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M. FOUQUÉ

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REPRODUCING SYSTEM

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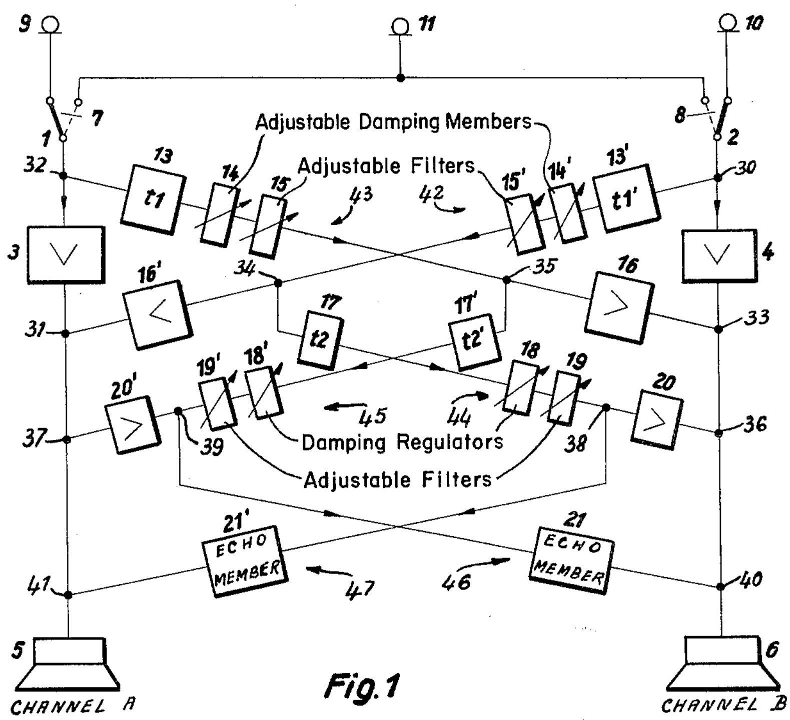

Fig. 1

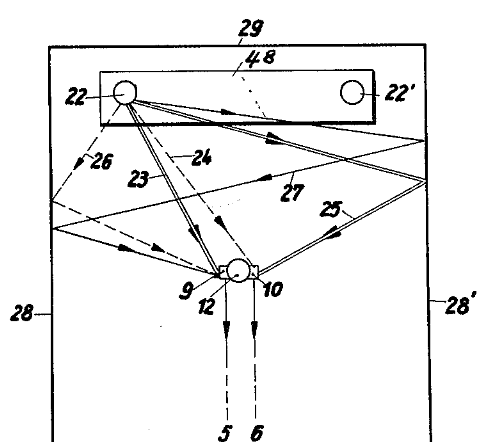

Fig. 2

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REPRODUCING SYSTEM

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The present invention relates generally to sound recording and/or sound reproduction systems using two reproduction channels, and especially to an arrangement for stereophonic reproduction.

As used herein, the term "studio" indicates the location of the actual sound source and of the pickup microphones, and the term "auditorium" indicates the location of the apparent sound source and of the loudspeakers which radiate the apparent sound. It should be understood that the "studio" and the "auditorium" may refer to either closed or open air spaces, and need not be separate or different from one another.

The "front" of an auditorium means the section where the sound reproducing equipment is located, which will usually be at one shorter side in the case of a rectangular space.

It is already known that amazingly natural stereophonic reproduction may be obtained with a system including two microphones located in a dummy simulating a human head, two separate amplifier channels, each connected with a microphone, and two earphones, one for each channel. The sound picked up by the microphones will be fed by the two amplifier channels to two separate earphone elements and thus to the ears of a listener. However, the disadvantage of this method is that when the listener moves his head, that is, turns it to one side, the listener receives the impression that the entire sound source is moving with his head. Also, there is a distinct disadvantage because of the fact that the listener is required to wear earphones.

Another system which is already known uses two loudspeakers connected with the amplifier channels in the manner described above wherein these speakers are placed at the front end of an auditorium not too far from the longitudinal centerline thereof. A stereophonic effect is thereby achieved. The loudspeakers should be spaced at a sufficient horizontal distance from each other. In arrangements of this type, the sound picked up on a direct path from the sound source by the recording microphones in a studio, will be properly duplicated during the reproduction in an auditorium, but this is not true for the sound which is reflected from the walls in the studio. In the studio, a listener will receive sound from the source from directions other than a direct path. The listener may very clearly sense this difference of direction and will miss its absence during reproduction in an auditorium, for the sound will seem to emanate only from the front of the auditorium. In this respect it is assumed that the damping of the auditorium walls is so great that the sound is not changed by additional reflections and echos in the auditorium.

In another known arrangement, in addition to the loudspeakers provided at the front of the auditorium, further loudspeakers are distributed along the sides and even along the rear walls thereof. These additional loudspeakers are fed with delayed portions of the signal in order to imitate, in the auditorium, the sound reflections from the walls of the studio. This will provide quite an improvement of the quality of the reproduction, and the listener will obtain a feeling or sense as to the type and size of the auditorium which could not be conveyed to him without these additional loudspeakers. The listener

will also sense the direction of the reflected sound in contrast to the direct sound radiated from the two loudspeakers at the front of the auditorium.

Although satisfactory results may be obtained with the above described arrangement, its use is restricted to those instances where large expenses can be readily justified, such as in cases when special results are to be achieved for special events. However, for general use this type of arrangement is out of the question due to the large expense involved in loudspeakers and in connection channels.

With these defects of the prior art in mind, it is a main object of this invention to provide a stereophonic or multiple channel system which provides a reproduction having natural qualities and which may be accomplished in a substantially simpler and less expensive manner than the prior art systems.

Another object of this invention is to provide a multiple channel reproduction system wherein the unrecorded reflected sounds from the walls of the studio are simulated during reproduction.

A further object of this invention is to provide a multiple channel reproduction system which achieves a surprising effect during reproduction in that the reproduced sound seems to emanate from points which are beyond the base line connecting the two loudspeakers, and there is an effective extension in size of the apparent sound source.

A still further object of this invention is to provide a multiple channel system wherein natural sounding reproduction may be provided even when single channel, rather than multiple channel, signals are used.

Yet a further object of this invention is to provide a system of the type described wherein the stereophonic effect is adjustable by means of simple adjustable members in the sound reproducing system.

These objects and others ancillary thereto are accomplished according to preferred embodiments of the invention, wherein a system for sound recording and/or sound reproduction is provided with two reproduction channels. In each of the channels, the separate signal portions active therein, which substantially correspond to the sound arriving from the sound source to a sound pickup or a receiver, have added thereto a signal portion derived from the other of the channels which is made effective in the one channel with a time delay.

In a practical embodiment of a system according to the present invention, a pair of crossing or crossover connections of the first order are provided. A first connection is made from the left channel to the right channel, and another one from the right channel to the left channel, and in each connection a delay member is provided. This delay member may be, for example, an electrical network, a simulated electrical network, or a network for transmitting mechanical or acoustic vibrations using appropriate electro-mechanical transducers.

In a preferred embodiment, each of the crossover connections of the first order is provided with the following elements in the corresponding transmission sequence: a member for adjusting the amplification or damping, which is substantially frequency independent within the operating frequency range; and, preferably, a filter having a variable transmission curve disposed within this range; and subsequently, in the direction of transmission, a unidirectional transmitting member, for example, an amplifier.

In accordance with this invention, further structure may be provided for subjecting the delayed signal derived from one channel to a further delay, and feeding this signal portion back to the channel from which it originated. In this type of arrangement, a crossover connection or transmission line of the second order will be provided at one branching point of each of the crossover connections or transmission lines of the first order at the input of the uni-directional transmitting member. Each crossover connection of the second order is then connected back to that channel from which the corresponding transmission line of the first order is fed.

Further crossover connections of higher orders may be connected from the branching point mentioned above of a crossover connection of a lower order to the channel from which the last-mentioned connection is fed. The crossover connections of higher order are similar to the connections of the first order in that each contains: a member for adjusting amplification or damping, which is substantially frequency independent within the working frequency range; and, preferably, a filter having a variable transmission curve disposed within this range; and subsequent to it in the direction of transmission, a uni-directional transmitting member, such as an amplifier.

In the crossover connection of the highest order, for example, the third order, echo simulating members may be provided instead of signal delaying members. This type of member for artificially generating an echo is already known in this art. It may be designed of purely electrical elements, or may also be used with the addition of mechanical or acoustical transmission members, the latter including electro-mechanical transducers.

If the signal portions in the two channels correspond to the direct sound and are coordinated stereophonic signals, then the delay times in the crossover connections of the same order may be adjusted to be substantially equal. However, the invention is by no means restricted to stereophonic reproduction. It has been found that an amazing effect may also be achieved when the signal portions of the two channels corresponding to the direct sound are identical, such as when a monaural signal is fed thereto. In this case, the delay times in the crossover connections of the first order will be adjusted to be different from one another. There will be an important improvement in the stereophonic effect due to the simulation of the sound reflected from the walls in the studio, which causes the listener to sense the sound as emanating from outside of a straight line connecting the two reproduction loudspeakers, just as in the case of genuine stereophonic reproduction. The desired improvement of the stereophonic effect and the remarkable expansion of the apparent sound source beyond the space between the speakers will thus occur in both the case when stereophonic signals are used, and in the case when a monaural signal is used and distributed over two channels.

Additional objects and advantages of the present invention will become apparent upon consideration of the following description when taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a block diagram illustrating the simplified reproduction system according to the present invention.

FIGURE 2 is a schematic diagram of a studio, illustrating the direct sound paths and the reflected sound paths.

With more particular reference to the drawings, input terminals **1** and **2** of two reproduction channels A and B, respectively, are provided and lead to respective channel amplifiers **3** and **4** and thence to the loudspeakers **5** and **6**. These loudspeakers are arranged in a well known manner at appropriate distances from one another at the front of an auditorium which may have a rectangular floor plan. Microphones **9** and **10** may be connected with terminals **1** and **2** by means of switches **7** and **8**. These microphones may be arranged in a well known manner in a so-called dummy head in positions where the ears would be, were this dummy head a human head. Alternatively, a single microphone **11** may be used and connected with terminals **1** and **2** by the switches **7** and **8**.

Instead of the microphones, any other device capable of providing two coordinated stereophonic signals of the type provided by the microphones **9** and **10**, or a monaural signal of the type provided by the microphone **11**, may be connected with the terminals **1** and **2**. The system according to the present invention which is connected with the terminals **1** and **2** may be connected to an apparatus for the monaural or binaural reproduction of sound from phonograph records. In the same manner, it is possible to connect terminals **1** and **2** of this system to the output of radio receiving apparatus for stereophonic broadcasts or for single channel broadcasts.

A transmission line **42** is connected from a point **30** between terminal **2** and the input of amplifier **4** of channel B, to the other channel A at point **31** in the output of amplifier **3**. In a similar manner another transmission line **43** is connected at point **32** between terminal **1** and the input of amplifier **3** of channel A, to the other channel B at point **33** in the output of amplifier **4**. These two transmission lines or crossover connections **42** and **43** of the first order each contain several transmission members for influencing the transmission time, the damping or amplification, respectively, and the frequency response. A further member is provided ater these afore-mentioned members in the transmitting direction and is active only in the desired direction of transmission. Such uni-directional transmission elements may be considered in this case to be amplifiers **16** and **16'**.

The most important of these transmission members, for influencing the transmission properties of the crossover connections, are time delay members **13** and **13'** in which a time delay t_1 or $t_{1'}$ is provided. As will be explained below, reflection of sound from a wall of a studio is imitated by the signal portions which are conducted over these crossover connections. Sound reflections of the first order are those which are reflected only once before being picked up or heard. Transmission lines **42** and **43** are of the first order because they are connected to simulate sound reflections of the first order.

The magnitude of the time delay to be caused in members **13** and **13'** may be directly derived from this function which the members are to accomplish. In a typical case it may substantially correspond to the time required for sound to travel a distance of 10 meters, or about 30 milliseconds. Generally, it will probably be sufficient for satisfactory results if these members cause a fixed or constant time delay. If it is desired to make this system even more adaptable, wherein it is capable of adjustment for longer transmission times for the imitated or simulated first order sound reflections, then, instead of having a constant or fixed time delay, members **13** and **13'** may have an adjustable time delay. Transmission elements within the operating frequency range in question and having transmission times of the magnitude mentioned, may be used without substantially distorting the shape of the sound curves, since they are sufficiently known in the technical art. Therefore, a specific description of these elements will be omitted.

In the crossover connections **42** and **43**, elements **13** and **13'** are followed by members **14** and **14'** which provide adjustable damping. These members may be provided, for example, by adjustable ohmic resistances inserted as cross members into the transmission line. Next in the chain of transmission members are the elements **15** and **15'** provided with adjustable filters with which the desired frequency responses of the transmission may be produced. Since the wall reflections of the first order are imitated by the signal portions transmitted by the crossover connections of the first order, both the reflection characteristics of the wall and the frequency response of such reflection characteristics in the electric simulation of the sound echo may be varied as desired by use of the members **14, 14'** and **15, 15'**.

Finally, in each of the crossover connections of the first order, there are amplifiers **16** and **16'** which are uni-directional transmitting elements. Branching points **34** and **35** are provided in the transmission lines **42** and

43, respectively, are connected to the amplifier inputs, and are used for connecting the transmission lines of the second order.

These crossover connections of the second order are provided with similar control members as the crossover connections of the first order. As indicated in the drawings, the second order transmission lines 44 and 45, are provided with delay members 17 and 17′ for providing a time delay t_2 and $t_{2'}$, damping regulators 18 and 18′, and filters 19 and 19′ having adjustable transmission curves. This chain of elements is followed by amplifiers 20 and 20′. The transmission lines of the second order each lead back to the channel from which the connected transmission line of the first order is fed. Thus, for example, the second order transmission line 44 is connected to the first order transmisison line 42 at point 34. This first order transmission line 42 is connected to channel B at 30, and the second order transmission line 44 is also connected to channel B, at point 36. In a similar manner the second order transmission line 45 is connected to channel A at point 37. These second order connections serve to simulate sound echos of the second order reflected from the walls of the studio. The time delays t_2 and $t_{2'}$ will be of the same magnitude as the delay values t_1 and $t_{1'}$.

It is possible to continue the chain of crossover connections in a similar manner to produce sound echos of higher order. However, practical experiments have indicated that separate simulation or imitation of sound echos of an order higher than the second order does not result in any additional advantages. Therefore, further wall reflections may be combined by echo members within the crossover connections of the third order. As indicated in FIGURE 1, third order transmission lines 46 and 47 are provided and are connected to the second order transmission lines 45 and 44, respectively, at points 39 and 38, respectively. The inputs of amplifiers 20 and 20′ are connected to the branching points 39 and 38. These third order transmission lines are connected to the channels at points 40 and 41, and include echo members 21 and 21′.

Suitable echo members are known in the technical art and therefore a specific description thereof will be omitted. Real echo chambers with loudspeakers and microphones used as coupling elements, or electric imitations of these echo chambers may be used as these echo members. Also, acoustical-mechanical echo members are known wherein the sound vibrations are coupled to a mechanical transmission member by means of electromechanical transducers. At the end of the transmission member the faded or echo signal arrives and is picked up again by a mechanical-electrical transducer and fed to the reproduction channel to be influenced, by means of amplifiers, if necessary. In this connection reference is made to the publication in the periodical "Radio Mentor," 1960, issue 10, pages 776 and 778.

Numerous hearing tests which have been conducted with unbiased persons have indicated that an important improvement of the acoustical pattern is achieved by the present invention. This invention renders it possible to begin with stereophonic or monaural sound recordings which are composed essentially of only the direct sound recorded by the recording microphone or microphones. The simulation of sound wall reflections is made possible by feeding a portion of the signal from one channel to the other as indicated in FIGURE 1, and an amazing stereophonic effect results. This would be particularly noticeable if a test record is used having a musical selection recorded stereophonically thereon, with the signals being only of the direct sound type. In following portions of the record the wall reflection signals are added thereto according to the method of the present invention. During the transition from the first part of the recording to the other, the listener will sense, in a striking manner, an expansion of the apparent sound source beyond the loudspeaker base, i.e., the distance between the loudspeakers. The listener suddenly perceives sound from directions which are lateral to the base so that an illusion is created by the artificially added wall reflections whereby sound seems to emanate from different directions than the one corresponding to the direct sound path which is reproduced by the very same loudspeakers. This phenomenon is apparently connected with the process of stereophonic listening which is not yet completely understood, and appears to be based upon the fact that the listener receives information as to the direction of the sound from the phase differences between a direct sound, the first wall reflection, the second wall reflection, etc.

Therefore, using this invention it is possible to reduce the distance between the loudspeakers without losing the stereophonic effect. This is of particular importance since it is frequently felt that stereophonic systems have a drawback due to the relatively large distance which must be provided between the reproducing loudspeakers. Frequently, the small size of the auditorium will present narrow limitations as to the spacing of the loudspeakers.

Monaural recordings may also be improved by using the present invention by arranging the time delays t_1 and t_1' to be different. Tests have indicated that even in this case, the origin of the artificially produced sound echos is sensed by the listener as emanating from outside of the loudspeaker base. Conventional single channel reproduction of radio apparatus can therefore be improved by using the present invention. A multiple channel system according to the present invention is particularly suitable for use in radio receivers. Even older stereophonic recordings, such as phonograph records which are not completely satisfactory, may be improved with the use of this invention.

The processes involved in stereophonic listening are very complicated and have not yet been completely investigated and explained. Therefore, no explanation which is completely satisfactory and logical in all details can be given for the amazing and striking effect created by the present invention. However, an explanation will be offered with reference to FIGURE 2 as to how these interconnections may be understood according to present day knowledge.

FIGURE 2 is a floor plan of a rectangular studio having side walls 28 and 28′ and a front wall 29. The rectangle 48 near front wall 29 designates the portion of the floor space in a studio in which the sound source will be arranged, for example, the various instruments of an orchestra. The explanation will particularly concern two sound sources 22 and 22′, each located at one end of the rectangle. It is assumed that the fictitious listener is placed on the longitudinal centerline of the room at approximately between the first and second thirds of the length of this room. At this point a dummy head 12 is arranged and is provided with microphones 9 and 10 in place of the ears.

Considering the sound from the source 22, the direct sound path 23 is indicated with double lines and will be received predominantly at the left ear of the listener or at the microphone 9 which corresponds to this ear. Sound path 24, indicated in dashed lines, is also a direct path, but is attenuated due to the partial shielding or blocking of sound by the head, and arrives at the right ear, or at microphone 10 corresponding to this ear. This direct sound arriving at the right ear will be omitted from a consideration of the present analysis since it has been found that the information provided by this portion of the direct sound is not of essential importance in stereophonic listening. There is probably a superimposed effect by the direct sound which arrives with a greater intensity and somewhat sooner at the left ear of the listener along path 23. This is not to dispute the fact that, by itself, the locating of source 22 by the listener is accomplished on the basis of direct sound alone. Thus, for example, in free space this will be done by the differences of intensity and phase of the sound impressions arriving along the paths 23 and 24.

If this direct sound alone were present at the ear of the listener, he would not receive any information permitting him to obtain a conception of the space in which he is located. Instead, he would have to gather the impression that the sound source 22 is in a limitless space where no wall reflections occur. Therefore, the conception of the size and type of the space or auditorium where the sound source is active only results from the perception of wall reflections of sound.

Wall reflections of the sound reach the listener along different paths, and not all of them have the same importance as to recognition of the type and size of the space, but they are of differing degrees of importance regarding their information value for this determination. The present invention is based on this factor. Considering the wall reflections of the first order arriving from the left sound source 22 from the right wall 28′ at the right ear of the listener or microphone 10, the reflected sound arrives along path 25 indicated by double lines. From this source 22, the reflected sound also arrives along path 26, reflected from the left wall 28 to the left ear or microphone 9. However, this latter reflected sound is of far less importance, for providing a listener with a sensation of the size and type of the space, than a reflected sound arriving along path 25.

This may be explained by the fact that there is less of a difference in the transmission time of path 26 as compared to path 23 and because of its arrival at the same ear of the listener as sound from path 23, so that there is a type of superimposed effect. But the reflected sound coming to the right ear of the listener along path 25 is very clearly sensed and is therefore capable of providing a listener with a clear sense of space.

The present invention uses this effect to simulate wall reflections by imitating the sound energy which is reflected from the right chamber wall 28′, by feeding into the right channel, or channel B, signal energy which is branched off from the left channel. As shown in FIGURE 2 the conductors for microphones 9 and 10 may lead to loudspeakers 5 and 6 of FIGURE 1. Thus, the arrangement of FIGURE 1 imitates the sound echo of path 25 within the crossing connections of the first order, or by a path from the sound source 22′ reflected from the left chamber wall 28 to the left microphone 9.

In a similar manner the effectiveness of the present invention can be explained for the sound wall reflections of the second order. FIGURE 2 shows a sound path 27 of the second order which emanates from sound source 22, is reflected from the right wall 28′, and is further reflected from the left wall 28 until it is picked up by the listener's left ear or the microphone 9. This sound arrives having a correspondingly greater time delay, after the impression belonging to the same sound which arrives along path 23, and which, by this time, has faded. The impression as to space which is generated by the simulation of the first wall reflection is intensified in the listener by the coordinated arrival of the second reflected signal on the opposite side. It may thus be seen that the electrical simulation or imitation of reflections in the manner indicated is quite capable of presenting a convincing feeling of space to the listener.

A striking and amazing effect is thus provided on the basis of the phase differences, when coordinated in a proper manner, between the direct signals and the reflected signals of the first and higher orders, together with the change of channels between the first and second reflected signals. Especially striking is the effect obtained when the reflected sound appears to come from the sides of the auditorium where no loudspeakers are present. It is this factor which presents the essential advantage of the present invention as compared with known arrangements, for simulating the reflected sound. Note that, in contradistinction to the prior art, in the present case additional loudspeakers need not be arranged at the side walls.

Generally, the desired effect may be obtained if the reflected signals of the first and second orders are fed to the reproduction channels over the crossover connections of the first and second orders as shown in FIGURE 1. Further wall reflections may be provided by an artificial echo supplied by the crossover connections of the third order 46 and 47. By means of the echo members 21 and 21′ the remaining reflections, higher than those of the second order, are blended with one another, since in higher orders the phase differences are no longer capable of being sensed. It has been found that using this system and combining the reflections of higher orders does not impair the advantages obtained by the present invention.

This invention may be used, not only in sound reproduction for improving the impression of sound energy already recorded or converted into electrical or other type of signals, but may also be used with particular advantage during the original recording process for the purpose of recording or converting the sound into electrical signals. If sound recording or reproduction is done in rooms having large damping and poor reflection of sound from the walls, the missing reflections and the echos may be electrically provided by the present invention.

It will be understood that the above description of the present invention is susceptible to various modifications, changes, and adaptations, and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

What is claimed is:

1. A system for recording or reproducing sound to simulate the original sound source as picked up by a receiver and as reflected from the walls of a studio, comprising, in combination: two interconnected channels, each channel including first means for providing one portion of the signal corresponding to the sound which arrives at a receiver from a sound source on a direct path in a studio, second means connected with the other channel for providing another portion of the signal corresponding to the sound which arrives at a receiver from a sound source on an indirect path in a studio and which is at least in part derived from the other channel, each second means including time delay means so that the other signal portion is provided with a time delay with respect to the one signal portion, and means for causing a further delay in a portion of the delayed signal of said second means and feeding it back to the same channel from which it originated.

2. A system as defined in claim 1, wherein said second means includes a pair of transmission lines of the first order, each connected between said channels, said time delay means being delay members in said lines.

3. A system as defined in claim 2, wherein each delay member includes an electrical network.

4. A system as defined in claim 2, wherein each delay member includes a simulated electrical network.

5. A system as defined in claim 2, wherein each delay member includes a network for transmitting mechanical vibrations and having electro-mechanical transducers.

6. A system as defined in claim 2, wherein each delay member includes a network for transmitting acoustical vibrations and having electro-mechanical transducers.

7. A system as defined in claim 2, wherein said two channels are coordinated stereophonic channels such that the signal portions corresponding to the direct path sound are coordinated stereophonic signals, said delay members being arranged with their delay times being substantially equal.

8. A system as defined in claim 2, wherein said delay members are arranged with their delay times being different when the signal portions of the two channels corresponding to the direct path sound are identical.

9. A system as defined in claim 2, wherein each first order transmission line includes means for adjusting the

damping which means are frequency independent over the operating frequency range, a filter having a variable transmission curve in the operating frequency range, and a uni-directional transmitting element.

10. A system as defined in claim **9**, wherein said uni-directional transmitting element is an amplifier.

11. A system as defined in claim **2**, wherein each first order transmission line includes means for adjusting the amplification which means are frequency independent over the operating frequency range, and a uni-directional transmitting element.

12. A system as defined in claim **9**, wherein said further delay causing means includes a pair of second order transmission lines, each line being connected at one end to a first order line between the input to said uni-directional transmitting element and the output of said delay member, and connected at the other end to the channel which acts as input for the associated first order transmission line.

13. A system as defined in claim **12**, comprising further higher order transmission lines connected between a transmission line of a lower order and the channel which feeds the last-mentioned line.

14. A system as defined in claim **12**, wherein each second order transmission line includes means for adjusting damping, said means being substantially frequency independent over the operating frequency range, a filter having a variable transmission curve in the operating frequency range, and a subsequent uni-directional transmitting element.

15. A system as defined in claim **13**, wherein the transmission lines of the highest order each includes an echo simulating member.

16. An arrangement for reproducing recorded sound to simulate the original sound source, comprising, in combination:

(A) a pair of reproduction channels defined by two reproduction systems for simulating the original sound source from a recording, each system including
  (1) first transducer means for transforming a recording into an electrical signal,
  (2) means connected with said first transducer means to amplify the electrical signal, and
  (3) second transducer means connected with said amplifying means for transforming the electrical signal into acoustical energy simulating the original sound source; and

(B) a transmission system interconnecting said channels and including
  (1) a first pair of transmission lines, each connected from a point between said first transducer means and said amplifying means of one channel to a point after said amplifying means of the other channel, each first transmission line including
    (a) a time delay member,
    (b) a damping member,
    (c) a filter member, and
    (d) an amplifer member
  (2) a second pair of transmission lines, each connected from a point in one of said first transmission lines between said filter member and said amplifier member to the channel from which the associated first transmission line initiates and connected after the connection point of said first transmission line, each second transmission line including
    (a) a time delay member,
    (b) a damping member,
    (c) a filter member, and
    (d) an amplifier member, and
  (3) a third pair of transmission lines, each connected from a point in one of said second transmission lines between said filter member and said amplifier member to the channel opposite that to which the associated second transmission line leads and connected after the connection point of said second transmission line, each third transmission line including an echo member.

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