Experiments and Experiences in Stereo*

PAUL W. KLIPSCH†

Summary—A considerable number of observations as well as formal experiments in High Fidelity Stereo sound are reported. Three-channel stereo with corner flanking speakers has been shown to achieve accuracy in both tonality and geometry. A large center speaker with small outriggers is observed to lack both tonality and geometry. A center speaker in the corner with wall outriggers is observed to produce a deeply curved stereo geometry. Limiting speakers to a bass range down to 300 cycles may preserve geometry, but not tonality.

Overly large bass speakers lead to a spatial and delay separation of bass and treble events. There is an optimum bass speaker size.

Wide spacing of speakers offers improved accuracy of stereo geometry. The array cannot normally exceed the speaker spacing, but because of the focusing effect of the center channel, it may be much narrower than the speaker spacing.

Numerous minor observations of radiation angle and polar response point up the desirability of corner speaker placement.

Large speakers may be placed at low or high level, but the dynamic range of small speakers is limited.

Corner speaker placement affects apparent room size and may be advantageously employed to improve the reverberation effects.

Wide Stage Stereo demonstrations using speaker spacing up to 50 feet or more are compared to home applications with 15-foot spacing.

High Fidelity Stereo is both high fidelity and stereo, and entails meeting the requirements of both.

Introduction

THE concept of a center loudspeaker with input derived from two sound tracks[1] has naturally led to many attempts to simplify and economize the hardware involved. In preferred form, the three-speaker stereo array would be as shown in Fig. 1. Note that in a room length-to-width ratio of the order of 1.2 or even 1.5, the preferred array is on the long wall of the room.

Large Center Speaker

For example, this writer's original work[2–5] contemplated large flanking corner speakers with a small center speaker. Why not a large center unit and two small flanking units? To evaluate this idea, the center unit was placed in a corner. The two flanking units—full treble range but with bass range limited to about 100 cycles—were placed against the walls as shown in Fig. 2. As expected, the recessive center unit produced a deeply curved source. Increase in volume of the center unit was attempted to overcome the precedence effect,[6–8] but the psychological effect was that of having the center unit jump from a recessive state into complete dominance as the volume was raised. This led to the conclusion that a nearly collinear speaker array is necessary to preserve stereo geometry.

Deviations from collinearity have been allowed up to 3 or 4 feet in wide arrays—about 40 to 50 feet—without deleterious effects. Limits have not been established, but it is this writer's tentative opinion that the error from collinearity should not exceed the proportion of about 2 feet in a 20 foot array.

Another idea has been the placement of a large speaker in the center of a collinear array, with small bass-restricted outriggers, as in Fig. 3. This can result

Fig. 1—Array for Wide-Stage Stereo as used in stereo geometry tests.

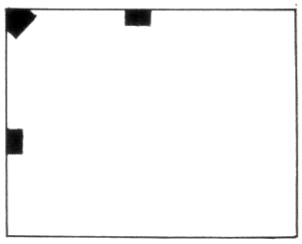

Fig. 2—Array attempted for economy. Delay effects of center speaker resulted in curved virtual source which could not be compensated by increased center channel volume.

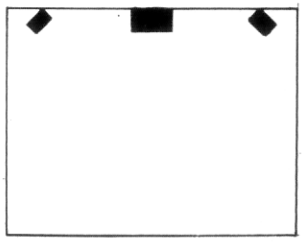

Fig. 3—Large center speaker with small limited-range "outriggers" can achieve stereo geometry but not fidelity of tonality.

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† Klipsch and Associates, Inc., Hope, Ark.

[1] Bell Telephone Labs. Staff, "Symposium on auditory perspective," *Elec. Engrg.*, vol. 53, pp. 9–32, 214–219; January, 1934.

[2] P. W. Klipsch, "Stereophonic sound with two tracks, three channels by means of a phantom circuit (2PH3)," *J. Audio Engrg. Soc.*, vol. 6, pp. 118–123; April, 1958.

[3] P. W. Klipsch, "Three channel stereo playback of two tracks derived from three microphones," IRE Trans. on Audio, vol. AU-7, pp. 24–36; March–April, 1959.

[4] P. W. Klipsch, "Corner speaker placement," *J. Audio Engrg. Soc.*, vol. 7, pp. 106–109, 114; July, 1959.

[5] P. W. Klipsch, "Wide-stage stereo," IRE Trans. on Audio, vol. AU-7, pp. 94–96; July–August, 1959.

[6] B. H. Deatherage and I. J. Hirsch, "Auditory localization of clicks," *J. Acoust. Soc. Amer.*, vol. 31, pp. 486, 492; April, 1959.

[7] K. Holt-Hansen, "Researches on the localization of sound," *Z. Psych.*, vol. 120, pp. 209–216; 1931.

[8] H. Wallach, E. B. Newman, and M. R. Rosenweig, "The precedence effect in sound localization," *Amer. J. Psychol.*, vol. 52, pp. 315–336; July, 1949.

in good stereo geometry if the center unit is truly full range. At one demonstration,[9] this writer sensed the bass from the center and treble from the wings, a form of pseudo stereo involving separation by displacing treble with respect to bass. The center bass with treble outriggers was proposed by de Boer in 1940.[10]

Small Outrigger Speakers

In another observed demonstration,[9] the center unit was full range but the flanking units were limited to 300 cycles bass range. The idea here was to take advantage of the concept that frequencies below 300 cycles contribute only slightly to the localization of sound. But the reference actually said, " . . . much of the stereophonic effect is preserved if . . . side channels reproducing above 300 cycles are employed. This is of great practical value for economic stereo reproduction. . . . For the . . . high fidelity demanded by motion-picture . . . reproduction, its use appears questionable. . . . " A scrutiny of the art, plus an experimental examination, dictates that each of the three speakers be as wide-range as possible. For example, in the corner-flanking speaker stereo array, a progressive improvement was experienced as the center speaker was extended in bass range from 300 down to 150, then to 100, and later to 50 cycles. This naturally follows from a concept that high fidelity must apply both to tonality and geometry. It was Snow[11] who proposed (1953) "the use of full range speakers at the flanks and the use of a smaller loudspeaker in the center without full low-frequency response as being sometimes possible." It must be reiterated, though, that over-all improvement results as speaker range is extended to the full spectrum.

"The dependence on the center speaker for the main part of the bass tonal range suffers from another effect. Any speaker is a better speaker by being in a corner, and the noncorner placement causes erratic response and bass loss over the bottom two octaves of bass range."[4]

These experiments and experiences with the large speaker in the center can be thought of as "measurements" with a simple right-or-wrong answer. "You can't make what you can't measure, because you don't know when you've got it made."[12]

Returning to the preferred array, the center channel is the focus of attention and should be of the highest quality. The center speaker used in the display at the Brussels World's Fair in 1958 employed the same tweeter and midrange drive units that were used in the flanking corner horn speaker systems. Anything less will sacrifice quality in the most conspicuous part of the stereo stage.

Practically, the center speaker retains the highest quality but may be permitted to have a less extended bass range than the flanking units; the flanking units are full range, and supply any fractional octave of bass omitted by the center unit. Each improvement in each speaker has resulted in an over-all improvement in quality. Currently, the eclectic system comprises two "Klipschorns"[13] on the flanks, a new center unit, designated the "Model CW,"[13] which has the same high frequency response as the large corner units, and a bass range which is less than 10 decibels down at 50 cycles.[14]

From these observations, the only logical conclusion is that the stereo array, to fulfill a maximum approach to the requirements of fidelity in tonality and geometry, must consist of corner-placed flanking units, with the maximum practical tonal range in the center unit. The corner-placed flanking units would obviously be maximized best in performance by being specifically designed for such corner placement.

Fidelity

Fidelity of reproduction involves fidelity of tonality and fidelity of geometry. Tonality involves frequency response, spatial distribution, freedom from distortion, dynamic range, signal-to-noise ratio, and spatial cohesiveness of bass and treble. Geometry involves the ability of a listener to locate sounds in the original generated geometry. In both monophonic and stereophonic sound reproduction, cohesiveness between bass and treble is necessary.

Much has been written on these points. Descriptions of some experiments have failed to appear in literature —properly perhaps, being failures—but since a knowledge of failures provides a means of avoiding the same ones, it would seem to be justified to mention them.

One of these has been the several attempts to build gigantic bass horns which resulted in a spatial separation of bass and treble. This is something of a monophonic geometry effect, and has been used as "pseudo stereo." Whether these are used monophonically or stereophonically, the effect is to hear the articulation and chest tones of speech coming from different areas.

Excessive Size of Bass Speaker

One such speaker system used a bass horn with an 18-foot air column and an 8×10-foot mouth. The bass source was separated from the treble not only laterally, but also longitudinally, resulting in a time delay of nearly 18 msec, with a resultant precedence effect that could not be compensated with preservation of any semblance of "fidelity." There was no question that the woofer afforded superb bass response, but there was no conceivable treble-range speaker which could be combined with it to afford reproduction resembling the original sound.

[9] Witnessed, but not performed by the author.

[10] K. de Boer, "Stereophonic sound reproduction," *Phillips Tech. Rev.*, vol. 5, pp. 107–114; April, 1940.

[11] W. B. Snow, "Basic principles of stereophonic sound," *J. Soc. Motion Picture and Television Engrs.*, vol. 61, pp. 567–589; November, 1953.

[12] I, Gardner, quoted by Dr. Dannehower in *The Bent of Tau Beta Pi*, p. 20; April, 1959.

[13] Trademarks of Klipsch and Associates, Inc.

[14] The "Model CW" was introduced about one year after the basic system was displayed at the Brussels World's Fair.

Stereo Geometry

In the realm of stereo geometry, the works of Steinberg and Snow[1] and this writer[5] appear to be the only reported studies to date (November, 1959). The measurement of accuracy of stereo geometry involves generating sounds over a systematic array, and having observers attempt to plot the virtual locations of the sounds solely by listening. These references indicate that three channels are necessary, and that, as the stage is widened, the center channel becomes of increasing importance. The apparent stage width cannot exceed the speaker spacing (except in certain bizarre arrangements dependent on the reflections from walls which above 500 cycles become seriously frequency-descriminative) but the virtual array may be less than the speaker array. In fact, in a collinear array the center channel may focus all events in the center simply by raising the output level of the center speaker. If the three speakers are properly "focused," accurate geometry results, and a soloist, an intimate group like a quartet, or a symphony orchestra occupy their proper virtual stage width and the individual performers may be pointed to with fairly small angular errors.

Miscellany

Radiation angle, "polar response," or spatial coverage of a speaker system rarely exceeds about 90°. A speaker located in a corner may cover the entire room.

Some written comment about "intersecting axes" of stereo speakers appear to contemplate spotlight rather than floodlight radiation characteristics. Most modern speakers offer reasonably wide angle response. Of course, the "spotlight" radiation angle speakers have no part in the art of "high fidelity."

An evaluation of the big corner horns has been the response at very low volume levels. At a level where the bass would fade out completely in ordinary speakers, the low range output was maintained without the artificiality of a "Fletcher-Munson compensation."

Stereo affords an apparent increase in sound level of from three to six db. Apartment dwellers may feel that three speakers should be three times as loud, but actually stereo offers the sensation of increased loudness in the room without an actual increase outside the room.

Properties of a Corner

Seemingly too obvious to need statement, yet often overlooked, are the properties of a corner. First, a corner provides sound reflective surfaces and affords a system of mirror images for a speaker placed therein, so the speaker is effectively eight times as big functionally as it is physically. Second, a corner is the most remote part of a room from an opposite corner, and a sound generated there can travel farther before the first reflection.

From these two thoughts, it should appear obvious that to take advantage of a corner the speaker first must be in the corner, in contact with all three surfaces, not on legs,[4] or spaced appreciably from the walls. Second, it must be in a real or natural corner to gain the benefit of being in the most remote part of the room from the first reflection. These are rules, not laws, but usually their violation sacrifices quality of sound reproduction to some degree.

Dynamics

One objective of 100 performers in a symphony orchestra is to play as softly as possible. An objective of a four-piece combo is to play as loudly as possible. Sound levels of 110 db intensity have been recorded at the pickup microphones of each type of musical ensemble. The sound reproducing system should be capable of producing this sound pressure level, or one of 30 to 40 db intensity, with equal accuracy. One advantage of a horn-loaded speakers system is its undistorted power-handling capacity plus the ability to render transients with accuracy at all power levels.

Optimum Speakers

This writer has concentrated his efforts largely on speaker design. One such design comprises a bass horn of only four feet of air column length, only two feet longer than the straight-axis midrange horn which comprises another essential part of the system. Experiments with this system show that displacement of the treble system by as little as three feet laterally or longitudinally resulted in a deteriorated response. Frequency response would have been substantially the same—since the total energy radiated at each frequency would remain the same—but the spatial and precedence effects were abnormal and the results could not be described as reproduction with fidelity.

Other experiments with the three-way corner speaker involved placing two of them back-to-back against a wall as in Fig. 4, each acting as a mirror image for the other. In π solid angle free space, the results should have been the same as for a single speaker in $\pi/2$ solid angle. But in an actual room, the bisection of the room by the line of symmetry between the two speakers reduced the effective size of the room and the entire response suffered, particularly the bass.[15] Here again is strong evidence to support corner placement of speakers for both monophonic and stereophonic applications. This "half room effect" may just as well be reversed, whereby corner speaker placement doubles the effective room size.

A large number of stereo demonstrations have been presented in which speaker arrays up to 50 feet or more have been employed. At the other extreme, a 13×15-

[15] P. W. Klipsch, "Room dimensions for optimum listening and half-room principle," IRE Trans. on Audio, vol. AU-6, pp. 14–15; January–February, 1958.

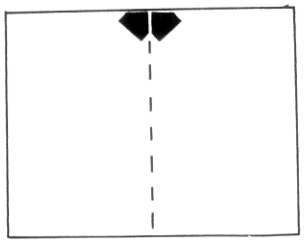

Fig. 4—The half-room effect of a large speaker against the wall reduces bass quality as well as spatial distribution of highs.

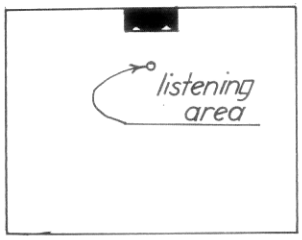

Fig. 5—The extreme in narrow-stage stereo limits the listening area to that occupied by a single person and is in contrast with the array of Fig. 1.

foot living room is being used with a big corner speaker on the right, a smaller one on the left, and a center channel, all arrayed on the 15-foot wall to give the maximum possible angle subtended by the listeners.

Stereo Listening Area

An effect of the "Wide-Stage Stereo" is to create a large listener area as in Fig. 1. Contrasted with the picture (Fig. 5) of one listener on the array axis of speakers spaced four feet apart, the 25-foot array in a 25×16-foot room affords nearly 300 square feet of listening area including off-axis areas adjacent to the side walls. Even before evolving ways to derive a center channel, this writer advocated wide spacing of speakers, and suggested the use of the long wall in an oblong room. Currently, a preference is expressed for rooms more nearly square, and this writer's personal opinion is that a room for stereo should not exceed a length-to-width ratio of more than about 1.4, although ratios as high as 1.6 have been successfully used—again placing the speakers on the long wall of the room.

Speaker Size

A certain philosophy has evolved over the years relative to speaker size. For a horn, the bass unit must be some minimum size for a given maximum wavelength to be transmitted, and a maximum size dictated by keeping the bass and treble cohesive. In direct radiators, the reduction in size is accompanied by a sacrifice of bass range or increased distortion. Corner placement seems to be the only way to keep the bass horn small enough to retain cohesion with the treble range. The same benefits of corner placement accrue to direct radiators, but to a somewhat lesser degree. Placing two corner speakers back-to-back doubles the effective size, but actually deteriorates the performance.

Experience with direct radiators indicates that size does not necessarily limit response, but for a given bass response the power output decreases as approximately the cube of the size. Or, if power output is increased, distortion increases as the square of the output; and for large diaphragm excursions, Doppler distortion may reach dominant levels. Corner operation of any speaker —including the direct radiator—improves the performance. For this reason, the direct radiator has been relegated to center channel stereo application, or for economy-dictated flanking units in stereo systems.

For example, to reproduce 35 cycles the corner horn speaker needs about 38 inches of height. Many smaller horn speakers have been built by this writer and others, all exhibiting either deficient bass, peaked response, distortion or other defects. Larger bass horns exhibit the disjuncted treble, and usually show enhancement in the form of boomy response. Noncorner units requiring still larger size aggravate the separation of bass and treble. Hence there is a narrow range of optimum size of a bass horn speaker.

Conclusion

The optimum stereo system in terms of "fidelity of tonality and geometry" must consist of three channels with corner flanking units. Corner horns offer the best type of flanking units, but even direct radiator flanking units should be placed in the corners. Wide spacing affords wide stage effects, but stage width may be controlled by sound output level of the center channel. The Wide-Stage Stereo concept is applicable to large halls with 50 feet or more array width, or small living rooms with only 10 to 12 feet array width. Even the narrowest arrays are benefited by the derived center channel.

Stereo arrays which are comprised largely of horn speakers offer excellent dynamic range, low distortion and transient response, which cannot be approached by direct radiator systems.

Flanking corner horn speaker systems would ordinarily be supplemented by a center channel with preferably horn-type midrange and tweeter, and direct radiation bass. By proper design, the center channel bass range may be rendered very low in distortion, and by partial dependence on the flanking units, dynamic range and transient response for the entire system may approach perfection.

The center channel is the focus of attention; its upper range response and its freedom from distortion must be impeccable. One bad speaker can bury the others under distortion. Sam Goldwyn has said "A bad story in 3-D is three times as bad"; this might be paraphased "bad speakers in 3-D are three times as bad." When stereo was young, any old speakers would "give the stereo effect," but fidelity is reaffirming its value and the novelty of "stereo effect" is passing.

Fidelity of tonality and geometry is to be achieved by recognition of the requirements of both.