Latest Developments in Stereophonic Sound

A REVIEW OF STEREOPHONIC SOUND RESEARCH

THE STORY OF THE STEREO DISC

RECORDING AND REPRODUCTION OF STEREOPHONIC DISC RECORDS

A REVIEW OF STEREOPHONIC SOUND RESEARCH

by

DR. HARRY F. OLSON

RCA Laboratories

Princeton, N. J.

TO ACHIEVE REALISM in a sound reproducing system four fundamental conditions must be satisfied, as follows: (1) The frequency range must be such as to include all the audible components of the various sounds to be reproduced. (2) The volume range must be such as to permit noiseless and distortionless reproduction of the entire range of intensity associated with the sounds. (3) The reverberation characteristics of the original sound must be approximated in the reproduced sound. (4) The spatial sound pattern of the original sound should be preserved in the reproduced sound.

Satisfying the first three conditions constitutes high fidelity, as the term is used today. The improvement in the performance of sound reproduction brought about by the advent of high fidelity has resulted in a greater interest in sound reproduction in all its aspects and ramifications than has existed at any time in its history. The next significant step in the consumer field is stereophonic sound which will satisfy condition four by providing auditory perspective of the reproduced sound. If the stereophonic sound reproducing system is a high-fidelity system, then all four conditions of realism are satisfied. However, the advantages of stereophonic sound are universal in that they can be demonstrated as distinct improvements in systems of all qualities of performance and frequency ranges.

The commercialization of stereophonic sound in the consumer field is developing at a rapid rate. For example, there are prerecorded stereophonic magnetic tape and stereophonic disk records with instruments for reproducing the recorded material.

Steps are now being taken with the object of developing practical stereophonic sound systems for frequency modulation radio, amplitude modulation radio and television sound which can be ultimately commercialized. The application of stereophonic sound in all the media could bring about a revolution in sound reproduction which might result in a large new business.

It is the purpose of this paper to present a general description of some of the aspects of stereophonic reproduction of sound as follows: a comparison with monophonic sound reproduction, auditory perspective, the applications in the home and the automobile, and the systems.

MONOPHONIC AND STEREOPHONIC SOUND REPRODUCING SYSTEMS

A monophonic sound reproducing system is a field-type sound reproducing system in which one or more microphones, used to pick up the original sound, are coupled to a single transducing channel which in turn is coupled to one or more loudspeakers in reproduction. A schematic diagram of a monophonic sound reproducing system is shown in Fig. 1. It is the most widely employed of all sound reproducing systems, and is used in disc phonographs, radio, sound motion pictures, television, magnetic tape reproducers and general sound systems. The sound at the microphone is reproduced at the loudspeaker. The transducer may be an amplifier, radio transmitter and receiver, a phonograph recorder and reproducer, a sound motion picture recorder and reproducer, a television transmitter and receiver, or a magnetic tape recorder and reproducer. The monophonic sound reproducer may be constructed to satisfy conditions 1, 2 and 3 on realism of sound reproduction. It cannot under any conditions satisfy condition 4.

The sterophonic sound reproducing system of greatest interest is a field type sound reproducing system in which two or more separately located microphones, used to pick up the original sound, are separately coupled to a corresponding number of independent transducing channels which in turn are separately coupled to a corresponding number of loudspeakers arranged in substantial geometrical correspondence to that of the microphones. A schematic diagram of a stereophonic sound reproducing system is shown in Fig. 2. The transducer may be an amplifier, radio transmitter and receiver, a phonograph recorder and reproducer, a sound motion picture recorder and reproducer, a television transmitter and receiver, or a magnetic tape recorder and reproducer. Two channels are used in the disc phonograph and radio. The stereophonic sound reproducer may be constructed to satisfy conditions 1, 2 and 3 on realism of sound reproduction. It can be constructed to provide auditory perspective of the reproduced sound and in this sense the stereophonic sound reproducer satisfies condition 4 on realism of sound reproduction.

Referring to Fig. 2 it will be seen that the subjective location of the reproduced sound sources corresponds to the physical location of the sound sources in the studio. A description of the subjective effects which lead to lateral and depth perception in stereophonic sound will be given in the section which follows.

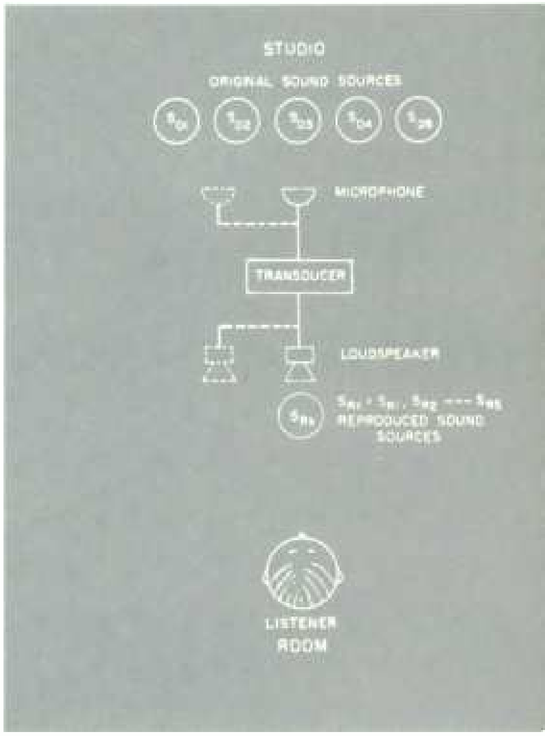
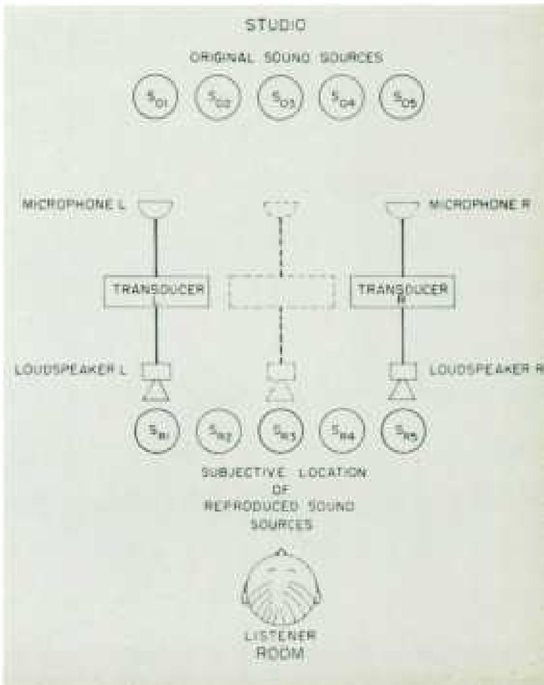


Fig. 1—A schematic diagram of a monophonic sound reproducing system.

Fig. 2—A schematic diagram of a stereophonic sound reproducing system.



AUDITORY PERSPECTIVE

Reproduction of sound in auditory perspective provides a subjective illusion of the distribution of the reproduced sound sources in lateral directions as well as depth in a geometrical correspondence which approximates the disposition of the original sound sources. A stereophonic sound reproducing system provides a means for the reproduction of sound in auditory perspective. It is the purpose of this section to describe the subjective aspects of the auditory perspective of the sound reproduced by a stereophonic sound reproducing system.

Lateral Localization. There are two factors that determine angular or lateral localization of a source of sound, namely, phase and intensity. The experiment which demonstrates angular or lateral localization with regard to phase and intensity is shown in Fig. 3. The same speech signal is reproduced from loudspeakers 1 and 2. The speech signal[2] from loudspeaker 1 can be delayed by means of the delay system. For each value of delay, the ratio of the voltage input to the two loudspeakers is varied until it is impossible to distinguish which loudspeaker appears to be the source. The results of this test are shown by the graph of Fig. 3. This experiment shows that there can be considerable unbalance in amplitude before the sound ceases to appear to come from the undelayed source. The above experiment shows that both phase and intensity plays a part in angular localization.

In performing the lateral localization experiments, some precautions must be taken to avoid errors in observation. For example, if the observer can see the loudspeaker he tends to point to either one or the other as a source of sound. This is a natural state of affairs because there are two visible sources of sound. Obviously, the sound must come from one or the other. In order to avoid this subjective bias, the loudspeakers were located behind a light-opaque-sound translucent screen. The arrangement[3] is shown in Fig. 4.

When the intensity and the phase of the sound emanating from the two loudspeakers is the same, the sound appears to originate from a point midway between the two loudspeakers, designated as S'_1. If the intensity of the sound emanating from both loudspeakers is the same but the phase of loudspeaker A′ of Fig. 4 is delayed two milliseconds with respect to loudspeaker B′, the sound appears to come from the point S'_4 of Fig. 4. If the delay is increased to five milliseconds, the sound appears to come from point S'_3 of Fig. 4. If the intensity of loudspeaker A′ is made 5 db higher than loudspeaker B′ and loudspeaker A′ is delayed 5 milliseconds with respect to loudspeaker B′, the sound appears to come from point S'_4. If the intensity of loudspeaker B′ is made 5 db higher than loudspeaker A′ but the phase of the sound emanating from the two loudspeakers is the same, the sound appears to come from point S'_3. If the intensity of loudspeaker B′ is made 2 db higher than loudspeakers A, but the phase emanating from the two loudspeakers is the same, the sound appears to come from point S'_4. If the intensity of the sound emanating from loudspeaker B′ is 5 db higher than loudspeaker A′ and the sound from loudspeaker A′ is delayed about 5 milliseconds, the sound appears to come from point S'_2. This experiment shows that the apparent position of the reproduced sound can be shifted over wide limits by varying the relative phases and/or relative intensities of the sound sources.

[1] The auditory perspective experiments reported in this paper were performed over a period extending from 1947 to 1955.

[2] Speech was used as the source of sound in all the auditory perspective experiments reported in this paper.

[3] In the experiments depicted in Figs. 4, 5, 6, and 7, the listener was asked to locate the apparent lateral location of the reproduced source of sound at the surface of the curtain. In other words, the apparent location of the source of sound with respect to depth was not determined. In the section on depth localization, experiments relating to the apparent location of the source of sound with respect to depth will be described.

DR. HARRY F. OLSON, internationally known pioneer in acoustics and Director of the Acoustical and Electromechanical Research Laboratory, RCA Laboratories, was elected recently to membership in the National Academy of Sciences, the nation's leading professional scientific organization.

As an extension of the above experiments, the stereophonic arrangement of Fig. 5 was employed. The configuration of the microphones and loudspeakers are shown in Fig. 5. A person speaking was located at the different positions S_1, S_2, S_3, S_4, and S_5 in the free-field room. The corresponding apparent locations of the reproduced sound in the listening room are shown as S'_1, S'_2, S'_3, S'_4, and S'_5 in the free field room. The relative estimated sound levels in decibels are also shown with position S'_1 designated as the reference level and was arbitrarily designated as 0 db. This experiment shows that the apparent position of the reproduced sound follows the actual position of the sound in the studio with small deviations. The deviations are as follows: The reproduced sound sources tend to be spread out in middle positions. The over-all spread of the reproduced sound sources is less than the distance between the loudspeakers. The reproduced sound level appears to be lower in the middle positions.

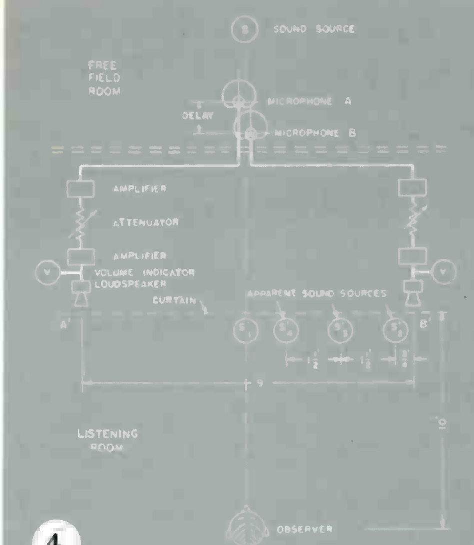
In the next experiment an attempt was made to reduce the spreading out and reduction of level of the reproduced sources in the middle positions. The configuration of the positions of the sound source in the studio, which were evolved so that practically equal spacing of the apparent sound sources in reproduction was obtained for the different positions of the sources in the studio, is shown in Fig. 6. The experiment of Fig. 6 shows that it is possible to obtain an equal spread of the sounds in reproduction. Furthermore, there is only a slight reduction in level for the middle positions.

In all the preceding experiments the listener has been located on a line perpendicular at the mid-point of the line joining the two loudspeakers. With the studio sound source positions the same as in Fig. 6, the listener was located 2¼ feet from the center line as shown in Fig. 7. The location of the apparent sources appeared as shown in Fig. 7. The apparent sources are concentrated towards the loudspeaker nearest to the observer. As would be expected the apparent intensity falls off with the distance from the loudspeaker nearest to the observer. In spite of the fact that the apparent sources are not equally spaced or of constant intensity, from a practical standpoint, the stereophonic aspects are preserved.

Depth Localization. In any true stereophonic sound reproducing system, there should be a sense of relative depth as well as a sense of lateral distribution. However, in this connection, it is generally recognized that a subjective effect of lateral distribution is more important than a subjective effect of relative depth. There are many factors which contribute to the sense of depth in stereophonic reproduction of sound. Some of the subjective effects of depth include a difference in the response frequency characteristics of the sources and a difference in the reproduced reverberation of the sources.

To determine the subjective effect of depth, an experiment was carried out as shown in Fig. 8. A person speaking was located at the positions S_1, S_2, S_3, S_4, S_5, and S_6 in the free-field room. The corresponding apparent estimated locations of the reproduced sound in the listening room are shown as S'_1, S'_2, S'_3, S'_4, S'_5, and S'_6. The relative estimated sound levels in decibels are also shown with position S'_1 designated as the reference level and was arbitrarily designated as 0 db. It appears that in this experiment the apparent locations in depth are determined by intensity.

In another experiment, the person speaking was located in the free field room at position S_1, of Fig. 8. The apparent location of the reproduced sound could be moved from the apparent location S'_1 in the listening room with a uniform over-all response characteristic to a position toward the listener when the response was accentuated in the frequency range from 1000 to 4000 cycles, or to a position away from the listener when the response was reduced in the same frequency range. The frequency range from 1000 to 4000 cycles plays an important role in determining



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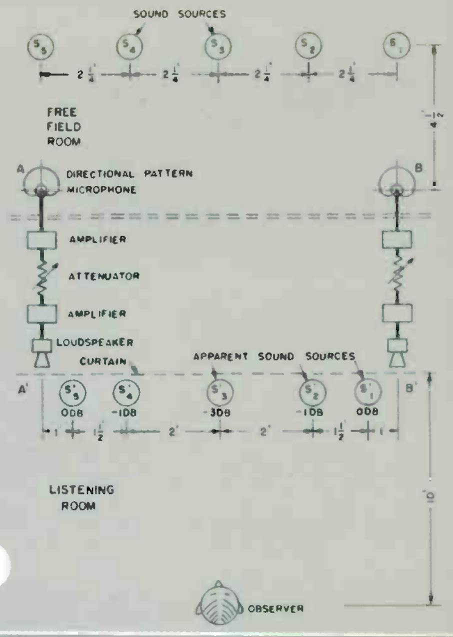

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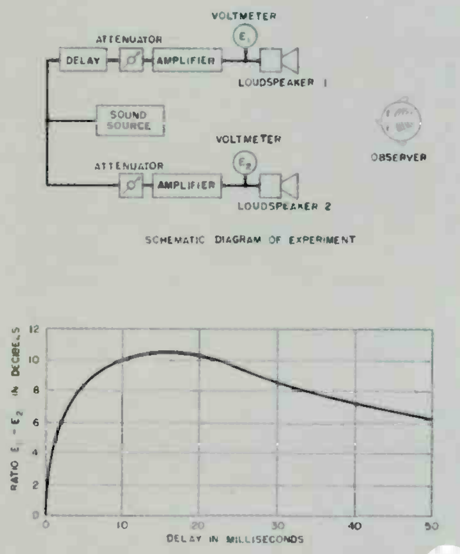

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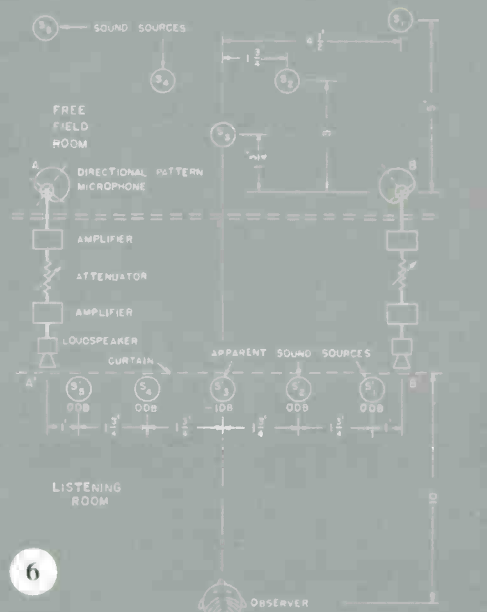

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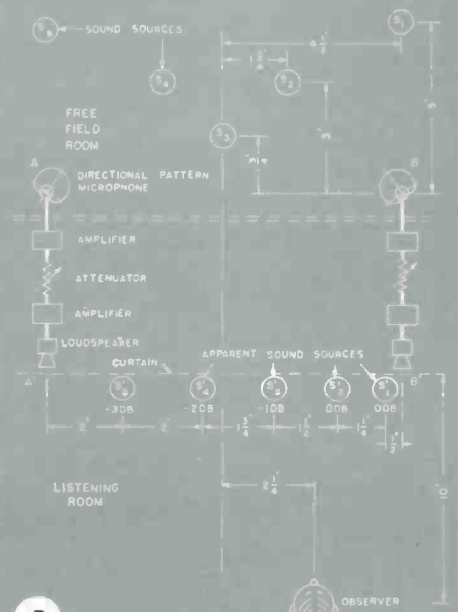

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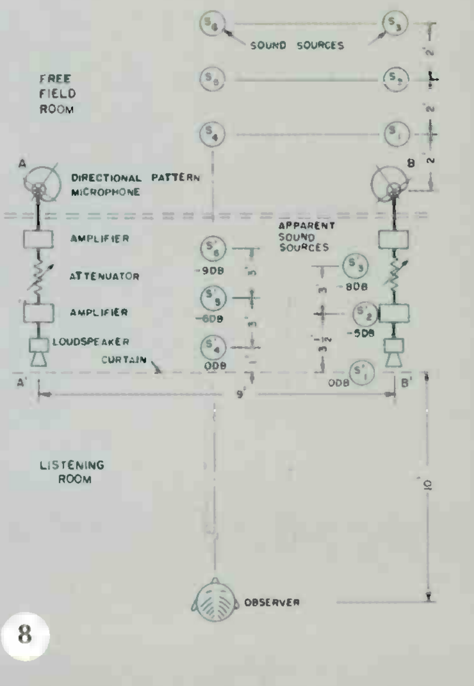

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Fig. 3—Schematic arrangement which illustrates the effect of phase delay and amplitude upon the localization of a sound source.

Fig. 4—Schematic arrangement which illustrates the effect of the relative delay and amplitude of two spaced sound sources in determining the apparent lateral location of the reproduced sound source.

Fig. 5—Schematic arrangement of stereophonic system showing the locations of the sound sources in the free-field room and the apparent sound sources in the listening room.

Fig. 6—Schematic arrangement of a stereophonic system showing the arrangement of the sound sources in the free-field room which will give a uniform spacing of the sound sources in the listening room.

Fig. 7—Schematic arrangement of a stereophonic system using the arrangement of the sound sources in the free-field room of Fig. 6 and showing the location of the apparent sound sources at the curtain in the listening room with the observer located 2¼ feet from the center line.

Fig. 8—Schematic arrangement of a stereophonic system showing the arrangement of the sound sources in the free-field room and the apparent location and relative sound level of the sound sources in the listening room.

the presence[4] of the reproduced sound. The presence is increased when the response in the region from 1000 to 4000 is increased. When the presence is increased, the effect is to move the source closer to the listener.

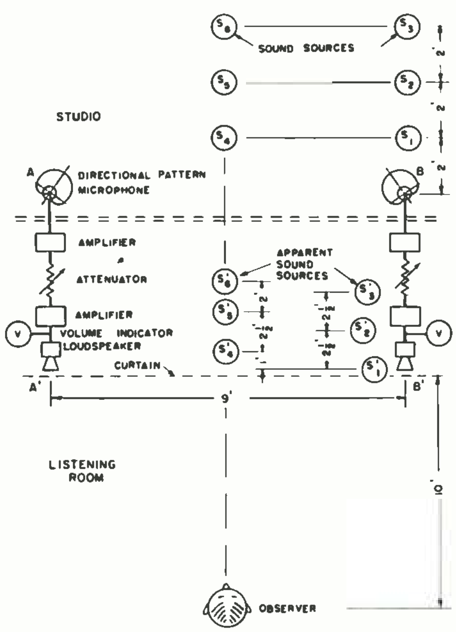
In another experiment, the person speaking was located in a room of 5500 cubic feet and reverberation[5] time of 0.7 second at positions S_1, S_2, S_3, S_4, S_5, and S_6 of Fig. 9. In this experiment the level of the reproduced sound was adjusted so that the output was the same for all locations of the reproduced sound. The corresponding relative locations of the reproduced sound in the listening room was S'_1, S'_2, S'_3, S'_4, S'_5, and S'_6. As the distance between the source of sound and the microphone is increased, the effective reverberation of the source of sound is increased. As the effective reverberation of the reproduced sound is increased, the presence is decreased. Therefore, the apparent location of the source of reproduced sound will move away from the listener as the effective reverberation of the reproduced sound is increased.

The systems and experiments depicted in Figs. 4, 5, 6, 7, 8 and 9 demonstrate that practical stereophonic reproduction of sound with the subjective effects of both lateral and depth distribution of the reproduced sound sources can be achieved by the use of a two-channel system.

[4] Olson, *Musical Engineering*, McGraw Hill Book Company, New York, N. Y., 1952.

[5] The reverberation time of the studio as a function of the frequency corresponds to that recommended in Olson, *Acoustical Engineering*, D. Van Nostrand Company, Princeton, N. J., 1957.

Fig. 9—Schematic arrangement of the apparatus of a two channel stereophonic sound system showing the arrangement of the sound sources in the studio and the apparent location of the sound sources in the listening room. The reproduced level of the sound was adjusted so that the output was the same for all locations of the reproduced sound.



REPRODUCTION OF STEREOPHONIC SOUND IN THE HOME AND IN AN AUTOMOBILE

The two major applications of stereophonic sound reproduction in the mass market or consumer field are in the home and in the automobile. It is the purpose of this section to describe the reproduction of sound in auditory perspective in a room and in an automobile.

Reproduction of Stereophonic Sound in a Room. The results of the subjective experiments in the preceding section can be translated to the reproduction of stereophonic sound in the home. A plan view of a typical living room for the reproduction of stereophonic sound in the home is shown in Fig. 10. The arrangement of the loudspeakers, the preferred listening area, and relative dimensions apply to practically any room in the average home. If the dimensional ratios and preferred listening area, depicted in Fig. 10, are maintained, the important subjective effects, namely, the angular and depth distribution of the sound sources will be maintained.

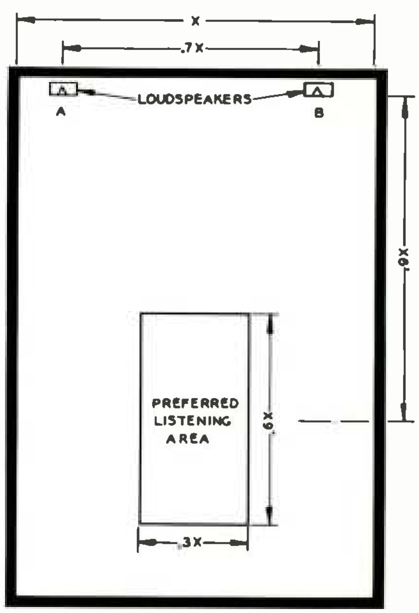
Reproduction of the Stereophonic Sound in an Automobile. The experiments on the stereophonic sound reproduction in an automobile were conducted with two different types of reproducers, namely, a two-channel magnetic tape reproducer and a two-channel disc phonograph. A schematic diagram of the apparatus used in the experiments is shown in Fig. 11. In order to evaluate the performance of stereophonic sound reproduction means were provided for comparison with a monophonic system. The change from stereophonic to monophonic sound reproduction was made by means of a switch. The loudspeaker system consists of a combination of a first-order gradient unidirectional loudspeaker employing a three-inch sound mechanism and a zero-order nondirectional loudspeaker employing a four by six inch elliptical mechanism. The directivity pattern of the unidirectional loudspeaker is a cardioid. The unidirectional loudspeaker covers the frequency range from 300 to 8000 cycles. The nondirectional loudspeaker covers the frequency range from 80 to 300 cycles. An electrical network allocates the power delivered to the two loudspeakers to the frequency ranges covered by the loudspeakers.

A plan view of the automobile and the location of the loudspeakers is shown in Fig. 12. The stereophonic loudspeakers are located on the top of the dash in the extreme corners. The monophonic loudspeaker is centrally located.

It has been established that excellent stereophonic sound reproduction can be achieved in a certain preferred area in a living room. The geometry of the loudspeakers and the listeners in the automobile shown in Fig. 12 are shown in Fig. 13. In a typical living room the two loudspeakers for stereophonic sound reproduction are usually separted by a distance of 8 feet. The location of the listeners in a living room for the same phase as that obtained in an automobile are shown in Fig. 13. There is also very close correspondence in the relative intensities of the direct sound at the listeners in the automobile and living room for the geometry of Fig. 13. The listeners in the living room are located within the area what has been the preferred listening area of Fig. 10. Recalling the results of the experiments of Figs. 3, 4, 5, 6, 7, 8, and 9, and comparing the phase and intensity relations at the listener in the automobile with those in the living room there is every reason to expect excellent stereophonic sound reproduction in an automobile. This conclusion has been confirmed under actual listening test of stereophonic sound reproduction of speech and music in an automobile.

The results of extended listening tests comparing the monophonic sound reproduction with stereophonic sound reproduction in an automobile has led

Fig. 10—The arrangement of a two channel stereophonic tape reproducing system in a room showing the optimum relative dimensions and the preferred listening area.



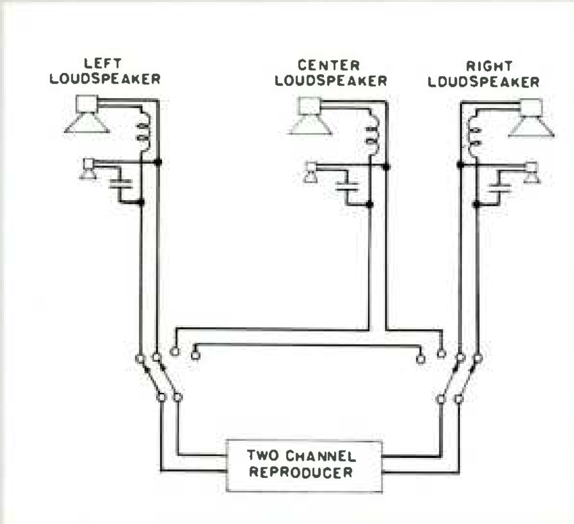


Fig. 11—Schematic circuit diagram of apparatus used in the reproduction of monophonic and stereophonic sound in an automobile.

to the following observations and conclusions.

Excellent auditory perspective is obtained from stereophonic sound reproduction in an automobile.

The recording studio characteristics, such as reverberation, etc., are more apparent in an automobile as compared to a living room due to a larger ratio of direct to generally reflected sound in the automobile. This appears to lead to more pleasing sound reproduction in the automobile.

There is more apparent low-frequency response in stereophonic sound reproduction as compared to the monophonic sound reproduction even though the measured response frequency characteristics are the same.

There is more apparent discrimination against ambient noise in stereophonic sound reproduction in an automobile as constrasted to monophonic sound reproduction with the sound from both reproduced at the same level. The improvement in discrimination against ambient noise is very important in a motor car because the ambient noise level is very high.

STEREOPHONIC SOUND SYSTEMS

The following transducers are ones most commonly used in the mass market or consumer field for the reproduction of sound, namely, the magnetic tape sound reproducer, the disc phonograph, the radio, and television.

Prerecorded stereophonic sound magnetic tape and stereophonic magnetic tape reproducers were commercialized in 1955. Stereophonic disc phonographs and stereophonic disc phonograph records were commercialized in 1958. Experimental broadcasting of stereophonic sound reproduction by means of frequency modulation multiplex was started in 1958. Frequency modulation radio receivers capable of receiving and reproducing the sound in auditory perspective were available in 1958. An experimental stereophonic sound amplitude modulation radio system was demonstrated in 1958 and was demonstrated in a broadcast in 1959. An experimental stereophonic-sound frequency-modulation multiplex element of a television system was demonstrated in 1959.

Stereophonic sound provides a large and significant step in achieving realism in sound reproduction. For this reason it is expected that stereophonic sound will ultimately be developed and commercialized in all of the media in the consumer sound reproduction complex.

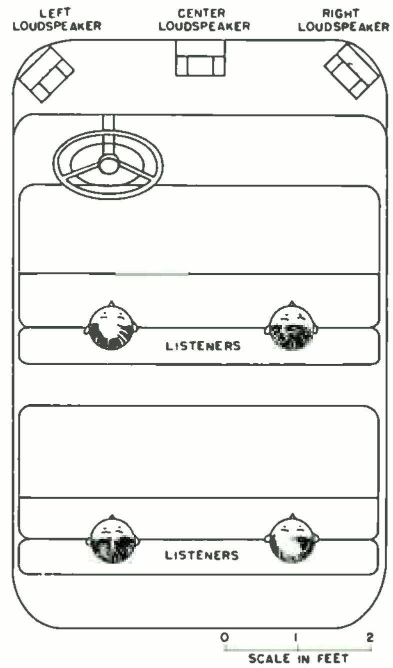


Fig. 12—A plan view of the loudspeaker system and the listeners for the subjective evaluation of monophonic and stereophonic sound reproduction in an automobile. The left and right loudspeakers were used for stereophonic sound reproduction and the center loudspeaker was used for monophonic sound reproduction.

The application of stereophonic sound in all the media could bring about a revolution in sound reproduction which might result in a large new business. The new business will be prerecorded stereophonic-sound magnetic tape and stereophonic-sound magnetic tape reproducers, stereophonic-sound disc records and stereophonic-sound phonographs, stereophonic-sound, amplitude-modulation radio transmitters and receivers, stereophonic frequency-modulation radio transmitters and receivers, and stereophonic-sound television transmitters and receivers. All these instruments and systems may ultimately displace existing instruments and systems.

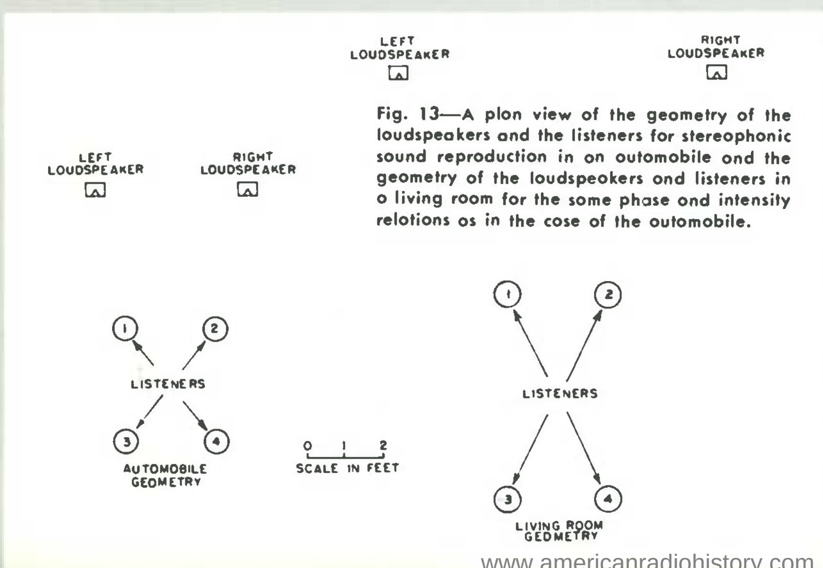


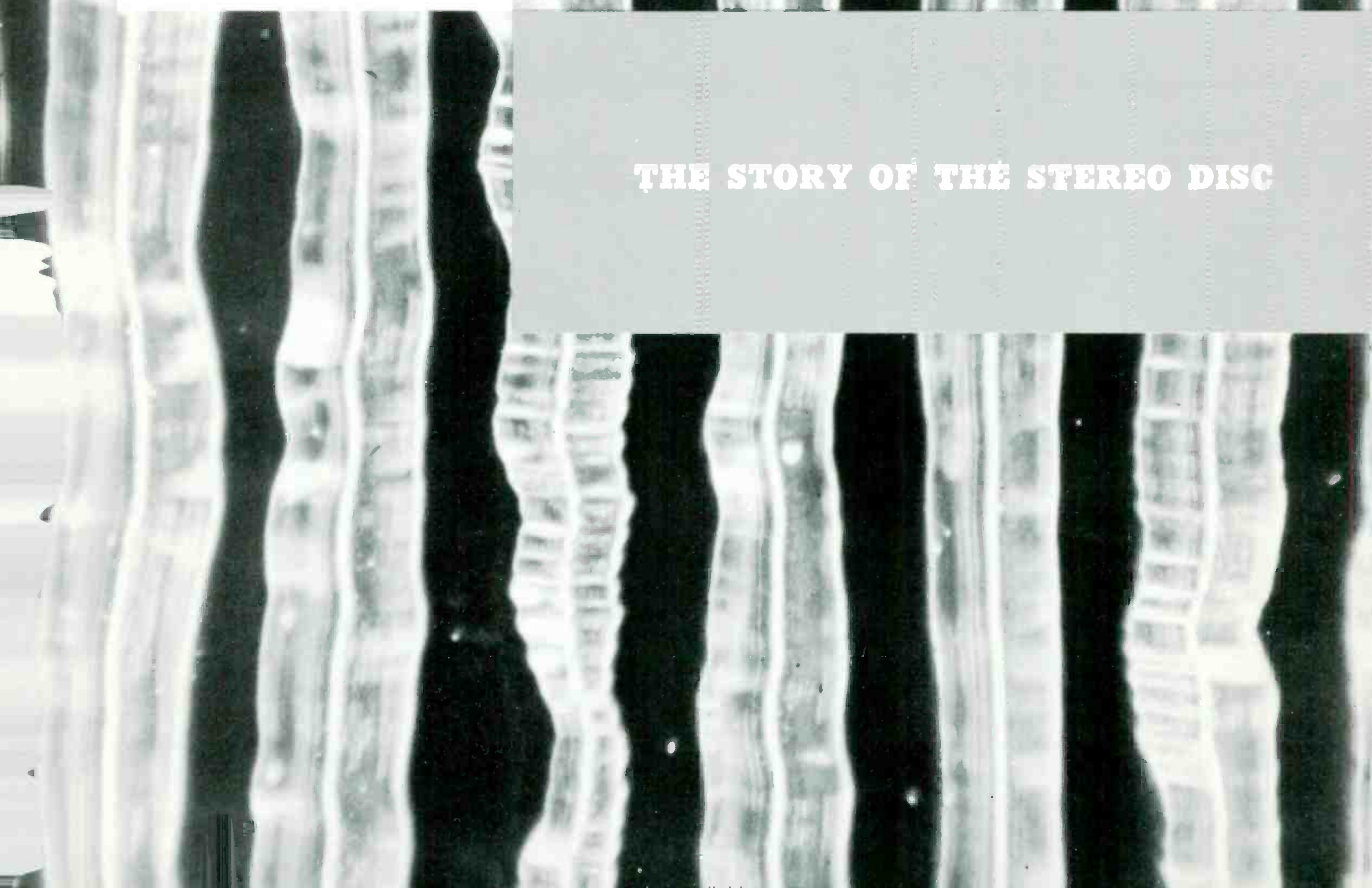
Fig. 13—A plan view of the geometry of the loudspeakers and the listeners for stereophonic sound reproduction in an automobile and the geometry of the loudspeakers and listeners in a living room for the same phase and intensity relations as in the case of the automobile.

H. E. ROYS received his BSEE from the University of Colorado, and joined RCA in 1930 in the phonograph section. In 1937 he became a member of the Advanced Development group of the Photophone section, and from 1941 to 1946 was located with this group in Indianapolis, working mainly on disc recording and reproducing problems. He returned to Camden in 1946 to General Engineering Development, as Manager of Optical and Recording Systems Development. He is now Manager, Engineering, RCA Victor Record Division at Indianapolis.

Mr. Roys is an authority in the fields of audio, acoustics and recording and his work in these areas has brought him several awards. Among these are an award by the National Association of Broadcasters for "Meritorious Service" for his work in the development of NAB recording and reproducing standards, and the Emile Berliner award from the Audio Engineering Society for his contributions to the audio art.

Mr. Roys is a member of Tau Beta Pi and Eta Kappa Nu. He is a Fellow of the Audio Engineering Society, the Acoustical Society of America, and the IRE.

THE STORY OF THE STEREO DISC



H. E. ROYS, Mgr.

Engineering

RCA Victor Record Division

Indianapolis, Ind.

STEREOPHONIC PHONOGRAPH RECORDS with two separate channels of information recorded in a single groove became a commercial reality in 1958, less than a year after the adopted system had been publicly demonstrated. A stereophonic system utilizes two or more independent channels, with separate microphones in recording and separate loud-speakers in reproduction, so arranged as to produce a sense of realism of recording-hall acoustics and location of the instruments in the orchestra with respect to lateral position and depth. The effectiveness of stereophonic reproduction was demonstrated by the Bell Telephone Laboratories in 1933 when an orchestra playing in Philadelphia was reproduced over loudspeakers located in Washington. The material was not recorded but was transmitted directly over telephone lines. Walt Disney used several sound tracks to obtain spread sound in *Fantasia*. Wide screen motion picture presentations in many cases employ multi-channel recordings to obtain stereophonic effects. Two track stereophonic tape for the home became common in the '50's and Emory Cook produced some commercial stereophonic records, laterally recorded, in which the two channels of information were recorded as separate inside and outside bands on the record.

EARLY HISTORY

The 45°-45° system adopted by industry and the one that has become a national and international standard almost overnight was disclosed in patents some twenty years ago. A. D. Blumlein, of Electric and Musical Industries, England, obtained two patents, British 394.325 in 1933 and U.S. 2,093,540 in 1937, and A. C. Keller and I. S. Rafuse obtained U.S. patent 2,114,471 in 1938 (assigned to the Bell Telephone Laboratories) which describe the 45°-45° system.

The Bell Telephone Laboratories cut stereophonic records during their experimental work but used the vertical-lateral (V-L) system (one channel vertically, the other laterally) instead of the 45°-45° system. There was little commercial interest in stereophonic records at that time so the experimental work was dropped.

THREE SYSTEMS

In September 1957 the Westrex Corporation, a subsidiary of the Western Electric Company, demonstrated stereophonic records cut in accordance with the 45°-45° system. These were private demonstrations, mainly to persons in the record industry. Shortly afterwards, in October 1957, they described and demonstrated the 45°-45° system at the Audio Engineering Society Convention in New York. This was probably the first public demonstration of the 45°-45° system. The system was again described[1] at the IRE National Convention in March 1958.

About the same time, in the fall of 1957, the Decca Company of London also demonstrated stereophonic records but these were cut in accordance with the vertical-lateral system. Somewhat later Jerry Minter demonstrated stereophonic records in which all of the information was recorded laterally, using an FM system with a carrier of about 30 kc to accommodate the additional information needed for stereophonic recording.

Thus in the latter part of 1957 the phonograph industry was presented with a problem of deciding which of the three systems should be selected as an industry standard. There was a strong desire, both in this country and abroad, that one and only one system be chosen and made available to the public.

INDUSTRY APPROACH

The approach taken by industry was indeed a very logical one. Engineering committee meetings of industry associations, Electronic Industries Association (EIA) and the Record Industry Association of America (RIAA) were held, information was presented concerning the different systems, and the problems were discussed openly and frankly. RCA Victor Record and Radio and "Victrola" Divisions commissioned M. S. Corrington, who had done an outstanding job on Tracing Distortion studies for the 45 rpm record, to make similar studies for the V-L and 45°-45° systems[2] and to make the information available to the engineering committees.

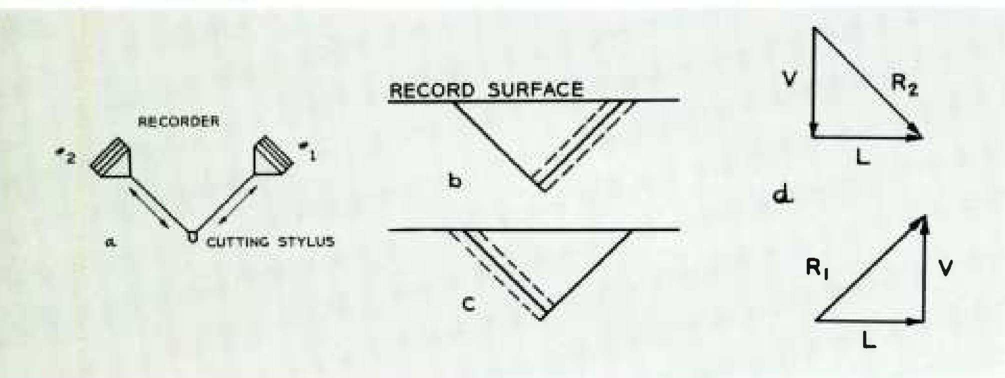


Fig. 1—(a) The recorder has two driving coils, 45 degrees with respect to the record surface and 90 degrees with respect to each other. The connecting member between each drive coil and the stylus is stiff under compression or tension but has lateral flexibility to permit bending.
(b) Groove variation with signal applied to coil #2.
(c) Groove variation with signal applied to coil #1.
(d) Vector diagrams showing that both vertical and lateral components exist with 45 degree modulation. Combining the vectors with the phasing illustrated will result in maximum lateral and minimum vertical modulation.

During the latter part of 1957 the Engineering Committee of the Record Industry Association of America decided in favor of the 45°-45° system and in early 1958 the Phonograph Committee of the Electronics Industry Association agreed with their decision. The agreement was welcomed by phonograph engineers for it cleared up many uncertainties and allowed them to concentrate their efforts on the 45°-45° system.

In March 1958 the Board of Directors of RIAA formally approved the

Fig. 2—Photograph of stereo grooves. Note how the groove width varies and modulation on one side does not always appear on the opposite side of the groove.

Engineering Committee's recommendation and proclaimed the 45°-45° system as an industry standard. The decision was welcomed in Europe for the European recording engineers at a meeting in November 1957 had already concluded that the 45°-45° system offered the greatest advantages and they were pleased that RIAA and EIA engineers had reached the same conclusion. Thus, less than six months after the first public demonstration, basic industry standards were agreed upon both nationally and internationally. This I believe is an unheard of precedent—industry reaching a worldwide agreement before production starts.

THE SYSTEM

The 45°-45° system uses a single stylus to cut the groove and, as the name implies, modulation takes place at an angle of 45 degrees with respect to the surface of the record (Fig. 1, a). Since the groove is "V" shaped with an included angle of 90 degrees, the groove walls are normally 45 degrees with respect to the record surface. Consequently for the 45°-45° system a signal from one channel varies the position of one groove wall about a mean (no signal condition) without changing the position of the other, Fig. 1, b and c.

For reproduction, the pickup also uses a single stylus and the configuration with the voltage generating device may be similar to that of the recorder illustrated in Fig. 1, a; the main consideration being the pickup be designed to produce two practically independent signals in accordance with the motion components along the two axes that are displaced 90 degrees with respect to each other and 45 degrees with respect to the record surface.

ADVANTAGES

Operation at 45 degrees provides a symmetrical arrangement that offers advantages in the design of both recorders and reproducers. The 45°-45° system may be considered as two independent vertical recording channels displaced 45 degrees with the surface of the record. Since these are alike, frequency response, distortion, and other characteristics are the same for each channel. For a vertical-lateral system they are different; tracing distortion showing one of the greatest differences. The frequency response is different because most designs of vertical-lateral combination pickups show the lateral mode of operation to have a greater high frequency response. This is because inertia is involved in the lateral mode of operation due to the arcuate motion of the stylus and moving system, whereas direct mass is involved in the vertical mode because of linear motion, and the effective inertia is less than the mass.

Another consideration, and by no means a small one, in favor of the 45°-45° system concerned a compatibility feature. By proper phasing of the two stereophonic signals to the recorder, a lateral modulation would be effected adding together the signals from both channels. Reproduction of this groove with a *suitable* lateral pickup would result in a combined output much the same as though the signals from the two channels were first combined electronically and then recorded with a standard lateral recorder. The vector diagrams of Fig. 1, d show that each 45 degree modulation displacement may be resolved into two components, one lateral and the other vertical. For a sound source located centrally with respect to the microphones of the two channels, sound waves will arrive at the two microphones essentially in phase. Assuming that the same phase relationship is maintained throughout the electronic amplifiers, the resulting groove modulation then depends upon the phasing of the two driving coils. These may be connected so that the resulting lateral modulation is the sum of the two lateral components. In this case the vertical components are opposing and the vertical modulation is low. The phasing of the vectors of Fig. 1, d illustrates these two conditions. Obviously it is desirable to phase the driving coils for additive or "in phase" operation so that good reproduction can be obtained with a suitable lateral pickup. The RIAA Engineering Committee so specified the phasing in their specification for the stereophonic record. The qualifying term "suitable" for the pickup is necessary in order to exclude those pickups with high vertical stiffness since they would be unable to properly track a groove that contains vertical as well as lateral modulation. The vector diagrams of Fig. 1, d show that both forms of modulation exist in a stereophonic groove.

COMPATIBILITY

P. C. Goldmark[3] seeking to make the stereophonic record usable on existing monophonic machines without changing the pickup, proposed that the vertical modulation be controlled dynamically and be so limited as not to exceed tracking capabilities of existing monophonic pickups, thus making it necessary to produce only one type of record—a modified stereophonic record.

Record manufacturers, however, not wishing to risk possible degradation of quality, decided to follow the recommendation of RIAA and produce monophonic and stereophonic records separately.

Monophonic records can be reproduced on stereophonic systems and in fact should sound better since, for one thing, the output is from two speakers. In addition, due to the small tip radius (0.7 mil) used for stereophonic reproduction tracing distortion will be less and the high frequency response somewhat greater than that obtained with the one mil tip normally employed for L.P. reproduction. There is no problem therefore with instruments designed for stereophonic reproduction. For existing monophonic equipment it may be necessary to replace the pickup with one having greater vertical compliance. This may be a stereophonic pickup, for stereophonic pickups are usually designed so that the two channels may be connected at the pickup and hence not require a change in wiring of either tone arm or instrument. If the pickup is replaced, less vertical force should be used because of the smaller tip so as to minimize record and stylus wear; otherwise, no other changes should be necessary.

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RECORDING AND REPRODUCTION OF STEREOPHONIC DISC RECORDS

by

B. J. WHITE and H. D. WARD

Record Engineering

RCA Victor Record Division

Indianapolis, Ind.

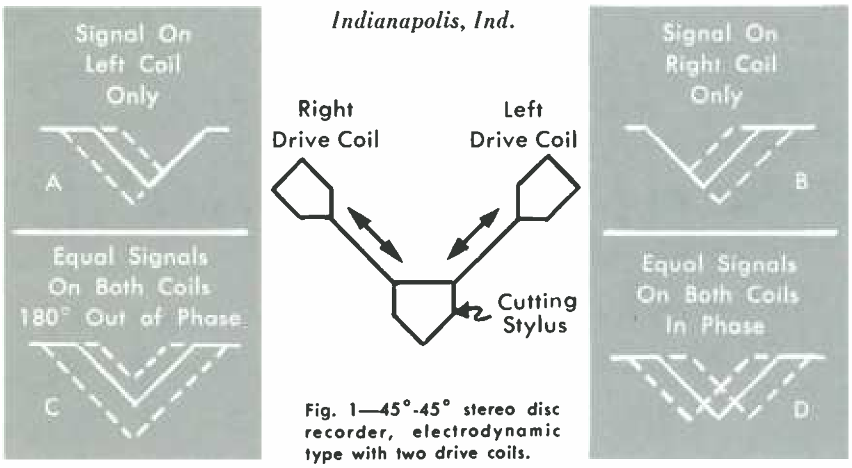


Fig. 1—45°-45° stereo disc recorder, electrodynamic type with two drive coils.

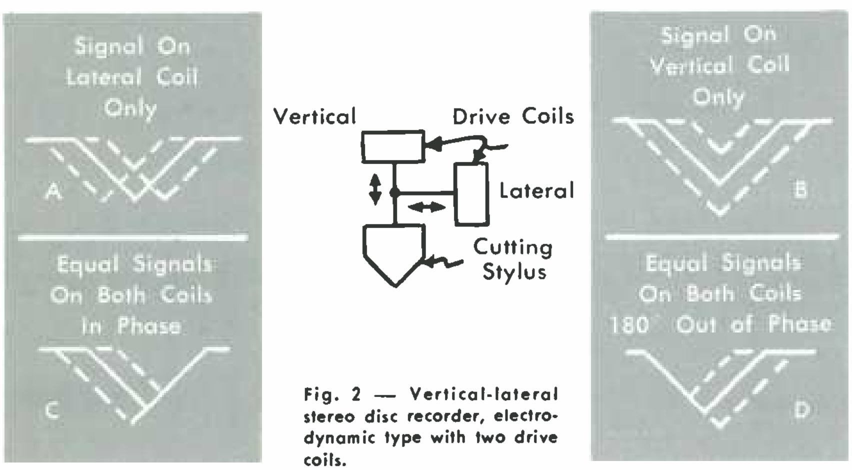


Fig. 2 — Vertical-lateral stereo disc recorder, electrodynamic type with two drive coils.

THE 45°-45° system described in the article by H. E. Roys was accepted by the record industry as the system which could produce the best over-all stereophonic performance on phonograph records. Provided with the characteristics of this basic system, the recording of stereo discs requires the consideration of many factors important to the consumer of phonograph records. Some of these factors, common to monophonic recording, are: recording level, available "playing time," the recording frequency characteristic, and constant reproduced frequency response from the outside to inside of disc.

Still other factors must be considered in stereophonic recording. Most important of these are recording level balance between channels and inter-channel phasing. In order to re-create the original stereo "sound picture" in proper perspective, channel balance and inter-channel phasing must be accurately preserved throughout the entire recording-reproducing process.

Geometric symmetry of the 45°-45° system has made solutions to the problem of balance and phasing much simpler than they would have been otherwise. Thus, along with the acceptance of the 45°-45° system, the record industry adopted the convention that "equal and in-phase signals fed to the stereo recording system shall produce lateral modulation on the disc." This is useful in recording and provides a convenient check on channel balance and phasing.

RECORDER CONSTRUCTION

The effect of two-channel signals combining to produce different modes of modulation is most readily shown by an example of recorder construction. Fig. 1 indicates four possible modulation modes obtained with individual and combined signals. The recorder shown is the 45°-45° type whose modulation axes are inclined 45° to the disc surface. Equal and in-phase mechanical motions of the drive coils are seen to cause the cutting stylus to move vertically. However, in order to comply with the phasing convention adopted, the polarity of one of the coils must be electrically reversed so that equal and in-phase signals will produce lateral modulation.[2]

Fig. 2 shows the basic construction of a vertical-lateral type of recorder. This type can be used, in conjunction with a sum and difference matrix, to record 45°-45° discs. The output of the sum matrix is fed to the lateral drive coil while the output of the difference matrix is fed to the vertical drive coil. Thus, equal and in-phase electrical signals will add in the sum matrix and energize the lateral coil. Also, equal signals 180° out-of-phase will add in the difference matrix and energize the vertical coil.

Both recorder types are commercially available and produce good results.

OPERATIONAL METHODS

For highest quality stereo recording, the two recording channels should be exact duplicates throughout their operational range. Frequency and phase response should match closely. To establish proper phasing, the channels are connected in parallel to a single oscillator. An oscilloscope, connected to the outputs of the two channels, should then display an in-phase Lissajous pattern throughout the entire frequency range. Conversely, a 180° signal input phase reversal should result in a 180° out-of-phase scope pattern. Providing the above is correct, the stereo disc system will then produce a lateral modulation, when fed in-phase, and a vertical modulation when fed out-of-phase. The same phasing care must be exercised in production of master tape source material.

Standard reference level for a lat-

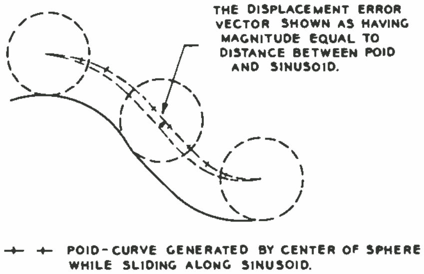


Fig. 3—Displacement error vector as a result of tracing distortion.

erally recorded signal is 5.5 cm/sec velocity at 1,000 cps. In the 45°-45° system, standard lateral level will produce velocities 3 db down in each channel, or 3.9 cm/sec. Initial cuts can be optically measured to give an approximate balance of the two channels. After this is done, in-phase 1-kc signals are fed to the channels to produce a lateral cut. This cut is then compared to a calibrated lateral 1-kc disc signal to determine necessary level adjustments to be made in each channel. A pickup and arm combination of reasonably good quality, when referenced to a lateral disc, can be depended upon to display channel balance to an accuracy of 0.2 db.

After establishing the level and balance at 1-kc, the over-all response can then be checked by the light pattern method. An in-phase (lateral) response cut can be compared with a 180° out-of-phase (vertical) response cut. If these two cuts compare favorably, it can be assumed that the individual channels will have a similar response. Phase shifts can be seen as a peak or dip in the front pattern and a corresponding dip or peak in the back pattern. Lacquer cutting problems in stereo are basically the same as in monophonic recording with some exceptions. Film build-up on stylus face and burnishing facets must be avoided. In lateral recording there is a build-up of substance from the lacquer which becomes heavy at a point just above the groove depth point, on the cutting stylus. In stereo this same condition can exist during sustained low-level portions, therefore, causing a severe marking or lining of groove walls during high level (deep groove) portions. It becomes apparent that greater care is necessary to maintain cleanliness of the stylus and avoid excessive heating.

PROCESSING CONSIDERATIONS

Recorded stereo lacquers are processed in the same manner as conventional monaural ones. However, greater care must be exercised in handling stereo stampers (negatives), after being separated from their molds (positives). Since the stampers are negatives, there will be high points of modulation projecting above average groove height. These points can be easily damaged if they are carelessly slid or scuffed. Back grinding of stampers should be done lightly enough to avoid pressure lines on the face. Surface condition of press molds is important also. Any fatigue lines or grinding chatter on these molds will usually appear on the finished record. Slight refinements of mold contour at the beaded edge portion of the disc led to some further noise reduction.

Most of these items collectively, have a bearing on the low-frequency noise spectrum. They generate noise in the 200 to 400 cycle region which is not to be confused with turntable rumble, usually 120 cycles or lower. When proper care is taken with each of these problems, the total 200 to 400 cycle noise (often termed "roar") can be lowered to a point of insignificance.

High-quality record compound is necessary because of the increased sensitivity of the stereo system to noises in the vertical plane.

PROBLEMS OF REPRODUCTION

The problems of disc reproduction fall into two categories: one, the problems of tracing geometry and, two, the problems of tracing mechanics. Basically, tracing geometry is concerned with the physical wave-lengths of modulation and the size of the reproducing stylus; that is, the ability of the stylus to resolve the modulation on the record. Tracing mechanics is concerned with the ability of the reproducing stylus to follow the motion imparted by the modulation on the record. The advent of stereo records has placed stringent requirements on both aspects of reproduction.

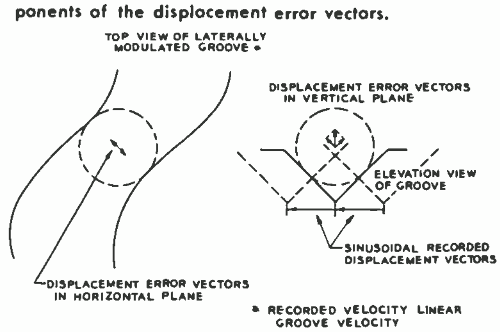
Tracing Geometry and Stylus Size

Tracing distortion, although generally small in a well-designed disc system, is inherent in disc reproduction and is a direct result of the geometry of the system. Fig. 3 shows a sphere sliding along a sinusoid. The sphere represents the tip of a reproducing stylus and the sinusoid corresponds to a modulated groove wall. The curve traced by the center of the sphere is called a poid. Representing the distance between the poid and a true sinusoid is the displacement error vector. It is evident from Fig. 3 that the center of a reproducing stylus of finite size will never trace a curve that exactly matches the modulation of the groove. However, the resulting tracing distortion can be kept low by a design compromise between modulation amplitude, linear groove velocity and reproducing stylus size.

As stated in the preceding article by H. E. Roys, tracing distortion in each channel of the 45°-45° stereo disc system is equivalent to that found in vertical disc recording.[3] Total distortion in the reproduction of a vertical recording is greater than that found in lateral recordings. This is because the lateral disc system, using a pickup electrically insensitive to vertical motion, is essentially a symmetrical or "push-pull" system, and even-order distortion components are cancelled. Fig. 4 shows the cancellation of even-order lateral components of the displacement error vectors. The vertical component of the displacement error vectors is referred to as "pinch effect," but is not reproduced by a properly designed lateral pickup. Each channel of a 45°-45° stereo pickup will of course reproduce the displacement error vector of the corresponding groove wall.

To allow for the distortion limitations in each channel of the 45°-45° system, it was necessary to reduce the radius of the reproducing stylus from the 1.0-mil size used with laterally recorded LP records. On the basis of distortion analysis by M. S. Corrington and others,[3] engineering committees of the record industry recommended a reduction in stylus radius to a nominal size of 0.7 mil. In addition, modulation levels in each channel of the 45°-45° system are reduced approximately 3 db as compared to LP records. These reductions in level

Fig. 4—Cancellation of even-order lateral components of the displacement error vectors.



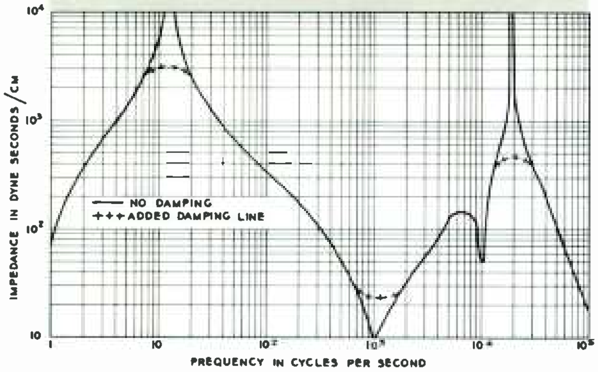


Fig. 5—A plot of mechanical impedance vs. frequency for a high quality lateral pickup-arm combination for LP records.

and stylus radius have resulted in less odd-order distortion components — more harsh to the human ear than are found in monophonic record reproduction. Even-order distortion components are greater in the 45°-45° system than in lateral recordings, but are not excessive.

Tracing Mechanics and Mechanical Impedance of the Pickup

The aspect of tracing mechanics involved in disc reproduction is generally as important for low distortion as the aspect of tracing geometry. Familiar to many who have played lateral disc records in their homes is the need for a pickup that will follow or "track" grooves without skipping or causing excessive wear.[4,5] With stereo pickups, the need for low-mechanical impedance is even greater because of the requirement of following any motion in the plane of modulation, that is, the plane formed by the modulation axes of the recorder. Problems of tracing mechanics are further complicated by the reduction in reproducing stylus radius. Record groove walls, being plastic, are subject to permanent damage if pressures on walls become excessive. Expressed mathematically, the pressure exerted by a spherical stylus on elastic walls is given by A. M. Max,[6] F. V. Hunt,[7] and others[8] as

$$P_m = K\sqrt[3]{\frac{W}{R^2}}$$

where K is a lumped constant, W is the "playing weight" or vertical tracking force, and R is the stylus radius. Although pressures normally encountered in disc reproduction do exceed the elastic limit of record materials, the above expression is useful in analyzing the degree of plastic deformation or relative wear rates of different disc systems. Thus, with the reduction of stylus radius from 1.0 to 0.7 mil for stereo records, the tracking force on the pickup should be halved to obtain ideally the same degree of wall deformation. The necessity of reducing the vertical tracking force on stereo pickups requires that the lateral mechanical impedance should be reduced accordingly. In the ideal case, the impedance should be approximately half that required in lateral pickups for LP records using a 1.0 mil stylus.

Reducing the mechanical impedance while driving two sensing elements in a stereo pickup is a considerable challenge to designers. Fig. 5 shows a plot of mechanical impedance vs. frequency for a high-quality lateral pickup-arm combination for LP records. The dominant poles of the mechanical system occur at a low frequency, referred to as "swinging resonance," and at a high frequency, called stylus-groove resonance. Swinging resonance is a resonance between the mass of the arm and compliance of the pickup armature. Stylus-groove resonance is a resonance between mass of the stylus and compliance of the groove walls. A reduction in mechanical impedance of pickups usually requires an increase in pickup compliance and a reduction of effective stylus mass, thereby moving troublesome resonances outside the audio spectrum.

CONCLUSIONS

Far from painting a gloomy picture of the prospects of stereo records, a realistic appraisal of the problems involved is necessary to insure progress of the art. In the short time since the introduction of the 45°-45° stereo disc system, several new recorders have appeared on the market. Stereo pickups that track well with playing weights as low as two to three grams have also appeared commercially. The general quality of stereo record reproduction is felt by many to be more than adequate. Most important, wide public acceptance of the new stereophonic medium is highly satisfactory.

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B. J. WHITE graduated from the University of Southern California in 1953 with a BS in E.E. degree. He joined RCA the same year as Design and Development Engineer in the recording field. His work includes research and development of magnetic tape and phonograph disc systems. Mr. White is a member of IRE and AES. He is Chairman Mechanical Recording Subcommittee and member of Recording and Reproducing Committee of IRE.

H. D. WARD attended Purdue University and entered the Air Force in 1943. He graduated from Sioux Falls AAF Radio School and Truax Field (Madison, Wisc.) specializing in JLS Aircraft, Blind Landing Systems. Mr. Ward joined RCA's Recording Engineering Section in 1946. He was instrumental in fine-groove recording development, including stylus design. As a development engineer in Indianapolis, Mr. Ward is responsible for all Test and Technical Series and disc recording and production.

Byron Finder.

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