

HEADPHONE REPRODUCING APPARATUS

BACKGROUND OF THE INVENTION

5 The present invention relates to a headphone reproducing apparatus, and more specifically to a headphone reproducing apparatus for localizing a sound image at a position away from a listener's head.

10 A conventional headphone reproducing apparatus for processing sound signals to localize a sound image at a position away from a listener's head will be explained hereinbelow with reference to the attached drawings.

15 Fig. 1 is a view showing transfer characteristics from a speaker to both the right and left ears of a listener, which can be obtained when sound signals are reproduced through a speaker. Further, Fig. 2 is a block diagram showing a conventional headphone reproducing apparatus, and Fig. 3 is a block diagram showing an FIR (Finite Impulse Response) type digital filter (a convolution calculator).

20 As shown in Fig. 1, when sound reproduced through a speaker 40 located at a position is heard by a listener, the sound transmitted from the speaker 40 to the listener 41 can be represented by two different transfer functions $h_l(n)$ (from the speaker 40 to a left ear 41L) and $h_r(n)$ (from the speaker 40 to a right ear 41R), respectively. Further, in the headphone reproducing apparatus as shown in Fig. 2, these two transfer functions $h_l(n)$ and $h_r(n)$ are synthesized with input signals $x(n)$ inputted through an input terminal 51. A sound image localized by the speaker 40 is thus reproduced through a headphone 52 in pseudo-speaker sound reproduction manner.

30 In the above-mentioned synthesis of the two transfer functions $h_l(n)$ and $h_r(n)$, impulse responses (i.e., the transfer functions) of both the left and right ears measured by use of a dummy head or by a listener are adopted, and the measured impulse responses are convolution-calculated with the input signals by use of a signal processing unit (e.g., digital signal processing

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unit).

In more detail, the input signals inputted through an input terminal 51 are divided into left channel signals and right channel signals. The divided signals are then applied to a left convolution calculator 53L and a right convolution calculator 53R, separately for convolution calculations. Further, the signals outputted from the two convolution calculators 53L and 53R are transmitted to a left channel 52L and a right channel 52R of a headphone 52, separately.

Here, the convolution calculations can be expressed as follows:

$$y_l(n) = x(n) * h_l(n)$$

$$y_r(n) = x(n) * h_r(n)$$

where

$x(n)$: discrete signal series of input signals

$h_l(n)$: impulse response from speaker to left ear

$h_r(n)$: impulse response from speaker to right ear

$y_l(n)$: headphone left-channel reproduced signal series

$y_r(n)$: headphone right-channel reproduced signal series

In order to execute the convolution calculations of the impulse responses (i.e., transfer functions), each of the two calculators 53L and 53R must be constructed as a multi-point FIR digital filter 60 as shown in Fig. 3. The multi-point FIR digital filter 60 includes one-sample delay devices 61, multipliers 62 each for executing convolution of the impulse response ($h(0)$ to $h(N)$ denote a multiplication value), and adders 63 each for adding outputs of the multipliers 62.

The conventional headphone reproducing apparatus constructed as described above has the following drawbacks. When the impulse responses (transfer functions) are convolved with the input digital signals sampled at a sampling frequency 44100 Hz, for instance, it is necessary

to repeat delays, multiplications and additions as many times as 44100 in order to convolve the impulse responses with the input signals for only one second.

5 In addition, when reverberation characteristics are also required to be reproduced under consideration of reflected sounds in a room, since the time lengths of the transfer functions lengthens, the number of the FIR type digital filters 60 must be further increased.

10 Thus, there exists a problem in that the scale of the hardware used for the digital signal processing unit is bulky, with the result that the realization of the pseudo-speaker sound reproduction by a headphone has been so far difficult.

15 Further, Japanese Patent Laid Open No. 3(1991)-250899 discloses a headphone reproducing apparatus that enables extra-head sound image localization with simple construction. In this apparatus, reflected sounds having different delay times and different signal levels are formed on the basis of monaural input signals. Left and
20 right cross-talk signals are then formed on the basis of signals obtained by adding the reflected sounds to the input signals. The reflected sounds and the formed cross-talk signals are both added to the input signals. And, the added signals are reproduced independently on the left and
25 right sides of a headphone.

In more detail, this conventional headphone reproducing apparatus has two reflected sound forming systems for right and left ears each having delay and multiplier. Two left and right signals are formed by adding two different
30 reflected sounds (reflected sounds for the left ears and reflected sounds for the right ears) to the input signals, respectively. Further, the right cross-talk signals are formed on the basis of the left signals passed through a right filter, and the left cross-talk signals are formed
35 on the basis of the right signals passed through a left filter, respectively. Further, the formed reflected sounds and the formed cross-talk signals are both added to the

input signals, separately on the left and right sides. The two added signals thus can be reproduced independently on the left and right sides of a headphone.

5 In addition, the Japanese Laid-open Patent discloses another headphone reproducing apparatus which has a single reflected sound forming system. In this case, the signals obtained by adding the reflected sounds to the input signals are divided into two signals by the single reflected sound forming system. In other words, the same
10 reflected sounds are used for both the left and right ears. Further, the left and right cross-talk signals are formed on the basis of the signals obtained by adding the reflected sounds to the input signals through two different left and right filters. Further, the formed reflected
15 sounds and the formed cross-talk signals are both added to the input signals, separately on the left and right sides. The two added signals thus can be reproduced independently on the left and right sides of a headphone.

In other words, in the conventional headphone
20 reproducing apparatus, in the case of the left ear, for instance, firstly, input signals are formed to which the left reflected sounds are added. The left cross-talk signals are then formed on the basis of the input signals to which the left reflected sounds are added. The input
25 signals to which the left reflected sounds are added and the left cross-talk signals are added to monaural input signals before reproduction.

In this conventional headphone apparatus construction as described above, however, since a plurality of the
30 reflected sounds are formed by changing only the delay times and the signal levels of the input signals, the directional feeling (transfer characteristics) are not synthesized. In other words, the reflected sounds are added to the input signals as they are, without providing
35 definite directional feeling for both the listener's left and right ears. In addition, the cross-talk signals formed on the basis of the reflected sounds are formed separately

on the left and right sides on the basis of the same signals to which reflected sounds are added. In other words, a cross-talk signals is not formed for each of the reflected sounds, respectively.

5 As a result, in the conventional headphone reproducing apparatus, although the sound can be somewhat spread out, each of the reflected sounds are not processed for each reflected sound. It is thus impossible to obtain a clear directional feeling to a sound source. In other words,
10 there exists a problem in that a sound field different from an actual room is reproduced, with the result that a realistic extra-head sound image localization cannot be achieved.

15 Further, a problem lies in the case where phase control is executed in such a way that the correlation between the left and right signals can be eliminated, in order to localize a sound image outside a listener's head. Since the sound image localization cannot be made definitely, there arises a problem in that the directional feeling of
20 a sound source is also not clear.

 In addition, in the conventional headphone reproducing apparatus, whenever the listener moves his or her head, since the sound source localization position is also moved, the sound feeling is not natural. This results in the
25 headphone sound reproduction lacking an actual feeling.

SUMMARY OF THE INVENTION

 With these problems in mind, therefore, it is the object of the present invention to provide a headphone
30 reproducing apparatus which can localize a sound image outside a listener's head by synthesizing the directional feeling (transfer characteristics) of a sound source, in spite of small-scale hardware.

 To achieve the above-mentioned object, the present
35 invention provides an apparatus for creating a virtual sound, a listener be feeling as if a sound came from a virtual sound source that imaginarily exists in a space

apart from the listener, the apparatus comprising: delay means for delaying a first-channel input audio signal and a second-channel input audio signal by predetermined delay times; first changing means for changing frequency characteristics of the first- and second-channel input audio signals to predetermined frequency characteristics; second changing means for changing sound levels of the first- and second-channel input audio signals to predetermined sound levels, the delay means and the first and second means being connected in series to each other; and reproducing means for reproducing the first- and second-channel input signals processed by the delay means and the first and second means as the sound that comes from the virtual sound source.

15 The first changing means may include a low-pass filter.

 The present invention further provides an apparatus for creating a virtual sound based on an input audio signal, a listener be feeling as if a sound came from a virtual sound source that imaginarily exists in a space apart from the listener, the apparatus comprising: delay means for delaying a first-channel input signal and a second-channel input signal, both being separated from the input audio signal, by predetermined delay times, changing frequency characteristics of the first- and second-channel input signals to predetermined frequency characteristics, and changing sound levels of the first- and second-channel input signals to predetermined sound levels; multi-stage delay means for delaying another signal separated from the input audio signal by a plurality of predetermined delay times to output multi-stage delayed signals; processing means for delaying a plurality of third-channel input signals and a plurality of fourth-channel input signals, the third- and fourth-channel input signals being separated from the multi-stage delayed signals, by a plurality of predetermined delay times, changing frequency characteristics of the third- and fourth-channel input signals to predetermined frequency characteristics, and

changing sound levels of the third- and fourth-channel input signals to predetermined sound levels; adding means for adding the first-channel input signal and all the third-channel input signals to each other, and second-
5 channel input signal and all the fourth-channel input signals to each other; and reproducing means for reproducing output signals of the fourth means as the sound that comes from the virtual sound source. The delay means and processing means may include a low-pass filter
10 for changing the frequency characteristics.

The apparatus may further include changing means for changing at least either of the delay times of the first means, the delay times of the second means, and the delay times, the frequency characteristics, and the sound levels
15 of the third means.

The apparatus may further include detecting means for detecting at least either of a position, a direction, and a movement of the listener. The changing means, in responsive to the detected position, direction or movement,
20 changes at least either of the delay times of the first means, the delay times of the second means, and the delay times, the frequency characteristics, and the sound levels of the third means.

25 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is transfer characteristics from a speaker to the left and right ears of a listener when sound signals are reproduced through the speaker;

30 Fig. 2 is a block diagram showing a conventional headphone reproducing apparatus;

Fig. 3 is a block diagram showing a general FIR type digital filter (convolution calculators);

35 Fig. 4 is a block diagram showing a first embodiment of the headphone reproducing apparatus according to the present invention;

Fig. 5 is a block diagram showing a second embodiment

of the headphone reproducing apparatus according to the present invention;

Fig. 6 is a block diagram showing a third embodiment of the headphone reproducing apparatus according to the present invention; and

Figs. 7A and 7B are graphical representations showing the case where the listener moves his or her head through an angle θ in the horizontal direction.

10 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be described hereinbelow with reference to the attached drawings.

15 Fig. 4 shows a first embodiment of a headphone reproducing apparatus according to the present invention. In Fig. 4, a headphone reproducing apparatus 10 has a direction filter 12 for transfer characteristic synthesizing. The direction filter 12 models acoustic components included in the transfer functions from a virtual sound source assumed to exist in a virtual space to the listener's left and right ears. And, the direction filter 12 synthesizes the directional feeling (transfer characteristics) with left- and right-channel signals divided from input signals applied through an input terminal 11.

25 The acoustic components such as time component, frequency component, and sound pressure component will be explained hereinbelow.

30 (1) Time component (a difference in arrival time from the sound source to both the listener's ears)

The time component is an acoustic component of the transfer function, which is caused by a difference in sound arrival time between both the listener's ears, that is, caused by a difference in distance from the sound source to both the listener's ears. Therefore, an appropriate time delay is adopted according to the angle and distance

of a virtual sound source relative to the listener. The adopted time component is synthesized with the input signals. For instance, with respect to both the listener's ears, the transfer characteristics from a virtual source to the remote ear are delayed by an appropriate time, as compared with the transfer characteristics from the same virtual source to the near ear.

(2) Frequency component (a difference in frequency characteristics from the sound source to the listener's ears)

The frequency component is an acoustic component of the transfer function, which is caused by positional relationship among the sound source, the listener's head and ears. In general, there exists such a tendency that the high frequency band of sound is attenuated more at the ear remote from the sound source, as compared with the ear near to the sound source. Because the sound reaches the remote ear after having traveled around the head. Therefore, the high frequency band characteristics of the transfer function are attenuated according to the angle and distance of the virtual sound source relative to the listener. And, the attenuated frequency components are synthesized with the input signals. For instance, with respect to the left and right ears, the high frequency characteristics of the transfer function from the virtual source to the remote ear are attenuated more, as compared with the high frequency characteristics thereof from the same virtual source to the near ear.

(3) Sound pressure component (a difference in sound volume level from the sound source to the listener's ears)

The sound pressure component is an acoustic component of the transfer function, which is caused by a difference in sound volume level, that is, caused by a difference in distance between the sound source and the ears. Therefore, the level of the transfer characteristics is increased or decreased according to the angle and distance of the

virtual sound source relative to the listener. And, the adjusted sound pressure component is synthesized with the input signals. For instance, with respect to the left and right ears, the sound volume level of the transfer characteristics from the virtual source to the remote ear is reduced by an appropriate value, as compared with the sound volume level of the transfer characteristics from the same virtual source to the near ear.

By use of the above-mentioned three acoustic components, the transfer characteristics from the virtual source to the left and right ears are synthesized with the input signals separately on the left and right sides of the headphone. Therefore, the headphone reproducing apparatus includes delaying circuits for modeling the time component of the transfer characteristics, frequency characteristic changing circuits for modeling the frequency component, and sound pressure changing circuits for modeling the sound pressure component, on each side of the headphone.

For instance, to fabricate these circuits by use of digital signal processing circuits, these circuits can be fabricated easily by use of a direction filter 12 having two delay circuits 13R and 13L, two low-pass filters (LPFs) 14R and 14L, and two multipliers 15R and 15L. Further, an IIR (Infinite Impulse Response) type digital filter of small-scale hardware can be used as the low-pass filters.

In Fig. 4, single-channel input signals are applied to the direction filter 12 through the input terminal 11, and then divided into left-channel signals and right-channel signals, respectively. Explanation of how the input signals are divided is omitted here.

In the direction filter 12, the delay circuit 13L, the LPF 14L and the multiplier 15L are connected in series for the left channel. Further, the delay circuit 13R, the LPF 14R, and the multiplier 15R are connected in series for the right channel.

The left and right channel signals are delayed by the

delay circuits 13L and 13R by a predetermined delay time, respectively. The frequency characteristics of the delayed signals are changed by the LPF 14L and 14R to predetermined frequency characteristics, respectively. Further, the
5 delayed and changed channel signals are further changed by the multiplier 15L and 15R to predetermined sound volume level, respectively. Both the delayed, and frequency and level-changed input signals are transmitted to a left channel 16L and a right channel 16R of a headphone 16,
10 respectively.

In the circuit configuration, the order of the series-connected delay circuit 13L, the LPF 14L, and the multiplier 15L, and also 13R, 14R, and 15R are not limited to only that as shown in Fig. 4 as long as the two series-
15 connected circuitries are separated in right and left channels. Further, the respective signal processing values (delay time, frequency characteristics, and sound volume level) are determined on the basis of the positional relationship between the virtual sound source and the
20 listener, as already explained. Further, when IIR type digital filters are used as the LPFs 14L and 14R and further the forward direction coefficients of the digital filters are scaled, it is possible to model the sound pressure components of both the channels, without using any
25 multipliers in particular.

As described above, the signals can be reproduced through the headphone 16 as sounds having directional feeling from the virtual sound source (located outside the listener's head) to the listener's left and right ears.

30 As a result, when the headphone reproducing apparatus 10 according to the present invention is used, the listener can feel as if he or she could hear sound from a direction of a virtual sound source located outside the head. In other words, since a sound source (i.e., a sound image) can
35 be located at a position away from the listener's head or since a pseudo-speaker sound reproduction can be achieved, the listener can enjoy the reproduced sound for many hours

without being much fatigued.

Further, in the headphone reproducing apparatus according to the present invention, the transfer characteristics can be synthesized with the input signals by the direction filter 12 having the delay circuits 13L and 13R, the LPFs 14L and 14R, and the multipliers 15L and 15R. It is thus possible to synthesize the transfer characteristics (more approximate to the actual transfer functions) with the input signals in real time. In addition, the headphone reproducing apparatus according to the present invention can be constructed by use of small-scale hardware of simple construction elements, as compared the conventional apparatus for executing the convolution calculations of the impulse responses.

A second embodiment of the headphone reproducing apparatus according to the present invention will be described hereinbelow with reference to Fig. 5.

In the actual perception of a sound image or a sound source, there exist some influences of the reflected sound and the reverberation within a room where the sound source is positioned, in addition to the influence by a difference in distance between the sound source and the two listener's ears. Further, it is also possible to recognize a sound source position by deciding the room size empirically on the basis of the room sound and the relative relationship between the room size and the room sound.

In other words, the reflected sound in a room exerts a great influence upon the sound source recognition. Therefore, in the case of the extra-head sound image localization by a headphone, the reflected sound exerts a great influence upon the sound source recognition. Therefore, when some directional feeling is provided for the reflected sound, the sound source can be recognized more easily by the listener.

Therefore, in the second embodiment, on assumption that a virtual sound source exists in a room having reverberation characteristics, a headphone reproducing

apparatus 20 reproduces reflected sounds each having directional feeling from each virtual room wall to both the listener's ears, in addition to the direct sound having directional feeling from the virtual sound source to both the listener's ears.

In Fig. 5, single-channel input signals applied through an input terminal 21 are divided into two signals. One of the two divided signals is given to a direction filter 12(T_0) of delay time T_0 and then outputted as the direct sound having directional feeling to both the left and right ears in the same way as with the case of the first embodiment.

The other of the two divided signals is given to a delay circuit 22, and then outputted as multi-stage delayed signals (the delay times are t_1 to t_N). The multi-stage delayed signals are applied to direction filters 12(t_1) to 12(t_N) respectively, and then outputted as the reflected sounds each having directional feeling to both the left and right ears, respectively.

Here, each of the direction filters 12(t_0) to 12(t_N) corresponds to the direction filter 12 of Fig. 4. Further, each of the signal processing values (delay time, frequency characteristics, and sound volume level) of these direction filters is decided on the basis of each of the directions of the reflected sounds. Further, the direct sound and the reflected sound are added to each other by adders 24₁ to 24_N for each of the left and right channels, and then given to the left channel 16L and the right channel 16R of the headphone 16, respectively.

Consequently, it is possible to reproduce the direct sound having directional feeling from the virtual sound source to both the left and right ears and the reflected sounds reflected from the room walls. In other words, a sound image can be located outside the listener's head (a sound image is not located inside the listener's head), with the result that the listener can hear the sound as if

the sound were generated by a sound source positioned within a room having reverberation characteristics. Further, since the direction filters $12(t_0)$ and $12(t_1)$ to $12(t_N)$ can be achieved by a simple element the same as the direction filter 12 of Fig. 4, the apparatus can be constructed by use of small-scale hardware.

In comparison with the prior art headphone reproducing apparatus as disclosed in the afore-mentioned Patent Application No. 3(1991)-250899, the headphone reproducing apparatus of the second embodiment according to the present invention is provided with the following features:

The direction filter $12(t_0)$ synthesizes the transfer characteristics between the virtual sound source and the listener's left and right ears with the left- and right-channel signals obtained by dividing the input signals, respectively.

On the other hand, the direction filters $12(t_1)$ to $12(t_N)$ synthesizes the respective transfer characteristics of the reflected sounds to the listener's left and right ears with the left- and right-channel signals each obtained by dividing each of the reflected sounds outputted by the delay circuit 22.

The adder 24_1 adds the left- and right-channel signal outputs of the direction filter $12(t_0)$ to the left- and right-channel signal outputs of direction filter $12(t_1)$, respectively. Next, the adder 24_2 adds the left- and right-channel signal outputs of the adder 24_1 to the left- and right-channel signal outputs of the direction filter $12(t_2)$, respectively. This addition goes on to the direction filter $12(t_N)$. And, the left- and right-channel signal outputs of the adder 24_N are given to the left channel 16L and the right channel 16R of the headphone 16, respectively.

In other words, the directional feeling from a single

virtual sound source to both the left and right ears can be synthesized, and additionally different directional feelings to both the left and right ears can be synthesized for each of the reflected sounds. As a result, it is possible to obtain a clear directional feeling of a virtual sound source and in addition to obtain a realistic extra-head sound image localization feeling as if the listener were hearing sound within a spacial sound field such as an actual room.

Further, in the case where the input signals (i.e., the sound source) are stereophonic signals, the headphone reproducing apparatus as described above is constructed for each channel of the stereophonic input signals to execute the similar signal processing, respectively. In this case, both the direct sound and reflected sounds each having the directional feeling to both the listener's left and right ears can be synthesized for each channel, and the synthesized sound signals are transmitted to the headphone. It is thus possible to localize the two sound images outside the listener's head under excellent stereophonic feeling conditions.

Further, in the case of a plurality (e.g., three or more) of different channels of input signals, it is possible to localize sound image per channel of the input signals outside the listener's head with the above-mentioned headphone reproducing apparatus provided for each of the channels of the input signals.

Further, it is also possible to add the original signals (not yet processed) to the processed signals and to transmit the added signals to the headphone. In this method, it is possible to change the sound image localization feeling according to the difference in signal volume level between the non-processed signals and the process signals.

Further, it is also possible to change the sound image localization feeling freely by changing the respective signal processing values appropriately. The sound image

localization feeling implies the position of the virtual sound source, the room mode, or shape and size of a room where the virtual sound source is located, etc. And, the signal processing values to be changed are those of the direction filter $12t_0$ to $12(t_N)$ and the delay circuit 22.

In this case, the more the signal processing values (delay time, frequency characteristics, and sound volume level) are changed, the more the sound image localization feeling can be changed precisely. On the other hand, the less the number of the signal processing values are changed, the more the apparatus construction can be simplified to that extent. In addition, when the signal processing values are changed gradually, it is possible to obtain such an effect as if the sound image were moving.

A third embodiment of the present invention will be described hereinbelow with reference to Fig. 6, in which the same reference numerals have been retained for similar elements having the similar functions as with the case of the headphone reproducing apparatus 20 shown in Fig. 5.

A headphone reproducing apparatus 30 has a head movement detector 31 and a controller 32. The head movement detector 31 detects the movement of the listener's head to which the headphone 16 is attached; that is, the head rotational direction, the head rotation angle, etc. The detected values are transmitted to the controller (e.g., CPU) 32. Further, the movement of the listener's head can be also calculated by the controller 32.

On the basis of the movement of the listener's head, the controller 32 changes the signal processing values of a delay circuit 22, and direction filter $12(t_0)$ to $12(t_N)$ in such a way that the sound image can be moved by the same movement rate in the direction opposite to the movement direction of the listener's head.

The head movement detector 31 is provided as follows: Two ultrasonic sensors are disposed on both the left and right sides of the headphone 16, and a detection signal

oscillator is disposed at a predetermined position away from the listener's head. The oscillator transmits detecting pulse signals to the two ultrasonic sensors at controlled timings. The oscillator further transmits a
5 detecting pulse signal transmitting signal to the controller 32. Upon receiving the detecting pulse signals, the left and right ultrasonic sensors output detection time signals to the controller 32. Each detection time signal represents what time it is at which each sensor receives
10 the detecting pulse signal. Upon receiving the detecting pulse signal transmitting signal from the oscillator and the detection time signals from the sensors, the controller 32 detects a time difference between the detecting pulse signal transmission and reception to detect two distances
15 between the oscillator and the left and right sides of the headphone, respectively or a difference in distance between the oscillator and the left and right sides of the headphone. The controller then calculates the head rotation angle based on the detected distance or distance
20 difference.

Further, it is possible to detect the three-dimensional movements and directions of the listener's head by disposing an additional sensor at another position (e.g., the top) of the headphone 16. Further, as the movement
25 detector 31, it is also possible to use infrared sensors, gyroscope sensors, gravity sensors for detecting inclination angles relative to the vertical direction, etc.

The controller 32, on the basis of the calculated head rotation angle, changes the signal processing values of the
30 delay circuit 22, and the delay circuits, LFPs, and multipliers of the direction filters $12(t_0)$ to $12(t_N)$. In detail, the controller changes the signal processing values in accordance with the calculating expressions and the set values determined according to the rotational direction and
35 the rotation angle both previously stored in a memory of the controller 32. The sound image thus can be moved by

the same rotation angle of the head movement in the direction opposite to the head rotational direction on the basis of the calculated head rotation angle.

5 Figs. 7A and 7B show the case where the listener's head is moved by an angle θ in the horizontal direction. In Fig. 7A, a virtual sound source is located at a point A relative to a listener 33 having the headphone 16.

10 Here, when the listener's head is moved by the angle θ in the horizontal direction as shown by Fig. 7B, in the case of the conventional apparatus, the localization point A of the virtual sound source is moved to a point B according to the head movement.

15 In the case of the apparatus 30 according to the present invention, however, the localization point A of the virtual sound source is moved by the angle θ from the point B in a direction opposite to the movement direction of the listener's head (i.e., the left horizontal direction from the point B). As a result, it is possible to keep the localization point A of the virtual sound source unchanged
20 at the point A.

In other words, even if the listener 33 moves his or her head, the extra-head localization position of the virtual sound source is kept unchanged and thereby the realistic sound image localization feeling can be realized.
25 It is thus possible to obtain a more realistic extra-head sound image localization feeling.

Further, in addition to the listener's head movement, the position, direction and movement of the listener's body relative to the virtual sound source can be detected by use
30 of position, direction and movement detectors. In this case, since the sound image localization feeling can be changed according to the position, direction and movement of the listener, it is possible to obtain more realistic extra-head sound image localization feeling.

35 As the position, direction and movement detectors, three or more detecting signal oscillators are disposed within a space where the listener exists. Furthermore,

when four or more oscillators are disposed on the mutually different planes, the three-dimensional position, direction and movement of the listener can be detected. In this case, two receivers are disposed on both the left and right side of the listener's head (or the headphone). And, the position, the direction and the movement of the listener's body relative to the virtual sound source can be detected by a processor.

The processor calculates the respective receiver positions (i.e., the listener's position) on the basis of the positions (coordinates) of the detection signal oscillators, time at which each detection signal is transmitted by the corresponding detection signal oscillator, and time at which each detection signal is received by the corresponding receiver. The processor then obtains vectors among the receivers, vectors indicative of the listener's direction obtained by rotating the vectors among the receivers by 90 degrees, vectors from the listener (each midpoint between the respective receivers) to the virtual sound source. And, the processor obtains the angle between the listener and the virtual sound source on the basis of an inner product of the calculated vectors between the respective receivers or the direction vectors and the vector between the listener (each midpoint between the respective receivers) to the virtual sound source.

When the above-mentioned position, direction and movement detectors are used, the position, direction and movement of the listener relative to the virtual sound source can be all detected easily and accurately. Thus, the signal processing values of the delay circuit 22, the direction filters $12(t_0)$ to $12(t_N)$ can be changed by the controller 32 according to the detected position, direction and movement of the listener. It is therefor possible to change the sound image localization feeling more realistically according to the position, direction and movement of the listener relative to the virtual sound

source.

As described above, in the headphone reproducing apparatus according to the present invention, the transfer characteristics (directional feeling) from the virtual
5 sound source to both the listener's left and right ears can be synthesized with the input signals. It is thus possible to achieve pseudo-speaker sound reproduction and further to localize the sound image outside the listener's head.

Further, the headphone reproducing apparatus according
10 to the present invention can be so constructed that the reflected sounds synthesized with the transfer characteristics (directional feeling) are added to the input signals respectively. It is thus possible to achieve pseudo-speaker sound reproduction as if the sound were
15 heard in a room having a reverberation effect and thereby to localize the sound image outside the listener's head more clearly.

Further, according to the present invention as shown in Fig. 6, the transfer characteristics can be synthesized by
20 use of the direction filter $12(t_0)$ (transfer characteristic synthesizing means) and the direction filters $12(t_1)$ to $12(t_N)$ (reflected sound transfer characteristic synthesizing means). Each direction filter has the delay circuits 13R and 13L, LFPs (frequency characteristic
25 changing means) 14R and 14L, and multipliers (sound volume changing means) 15R and 15L, as shown in Fig. 4. The transfer characteristics thus can be synthesized more realistically in spite of small-scale hardware.

Further, when the signal processing values are changed
30 in the delay circuit 22, direction filters $12(t_0)$ to $12(t_N)$ as shown in Fig. 6, various sound field can be achieved in spite of the simple apparatus construction. In addition, it is also possible to obtain such an effect as if the sound image is moving.

35 Further, the present invention can be provided with the detectors for detecting the position, direction and

movement of the listener in order to, based on the detected values, change the processing values of the delay circuit 22, direction filters $12(t_0)$ to $12(t_N)$ as shown in Fig. 6. In this case, since the extra-head virtual sound source
5 localizing position can be kept unchanged even if the listener moves, it is possible to realize more realistic extra-head sound image localization feeling.

WHAT IS CLAIMED IS:

1. An apparatus for creating a virtual sound, a listener be feeling as if a sound came from a virtual sound source that imaginarily exists in a space apart from the listener, the apparatus comprising:

delay means for delaying a first-channel input audio signal and a second-channel input audio signal by predetermined delay times;

first changing means for changing frequency characteristics of the first- and second-channel input audio signals to predetermined frequency characteristics;

second changing means for changing sound levels of the first- and second-channel input audio signals to predetermined sound levels, the delay means and the first and second means being connected in series to each other; and

reproducing means for reproducing the first- and second-channel input signals processed by the delay means and the first and second means as the sound that comes from the virtual sound source.

2. The apparatus according to claim 1, wherein the first changing means includes a low-pass filter.

3. An apparatus for creating a virtual sound based on an input audio signal, a listener be feeling as if a sound came from a virtual sound source that imaginarily exists in a space apart from the listener, the apparatus comprising:

delay means for delaying a first-channel input signal and a second-channel input signal, both being separated from the input audio signal, by predetermined delay times, changing frequency characteristics of the first- and second-channel input signals to predetermined frequency characteristics, and changing sound levels of the first-



and second-channel input signals to predetermined sound levels;

multi-stage delay means for delaying another signal separated from the input audio signal by a plurality of predetermined delay times to output multi-stage delayed signals;

processing means for delaying a plurality of third-channel input signals and a plurality of fourth-channel input signals, the third- and fourth-channel input signals being separated from the multi-stage delayed signals, by a plurality of predetermined delay times, changing frequency characteristics of the third- and fourth-channel input signals to predetermined frequency characteristics, and changing sound levels of the third- and fourth-channel input signals to predetermined sound levels;

adding means for adding the first-channel input signal and all the third-channel input signals to each other, and second-channel input signal and all the fourth-channel input signals to each other; and

reproducing means for reproducing output signals of the fourth means as the sound that comes from the virtual sound source.

4. The apparatus according to claim 3, wherein the delay means and processing means include a low-pass filter for changing the frequency characteristics.

5. The apparatus according to claim 3, further comprising changing means for changing at least either of the delay times of the first means, the delay times of the second means, and the delay times, the frequency characteristics, and the sound levels of the third means.

6. The apparatus according to claim 5, further comprising detecting means for detecting at least either of a position, a direction, and a movement of the listener,



the changing means, responsive to the detected position, direction or movement, changing at least either of the delay times of the first means, the delay times of the second means, and the delay times, the frequency characteristics, and the sound levels of the third means.

