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The Easy and the Hard Part of Controlling the Acoustics Of Rooms

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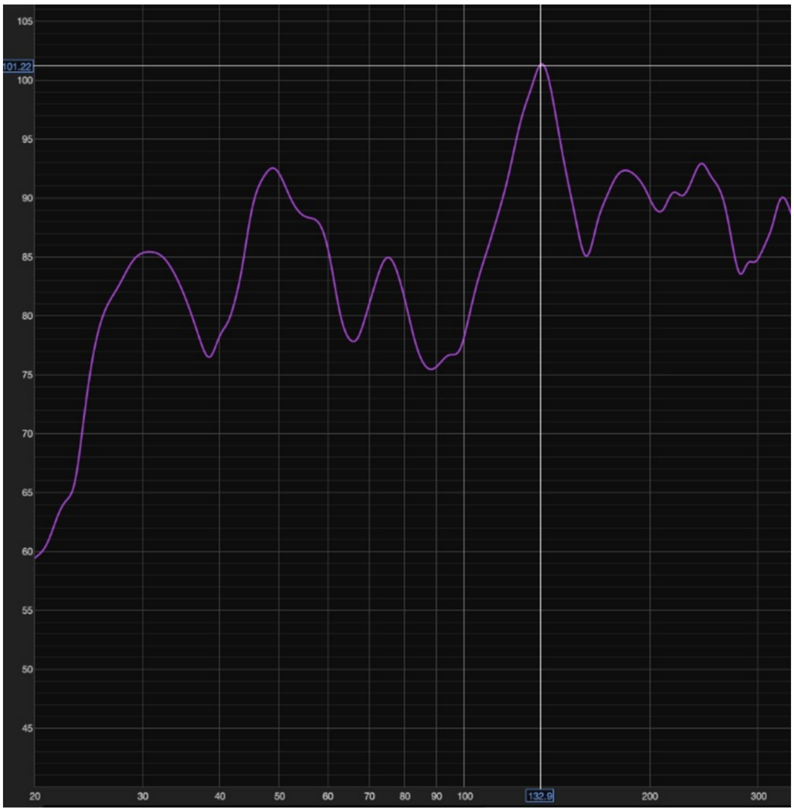
From time to time, audiologists are asked about strategies (and products) that can be used to reduce the echoes in rooms in hopes of improving speech intelligibility or to “flatten” the room’s acoustics for music listening and playing. Other than seeking out the assistance of an acoustic or audio engineer (which actually can be well-worth the expenditure), this is a primer on how sound behaves in a room, and how it can be modified. An audiologist may be approached by an “audiophile” who has done a spectral sweep of a room and noticed an unwanted resonance at 120 Hz or 130 Hz, for example. How can we best respond to this inquiry?



All sound—including speech and music—can be classified as “low frequency” or “high frequency”. These gross categories are different for speech and music and sometimes lead to confusions. “Low frequency” for speech means 250-500 Hz whereas low frequency for music is on the left side of the piano keyboard (below 250 Hz), but suffice it to say that “in general” low frequency sounds have long wavelengths and are acoustically “blind”. Low frequency sounds do not “see” obstructions such as walls and furniture, and can be heard in the next room with minimal attenuation. The longer wavelengths associated with lower frequency sounds provide us with the best explanation. As long as the obstruction (such as a wall) is less than ½ the wavelength of the sound, that obstruction will have no effect- that is, long-wavelength low frequency sounds will pass through the obstruction as if it were not even there. The wavelength of 250 Hz (middle C on the piano) is 136 cm or around 4 ½ feet. A wall or obstruction would have to be at least ½ of 136 cm (68 cm or 2 ¼ feet) to be attenuated, and there are very few walls that are at least 2 or 3 feet thick. Understandably, it is very difficult to rid a room of unwanted resonances and sound in the lower frequency region.

In contrast, higher frequency sounds have shorter wavelengths, and using the "1/2 wavelength rule", it may only require an obstruction of a few cm (or even the width of a face mask) to attenuate these higher frequency sounds.

Understandably, there need to be different acoustic treatment strategies for the attenuation or flattening of unwanted sounds or room resonances for the lower frequency bass notes than for the higher frequency treble notes. This is as much the case for a classroom as it is for a concert hall, or a music production room in someone's basement. And the acoustic treatment can (and initially should be) as simple as relocating a desk, or even using a separate bass speaker so that the main speaker doesn't have to work as hard.

The Very East Part:

It may very well be the case that the location of a desk or listening area in a room is the culprit- perhaps being too close to a wall or a corner where unwanted sound can build-up… so before anything significant is changed, just try moving around the furniture.

The Easy Part:

In general, the presence of certain obstructions such as wall coverings, furniture, the presence of people in the room, acoustic tiling for the ceiling, and room carpeting can all serve to attenuate unwanted higher frequency sound reflections and sound buildups. For example, libraries are ideal in the sense that unwanted reflections are attenuated by the presence of books shelves, carpeting, and soft cushy chairs. In contrast, school gymnasiums can be an acoustic nightmare.

The More Difficult Part:

The control of low frequencies in a room is a bit more difficult since they are myopically blind to obstructions. For low frequency sounds, placing a baffle in front of a loudspeaker, or indeed placing a loudspeaker upside down and backwards and behind a couch, will have no effect on the sound. And low frequency sounds coming from a loudspeaker are also non-directional so the loudspeaker can be aimed in any direction without much of an effect. This is why home theatre stereo systems are called "5.1" despite having 6 individual loudspeakers- the bass speaker- the 6th speaker- can be placed anywhere and does not contribute to the spatial separation of the sound.

There can be many resons for an unwanted build-up of low frequency sounds in a room. It may be that a person's desk or where they happen to be sitting is too close to a corner, or a wall. Moving the chair and/or desk away from corners could improve the sound quality as this will decrease the bass response slightly. There is no such thing as a bass frequency "baffle". It would need to be at least 4-5 feet in thickness and would take up an appreciable amount of the room space. Instead, a Helmholtz resonator would be needed.

Low Frequencies and a Helmholtz Resonator:

We have seen (heard?) Helmholtz resonators whenever we blow across the top of a pop bottle. Essentially two things are required- a narrowing or small hole (such as the pop bottle neck) and a volume of semi-trapped air behind the hole. And by varying the hole size and/or the volume of trapped air, we can change the Helmholtz resonant frequency. Sounds in the room that are near that Helmholtz resonant frequency will be "sucked" out of the room and into the resonator. They are quite easy to build and require a fairly large sized box with a "tuned" hole. We run in to this in the study of speech acoustics- high vowels such as [i] and [u] have a narrow constriction between the blade of the tongue and the roof of the mouth, and due to this narrowing (or constriction), have a very low frequency first formant (F1). Less constricted vowels such as [e] or [a], have higher frequency first formants… a greater cross-sectional area of air flow between the blade of the tongue and the roof of the mouth.

And here is how you can tune it to remove unwanted lower frequency resonances…

F = speed of sound/pi (area of hole/volume) ^{½}

This equation is actually quite simple. It merely says that the resonant frequency (that will suck away any unwanted low frequency sound) is proportional to the cross-sectional area of a hole (or series of smaller holes) and inversely proportional to the volume of the wooden enclosure. I typically use ¾" plywood to make a box that is around 4 feet high with sides about 15-20", screwed together and caulked along the seams. And to take up less room, one can create a triangular box that traverses any corner of a room diagnonally. Table I shows typical Helmholtz resonances for such a box (4' tall x 15" x 15" on a side, with the front of the triangle being 21.5") but with different sized and/or equivalently, number of smaller holes. This box can be placed in the corner of a room (and, with baffles and wall treatment to handle the higher frequencies), can "smooth" out the acoustics quite nicely.

When it comes to "conventional wisdom" (e.g. a Google search), you may run in to a phrase called a "bass trap". These are boxes that are simply filled with foam rubber and may have a slight bias towards the bass notes, but are essentially just sound dampers. These can work well for attenuating echoes in rooms (as can furniture and the presence of people) but they are misnamed, and in many cases merely a marketing name. For these to have any specificity towards only attenuating unwanted low frequency resonances one needs to use a Helmholtz resonator which has a tuned hole in the box. For the example of an audiophile who wants to remove a 120 Hz resonance, a 1.5" (or 3.81 cm) diameter hole would be required for a box of this size.

Diameter of hole (inches)	Diameter of hole (cm)	Resonant Frequency (Hz)
0.5	1.27	42
1.0	2.54	81
1.5	3.81	123

2.0	5.0	161
2.5	6.25	203
3.0	7.6	247

Table I: For a triangular shaped box that is 4 feet tall and 15" on each side that can be placed in the corner of a room, in order to build a Helmholtz resonator that will remove 120 Hz, the hole needs to be 1.5" in diameter (or 3.81 cm). Larger holes (or more holes adding to the same cross sectional area) will create a box with a higher resonant frequency. These data are only approximate and the actual resonance may be slightly lower due to an "end correction", which is related to the thickness of the (3/4") wood used.

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