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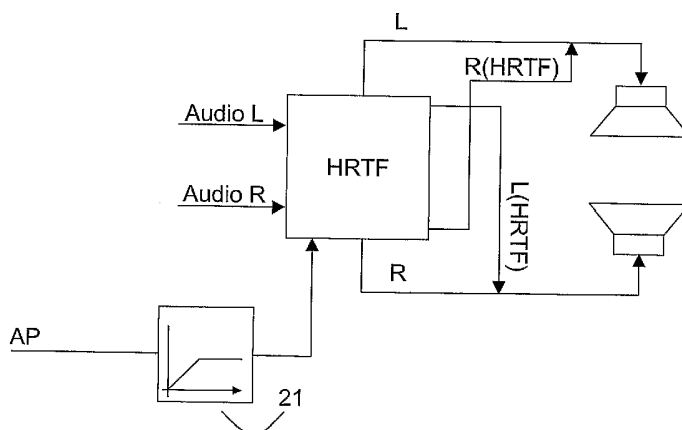
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(54) Title: METHOD AND ARRANGEMENT FOR LOCATING AURAL EVENTS SUCH THAT THEY HAVE A CONSTANT SPATIAL DIRECTION USING HEADPHONES



(57) Abstract: In a method for locating aural events, which are reproduced via headphones (11), with virtual placement outside the head of a listener (1) such that they have a constant spatial direction, the audio signals are influenced by a head-related transfer function (HRTF) such that the in-head localization which is typical of headphone reproduction is avoided. To avoid the effect of aural events which move with the head, the movement of the head is detected and the signals for the left and right channels of the headphones (11) are adjusted such that the direction (6) from which the aural event appears to come remains constant. The position of the head is detected either relative to the trunk of the listener (1) or absolutely in the listening space. When detecting the absolute position of the head, the position signal is routed via a high-pass filter (21), so that rapid changes in the head-position for a relatively short time are forwarded to a filter tracking circuit essentially unchanged. Changes in the head-position for a longer time result, according to the transfer time of the high-pass filter (21), in the correction of a preferred direction (4) from which the aural event is perceived. In addition, an arrangement for carrying out the inventive method is proposed.

**Method and arrangement for locating aural events such
that they have a constant spatial direction using
headphones**

5 The invention relates to the binaural reproduction of
aural events using headphones. In particular, the
invention relates to headphones which detect the
rotational movements of the head and are used to keep
the position of a virtual sound source outside the head
10 constant.

When reproducing aural events using conventional
headphones, the problem of in-head localization
frequently arises. In-head localization involves sound
15 sources being mapped virtually inside the head, which
sound sources would be mapped on a virtual stage in
front of the listener if the aural events were
reproduced on loudspeakers situated in front of the
listener. The localization of individual sound sources
20 in the aural event, for example individual instruments
in an orchestra, is thus complicated or even
impossible.

Figure 1 shows a schematic illustration of the
25 reproduction of a sound event on two loudspeakers 2, 3
arranged in front of a listener 1. Normally, a
preferred direction in this arrangement is at the front
as seen from the trunk. The preferred direction is
indicated by a dashed arrow 4. The sound event is
30 represented by symbolic wavefronts which are shown in
the figure by concentric circle segments emanating from
the loudspeakers 2 and 3. The sound event can be
localized at the left and right ears of the listener as
a result of the amplitude, propagation-time and phase
35 differences and also as a result of different frequency
components in the signals from the left and right
loudspeakers. The virtual direction from which the
sound event is heard is indicated by the arrow 6. In

- 2 -

Figure 2, the listener 1 has changed position. The loudspeakers 2, 3 are on his left. The preferred direction 4 is pointing to the right. As a result of the now changed propagation times, amplitudes, phases and frequencies of the signals arriving at the left and right ears the virtual position 6 of the sound source in the listening room remains constant. The aural event is perceived to come from the left. The aforementioned factors of propagation time, amplitude, phase and frequency can be converted into a transfer function, which is also referred to as the HRTF or HRT function (Head-Related Transfer Function).

Figure 3 shows a schematic illustration of in-head localization. The loudspeakers 8, 9 are arranged on the head such that they can move with it, as is normal for headphones. The signals in the left channel L and in the right channel R are sent only to the respective left and right ears. As in Figures 1 and 2, the sound event is shown by concentric circle segments which represent wavefronts of the sound. In the case of headphone reproduction, however, the signals in the channel which is intended for one ear are not sent to the respective other ear. The listener obtains the impression that the sound event is playing inside his head, as indicated by the point 7. In Figure 4, the listener has changed his position, as in Figure 2. However, since the loudspeakers have likewise changed position, nothing changes about the perceived direction of the sound event.

To avoid in-head localization, it is possible to process the signal which is coming from the signal source and is reproduced on the headphones such that the reproduction on the headphones corresponds to the reproduction of the same signal on a stereo loudspeaker arrangement, as in Figure 1. However, these

- 3 -

improvements still do not eliminate a further effect which is typical of headphone reproduction. When the person listening to headphones turns his head during playback, the perceived aural events move
5 coincidentally in sync. Figures 5 and 6 schematically show the situation described above. In Figure 5, headphones 8, 9 supply the left and right ears of the listener 1 with signals which contain not only the signals L, R which are respectively intended for the
10 left and right ears but also portions of the signals L(HRTF), R(HRTF) which are respectively intended for the other ear. These additional signals L(HRTF), R(HRTF) are produced by applying an HRTF to the respective original signal L, R. The listener perceives
15 the sound event as coming from outside the head, illustrated in the figure by arrow 6. The direction from which the sound event appears to come preferably corresponds to the preferred direction 4 shown by the dashed arrow 4. If the listener 1 now turns his head or
20 changes his position, the perceived position of the sound event moves coincidentally with the change in the listener's position. This situation is shown schematically in Figure 6.

25 This phenomenon cannot normally be observed for rotational head movements by the listener during the normal listening process or during single-channel or multichannel loudspeaker reproduction. The reason for this is the fact that rotational head movements by the
30 listener cause the monaural and interaural transfer factors of the outer ear, the frequency characteristics of said transfer factors for stationary sound sources being characteristically dependent on the sound-source distance and direction, to change in line with the
35 current distance and direction of the respective sound source. These continuous changes in the monaural and interaural transfer factors which are accompanying the

- 4 -

rotational head movements are evaluated by the brain such that the perceived aural events remain stationary despite the movement of the head. In case of normal headphone reproduction, even with additional measures
5 to counter in-head localization, it is not possible to perceive an aural event's stationary position which is felt to be familiar and natural, because the two headphone systems acting as sound sources move with the head. In this context, a change in the monaural and
10 interaural transfer factors does not occur.

In addition to the method for avoiding in-head localization, rotational movements of the head are therefore evaluated and the signals for the left and
15 right ears are altered such that a stable virtual position for sound sources in space becomes established. This situation is shown schematically in Figures 7 and 8. The initial situation in Figure 7 corresponds to Figure 5. In Figure 8, the listener has
20 changed his position. The associated change in the signals for the left and right ears is illustrated by the signals L' , L' (HRTF), R' , R' (HRTF). Despite the coincidentally moving loudspeakers 8, 9, the aural event is perceived as coming from the original
25 direction 6.

This inherently positive property may be perceived as a drawback when the listener is not sitting still and is listening to a performance. When the listener is moving
30 himself, such as when jogging, the aural event remains virtually still in space whenever there is a change of direction. If the listener now changes direction, then the virtual direction from which the listener hears the aural event also changes. So as now to hear the aural
35 event from the preferred direction again, that is say normally from the front, it is known practice to set the normal direction or preferred direction manually.

- 5 -

When the listener is frequently changing direction, however, this method is inconvenient.

It is therefore desirable to specify a method which is used to perceive aural events as having a constant spatial direction on average, i.e. as coming from one preferred direction on average in virtually stationary fashion, even when the listener is moving, without restricting the ability to locate individual sound sources in the aural event. It is also an object of the invention to specify an arrangement for locating aural events such that they have a constant spatial direction using headphones.

The methods according to independent Claims 1 and 3 and also the arrangement according to independent Claim 8 achieve this object. Advantageous developments and refinements of the invention are specified in the subclaims.

In the inventive method according to Claim 1, changes in the position of the listener or of his head which are for a limited time or are relatively frequent are detected and a control variable is derived therefrom. Normally, the head points in one preferred direction when listening to aural events, normally forwards in the direction of the front of the trunk. A change in the position of the listener which is for a limited time or is relatively frequent is when the listener turns his head, for example. The signals for the left and right ears are adjusted, on the basis of the position of the listener or of his head, using variable filters for the HRT function such that the direction from which the aural event appears to come remains stable in space, that is to say has a constant spatial direction. A change in the position of the listener which is for a longer time or is relatively infrequent

- 6 -

results in the direction from which the aural event appears to come being matched to the new preferred direction.

5 In one embodiment of the inventive arrangement, the transfer path for the control variable for the position to the variable filters for the HRT function comprises a high-pass filter. As a result, changes which are for a relatively short time or are relatively frequent are
10 forwarded almost unchanged to a filter tracking circuit which actuates the variable HRT filters. On the other hand, changes which are for a relatively long time or are relatively infrequent are forwarded merely in attenuated form. Changes of direction which are larger
15 in terms of magnitude result in the preferred direction being corrected after a certain time according to the time constant of the high-pass filter. One advantageous cut-off frequency for the high-pass filter is in the order of magnitude of 0.1 Hz. Depending on listening
20 habits or the desired effect, however, other cut-off frequencies are also conceivable.

In one exemplary embodiment, the absolute position of the listener is determined using a beacon transmitter,
25 which is arranged stationary in the listening room, and two receivers, which are arranged on the head or on the headphones and on the trunk of the listener. The beacon transmitter radiates a beacon signal which is received by the receivers. A control circuit evaluates
30 properties of the beacon signal received by the receivers and uses these to ascertain the relative position of the head in relation to the trunk. The beacon signal used may be radio signals, light signals or ultrasonic signals, or combinations of these. The
35 beacon signals are preferably in modulated form. Evaluatable properties of the beacon signal are, by way of example, the amplitude, the phase, the propagation

- 7 -

time or combinations of these. The ascertained position of the head is forwarded to the variable HRT filters as a control variable for adjusting the virtual position of the aural event.

5

In another exemplary embodiment, the absolute position of the listener is ascertained by evaluating the earth's magnetic field or by an inertia sensor. Changes in the signals from a suitable receiver for the earth's magnetic field can immediately be translated into a changed absolute direction. The inertia sensor, e.g. an acceleration pickup or a gyroscope system, shows, depending on complexity, changes of direction about one or more axes. The changes of direction or the changed absolute direction is/are supplied to the control circuit for controlling the variable HRTF filters.

The absolute position in space can also be detected by evaluating GPS (Global Positioning System) signals.

20

It is also conceivable to use a broadcast radio station or a mobile radio station or the like as stationary beacon transmitter. If the beacon transmitter is at a sufficiently great distance from the position of the listener, the error which arises for linear movements by the listener is negligible in comparison with the desired detection of the rotational movements.

In embodiments which detect absolute changes of position, there is advantageously a high-pass filter system which forwards short, highly frequent changes to the control circuit largely unchanged. Changes for a relatively long time which are relatively infrequent are taken into account to less of an extent. In this context, the preferred direction is matched to an altered position for the listener according to the cut-off frequency of the high-pass filter.

- 8 -

In an exemplary embodiment of the inventive method according to Claim 3, the position of the head of the listener relative to the trunk is determined. To this
5 end, a beacon transmitter is attached to the trunk of the listener and a receiver is provided on the head or on the headphones. The beacon signals are identical to those from the exemplary embodiments described above. Since the preferred direction normally points forwards
10 from the trunk, and the head is not normally turned from the preferred direction for a relatively long time, the preferred direction is not reset in the case of this method.

15 In addition, in the exemplary embodiment described above, a magnetic field produced by the beacon transmitter can serve as the beacon signal. In this case, the orientation of the field lines and/or the strength of the magnetic field can be evaluated in
20 order to ascertain the position of the head of the listener.

In one preferred embodiment, a playback appliance worn on the listener's body and the headphones are equipped
25 with means for determining the absolute position in space. In this case, the difference between the position signals from the playback appliance and the headphones is forwarded to the control unit, the difference essentially corresponding to the rotation of
30 the head with respect to the trunk.

Playback appliances worn on the body within the scope of the invention include, inter alia, portable CD players, MP3 players and radio receivers. In principle,
35 any appliances which are suitable for reproducing audio information may be used within the scope of the invention.

- 9 -

The invention will be explained in more detail below with reference to the drawing, in which:

- 5 Figure 1 shows a first schematic illustration of the directional location of aural events in the case of stereophonic reproduction via loudspeakers;
- 10 Figure 2 shows a second schematic illustration of the directional location of aural events in the case of stereophonic reproduction via loudspeakers;
- 15 Figure 3 shows a first schematic illustration of in-head localization in the case of reproduction of aural events via headphones;
- 20 Figure 4 shows a second schematic illustration of in-head localization in the case of reproduction of aural events via headphones;
- 25 Figure 5 shows a first schematic illustration of the virtual localization of aural events outside the head in the case of reproduction via headphones;
- 30 Figure 6 shows a second schematic illustration of the virtual localization of aural events outside the head in the case of reproduction via headphones;
- 35 Figure 7 shows a first schematic illustration of the virtual localization of aural events outside the head in the case of reproduction via headphones while taking into account the head position;

- 10 -

Figure 8 shows a second schematic illustration of the virtual localization of aural events outside the head in the case of reproduction via headphones while taking into account the head position;

Figure 9 shows a first schematic illustration of the detection of the absolute head position in the case of reproduction of aural events via headphones;

Figure 10 shows a second schematic illustration of the detection of the absolute head position in the case of reproduction of aural events via headphones;

Figure 11 shows a third schematic illustration of the detection of the absolute head position and of the tracking of a preferred direction for an aural event in the case of reproduction of aural events via headphones;

Figure 12 shows a first schematic illustration of the detection of the relative head position in the case of reproduction of aural events via headphones;

Figure 13 shows a second schematic illustration of the detection of the relative head position in the case of reproduction of aural events via headphones;

Figure 14 shows a third schematic illustration of the detection of the relative head position in the case of reproduction of aural events via headphones;

- 11 -

Figure 15 shows a schematic illustration of an arrangement for tracking the virtual direction of an aural event when detecting the relative head position;

Figure 16 shows a schematic illustration of an arrangement for tracking the virtual direction of an aural event when detecting the absolute head position.

In the figures, identical reference symbols denote elements which are the same or similar.

Figures 1 to 8 have already been described further above and are therefore not explained in more detail below.

Figures 9, 10 and 11 show schematic illustrations of the detection of the absolute head position in the case of reproduction of aural events via headphones. Figure 9 shows the initial situation. A listener 1 is wearing headphones 11 for binaural reproduction of aural events. The headphones 11 are fitted with a sensor 12. A further sensor 16 is fitted on the body of the listener 1. A fixed point 13 situated in the listening room emits a beacon signal. The beacon signal is indicated by dashed arrows from the beacon transmitter 13 in the direction of the sensors 12 and 16. The arrows enclose an angle α_1 . The position of the head in relation to the trunk can be determined by the differences in the positions of the sensors 12 and 16 in relation to the fixed point 13. A signal source (not shown in Figure 9) delivers an audio signal to the headphones 11. The nature of the audio signal is such that the listener 1 perceives an aural event as coming from the direction 6. The dashed arrow 4 indicates a

- 12 -

preferred direction from which aural events are normally heard as a preference. In Figure 10, the listener's head is turned to the right from the preferred direction. As a result of the head turning, the headphones 11 and hence also the sensor 12 are likewise turned from their original position. The sensor 12 receives the beacon signal from the test transmitter 13 at the new position. The sensor 16 receives the beacon signal at the original position. By evaluating particular properties of the beacon signal, such as propagation time, phase and/or amplitude, it is possible to evaluate the angle of rotation of the head in relation to the trunk. In Figure 10, the rotation of the head and the associated spatial shift of the sensor 12 are indicated by the angle α_2 between the dashed arrows from the beacon transmitter 13 to the positions of the sensors 12 and 16. A signal representing the rotation of the head is forwarded to the audio signal's signal source (not shown in Figure 10) or to a control circuit (likewise not shown). The control circuit containing variable HRTF filters adjusts the audio signals for the left and right ears of the listener 1 such that the aural event is perceived as coming unchanged from the direction 6. The unchanged position of the trunk of the listener 1 in comparison with Figure 9 indicates that the rotation of the head is taking place for limited time or quickly. In Figure 11, the listener from Figures 9 and 10 has turned his body to the right. The change in the position of the sensors 12 and 16 in relation to the fixed point of the beacon transmitter 13 results in an angle α_3 between the arrows which represent the beacon signal. Although the angle α_3 has altered with respect to the angle α_1 , the position of the head in relation to the trunk or of the sensors 12 and 16 in relation to one another can be determined as unchanged. As a result of the rotation of the trunk of the listener, the preferred direction 4

- 13 -

has likewise been rotated. The rotation of the trunk of the listener 1 is normally a movement for a longer time or which lasts longer than the rotation of the head. A high-pass filter (not shown in Figure 11) in the control circuit (likewise not shown) results in the direction from which the aural event appears to come initially remaining still at the position 6'. Depending on the cut-off frequency of the high-pass filter, the variable HRTF filters are then adjusted such that the aural event is perceived as coming from the direction 6 again. Depending on the design of the filters and of the control circuit, virtual directions 6'' are transitionally possible in this case.

The system described with reference to Figures 9, 10 and 11 and the underlying method can be used to advantage whenever it is possible to determine the absolute position of the sensors in space. Conceivable beacon-signal transmitters are listed further above in the description of the invention. This embodiment of the inventive arrangement or of the inventive method makes use of the finding that the head is normally oriented in the preferred direction when listening to audio signals via headphones. Deviations from the preferred direction 4 are normally of short duration in time and/or are carried out relatively quickly. A longer alteration in the head position results in the direction 6 from which the aural event appears to come being matched to an altered preferred direction.

Figures 12, 13 and 14 show a further refinement of the inventive arrangement or of the inventive method. Figure 12 shows the initial situation. A listener 1 uses headphones 11 to perceive an aural event as coming from the direction 6. The source of the audio signal and the control circuit for localizing aural events outside the head are not shown in the figure. The

- 14 -

preferred direction is indicated by the dashed arrow 4. The headphones 11 are fitted with a sensor 12. A beacon transmitter 14 is fitted to the trunk of the listener. In this case, the beacon transmitter 14 may be in the form of a stand-alone beacon transmitter or in the form of part of the signal source. The position of the beacon transmitter on the trunk of the listener 1 is restricted merely by the type of beacon signals used. In addition, a plurality of beacon transmitters and/or a plurality of sensors may also be provided. The sensor 12 detects its position in relation to the relative fixed point of the beacon transmitter 14. In Figure 13, the head of the listener 1 is turned from its original position. The sensor 12 detects the change in its position in relation to the relative fixed point 14. The signal representing the change of position is routed to the variable HRTF filters in the control circuit (not shown in the figure). The control circuit adjusts the audio signals for the left and right ears such that the aural event is perceived as coming from the direction 6. In this case, the preferred direction 4, like the direction 6, is unchanged from Figure 12. In Figure 14, the listener 1 has turned his entire body. The position of the head and hence the position of the sensor 12 in relation to the relative fixed point 14 are unchanged from Figure 12. The aural event is perceived as coming from the preferred direction 4 which has rotated with the body. In this context, the direction 6, like the preferred direction 4, has been turned coincidentally with the rotation of the body.

Figure 15 shows a schematic illustration of an arrangement for tracking the virtual direction of an aural event. Audio signals AudioL, AudioR coming from a source which is not shown in the figure are sent to a control circuit HRTF which processes the audio signals in line with a head-related transfer function (HTRF). A

- 15 -

signal RP representing the position of the head in relation to the trunk of the listener is supplied to the control circuit HRTF. The HRTF control circuit produces output signals for the left and right
5 channels, which permit virtual localization of the reproduced aural event, taking into account the relative position of the head in relation to the trunk.

Figure 16 shows a schematic illustration of an
10 arrangement for tracking the virtual direction of an aural event, with the absolute position of the listener in the listening room being detected. As shown previously in Figure 15, a control circuit HRTF is supplied with audio signals for the left and right
15 channels. In addition, the control circuit HRTF is supplied with a signal AP representing the absolute position via a high-pass filter 21. The control circuit HRTF outputs signals for the left and right channels which have been altered on the basis of the signal AP
20 such that it is possible to perceive an aural event to have a stable spatial direction.

- 16 -

Patent Claims

1. Method for locating the position of aural events with virtual placement outside the head of a listener
5 (1) such that they have a constant spatial direction using sound transducers (11) which move with the head, the left and right ears being supplied not only with signals which are intended for the respective ear but also with portions of the signal which is respectively
10 intended for the other ear, characterized in that a movement of the head from a preferred direction (4) relative to the virtual position (6) of the aural event is detected, a head-position change for a limited time causes the signals to the right and left ears to be
15 adjusted such that the virtual position (6) of the aural event does not move coincidentally, and in that a head-position change for a longer time is followed by the virtual position (6) of the aural event being moved in a new preferred direction (4).

20

2. Method according to Claim 1, characterized in that head-position changes for a limited time are identified by differentiating a signal which represents the movement and/or the rotation of the head.

25

3. Method for locating the position of aural events with virtual placement outside the head of a listener
(1) such that they have a constant spatial direction using sound transducers (11) which move with the head,
30 the left and right ears being supplied not only with signals which are intended for the respective ear but also with portions of the signal which is respectively intended for the other ear, characterized in that a movement of the head from a preferred direction (4)
35 relative to the trunk is detected and the signals for the right and left ears are adjusted such that the virtual position (6) of the aural event in relation to

- 17 -

the trunk remains constant.

4. Method according to one or more of the preceding claims, characterized in that the movement of the head
5 in relation to a reference point (13, 14) is ascertained by measuring the propagation time, amplitude and/or phase of a beacon signal.

5. Method according to Claim 4, characterized in that
10 the beacon signal used is modulated light, ultrasonic signals and/or radio waves.

6. Method according to one or more of the preceding Claims 1 to 3, characterized in that the movement of
15 the head is detected using an inertia sensor, an acceleration pickup and/or by evaluating a magnetic field.

7. Method according to one or more of the preceding
20 claims, characterized in that the preferred direction (4) points forwards from the front of the trunk.

8. Arrangement for locating the position of aural events with virtual placement outside the head of a
25 listener (1) such that they have a constant spatial direction using sound transducers (11) which move with the head, having a control circuit which can be used to supply the left and right ears not only with signals which are intended for the respective ear but also with
30 portions of the signal which is respectively intended for the other ear, characterized in that means (12, 13, 14, 16) for detecting a movement of the head from a preferred direction (4), means for determining the length of time, the speed of the movement and/or the
35 absolute position of the head, and means for influencing the virtual position (6) of the aural event are provided.

- 18 -

9. Arrangement according to Claim 8, characterized in that the means (12, 13, 14, 16) for detecting the movement of the head detect a movement relative to the virtual position (6) of the aural event or relative to the trunk.

10. Arrangement according to Claim 9, characterized in that the means (12, 13, 14, 16) for detecting the movement of the head comprise at least one beacon-signal transmitter (13, 14) and at least one receiver (12, 16), wherein the movement of the head is ascertained by evaluating the propagation time, amplitude, the phase and/or the direction of the beacon signal between the beacon-signal transmitter (13, 14) and the receiver (12, 16).

11. Arrangement according to Claim 10, characterized in that the beacon-signal transmitter (13, 14) is arranged at a fixed location in a listening room or on the trunk of the listener, and at least one receiver (12) is arranged on the head of the listener.

12. Arrangement according to Claim 11, characterized in that the beacon signals comprise modulated light, ultrasonic signals, magnetic fields and/or radio waves.

13. Arrangement according to Claim 8, characterized in that the means for detecting the movement of the head comprise acceleration pickups.

14. Arrangement according to one or more of the preceding Claims 8 to 13, characterized in that the means for determining the length of time and the speed comprise high-pass filters (21) and/or low-pass filters.

- 19 -

15. Arrangement according to one or more of the preceding Claims 8 to 14, characterized in that the means for influencing the virtual position (6) of the aural event comprise means for influencing the phase,
5 the propagation time, the amplitude, the frequency and/or means for mixing the audio signals for the left and right channels.

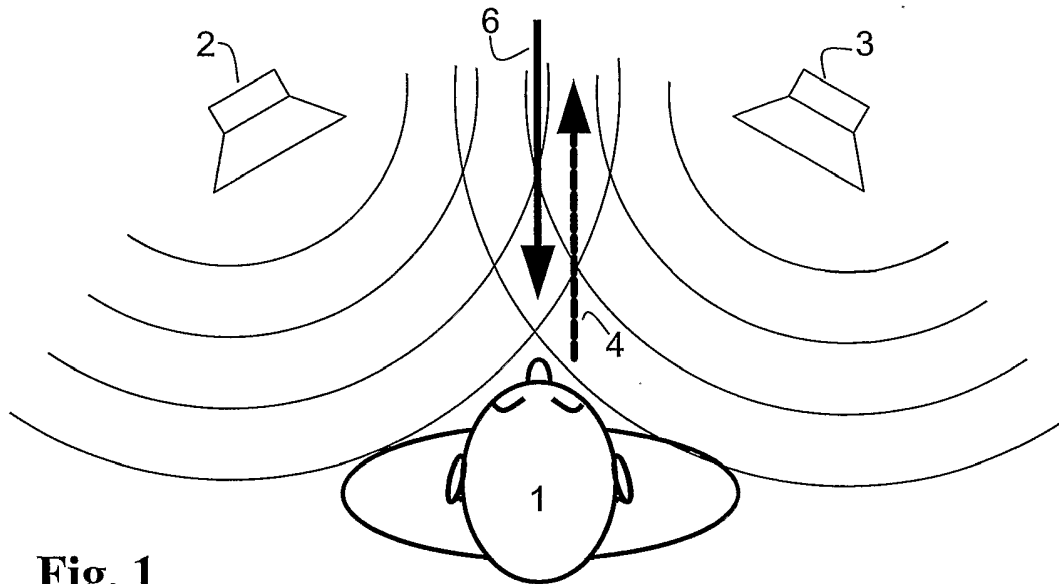


Fig. 1

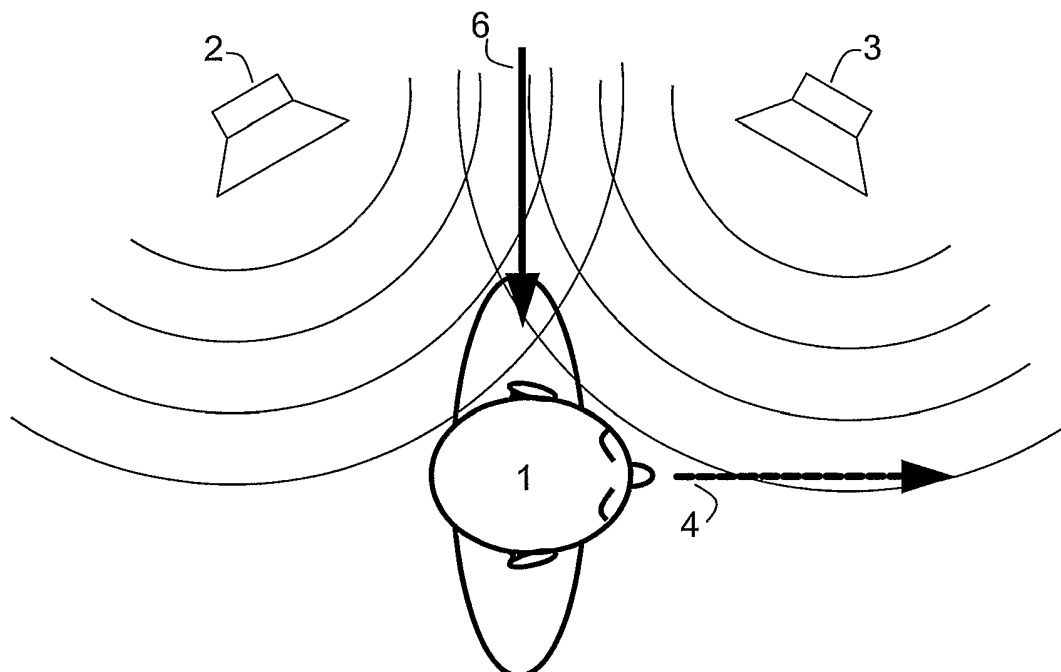


Fig. 2

2/8

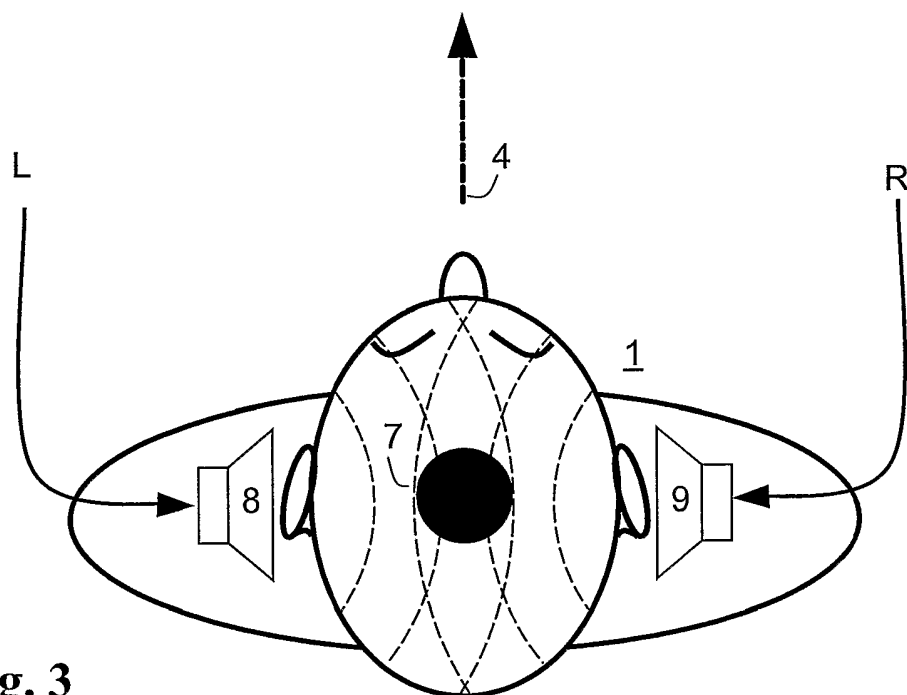


Fig. 3

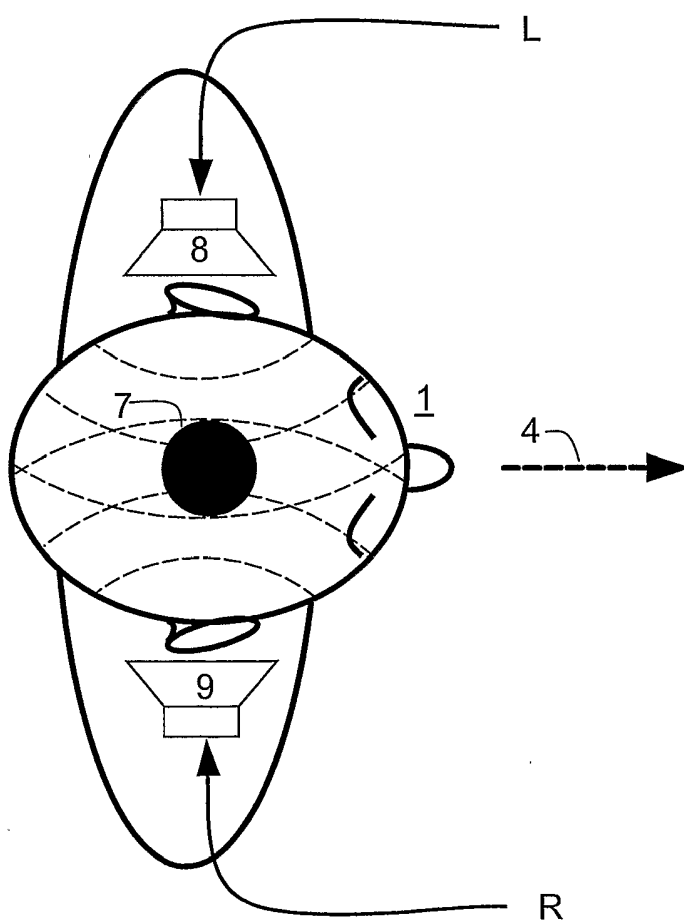


Fig. 4

3/8

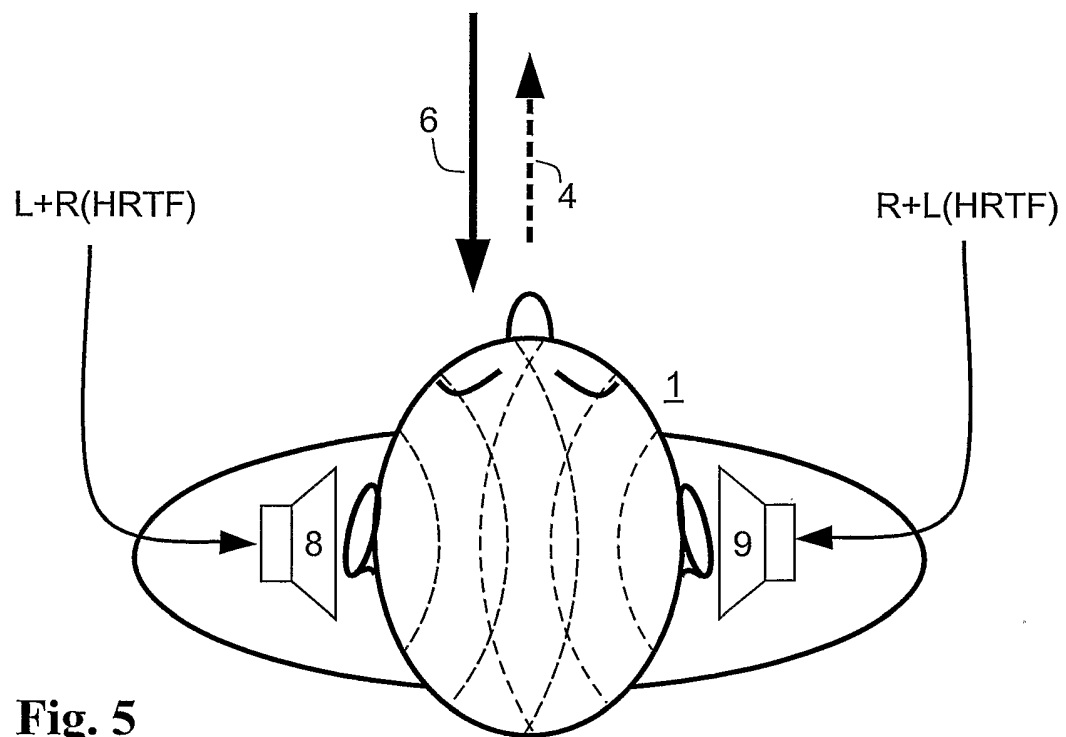


Fig. 5

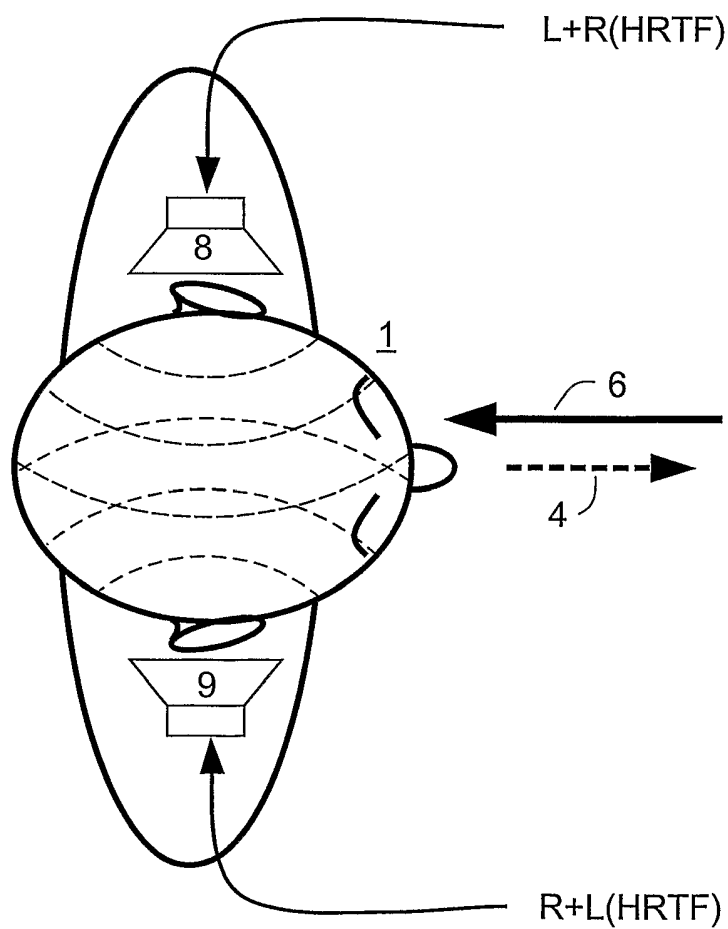


Fig. 6

4/8

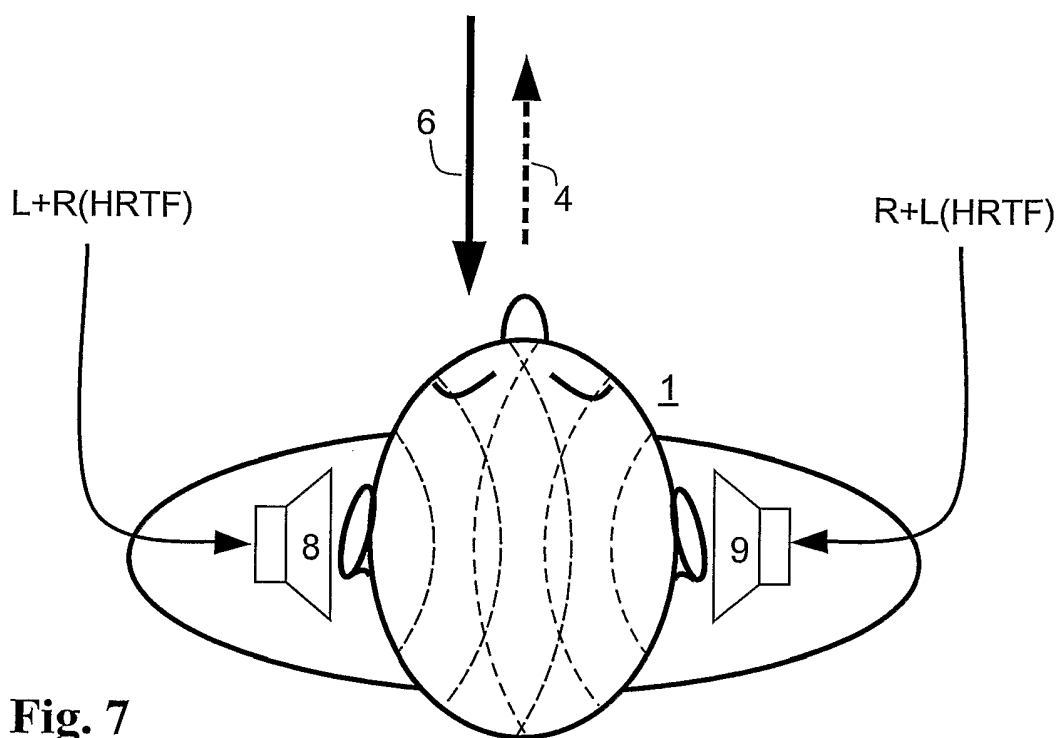


Fig. 7

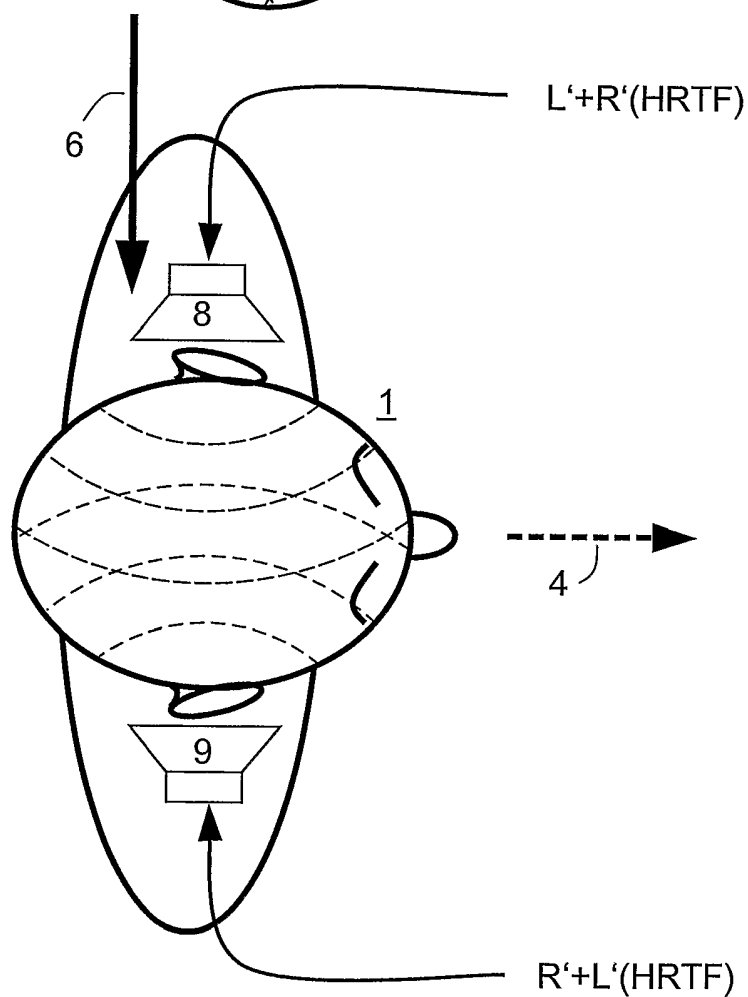
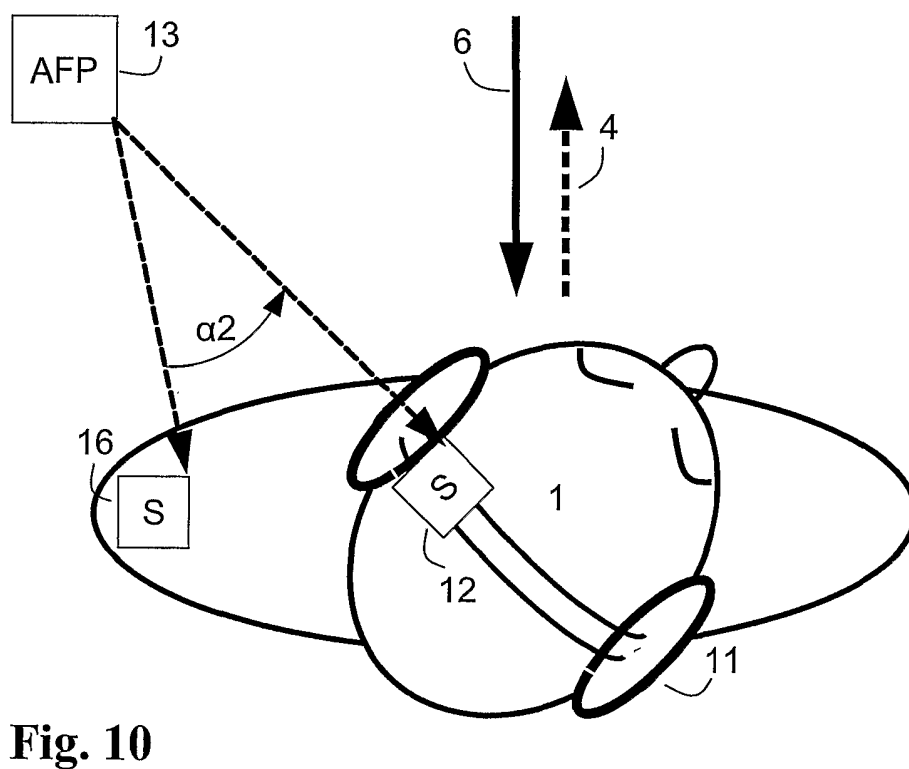
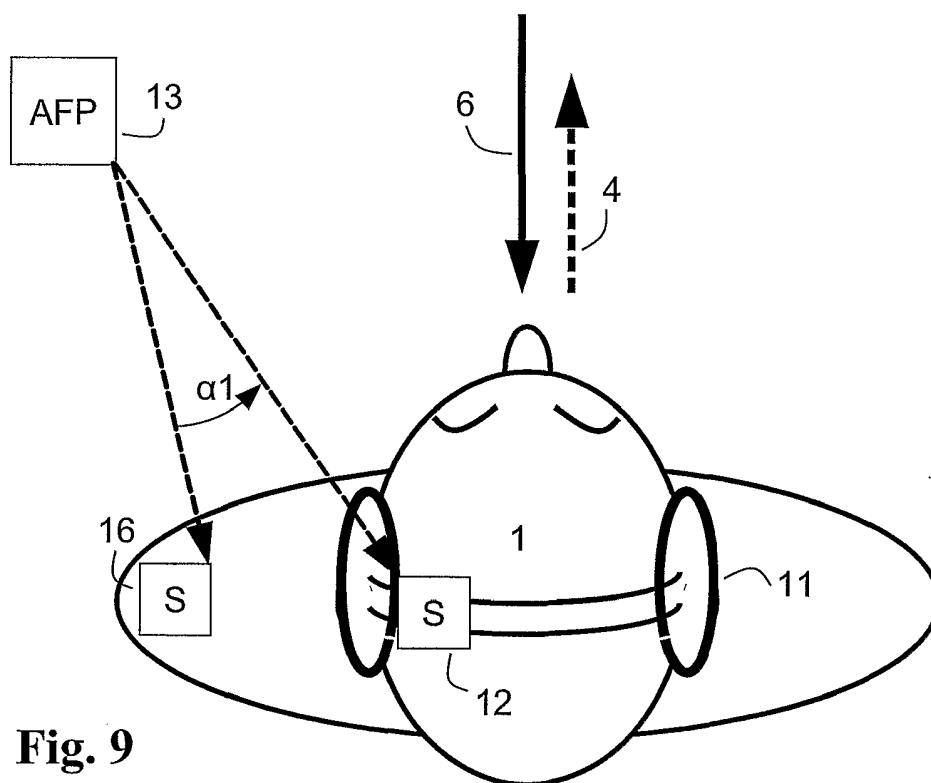
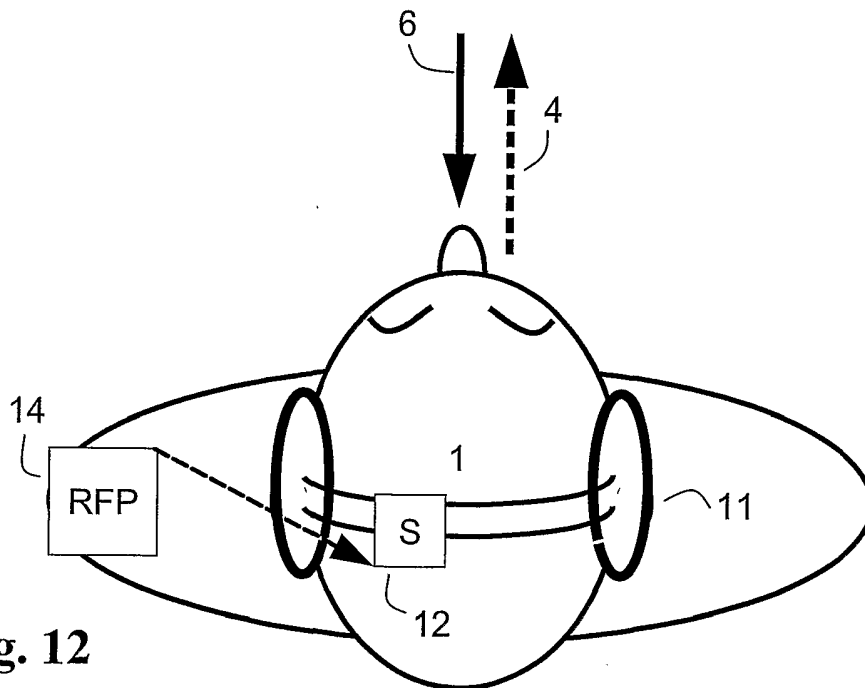
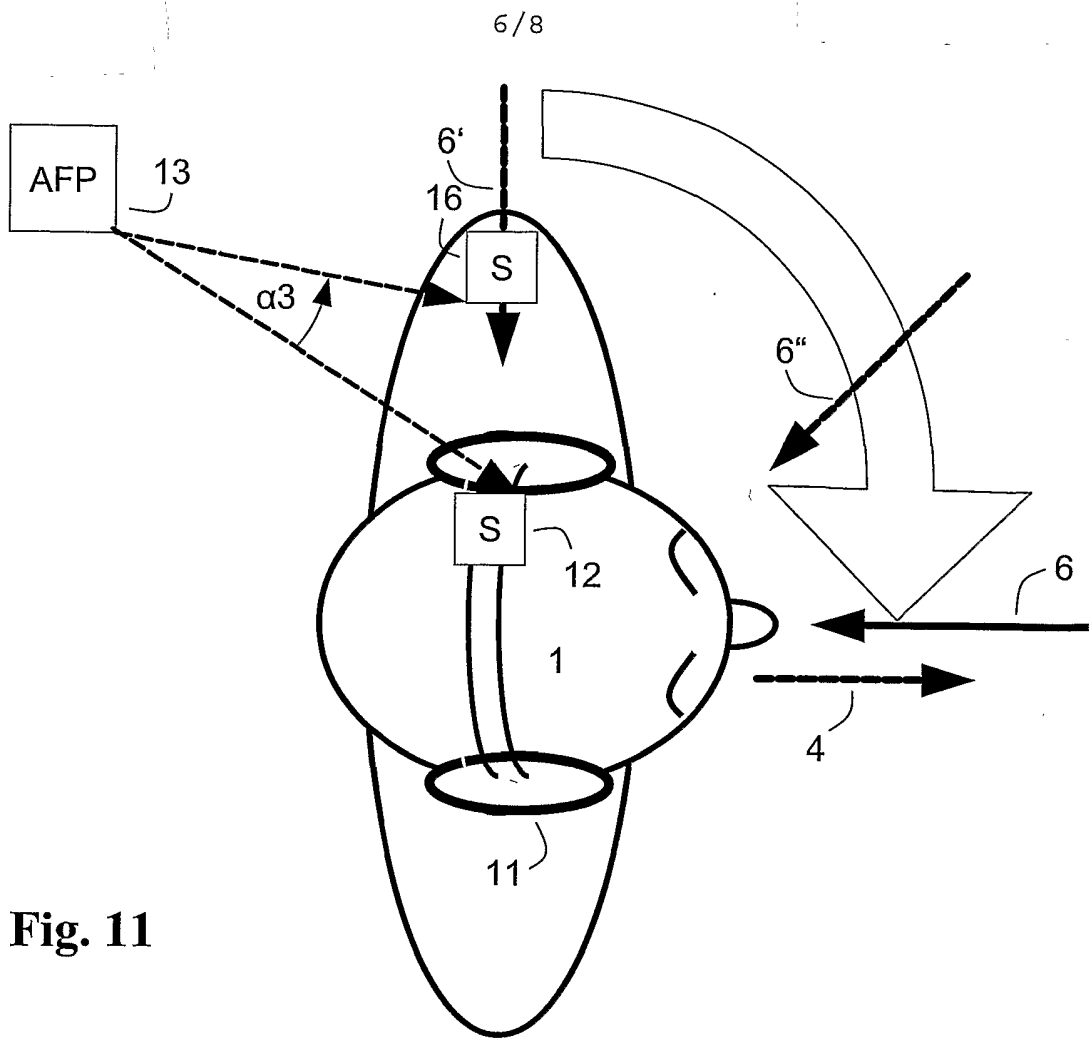


Fig. 8

5/8





7/8

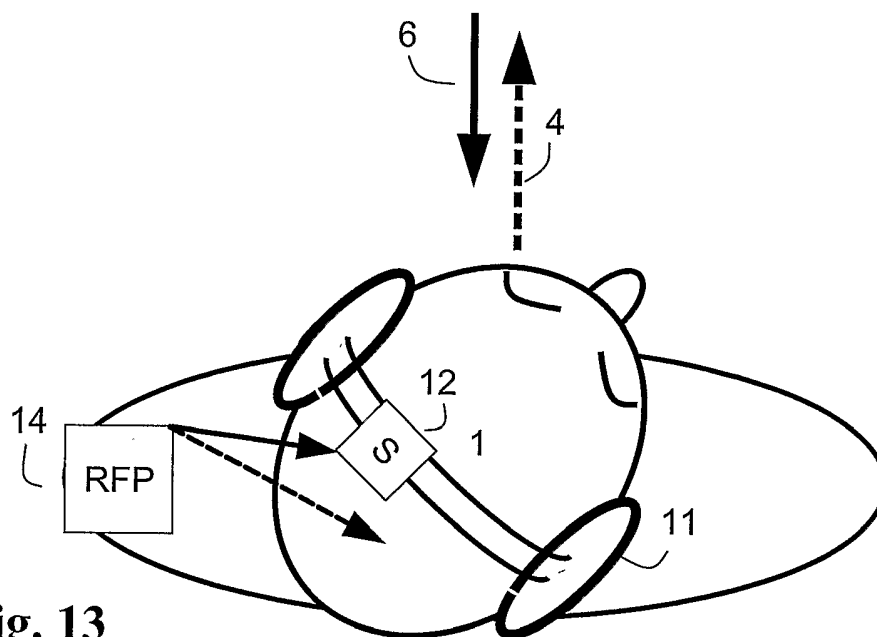


Fig. 13

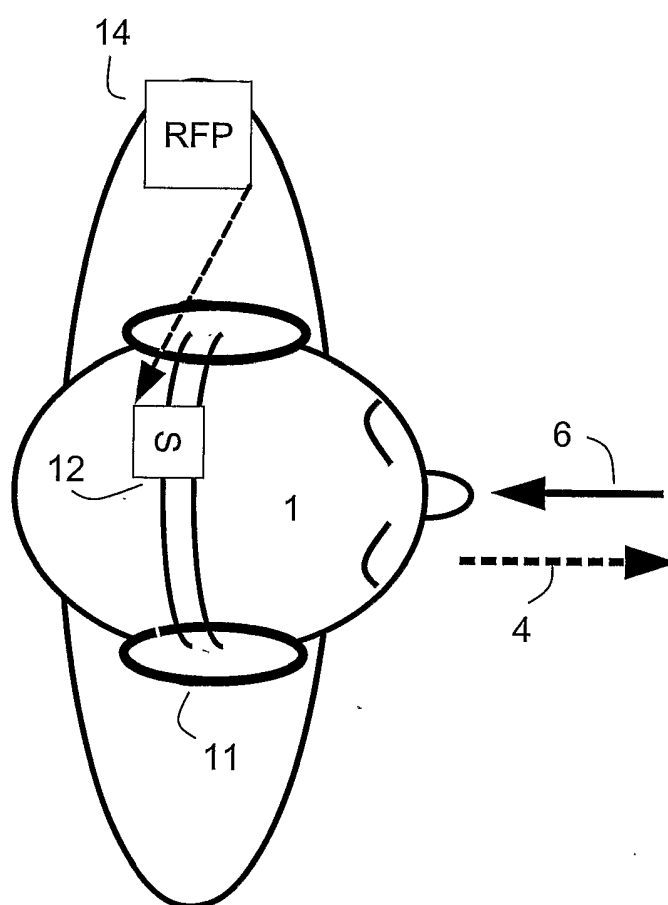


Fig. 14

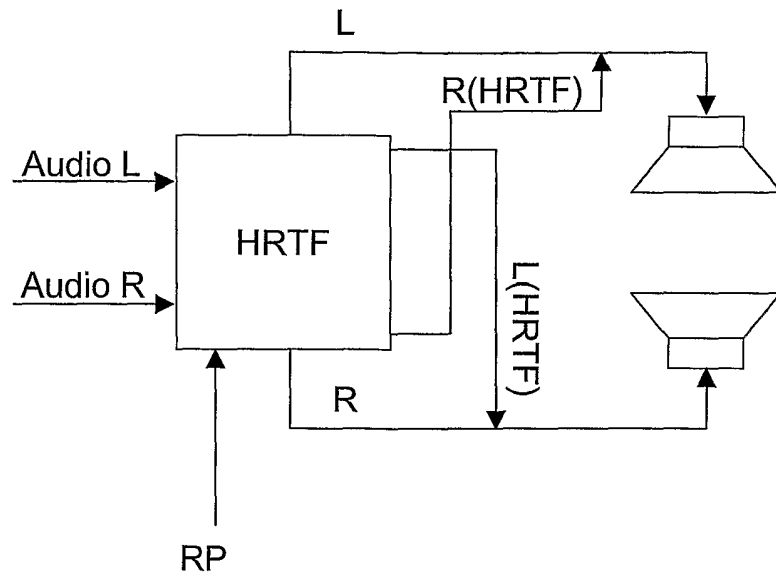


Fig. 15

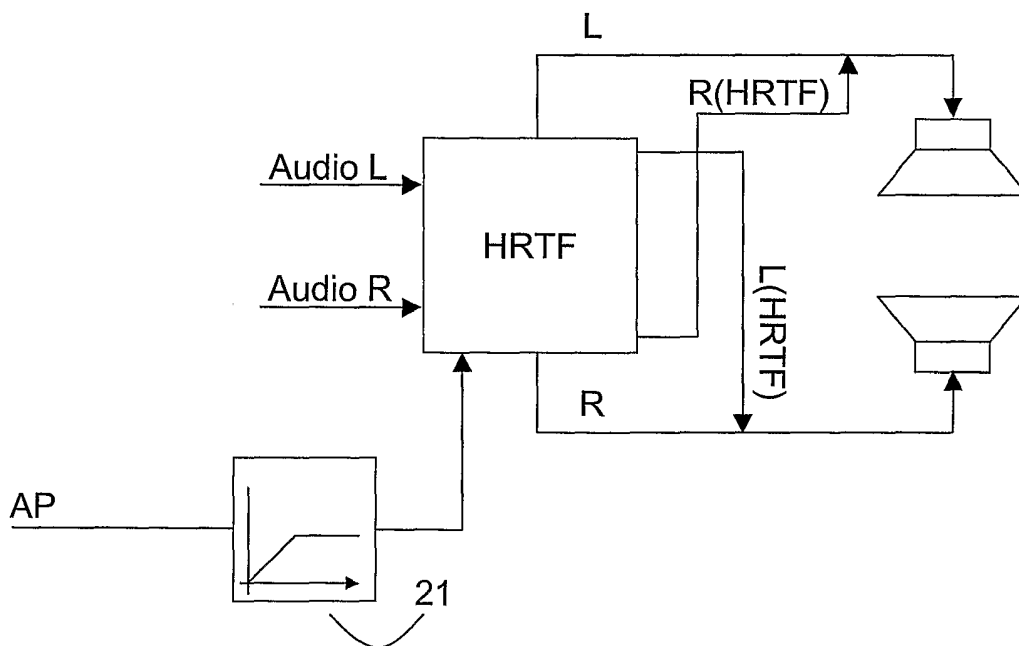


Fig. 16