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3,022,378

MONAURAL-BINAURAL TRANSMISSION OF SOUND

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2 Sheets-Sheet 1

FIG. 1

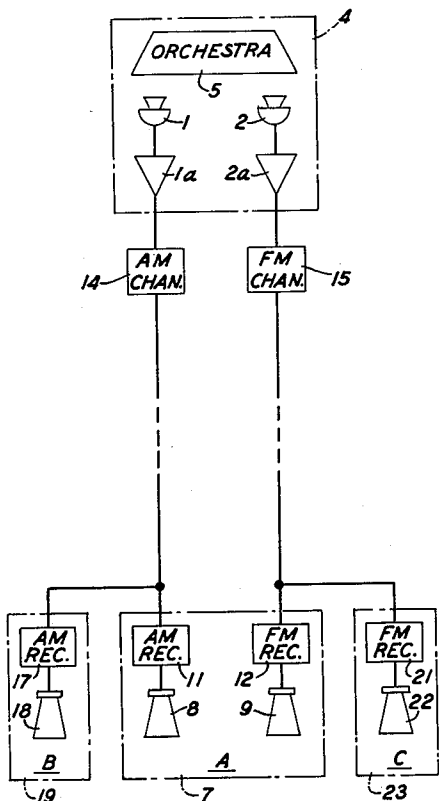
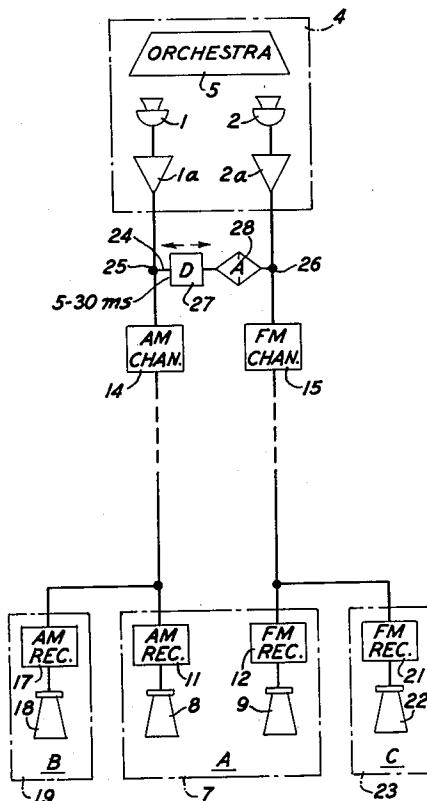


FIG. 2



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FIG. 3

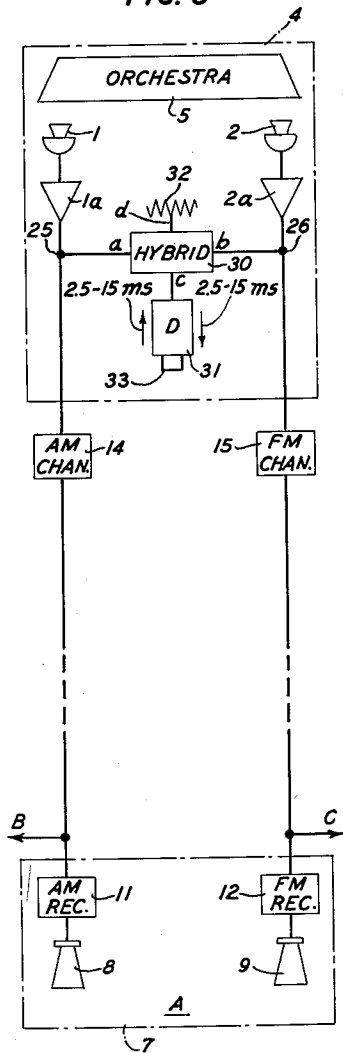
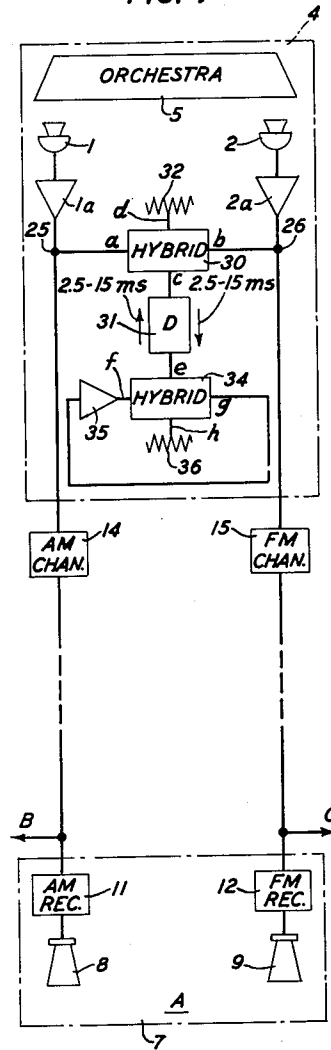


FIG. 4



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3,022,378 MONAURAL-BINAURAL TRANSMISSION OF SOUND

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13 Claims. (Cl. 179-1)

This invention is concerned with the high quality transmission of sound signals, e.g., musical programs. Its principal object is to provide for the interchangeability, at the choice of the listener, as between multichannel stereophonic reproduction and single channel transmission.

As the art of transmitting and reproducing sound signals advances, an increasing amount of attention is paid to refinements. One such refinement, which is presently becoming of increasing importance, is to increase the listener's impression of realism or "presence" by employment of binaural or stereophonic techniques. In its simplest form a system of this character comprises at least two wholly independent channels leading from a studio housing an extended sound source, e.g., an orchestra engaged in the performance of a musical composition. Each channel is complete with a microphone at the studio, a sound reproducer in the listener's room, and an intervening transmission medium. Various well-known techniques may be employed to maintain complete independence of each channel from the others. For example, if the program is broadcast by radio transmission the broadcast carrier frequencies may be different. A presently popular approach is to employ the same carrier frequency for both of two channels, utilizing the output of one microphone to modulate the amplitude of its carrier wave and utilizing the output of the other microphone to modulate the frequency of its carrier wave.

With such systems the microphones are ordinarily placed on a line parallel with the front of the stage and are spaced apart along this line, one being placed toward the right-hand end of the stage and the other toward the left-hand end.

When two such channels are individually connected to earphones in such a fashion that the listener's right ear hears only the output of one microphone and his left ear hears only the output of the other, very pronounced, even startling, impressions of the spatial distribution of the sound source are the result. To avoid the inconvenience of wearing earphones and to permit all the occupants of a room to hear the program it is customary to employ loudspeakers instead of individual earphones. When such loudspeakers are appropriately disposed a realistic impression of the spatial disposition of the orchestra or other sound source is the result.

It happens, however, that it is not always convenient or even possible for a listener to utilize both of such channels. When, for instance, in the example given he is provided only with an amplitude modulation radio receiver and a single reproducer the music or other sounds which he receives are unbalanced to an annoying extent. This is because of the asymmetrical disposition of the single microphone to which his receiver is in effect connected. Thus the quality of the musical program which he receives is distinctly poorer than it would be with a single microphone symmetrically located in the studio.

The same situation arises in still more extreme form when three or more channels are employed, in which case one microphone is located close to one end of the studio stage, another microphone is located close to the other end of the studio stage, while the third is located

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at the center of the stage and too close to the central part of the sound source for balanced reproduction. In this situation a listener who is in effect connected to only one of the end microphones receives an impression of a highly unbalanced performance.

My Patent 2,819,342, granted January 7, 1958, provides a cure for this difficulty, permitting the single channel listener to take full advantage of all the studio microphones that are in operation. It does so by the addition of unidirectional cross-coupling paths, each extending from the output point of one microphone to the input point of the transmission channel connected to one of the other microphones. Each such cross-coupling path includes a delay device which is proportioned to delay signal transmission through such cross-coupling path by about 5-30 milliseconds relatively to the transmission over the direct paths. Transmission by each cross-coupling path only in the single desired direction is ensured by including in it a unidirectional device such as a buffer amplifier. With this arrangement the single channel listener receives sound signals originating in all the microphones, the signals originating in the microphone to which he is directly connected being undelayed and the others delayed by 5-30 milliseconds.

In the case of a sound source that is substantially closer to one microphone than to the other, the delayed signal is virtually unnoticeable. In the case of a centrally located sound source, the impression formed in the listener's mind by a delay of this magnitude is merely one of reverberation; i.e., his impression is that the sound signals are originating in a "live" studio as distinct from a "dead" one. On the other hand, a listener who is provided with the two or more channels and takes full advantage of the disposition of the microphones at the studio for the sake of the realism thus produced receives the output of each microphone as in the ordinary stereophonic system. He also receives in each of his reproducers a delayed reproduction of the output of each other microphone. Such delayed reproduction, however, does not noticeably reduce the sense of directionality achieved by way of the undelayed reproduction. The system thus takes advantage of the "Haas" effect, now a well established phenomenon which is described by its discoverer in *Acoustica*, vol. 1, No. 2, pages 49-58, 1951, wherein it is shown that a hearer's impression of the direction from which he receives a sound is determined principally by which one of two sounds of like character first reaches him.

The present invention stems from the realization that it is possible to achieve substantially the same distribution, both in space and in time, of the reproduced sounds, and therefore to produce substantially the same impression of realism in the listener, with a smaller number of individual delay devices than that required by the system of the earlier patent and without resort to the unidirectional transmission devices that are featured in that patent. Taking a system of two channels as an example, the present invention provides a single bidirectional or reciprocal cross-coupling path between them, thus cutting the number of delay devices in half and eliminating the unidirectional devices altogether. This substantial economy of circuit components is rendered possible by selection, for the delay device, of a component that is constructed to carry two message waves simultaneously and together, one traveling in one direction and the other traveling in the opposite direction, and without interference between them. Additionally, in order that each microphone shall be able to deliver its message wave equally well to the cross-coupled reproducer as to the directly coupled reproducer, and similarly that each reproducer shall accept energy equally well from the cross-

coupled microphone as from the directly coupled microphone, certain impedance match requirements are observed. Specifically, the delay device, which constitutes the principal component of the cross-coupling path, may be constructed to have a characteristic impedance that is equal to the impedance of the combined incoming and outgoing portions of each of the direct channels to which it is coupled. In accordance with the known behavior of characteristic impedance elements, the impedance seen at each end of the cross-coupling path, looking through it and through the direct channel coupled to its other end, has nearly the same magnitude as the impedance seen from the same point looking into the nearest direct channel alone. Each microphone then "sees" an effective impedance constituted of two impedances in parallel, of which one is that of its own direct channel while the other is that of the cross-coupling path and the other direct channel, coupled together in tandem. The message wave that originates at each microphone, therefore, divides equally between the two paths, reaching the directly coupled reproducer first and then, after a delay of 5-30 milliseconds, reaching the cross-coupled reproducer. The small amount of attenuation that inevitably attends transmission of a wave through the delay device of the cross-coupling path, far from being harmful, is generally of advantage in accentuating the listener's impression of directionality.

The invention will be fully apprehended from the following detailed description of preferred illustrative embodiments thereof taken in connection with the appended drawings in which, for simplicity of illustration each electrical energy path is represented by a single line. In actuality, of course, two conductors are normally required. In these drawings:

FIG. 1 is a block schematic diagram showing a conventional binaural sound transmission system reduced to its simplest terms;

FIG. 2 is a block schematic diagram showing binaural-monaural sound transmission apparatus in accordance with the invention in one embodiment;

FIG. 3 is a block schematic diagram showing apparatus in accordance with another embodiment; and

FIG. 4 is a block schematic diagram showing a modification of the apparatus of FIG. 3.

Referring now to the drawings, FIG. 1 shows a left-hand microphone 1 and a right-hand microphone 2 spaced apart on the stage of a studio 4 on which is an extended sound source 5 such as an orchestra engaged in the performance of a musical composition. In the residence 7 of a first listener A, which may be located at a distance, are two sound reproducers 8, 9 spaced apart for stereophonic reproduction, each supplied with voice frequency signals from a receiver 11, 12. The receiver 11 of the left-hand reproducer 8 is coupled to the left-hand microphone 1 by way of an amplifier 1A and a first transmission channel 14, and the receiver of the right-hand reproducer 9 is coupled to the right-hand microphone 2 by way of an amplifier 2A and a second transmission channel 15. These channels, which may be of any desired variety, are completely decoupled from each other, as for example by employment of amplitude modulation radio transmission in the left-hand channel and frequency modulation transmission in the right-hand channel. The respective receivers 11, 12, are, of course, designed accordingly. With this arrangement the listener A receives high quality sound reproduction which includes a realistic impression of the spatial distribution of the orchestra 5 or other sound source in the studio 4.

An additional amplitude modulation receiver 17 and a sound reproducer 18 are coupled to the left-hand channel 14. They are indicated as being located in the residence 19 of a second listener B who is provided with no other receiving or reproducing facilities. A frequency modulation receiver 21 and a reproducer 22 are coupled to the right-hand channel 15 and are shown as being located in the residence 23 of a third listener C who again

is provided with no other receiving or reproducing facilities.

Evidently the listener B, with his amplitude modulation receiver and reproducer, receives the output only of the left-hand microphone 1, while the listener C with his frequency modulation receiver and reproducer receives the output only of the right-hand microphone 2. Because of the asymmetrical location of each of these microphones with respect to the orchestra 5 or other extended sound source, the reproduced music appears to the listener B to be unbalanced in one way and to the listener C to be unbalanced in another way.

FIG. 2 shows a system in accordance with the invention wherein the studio 4, the sound source, e.g., the orchestra 5, the microphones 1, 2, the amplifiers 1A, 2A, the transmission channels 14, 15, the sound reproducers 8, 9, 18, 22 and the interconnections between these components are as before. FIG. 2 differs from the conventional system of FIG. 1, however, by the addition of a bidirectional cross-coupling path 24 interconnecting the output point 25 of the left-hand microphone amplifier 1A with the input point 26 of the right-hand transmission channel 15 and containing a delay device 27. Evidently, this cross-coupling path also interconnects the output point 26 of the right-hand microphone amplifier 2A with the input point 25 of the left-hand transmission channel 14. A bidirectional amplifier 28 may be connected in tandem with the delay device 27 to offset any losses it may introduce, although such losses may be of advantage.

The delay device 27, which constitutes the principal component of the cross-coupling path 24, may be constructed to have a characteristic impedance Z_0 that is equal to the impedance of the parallel combination of the incoming and outgoing portions of each of the direct channels 14, 15 to which it is coupled. In accordance with the known behavior of characteristic impedance elements, the impedance seen at each end 25, 26, of the cross-coupling path 24 looking through it and through the direct channel coupled to its other end, has closely the same magnitude as the impedance seen from the same point looking into the nearest direct channel alone. Each microphone amplifier then "sees" an effective impedance constituted of two impedances in parallel, of which one is that of its own direct channel while the other is that of the cross-coupling path and the other direct channel, coupled together in tandem.

When the cross-coupling path is located at the studio so that the path from each microphone to the junction point of the outgoing channel with the cross-coupling path is short, the simplest way to accomplish this result is by providing a preamplifier, immediately following each microphone, that has an output impedance that is high compared with all other impedances of the system. In this case the characteristic impedance of the cross-coupling channel can be matched, at each end, to the impedance of the outgoing direct channel alone. When for any reason this simple solution is impossible as, for example, when the signal from the microphone or its preamplifier must be carried for a long distance before reaching the junction point, the impedance of the incoming portion of each direct channel must be taken into account in proportioning the elements of the cross-coupling path so that its characteristic impedance shall match the parallel combination of the incoming and outgoing portions of the direct channel. A well-known network, such as a three-winding transformer, can be utilized to effect a three-way match at each of the junctions; that is to say, the impedance of the incoming link of the direct channel matches the parallel combination of the cross-coupling path with the outgoing portion of the direct channel while, at the same time, the incoming and outgoing portions of the direct channel taken together in parallel, match the impedance of the cross-coupling path. Similarly, a match can be effected between the impedance of the outgoing portion of each channel and the parallel combination of

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the incoming portion of the same channel with the cross-coupling path.

In the operation of the system of FIG. 2, consider first the two sound reproducers 8, 9 that are located together in A's residence and disposed in appropriate fashion for binaural reproduction. A sound originating close to one microphone, for example, the left-hand microphone 1, e.g., the sound of an orchestra instrument played by a performer who is seated close to this microphone, reaches the hearer by two paths. It reaches him first by way of the direct path, namely the channel 14 and the left-hand reproducer 8. After a delay of 5-30 milliseconds introduced by the delay device 27, it reaches him by way of the indirect path constituted of the cross-coupling path 24, the channel 15 and the right-hand reproducer 9. In accordance with the Haas effect the listener A recognizes the sound as reaching his ears from the left-hand reproducer 8 and not from the right-hand one 9. Inasmuch as the same consideration hold for partial sounds originating in other portions of the studio, the listener A, who is provided with both channels, both receivers and both reproducers, receives the impression that the orchestra 5 is spread out spatially before him.

Consider, to the contrary, the two reproducers that are located in the two wholly separated residence of which the left-hand one 19 is equipped with an amplitude modulation receiver 17 and the right-hand one 23 with a frequency modulation receiver 21. The two listeners B and C are obviously restricted to single channel reception. However, each one receives sound originating at both microphones 1, 2 and consequently the apparent point of origin of such sounds is at a location intermediae between the two microphones so that no impression of orchestra imbalance is received. Under such conditions he receives the sounds originating at one microphone directly and those originating at the other microphone after a short time delay which, however, is noticeable, only as a slight increase in the apparent reverberative quality of the studio.

Thus the single bidirectional cross-coupling path 24, with one delay device 27, accomplishes the same purposes as do the two paths, two delay devices and two buffer amplifiers of the patent referred to above, and the length and cost of the principal component, the delay device, have been reduced by a factor 2.

FIG. 3 depicts a system, otherwise the same as that of FIG. 2 and from which, to avoid needless repetition, the receivers of listeners B and C are merely indicated. By virtue of this modification the length, and therefore the cost, of the bidirectional delay device is further reduced by an additional factor 2. The cross-coupling path that interconnects the point 25 of the left-hand channel with the point 26 of the right-hand channel includes a hybrid coil 30 of which a first terminal *a* is connected one of the direct channels 14, a second terminal *b* to the other direct channel 15, a third terminal *c* to the input point of a delay device 31 and a fourth terminal *d* to a conventional hybrid balancing network 32. The delay device 31 itself is terminated for complete reflection, e.g., by a short circuit 33 or an open circuit. The delay device 31 is proportioned to delay a wave in the course of propagation from one end to the other by 2.5-15 milliseconds, and hence to introduce a delay of 5-30 milliseconds in each full round trip.

By appropriate design of the hybrid coil 30 and of the delay device 31, the impedance seen at the junction 25 looking through the hybrid coil 30 and into the cross-coupled channel 15 is made equal to the impedance seen at the same junction looking through the direct channel 14 to the directly coupled reproducer 8. The same impedance adjustment is provided at the other junction 26. Hence the effective impedance Z_e seen by each microphone is equal to

$$\frac{Z_d}{2}$$

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With this arrangement any wave originating at the left-hand microphone 1 reappears first at the directly coupled reproducer 8 and then, after a delay of 5-30 milliseconds, reappears at both reproducers 8, 9 together. To this extent the performance of the system of FIG. 3 and the consequent impressions produced in the listener A differ from those in the system of FIG. 2. The simultaneous reproduction of the delayed wave at both reproducers 8, 9 produces in the listener the impression of a centrally located virtual source.

As in the case of the system of FIG. 2 a listener who is provided with only one reproducer receives undelayed sound from the microphone to which he is directly connected and delayed sound from the other microphone so that, for him, the imbalance in reproduction due to the asymmetrical location of his direct coupled microphone on the stage is reduced as compared with what would be the case without the cross coupling of the invention. In addition, the delayed reproduction of the sound originating in his directly coupled microphone serves as artificial reverberation and adds to the sonorousness of his reproduced sound.

FIG. 4 shows a modification of FIG. 3 in which the reflecting termination of the delay line is replaced by a hybrid coil 34. Downcoming wave energy, after suffering a delay of 2.5-5 milliseconds from the delay device 31, enters the hybrid coil 34 at terminal *e* where it divides between terminal *f* and terminal *g*. Outgoing wave energy at terminal *f* is blocked by a unidirectional amplifier 35. Energy outgoing at terminal *g* is supplied through this amplifier 35 to terminal *f* where it divides between a balancing net 36 connected to terminal *h* and the delay device 31 connected to terminal 1. Thereupon, it returns to the cross-coupling path undergoing a second delay of 2.5-15 milliseconds in doing so.

The two energy divisions in the hybrid coil 34 require the amplifier 35 to offset them. The amplifier 35 may, if desired, readily be proportioned to offset the losses introduced by the two traverses of the delay device 31 as well.

In any of the three forms shown in FIGS. 2, 3 and 4, the invention may readily be extended to the case of three or more microphones with three or more individual direct channels each with its own reproducer, by provision of a bidirectional cross-coupling path from the channel of each microphone to the channel of each other microphone.

The system of my Patent 2,819,342 with its unidirectional cross-coupling paths, each including a delay of appropriate magnitude, can be utilized without change in the simulation of space effects in contrast to their true reproduction. Faulkner Patent 2,768,237, granted October 23, 1956, shows a sound system of this type for effecting such simulation. Insofar as the system of the present invention produces the same effects as the system of my patent with economy of apparatus, it can evidently be utilized for simulation of space effects as well as for their reproduction.

What is claimed is:

1. Apparatus for generating and transmitting stereosignals which comprises, in combination with a pair of microphones disposed in mutually spaced relation to a sound source in a fashion selectively to receive energy originating in and spreading in different directions from said source, a pair of input points, each arranged to receive energy derived from one of said microphones, a direct transmission channel extending from each of said input points, a reproducer supplied by each of said channels, and a single, reciprocal cross-coupling path interconnecting said channels and providing for simultaneous two-directional transfer of energy from each one of said channels to the other of said channels, said cross-coupling path including means for delaying the transmission of signals therethrough by a preassigned time interval in the range 5-30 milliseconds.

2. Apparatus as defined in claim 1 wherein said cross-coupling path comprises a delay device connected in series between said direct channels and common to both directions of said two-directional flow of energy.

3. In combination with apparatus as defined in claim 2, a bidirectional amplifier connected in series with said delay device.

4. Apparatus as defined in claim 1 wherein said cross-coupling path includes two terminals of a hybrid coil connected in series with said path, wherein a third terminal of said hybrid coil is connected to a balancing network and a fourth terminal is connected to one end of a bidirectional delay device, the other end of said delay device being terminated for substantially complete return of signal energy reaching it from said one end.

5. Apparatus as defined in claim 4 wherein said delay device is proportioned to delay, by one-half of said preassigned interval, signals traveling through it once, from either end to the other end.

6. Apparatus as defined in claim 4 wherein said termination is a short circuit.

7. Apparatus as defined in claim 4 wherein said other end of said delay device is connected to one terminal of a second hybrid coil, wherein the second terminal of the second hybrid coil is connected to the third terminal by way of a unidirectional amplifier and wherein a balancing network is connected to the fourth terminal of the second hybrid coil.

8. Apparatus as defined in claim 1 wherein each of said direct channels is proportioned to present, at its input point, an impedance Z_d , and wherein the cross-coupling path is proportioned to have a characteristic impedance, seen from either end, that closely matches the impedance of the direct channel to which it is connected at its other end.

9. Apparatus as defined in claim 1 wherein the several direct paths and the cross-coupling path are so proportioned as to present, to each of said input points, an impedance that is constituted of two impedances of substantially equal magnitudes in parallel, of which one is that of the direct channel connected to that input point while the other is that of the tandem combination of the cross-coupling path with the other direct channel.

10. In combination with apparatus as defined in claim 1, an additional reproducer, acoustically isolated from all other reproducers, and means for supplying said additional reproducer with signals received from only one of said channels.

11. Apparatus for generating and transmitting stereosignals representative of sounds originating in an extended

sound source which comprises a pair of microphones disposed in spaced relation to each other and to said source in a fashion selectively to receive sound energy from various parts of said source, an amplitude modulation transmission channel and a frequency modulation transmission channel, a direct path for supplying output energy of each of said microphones directly to one of said channels, and a single reciprocal cross-coupling path interconnecting said channels, said cross-coupling path including means for delaying the transmission of signals therethrough by a preassigned time interval in the range extending from 5 milliseconds to 30 milliseconds.

12. In combination with apparatus as defined in claim 11, an amplitude modulation receiver and a frequency modulation receiver, means for supplying each of said receivers with the signals of one of said channels, a reproduction chamber, a pair of sound reproducers disposed in spaced relation within said chamber for stereoreproduction of sound, and connections for supplying each of said reproducers with output signals of one of said receivers.

13. Apparatus, compatible with monaural and binaural reception, for processing sound waves picked up by individual microphones disposed in a spaced relation to each other and delivered by individual reproducers that are similarly disposed, which comprises a pair of direct transmission channels, one such channel extending from each of the microphones to one of the reproducers, and, cross-coupling said channels, a single, electrically symmetrical, bidirectionally conducting path, including signal retarding means, for commonly conveying a retarded replica of the signals directly transmitted by each channel to the other channel, and for supplementing, in each channel, the direct signal of that channel with the retarded replica of the signal from the other channel, the symmetry of said cross-coupling path serving to ensure that the supplementation is of like degree in the two channels.

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