A Stereophonic Magnetic Recorder*

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Summary—A high-quality, three-channel stereophonic recorder and playback unit was built for experimental work, to determine the requirements of a unit suitable for home entertainment. The experimental unit was purposely designed to give higher quality than is required for the home, so that the various characteristics could be degraded until performance was unsatisfactory. Results of tests indicate that two channels are adequate for a small room, and that a control track for volume expansion is unnecessary. Experiments were made with loudspeaker and microphone locations, best results being obtained with a "dihedral" mounting of two loudspeakers. This arrangement allows the design of a stereophonic reproducer in a single cabinet, and appears practical for home use.

Introduction

When one listens directly to an artist or orchestra, one of the most important factors which contributes to naturalness of the sound is binaural hearing. The left ear of the listener picks up a sound which is different in amplitude and phase from the sound picked up by the right ear. The two sounds are combined by the human hearing mechanism in such a way that the listener can judge the direction from which the sound comes, and, in addition, the psychological effect is to create a feeling that the sound source is "present."

One of the shortcomings of present-day sound-reproduction systems is that they are single-channel, and give a "flat picture" of the sound, rather than a three-dimensional presentation. To obtain binaural sound reproduction, a two-channel system as illustrated in Fig. 1 may be used. Sound is picked up by microphones placed in the "ears" of a dummy head. Each microphone has its own amplifier, which is fed into corresponding earpieces of a set of headphones. A person listening to sound through a binaural system has the illusion that the sound originates in the room, rather than in the phones. The effect is very striking to one who is used to hearing monaural sound from a headset.

Since wearing earphones is inconvenient, it is advantageous to set up a system with loudspeakers. A loudspeaker arrangement of this type is called a stereophonic system. Although it cannot give the results of a true binaural system, for a number of reasons, the improvement over monaural listening is quite marked. Experiments with binaural and stereophonic sound systems in the past have been made with certain objects in mind:

(a) Laboratory experiments to investigate the mechanism of binaural sound.

(b) Demonstrations to illustrate the advantages of binaural over monaural sound.

(c) Grand-scale demonstrations to show the utmost in high-fidelity reproduction.[1,2]

(d) Systems to give the illusion of side-to-side movement in motion pictures, corresponding to the source pictured on the screen.[3]

(e) Systems to create novelty effects in connection with motion pictures (the sounds not necessarily being intended to give the illusion of originating from a source pictured on the screen).[4]

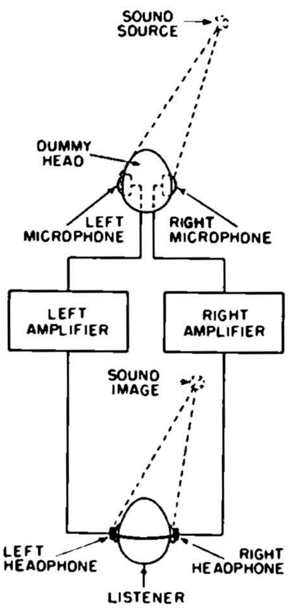

Fig. 1—Binaural sound-reproduction system.

Efforts to bring stereophonic sound into practical use have been directed toward entertainment in the theater and concert hall, since it became apparent that the complexity and cost of a stereophonic system was greater than any other single project that had yet been attempted in the field of sound reproduction.

For example, the "portable" equipment for "Fantasia's" road show had eleven 62-inch racks of amplifiers, plus power supplies and other equipment. It was

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[1] "Symposium on auditory perspective," *Elec. Engineering*, vol. 53, p. 9; January, 1934.

[2] H. Fletcher, et al., "The stereophonic sound film system," *Jour. Soc. Mot. Pic. Eng.*, vol. 37, p. 331; October, 1941.

[3] J. P. Maxfield, "Demonstration of stereophonic recording with motion pictures," *Jour. Soc. Mot. Pic. Eng.*, vol. 30, p. 131; February, 1938.

[4] W. E. Garity and W. Jones, "Experiences in road-showing Walt Disney's 'Fantasia'," *Jour. Soc. Mot. Pic. Eng.*, vol. 39, p. 6; July, 1942.

packed in forty-five cases weighing an average of 330 pounds per case, and occupied half of a standard freight car.

It appears that, even for theater use, which could stand the cost, the complexity of optical sound-on-film stereophonic systems has been great enough to prevent them from being adopted generally. Magnetic recording has been suggested, but it is still in the experimental stage.[5,6]

Stereophonic sound is, therefore, a subject that is always discussed with great enthusiasm, but nobody does anything about it. Everyone agrees that it is an excellent system, but nobody can find a practical use for it.

One field that seems to have been neglected is that of home entertainment. In fact, home entertainment is often cited as an example of a field in which stereophonic sound is entirely impractical. Stereophonic reproduction for the home brings up a number of problems which are entirely different from problems of reproduction in the concert hall or theater. For instance, the listening room in a home is very much smaller, and the listener is closer to the loudspeakers. With loudspeakers on each side of the room, he cannot back away a distance comparable to the distance between loudspeakers; in fact, the seating arrangement is often such that the listener faces the broader wall. Since the listener is free to move about the room to a considerable extent, the stereophonic illusion should be present throughout the room. Acoustics of the room are generally fixed and little can be done about them, so the home stereophonic reproducer should be adaptable to various shapes and layouts of living rooms.

Experimental Stereophonic System

Over-All Requirements

A magnetic recording system seemed to be the only one capable of approaching the economic requirements of a home unit. To investigate the possibilities of home stereophonic entertainment, a tape recorder and playback unit was built to meet the following specifications:

Number of channels	—three
Frequency response	—flat from 50 to 10,000 cycles within 5 db
Distortion	—less than 4 per cent intermodulation distortion, or 1 per cent harmonic distortion at normal recording levels
Dynamic range	—60-db spread between maximum modulation level and noise level
Wow and flutter	—less than 0.1 per cent

[5] M. Camras, "Magnetic sound for motion pictures," *Jour. Soc. Mot. Pic. Eng.*, vol. 48, p. 14; January, 1947.

[6] M. Camras and R. E. Zenner, "Binaural magnetic recorder," presented, Acoustical Society of America, 33rd Meeting, Hotel Pennsylvania, New York, N. Y., May 9, 1947.

The experimental model was purposely designed for better performance than was thought necessary for home application, because it would be used for recording as well as for playback. Also, with the higher-quality system, experiments could be made in which each of the characteristics would be degraded until the performance was unsatisfactory. Thus the requirements for a home system could be established.

Stereophonic Tape

The drive unit for the stereophonic system is shown as the left-hand unit in Fig. 2. It accommodates a 7-inch reel of either $\frac{1}{4}$- or $\frac{1}{2}$-inch-wide tape. At the normal running speed of 1 foot per second, a full reel of $\frac{1}{4}$-inch tape plays for 20 minutes. A full reel of $\frac{1}{2}$-inch tape plays for 20 minutes on one edge, after which it is turned over and played for 20 more minutes on the other edge, giving a total of 40 minutes. Fig. 3(a) shows the arrangement and dimensions of the magnetic tracks on the $\frac{1}{4}$- and $\frac{1}{2}$-inch tapes.

Stereophonic Heads

The stereophonic heads are arranged as in Fig. 3(b). An erase head extends across the entire width of the tape and clears off all three channels. The record heads are staggered along the length of the tape, to permit mechanical and electrical isolation. At the section where head No. 1 is recording on track No. 1, the other two tracks are covered by a keeper made of high permeability alloy. The same applies to the other heads.

For simplicity, the same heads are used also for pickup. In this case, when the No. 1 head is picking up, the adjacent channels are "short-circuited" out by keepers to prevent crosstalk. The other channels are protected in the same way. Without keepers, it has been found that heads are sensitive to recordings on channels as far as $\frac{1}{8}$ inch or more from the head, the effect being especially pronounced at low frequencies.

Amplifiers

Fig. 2 shows the three units which comprise the complete stereophonic system except for the microphones and loudspeakers. At the left is the drive unit, already

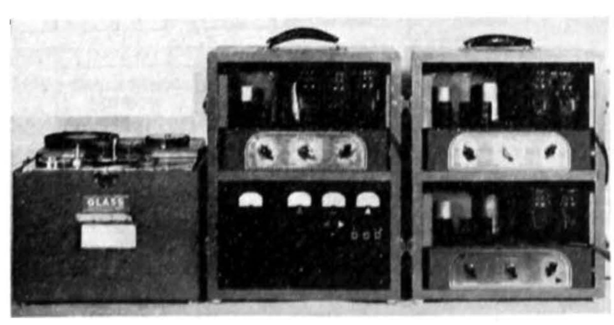

Fig. 2—Stereophonic system

described. The lower section of the center unit is the master-control panel and oscillator. The upper half of the center unit is the amplifier for channel No. 1, and the sections of the right-hand unit are amplifiers for channels Nos. 2 and 3.

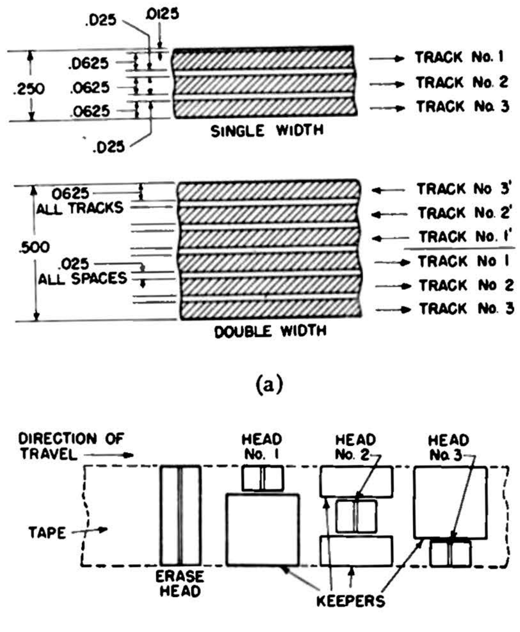

Fig. 3—Stereophonic magnetic tape and heads. (a) Tape dimensions. (b) Head arrangement.

Typical Three-Channel System

A block diagram of a typical recording setup for the three-channel stereophonic system is shown in Fig. 4. Western Electric 639B cardioid microphones were used for pickup of the original sound. Altec Lansing loudspeakers on each side, as well as in the center of the room, were used for reproduction.

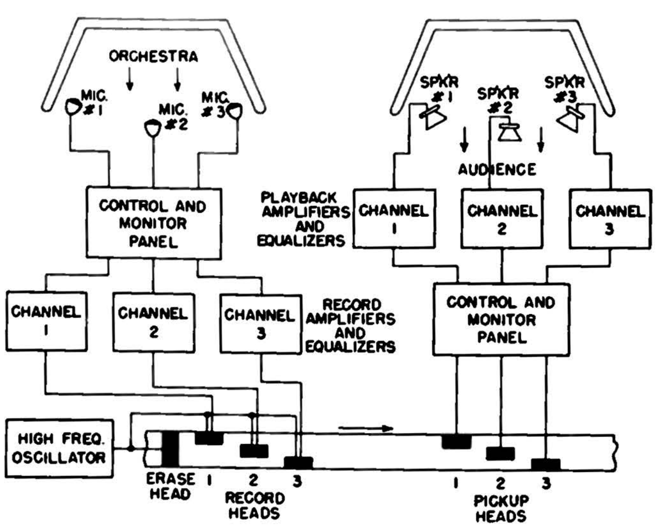

Fig. 4—Block diagram of the stereophonic magnetic recording and playback system

Results of Experiments

Methods of Adjusting Gain

To control the relative gain of the separate channels, the most obvious method is to adjust them separately so that a standard sound intensity in any microphone will set up a standard sound intensity near the corresponding reproducing loudspeaker on playback. Ordinarily, the maximum sound intensity picked up by the different microphones during a rendition will be different. This allows the use of a method for setting as shown

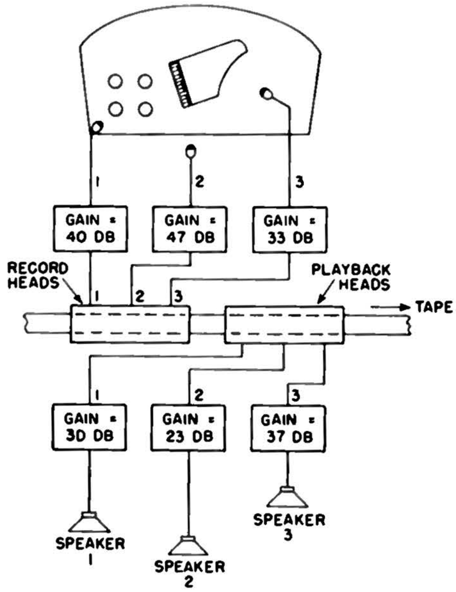

Fig. 5—Method for setting gain of stereophonic channels.

in Fig. 5, where, during recording, the gain of each channel is set at the maximum point that will not produce overload of the recording at any time. On playback, the gains of the amplifiers are set in inverse ratio to the recording amplification. Thus, the playback amplifiers may be set to compensate for the different gains of the record amplifiers, as well as unequal efficiencies of microphones, heads, loudspeakers, acoustic phenomena, etc., and a maximum signal-to-noise ratio is obtained.

Use of a Control Track

With three channels available, one of the possibilities to be explored was the use of two channels for audio, and the third channel as a control track, to vary the volume of the audio channels and thus increase the dynamic range. It was soon found, however, that the dynamic range offered by the audio channels was entirely adequate for home use without resort to compression and expansion. With music reproduction at a comfortable volume level, the ambient room noise of both the recording and the listening rooms was enough to mask the ground noise. It was decided, therefore, that a control channel was an unnecessary complication.

Comparison of the Two-Channel and Three-Channel Systems

Even at the start, it was felt that two channels should be enough for a small room, rather than three. Experiments were made with two and with three channels to determine their relative merits. For solo work and for announcements, the center channel adds realism by giving the effect of clarity and nearness. This is understandable, for, if only the outside channels are used, the sound has to travel a considerable distance before it is picked up by the side microphones, and the ratio of reverberant to direct sound is high. A similar effect occurs on playback through the side loudspeakers. The situation can be improved without adding a third channel by using a separate microphone for the soloist or announcer, and feeding its output into both of the side channels as shown in Fig. 6.[1] An additional loudspeaker could be used on playback, but this also has some disadvantages.

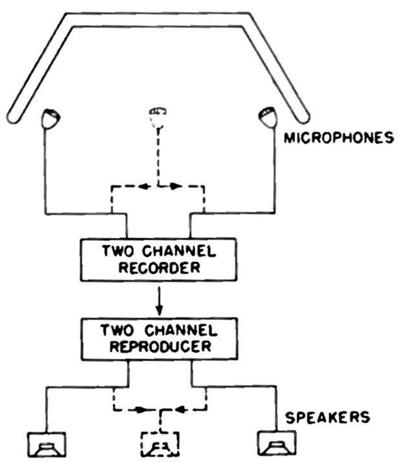

Fig. 6—Experimental two-channel system.

A number of experiments made with orchestral music and other sound indicated that they could be handled adequately by a two-channel system. It would seem that, even for announcements and solos, the lack of a center channel would only give the illusion that the performer is further away from the listener, and for home entertainment this illusion might even be desirable. All things considered, it was decided that a two-channel system gave results that were sufficiently good for a home unit.

Loudspeaker System

The first experiments were made with loudspeakers set up as in Fig. 7(a), since it seemed logical that the best place for the loudspeakers was against the sides of the room and spaced apart. Fair results were obtained with the listener in position *a*, but when the listener stood to one side of the room, as at *b*, the closer loudspeaker predominated. Positions such as *c* were unfavorable because the listener was conscious of two sources. The arrangement of Fig. 7(b) was even worse in this respect.

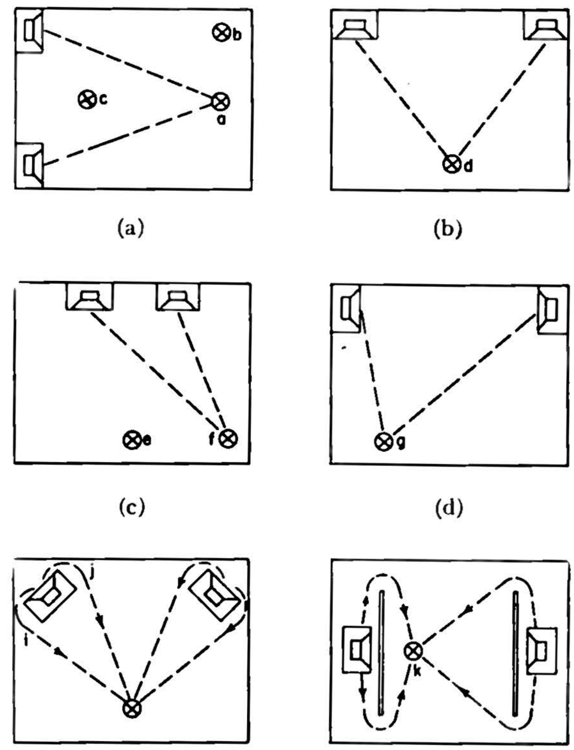

Fig. 7—Experiments with loudspeaker placement.

The loudspeakers were now moved closer together in several steps, until they were next to each other. They are shown in an intermediate position in Fig. 7(c). When the loudspeakers were fairly close, the sound no longer seemed to come from two separate point-sources, but at the same time the apparent "spread" of the orchestra was reduced.

To reduce the distorted spatial effects for a listener in a position such as *f* in Fig. 7(c), a sidewise loudspeaker position as in Fig. 7(d) was tried. With such an arrangement, the left-hand loudspeaker is closer to a listener in position *g*, but the right-hand loudspeaker faces him more directly and compensates for the increased distance. By control of the variables, it is possible to work out good compensation over much of the room area.

With all of the above arrangements, a careful listener can usually pick out the location of each loudspeaker, even when blindfolded. It seems that higher-frequency sound can be localized very closely at the loudspeaker cone, especially if the listener is allowed to move his head. When a listener is trying to locate the sound, we find that he turns his head back and forth several times until he has it "fixed." Then he faces the source and points to it.

A listener in the home is not obliged to keep facing in a particular direction, as someone at a concert usually does. Seats in a living room seldom face in one direction. Also, the listener is free to get up and walk about the room. To decrease localization effects, a number of schemes were tried for diffusing the sound. In Fig. 7(e) the loudspeakers were turned toward the corners of the room. The sound has to come from *i* or *j* or both, and gives the effect of a larger source. Systems as shown in Fig. 7(f) were also tried. Here some rather large baffle boards were put in front of the loudspeakers to prevent direct radiation. This arrangement gave the interesting effect of having the entire room filled with music, and was effective over a considerable portion of the room area.

A great many other schemes were tried until one was evolved which gave exceptionally good results. This system is shown in Fig. 8. The loudspeakers are placed fairly close together and at an angle to each other facing the wall. Upon first inspection it would not seem that this system could give results as good as with widely spaced loudspeakers. Yet actual listening tests showed that the sound seemed to come from all parts of the front wall (such as *p*, *q*, *r*, *s*,), as well as from the sides (areas *n*, *o*, *t*, *u*). The illusion was present over almost the entire room. Troublesome echo effects that were noticeable with the other loudspeaker arrangements were absent with the new system.

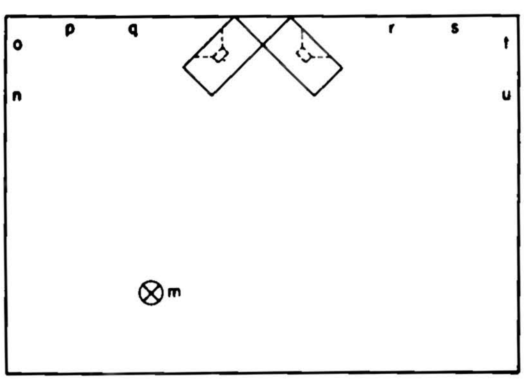

Fig. 8—Dihedral loudspeaker system.

A possible explanation of this effect is given by Fig. 9(a). The reflected sound from loudspeaker (1) acts as if it came from the virtual source (1′), which is located over to the left, beyond the room boundaries. Similarly, virtual source (2′) is located beyond the right-hand wall. Only the short-wavelength higher-frequency sounds will behave in this manner, but it is this class of sounds that the ear uses for localizing a source. As has been noted before, the high-frequency components beaming from a loudspeaker are responsible for the feeling of a point source when an observer faces the loudspeaker. A good proportion of the sounds arrive directly from the loudspeaker and by reflection from the front wall, so that the sound sources appear pretty well spaced along the front. The acoustic conditions can be modified by treating the walls at *x* and *y*. Draperies hung at *x* gave improved results under some conditions.

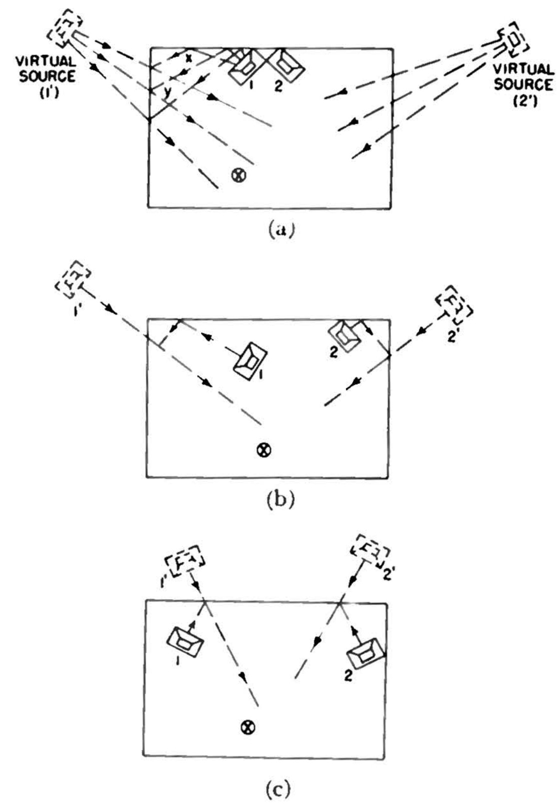

Fig. 9—Operation of reflective loudspeaker systems.

By changing the loudspeaker location, the virtual sources can be moved as shown by Fig. 9(b). They can be moved inside the side wall boundaries, if arranged as in Fig. 9(c). The arrangement need not be symmetrical, as in Fig. 9(a), but can be nearer to one corner, etc., depending on the interior decoration scheme, location of doors and windows, and other acoustical conditions. Relative input power to each loudspeaker should also be adjusted, and some extra emphasis of high frequencies may be desirable in order to compensate for absorption of the walls.

Microphone Placement

For a dihedral sound projection system, placement of the original pickup microphones is important. They could be spaced far apart, at the approximate location of the virtual loudspeaker images of Fig. 9(a), if the recording studio is large enough. Or, if the added reverberation is not detrimental, they could be substituted for the loudspeakers in the setup of Fig. 9(a). An excellent arrangement is shown in Fig. 10. Directional microphones are used, spaced apart about the same distance as the loudspeakers. A sound-absorbing baffle can be placed between the microphone for improved isolation. With pickup as in Fig. 10, the phase relations of reproduced sound from dihedral loudspeakers can be made correct, regardless of the relative acoustics of the record and listening rooms. An announcer or soloist can operate in front of one or both microphones with results that are very satisfactory.

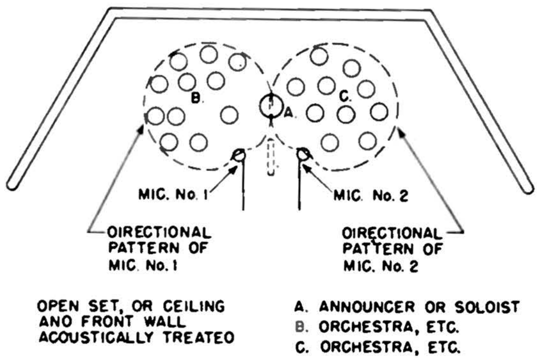

Fig. 10—Microphone placement for dihedral recording.

Home Stereophonic Unit

As a result of tests with the experimental stereophonic system, the design for a home model shown in Fig. 11 was evolved. The dihedral system of projection allows the machine to be built as a single unit. The drawers at the top house the stereophonic tape drive, the dual-channel amplifier, and a conventional-type radiophonograph combination. Two loudspeakers in bass-reflex housings are set at an angle and face toward the back. A grille-work on the face is for decorative purposes, although it is possible to put a third loudspeaker in front for a center channel.

There is a marked advantage in using the dihedral loudspeaker system, even with the conventional single-channel radio or phonograph. The sound seems to come from an area rather than a point, and is more full and more pleasant than with a single loudspeaker in front of the cabinet.

Whether there may be stereophonic AM or FM broadcasting sometime in the future is hard to predict. If there are a sufficient number of home stereophonic units, it is conceivable that large metropolitan areas would have at least one stereophonic broadcasting station. The second channel could be received by a separate external adapter unit, if a dual receiver were not already built into a large set.

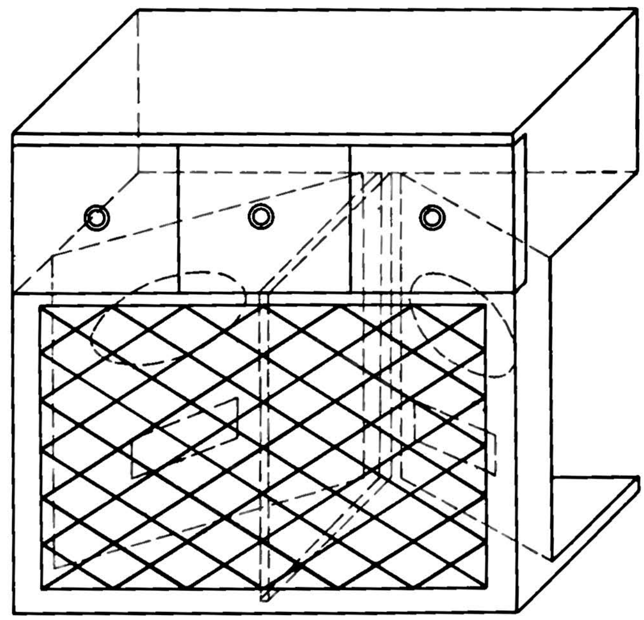

Fig. 11—Home stereophonic unit.

Conclusions

A home stereophonic system has been developed which provides new listening pleasure for home entertainment. The unit is usable in the average living room, and its cost is low enough to allow widespread use.

Transient-Response Equalization Through Steady-State Methods*

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Summary—**This paper describes a steady-state method for matching the pulse-response characteristics of two or more networks using only a sinusoidal signal generator and a cathode-ray oscilloscope. Photographs of the patterns displayed on the screen of the oscilloscope, and analyses to permit rapid determination of the network adjustments to effect equal pulse-response characteristics, are presented.**

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Introduction

For some purposes, the relative transient response of two or more networks may be of greater interest than the absolute transient response of either network alone. Examples are found in the pulse-response characteristics of laboratory comparators[1] and instantaneous cathode-ray-tube direction

[1] R. A. Watson-Watt, J. F. Herd, and L. H. Bainbridge-Bell, "Applications of the Cathode Ray Oscillograph in Radio Research," His Majesty's Stationery Office, London, pp. 123–125; 1933.