(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 443 798 A2

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
04.08.2004 Bulletin 2004/32

(51) Int Cl.[7]: **H04R 3/00**

(21) Application number: **04002886.2**

(22) Date of filing: **10.02.2004**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR
Designated Extension States:
AL LT LV MK

(71) Applicant: **PHONAK AG**
8712 Stäfa (CH)

(72) Inventor: **Bock, Friedrich**
71334 Waiblingen-Hegnach (DE)

(74) Representative: **Troesch Scheidegger Werner AG**
Schwäntenmos 14
8126 Zumikon (CH)

(54) **Real-ear zoom hearing device**

(57) There is proposed a hearing device with a behind-the-ear microphone arrangement (1) not to be placed in the ear canal (5) whereat beamforming (9) provides for substantially constant amplification independent of direction of arrival of an acoustical signal at a predetermined frequency (10) and provides above such frequency directivity so as to reestablish a head-related-transfer-function of the individual.

EP 1 443 798 A2

Printed by Jouve, 75001 PARIS (FR)

Description

[0001] The present invention departs from needs which have been recognized at behind-the-ear hearing devices, thereby especially at behind-the-ear hearing aid devices. Nevertheless, although departing from such devices, the present invention may be applied to all hearing systems where there is applied a microphone arrangement not within the ear canal, thereby especially behind the pinna of an individual's ear, the output of which operationally acting on an electrical to mechanical output converter which is applied to the same and/or the other ear of the individual. The hearing device may be a device for increasing hearing capability or a hearing protection device.

[0002] Today's behind-the-ear hearing devices and thereby especially behind-the-ear hearing aid devices may controllably be enabled to operate in the so-called omnidirectional mode. The microphone arrangement which, for this mode, may consist of one omnidirectional microphone, provides per se for an omnidirectional transfer characteristic, which means that acoustical signals impinging on the microphone arrangement are converted to an electrical output signal with a predetermined constant amplification irrespective of the direction with which such acoustical signals impinge on the arrangement. Nevertheless, once applied adjacent to the top of or behind the pinna, the acoustical to electrical transfer characteristic becomes not anymore independent of the direction at which acoustical sources appear to the microphone due to the so-called head-related transfer function HRTF, which results in some degree from "shadowing" of the acoustical signals dependent where the acoustical signal source is located with respect to the microphone arrangement.

[0003] When an individual's ear acoustical reception characteristic is investigated per se, e.g. by means of a complete-in-the-canal hearing device, CIC, as a standard the following transfer characteristics are recognized:

[0004] When, according to fig. 1, 0° direction is defined in the direction at which individual's head H faces and 90° direction is defined perpendicularly thereto in a direction pointing outwards of individual's right ear E_R one recognizes at this right ear a transfer characteristic at a frequency f of 0.5 kHz of acoustical signals as shown in fig. 2. As may be seen the acoustical signals from acoustical sources seen under an angle of 180° to 0° are considerably attenuated, which is predominantly caused by the shadowing effect of individual's head, i. e. by the HRTF. In directions symmetrically to the 90° directivity axis, i.e. at about 45° and at about 135°, the amplification is substantially equal.

[0005] In fig. 3 as well as in fig. 4 the respective transfer characteristics are shown for acoustical signals at 1 kHz and at 2 kHz.

[0006] In fig. 5 the transfer characteristic is shown at 4 kHz. When comparing the transfer characteristics at 2 kHz, with that at 4 kHz, according to the respective figs. 4 and 5, one recognizes an increased directivity of the transfer characteristics at 4 kHz. In fact, departing approx. at frequencies of 2 kHz of the acoustical signals, the directivity of the pinna becomes effective. Nevertheless, as frequencies above 7 kHz are of no interest whenever speech understanding is addressed, with an eye on such speech understanding, it is important to note that the pinna provides for a beam forming effect in a frequency band of 2 kHz to 7 kHz, thus with a significant frequency at 5 kHz. The beam forming effect results in a higher amplification in 45° direction than in the 135° direction. Nevertheless, also for applications of the device, where at least not speech understanding is predominantly addressed, the 5 kHz frequency is significant for pronounced pinna directivity effect.

[0007] As was mentioned above, the transfer characteristics as exemplified by figs. 2 to 5 are transfer characteristics at respective acoustical signal frequencies of an individual's ear per se.

[0008] When applying to such individual a microphone arrangement not in the ear canal, e.g. behind the pinna, as is customarily done by applying a behind-the-ear hearing aid device, the directivity characteristic of the pinna becomes moot, whereas the HRTF-based characteristic as of the figs. 2 to 4 is still effective.

[0009] Thus, an intrinsically omnidirectional beam former with microphone arranged not in the ear canal, thus especially behind the pinna will establish a transfer characteristic with substantially equal amplification symmetrical to the 90° direction. The pinna-caused beam forming characteristic with an attenuation of signals impinging from 45° relative to such signals from 135° which according to fig. 4 is about +6 dB is lost. It results therefrom that whenever the hearing device enabled or controllably switched in omnidirectional mode will not establish for a transfer characteristics which accords to natural beam forming of the ear at frequencies above 2 kHz and, with respect to speech understanding, in the relevant frequency band up to about 7 kHz, but will establish as shown in fig. 5 by dashed lines a transfer characteristic as if no pinna was present.

[0010] It is an object of the present invention to provide a hearing device with a microphone arrangement to be placed not in the ear canal and thus especially behind the pinna of the ear of an individual which, at least in one operating mode, provides for a transfer characteristic at least similar to that of the natural ear.

[0011] This object is achieved by a hearing device with a behind-the-ear microphone arrangement to be placed not in the ear canal of an individual's ear, wherein the microphone arrangement has at least one microphone with an output, the device further having an electrical/mechanical output converter and has a further microphone and a beam former unit. Latter has at least two inputs and an output. One input of the beam forming unit is operationally connected to the output of the one microphone and the second input of the beam former unit is operationally connected to the output of the further microphone. The output of the beamformer unit is operationally connected to an input of the output converter and establishes together with the one and the further microphones a transfer characteristic of acoustical signals impinging on the one and the further microphones to an electrical signal at the output of the beam former unit with an amplification which is dependent on the direction with which acoustical signals impinge on the microphone and on the frequency of such acoustical signals. With 0° direction being defined in direction of individual's facing and 90° direction substantially in ear canal outside direction of the ear considered, the transfer characteristic established by the beam former unit and the at least two microphones has the following features:

- A substantially constant amplification independent of the direction of impinging at a frequency of the acoustical signal of 1 kHz, and
- for a direction of 45° a larger amplification than for a direction of 135° of said acoustical signals impinging on the microphones at a frequency of 5 kHz.

[0012] Thus, on one hand the beam former unit behaves at frequencies below 2 kHz, as at the significant frequency of 1 kHz, like an omnidirectional microphone. Applied to the head, the HRTF is effective as at the unequipped ear. At higher frequencies above 2 kHz as established by the characteristic frequency of 5 kHz, the beam former unit and microphones establish an increased amplification in forwards direction as in the 45° direction compared with attenuation in the backwards direction of 135°. This simulates the pinna directivity effect.

[0013] The ratio of amplification in 135° direction to amplification in 45° direction is selected to be approx. -6 dB. Thus, in a preferred embodiment of the hearing device according to the present invention at a frequency of 5 kHz of impinging acoustical signals the amplification in 45° direction is at least approx. 6 dB higher than the amplification in 135° direction.

[0014] As was already addressed above hearing devices of the addressed type and thereby especially behind-the-ear hearing devices are customarily equipped with different operating modes or programs which may be manually or automatically enabled, be it by remote control or by automatic evaluation of the acoustical surrounding. Thereby, it is customary to provide in context with such switchable operating modes different selectively enabled beam forming abilities. With an eye on such multimode hearing devices and according to the present invention one operating mode is characterized by the mode which was described, i.e. the mode enabling natural ear simulation due to the specific, frequency-dependent beam forming.

[0015] In spite of the fact that within the scope of the present invention the further microphone which is necessary for establishing beam forming ability and which may be provided remote from the microphone arrangement to be applied behind the pinna is most preferably provided as a part of the addressed microphone arrangement. Further, the device according to the present invention is preferably a behind-the-ear hearing device and thereby especially a behind-the-ear hearing aid device. We understand as a behind-the-ear device a device with an output converter applied to the same ear as the microphone arrangement. In a further mode the addressed further microphone is part of a second hearing device to be placed at the second ear of the individual so that the device according to the present invention is e.g. part of a binaural hearing system.

[0016] Further, the hearing device may be a device for increasing hearing capability or may be a device for hearing protection i.e. attenuating the effect of acoustical signals.

[0017] The present invention shall now be further exemplified with the help of further figures. They show:

Fig. 6 a schematic simplified signal flow/functional block diagram of a hearing device according to the present invention;

Fig. 7 by means of a schematic representation of a behind-the-ear hearing aid device, a preferred arrangement of the at least two microphones to be provided for establishing a device according to the present invention and

Fig. 8 by means of schematic representation in analogy to that of Fig. 7, a further preferred embodiment of a hearing device according to the present invention.

[0018] According to fig. 1 a microphone arrangement 1 of the device according to the present invention comprises at least one microphone 3, e.g. and in the most simple form of realization with an omnidirectional transfer characteristic as schematically shown at T_1. The microphone arrangement 1 is e.g. to be placed behind e. g. adjacent the top of individual's ear pinna 5. Remote from microphone 3 there is provided a further microphone 7, which, again in the simplest form, has an omnidirectional transfer characteristic T_7. The respective electrical outputs A_3, A_7 of the microphones 3 and 7 are operationally connected to a beam former unit 9. In a most simple form of realization the beam former unit 9 is a "delay and add" beam former unit. Nevertheless, for more sophisticated tailoring of the beam forming action of the unit 9 such beam forming unit may be realized as described in details in the WO 99/04598, in the WO 01/60112 or in the WO 99/09786, all of the same applicant as the present application. Thereby, the skilled artisan is aware of a multitude of different forms of realizing such a beam forming unit. According to the present invention the microphones 3, 7 and the beam former unit

9 provide for an omnidirectional characteristic up to about 2 kHz and, for higher frequencies, turn to a directional beam forming characteristic as e.g. to a first order cardoid transfer characteristic.

[0019] As exemplified in fig. 6 in a most simple way of realization, this is achieved by having the electrical signal from the output A_7 of the further omnidirectional microphone 7 first led via a high-pass filter unit 10 with a cut-off frequency at about 2 kHz before feeding such signal to the adding unit 11 of the beam forming unit 9. The electrical signal at the output A_3 of microphone 3 is fed via the delay unit 13 to the adding unit 11 as well known to the skilled artisan for delay and add beam forming technique.

[0020] Thus, up to the cut-off frequency of about 2 kHz the microphone 7 is not effective with respect to beam forming and thus the output signal at A_{11} of adding unit 11 will establish for the omnidirectional characteristic according to T_1 of microphone 3. It is only starting at the cut-off frequency of filter unit 10 that the further microphone 7 becomes effective with respect to beam forming and establishes at the output A_{11} a first order cardoid transfer function according to T_{11} (< 2 kHz) for frequencies of acoustical signals impinging on the microphones 3 and 7 above the cut-off frequency of filter unit 10.

[0021] The output A_{11} of the adding unit 11 or more generically of beam forming unit 9 is operationally connected to an electrical/mechanical output converter 15 as to a loudspeaker unit of the device.

[0022] When applied to individual's ear the transfer characteristic T_{11} will be subjected to individual's HRTF so that the established transfer characteristic will substantially be shadowed by individual's head between 180° and 0° resulting in a transfer function T_{110} as schematically also shown in fig. 6.

[0023] The at least two microphones 3 and 7 which have to be provided to establish the desired beam forming according to the present invention are further preferably used to realize at the hearing device additional desired beam characteristics by techniques as e.g. shown in the above mentioned references, so as to operate the device in different operating modes, e.g. acoustically focusing on desired acoustical sources, thereby attenuating unwanted noise. In such a case the specific frequency-dependent beam forming as exemplified by fig. 6 is realized only as one of more than one different operating modes of the hearing device. Further, and as shown in fig. 6 the further microphone 7 must, generically, be remote from microphone 3. It thereby may be part of a hearing device applied at the second ear, e.g. as a part of a binaural hearing system. Preferably and as shown schematically in fig. 7, both microphones are parts of the microphone arrangement 1 which is placed adjacent the top of the pinna, thus forming part of one integrated single behind-the-ear hearing device, thereby especially of a hearing aid device.

[0024] In Fig. 8, there is shown a further preferred embodiment of the hearing device according to the present invention. It was already addressed that preferably more than one different operating modus of the hearing device are preferably provided. In Fig. 8, there is shown a first beam forming unit 9 which operates as was already described, i.e. simulating the directional behaviour of the pinna. Unit 9_x represents a second beam former program or unit, whereat, according to specific needs at a specific acoustical situation, a different beam forming action is implemented. The outputs A_9 and A_{9x} of the units 9 and 9_x are operationally connected to a weighting unit 13 which has an output A_{13} operationally connected to the electrical input of the electrical/mechanical output converter 15. As schematically shown within weighting unit 13 and preferably controlled at a control input C_{13}, the ratio, with which the output of unit 9 and the output of unit 9_x take effect upon the output A_{13}, may be adjusted. Thus, and as also schematically shown in Fig. 8a, the hearing device may be switched abruptly from the operating mode controlled by unit 9 to the operating mode controlled by unit 9_x by abruptly enabling output A_9 to take effect on output A_{13}, thereby disabling output A_{9x} from taking such effect. This is shown by the courses (a) within Fig. 8a. Instead of abruptly switching such effect, and as shown by the courses (b), the effect of the at least two modi may steadily be varied by adjusting the weighting coefficients α_9 and α_{9x} in unit 13 as by the control input C_{13}.

[0025] In Fig. 8, the device incorporating the two operating modes is shown and exemplified with two "units" 9 and 9_x, whereby, and as clear to the skilled artisan, the two units 9 and 9_x may be realized by one single unit with a programmed transfer function. The ratio of effects, as controlled by unit 13 of Fig. 8, is then established e.g. by respectively adjusting, steadily or abruptly, coefficients of the program.

[0026] Further, and with an eye on Fig. 6, it is to be noted that the device, according to the present invention, has been shown especially with beam former unit 10 rather in analog technique. Nevertheless, it is perfectly clear that preferably beam forming is performed within a digital signal processing unit, whereby the output signal of the microphone is analog to digital converted and preferably time-domain/frequency-domain converted to allow signal processing in frequency domain. Before feeding the output signal to the ectrical/mechanical output converter, the computed output signal is reconverted from digital to analog and, respectively, from frequency domain to time domain.

Claims

1. A hearing device with a behind-the-ear microphone arrangement (1) not to be placed in the ear canal (5) of an individual's ear, said microphone arrangement (1) having at least one microphone (3) with an output (A_3), further comprising an electrical/mechanical output converter (15), **characterized by** a

further microphone (7), a beam former unit (9) having at least two inputs and an output, one input being operationally connected to the output of said one microphone (3), the second input being operationally connected to the output of said further microphone (7), the output of said beam former unit (9) being operationally connected to an input of said output converter (15), said beam former unit together with said one and said further microphone having a transfer characteristic of acoustical signals impinging on said one and said further microphones (3, 7) to an electric signal at said output (A_{11}) of said beam former unit (9), the amplification thereof being dependent on direction with which said acoustical signals impinge on said microphones (3, 7) and on frequency of said acoustical signals, said direction being 0° in direction of individual's facing and 90° substantially in ear canal outwards direction of said ear, said transfer characteristic having the following features:

- a substantially constant amplification independent of said direction of impinging at said frequency of 1 kHz,
- for said direction being 45°, a larger amplification than for said direction being 135° at said frequency of 5 kHz.

2. The hearing device of claim 1, wherein said amplification at said 45° direction is larger by approx. +6 dB than said amplification at said 135° direction, said frequency being 5 kHz.

3. The device of claim 1 or 2 having at least two controllably enabable operating modi with respect to transfer characteristic of acoustical signals impinging on said one and said further microphones (3, 7) to said electric signal at said output (A_{11}), one of said transfer characteristics being said transfer characteristic.

4. The device of claim 3 further comprising a controlled weighting unit controllably establishing the ratio of effect of said at least two operating modi upon said transfer characteristic.

5. The device of claim 4, wherein said controlled weighting unit steadily changes said ratio.

6. The device of one of claims 1 to 5, said further microphone (7) being part of said microphone arrangement (1).

7. The device of one of claims 1 to 6, said further microphone (7) being part of a second hearing device to be applied at a second ear of said individual.

8. The device of one of claims 1 to 7 being a behind-the-ear hearing device.

9. The device of one of claims 1 to 8 being a behind-the-ear hearing aid device.

10. The device of one of claims 1 to 8 being a hearing protection device.

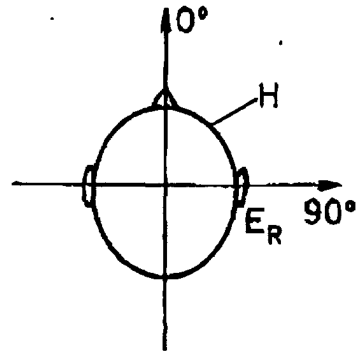

FIG.1

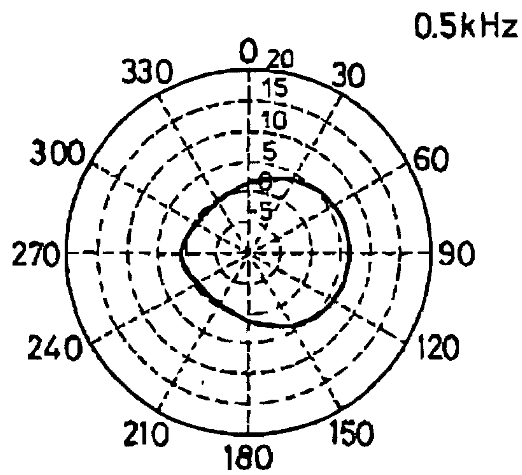

FIG.2

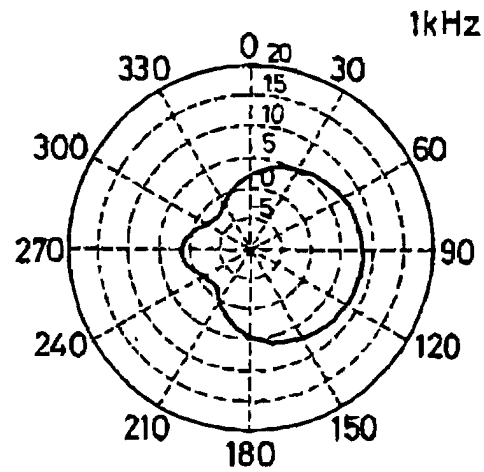

FIG.3

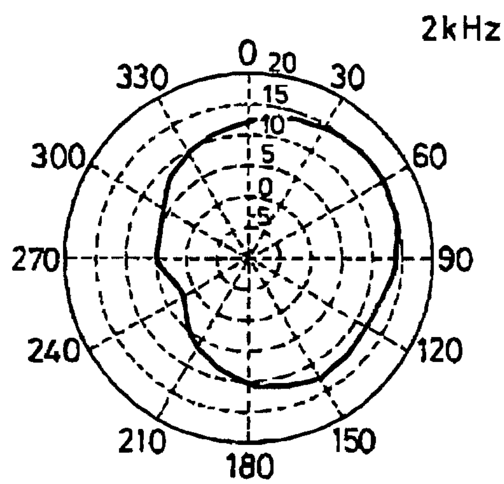

FIG.4

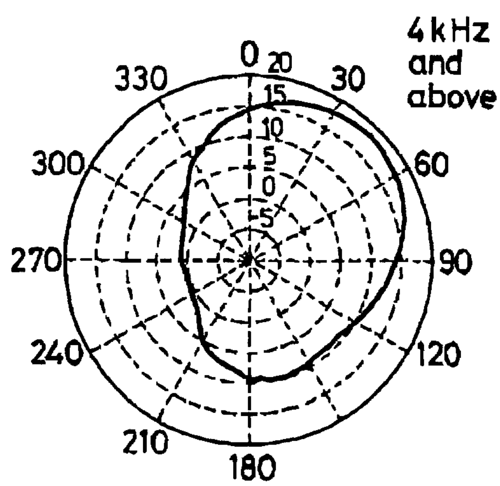

FIG.5

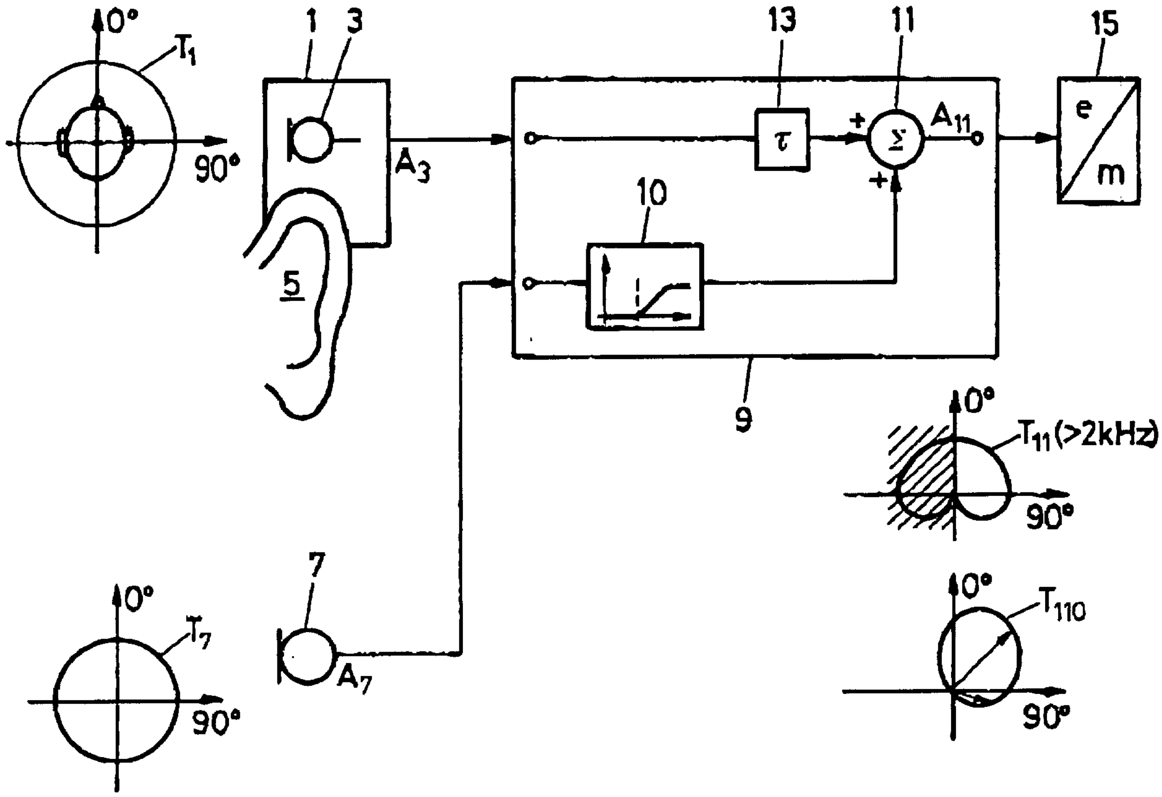
0°
T1
90°
1
3
A3
5
13
11
τ
Σ
A11
+
+
10
9
15
e
m
0°
T11 (>2kHz)
90°
0°
T110
90°
7
0°
T7
90°
A7

FIG.6

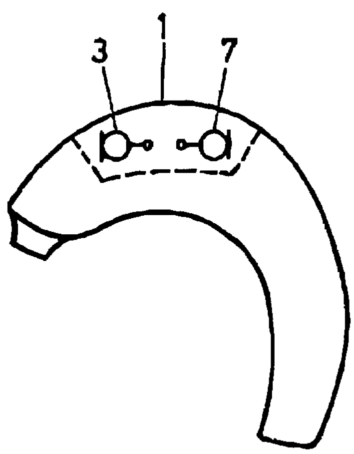
3
1
7

FIG.7

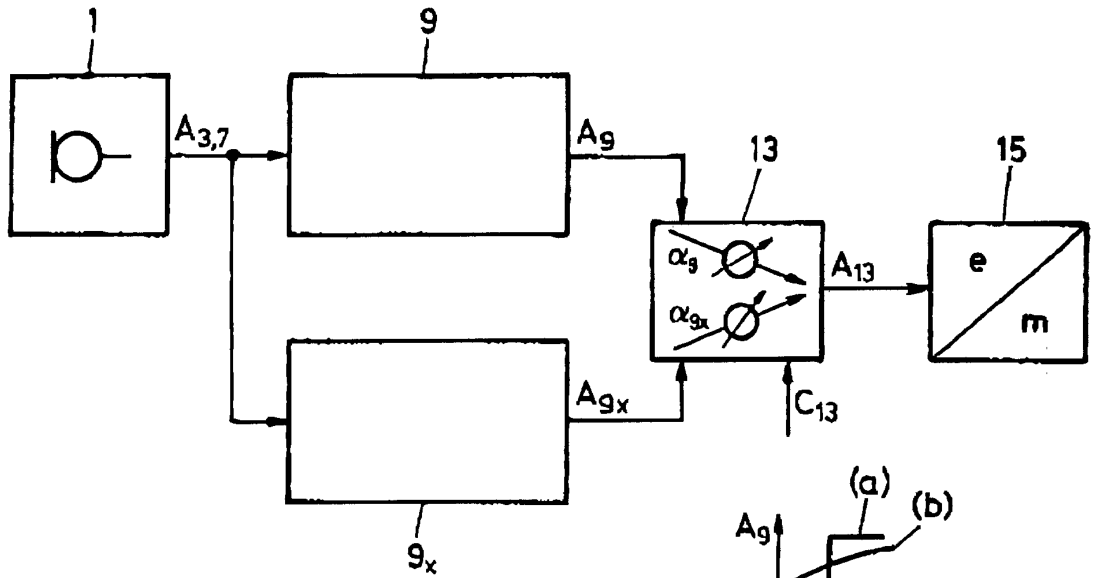

FIG. 8

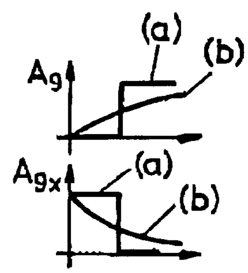

FIG. 8a