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THE SPEAKER AND THE LISTENER

Where to position them within the listening room – and why

By Roy Allison

Speaker designers, testers, and users have for many years argued about the proper acoustic environment in which to test loudspeaker systems. The central problem has always been the lack of correlation between the various response curves obtained in an anechoic test chamber, in a reverberant test chamber, and in a "normal" listening room. Although the curves obtained in the two test chambers are repeatable, and although when used together they do predict, to some degree, a system's performance in a normal room, the correlation is far from perfect. There is nothing inherently "wrong" with the chamber test techniques, but they cannot take into account the random acoustic factors that are introduced when a speaker is placed in a real room with unknown damping qualities, unspecified dimensions, and at unpredictable distances from adjacent room surfaces. Under such circumstances, speakers with smooth, flat *measured* response curves can develop quite audible dips and peaks in their sound output; others may lose clarity or suffer from subtle, distorting coloration.

Most of us are aware of—and can deal reasonably well with—the damping effects of the room. Simply stated, the "softer" the rugs, drapes, and furniture, the greater the high-frequency absorption and the less chance that the sound will be overly bright. Fortunately, most room furnishings provide acoustic absorption (damping) within the proper range. However, as many listeners have discovered to their dismay, improving room acoustics can involve a lot more than just proper damping.

Some sensitive and critical audiophiles have spent months moving their speaker systems about, checking the sonic effect of one randomly selected room location after another. They know what they are listening for, but they lack guidelines that will help them achieve it. Roy Allison, who has been particularly concerned with room/speaker interface problems, has worked out, with the aid of a computer, the specific effects of the major speaker- and listener-position variables encountered in a conventional listening room. It should be obvious that *all* the random room factors have not been reduced to an easily applied formula, but the article that follows should enable you to eliminate at least one important and disturbing unknown from the complex speaker/room/listener equation.

Larry Kle
Technical Editor

A NEWCOMER to high-fidelity sound reproduction soon discovers that the sound of a given speaker system is profoundly affected by the acoustical characteristics of the room in which it is being used. Not quite so evident, however, is the fact that there are also significant, audible changes in frequency balance as the position of the speaker—or of the listener—changes even slightly in the room.

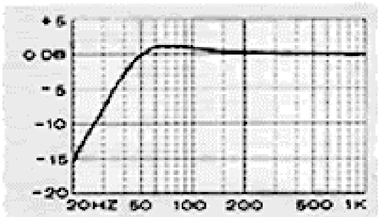
The effects of all these variables have often been touched upon in a general way in articles dealing with room size, construction materials, and furnishings. Only recently, however, has it become possible to develop quantitative data on two important aspects of the complicated speaker/room/listener relationship. First, if a speaker system's position with respect to the nearest three room boundaries (two walls plus the floor or ceiling) is known, the room's effect on the speaker's acoustic power output can be predicted quite accurately. Second, at least a close approximation of the way room boundaries affect the sound field at various *listener* locations can also be calculated if we know the distance of the listener's head from the nearest three room surfaces.

When sound is fed into a room, it reflects successively from one room-boundary surface to another. This effect is known as reverberation. In those areas that are only a small fraction of a wavelength away from such a boundary, the direct and reflected sound pressure are in phase, and therefore combine by simple addition. For an area close to any one room surface but not to others (such as the center of a large wall), the maximum increase in sound pressure above that measured in the middle of the room (assuming that sound energy is arriving at the boundary equally from all directions) is 3 dB. (Note that in all our examples we are assuming that the sound field is diffuse—that is, it reaches the boundary after having been reflected from all directions.)

If the listener moves farther away from the reflecting surface (or if the wavelength is decreased by making the frequency higher), the reflected sound energy will eventually arrive back at the observation point opposite in phase to the direct sound, causing the sound pressure at that point to be about 1 dB lower than it is in the middle of the room. This pressure minimum occurs at a distance of 0.35 wavelength from the boundary. Beyond that distance the effects of the boundary are minor. A speaker system's acoustic power output at low frequencies is in direct proportion to the resistive load presented by the air surrounding it, and that load depends on the speaker's proximity to room boundaries. The measured effect of this loss on a speaker's power output is of precisely the same magnitude as the audible variation in sound pressure for listeners near room boundaries. There is, however, no dependence on a diffuse field in the room, because the speaker's output at low frequencies is omnidirectional.

Near the intersection of *two* room boundaries the additive reflections can increase the sound pressure by a factor of four, or a maximum of 6 dB. And the sound pressure at a location that is only a small fraction of a wavelength distant from a *three*-boundary intersection (two walls and a ceiling or floor) is increased nearly eight times by the multiple in-phase reflections, for a maximum boost of 9 dB. Thus the gain in sound pressure at very low frequencies is inversely proportional to the solid angle represented by nearby listening-room boundaries.

Figure 1. Relative power output vs. frequency for a "standard" speaker system with a 50-Hz bass resonance. This is a normal anechoic performance for many current speaker systems.



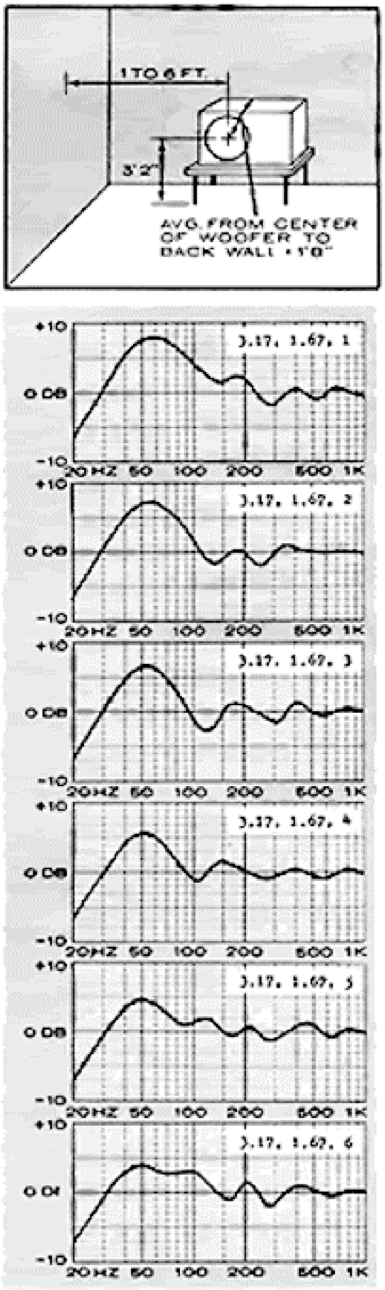
This proportionality does not, however, hold for the maximum reduction in sound pressure at the observation point which occurs when reflections are in phase opposition to the direct sound. At a single boundary (wall, floor, or ceiling) the sound pressure is reduced by 1 dB, as we have seen. But at a point approximately 0.3 wavelength distant from two intersecting room surfaces, the sound pressure reduction is 3 dB, and at about 0.3 wavelength distant from a three-boundary intersection the reduction is 11 dB!

This phenomenon has severe audible consequences. If a microphone (or a listener's head) is located close to and equidistant from a three-surface room corner, the sound pressure will vary over a range of 20 dB (+9 to −11 dB) as the audio signal frequency (and hence the wavelength) changes, although the sound pressure in the middle of the room remains constant. Fortunately, the variation is less for locations off the line of symmetry from the corner, but it is still of considerable magnitude.

These relationships were first spelled out in several papers by scientists at the National Bureau of Standards. The mathematical operations required to plot a "response curve" for a particular speaker or listener location are tedious, but a large computer, properly programmed, can make short work of the dreary calculations. The curves presented with this article were plotted from data supplied by such a computer. They are of two kinds: first, there are speaker power output vs. frequency curves showing how the calculated power output of a standard "ideal" speaker system changes as its position in the room is varied. Second, there are curves showing the additional influence of room boundaries on the sound heard by listeners sitting in typical positions in a room. In addition, there are a few curves showing the result of combining a speaker's response for a particular room location with a specific listener position.

The theoretical basis for predicting a listening room's influence on speaker acoustic-power output has been tested experimentally and found to be applicable to real home listening rooms and speaker systems. Therefore, the loudspeaker/room curves shown herein can be relied on completely. Somewhat less confidence should be placed in the listener-position curves, however, since they assume a totally diffuse sound field such as might occur in a concert hall, and the home listening room suffers from resonance modes (standing waves) which are directional and, in a

Figure 2. Power output vs. frequency curves for the standard speaker system of Figure 1 as measured in a typical listening room. The numbers on the charts show distances (in feet) from center of woofer to the floor, to the back wall, and to the nearest side wall. Curves are typical for the system placed on a table or a bookshelf 32 inches high with its back near a rear wall and at gradually increasing distances from a side wall.

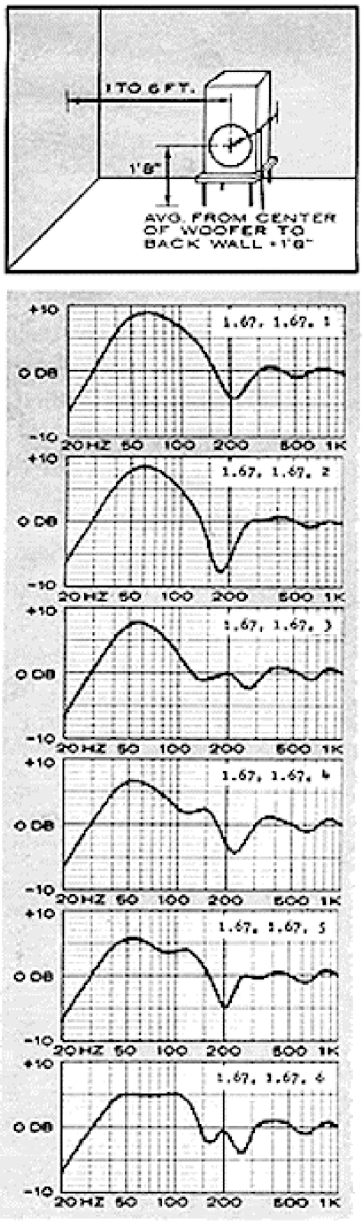


small room, usually widely spaced in the low-frequency range. However, with the usual listener locations, the resonance modes tend to coincide with and reinforce the normal boundary effects at listener positions.

Speaker Position

To show how speaker output is affected by a real room, it is convenient to start with a "standard" or reference speaker. Figure 1 is a power-output *vs.* frequency curve (measured in an anechoic chamber; a near-field response measurement would yield the same curve) for a hypothetical "standard" speaker. The performance and the physical arrangement of the system are quite close to those of many high-price bookshelf units now on the market. This hypothetical system has a cabinet with dimensions of about 1 x 1 x 2 feet, and its woofer is mounted toward one end of the front panel. The system's normally damped bass resonance is at 50 Hz. (Although this hypothetical system is an acoustic-suspension type, the design principle is actually not relevant. The room effects to be shown would apply to any type of speaker system except those using bass corner horns; only the distance from the driver to the three nearest room boundaries is important.)

Figure 3. The standard system placed on a base or low table about 1 foot high with the woofer end of the cabinet down, the back near the rear wall, and the distance to the side wall increasing in 1-foot increments.

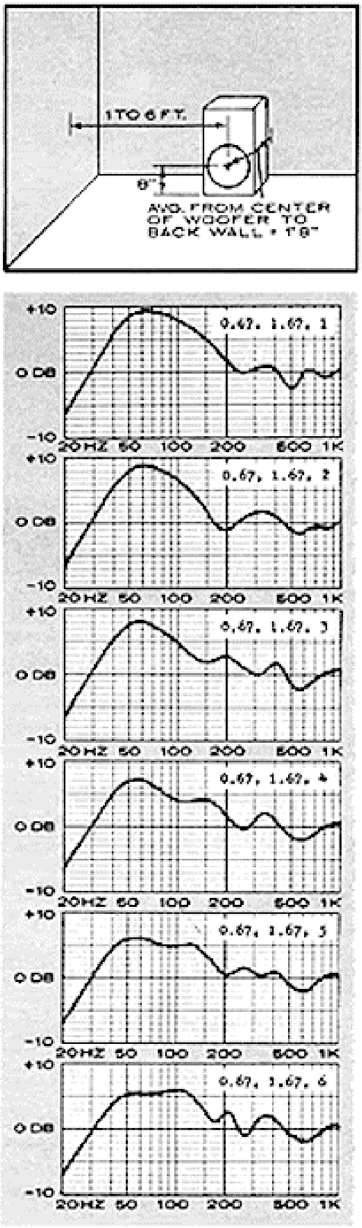


Suppose we take this standard speaker system into a home listening room and put it on a 32-inch-high table or shelf, with its back close to the wall. The center of the woofer will be 3.17 feet from one room boundary (the floor), and its average path length along the exterior surface of the cabinet to the rear wall will be about 1.67 feet. Figure 2 is a family of acoustic power-output curves obtained as the system is moved gradually away from the side wall, with its center at distances varying from 1 to 6 feet. It is evident that as the distance to the side wall is increased, the peak in output centered at 50 to 60 Hz decreases. In fact, the 6-foot side-wall spacing causes an output variation from normal of only about ±3 or ±4 dB. None of the curves looks exactly like the system's *anechoic* curve, however, and in most domestic rooms it would not of course be feasible to locate a stereo speaker six feet or so from the nearest side wall.

If we take the speaker off the shelf and put it on a 1-foot base or stand with the woofer end of the cabinet at the bottom, the woofer's center will be roughly 20 inches or 1.67 feet above the floor. Its average path length to a rear wall remains 1.67 feet if the cabinet back is placed close to the wall. Adjusting the base location so as to vary the distance to the side wall, we obtain the family of curves shown in Figure 3. It is obvious that the bass peak here is greater than for the corresponding shelf positions. Also, the fact that the woofer remains at the same distance from two of the boundaries tends to "pull" the acoustic power dip toward a common frequency (200 Hz) for all the curves and to make its average severity greater than would be the case for unequal distances. It is rarely a good idea, therefore, to stand a speaker system on a short base.

The curves in Figure 4 are similar to those in Figure 3, except that the woofer end of the cabinet now rests on the floor. As a result, the 1.67-foot woofer-center distance of Figure 3 becomes 0.67 feet (8 inches), with a resulting improvement in overall smoothness. The suck-out at 200 Hz is now gone. A study of the three sets of curves shown so far does, in fact, suggest a useful rule of thumb for the installation of conventional speaker systems: *the more different the distances from the*

Figure 4. Response in a real room for the standard system with the woofer end of the cabinet on the floor, back close to the rear wall, and at 1-foot increments of distance from a side wall.



woofer to the three nearest room boundaries, the smoother the acoustic power-response curve will be. That rule is verified in general by the set of curves shown in Figure 5. We have left the woofer end of the cabinet sitting on the floor but have moved the system forward so that the woofer is about three feet from the rear wall. Again, curves are shown for six different distances up to 6 feet from a side wall. The most irregular curves (aside from the 50- to 60-Hz bass peak) are those for which two dimensions coincide or are quite close.

Figure 6 shows the result of positioning the system on a pedestal somewhat away from the rear wall. The woofer is assumed to be 3 feet above the floor and 2 feet from the back wall, and the speaker is again moved varying distances away from a side wall. Some of the power curves are relatively smooth, particularly those at greater distances from the side wall. When two dimensions coincide, however, as at the 3-foot distance, there are larger variations. (It should be made clear that the same results would be obtained if we kept the woofer's center 2 feet above the floor—or 2 feet below the ceiling—and 3 feet from the rear wall. It is the *combination* of distances that matters.)

Next, if we install this standard speaker diagonally across a wall intersection, the distance from the center of the woofer to each wall will be about 1⅓ feet. Power response in this case is very uneven no matter how far the system is raised above the floor, as Figure 7 shows. A corner is therefore *not* a good place to install any system *not specifically designed for it.*

Figure 5. Real-room response of the standard system. Here the woofer end of the cabinet is on the floor and the distance to the rear wall is 3 feet. Response changes radically as the distance to a side wall is increased incrementally from 1 to 6 feet.

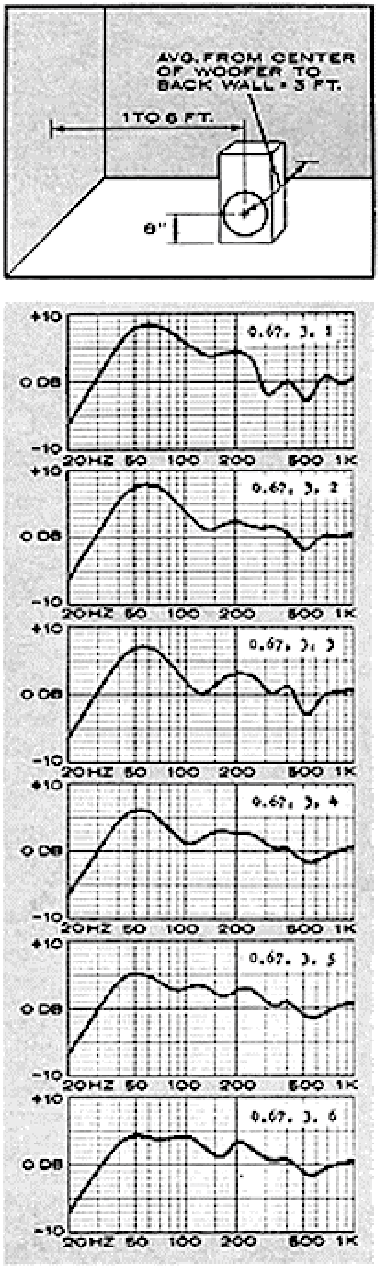
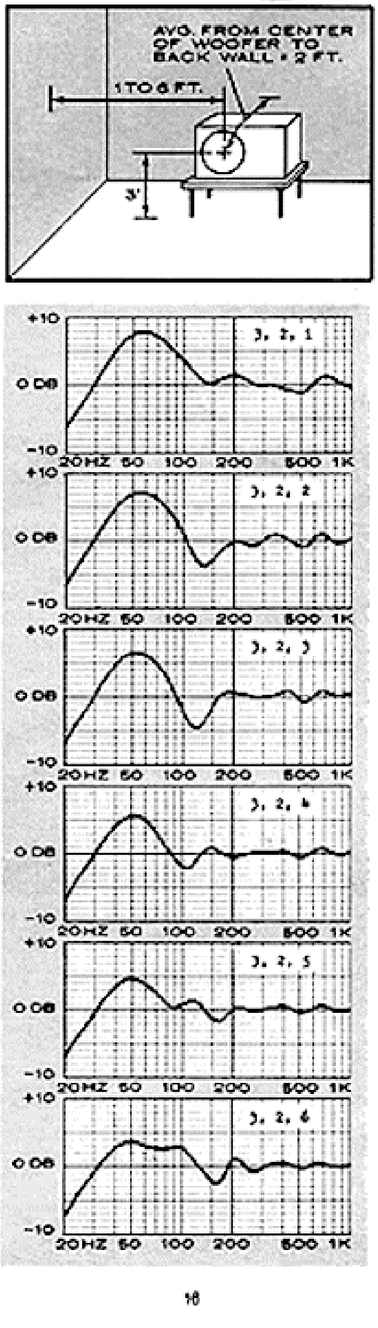


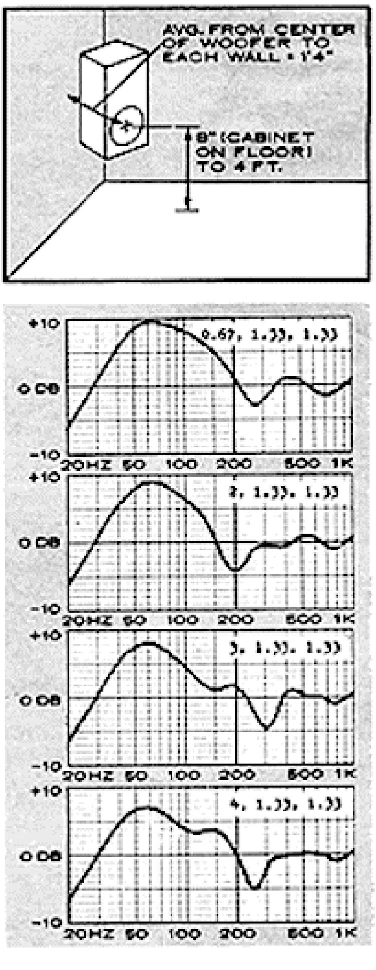
Figure 6. The standard box's real-room response when the woofer is 3 feet above the floor, 2 feet from the rear wall (or vice versa), and at 1-foot increments of distance from the side wall.



Listener Location

In most domestic listening rooms

Figure 7. Cater-corner placement of the standard system produces the output curves shown for four distances of woofer center above the floor.



there are fewer practical choices for locating the listener than for locating the speaker. For example, few audiophiles, however dedicated, would be comfortable sitting on a midwall shelf. Also, the height dimension is virtually constant since a seated listener's ears will hardly ever be less than 36 inches and never more than 42 inches above the floor. For our purposes, it is safe to assume a standard height of 1 meter (3.3 feet). Sofas and chairs are usually placed close to or against one wall, and a seated listener's ears will therefore usually be 1.1 feet (13 or 14 inches) away from a wall. Figure 8 shows the calculated effect of the room boundaries on the sound pressure for listeners on a chair or sofa against one wall and at distances from 2 to 7 feet from an intersecting wall. The worst response is displayed, as expected, by the curve for the 3-foot side wall distance since it is nearly the same as the height dimension. Also as expected, the shape of the bass peak depends on the distance to the side wall.

Another common sofa arrangement is L-shaped, with the listener seated several feet away from the room wall opposite the speakers. This in effect moves the listener toward the room center, placing him, say, 5½ feet or so from the rear wall. Figure 9 shows the room-boundary effects for listeners seated at distances from 2 to 7 feet from the nearest side wall. It is apparent that these curves are in general rougher than those for positions closer to a wall. The reason is that, with two of the distance dimensions fixed at 3.3 feet (listener height) and 5.5 feet (approximate rear-wall distance), there are not likely to be large differences in the three dimensions. However, the general shape of these curves is not necessarily bad, as we shall see.

The remaining common seating position is in a room corner. If a chair is placed well into the corner, a seated listener's head will be about 1½ feet from each wall, with the result shown by the upper curve in Figure 10. Bad enough. But if a corner chair is used as part of a seating arrangement with a sofa along a wall, it will usually be situated well out from the corner. Then the unfortunate occupant of the chair may find that his head is about 3 feet distant from each wall. The distance to the floor is almost the same, and when all three dimensions nearly coincide, the result is awful, as can be seen from the middle curve in Figure 10. Minor adjustments in the chair's corner position can be of some help. The lower curve in Figure 10 is for a listener located 4 feet from one wall and 2½ feet from the other. It can nevertheless be said that corner positions are no more desirable for listeners than they are for conventional box speakers.

Combining Positions

If the sound field were perfectly diffuse at low frequencies in your particular listening room (it isn't), and if the room's sound-absorption properties were the same at all frequencies, you could simply add the acoustic power-output curve of your ideal speaker in a given room position to whichever listening-position curve you select, and you would have a precise overall speaker/room/listener response curve. Naturally you would try to find complementary curves, so that the hills in the speaker-output curve would be canceled by valleys in the listening-position curve, and vice versa.

There are indeed a few combinations for which this works quite well. Figure 11, for example, shows a curve ob-

Figure 8. Room-boundary reflections also alter sound pressure at listener locations. Curves show boundary augmentation for a listener seated close to one wall and at various distances from another. Curves would represent sound pressure vs. frequency if a diffuse, uniform sound field existed in the middle of the room.

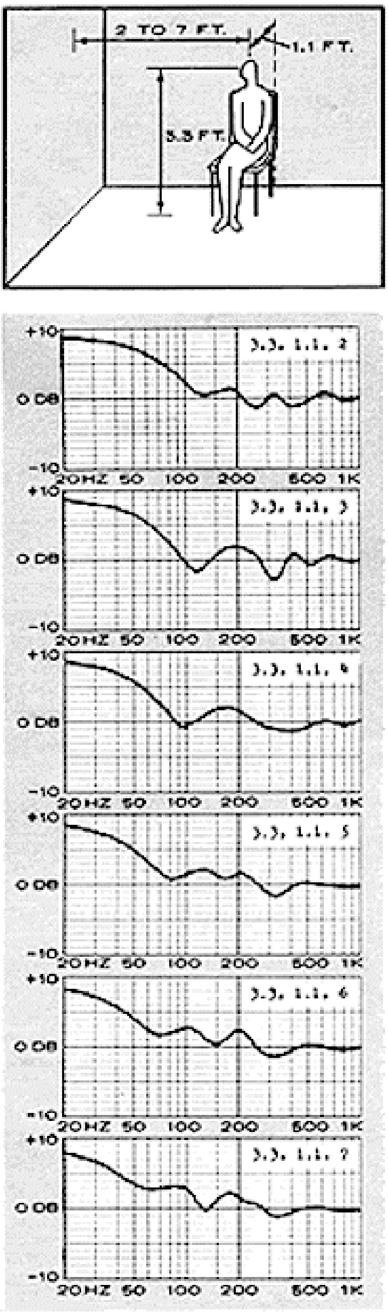


Figure 9. Boundary effects on sound pressure for a listener seated 5½ feet from one wall and at 1-foot increments between 2 and 7 feet from a side wall.

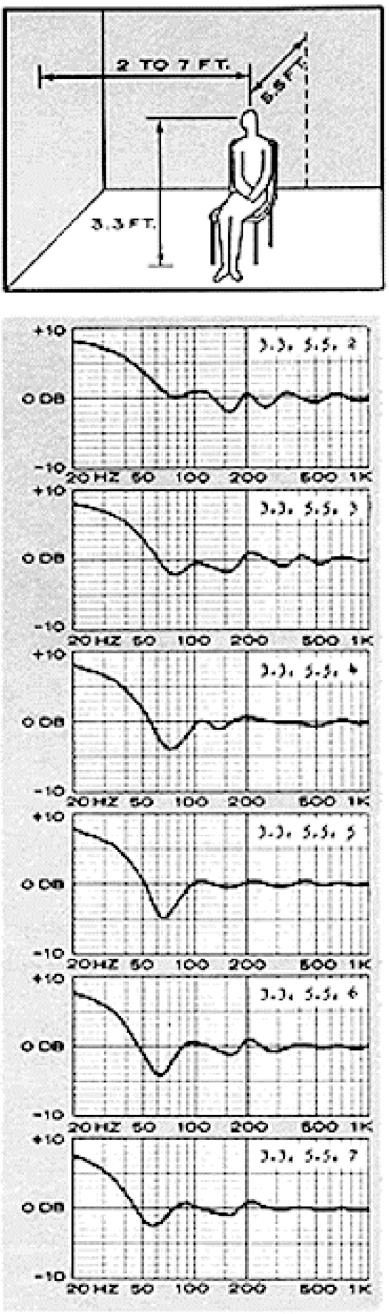
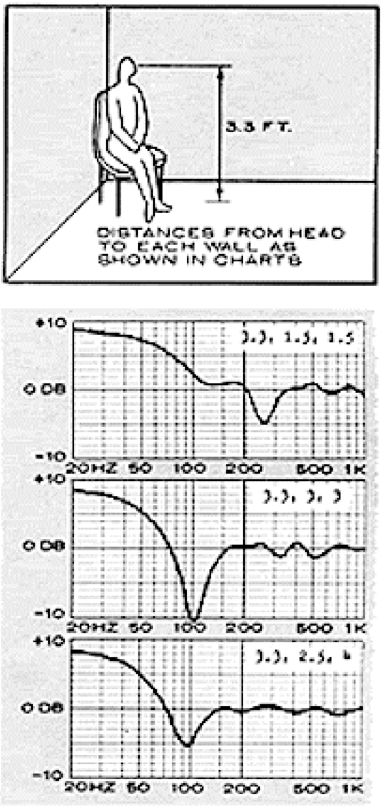


Figure 10. Effects of room-boundary reflections on the sound field for a listener seated close to a corner. Height is constant at 3.3 feet; other dimensions shown are distances to the nearby walls. Note huge variation when the three distances are nearly identical.



tained by simple arithmetical addition of the values from the 4-foot speaker spacing curve, Figure 2, and the 7-foot listener-spacing curve, Figure 9. Note that these positions may or may not be practicable in your living room. The amount of bass rise shown is no cause for alarm; it may be about right to balance the bass that gets lost through normal flexing of the room walls.

Another fairly smooth combination, though with considerably more extreme bass, is that shown in Figure 12. This combines the 5-foot speaker-spacing curve of Figure 3 with the 6-foot listener-spacing curve of Figure 8. Combinations as smooth as these are rare, but they are worth looking for. A combination that might be established by room-decor considerations could produce a curve as bad as that shown in Figure 13, and there are many even worse combinations possible, as inspection of the other curves will prove.

As mentioned, much of the bass rise shown in these curves is not actually heard in most rooms (which is all to the good) because the room boundaries are not sufficiently stiff at low frequencies to retain it all. And, also as noted before, rooms of home-listening-room size do not provide diffuse sound fields at low frequencies. Since all loudspeakers are not as inherently flat as our reference standard, does this mean that the curves are useless or unreliable? Not at all. It means that if you use this information to establish the speaker and seating locations *you will be able to reduce the unknown variables significantly* and thereby improve your odds. Even if you ignore the listener-position curves and simply put your speakers where the curves show the room will treat them kindly, you can expect audible improvement.

As is evident, the worst aberrations occur well within the operating ranges of most woofers. Such peaks and dips *cannot* be removed by a speaker's balance adjustments or level controls, but only by changes in the speaker's position. True, some compensation by means of narrow-band equalizers is possible once we know how much boost and cut is needed and precisely where in the frequency range to apply it. But equalizers can also increase amplifier power requirements and speaker distortion. And, in any case, it certainly makes sense to optimize the acoustical situation physically *before* resorting to electronic correction.

It should be noted that *each* speaker system's performance in a stereo setup is determined individually by its position with respect to nearby room surfaces. To the extent that a pair of stereo speakers are producing the same material within the affected frequency range (this is most likely to be true in the bass region), it may be possible to achieve partial compensation of power-response aberrations by choosing appropriate differences in position for the two speaker systems. It can certainly be said that the most uniform power output will *not* be obtained from a pair of conventional stereo speaker systems if they are placed symmetrically in a room, for in such a situation *each system will have the same aberrations.*

Figure 11. In some cases, a conventional speaker system can be so located that its power-output curve is complementary to the boundary augmentation at a given listener position. This room/listener curve is obtained by adding the power output of the standard box in position 3.17, 1.67, 4 (Figure 2) to the listener-position curve 3.3, 5.5, 7 (Figure 9). Bass rise shown would probably be beneficial (see text).

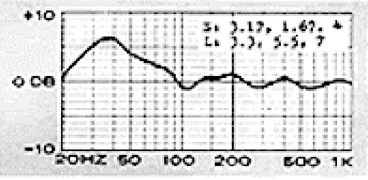


Figure 12. Another room/listener curve, relatively smooth but with strong bass. Speaker-output curve 1.67, 1.67, 5 of Figure 3 was added to listener-position curve 3.3, 1.1, 6 of Figure 8.

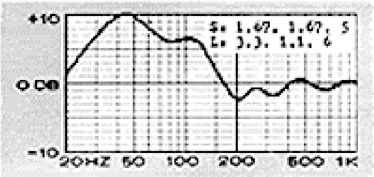
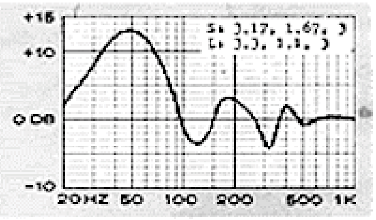


Figure 13. A room/listener curve that might be obtained by addition of random but typical speaker and listener-position curves. There are many worse combinations.



WHAT all these investigations make clear, of course, is that we need speaker systems whose woofers will be uniformly loaded by a room throughout their assigned frequency range without being unduly influenced by their position in the room. It is perfectly feasible to design systems of that kind—some, in fact, are now being made.* But until there are more of them available, we can help the standard speaker boxes provide better sound simply by being careful where we put them—and our listening selves. □

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*Specifically, the loudspeaker systems manufactured by Allison Acoustics, Inc., whose designs are based on the research cited.