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(54) Title: A METHOD FOR OPERATING A HEARING DEVICE AS WELL AS A HEARING DEVICE

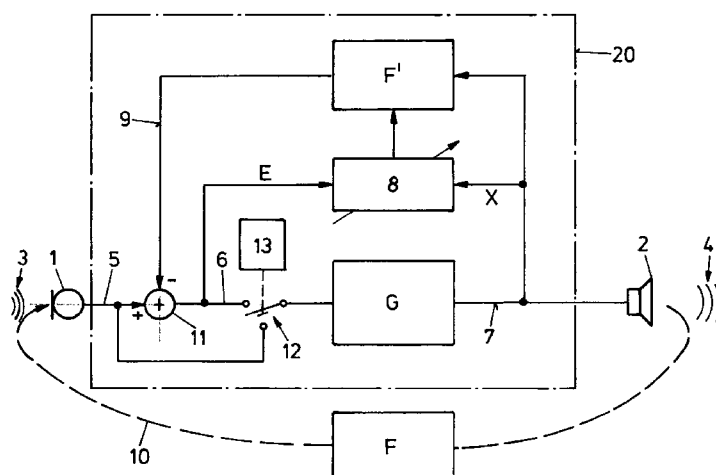


FIG. 2

(57) Abstract: A method for operating a hearing device comprising the steps of generating an input signal (5) of an acoustic signal (3) by an input transducer (1), generating an output signal (7) by applying a gain function (G) to the input signal (5) or a corrected input signal (6), generating an acoustic output signal (4) of the output signal (7) by an output transducer (2), estimating a feedback transfer function (F') describing an acoustic feedback path (10) from the output transducer (2) to the input transducer (1), taking into account the corrected input signal (6), the output signal (7) and an adapting speed (v), generating an estimated feedback signal (9) by applying the output signal (7) to the estimated feedback transfer function (F'), subtracting the estimated feedback signal (9) from the input signal (5) to obtain the corrected input signal (6), and adjusting the adapting speed (v) for adapting the estimated feedback transfer function (F') to changing feedback conditions.

A method for operating a hearing device as well as a hearing device

5 The present invention is related to a method for operating a hearing device as well as to a hearing device.

Basically, hearing devices are used for compensating a hearing loss of a patient by applying a gain to the acoustic signal recorded by a microphone. The amplified acoustic signal is then fed to the receiver that is placed in front of the ear drum of the patient. A common problem for such hearing devices is that of acoustic feedback. Even in the best designed hearing devices, not the entire amplified acoustic signal is delivered to the ear-drum. A small portion of the amplified acoustic signal leaks back to the hearing device microphone forming an acoustic feedback loop. If the gain of the hearing device is sufficiently high, this acoustic feedback will cause a self-generating oscillation to occur, resulting in an unwanted and highly unpleasant whistling sound. These acoustic oscillations prevent the hearing device from being used.

25 Many hearing device manufacturers have therefore developed so called feedback cancellers that reduce the occurrence of feedback in that the feedback signal is estimated and subtracted from the input signal. The estimation of the feedback signal is based on an LMS-(Least Mean Square)-type adaptive filter implemented in the frequency domain, for

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example. Most feedback cancellers in hearing devices use similar algorithms since digital hearing devices have appeared on the market. In general, these types of algorithms all suffer from the same problems and trade-offs in terms of adaptation speed, accuracy and sound quality. First, the adaptation speed and the accuracy are interrelated in that a fast algorithm implementing a high adaptation speed results in a rather inaccurate feedback cancelling while an algorithm with a precise feedback cancelling is always rather slow. A slow algorithm has the drawback that, when feedback occurs, the algorithm cannot react quickly enough, which leads to the above-mentioned whistling sound until the slow adaptive filter has taken care of the situation.

Another common problem with feedback cancellers in hearing devices is the generation of sound artifacts, especially for tonal input signals.

There are a large number of methods that describe different variations of feedback cancelling systems. For example, US-4 731 850 and US-4 879 749 describe a hearing device with an electrical feedback path to cancel acoustic feedback. Other techniques are described in EP-A2-1 398 993, EP-A1-0 406 469 and DE-B3-102 44 184 but none of them provide a solution to prevent the above-mentioned drawbacks.

Therefore, it is an object of the present invention, accordingly, to provide a new and improved hearing device

that is free of at least one of the above-mentioned deficiencies of the prior art.

This and further objects are solved by the features given
5 in claim 1. Further embodiments as well as a hearing device are given in further claims.

First, the present invention is directed to a method for operating a hearing device. The inventive method comprises
10 the steps of:

- generating an input signal of an acoustic signal by an input transducer,
- generating an output signal by applying a gain function to the input signal,
- 15 - generating an acoustic output signal of the output signal by an output transducer,
- estimating a feedback transfer function describing an acoustic feedback path from the output transducer to the input transducer, taking into account a corrected
20 input signal, the output signal and an adapting speed,
- generating an estimated feedback signal by applying the output signal to the estimated feedback transfer function,
- subtracting the estimated feedback signal from the
25 input signal to obtain the corrected input signal, and
- adjusting the adapting speed for adapting the estimated feedback transfer function to changing feedback conditions.

An adjustment of the adapting speed in function of changing feedback conditions has the advantage that the estimation of the feedback transfer function can be adjusted fast, if needed, e.g. for high total gain situations, or can be
5 adjusted accurately if needed, e.g. for rather low total gain situations. It is noted that the term "total gain" must be understood as the overall loop gain of the control loop, in particular comprising the gain of the feed forward path and the gain of the feedback path. The invention
10 described therefore presents a new approach making it possible to accurately estimate the feedback path even with low gain settings, while maintaining a fast adaptation.

A corresponding but differing inventive method for
15 operating a hearing device comprises the steps:

- generating an input signal of an acoustic signal by an input transducer,
- generating an output signal by applying a gain function to a corrected input signal,
- 20 - generating an acoustic output signal of the output signal by an output transducer,
- estimating a feedback transfer function describing an acoustic feedback path from the output transducer to the input transducer, taking into account the
25 corrected input signal, the output signal and an adapting speed,
- generating an estimated feedback signal by applying the output signal to the estimated feedback transfer function,

- subtracting the estimated feedback signal from the input signal to obtain the corrected input signal, and
 - adjusting the adapting speed for adapting the estimated feedback transfer function to changing
- 5 feedback conditions.

Further embodiments of the method according to the present invention comprise the steps of:

- determining an estimated total gain defined by the
- 10 gain function and the estimated feedback transfer function, and
- adjusting the adapting speed as a function of the estimated total gain.

15 In further embodiments of the method according to the present invention, the adapting speed is proportional to the estimated total gain.

In further embodiments of the method according to the

20 present invention, the step of estimating the feedback transfer function is obtained by applying the following formula:

$$F'(n, k) = F'(n-1, k) + \mu(G'_{\text{tot}}) \times \Delta(n, k)$$

25

wherein μ is a step size that is proportional to the adapting speed v , which is a function of the estimated total gain G'_{tot} , and $\Delta(n, k)$ is a measure for a difference between a true feedback transfer function (F) and the

30 estimated feedback transfer function (F').

In further embodiments of the method according to the present invention, a Least-Mean-Square algorithm is used for estimating the feedback transfer function.

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Still further embodiments of the method according to the present invention comprise the steps of:

- 10 - determining an estimated total gain defined by the gain function and the estimated feedback transfer function,
- comparing the estimated total gain with a predetermined gain, and
- applying the input signal generated by the input transducer to the gain function if the estimated total
15 gain is below the predetermined gain,
- applying the corrected input signal to the gain function if the estimated total gain is equal or above the predetermined gain.

20 In further embodiments of the method according to the present invention, wherein the predetermined gain is 5 to 20 dB, particularly 5 to 10 dB, below a critical gain defined by the gain function and the feedback transfer function, at which critical gain just no feedback occurs.

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In addition, the present invention is also directed to a hearing device that comprises:

- an input transducer,
- a signal processing unit,

- an output transducer, the input transducer being operatively connected to the signal processing unit that is, on its output side, operatively connected to the output transducer,

5 wherein the signal processing unit comprises:

- an addition unit,
- a gain function block,
- an estimated feedback function block,
- an adaptive unit operatively connected to the
10 estimated feedback function block, the input transducer being fed to one input of the addition unit and an inverted output of the estimated feedback function block being fed to the other input of the addition unit having its output operatively connected
15 to the adaptive unit as well as to the gain function block, which is, on its output side, operatively connected to the adaptive unit, the estimated feedback function block and to the output transducer, and
- means for adjusting an adapting speed for adapting the
20 estimated feedback transfer function to changing feedback conditions.

A corresponding but differing inventive hearing device comprises:

- 25 - an input transducer,
- a signal processing unit,
- an output transducer, the input transducer being operatively connected to the signal processing unit

that is, on its output side, operatively connected to the output transducer,

wherein the signal processing unit comprises:

- an addition unit,
- 5 - a gain function block,
- an estimated feedback function block,
- an adaptive unit operatively connected to the estimated feedback function block, the input transducer being fed to one input of the addition unit
- 10 and an inverted output of the estimated feedback function block being fed to the other input of the addition unit having its output operatively connected to the adaptive unit, the output of the input transducer being further operatively connected to the
- 15 gain function block, which is, on its output side, operatively connected to the adaptive unit, the estimated feedback function block and to the output transducer, and
- means for adjusting an adapting speed for adapting the
- 20 estimated feedback transfer function to changing feedback conditions.

Further embodiments of the inventive hearing device comprise:

- 25 - means for determining an estimated total gain defined by the gain function and the estimated feedback transfer function, and
- means for adjusting the adapting speed as a function of the estimated total gain.

In still further embodiments of the inventive hearing device, the adapting speed is proportional to the estimated total gain.

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Still further embodiments of the inventive hearing device further comprise:

- a switch unit,
 - a switch control unit controlling the switch unit in
- that it either operatively connects the output of the input transducer or the output of the addition unit to the gain function block.

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It is pointed out that the present invention is directed to every possible combination of the above-mentioned embodiments. Only those combinations are excluded that would result in a contradiction.

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The present invention will be further described in the following by referring to drawings showing exemplified embodiments of the present invention.

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Fig. 1 shows a simplified block diagram with a flow chart of a first embodiment of a hearing device according to the present invention, and

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Fig. 2 shows a simplified block diagram with a flow chart of a second embodiment of a hearing device according to the present invention.

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Fig. 1 schematically shows a block diagram of a hearing device comprising an input transducer 1, a signal processing unit 20 and an output transducer 2. The input transducer 1, e.g. a microphone, is connected to the signal processing unit 20, represented in point-dashed lines, which is on its output side connected to the output transducer 2, e.g. a loudspeaker, that is also called receiver in the technical field of hearing devices. Within the signal processing block indicated by 20, a signal flow chart is depicted to illustrate the processing performed by the signal processing unit 20. However, it is pointed out that additional processing schemes may be implemented in the signal processing unit 20.

Basically, an acoustic input signal 3 is picked-up by the input transducer 1 that generates an input signal 5. The input signal 5 may be available in digital form. Furthermore, the input signal 5 may also be transferred from the time domain into the frequency domain by a Fourier transformation or any suitable transformation.

The input signal 5 is fed to an addition unit 11 to generate a corrected input signal 6. The corrected input signal 6 is obtained by subtracting an estimated feedback signal 9, which is further described below, from the input signal 5. In Fig. 1, the subtraction is represented by an addition of the input signal 5 and the inverted estimated feedback signal 9. A gain function G is applied to the corrected input signal 6 to obtain an output signal 7 being

applied to the output transducer 2 for generating an acoustic output signal 4.

As can be seen from Fig. 1, the corrected input signal 6 as well as the output signal 7 are fed to an adaptive algorithm unit 8, in which an adaptive algorithm is applied for optimizing an estimated feedback transfer function represented by F' . The estimated feedback transfer function F' is an estimation of a true feedback transfer function F describing an acoustic signal path between the output transducer 2 and the input transducer 1. In general, the true feedback transfer function F is dependent on a fit of the hearing device in the ear of the patient, a loose fit resulting in a higher likelihood for feedback occurrence. Of course, the occurrence of feedback is also dependent on the applied gain.

The adaptive algorithm has the task to precisely adapt the estimated feedback transfer function F' in order to give a good estimate of the actual feedback signal 10. On the other hand, the adaptive algorithm has to quickly adapt to changing conditions in order to prevent any feedback. A precise estimation of the feedback signal is most important to eliminate feedback in the input signal 5 by subtracting the estimated feedback signal 9 to obtain the corrected input signal 6 that is free of any feedback signal parts. As has been pointed out in the introductory part of this application, the adapting speed and the precision are contradictory optimizing conditions that cannot be met at the same time.

The present invention proposes to adapt also the adapting speed of the adapting algorithm. This inventive concept is further explained in detail by referring to an example of an adaptive algorithm:

For example, a LMS-(Least Mean Square) algorithm is used in the adaptive algorithm unit 8. Such an algorithm can be expressed as the recursive formula as follows:

$$F'(n,k) = F'(n-1,k) + \mu \times \frac{\overline{X(n,k)}E(n,k)}{E\|X(n,k)\|^2} \times 2,$$

where X is the output signal 7, E is the corrected input signal 6 and μ is the step size of the algorithm. The already mentioned fundamental problem of the algorithm is that while it requires a large value for the step size μ to react quickly to changes in the feedback transfer function F to be modeled, large values for the step size μ create a large mismatch between the estimated feedback transfer function F' and the true feedback transfer function F .

A large step size μ will cause the coefficients of the estimated feedback transfer function F' to fluctuate strongly around the optimum value as they can change by a large amount at each update step. Especially if a total gain G_{tot} defined by the gain function G and the true feedback transfer function F is low, the estimation of the feedback transfer function F' will be inaccurate. In practice this means that a high adaptive step size μ is

required to keep the adaptation quick enough, but in situations with low total gain G_{tot} a low adaptive step size μ is required to obtain an accurate estimate of the feedback transfer function.

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As has been already pointed out, known feedback cancellers had a constant step size. This allowed the system to be quick enough, but was unable to provide a valid estimate in low total gain situations.

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The method according to the present invention provides an accurate estimate of the feedback transfer function F at low and at high total gains G_{tot} .

15 In order to obtain an accurate estimate of the feedback transfer function F for a low total gain G_{tot} as well as for a high total gain G_{tot} , it has been proposed to adaptively adjust the step size μ according to the currently estimated total gain G'_{tot} . The estimated total gain G'_{tot} is expressed
20 in this case as follows:

$$G'_{\text{tot}}(n, k) = G(n, k)F'(n, k)$$

Where $F'(n, k)$ is the estimated feedback transfer function
25 in the frequency domain. The LMS-update of the estimated feedback transfer function F' is obtained as follows:

$$F'(n, k) = F'(n-1, k) + \mu(G'_{\text{tot}}) \times \Delta(n, k)$$

Accordingly, the step size μ is a function of the total gain G'_{tot} and basically scales the error term Δ . The lower the estimated total gain G'_{tot} , the lower the step size μ will be, and vice versa. The mechanism essentially allows

5 the feedback canceller to stay fast and reactive in critical situations, i.e. high total gain G_{tot} situations, while producing an accurate estimate in low total gain G_{tot} situations.

10 The estimated total gain G'_{tot} can also be used to differentiate between critical vs. uncritical situations. The feedback canceller is in practice only needed in critical situations. When the hearing device is in a very stable, low total gain G_{tot} situation, the feedback

15 canceling function can be turned off without danger of whistling occurring. If the adaptive algorithm is quick enough to detect a sudden change in the total gain G_{tot} for the worse, the cancellation can be switched on again in time to avoid feedback. This is illustrated in Fig. 2.

20 Fig. 2 differs from the flow chart depicted in Fig. 1 in that the signal to which the gain function G is applied is either the corrected input signal 6 or the input signal 5 directly coming from the input transducer 1. Thereto, a

25 switch unit 12 that is controlled by a switch control unit 13 is provided in the path between the addition unit 11 and the gain function block G . As explained above, the switch control unit 13 will instruct the switch unit 12 to feed the corrected input signal 6 to the gain function block G

30 in critical conditions, i.e. in case the total gain G_{tot}

exceeds a critical value (referred to as predefined gain below). In uncritical total gain G_{tot} situations, the input signal 5 of the input transducer 1 is directly fed to the gain function block G in order not to superimpose any sound artifacts that may result from the adaptive algorithm in low total gain G_{tot} situations.

It is pointed out that the corrected input signal 6 is calculated, although it is not used in the main signal path containing the gain function G. However, it is used to keep the adaptive algorithm up-to-date all the time in order that the switch unit 12 can quickly switch from the input signal 5 to the corrected input signal 6 whenever there is a need to do so. In order to be able to switch the feedback cancellation out of the audio path, but still maintain the closed loop system necessary for the adaptive algorithm to run, this dual-path mechanism is used: The first path always contains the corrected input signal 6 and is fed to the adaptive algorithm block 8. The corrected input signal 6 is never actually fed to the hearing device output, i.e. the output transducer 2. The second path contains the input signal 5 that is fed to the hearing device output via the gain function G. The estimated feedback signal 9 can be switched in and out of the audio path, frequency bin by frequency bin, if necessary.

Online on/off switching of feedback canceller functions: In situations where a low total gain G_{tot} and therefore no feedback occurs, it is possible to switch off certain functions of the hearing device in order to improve sound

quality. However, an accurate estimate even at a low total gain is required.

In a further embodiment of the inventive method, a decision
5 is taken by the switch control unit 13 whether the input
signal 5 or the corrected input signal 6 is applied to the
gain function G . The actual estimated total gain G'_{tot} is
thereby compared to a predetermined gain. If the estimated
total gain G'_{tot} is below the predetermined gain, the switch
10 control unit 13 switches the switch unit 12 such that the
input signal 5 generated by the input transducer 1 is
applied to the gain function G . If the estimated total gain
 G'_{tot} is equal or above the predetermined gain, the switch
control unit 13 switches the switch unit 12 such that the
15 corrected input signal 6 is applied to the gain function G .

Thereby, artifacts that are generated by the adaptive
algorithm for a rather low total gain G_{tot} can be eliminated
because these artifacts are not introduced in the signal
20 path.

It is pointed out that instead of adjusting the adaptive
step size μ , one may also speak of adjusting a speed v of
the adaptive algorithm. To speak of an adaptive speed v
25 that is changed as a function of the estimated total gain
 G'_{tot} when estimating the feedback transfer function F' is
in fact the same as speaking of an adaptive step size μ .
Both terms are closely interrelated that can be expressed
by the following formula, for example:

- 17 -

$$v = \frac{\mu}{T},$$

wherein v is equal to the adaptive speed, μ is equal to the adaptive step size, and T is the sampling rate of the
5 signal.

Claims

1. A method for operating a hearing device comprising the
5 steps of:

- generating an input signal (5) of an acoustic signal (3) by an input transducer (1),
- generating an output signal (7) by applying a gain function (G) to the input signal (5),
- 10 - generating an acoustic output signal (4) of the output signal (7) by an output transducer (2),
- estimating a feedback transfer function (F') describing an acoustic feedback path (10) from the output transducer (2) to the input transducer (1),
15 taking into account a corrected input signal (6), the output signal (7) and an adapting speed (v),
- generating an estimated feedback signal (9) by applying the output signal (7) to the estimated feedback transfer function (F'),
- 20 - subtracting the estimated feedback signal (9) from the input signal (5) to obtain the corrected input signal (6), and
- adjusting the adapting speed (v) for adapting the estimated feedback transfer function (F') to changing
25 feedback conditions.

2. A method for operating a hearing device comprising the steps of:

- generating an input signal (5) of an acoustic signal (3) by an input transducer (1),
- generating an output signal (7) by applying a gain function (G) to a corrected input signal (6),
- 5 - generating an acoustic output signal (4) of the output signal (7) by an output transducer (2),
- estimating a feedback transfer function (F') describing an acoustic feedback path (10) from the output transducer (2) to the input transducer (1),
- 10 - taking into account the corrected input signal (6), the output signal (7) and an adapting speed (v),
- generating an estimated feedback signal (9) by applying the output signal (7) to the estimated feedback transfer function (F'),
- 15 - subtracting the estimated feedback signal (9) from the input signal (5) to obtain the corrected input signal (6), and
- adjusting the adapting speed (v) for adapting the estimated feedback transfer function (F') to changing
- 20 feedback conditions.

3. The method of claim 1 or 2, further comprising the steps of:

- determining an estimated total gain (G'_{tot}) defined by
- 25 the gain function (G) and the estimated feedback transfer function (F'), and
- adjusting the adapting speed (v) as a function of the estimated total gain (G'_{tot}).

4. The method of claim 3, wherein the adapting speed (v) is proportional to the estimated total gain (G'_{tot}).

5. The method of one of the claims 1 to 4, wherein the step
5 of estimating the feedback transfer function (F') is obtained by applying the following formula:

$$F'(n, k) = F'(n-1, k) + \mu(G'_{tot}) \times \Delta(n, k)$$

10 wherein μ is a step size that is proportional to the adapting speed v , which is a function of the estimated total gain G'_{tot} , and $\Delta(n, k)$ is a measure for a difference between a true feedback transfer function (F) and the estimated feedback transfer function (F').

15

6. The method of one of the claims 1 to 5, wherein a Least-Mean-Square algorithm is used for estimating the feedback transfer function (F').

20 7. The method of one of the claims 1 to 6, further comprising the step of:

- determining an estimated total gain (G'_{tot}) defined by the gain function (G) and the estimated feedback transfer function (F'),
- 25 - comparing the estimated total gain (G'_{tot}) with a predetermined gain, and
- applying the input signal (5) generated by the input transducer (1) to the gain function (G) if the estimated total gain (G'_{tot}) is below the predetermined
30 gain,

- applying the corrected input signal (6) to the gain function (G) if the estimated total gain (G'_{tot}) is equal or above the predetermined gain.

5 8. The method of claim 7, wherein the predetermined gain is 5 to 20 dB, particularly 5 to 10 dB, below a critical gain defined by the gain function (G) and the feedback transfer function (F), at which critical gain just no feedback occurs.

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9. A hearing device comprising:

- an input transducer (1),
- a signal processing unit (20),
- an output transducer (2), the input transducer (1)
- 15 being operatively connected to the signal processing unit (20) that is, on its output side, operatively connected to the output transducer (2),

wherein the signal processing unit (20) comprises:

- an addition unit (11),
- 20 - a gain function block (G),
- an estimated feedback function block (F'),
- an adaptive unit (8) operatively connected to the estimated feedback function block (F'), the input transducer (1) being fed to one input of the addition unit (11) and an inverted output of the estimated
- 25 feedback function block (F') being fed to the other input of the addition unit (11) having its output operatively connected to the adaptive unit (8) as well as to the gain function block (G), which is, on its

output side, operatively connected to the adaptive unit (8), the estimated feedback function block (F') and to the output transducer (2), and

- means for adjusting an adapting speed (v) for adapting the estimated feedback transfer function (F') to changing feedback conditions.

10. A hearing device comprising:

- an input transducer (1),
- a signal processing unit (20),
- an output transducer (2), the input transducer (1) being operatively connected to the signal processing unit (20) that is, on its output side, operatively connected to the output transducer (2),

wherein the signal processing unit (20) comprises:

- an addition unit (11),
- a gain function block (G),
- an estimated feedback function block (F'),
- an adaptive unit (8) operatively connected to the estimated feedback function block (F'), the input transducer (1) being fed to one input of the addition unit (11) and an inverted output of the estimated feedback function block (F') being fed to the other input of the addition unit (11) having its output operatively connected to the adaptive unit (8), the output of the input transducer (1) being further operatively connected to the gain function block (G), which is, on its output side, operatively connected to

the adaptive unit (8), the estimated feedback function block (F') and to the output transducer (2), and

- means for adjusting an adapting speed (v) for adapting the estimated feedback transfer function (F') to changing feedback conditions.

11. The hearing device of claim 1 or 2, further comprising

- means for determining an estimated total gain (G'_{tot}) defined by the gain function (G) and the estimated feedback transfer function (F'), and
- means for adjusting the adapting speed (v) as a function of the estimated total gain (G'_{tot}).

12. The hearing device of claim 11, wherein the adapting speed (v) is proportional to the estimated total gain (G'_{tot}).

13. The hearing device of one of the claims 9 to 12, further comprising:

- a switch unit (12),
- a switch control unit (13) controlling the switch unit (12) in that it either operatively connects the output of the input transducer (1) or the output of the addition unit (11) to the gain function block (G).

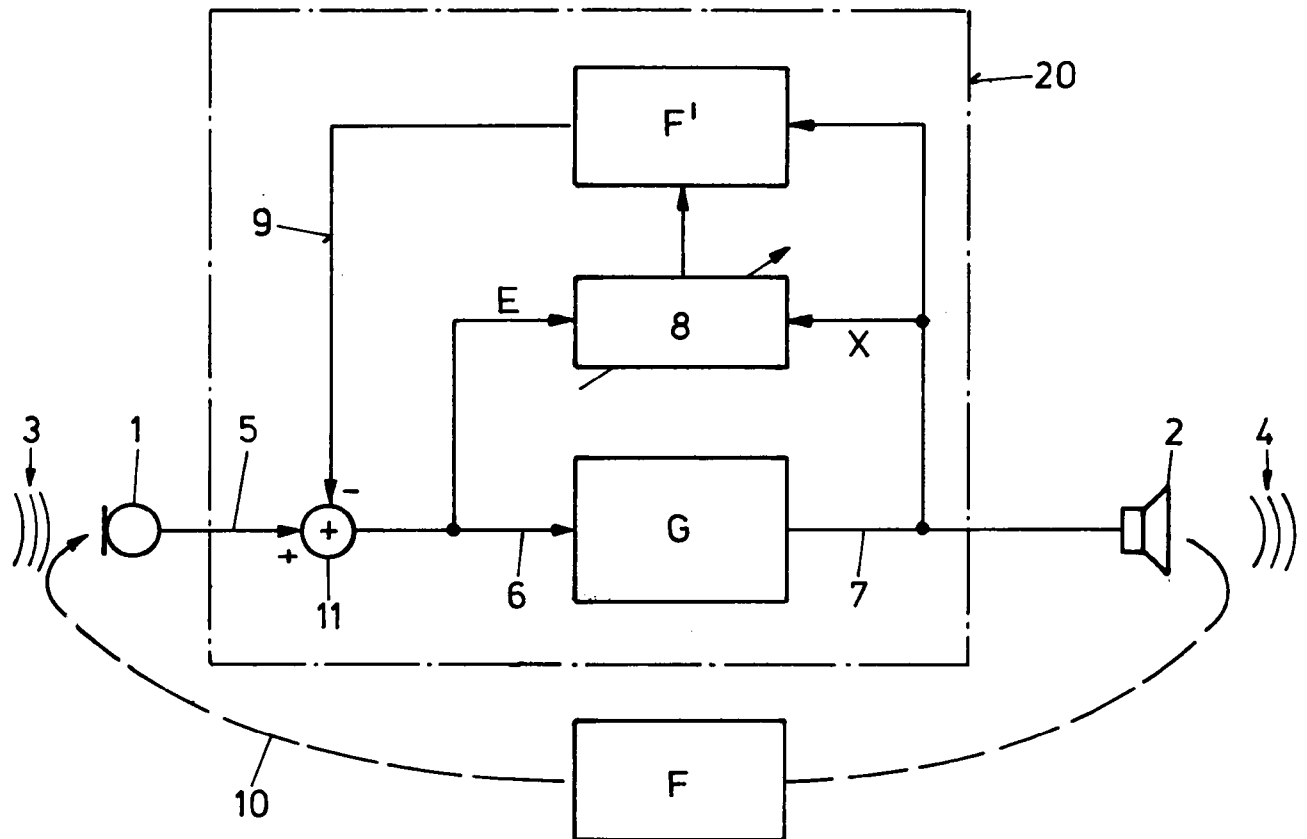


FIG.1

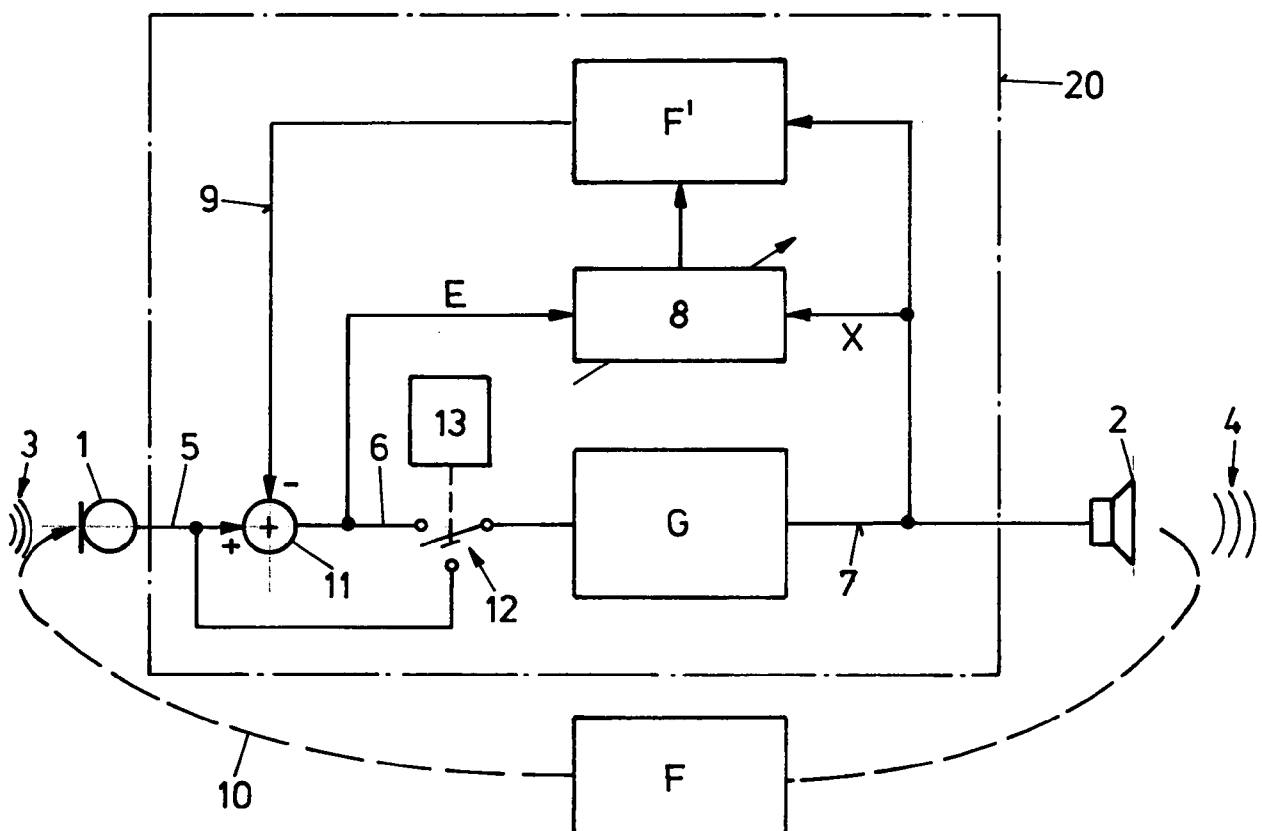


FIG. 2