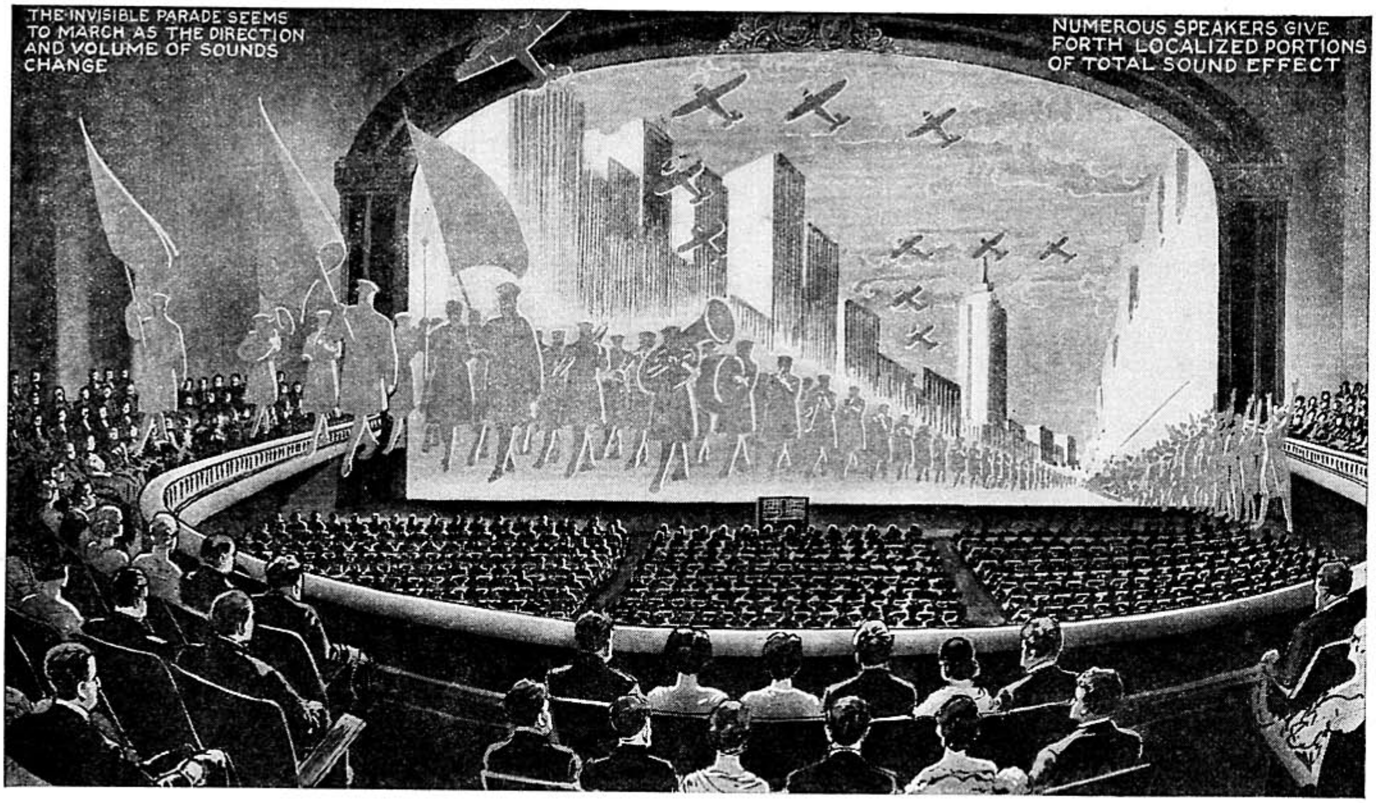
THE THIRD DIMENSION IN MUSIC



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THIRD dimension, auditory perspective, solid or sculptured music, directional audio, binaural reproduction, stereophonic sound—call it what you will, the effect achieved in the sound system recently demonstrated before members of the American Institute of Electrical Engineers and Institute of Radio Engineers, at the Engineering Societies' Building, by the Bell Telephone Laboratories, was *naturalness* of sound reproduction in the complete sense of the word.

It is impossible to point a finger at any one part of the system and say, "*there* is the 'secret' of the true-to-life sound reproduction." Rather, it is necessary to accept as the explanation, the entire ensemble—every component of which has been designed to meet a specific demand.

Auditory Perspective

"Sound," whether it is vocal or instrumental, is generally divided into only two components: (1) volume, which gives "height" to sound; and (2), frequency, which gives "width." There is, however, a third component, more physiological than physical, without which no sound seems to be "natural"—this is the "sense of distance and direction" or "depth" (the third dimension—"perspective").

Although volume and frequency are thus shown to be fundamental considerations in discussing sound, apparatus designs to enhance the characteristics of one or the other present little that is new (See, "A Super-Power and -Quality P.A. System," RADIO-CRAFT, December, 1933). Reproduction in auditory perspective, however, introduces a more modern technique, the design, construction and operation of equipment for which bids fair to open to sound technicians a field of activity perhaps as lucrative as have been "P.A." and the "talkies."

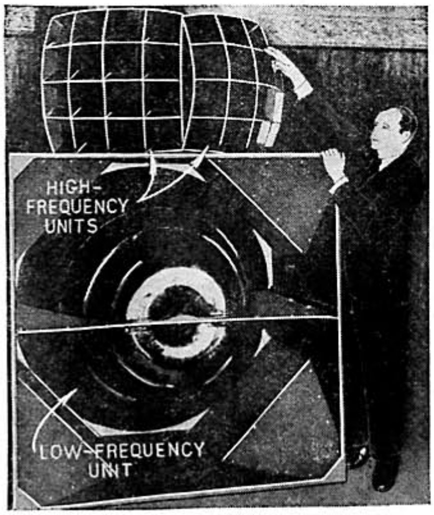
The practical results that can be secured with a system designed to reproduce (or even accentuate) all the elements of sound reproduction in perspective are amazing; only by actually experiencing them can they be fully appreciated. If the listener closes his eyes *apparent* effects seem to be *actual* ones.

Thus, the audiences of trained engineers that critically listened to demonstrations in the Engineering Societies' Building found it difficult to distinguish between the two.

Novel Effects of Sound Perspective

Apparently a man on the stage of the auditorium, near the right proscenium and in back of a curtain, sawed through a thick piece of wood; the clatter as the piece of wood hit the floor was unmistakable. All heads turned to the left as, in answer to a request for a hammer, a second person voiced acknowledgement! The succeeding sounds of nails being driven into the board, the hammer banging to the floor, and left- and right-stage conversations between the two men were "true to life." A bugler appeared in front of the curtain, raised a bugle to his lips, and started to play. After playing a few bars he removed the bugle from his lips and walked off the stage; the bugle continued to play, however, seemingly at the exact spot on the stage he had previously occupied! A tap dancer next appeared, moving his feet in rhythm with music. In the middle of the "act" he ceased all motion—but the dance went on! And, when our visible performer walked off the stage the "ghost artist" continued with the show, seemingly traveling back and forth across the stage!

"Depth," the "third dimension," is introduced in sound perspective by Bell Telephone Laboratories engineers. The author discusses many of the factors involved in the new system; advanced technicians may wish to set up equipment experimentally duplicating some of the sound effects he describes.



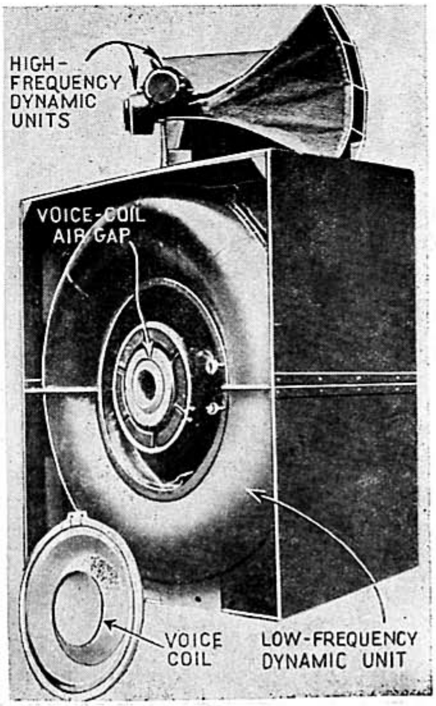


Fig. A, above

Front view of the reproducer assembly. The high-frequency units comprise two 16 section trumpets.

Fig. B, right

Rear view. Note the very great diameter of the low-frequency voice coil. The reproducer assembly is designed to deliver an output of 100 db!

A dramatic sketch was enacted with invisible participants. As they seemingly changed their positions on the stage, the audience, almost as one person, turned their heads accordingly! Orchestral music was more enjoyable due to the seeming position of the artists, the groups being identified by their instruments. A singer apparently walked about the stage.

However, the most dramatic effect was reserved for the finale. The effect to be produced was that of a person shooting a firearm, the projectile whistling through the air in transit from left-stage to right, and the target being hit. Although it was amusing to seemingly hear a shot, follow the bullet across-stage and hear it smack the target, it was more amusing and even bewildering when the tables were turned—the target was struck, the bullet whistled across-stage from right to left, and then the "starting" shot was fired! (Of equal interest to the technician was the duplication of these William Tell activities—first produced *mechanically* — by *electrical* means.)

An amazed audience now watched a curtain of theatrical gauze rise, to reveal —not a soul! There were to be seen only three reproducers ("loudspeaker") assemblies, one of which is illustrated in Fig. A; a rear view is Fig. B.

These effects of auditory perspective were accomplished by employing three independent microphones connected by three amplifying channels to three of the "loudspeaker" assemblies, as shown in Fig. 1. (For the demonstration the orchestra, performers and microphones were located in an auditorium on the 5th floor of the building; the amplifying, monitoring and reproducing equipment, in the auditorium on the second floor.)

Additional Sound "Tricks"

In order to fully demonstrate the capabilities of this ultra-modern sound system the apparatus was designed to deliver 1000 W. of audio power to the loudspeaker assemblies, each of which is reported as having the remarkable efficiency of 50%; and the frequency range was designed to cover, without appreciable distortion, from 40 to 15,000 cycles!

Such wide extremes of power and frequency makes possible many unusual effects. Thus, for instance, it was interesting to watch the audience crane their necks in an effort to follow a phantom airplane as it rapidly approached from an imaginary horizon, circled "overhead," and then disappeared in the distance. The sound of an ordinary door signal buzzer was raised in volume until it resembled a miniature trip-hammer. The tap dancer, previously mentioned, was made to sound like a noisy giant. The volume of a 30 piece orchestra was increased until it equaled the "acoustic size" of a 300 piece orchestra (and thus demonstrating super-orchestral effects). At the same time, the volume of a vocal soloist was raised with each increment of orchestral volume so that the singer was never drowned out.

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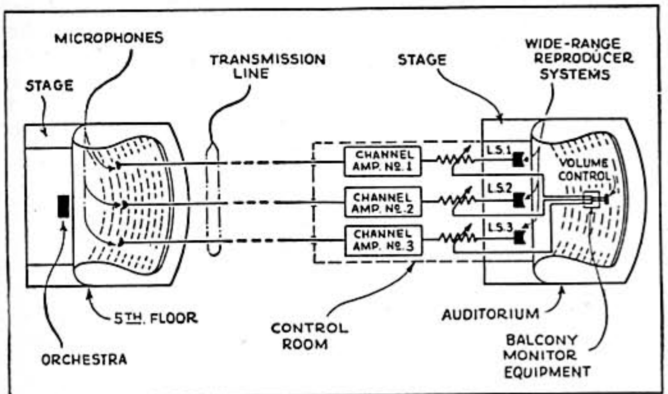

Fig. 1, above

The equipment for "three dimension" sound requires three microphones, amplifiers and speakers.

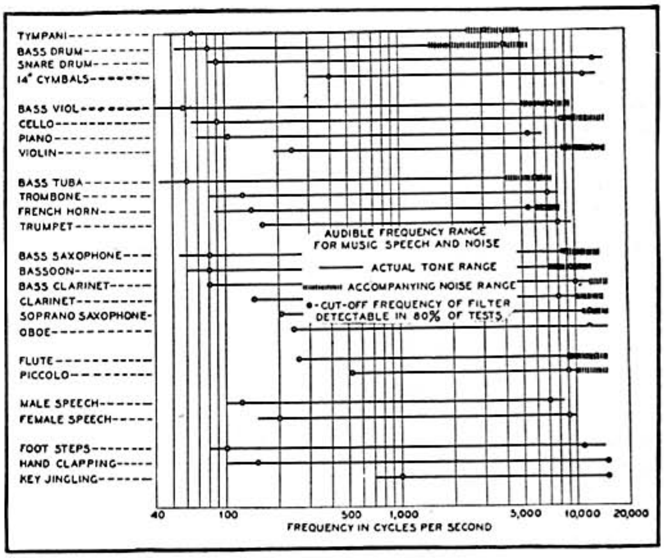

Fig. 3, right

Frequency, and noise ranges in music, etc.; figures which indicate the need for a 40 to 15,000 kc. sound system range.

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A violin soloist was given a gigantic violin.

The effects, and additional ones involving the use of frequency cut-off filters, were at all times under the full control of a monitor operator centrally located in the balcony.

For example, the previously-mentioned experiment of a bullet shot, its passage through the air and its striking a target, was achieved by having an assistant slap two boards together in front of the left microphone (on the 5th floor of the building) for the "shot"; a second assistant rapidly ran across-stage from left to right, blowing a whistle, to indicate the sound of the bullet in slow motion through the air; a third assistant hit a gong to indicate that the target had been struck. However, the monitor operator very cleverly simulated this effect with the performers in front of only *one* microphone by the simple process of "fading" the microphone output into the individual audio channels, feeding each speaker assembly as required; thus, with a twist of his wrist he reproduced the effect of the bullet whistling across-stage, yet without any of the assistants moving!

A very satisfactory degree of auditory perspective may be obtained with only two independent channels ("binaural" operation), but the presence of the third channel considerably enhances the effect, and is of very great advantage when a soloist accompanies the orchestra. With reproductions in auditory perspective, the center channel (connected to a special microphone in front of the singer) allows her voice to be amplified independently of the orchestra, and thus always to be kept at a slightly higher level.

The factors involved in attempting to simulate at a remote point the esthetic effects of original sounds should be learned by everyone interested in good sound reproduction. For this reason the following explanation is given of some of the factors involved in the design of the new sound system.

Frequency and Power Requirements

For high-grade reproduction of sounds the range of frequencies that the system must transmit is determined by the range of hearing rather than by the kind of sound that is being reproduced.

Persons having normal hearing can hear pure tones ranging in frequency from 20 to 20,000 cycles. However, note that in order to sense the sounds at *either end* of this range the sounds at these extremities of the frequency range must have very high intensity. In music these frequencies usually are at such low intensities that the elimination of frequencies below 40 cycles and those above 15,000 cycles produces no detectable difference in the reproduction of symphonic music. However, the elimination of frequencies above 13,000 cycles produced a detectable change in the reproduced sound of the snare drum, cymbals, and castanets; and the elimination of frequencies below 40 cycles, of the bass viol, the bass tuba, and particularly of the organ.

Besides these requirements of frequency response the system must also be capable of handling *sound powers* that vary through a very wide range. For the type of symphonic music now produced by the large orchestras, for example, this range would be about 10 million-to-1, or 70 db. However, since the orchestra is limited in its power range it becomes desirable to design a system that will permit this power to be augmented by amplification in order to obtain enhanced sound effects. An ideal transmission system should, therefore, be capable of reproducing a sound as faintly as the ear can hear and as loudly as the ear can tolerate.

Directional Characteristics

An audience, when listening directly to an orchestral production, senses the spatial relations of the instruments of the orchestra as a result of their ability to localize the direction, and to form some judgment of the distance from a sound source. This spatial character of the sounds gives to the music a sense of depth and of extensiveness *which, for perfect reproduction, should be preserved.*

The music which we hear comes to us in part directly, and in part by reflection from the walls; both contribute to the esthetic value of the music. However, inasmuch as many of the tones of a musical selection are of short duration, the direct sound is of great importance—*it is this sound alone which enables us to localize the source.* In general, instruments of lower register are less directive than those of higher register.

For efficiently radiating frequencies as low as 40 cycles a horn of large dimensions is required; the "folded" type of horn is preferable, but it transmits high-frequency tones very inefficiently. Therefore, the reproducer "assembly" was constructed of two units, one, of the folded type, for the lower and the other, of trumpet type, for the high frequencies, as shown in Figs. A and B, with an electrical network to divide the current into two frequency bands, the point of division being about 300 cycles.

Each of the high-frequency horns shown in Figs. A and B has 16 separate divisions, each with an exponential taper. This design "sprays" the audience with the higher frequency sounds which, being highly directive, give the sense of direction.

The output frequency characteristics of the combined low- and high-frequency reproducers is shown in Fig. 2.

Frequency Ranges

That the wide frequency range of this system is essential to natural reproduction is evident by reference to Fig. 3, which shows the audible frequency ranges for a number of different sounds; this graph differs from others in that it shows the "accompanying noise range" of sounds that tend to produce the illusion of naturalness. These sounds include lip noises, key clicks on musical instruments, "buzz" of reeds, and hissing of air. The short, heavy portions of the line indicate the frequency ranges thought to convey the "tone quality" of the instruments; and the short, vertical lines define the ranges of noise. In some cases noise and tone seem inseparably blended. This is a factor that previous designers of sound amplifiers and reproducers do not seem to have taken into account. Of course, in the case of radio program reception the point is not brought up, since the frequency range of the transmitter, operating on 200 to 550 meters, is only 5 kc. (new, experimental transmitters have recently been licensed to transmit an audio band 10 kc. wide, on three wavelengths below 200 meters—this is, indeed, good news for those who want to enjoy high-fidelity radio programs).

The qualitative observations made on various sounds by a number of trained observers, as frequency-range filters were cut into and out of circuit, are summarized in Table I; in this tabulation, "L.F." means "lowest fundamentals." This table, and the previous discussion show, further, the necessity for an amplifier and reproducer frequency range of 40 to 15,000 cycles, for "natural" reproduction. It is of interest to note that the dynamic reproducer used in the ordinary domestic radio set is seldom capable of efficiently reproducing sounds lower than about 100 cycles or higher than about 6,000 cycles!

Now that we have been given a "taste" of what may be accomplished toward natural reproduction in audio perspective we look forward to a new day in sound technique. It

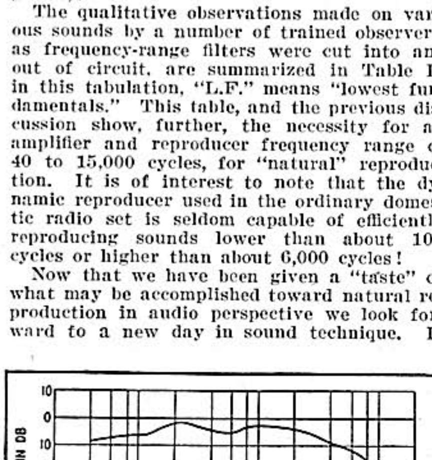

Fig. 2

Average over-all reproduction-ratio characateristics of the reproducer system. It departs from uniformity only about 2.5 db. plus or minus, between 40 and 15,000 cycles. Measurements were made by supplying "warbling" frequencies to the voltage amplifier and measuring the sound pressure in the "listening area" of a room.

will be only a matter of time until public address systems, talkies, radio sets and sound re-enforcement systems incorporate "three dimension sound."

The writer extends credit to Bell Telephone Laboratories, the Acoustical Society of America, American Institute of Electrical Engineers, and the Institute of Radio Engineers for the use of material and illustrations incorporated in this article, which has been written partly to describe a new development in sound reproduction; and partly to show the limitations and possibilities of existing sound systems of all types.

TABLE I

Tympani—No important frequencies below 65 cycles. (Drum tuned to 96 cycles.) Actual tone range ends around 2,000 cycles. Prominent drum rattle and beating noises to around 5,000 cycles.

Bass Drum—No important frequencies below 70 cycles. Actual tone range ends around 1000 cycles. Prominent drum rattle and beating noises to around 5,000 cycles.

Snare Drum—No important frequencies below 100 cycles. Actual tone consists of rattle extending to very high frequencies.

14" Cymbals—No important frequencies below 350 cycles. Low frequencies prominent when one cymbal is struck with a hard stick. High frequencies prominent when two cymbals are clashed together.

Bass Viol—L.F. fairly important, slightly more on plucked than on bowed notes. Considerable bowing noise.

Cello—L.F. fairly important. Tone very rich in harmonics. Moderate bowing noise.

Piano—L.F. unimportant for first octave. 100 cycle high-pass filter only slightly noticeable. Upper notes practically pure tones.

Violin—L.F. important. Tone rich in harmonics. Noises and tone blended.

Bass Tuba—L.F. fairly important. "Pedal" notes —fundamentals around 20 cycles—contain fewer very low frequencies than regular notes. Moderate blowing and key noises.

Trombone—L.F. not very important below 130 cycles. Middle register has greatest harmonic content. Inappreciable noise.

French Horn—L.F. unimportant below 130 cycles. Middle register has most volume and harmonics. High register gives rather pure tones. Harmonics least prominent of any instrument tested.

Trumpet—L.F. fairly important. Lowest register has greatest high-frequency "blatt." Tones purer at higher pitches. Inappreciable noise.

Bass Saxophone—L.F. not very important below 90 cycles. Highest register rather unmusical and unpleasant. Considerable blowing and key noise.

Bassoon—L.F. fairly important. Prominent reed noise on lower register. Moderate key slap.

Bass Clarinet—L.F. very important. Tone goes to very high frequencies on upper register. Prominent reed noise on lower register becoming blended with tone on upper register.

Clarinet—L.F. very important. Medium range has largest harmonic content. Highest range gives much purer tones. Moderate blowing and reed noises at very high frequencies.

Soprano Saxophone—L.F. very important. Powerful harmonics making very harsh tone. Moderate reed noise above 10,000 cycles, less than that of clarinets.

Oboe—L.F. important. Most "reedy" tone of all tested. Tone extremely rich in harmonics of high order, especially middle register. Noises blended with tone.

Flute—L.F. very important. Middle register has most harmonics. Highest register produces almost pure tones. Much blowing and mechanism noise on highest register.

Piccolo—L.F. very important. Middle range most musical and free from noise. Highest few notes are very powerful but are practically pure tones. Much blowing noise and rumble on all registers.

Footsteps—No important frequencies below 100 cycles. High frequencies up to about 10,000 or 12,000 cycles required.

Handclapping—No important frequencies below 150 cycles, but requires the entire audible range on the high frequency end. Sounds fairly natural with 8,500 cycle cut-off.

Key Jingling—Bunch of 22 keys shaken on 4" wire loop—No important frequencies below 500 cycles but requires entire audible range on the high-frequency end. Tone very unnatural with 8,500 cycle cut-off.