# Stereophonic Reproduction

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**A basic discussion of the reasons behind our ability to locate sounds simply by hearing them, together with practical requirements of stereophonic sound systems.**

THERE IS LITTLE DOUBT that the best examples of current sound reproducer equipment meet most of the known criteria for a high quality monaural system and in consequence there does not appear to be a great deal of opportunity for further improvement in subjective quality if present techniques are merely subject to greater refinement. For example an amplifier having a frequency characteristic flat to .01 db and a distortion content below .01 per cent is not subjectively better than an alternative design flat to 0.1 db (or even 1 db) and a distortion content of 0.1 per cent. In spite of this state of (pseudo) perfection no competent critic would consider that the best possible monaural reproduction of anything but a soloist could be mistaken for the real thing, and until we can deceive most of the people for most of the time there is room for improvement in techniques.

The pleasure derived from listening to a live orchestra is compounded of many factors, most which are adequately dealt with by a laboratory type of monaural reproducer system, but if we are to have a *perfect reproduction* of the original there are many marginal factors that require further attention. An orchestra generally occupies a platform 60 to 100 ft. wide and 20 to 30 ft. deep and this spatial distribution contributes to the pleasure derived from listening. There is merit in mere size. An orchestra that makes use of all the instruments all the time is flat and uninteresting and is rarely employed. Instead the listeners interest is excited and maintained by constant change in the prominence given to the various instrumental combinations. Thus the centre of the listeners' interest moves about the stage, the remaining instruments forming a pleasant but unobtrusive background to the focal zone on which the listeners immediate interest is concentrated.

#### Reduction of Source Width

A monaural reproduction is completely unsatisfying in this respect, the whole of the 100 by 30 ft. source being compressed and strangled to emerge from an 8- or 10-in. diameter hole, with the result that there is no possibility of identifying or appreciating the individual instruments or sections of the orchestra on the basis of their spatial distribution. The pleasure to be derived from the movement of the sound source is irrevocably lost.

A similar result is obtained from a monaural reproduction of the normal movement of actors about a set or stage. Movement in depth is moderately well reproduced if the reverberation conditions are satisfactory but all movement across the stage is reproduced as movement in depth. Thus all the action appears to take place in a tunnel with a microphone at its mouth.

Current microphone techniques aim to hide this defect by such procedures as employing a microphone boom to support the microphone just out of the picture and over the head of the speaker—the standard film and TV practice.

A monaural system is at a further disadvantage in that a single microphone is unable to discriminate against room noise or reverberant sound, with the result that all recording and broadcast studios must be acoustically treated to obtain a reverberation time much below that known to be optimum if a tolerable result is to be obtained with a monaural reproducer system. Similarly, noise from the audience coughing and shuffling appear to be enormously enhanced when heard over a monaural system. A simple but remarkably satisfying demonstration of the magnitude of this effect can be obtained by anyone with normal hearing and access to a hearing aid of the normal monaural type. Conversation that is easily understood and appears to be without any noticeable background when using two ears, appears against a marked background of reverberation and other room noises requiring considerable concentration if it is to be understood when the monaural hearing aid is used. Kock has shown that the human hearing mechanism automatically discriminates against noise when it approaches the head from a direction which differs from that taken by the desired sound. This binaural discrimination in favor of the wanted sound amounts to as much as 10 to 15 db, and is entirely lost when a monaural system is used.

A further and somewhat unsuspected result of this binaural discrimination is a marked increase in the clarity of speech and an apparent decrease in intermodulation distortion when reproducing music from a large source such as an orchestra. In fact it gives to the reproduction of a large orchestra the degree of clarity characteristic of a small orchestral combination.

It is suggested that Chinn's preferred frequency range tests using reproduced program material cannot be compared with Olson's tests using live material as in the latter tests the audience were listening "binaurally." The difference in conclusions largely represents the difference between monaural and binaural reproduction.

It is apparent that at the present time few of the advantages of a stereophonic system can be expressed numerically and recourse must be made to expressing opinions until such time as we have some system of indicating the overall subjective appeal of a reproducer system. A number of organizations have worked on the problems of stereophony both in Europe and in America and have recorded their opinions on the advantages of stereophonic systems.

Thus, tests by Bell Labs indicated that a stereophonic system having an audio bandwidth (per channel) of 3750 cps was considered by an audience to have the same aesthetic appeal as a monaural system 15,000 cps wide. J. P. Maxfield of Bell Labs has stated "I would rather hear a two channel reproduction flat to 6,000 cps than a single channel system flat to 15,000 cps; it is more pleasing, more realistic, more dramatic." This is a concise indication of the writer's opinion after more than a year's work on the subject, with the opportunity of hearing the systems developed by three of the leading European concerns.

#### Explanation of Stereophony

Without further discussion of the virtues of a stereophonic system, the mechanism of the stereophonic effect will be discussed as this is probably the best approach to an understanding of the technical requirements of a stereophonic system.

Mother Nature has provided us with two ears and these enable us to sample the sound field at two points spaced apart by the width of the head. From the differences that exist at the two ears and with the benefit of long experience, the ear - nervous system - brain combination can estimate the position of a sound source with remarkable accuracy, giving the same three-dimensional significance to the acoustic environment as the possession of two eyes gives to the visual environment.

For any sound source not in the median plane the sound at the left ear will differ from the sound at the right

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ear in three major respects.

1. Referring to *Fig.* 1 it will be seen that a sound from a source on the right side will strike the right ear before the left ear, the time difference being a maximum when the source is on one side and in line with the two ears. In this position the time difference is .00063 sec corresponding to an ear separation of 21 cm.

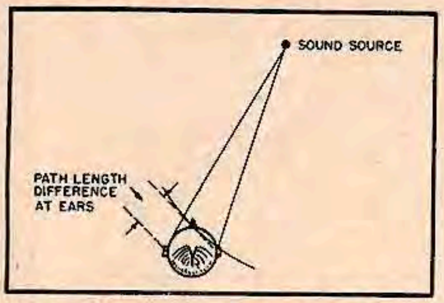


**Fig. 1. Difference in path length and time of arrival when sound source is not in median plane.**

2. There will be an intensity difference at the two ears, this difference being a function of the frequency of the sound. The intensity difference is frequency dependent as it is mainly the result of diffraction round the head.

3. Most everyday noises have a complex frequency spectrum and as the diffraction losses are a function of frequency the frequency spectrum at the two ears will also differ.

These differences justify further discussion. The reason for the difference in time of arrival at the two ears is evident and requires no further explanation, but the question immediately arises as to which part of the sound-wave cycle is accepted by the ear as determining the time of arrival at that ear. On an impulsive sound having a steep wave front it may be assumed that the arrival of the wave front is recognized, but on a repetitive waveform there is difficulty in understanding just how the ear recognizes the difference between successive cycles with identical waveform. A high-frequency wave passing from right to left will have several cycles pass the right ear before the first cycle reaches the left ear, and the right ear may not know just how many cycles have passed at the instant the first cycle reaches the left ear. This rather suggests that there may be difficulty in fixing the position of a high-frequency source having a frequency such that more than half to one cycle of the wave can be accommodated in the space between the ears. Taking the velocity of sound as 33,000 cm/sec and the ear spacing as 21 cm, it might be expected that frequencies above 800 cps (half wave=21 cm) might present difficulties in location and it is worth noting that this is found to be the case in practice.

Using a very elegant test technique, Galambos has taken simultaneous photographs of the sound waveform and the nerve response that results from the sound, and these show that the nerve discharge always occurs at the first positive peak. This suggests that the brain has adopted the first positive peak as a reference point and that in measuring time intervals to fix the position of a sound source in space, it notes that interval between the first positive peak arriving at the left and right ears. This process must be repeated at fairly frequent intervals if a moving source is to be followed and it is suggested that the intervals between syllables might well form the convenient gaps from which to commence each new measurement of "time of arrival" difference.

The loudness difference at the two ears is mainly due to the presence of the head between the ears. Any obstacle placed in a sound field distorts that field, producing an increase of pressure on the side facing the oncoming sound wave and a decrease in pressure on the reverse side—a process known as diffraction. The pressure difference between the two sides is a function of the ratio of obstacle diameter to wavelength of incident sound, and for a given size of obstacle will increase as the frequency of the incident sound rises (i.e., wavelength falls). An exact calculation of the field distortion is a problem of great difficulty but as we are only interested in diffraction around a human head, Weiner's measured results are satisfactory. These are shown in *Fig.* 2 and

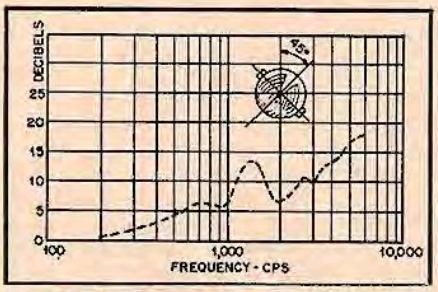


**Fig. 2. Ratio of sound pressure (in db) at ears for an angle of 45 deg. to the source.**

indicate that the pressure difference at the two ears has risen to 8 db at 1000 cps and 17 db at 6000 cps. Pure tones are not of significant importance in everyday life where the usual sounds—such as speech, music, and noise—have energy scattered throughout the whole frequency spectrum. On a complex sound the resultant pressure difference at the two ears will obviously depend upon the frequency spectrum of the energy in the sound. Steinberg has calculated the pressure difference and hence the loudness difference for normal speech and his results are shown in *Fig.* 3 from which it will be seen that up to angles of 40 deg from the median the loudness difference in db is almost directly proportional to the angle turned through by the head.

The third major difference noted is that as the diffraction effects are a function of frequency, with a resulting difference in the frequency characteristic of a sound at the two ears. With experience the brain may be able to use this difference to provide a clue to localization.

For sounds originating in the median plane all these differences vanish as the

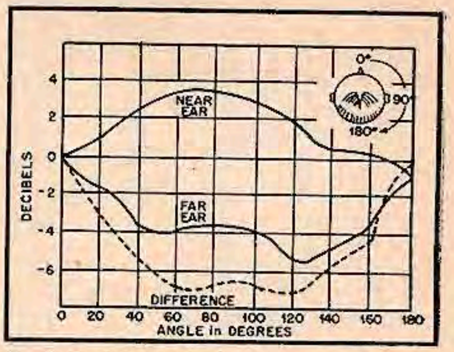


**Fig. 3. Variation in loudness as a speech source is rotated in a horizontal plane around the head.**

source is then symmetrically disposed with respect to the two ears, a condition that holds at all angles of elevation. It is to be expected that the precision of location in the vertical plane would be poor and in practice this is found to be the case. Discrimination between back and front is also found to be poor unless the head is free to make some exploratory movement. The slightest rotation of the head provides adequate discrimination between front and rear, presumably as a result of the brain noting the direction of the change in the time differences at the two ears.

It will be seen that there are three main differences in the sounds at the two ears—a time of arrival difference, a loudness difference, and a frequency-characteristic difference. At present there is no conclusive proof as to which of these provides the real clue to localization in practice. It seems highly likely that all three make contribution, with time and loudness differences providing the major clues.

#### Practical Stereophonic Systems

Consideration can now be given to methods of achieving stereophonic reproduction via an electrical reproducer system, knowing that we must maintain the time and amplitude differences present at the pickup points in the studio. There are two approaches to this problem, the first that of taking two samples of the sound field and transferring these two samples to the remote listener's ears through completely separate electrical systems and two headphones as shown in *Fig.* 4. Two entirely separate systems are obviously necessary as the left- and

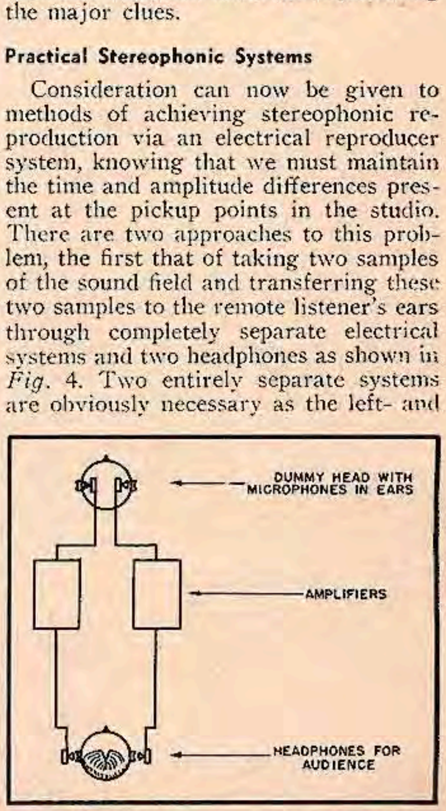


**Fig. 4. Stereophonic reproduction with headphones.**



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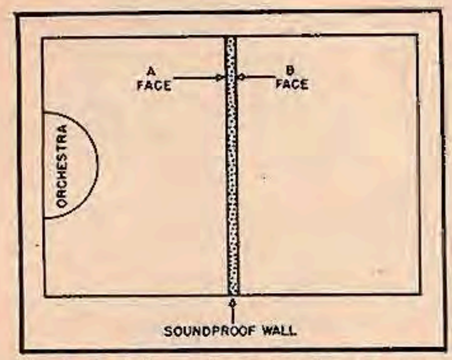


Fig. 5. A wall can be rendered sound transparent if face A is covered with microphones connected through individual amplifiers to loudspeakers on face B.

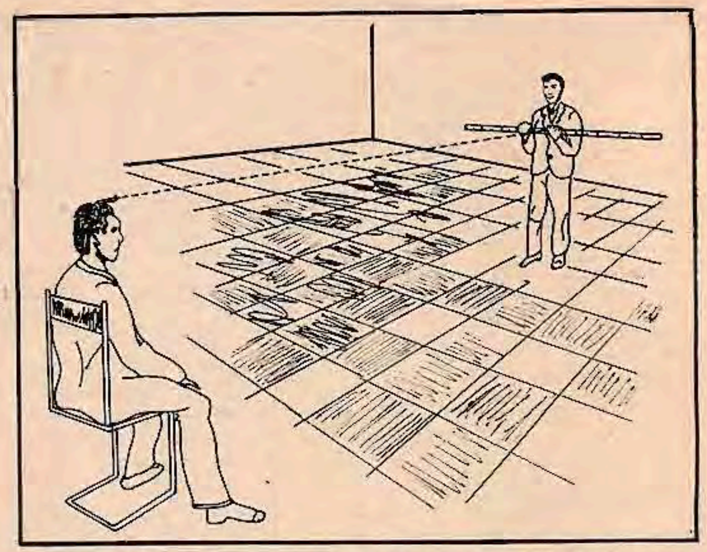

Fig. 8. Method of error measurement in sound location tests.

right-ear signals cannot be allowed to contaminate each other. At the transmitter end the sound pickup consists of two high-quality microphones mounted in a space model of the human head to simulate the acoustic field distortion produced by the head in practice. After amplification the signals are conducted by two separate channels to the two earphones. The results of this are extremely impressive but the necessity of wearing headphones militates against its use and it would appear unlikely to find favor with the general public unless the headphone cords are dispensed with. This could be accomplished by introducing two local (domestic) low-power radio transmitters with miniature receivers mounted on the headband—a procedure fairly common in film and TV studios for transmitting instructions to the operators of mobile cameras monaurally.

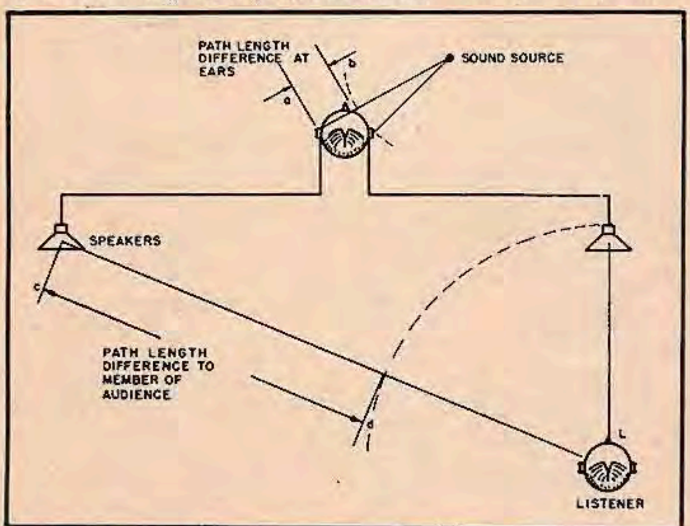


Fig. 6. Path-length discrepancy using closely spaced microphones and two-speaker system.

If the listener's ears cannot be transported to the studio it is possible to adopt the alternative approach and transport the acoustic field to the listener. The principles involved will be understood by referring to *Fig.* 5 showing a long hall divided into two separate sections by a soundproof transverse wall at A. This wall can be rendered sound transparent (unidirectionally) by covering the A face with a large number of microphones each connected through an amplifier to a loudspeaker on the B face of the wall. Any sound field approaching the A face would be reproduced on the B face and the audience in the B section would be unaware of the dividing wall. While this procedure would be reasonably effective it is commercially impractical, as a separate line and amplifier are required between each microphone and its associated loudspeaker. Some means of reducing the number of microphones and loudspeakers is required.

In the vast majority of stage plays and most films the action is largely concentrated at ground level and as localization in the vertical plane is rather poor in any case it seems reasonable to assume that the "vertical" information need not be transmitted. This eliminates the need for all the loudspeakers except the bottom row, a very considerable simplification. With present techniques two or three separate channels are all that can be accommodated on tape, disc, or film, so it appears advisable to check the performance of two- and three-channel systems.

In a simple two-channel system, localization is weakest in the center just where it is desirable that it should be at its best and the addition of the third

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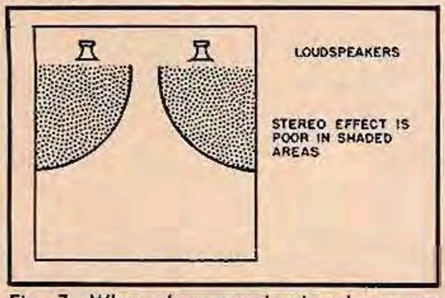


Fig. 7. When close-spaced microphones are with loudspeakers, the stereo effect is limited to the clear area.

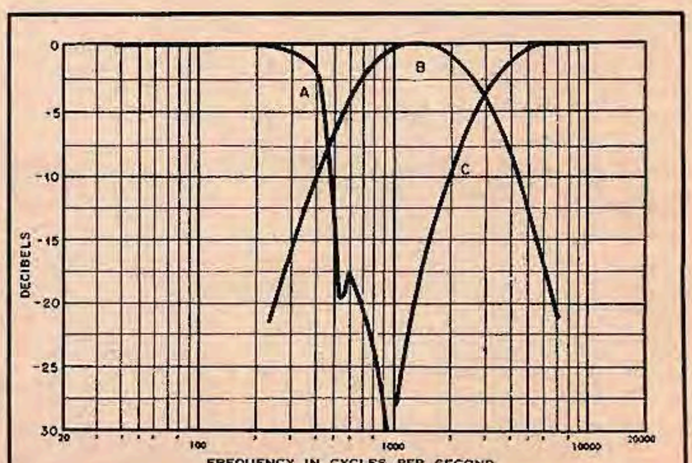


Fig. 9. Filter characteristics. (A) low-pass filter; (B) band-pass filter; and (C) high-pass filter.



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