Binaural or Stereophonic?

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The author clarifies the meanings of the two words which have been used to describe this latest of interesting innovations in the field of sound reproduction.

SOME CONFUSION apparently still exists in the minds of many regarding the definition and connotation of the words *binaural* and *stereophonic*. Binaural means, literally, "two-eared." It refers to the fact that the sense of hearing in both ears, plus the brain, makes it possible for us to analyze sound, to discriminate against unwanted sounds and, to a large extent, to localize the source of a sound. Stereophonic, on the other hand, means "three-dimensional sound," or a sound source "in the round," much as we perceive it in actual experience. It can be stated, then, that one uses his binaural sense to perceive stereophonic impressions. This is much like saying that one uses his binocular sense of vision to achieve stereoscopic or three-dimensional impressions. If we stop up one ear with a finger when listening to someone in a noisy place, we will observe how the ability to discriminate against the background noise disappears and the ability to localize the source of sound vanishes. Or, if we shut one eye, our judgment of depth is gone and, although we know better, all objects are as on a flat surface. Compare a monocular snapshot with the modern stereophoto or, for that matter, with grandma's "Trip to Egypt" via the old-fashioned stereoscope. The difference is remarkable.

Modern tape recording has achieved, (a) an easy recording method, (b) the ability to record more than one channel at a time on the same tape, and (c) reasonable expense. It is inevitable that someone would think of trying to capture sound stereophonically. Our attention has again been directed to the Bell Labs experiments[1] of 1933 with the Philadelphia Orchestra performing at home and being reproduced in Washington with startling realism, facts lost sight of for nearly a generation. In 1948, Camras[2] gave a demonstration of three-channel recording for Armour magnetic recorder licensees. And in 1950 the author, then with another company, was asked rather bluntly at a Society of Automotive Engineers roundtable discussion, why the recorders that he had sold some of the members did not reproduce properly, with the question, "Why does the recording of an auto going over a cobblestone pavement sound like a male singer with a cracked voice humming in the bathroom instead of an auto on cobblestones?" Money had been invested in supposedly good equipment, but the reproduced sounds were not considered natural or normal. Some form of distortion seemed to be present.

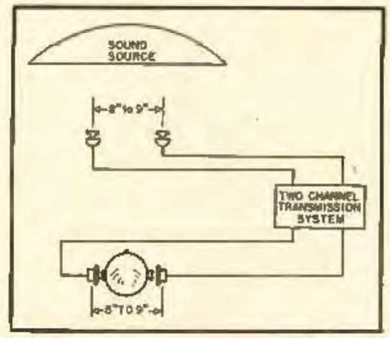

Fig. 1. The elements of a true binaural system.

If one reflects on the difficulties encountered in achieving "realistic" sound effects for ordinary broadcasting (monaural), where crumpled Cellophane sounds like a raging fire in the north woods and a cantaloupe dropped on the floor portrays the victim's head being bashed in, he realizes that all single-channel reproduction gives only an approximation of the original sound—our imagination fills in the deficiencies. For instance, a symphony over the network sounds like a symphony, with which we are reasonably familiar. But recordings of autos on cobblestones do not sound normal, for this sound is a bit unusual and our imagination does not help out much.

Let us consider the "auto-on-cobblestone" problem briefly. Since the one recording microphone, placed in the driver's position, had no analytical or discriminatory power of its own, it recorded faithfully what it heard and, for the first time (perhaps) the auto researchers heard, in truth, what they didn't hear—a hard fact to realize. Obviously, the solution was to restore the natural sense of binaural hearing by using two complete and separate sound transmission channels, from microphones to headphones, one channel to each ear. This was suggested, and one organization tried it with successful results.[3] Oddly enough, loudspeaker reproduction, at that time, was not successful for reasons which will become clear as we continue.

Microphone Placement

Apparatus intended for one field often ends up in another. Gene Carrington, educational director and lecturer for a large midwestern organization, learned of the foregoing and made orchestral recordings at Interlochen (Michigan) Summer Music Camp under the direction of Dr. Joseph Maddy. Mr. Carrington conducted experiments with respect to the placement of the two mikes with separations varying from many feet to about the distance of a human's two ears. Headphone listening showed that the sound was most realistic when the mikes were about 8 or 9 inches apart. And the demonstration was astonishing in its realism; one seemed to be standing right in the midst of the orchestra. During the past year, several demonstrations of "binaural" sound have been presented, using two loudspeakers—one for each channel—in a large room. The results were puzzling to many people who attended these demonstrations—until they heard similar demonstrations with headphones. Then they understood what was being attempted. Suddenly "three-dimensional sound," whether reproduced binaurally over headphones or stereophonically over loudspeakers, has become most popular. But this popularity has raised another question. Why don't these demonstrations work so well with loudspeakers? After all, it is mighty inconvenient to listen for any length of time to headphones, and loudspeakers reach larger audiences less expensively.

The answer is that loudspeakers do work very well when properly handled. And here entered the confusion between "binaural" and "stereophonic."

If we refer to *Fig.* 1, where we have two closely spaced microphones in a sound field, and a two-channel system connecting them to separate earphones, it becomes obvious that we are merely extending the diaphragms of our two ears electrically. Actually, of course, we are extending the diaphragms of the individual headphone receivers, electrically, to the physical placement of the diaphragms of the microphones. The time factor may be suitably delayed by the insertion of a simultaneous, two-track recorder in the bilateral transmission system. In other words, our ears seem to be where the microphones are physically placed. We have re-oriented our ears geographically and individually. The theorem of proportionality exists: mike-to-mike spacing is equal to the earphone-to-earphone spacing, and our brain functions normally to fuse the two

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[1] *Electrical Engineering*, Jan. 1934, Vol. 53, No. 1, six articles.

[2] Marvin Camras, in *Proc. I.R.E.*, April 1949, Vol. 37, No. 4.

[3] *J. Acous. Soc. Am.*, Nov. 1952, Vol. 24, No. 6.

separate signals arriving from each of our two ears. The resultant sensory perception is astonishingly like listening in the spot where the mikes were placed. Of course, we are assuming that we have paid attention to the proper phasing of the mikes, amplifiers, and headphones, and haven't interchanged sides. Disturbing but interesting effects result from such maladjustments. And the quality of the reproduced signal, as always, depends on several factors present in the system: frequency response, distortion, noise, flutter, wow, etc.

But we soon discover that listening to headphones makes the sound appear to be behind, rather than in front of us. This is a fact brought out by Bell Telephone's "Oscar" exhibit at the 1933 Chicago Worlds Fair and now permanently displayed at the Chicago Museum of Science and Industry. And it is also just as tiring today to be squeezed by a headset as when the crystal radio was in vogue. The apparent answer to the problems is obvious. Reproduce the signals over loudspeakers, of course. This will put the sound in front of us, and will be more convenient for listening. But while the sound as we hear it from the two loudspeakers sounds different from single channel listening, it still doesn't sound quite right. Remember, we still have the mikes placed only 8 or 9 inches apart. We have suddenly invented a new system of listening: "bistereonauralphonic" or a cross between two different concepts—which is meaningless. See *Fig. 2*. The placement of the speakers is unimportant here, as no arrangement will give the desired effect. It doesn't matter whether we set the speakers at an angle so that their axes intersect, as at (A) in *Fig. 2*, or so that they are square with each other. Speaker manufacturers pride themselves today on the non-directionality and wide-angle dispersion of their products. What happens under these conditions of close mike spacing and wide speaker spacing? If we stand somewhere in front of the speakers, we no longer receive sound meant for the left ear only in the left ear, and right-ear sound only in the right ear, but rather we receive sound in both ears meant for individual ears only. Our original mike placement simulated our relative ear positions, not the loudspeaker positions. This results in a brand new sensory experience which puzzles that superb analytical instrument called a brain, for the sound is twice mixed: once in the air, because each ear hears sound from each speaker, not just from one as it should; and once in our brain. Since we hear left and right sound in both ears simultaneously, with head diffraction lags, etc., our brains are led to the mental conclusion that we hear two speakers. This leads to the inescapable conclusion that we are befuddled, and this type of reproduction becomes a new and novel experience to be sure. This is certainly not the type of reproduction for which we search, namely that of reproducing the original sound stereophonically (i.e. "in the round"). But with this system there is, however, one point or group of points lying on the perpendicular bisecting vertical plane between the two speakers where, due to phase relationship and standing wave patterns in the reproducing room, we can hear sound from the left speaker predominantly in the left ear and vice versa. Here the results are somewhat more satisfactory. A slight shift of the head will make this interesting phenomenon disappear, and again both sound sources will be heard in both ears simultaneously. This narrow central "binaural" plane limits the number of happy listeners to those who can stand close together in tandem.

Corrective Measures

The answer to this predicament is immediately obvious to anyone familiar with acoustics. In the case of the binaural setup of *Fig. 1*, we are not concerned with listening room acoustics, obviously, and this occasionally has its advantages. Also, we are not too much concerned with the recording studio acoustics, since our built-in analyzer (brain) compensates for almost all of the acoustic shortcomings of that room, such as excessive reverberation, unwanted echo, etc. This we have learned to do unconsciously since earliest childhood. We use here our binaural sense in the proper and usual manner.

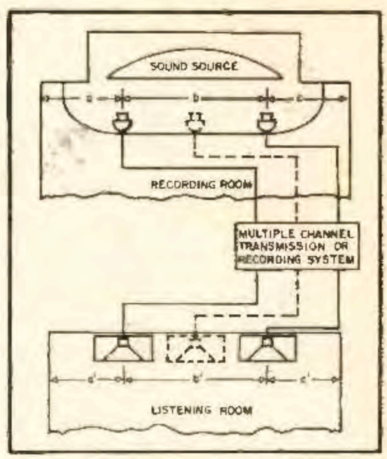

Fig. 3. The true stereophonic system. When three channels are used, distance becomes greater than when only two channels are employed.

But now, since we wish to reproduce this sound over speakers, we must take the listening-room acoustics into consideration. In fact, the listening room becomes an extension of the recording room. Of course, this has always been true in the case of a one-channel system, but not nearly as obviously so as it now is in the case of the two- or three-channel stereophonic system. After all, we are now trying to re-create that special effect in the listening room which existed in the concert hall.

Let us suppose for a moment that we wished to reproduce a concert, by means of loudspeakers, in the same hall as that in which it had been previously recorded. In reality we should have an infinite number of speakers arranged across the stage and several layers high in order to reproduce a similar full wave front. But for the sake of economy we use only two (or three) and spread them, one to the left, one to the right (and preferably another in the center). If we space two of them at, say, the one-third points across the stage as in *Fig. 3* where $a = b = c$), then, by proportionality, the microphones used to pick up the original sound should have occupied the same positions now occupied by the speakers. Sound is then radiated from the points where it was originally picked up. This is a most important factor, a factor relating to the theorem of proportionality. The recording system has merely delayed the element of time. The speakers then deliver approximately the same acoustic pattern into the room that was picked up at those points by the microphones. Sound from all over the stage reaches the various

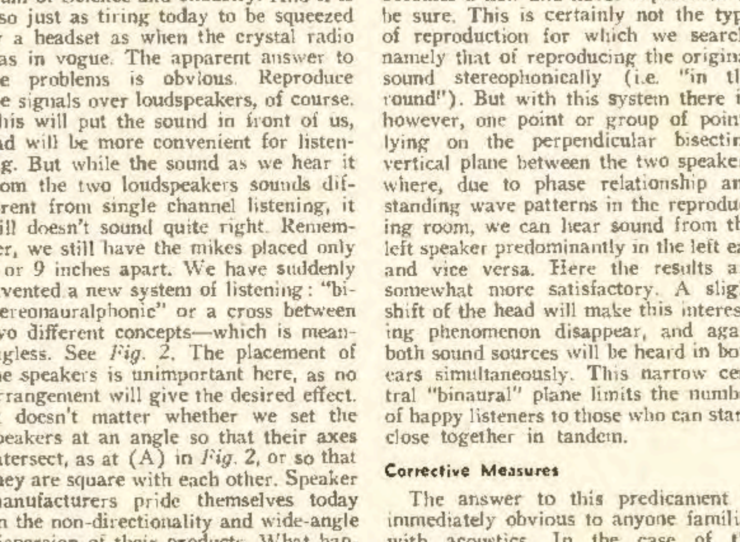

Fig. 2. "Bistereonauralphonic," or mixed and meaningless system.

Fig. 4. A complete portable stereophonic recorder, with amplifiers and power supply.

microphones at varying sound levels and times. These factors are necessary to the proper re-creation of the speaker-reproduced pattern.

If the microphones had been spaced "ear distance" (i.e. about 9 inches apart), as was done in a recent demonstration, and the loudspeakers a similar distance apart to maintain proportionality, rather a neat trick which was not done, we would have had in effect a one-channel system. This would accomplish little toward our ends. But with the speakers spaced widely, we lose the necessary proportionality and achieve only our unrealistic "bistereonauralphonic" system. Conclusion: the mikes should be spaced as far apart for this type of recording (stereophonic) as the speakers are to be spaced. We must know beforehand what sort of reproducing system is to be used.

Next we add the problem of placing the speakers not in the original room where the sound was recorded, but rather in some other and usually much smaller room, perhaps a living room, whose major dimension is less, perhaps than the distance between the recording microphones. Should we, therefore, reduce the spacing of the mikes? Experiment says no. Experiment also shows that if we space the speakers in approximately the same general lateral arrangement in the smaller room as in *Fig.* 3, where $a'=b'=c'$, maintaining approximate proportionality, the results are satisfactory. In fact, the sensitive central plane of "binaural" position, referred to previously, disappears and the auditor is free to move anywhere within the listening room. He will experience a similar sensation as though he were to move to various parts of the original auditorium. Placing the speakers in the corners of the room facing diagonally inward or placing them close to side walls appears not to work as well as spacing them a little way in from the walls and square with the room, as in *Fig.* 3. In so doing apparently a more normal sidewall reflection and multiple image pattern is set up in the room, thus simulating more closely the recording set-up. This helps blend the sound pattern in the room. Corner speakers do not set up such an image pattern.

In general, it is necessary to know where and in what manner the sound is to be reproduced before the proper microphone placement can be stated. For headphone listening, mikes should best be spaced a person's head-width apart. A bag of sawdust between the mikes, simulating one's head, is of unknown

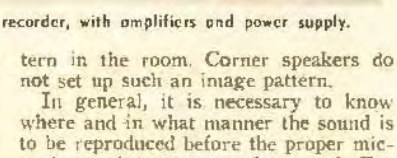

Fig. 6. Diagram of the arrangement of the Ampex stereophonic head assembly.

value. For loudspeaker listening the acoustics of both the recording and listening rooms must be taken into consideration without fail. A wide spacing of the mikes is indicated so that the theorem of proportionality will be maintained. When two channels are used, the mike spacing and position should be chosen with respect to the group size and arrangement so that all sections of the group will appear balanced in the reproduction. An overly wide spacing of the mikes will leave a "dead" spot in the pickup between the mikes (and speakers) at the center of the group. This is where the third channel, in the center, becomes helpful by really rounding out the stereophonic system. The Bell Labs experiments[1] showed that three channels were an optimum minimum number, but that two would work satisfactorily, if properly handled.

The insertion of a dual AM and FM simultaneous broadcast radio link does not change any of the conditions set forth, obviously, but does limit the system to two channels. Separate-sideband AM transmission plus FM has been suggested for a three-channel system, but appears to be still in the future.

It should be repeated that the quality of the total system will limit the naturalness of the reproduction. This was clearly demonstrated at the November, 1952, concert of the University of Illinois Symphony Orchestra, conducted by Leopold Stokowski, at Urbana, Illinois, where the author was invited to transmit the concert stereophonically to an overflow crowd in a relatively large but acoustically different auditorium on another part of the campus. Stereophonic recordings were made simultaneously. During the rehearsal two cardioid mikes were tried, followed by two modern condenser mikes. The former, designed many years ago, have an increasingly attenuated response above 9,000 cps. The condenser mikes have good high end response. Several of the musical faculty present commented on the noticeable difference, and the more nearly true string and oboe tone resulting from the switch. No other elements of the system were changed.

One controversial point might be raised here. What mike pickup pattern should be used? The author prefers a cardioid pattern, but with a wide frequency response. This pattern seems to help stereophonic reproduction because the pickup thus is one-sided, while the speaker reproduction is other-sided. This would seem to help in making the listening room an extension in fact of the recording studio.

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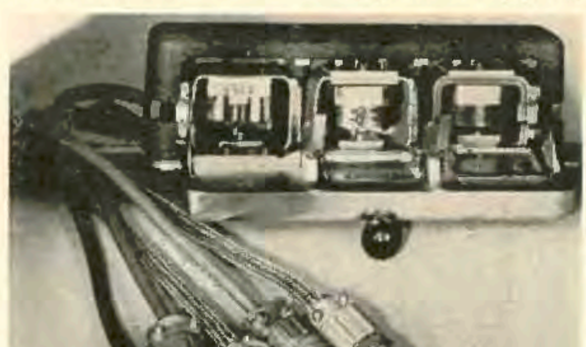
Fig. 5. Stereophonic head assembly, employing a full-track erase head at the left, a two-track record head, and a two-track playback head at the right.



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Something should be said about suitable tape recording equipment. *Figure* 4 shows a typical two-channel portable recorder. One case contains the tape transport mechanism, another contains two separate record and simultaneous playback amplifiers, one set for each of the two tracks. The third contains the power supplies for the amplifiers. The erase/bias oscillator, mounted in one amplifier, supplies bias directly to one channel and through a buffer amplifier to the other, so that the same bias frequency is used in each recording head, thus eliminating the beat frequency which would result from using two separate oscillators of approximately the same frequency. *Figures* 5 and 6 show the head assembly with a full track erase head, two side-by-side record heads which record two simultaneous tracks, running parallel along the length of the tape, and two appropriate pickup heads. Tape motion is from left to right across the heads. Thus the tape is first erased, then recorded upon, and then monitored a fraction of a second later over the playback system. The record heads are well shielded between the two and have 50 db attenuation on cross-talk between channels. The gaps of both the record and playback structures are critically aligned in parallel so that the time error between the two separate tracks is less than .00003 sec. at 15 in./sec. tape speed, or .00006 sec. at 7½ in./sec. This has an interesting sidelight. Tapes recorded stereophonically (or binaurally) on this type of inline gapped head may be played back on a standard full-track reproducer in an entirely satisfactory one-channel manner. This makes it possible to produce pre-recorded stereophonic tapes which may be played on either a stereophonic or a standard playback machine.

It will be noted that binaural headphone listening to orchestral music, for example, appears to give a much greater sensation of a completely "new" way of listening, and that loudspeaker stereophonic listening (correctly done) is not as astonishing. Headphone binaural listening is best for many special investigative problems. But speaker reproduction should sound more natural than the headphone method because we are used to being in a room-acoustic environment. In fact, it is for this very naturalness that we search.

The author is indebted to his early teachers in acoustics, his many customers, his associates, and several midwest university musical organizations for background and experimental set-ups which have led to the conclusions set forth above. Some of the conclusions reached might be somewhat controversial. Much three-dimensional acoustics still is. As one acoustican has said: "In no branch of science is the theory so simple and the measurement so difficult."