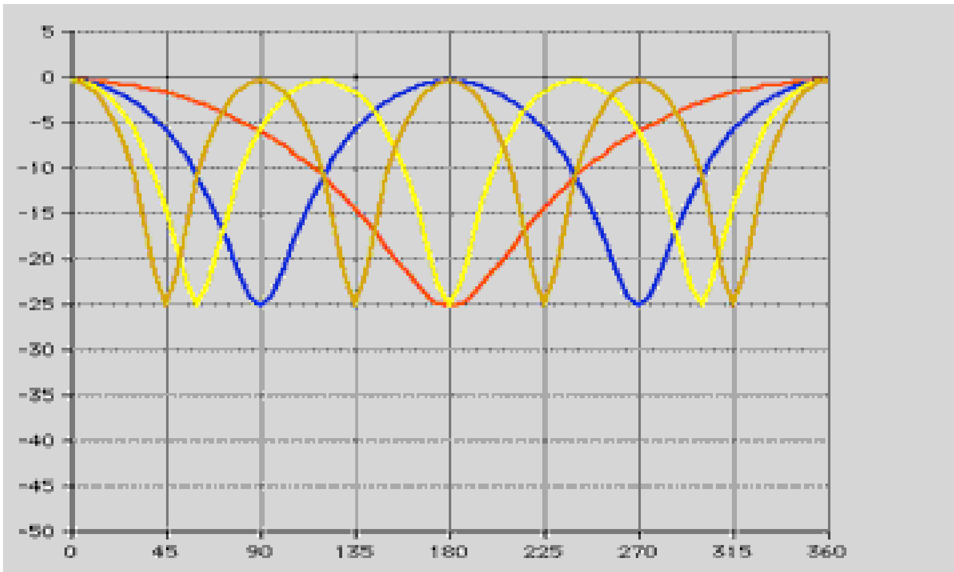
If none of your candidate rooms can meet the above shape and noise requirements, some construction may be necessary. Room shape issues can be mitigated with absorption and construction. Noise coming into and out of the room can be reduced by a number of well-known techniques such as alternating (or double-stud) walls, fiberglass filling, gap filling, using soundproof doors, etc.

For your room conversion, adding a new wall inside the room offers interesting design and acoustic possibilities.

If you just can't escape noisy compressors, etc., low-frequency active noise cancellation can be employed to help silence these intruders.

C. Room Modes Survey

Sound waves bounce off the walls, ceiling and floor. At higher frequencies, this can be useful and can create pleasing reverberation. At low frequencies, wave cancellation creates strong nulls that modify bass response and can virtually kill bass at some frequencies.



SAI Room Mode Calculator, Modes 1 through 4

If the walls, floor, and ceiling are very rigid, room modes are clearly defined and can be easily calculated. For example, for the front-to-back room modes, a null will occur in a plane in the center of the room. The frequency of this null will be:

F = 167/(Room length in Meters).

Other nulls are expected at frequencies determined by exchanging 167 above with 334, 501 and 668.

> Why are we concerned about nulls? Can't we just equalize them out? Yes, if the nulls are shallow. But a null 25 dB deep requires a substantial amount of equalization and amplifier power. Then listeners seated away from the nulls will experience some extraordinarily loud bass. The people in rooms down the hall will also notice. So we need to make the bass nulls as shallow as possible.

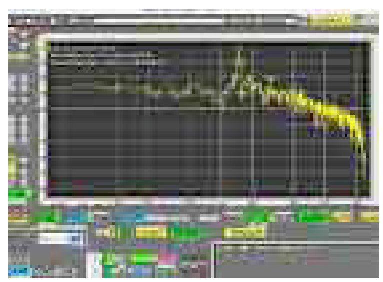
Now, real non-rigid rooms have resonant walls and floors, and suspended ceilings. We need to do some measurement. To evaluate the real room's bass modes, we need to find where the nulls are and how deep they are. This determines where the “real” walls are, and how well they reflect sound. Here’s how we do that...

First, place a subwoofer in the listening room’s corner near where your sound system will go. In this position, it will excite the front-rear modes, the vertical modes, and the side-to-side room modes.

> Why would we want to excite all those room modes? The corner location “couples” to those modes and makes the most bass in that location. If the modes are otherwise unmanageable, we may be forced to leave the corner.

If you have a spectrum analyzer, you can play white or pink noise through your subwoofer and move the measurement microphone around to find room nulls. This is a quickly done process.

If you don’t have a spectrum analyzer setup, you can make one using your handheld sound meter, an RCA-to-1/8 inch cable, a laptop with a decent sound card, and some spectrum analyzer software. This software needs to offer an FFT resolution of 2 Hz or less to allow the tester to see the full depth of the nulls. A good spectrum analyzer is Room EQ Wizard freeware. See the link in section VI that follows.



Radio Shack Sound Meter with FFT Analyzer Software

> With his laptop, the author uses a Behringer measurement microphone with an external USB audio interface. This is another inexpensive option you may wish to use.

As you move the mic around, you will likely find nulls of 20 dB or more. A strong set of nulls are in the room center, and others are seen throughout the room. Look back at the mode calculator image and you’ll see just how many nulls modes 1 through 4 can generate.

Next, determine the desired seating position. If that happens to be in a null, see if it can be moved. If not, construction of a new wall or use of bass absorption could be indicated (see room tuning below).

In most listening rooms, relative freedom from modes 1 through 3 can be obtained with the subwoofer moved out from the wall to about Room Length x 0.17 and the seating position at around Room Length x 0.7. If the ceiling is high, you may need to move the subwoofer up to minimize coupling to listener's ears by vertical modes. Be aware that moving the subwoofer away from the corner position may require more subwoofer amplifier power.

While you're testing room modes, you can also test for rattles. Switch the signal generation software to make a slow sine sweep from 20 Hz to 300 Hz or more. Turn up the volume a bit and fix those rattles before final trim, etc. goes on.

II. Room Tuning, Part One: Room Mode Suppression

If speaker and listener positioning can be adjusted to provide a reasonably smooth and equalizable bass response, this next step can be omitted. But if this is not practical, bass absorption can be added to reduce nulls to more manageable levels.

Bass absorption is best done in the rear corners of a listening room. The room's corners catch all the axial modes.

The most straightforward way of absorbing bass is to pass sounds through slots in a wall, then through an absorber such as fiberglass into a rather significant volume of more fiberglass and/or air. Other methods include use of Helmholtz resonators and damped resonant panels. These latter two may not be suitable for acoustic music reproduction and could make the bass "slow".

> It sounds counterproductive to discuss absorbing bass, but softening nulls can actually result in more bass in the listening position and better bass distribution. Bass absorption will also help reduce bass reverberation time should that be needed (see section VI. Absorption below).

A more advanced mode suppression technique is to use multiple subwoofers with suitable amplitude and phasing control, but I would use this only if a large area of seating was needed in a small-to-medium sized room. Stroud Audio can help you implement such a system.

III. Speaker Selection

If you are a manufacturer or retailer of a single brand of speaker systems, the choice is simple: pick the top of your loudspeaker line. If you manufacture or sell loudspeakers, perhaps you would want to incorporate your products in a custom-built enclosures.

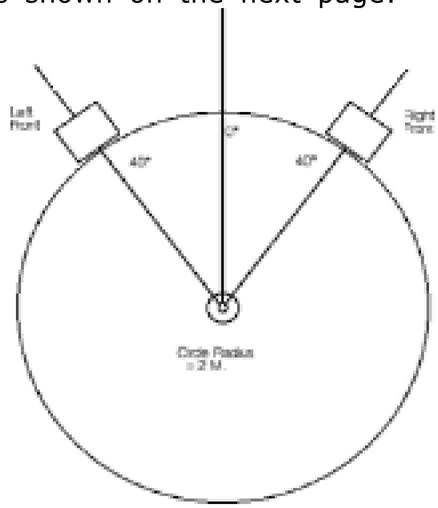
Whatever non-acoustic factors influence your decision, the speakers you choose or build should meet the following criteria. They should:

1. Provide a system response of at least 30 Hz to 18 kHz
2. Produce smooth on-axis and smoothly-falling off-axis responses
3. Be capable of producing 110 dB of sound pressure level without noticeable distortion (120 dB bass).

4. Exhibit no intermodulation distortion at moderate levels.
5. Be capable of precise imaging, especially front center imaging.

IV. Speaker Positioning

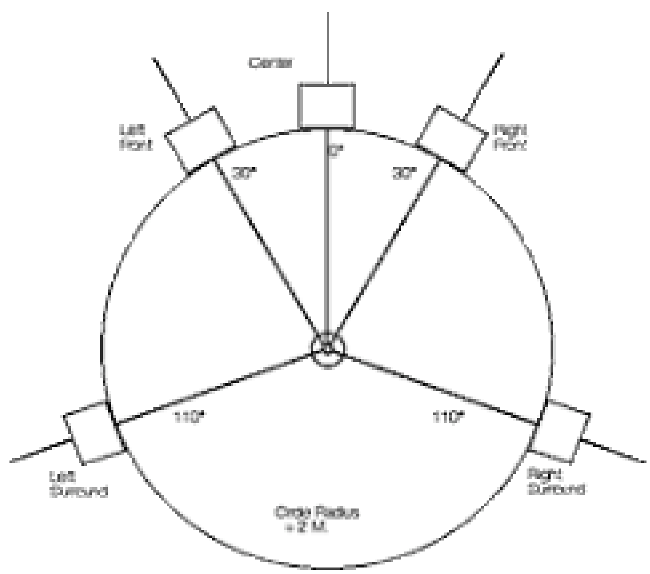
You next need to determine a position your loudspeakers, either for stereo or multichannel reproductions. For stereo reproduction, position the front speakers as shown on the next page:



Stereo Speaker Layout

Some like a 30 degree position: SAI prefers the 40 degree position, as it provides a slightly higher sense of envelopment.

For multichannel reproduction, the most widely used speaker positioning layout is the one recommended in ITU-R BS.775-1:

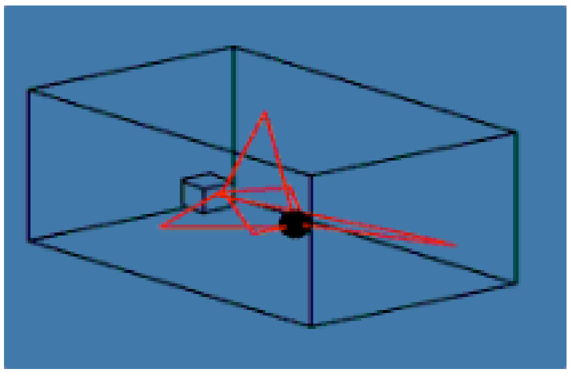


ITU-R BS.775-1 Multichannel Speaker Layout

SAI recommends that the rear speakers be mounted somewhat above ear level. This helps prevent unwanted source localization.
There are some seven channel systems which add two additional rear speakers to the mix. Many find this effect a most pleasing addition to the standard 5.1 arrangement. SAI has tested many listeners using a system with delayed rear speakers that was significantly preferred over the standard 5.1 listening room setup.

V. Room Tuning, Part Two: Managing Reflections

Now that your speaker positions have been identified, we can begin to manage room reflections. SAI uses the ray-tracing method, which is easily implemented using a mirror.



Sound as if it were Light Beams

We are most interested in the control of frequencies above 500 Hz, as reflections at these frequencies create combing and can damage sound quality. And at these higher frequencies, sound tends to bounce off surfaces much like light does (if the surfaces are large compared to the sound’s wavelength). Thus, the mirror.

Our objective is to minimize early reflections to the listening position from the floor and ceiling, and to soften excess early reflections from the walls.

> Note that speaker selection can impact the need for reflection control. Large, flat-panel speakers, for instance, do not project significant energy at the floor, ceiling or side walls. Both front and rear walls may need additional reflection control, however.

To begin, have someone sit in the prime listening position. Place your mirror flat against surfaces on all four walls, ceilings and floors where the “listener” can see each of the speakers. Those are the points where the sound “rays” will bounce off of these surfaces.

For the walls, it is not necessary or even desirable to eliminate reflection, but rather to reduce its intensity. This is done with shapes that 1) diffuse, such as half-cylinders, quadratic residue diffusers (SAI doesn't prefer these), etc., or 2) that deflect, such as non-typical wall shapes.

For the listening room's ceiling and even the floor, reflections should be minimized to the greatest extent possible. That is because the combing that these reflections cause cannot be easily "resolved away" by the human's directional hearing mechanism. This is done with reflecting panels and blocking surfaces. They look somewhat strange on the floor, but they make a substantial difference in the spectrum presented to the listener. These objects suppress floor bounce much better than carpet, which basically turns down the treble.

> Note that I haven't mentioned absorption of potential early reflection. This can of course be done, but only as a part of an overall absorption strategy (see below).

I wouldn't worry quite as much about reflections from rear channel speakers. It's more important to control reflections from center, front right and front left speakers.

VI. Room Tuning, Part Three: Absorption

I'm not a big fan of adding absorption. In most listening rooms, the fluffy couch or chair cushions, the vibrational loss of ceilings and walls, and softer quality of most people serve as adequate absorption.

> Widely known "egg crates" from packing cartons, carpets, and other thin absorptive materials tend to absorb only higher frequencies, and this can "dull" the listening room. Use these only if higher frequency absorption is desirable from the reverberation testing described below.

To determine the need for absorption, it is useful to measure the reverberation time of the room. This is where we really want a waterfall plot of time, energy and response. Or at least a time-gated series of frequency responses. But you can come reasonably close with the simple setup you have now.

SAI recommends your downloading Room EQ Wizard from http://www.hometheatershack.com/roomeq/ This freeware has a powerful analysis capability that can measure room reverberation time along with many other measurements. You can use this software with your frequency measurement setup.

For music listening, the reverberation time, or RT_{60}, should be from 0.3 to 0.6 seconds from 200 Hz to 4 kHz with a little more acceptable range for the bass and higher treble. In fact, you don't really need any bass reverb below 200 Hz.

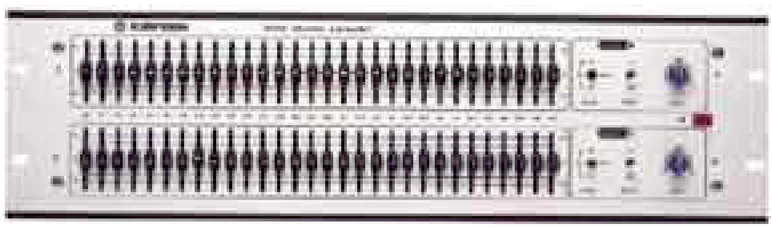
If more low-frequency absorption is needed, you may need to add more resistive absorbers in the same places you would add bass absorption for room mode control (see section II. Room Mode Suppression above).

VII. System Equalization and Power

Now the speakers are in place and the room has been tuned. The systems will doubtless sound quite good, but it will not reach it’s full potential without equalization.

This is best done with your spectrum analyzer setup and a good set of trained ears. You would best use 1/3 octave real time analyzer software for this. You can find these on the internet and load them into your laptop.

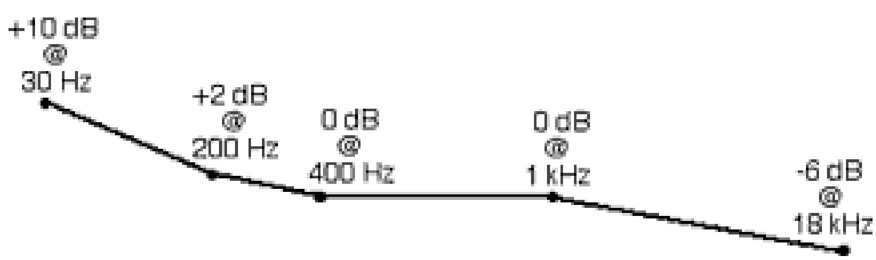
Often, the preamplifier's tone controls will do a credible job of equalization. For more difficult situations, a 1/3 stereo octave equalizer will be required.



Klark Teknik Third Octave Stereo Equalizer

When your speakers aren’t as smooth in response as you’d like, full parametric equalization can be used. Remember that every channel needs its own equalization.

The correct frequency response target is not a flat line. The recording industry adjusts its response to the sound of an anechoically flat speaker in a real room. This means that the bass is lifted and the treble is slightly rolled off. The target curve looks something like this:



Equalization Target, or “House” Curve

Please note that the actual shape of the House Curve varies depending on room size, absorption, and speaker dispersion characteristics.

If you're using a separate subwoofer, it is best to adjust the entire system for flat response, then adjust "upstream" of the crossover to fit the target curve.

There is another important step to making your new listening room sound even better. This involves including a properly calibrated "loudness compensation" characteristic in your preamplifier circuitry. Loudness compensation corrects the perceived spectral balance at low levels by boosting bass, and to some extent, treble. Most listening rooms don't use loudness, and this makes them sound thin when users are playing music softly.

Most loudness compensation is at some volume levels excessive and at other levels, totally inadequate. The best loudness compensation lifts bass and treble gradually as volume is lowered, reaching boost levels of perhaps 25 dB at 40 Hz.

You may get arguments about the "correctness" of using loudness. To settle this, have your critics sit in the listening position and set the correct EQ at low, medium, and higher levels. Always start each EQ setting with an "incorrect" bass EQ to make sure the listeners really listen to their EQ. Averaging their low, medium and high level EQ's then specifies your system's loudness curve. Since the critics set the curve, how can they argue with the result?

In our own listening setups, SAI uses a computer with multichannel audio software such as Ableton Live. In addition to EQ and signal assignments, such programs can offer time delays and cross-feeds as needed.

Now about power: your amplifiers should produce enough power to produce 110 dB SPL at the listening position with your speakers. Let's assume your speaker's sensitivity is 88 dB 1 watt/1 meter. In the listening position, the output of two speakers would be maybe 85 dB (with 1 watt in each speaker). To reach 110 dB, you need 25 dB more power that 1 watt, or around 18 watts! Give it a factor of 4 to keep you out of clipping and the amplifier power will need to be about 70 watts/channel.

The same process applies to the subwoofer, but I would shoot for another 10 dB just for fun. With the same speaker sensitivity of 88 dB, that gets us to about 200 watts for the sub amp. If you don't use a subwoofer and run the whole system full range, I would use a 300 watt/channel amplifier. That's why I like subwoofers.

VIII. Listening Tests

Now with the system tuned electronically, you need to assemble your trained listeners and make minor bass and treble adjustments as they see fit.

This part always makes me nervous, as some trained listeners are not calibrated to reasonable standards. The proper standards are frequency responses like those intended by the artist and presented in the recording studio's listening room. No exaggerated bass, etc. If they drift away from the target curve by a significant amount, you might consider using another set of trained listeners.

Now you should have a listening room of which you can be proud. Please know that when anything in the room is changed, like curtains, carpets or new furniture, fresh equalization could be required.

Thank you for downloading Stroud Audio Inc.'s listening room paper. Please let me know if we can be of service for any of your acoustic needs.

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