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(54) **Title:** HEARING AID CONTROLLED BY BINAURAL ACOUSTIC SOURCE LOCALIZER

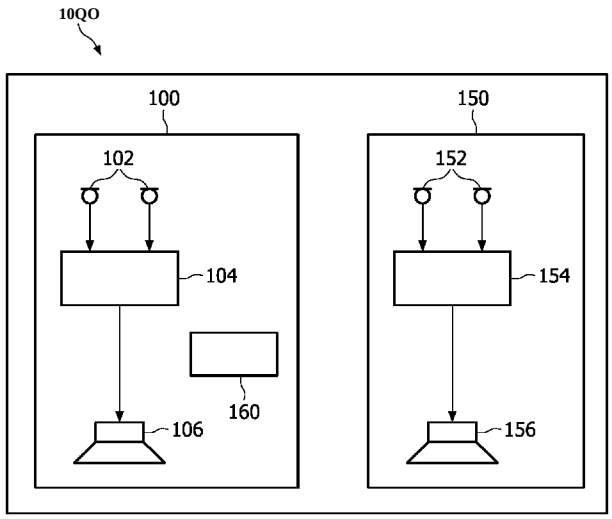


**FIG. 1**

(57) **Abstract:** An adaptive directional hearing aid system comprising a left hearing aid and a right hearing aid, wherein a binaural acoustic source localizer is located in the left hearing aid or in the right hearing aid or in a separate body- worn device connected wirelessly to the left hearing aid and the right hearing aid, the binaural acoustic source localizer configured to receive input signals from the left hearing aid and the right hearing aid and generate a control signal to control the update of a first adaptive beam former in the left hearing aid and a second adaptive beam former in the second hearing aid is disclosed. The disclosed system improves speech intelligibility and listening comfort for the user in noisy environments.

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— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

# Hearing aid controlled by binaural acoustic source localizer

## FIELD OF THE INVENTION

The subject matter relates in general to hearing aids, and more specifically to a control mechanism of hearing aids.

## BACKGROUND OF THE INVENTION

Patent document US 2007/0098192 discloses a hearing aid/spectacles combination. In an embodiment, the spectacle frame has a microphone array in a first spectacle arm. The microphone array is able to pick up a sound signal and is able to transmit a processed signal, produced on the basis of the sound signal, to the first reproduction unit. The hearing aid/spectacles combination includes a sound registration module that includes the microphone array; a beam forming module for forming a direction-dependent processed signal; a reproduction adaptation module for controlling a reproduction characteristic of the processed sound signal produced by the first reproduction unit; a reproduction module that comprises the first reproduction unit; and a reproduction control module for controlling a reproduction characteristic of the processed sound signal produced by the first reproduction unit.

Such devices generally use adaptive beam forming algorithms that adaptively identify and enhance the desired signal and attenuate the most dominant interferences in the output of the hearing aid. The adaptive beam former has to be robust. Generally, some parts need to be adapted when the microphone signals consist predominantly of the desired speech signal to be enhanced; other parts are to be adapted when mainly interference is present. Update control therefore requires the correct detection of desired signals and interferences both in time and frequency.

Furthermore, such devices generally make use of wireless signal transmission that gives rise to several problems for e.g.

i) the high bandwidth required for audio signal transmission can exhaust the battery.

ii) the total signal latency of the hearing aid, from the microphone to the loudspeaker, may not exceed 5 - 7 ms.

Hence, a first object of the invention is to provide an adaptive directional hearing aid system that improves beam former update control while reducing the required bandwidth for wireless signal transmission and avoids the problems of increased signal latency.

It is a second object of the invention to provide a method of controlling an adaptive directional hearing aid system that improves beam former update control while reducing the required bandwidth for wireless signal transmission and avoids the problems of increased signal latency.

It is a third object of the invention to provide a software program that improves beam former update control while reducing the required bandwidth for wireless signal transmission and avoids the problems of increased signal latency.

## SUMMARY OF THE INVENTON

The first object of the invention is realized by providing an adaptive directional hearing aid system comprising a left hearing aid and a right hearing aid, wherein a binaural acoustic source localizer is located in the left hearing aid or in the right hearing aid or in a separate body-worn device connected wirelessly to the left hearing aid and the right hearing aid. The binaural acoustic source localizer is configured to receive input signals from the left hearing aid and the right hearing aid and generate a control signal to control the update of a first adaptive beam former in the left hearing aid and a second adaptive beam former in the second hearing aid.

The first object of the invention is achieved by exploiting the advantages of a binaural microphone array. By using input signals from both the hearing aids, the binaural acoustic source localizer is able to estimate the direction of arrival of incoming sounds with very high accuracy, which would not be possible in a single hearing aid. For example, a sound localizer which is especially suited for this task has been disclosed in the patent document US 6774939. The inventors have found that this sound localizer does not need full-band input signals sampled at, e.g., 32 KHz; an input sample rate of approximately 8 KHz is sufficient to reach a high accuracy, saving transmission bandwidth. Moreover, the use of a compression scheme introducing latency is not a problem as long as the latency does not exceed approximately 20 ms. This is due to the fact that the transmitted signal is only used for enhancing detections and is not part of the signal chain.

It is important that there is at least a certain consistency in the processing applied in the left hearing aid and the right hearing aid for maintaining binaural cues. The use of a common update control signal helps in this context.

The invention needs only minimal additional components namely a binaural acoustic source localizer and does not add much to the cost of the hearing aid system. Furthermore, the update of the adaptive beam former in the left hearing aid and the right hearing aid can be implemented in software with no or only minimal changes in hardware and hence does not add to the cost of the overall system.

In an embodiment, the binaural acoustic source localizer comprises:

- a direction determination unit to determine the direction of arrival of the signals from the most dominant sound source(s);
- a control signal generation unit to generate a common update control signal; and
- a transmitter to transmit the generated common update control signal to the first adaptive beam former and the second adaptive beam former via a communication link.

This is advantageous since desired sound sources can be distinguished from interference by identifying the direction of arrival of the sound. For example, during a conversation in a noisy environment, it may be assumed that the wearer of the hearing aid is more or less facing his/her conversation partner. Sound sources arriving from directions deviating from the frontal direction by more than a certain amount may be considered as interferences. This improves speech intelligibility and listening comfort for the user in noisy environments.

Further, if the binaural acoustic source localizer is implemented on one of the hearing aids, we need to transmit the generated control signal only to one adaptive beam former via a communication link; the other beam former is on the same hearing aid. In case the binaural acoustic source localizer is implemented on a separate body-worn device, then the generated control signal needs to be transmitted via a communication link to both the hearing aids namely the left hearing aid and the right hearing aid.

Further, the binaural acoustic source localizer contains an adaptive filtered sum beam former which determines impulse responses between a sound source and the microphone of the left and the right hearing aid, respectively. This is achieved by maximizing the power of the beam former output, which is the filtered sum of the microphone signals, under a constraint on the filter norm. The impulse responses determined

in this way are cross-correlated and the lag corresponding to the largest peak in the cross-correlation function is determined. The direction of arrival is calculated from this delay. Furthermore, interpolation can be applied to the cross-correlation function to increase the spatial resolution.

In a still further embodiment, the adaptive directional hearing aid system comprises:

- a first processing unit located in the left hearing aid to process the signals received from one of the plurality of microphones located in the left hearing aid and input the processed signals to the binaural acoustic source localizer; and
- a second processing unit located in the right hearing aid to process the signals received from one of the plurality of microphones located in the right hearing aid and input the processed signals to the binaural acoustic source localizer.

The first processing unit and the second processing unit are arranged to carry out processing such as bandwidth reduction, word length reduction, coding or any other form of bit rate reduction. Bandwidth reduction, word length reduction, coding result in reduction of the required communication bit-rate. This results in power savings.

In a still further embodiment, the adaptive directional hearing aid system further comprises:

- a first directional pre-processing unit located in the left hearing aid to transform the signals received from the array of at least two microphones located in the left hearing aid into a set of new signals, the set of new signals possessing a certain amount of directionality;
- a first processing unit located in the left hearing aid to process the set of new signals and input the processed set of new signals to the binaural acoustic source localizer;
- a second directional pre-processing unit located in the right hearing aid to transform the signals received from the array of at least two microphones located in the right hearing aid into a set of new signals, the set of new signals possessing a certain amount of directionality; and
- a second processing unit located in the right hearing aid to process the set of new signals and input the processed set of new signals to the binaural acoustic source localizer.

It is noted here that the set of signals include the case of one single new signal. This has the advantage that the directional preprocessing makes the binaural acoustic source

localizer robust in the presence of diffuse background noise and reverberation. Furthermore, as it is reasonable to assume in hearing aid applications that the desired source is in front of the user, it is sufficient to transmit only the forward facing cardioid signal.

The left hearing aid and the right hearing aid each are equipped with two or more microphones. The microphone signals are transformed into a set of new signals that already exhibit a certain amount of directionality. Two cardioid responses are created, one facing forward and one facing backward. The preprocessed microphone signals are used as inputs to the first adaptive beam former and the second adaptive beam former which is adaptive to both the desired source and the interferences.

The signals preprocessed by the forward facing cardioid processing are each down sampled, compressed and/or reduced in word length. Many possible schemes can be thought of here. One of the bit rate-reduced signals, (in our case that from the left hearing aid), is sent to the other hearing aid (i.e. the right hearing aid) using wireless transmission. The two signals are used as inputs to an estimator. The task of the estimator is to estimate the difference in sound propagation delay between the left hearing aid and the right hearing aid. The direction of arrival of the incoming sound is determined from this delay. Depending on the estimated direction of arrival, an update controller sends update control signals to the first adaptive beam former and the second adaptive beam former. The control signal for the first adaptive beam former is sent through a wired communication link whereas to the second adaptive beam former is sent through a wireless communication link.

Further, if the binaural acoustic source localizer is implemented on one of the hearing aids, we need to transmit the generated control signal only to one adaptive beam former via a communication link; the other beam former is on the same hearing aid. In case the binaural acoustic source localizer is implemented on a separate body-worn device, then the generated control signal needs to be transmitted via a communication link to both the hearing aids namely the left hearing aid and the right hearing aid.

In a still further embodiment, the binaural acoustic source localizer is combined with a monaural signal detector. This has the advantage that it further reduces the required transmission bandwidth. For instance, a coarse monaural acoustic source localizer can be employed in the left hearing aid to detect whether or not an incoming signal is in the front half plane. It is sufficient for the hearing aid to transmit the (down sampled/coded) signal only when a signal is active in that region, since in the hearing aid domain the source of interest can safely be assumed to lie in the front half plane. Similarly, transmission is not required if the signal is detected to be the voice of the wearer of the hearing aid.

The second object of the invention is achieved by providing a method of controlling an adaptive directional hearing aid system comprising a left hearing aid and a right hearing aid. The method comprises:

- providing a binaural acoustic source localizer in the left hearing aid or in the right hearing aid or in a separate body-worn device connected wirelessly to the left hearing aid and the right hearing aid;
- feeding signals from the left hearing aid and the right hearing aid to the binaural acoustic source localizer; and
- generating a control signal to control the update of a first adaptive beam former in the left hearing aid and a second adaptive beam former in the right hearing aid.

The third object of the invention is achieved by providing a software program comprising program code means for performing the method of controlling an adaptive directional hearing aid system as described in the previous paragraph when said software program is run on a processor.

## BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects of the invention will be further elucidated and described with reference to the drawings in which:

Fig. 1 shows an exemplary adaptive directional hearing aid system according to the present subject matter;

Fig. 2 shows an embodiment of a binaural acoustic source localizer;

Fig. 3 shows an embodiment of the adaptive directional hearing aid system; and

Fig. 4 shows a further embodiment of the adaptive directional hearing aid system;

In Fig's 1 - 4, the elements that have the same construction and function have been designated by the same reference numerals.

## DETAILED DESCRIPTION OF THE EMBODIMENTS

Referring to Fig. 1, the adaptive directional hearing aid system 1000 comprises a left hearing aid 100 and a right hearing aid 150 that can be worn by a user. The left hearing aid 100 comprises:

i. an array of microphones 102 to receive incoming sound signals from listening environment

ii. a first adaptive beam former 104

iii. a first reproduction unit 106

The array of microphones 102 are used to receive the incoming sound signals from a listening environment. The first adaptive beam former 104 serves to form a sound beam such that sound from a specific direction can be amplified as desired compared with sound from other directions. Thus a direction-dependant sound signal can be generated so that the user is able to distinguish sound from a specific direction from sound from other directions. The first reproduction unit 106 reproduces the direction-dependant sound signals. The right hearing aid 150 comprises:

i. an array of microphones 152 to receive incoming sound signals from a listening environment

ii. a second adaptive beam former 154

iii. a second reproduction unit 156

The array of microphones are used to receive the incoming sound signals from a listening environment. The second adaptive beam former 154 serves to form a sound beam such that sound from a specific direction can be amplified as desired compared with sound from other directions. Thus a direction-dependant sound signal can be generated so that the user is able to distinguish sound from a specific direction from sound from other directions. The second reproduction unit 156 reproduces the direction-dependant sound signals.

The adaptive directional hearing aid system according to the present invention comprises a binaural acoustic source localizer located in the left hearing aid or in the right hearing aid or in a separate body-worn device connected wirelessly to the left hearing aid and the right hearing aid. The binaural acoustic source localizer is configured to receive input signals from the left hearing aid and the right hearing aid and generate a control signal to control the update of the first adaptive beam former 104 and the second adaptive beam former 154.

Referring to Fig. 1, the binaural acoustic source localizer 160 is located in the left hearing aid 100. The binaural acoustic source localizer 160 receives input sound signals from the left hearing aid and the right hearing aid. The binaural acoustic source localizer 160 processes the received input signals and generates a control signal. The generated control signal is sent to the first adaptive beam former 104 in the left hearing aid and to the second adaptive beam former 154 in the right hearing aid via a communication link. The

communication link can, for example, be wired to transmit the control signals to the first adaptive beam former 104 in the left hearing aid. On the other hand, the communication link can, for example, be wireless to transmit the control signals to the second adaptive beam former 154 in the right hearing aid. The control signals can be, for example, program settings, gain settings or environmental classification results.

Further, if the binaural acoustic source localizer is implemented on one of the hearing aids, we need to transmit the generated control signal only to one adaptive beam former via a communication link; the other beam former is on the same hearing aid. In case the binaural acoustic source localizer is implemented on a separate body-worn device, then the generated control signal needs to be transmitted via a communication link to both the hearing aids namely the left hearing aid and the right hearing aid.

Referring now to Fig. 2, in an embodiment the binaural acoustic source localizer 160 comprises:

- a direction determination unit 202 to determine the direction of arrival of the signals from the most dominant sound source(s);
- a control signal generation unit 204 to generate a common update control signal; and
- a transmitter 206 to transmit the generated common update control signal to the first adaptive beam former 104 and the second adaptive beam former 154 via a communication link.

This is advantageous since desired sound sources can be distinguished from interference by identifying the direction of arrival of the sound. For example, during a conversation in a noisy environment, it may be assumed that the wearer of the hearing aid is more or less facing his/her conversation partner. Sound sources arriving from directions deviating from the frontal direction by more than a certain amount may be considered as interferences. This improves speech intelligibility and listening comfort for the user in noisy environments.

Further, the binaural acoustic source localizer contains an adaptive filtered sum beam former which determines impulse responses between a sound source and the microphone of the left and the right hearing aid, respectively. This is achieved by maximizing the power of the beam former output, which is the filtered sum of the microphone signals, under a constraint on the filter norm. The impulse responses determined in this way are cross-correlated and the lag corresponding to the largest peak in the cross-correlation function is determined. The direction of arrival is calculated from this delay.

Furthermore, interpolation can be applied to the cross-correlation function to increase the spatial resolution. The detailed working of the source localizer is described in the patent document US6774934, which is herewith incorporated by reference.

Referring now to Fig. 3, in an embodiment the adaptive directional hearing aid system 1000 comprises

- a first processing unit 302 located in the left hearing aid 100 to process the signals received from one of the plurality of microphones 102 located in the left hearing aid and input the processed signals to the binaural acoustic source localizer 160; and
- a second processing unit 304 located in the right hearing aid 150 to process the signals received from one of the plurality of microphones 152 located in the right hearing aid and input the processed signals to the binaural acoustic source localizer 160. The first processing unit 302 and the second processing unit 304 are arranged to carry out processing such as bandwidth reduction, word length reduction, coding or any other form of bit rate reduction. Bandwidth reduction, word length reduction, coding results in reduction of the required communication bit-rate. This results in power savings.

Referring now to Fig. 4, in a still further embodiment the adaptive directional hearing aid system comprises

- a first directional pre-processing unit (402) located in the left hearing aid to transform the signals received from the array of at least two microphones 102 located in the left hearing aid into a set of new signals, the set of new signals possessing a certain amount of directionality;
- a first processing unit (404)) located in the left hearing aid to process the set of new signals and input the processed set of new signals to the binaural acoustic source localizer 160;
- a second directional pre-processing unit (452) located in the right hearing aid to transform the signals received from the array of at least two microphones 152 located in the right hearing aid into a set of new signals, the set of new signals possessing a certain amount of directionality; and
- a second processing unit (454) located in the right hearing aid to process the set of new signals and input the processed set of new signals to the binaural acoustic source localizer 160.

It is noted here that the set of signals include the case of one single new signal. This has the advantage that the directional preprocessing makes the binaural acoustic source localizer robust in the presence of diffuse background noise and reverberation. Furthermore,

as it is reasonable to assume in hearing aid applications that the desired source is in front of the user, it is sufficient to transmit only the forward facing cardioid signal.

The left hearing aid and the right hearing aid each are equipped with two or more microphones. The microphone signals are transformed into a set of new signals that already exhibit a certain amount of directionality. Two cardioid responses are created, one facing forward and one facing backward. The preprocessed microphone signals are used as inputs to the first adaptive beam former and the second adaptive beam former which is adaptive to both the desired source and the interferences.

The signals preprocessed by the forward facing cardioid processing are each down sampled, compressed and/or reduced in word length. Many possible schemes can be thought of here. One of the bit rate-reduced signals, (in our case that from the left hearing aid), is sent to the other hearing aid using wireless transmission. The two signals are used as inputs to an estimator. The task of the estimator is to estimate the difference in sound propagation delay between the left hearing aid and the right hearing aid. The direction of arrival of the incoming sound is determined from this delay. Depending on the estimated direction of arrival, an update controller sends update control signals to the first adaptive beam former and the second adaptive beam former. The control signal for the first adaptive beam former is sent through a wired communication link whereas to the second adaptive beam former is sent through a wireless communication link.

In a still further embodiment, the binaural acoustic source localizer is combined with a monaural signal detector. This has the advantage that it further reduces the required transmission bandwidth. For instance, a coarse acoustic source localizer can be employed in the left hearing aid 100 to detect whether or not an incoming signal is in the front half plane. It is sufficient for the left hearing aid to transmit the (down sampled/coded) signal only when a signal is active in that region, since in the hearing aid domain the source of interest can safely be assumed to lie in the front half plane. Similarly, transmission is not required if the signal is detected to be the voice of the wearer of the hearing aid.

A person skilled in the art can implement the described embodiments of the adaptive directional hearing aid system in software or in both hardware and software. It will however be evident that various modifications and changes may be made without departing from the broader scope of the invention, as set forth in the appended claims. Further, in the claims any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of elements other than those listed in a claim or in the description. The word "a" or "an" preceding an element does not

exclude the presence of a plurality of such elements. The figures and description are to be regarded for illustrative purposes only and may not be used for restricting the invention.

The invention is summarized by providing an adaptive directional hearing aid system 1000 comprising a left hearing aid 100 and a right hearing aid 150, wherein a binaural acoustic source localizer 160 is located in the left hearing aid or in the right hearing aid or in a separate body-worn device connected wirelessly to the left hearing aid and the right hearing aid, the binaural acoustic source localizer configured to receive input signals from the left hearing aid and the right hearing aid and generate a control signal to control the update of a first adaptive beam former 104 in the left hearing aid and a second adaptive beam former 154 in the second hearing aid. The disclosed system improves speech intelligibility and listening comfort for the user in noisy environments.

CLAIMS:

1. An adaptive directional hearing aid system comprising a left hearing aid and a right hearing aid, wherein a binaural acoustic source localizer is located in the left hearing aid or in the right hearing aid or in a separate body-worn device connected wirelessly to the left hearing aid and the right hearing aid, the binaural acoustic source localizer configured to receive input signals from the left hearing aid and the right hearing aid and generate a control signal to control the update of a first adaptive beam former in the left hearing aid and a second adaptive beam former in the second hearing aid.

2. The adaptive directional hearing aid system as claimed in claim 1, wherein the binaural acoustic source localizer comprises:

- a direction determination unit to determine the direction of arrival of the signals from the most dominant sound source(s);
- a control signal generation unit to generate a common update control signal; and
- a transmitter to transmit the generated common update control signal to the first adaptive beam former and the second adaptive beam former via a communication link.

3. The adaptive directional hearing aid system as claimed in claim 2, further comprising:

- a first processing unit located in the left hearing aid to process the signals received from one of the plurality of microphones located in the left hearing aid and input the processed signals to the binaural acoustic source localizer; and
- a second processing unit located in the right hearing aid to process the signals received from one of the plurality of microphones located in the right hearing aid and input the processed signals to the binaural acoustic source localizer.

4. The adaptive directional hearing aid system as claimed in claim 2, further comprising:

- a first directional pre-processing unit located in the left hearing aid to transform the signals received from the array of at least two microphones located in the left

hearing aid into a set of new signals, the set of new signals possessing a certain amount of directionality;

- a first processing unit located in the left hearing aid to process the set of new signals and input the processed set of new signals to the binaural acoustic source localizer;
- a second directional pre-processing unit located in the right hearing aid to transform the signals received from the array of at least two microphones located in the right hearing aid into a set of new signals, the set of new signals possessing a certain amount of directionality; and
- a second processing unit located in the right hearing aid to process the set of new signals and input the processed set of new signals to the binaural acoustic source localizer.

5. The adaptive directional hearing aid system as claimed in claims 1- 4, wherein the binaural acoustic source localizer is combined with a monaural signal detector.

6. A method of controlling an adaptive directional hearing aid system comprising a left hearing aid and a right hearing aid, the method comprising:

- providing a binaural acoustic source localizer in the left hearing aid or the right hearing aid or in a separate body-worn device connected wirelessly to the left hearing aid and the right hearing aid;
- feeding signals from the left hearing aid and the right hearing aid to the binaural acoustic source localizer; and
- generating a control signal to control the update of a first adaptive beam former in the left hearing aid and a second adaptive beam former in the right hearing aid.

7. The method of controlling the adaptive directional hearing aid system as claimed in claim 6, the method further comprising the steps of:

- determining the direction of arrival of the signals from the most dominant sound source (s);
- generating a common update control signal; and
- transmitting the generated common update control signal to the first adaptive beam former and the second adaptive beam former via a communication link.

8. A software program comprising program code means for performing the method of claim 7 when said software program is run on a processor.

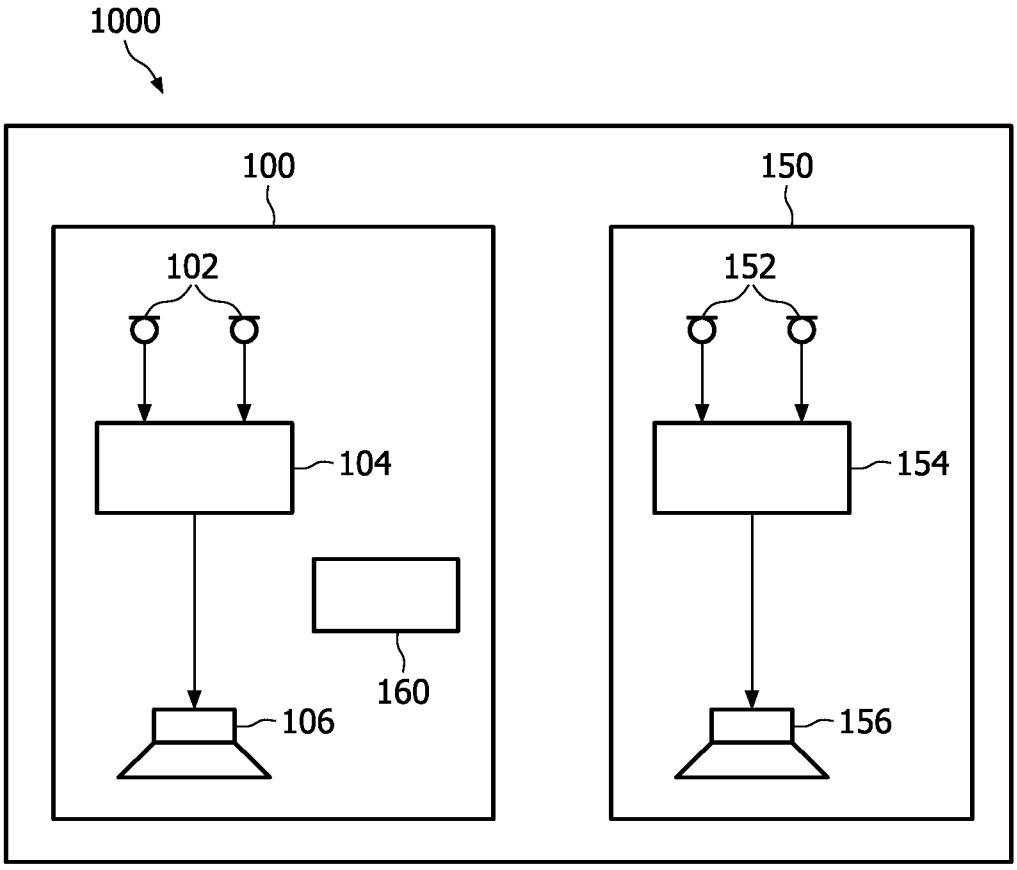


FIG. 1

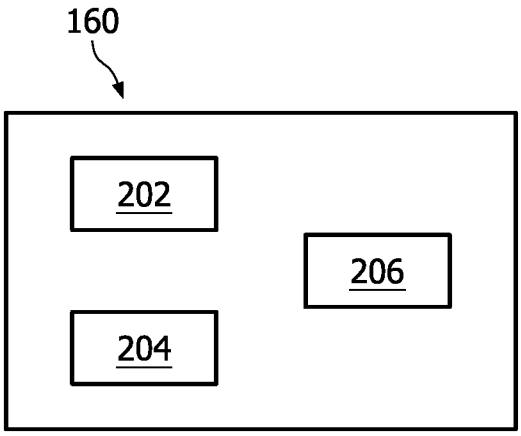


FIG. 2

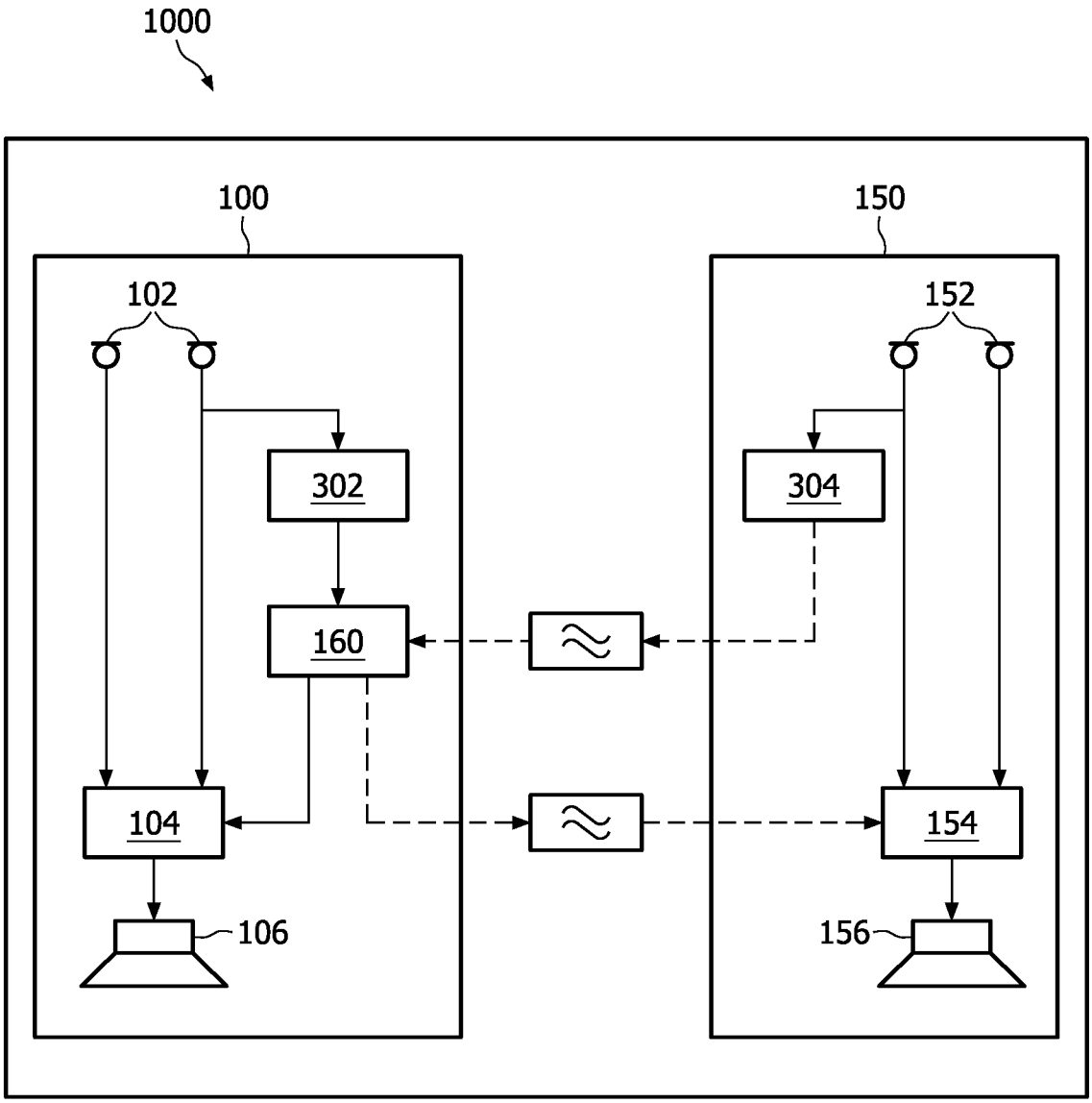


FIG. 3

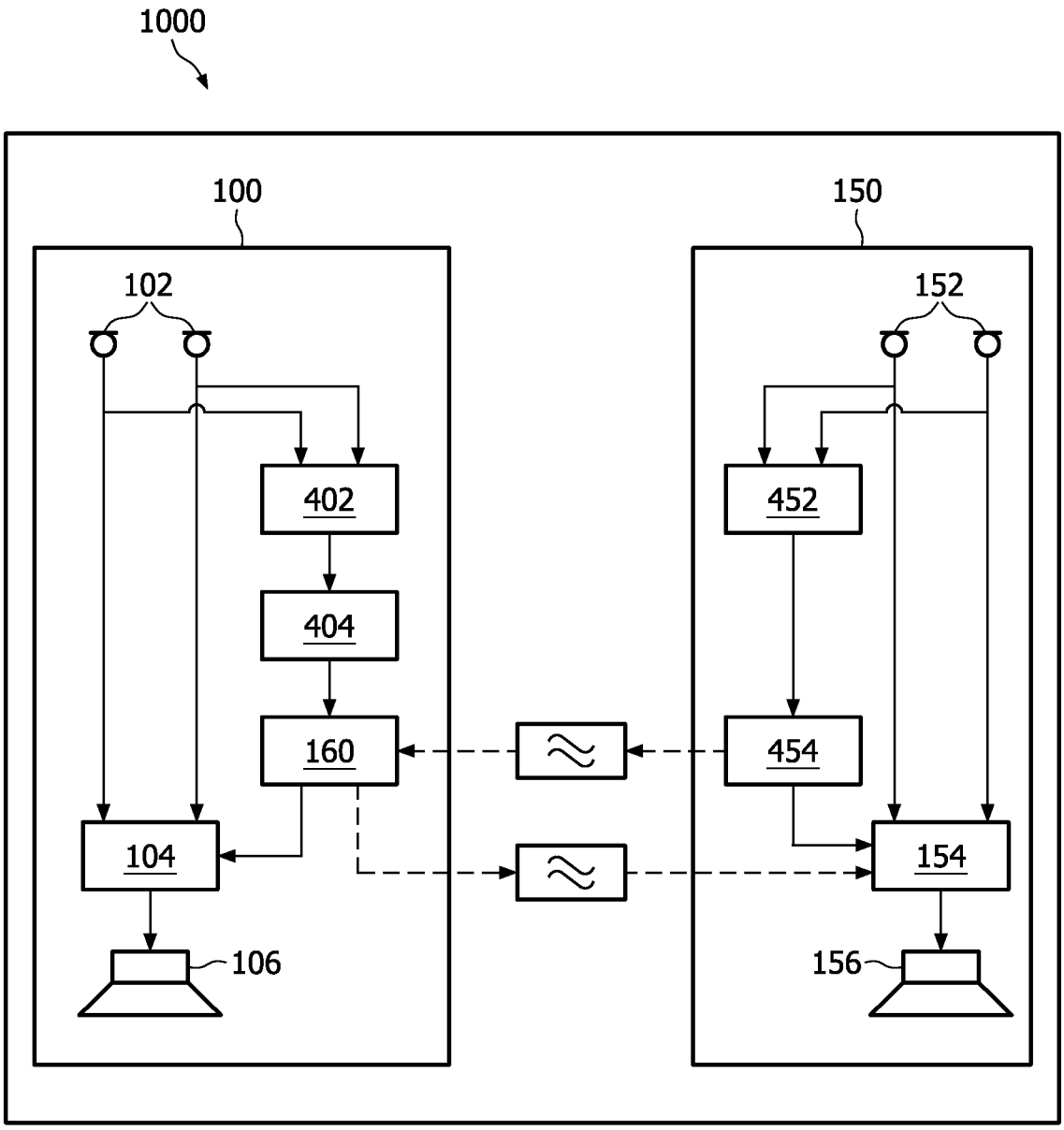


FIG. 4

# INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2008/054986

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. H04R25/00

According to International Patent Classification (IPC) or to both national classification and IPC

**B. RELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical search terms used)
EPO-Internal , WPI Data

**C. DOCUMENTS** CONSIDERED TO **BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No |
|---|---|---|
| X | **US 2004/175008 Al (ROECK HANS-UELI [CH] ET AL) 9 September 2004 (2004-09-09) page 1, paragraph 3 - page 10, paragraph 112; figures 5-10** | **1-8** |
| A | **WO 2004/028203 A (STICHTING TECH WETENSCHAPP [NL]; SIPKEMA MARCUS KAREL [NL]; BOONE MARI) 1 April 2004 (2004-04-01) cited in the application page 3, line 25 - page 28, line 23; figures 1-10** | **1-8** |
| A | **US 2002/131613 Al (JAKOB ANDREAS [CH]) 19 September 2002 (2002-09-19) page 2, paragraph 31 - page 5, paragraph 57; figures 1-7** | **1-8** |

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[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

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| 17 Apri l 2009 | **28/04/2009** |

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| European Patent Office P B 5818 Patentlaan 2<br>NL - 2280 HV Ri\|swi\|k<br>Tel (+31-70) 340-2040,<br>Fax (+31-70) 340-3016 | Duffner, **OrIa** |

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