Nov. 23, 1965 M. J. PALLADINO 3,219,757

SOUND REPRODUCTION FROM MONAURAL INFORMATION

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FIG. 1

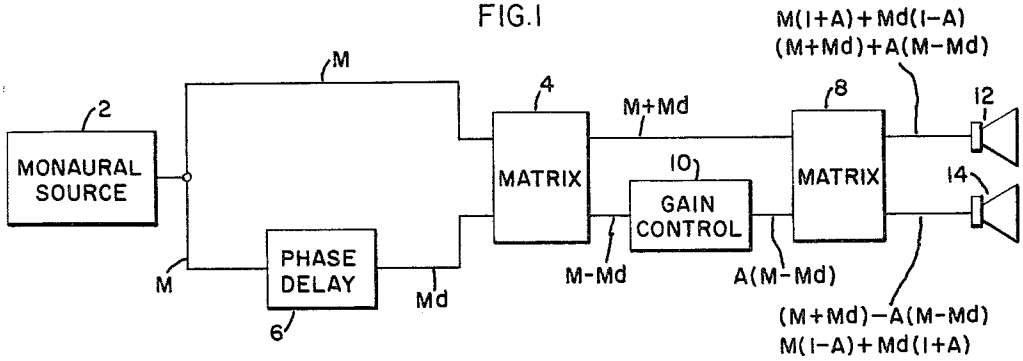


FIG. 2

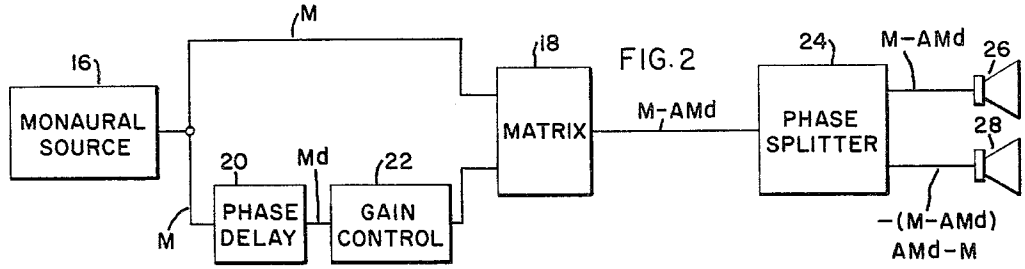


FIG. 3

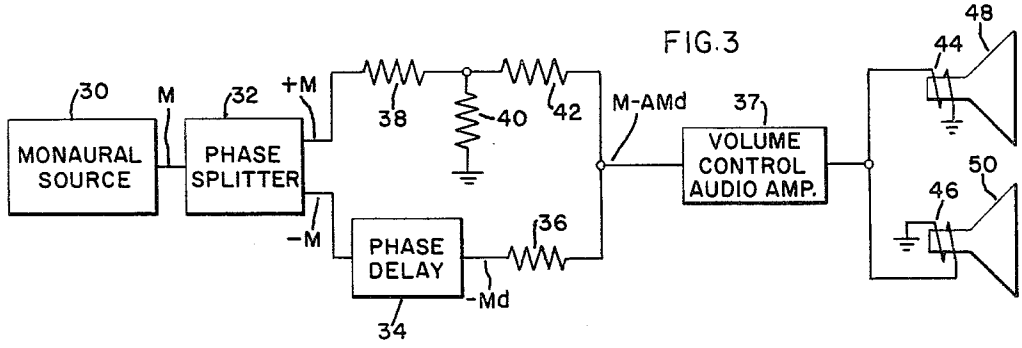
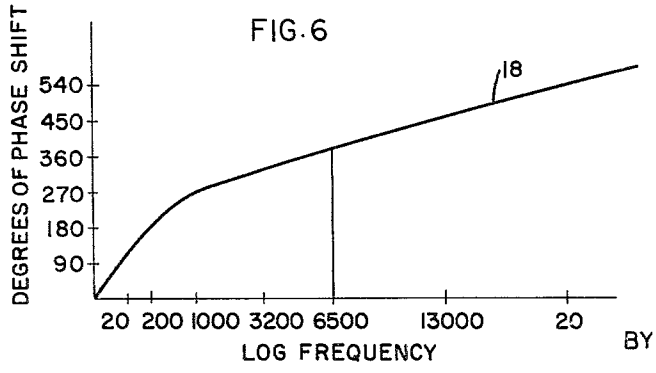


FIG. 6



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FIG.4

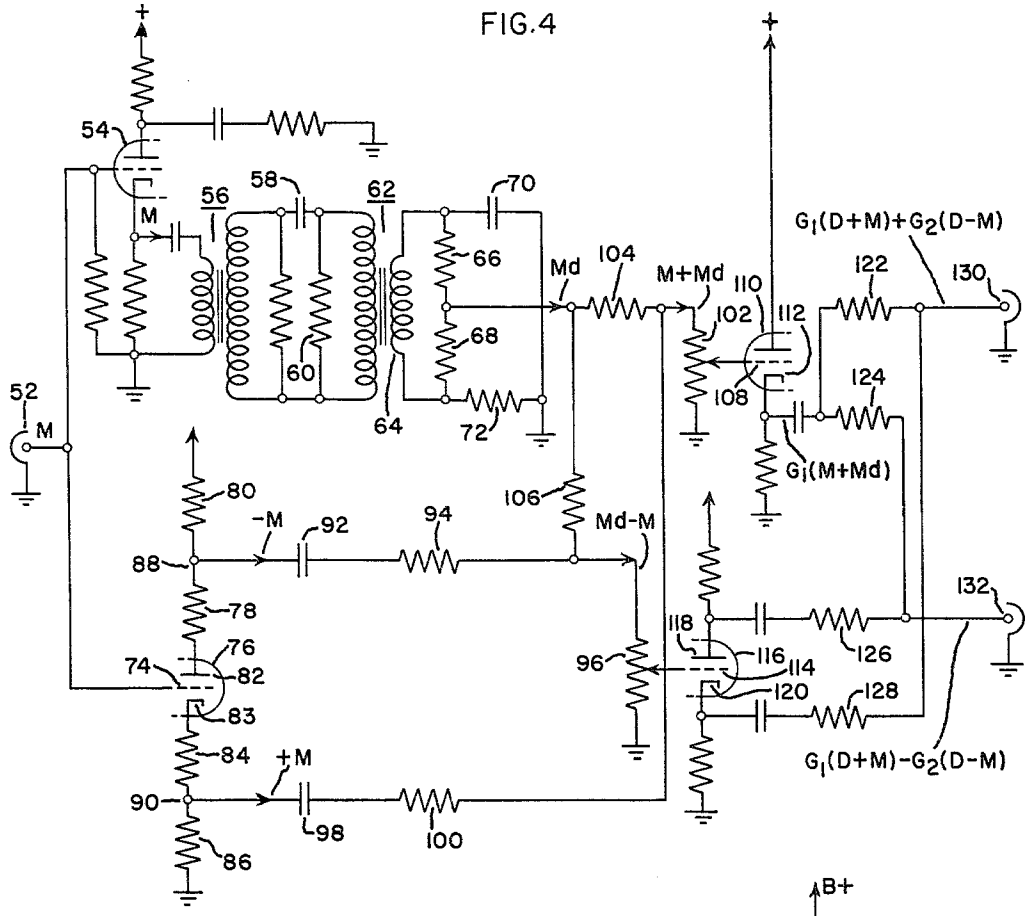
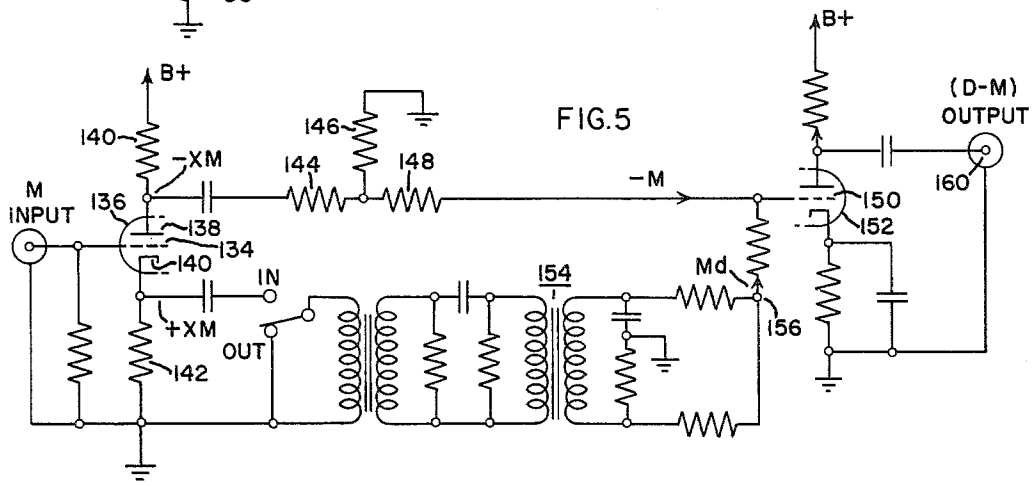


FIG.5



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SOUND REPRODUCTION FROM MONAURAL INFORMATION

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5 Claims. (Cl. 179—1)

This invention relates to methods and apparatus for enhancing the realism of sound produced from monaural information.

When one is listening to a live performance, one senses the direction from which the sounds come by the slight differences in amplitude or phase of the sound waves impinging on the left and right ears. By monaural information is meant information as to the sound that would impinge on one ear. Accordingly, one cannot sense from sound reproduced or produced from monaural information the direction from which the original sounds came. For example, in present radio transmission, if the sound produced by an orchestra is converted into a corresponding electrical signal by a single microphone and transmitted to a receiver where the signal is used to energize a single loudspeaker, the listener has no way of determining the location of the different instruments in the orchestra. The same situation prevails in a recording system wherein the recording media has a single track containing information as to the sound striking a single microphone. The telephone is another example of a sound system in which only monaural information is provided. Even if a plurality of spaced microphones are used in radio transmission, the signals provided by each are combined to form a single composite signal which contains no directional information. The same is true if a single track recording is made of the signals provided by a plurality of microphones. Conference calls in a telephone system likewise contain no directional information.

It might appear that if the signals in these systems were applied to spaced loudspeakers that directional effects could be produced, but the fact of the matter is that the sound would appear to come from a point midway between the speakers if they are equidistant from the listener. If the listener is closer to one speaker than the other, he may obtain information as to the speaker location but he will obtain no information as to the relative directions of the sounds being reproduced.

It is an object of this invention to provide improved ways and means for producing sound from monaural information in such manner as to create the illusion that the sounds are coming from different directions.

In one previous attempt to create an illusion of direction, the monaural sound is reproduced at one speaker slightly before it is reproduced at another. Whereas this provides some illusion of direction, it also causes an echo effect that many listeners find unpleasant.

Accordingly, it is another object of this invention to provide improved ways and means for producing sound from monaural information in such manner that directional effects are produced and echo effects minimized.

Briefly, one way of accomplishing these objectives, in accordance with the principles of this invention, is to produce at each of two spaced points sounds corresponding to the monaural information as well as to the monaural information delayed. The relative amounts of the sound corresponding to the monaural information and

the monaural information delayed have significant effects, and it is preferable that the delay vary in a non linear manner with frequency. Furthermore, the sounds corresponding to the monaural information are produced with opposite phases at the two speakers, and the same is true of the sounds corresponding to the monaural information delayed.

The manner in which this invention operates to attain the previously stated objectives may be more clearly understood from the following detailed discussion taken in conjunction with the drawings in which:

FIG. 1 is a block diagram of an apparatus capable of producing sound at two separate speakers in accordance with the principles of this invention,

FIG. 2 is a block diagram of another and somewhat simpler arrangement for producing audio signals at separate speakers in accordance with the principles of this invention,

FIG. 3 is an alternative arrangement to that shown in FIG. 2,

FIG. 4 is a schematic diagram of a circuit for producing signals in a manner similar to that of the arrangement shown in FIG. 1,

FIG. 5 illustrates in schematic form one way in which the delay of the various previous figures may be achieved, and

FIG. 6 is a graph illustrating the phase delay characteristics of the delay mechanism illustrated in FIG. 5.

In FIG. 1, source 2 provides electrical signals M containing monaural information. The signal M is applied directly to an input of a matrix 4 and also to the input of a delay means 6 wherein it is delayed, preferably in a non linear manner, e.g. as indicated in FIG. 6. The delayed signal Md is applied to another input of the matrix 4 which functions in a manner well known to those skilled in the art to produce at an output a signal $M+Md$ and at another output a signal $M-Md$. The sum signal $M+Md$ is applied to an input of a matrix 8 and the difference signal $M-Md$ is applied to a gain control means 10, which produces a signal $A(M-Md)$ wherein A is the gain factor. The signal $A(M-Md)$ is applied to the other input of the matrix 8. In a manner well known to those skilled in the art, the matrix 8 provides at one output the summation of these input signals

$$(M+Md)+A(M-Md)$$

and at the other output the difference between the input signals $(M+Md)-A(M-Md)$. The factor A merely indicates the relative amplitude of the difference signal with respect to the sum signal. A loudspeaker or other sound transducer 12 is connected to one output of the matrix 8 and another speaker 14 is connected to the other output. The signals at the respective outputs of the matrix 8 may also be represented by the expressions

$$M(1+A)+Md(1-A) \text{ and } M(1-A)+Md(1+A)$$

It will be assumed the sounds produced by the loudspeakers will correspond to the applied signals.

It is observed that the signals applied to each speaker contain some monaural information, M, as well as monaural information delay Md. The following table illustrates the signals applied to the speakers 12 and 14 for various values of A. When A is 0, both speakers are energized with the same signal $M+Md$ and hence only an echo effect is produced, but in general the delay is so short that the echo effect is very small.

A	Speaker 12	Speaker 14.
0	M+Md	M+Md.
½	1.5 M+0.5 Md	0.5 M+1.5 Md.
1	2 M	2 Md.
2	3 M—Md	3 Md—M.
3	4 M—2 Md	4 Md—2 M.

No directional effects are produced as the same sound emanates from speakers **12** and **14**. For fractional values of A the signals applied to the speakers **12** and **14** are identical except for the amplitudes of the monaural components, M, and the monaural relayed components, M*d*. When A is unity, the monaural signal (2M) is applied to the speaker **12** and monaural signal delayed (+2M*d*) is applied to the speaker **14**. The fact that the coefficient of each signal is 2 only effects the loudness of the sound. This is the situation previously referred to which produces an undesirable echo and little or no directional effects. For values of A greater than unity, however, marked directional effects are produced. It will be observed that the amplitude of the monaural signal, M, applied to one speaker is the same as the amplitude of the monaural signal delayed, M*d*, applied to the other speaker. Furthermore, the monaural signal M is applied to each speaker in opposite phases, and the monaural signal M*d* is applied to the speakers with opposite phases. Particularly marked directional effects occurred when A had a value of 3. In some cases the sound appeared to come from behind the listener rather than from the speakers **12** and **14**.

Just why such directional effects are produced is not clearly understood, and it is not contended that they are accurate because there is no true directional information in a monaural signal. The advantage in the system lies in the fact that the listener receives directional effects that simulate a live performance. It is not essential that the coefficients be precisely as calculated by inserting different values of A in the formulas, but it does appear that the monaural sound M and the phase delayed monaural sound M*d* should be produced by each speaker, that the sound M should be produced by one speaker in an opposite phase to the production of the sound M at the other, and that the sound M*d* also be produced in opposite phases by the two speakers. It further appears that the strength of the sound M produced at one speaker be greater than strength of sound M*d* and that the reverse situation attain at the other speaker.

It should be noted that the signal M*d* is a phase delayed signal M and not a time delayed signal M. The distinction is that in a time delayed signal all frequencies are delayed by the same amount of time whereas in a phase delayed signal the time delays for the various frequencies differ from one another. A time delayed signal results in echo effects, but does not simulate directional effect, whereas a phase delayed signal does simulate directional effects. It may be desirable to have M*d* represent a combination of time delay and phase delay, but phase delay is essential portion of such a signal. Curve **18** of FIG. 6 illustrates a plot of a one desired phase shift on a linear scale against frequency of a logarithmic scale. It is thought that an integral number of cycles of delay at some mid audio range frequency, i.e. between 3000 and 10,000 cycles is desirable. Those skilled in the art will recognize that where the term phase delay is used with any single frequency used as a reference, the phase shift on one side thereof is a phase advance and on the other side a phase delay. Hence, it would be possible to delay frequencies on one side and advance the phase of the frequencies on the other and recombine them. Such an arrangement is within the meaning of phase delay as used herein.

FIG. 2 illustrates a simple embodiment of this invention, but the directional effects produced do not seem to be as pronounced. Monaural signals from a source **16** are applied to one input of a matrix **18** and to a delay means **20**, which preferably has a characteristic of the type illustrated by the curve **18** of the FIG. 6. The monaural delayed signal M*d* thus produced is applied to a gain control means **22** so as to produce a signal AM*d* which is applied to another input of the matrix **18**. In this paritcular case, the matrix **18** can be a simple subtraction device, which will provide a signal *M—AMd*. This signal is applied to a phase splitting means **24** which provides out of phase signals *M—AMd* and *AMd—M* for loudspeakers **26** and **28** respectively. The following table indicates the signals applied to the speaker and hence the sounds produced thereby for various values of A.

A	Speaker 26	Speaker 28.
0	M	—M.
½	M—0.5 Md	0.5 Md—M.
1	M—Md	Md—M.
2	M—2 Md	2 Md—M.
3	M—3 Md	3 Md—M.
5	M—5 Md	5 Md—M.

It has been found that the best directional effects are produced when $A=5$. For values of A greater than unity one speaker receives more +M*d* than M and the other more —M*d* than M, and each is applied to the respective speakers in opposite phase relationship. The main difference is that the coefficients for M signals applied to the speakers are the same and the coefficients for the M*d* signals are the same whereas previously the coefficients were interchanged. It would be possible in either the system of FIG. 1 or the system of FIG. 2 to reverse the polarities of the signals applied to each of the speakers. If this is done for the case where $A=3$ in the system of FIG. 2, the signals applied to the speakers are $3Md—M$ and $M—3Md$. The first signal is the same as one of the signals in the system of FIG. 1 where $A=2$, but the second is slightly different because the corresponding signal in FIG. 1 is $3M—Md$.

It will also be noted that when A is less than unity the signals provided to the speakers are different in phase relationship. This indicates that some directional effect may be produced for values of A less than unity in FIG. 2, whereas this was not the case in FIG. 1. Furthermore, in FIG. 1, fractional values of A caused the signals applied to each of the speakers to be of the form $xM+Md$ and these produce the slight echo effects previoussly referred to. This does not occur in the arrangement of FIG. 2.

In FIG. 3 the same signal *M—AMd* is derived in a different manner. A source **30** supplies a monaural signal to a phase splitter **32**, which in a well known manner provides a signal +M at one output and a signal —M at the other. The —M signal is applied to a delay means **34**, and the resulting signal —M*d* is completed via a resistor **36** to the input of a volume control and audio amplifier **37**. A T arrangement of resistor **38**, **40** and **42** serves to couple a reduced amount of the +M signal to the input of the amplifier **36**. The coefficient A merely indicates as before the relative amplitude between M*d* and M, and the arrangement of FIG. 3 merely illustrates that this relationship can be derived by reducing the amplitude of M; in the other arrangements the relationship was established by amplifying M*d*. The signal *M—AMd* appears in amplified form at the output of the amplifier **37** and is applied to voice coils **44** and **46** associated respectively with loudspeakers **48** and **50** in opposite phases so that the loudspeaker **50** produces sound in accordance with the negative of this signal or *AMd—M*. The reversed connection to the voice coils then serves the same function as the phase splitter **24**.

FIG. 4 illustrates in schematic form a circuit means that operates in a different way to produce the same type of final signals as are produced in the arrangement of FIG. 1. The principal difference lies in the fact that the matrix for deriving the *M+Md* and *M—Md* signals has three inputs to which the signals M*d*, M, and —M are respectively applied. The signal M from a source **52** is applied to a cathode follower **54** and is coupled by a step-up transformer **56** to a capacitor **58** and resistor **60** that

provide some phase delay. The delayed voltage appearing across the resistor **60** is applied to a step-down transformer **62** having a secondary winding **64**. Resistors **66** and **68** are connected in series across the secondary winding and ground so as to provide additional phase delay. The delayed monaural signal M*d* appears at the junction of the resistors **66**, **68** and is coupled to an input of a matrix.

The monaural signal M is also applied to a grid **74** of a phase splitting amplifier **76**. Resistors **78** and **80** are connected in series between the anode **82** and a B+ voltage source, and resistors **84**, **86** are connected in series between the cathode and ground. The relative values of these resistors taken in conjunction with the gain of the amplifier **76** determines the coefficients A and B of the signals $+a$M and $-a$M that respectively appear at junctions **88** and **90**. A coupling capacitor **92** and a resistor **94** are connected in series between the junction **88** and the ungrounded end of a potentiometer **96**. In a similar manner, the $+a$M signal is coupled by a capacitor **98** and a resistor **100** to the ungrounded end of a potentiometer **102**. The M*d* signal is applied to the ungrounded end of the potentiometer **102** via a resistor **104** and to the ungrounded end of the potentiometer **96** via a resistor **106**. It will be noted that the amount of the $-a$M signal applied to the potentiometer **96** is reduced by an amount depending on the relative resistance of the resistor **94** and the potentiometer **96** and further that a certain fraction of the $+a$M signal will appear at the top of the potentiometer **96**, the amount depending on the resistance of the resistors **100**, **104**, **106** and of the potentiometer **96**. By suitable selection of these resistances, the signal at the top of the potentiometer **96** can be made to be $Md-M$. A similar situation exists in relation to another potentiometer **102**, and suitable selection of its resistance and the resistances of resistor **104**, **106**, **94** and **100** as well as the resistance of the potentiometer itself will cause a signal $M+Md$ to appear at the ungrounded end of the potentiometer **102**. The values of the resistance of the resistors **68**, **72** may also have some effect. Although various values may be used, the following have been found effective.

R66=R68=R76=330K; R102=R96=500K;
R104=R106=R44=R100=100K

The coefficient also depends on the absolute and relative value of the resistors **78**, **80** in the anode circuit of the phase splitter **76** and also on the absolute and relative values of the resistors **84**, **86** in the cathode circuit. The following values were found satisfactory when one-half of a 12AU7 tube was used:

R28=R24=1.1K and R80=R86=1.6K

These latter resistances are rather low in order to prevent the M*d* signal from being applied with any significant amplitude to the anode **82** or the cathode **83**.

A portion of the $M+Md$ signal is selected by this potentiometer **102** and applied to the grid **108** of a cathode follower stage **110** with the result that a signal

$$G_1(M+Md)$$

appears at the cathode **112**. A portion of the signal $Md-M$ is selected by the potentiometer **96** and applied to the grid **114** of a phase splitting amplifier **116** with the result that a signal $-G_2(Md-M)$ appears at its anode **118** and a signal $+G_2(Md-M)$ appears at its cathode **120**. A matrix formed by equal resistors **122**, **124**, **126** and **128** coupled as indicated will produce at an output terminal **130** a signal $G_1(Md+M)-G_2(Md-M)$. Their signals are the same type as provided by the arrangement of FIG. 1 and are identical if G_1 is unity and $G_2=A$.

FIG. 5 is a schematic diagram of a circuit that is similar to the arrangement of FIG. 2, the main differences being that the polarity of the signal is reversed. A monaural signal M is applied to a grid **134** of a phase splitting amplifier **136** which produces at its anode **138** a signal —X.M. and at its cathode **140** a signal +XM when x is a coeffiecient depending on the value of the plate resistor **140**, the cathode resistor **142** and the characteristics of the amplifier **136**. Resistors **144** and **146** are coupled to the anode **138** and are so proportioned as to reduce the signal —XM to —M. This signal is coupled via a resistor **148** to the control grid **150** of an audio power amplifier **152**. The +XM signal at the cathode **140** is applied to a phase delay means generally indicated at **154**, which on inspection can be seen to be similar to the delay means, comprised of transformers **56**, **62** in FIG. 4. As can be understood by one skilled in the art, a delayed monaural signal M*d* will be produced at the point **156**. A resistor **158** connected between the point **156** and the grid **150** serves to add the —M and $+Md$ signals to produce a signal $Md-M$ which is amplified by the audio amplifier **152** and appears at this output terminal **160**.

This invention apparently produces directional effects that appear to simulate a live performance because of the fact that in listening to a live performance, two types of sound waves impinge on the ears. One wave follows a direct path between the source and each ear, and the other is the integrated effect at each ear of all the reflections from all objects in the area. The first wave gives a primary indication as to direction by virtue of the fact that it has different phases at the two ears. In this invention some directivity is produced by the delayed monaural signals provided by the two speakers. The use of a phase delay like that illustrated by curve **18** of FIG. 6 appears to simulate the second wave referred to. Perhaps the simulation would be improved if each frequency could be produced with different phase relationships, but this would be relatively expensive. The products of the sounds of different frequency at different phases provide a highly satisfactory simulation and also enhances the directional effects for reasons previously discussed.

What I claim is:

1. Apparatus for enhancing the realism of sound produced from monaural information comprising a first loudspeaker, a second loudspeaker, said first and second loudspeakers being relatively spaced so that the sounds emanated therefrom appear to come from spaced points, means for energizing said first speaker with signals

$$(M(1+A)+Md(1-A))$$

and means for energizing said second speaker with signals $(M(1-A)+Md(1+A))$, wherein M is a signal representing monaural information, M*d* is a signal representing monaural information that is phase delayed, and A represents a gain factor which is a number other than 0 or 2.

2. Apparatus as set forth in claim **1** where A is approximately 3.

3. Apparatus for enhancing the realism of the sound produced from monaural information comprising a first loudspeaker, a second loudspeaker, said first and second loudspeakers being relatively spaced so that the sounds emanated therefrom appear to come from spaced points, means for energizing said first speaker with signals

$$M-AMd$$

means for energizing said second speaker with signals $AMd-M$, wherein M is a signal corresponding to the monaural information, M*d* is a signal corresponding to the monaural information delayed, and A represents a gain factor which is a number other than 0.

4. Apparatus as set forth in claim **3** wherein A is approximately 5.

5. A circuit comprising an input terminal to which a signal M may be applied and first and second output terminals, means coupled between said input terminal and

said first output terminal for applying to said first output terminal a signal $M(1+A)+Md(1-A)$, means coupled between said input terminal and said second output terminal for applying to said second output terminal a signal $M(1-A)+Md(1+A)$ wherein A represents a gain factor which is a number other than 0 or 2 and M*d* is the signal M with a phase delay.

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