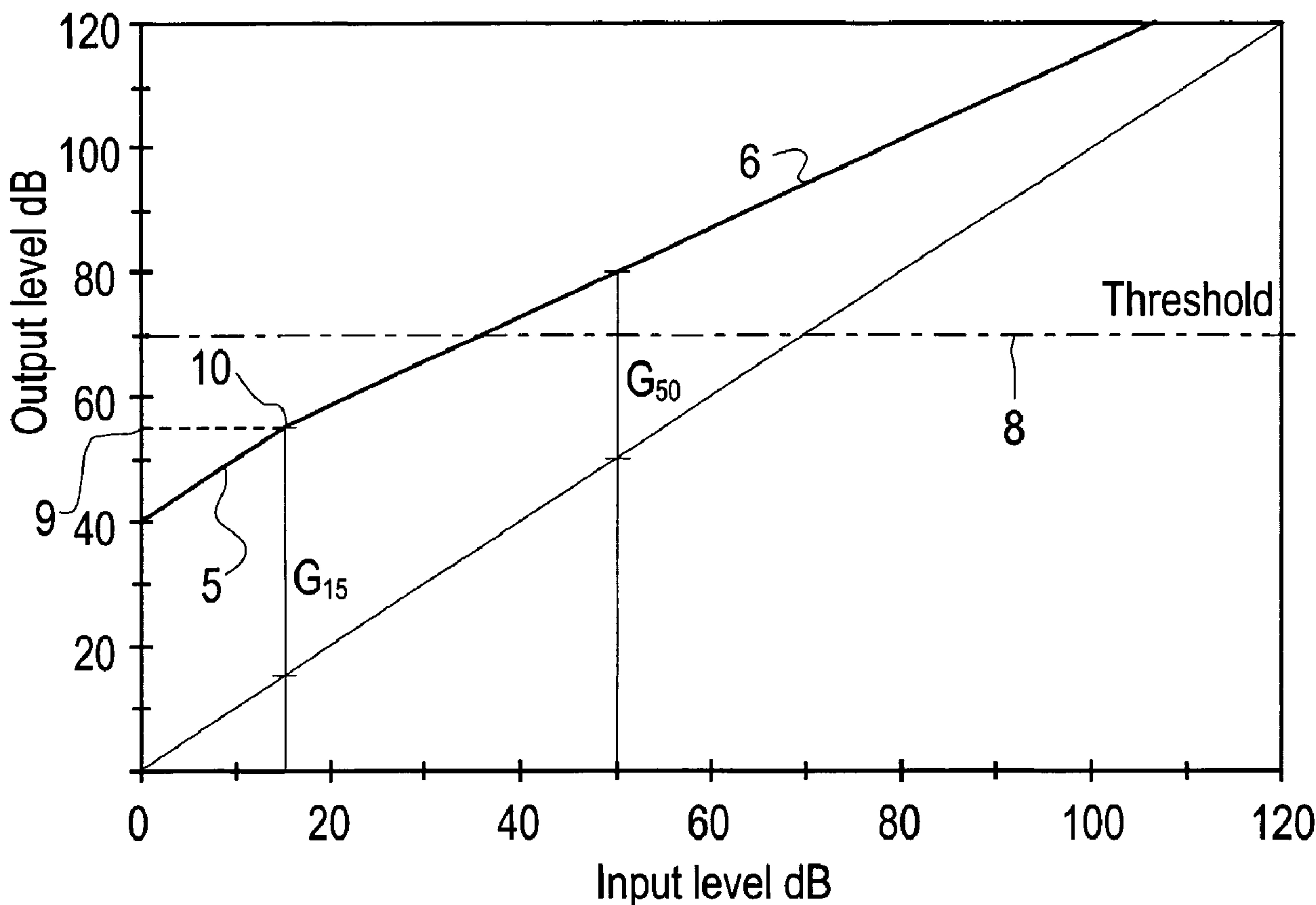




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 (54) Title: HEARING AID AND A METHOD OF PROCESSING A SOUND SIGNAL



(57) Abrégé/Abstract:

A multichannel hearing aid comprising at least one frequency channel having a compressor with a compression threshold at an output level below the hearing threshold and an attack time above 0.5 seconds whereby hearing of a sudden sound in a stationary

(57) **Abrégé(suite)/Abstract(continued):**

sound environment is facilitated. With this compressor, the amplification of low signal levels may be increased compared to the prior art, as the compressor kicks in to generally suppress steady noises. The gain may generally be increased as high as feasible in view of the microphone baseline noise, which should preferably be kept below the hearing threshold. Thus the user of the hearing aid will generally have the option of a higher gain of low level sounds that is generally not feasible with prior art hearing aids.

### **ABSTRACT**

A multichannel hearing aid comprising at least one frequency channel having a compressor with a compression threshold at an output level below the hearing threshold and an attack time above 0.5 seconds whereby hearing of a sudden sound in a stationary sound environment is facilitated. With this compressor, the amplification of low signal levels may be increased compared to the prior art, as the compressor kicks in to generally suppress steady noises. The gain may generally be increased as high as feasible in view of the microphone baseline noise, which should preferably be kept below the hearing threshold. Thus the user of the hearing aid will generally have the option of a higher gain of low level sounds that is generally not feasible with prior art hearing aids.

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## HEARING AID AND A METHOD OF PROCESSING A SOUND SIGNAL

## FIELD OF THE INVENTION

The present invention relates to hearing aids and to methods of processing  
5 sound signals. The invention more specifically relates to a hearing aid with a  
compressor that is active at very low sound levels. The invention, still more  
specifically, relates to a hearing aid that alerts the user of the occurrence of a sudden  
sound in a stationary sound environment.

## 10 BACKGROUND OF THE INVENTION

As used in this context, a hearing aid is understood as generally comprising  
a device with an input transducer for transforming an acoustic input signal into a first  
electrical signal, a signal processor for generating a second electrical signal based on  
the first electrical signal, an output transducer for conversion of the second signal into  
15 sound, and a battery for supplying energy to the signal processor.

Typically, a hearing aid has a housing holding the input and the output  
transducer, the battery and the signal processor. The housing is adapted to be worn,  
i.e. behind the ear, in the ear, or in the ear canal, and the output of the output  
transducer is led to the eardrum in a way that is well-known in the art of hearing aids.  
20 The processor will generally be adapted for processing the electric signal in order that  
the resulting acoustic output signal compensates a hearing deficiency of a user.

US-A-4,777,474 provides an alarm system for the hearing impaired,  
comprising a base station radio transmitter adapted to transmit, upon detection of an  
alarm state, a signal to a portable unit. The portable unit includes all parts of an  
25 ordinary hearing aid together with a radio receiver to receive the signal transmitted by  
the base station.

WO 99/34642 discloses a hearing aid with an automatic gain control, effected  
by detecting an input sound level and/or an output sound level and adapting the output  
sound level supplied by the hearing aid in response to the detected sound level by  
30 controlling the gain of the hearing aid towards an actual desired value of the output  
sound level. The gain control is effected at increases and decreases, respectively, of  
the input sound level by adjusting the gain towards the actual desired value with an

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attack time and a release time, respectively, which are adjusted in response to the detected sound level to a relatively short duration providing fast gain adjustment at high input and/or output sound levels and to a relatively long duration providing slow gain adjustment at low input and/or output sound levels.

5           It is well known in the art to provide a hearing aid having a compressor with a characteristic that has two linear segments that are interconnected at a knee-point. The knee-point is typically placed at 50 dB SPL input level, close to the level of normal speech in order to allow a high level of amplification of speech. Below the knee point, the linear segment has substantially no compression, i.e. the gain is a constant gain  
10 adapted for compensating the hearing loss at low input signal levels. Above the knee point, the segment has a compression ratio above 1, typically 2:1, for compensating for recruitment. Recruitment is a sensorineural hearing loss whereby loudness increases rapidly with increased sound pressure just above the hearing threshold and increases normally at high sound pressures.

15           Many hearing aid users being situated in a stable sound environment desire to be able to hear a faint, sudden change in the sound environment, such as a sudden occurrence of a faint sound. For example, being at home, a hearing aid user may desire to be able to hear that a baby starts crying, or that water starts running, that somebody is present at the door, etc. The hearing aid user can increase the gain of  
20 the hearing aid to accomplish this but then the hearing aid user may be bothered by other sounds in the stationary sound environment, such as the sound of a ventilator, traffic noise, etc, that might then also be amplified to surpass the hearing threshold. The hearing threshold is the lowest sound level at which sound is perceptible.

## 25 SUMMARY OF THE INVENTION

It is an object of the present invention to provide a hearing aid that makes it possible for the user to hear a faint, sudden sound occurring in a stationary sound environment without being bothered with stationary sounds.

According to an aspect of the present invention, there is provided a  
30 multichannel hearing aid with a microphone, an output transducer and a signal processor, wherein the signal processor has at least one frequency channel having a compressor, wherein the compressor is provided with a compression threshold at an

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output level below the hearing threshold, with a knee point situated below 25 dB SPL input level, and with an attack time above 0.5 seconds, whereby hearing of a sudden sound in a stationary sound environment is facilitated.

According to another aspect of the present invention, there is provided a  
5 method of processing a sound signal in a hearing aid, comprising the steps of converting an acoustic signal into an electric signal, processing the electric signal in a signal processor having in at least one frequency channel a compressor, and converting the processed signal into a sound signal, wherein the compressor has a compression threshold at an output level below the hearing threshold, a knee point  
10 situated below 25 dB SPL input level, and an attack time above 0.5 seconds.

According to a further aspect of the present invention, there is provided a method of processing a sound signal in a hearing aid, comprising the steps of converting an acoustic signal into an electric signal, compressing the electric signal in a signal processor in at least one frequency channel according to a compression  
15 characteristic with an attack time above 0.5 seconds and a first and a second segment, the first and second segment being interconnected at a knee point at an output level below the hearing threshold, the first segment being situated below the knee point and having substantially no compression and the second segment being situated above the knee point and having a compression ratio greater than 1.4 to produce a  
20 compressed signal, processing the compressed signal in the signal processor in order to produce a processor output signal suitable for compensating a users hearing deficiency, converting the processor output signal into a sound signal and relinquishing compressing the signals upon the expiry of a release time above 5 seconds.

According to the present invention in yet another aspect, the above-mentioned  
25 and other objects are fulfilled by the provision of a multichannel hearing aid with a microphone, an output transducer and a signal processor, wherein the signal processor has at least one frequency channel having a compressor, wherein the compressor is provided with a compression threshold at an output level below the hearing threshold and with an attack time above 0.5 seconds, whereby hearing of a  
30 sudden sound in a stationary sound environment is facilitated.

In the hearing aid according to the present invention, the gain may generally be increased as high as feasible in view of the microphone baseline noise, which

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should preferably be kept below the hearing threshold. Thus the use of the hearing aid according to the invention will generally have the option of a higher gain of low level sounds than generally feasible with prior art hearing aids.

According to the invention in a second aspect, the above-mentioned and other  
5 objects are fulfilled by the provision of a method of processing a sound signal in a hearing aid, comprising the steps of converting an acoustic signal into an electric signal, processing the electric signal in a signal processor having in at least one frequency channel a compressor with a compression threshold at an output level below the hearing threshold and an attack time above 0.5 seconds, and converting the  
10 processed signal into a sound signal.

The compressor is provided with a slow attack time above 0.5 seconds. The slow attack time permits transient sounds to be amplified without distortion to be clearly perceptible to the user. In advantageous embodiments, the attack time is above 1 second, for example 2 seconds or more.

15 The compressor may have a long release time, e.g. 10 times the attack time, for recovering the gain upon the vanishing of high level sounds.

It is an important advantage of the present invention that the gain of the hearing aid is high at low signal levels while the microphone noise is still kept just below the hearing threshold. When a sudden sound occurs, the sound is amplified  
20 with the current large gain to provide an output signal above the hearing threshold so that it can be heard by the hearing aid user. If the sudden sound persists for a longer time than the attack time of the compressor, the gain will decrease with time, gradually lowering the hearing aid output signal as far as permitted by the compression ratio, and possibly causing the faint sudden sound to be no longer amplified above the  
25 hearing threshold. Thus the sudden sound can be heard by the hearing aid user for substantially the attack time of the compressor which is a sufficient period for the user to be alerted by the sound.

According to an advantageous embodiment, the hearing aid signal processor may have a plurality of channels, preferably more than 6 channels, more preferred  
30 more than 8 channels, most preferred more than 10 channels, e.g. 15 channels.

According to another advantageous embodiment, the knee point is situated below 25 dB SPL input level, more often below 20 dB SPL input level, for example

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below 15 dB SPL. This allows for a maximum of gain at sound levels close to the lowest level audible to people with normal hearing. The maximum of gain selected for a particular user will depend on his particular hearing deficiency and the fitting rule. Generally a complete compensation of the hearing deficiency is not feasible for reasons such as user comfort. The amount of faint sounds that may be amplified sufficiently to be audible to the user may vary according to the specific circumstances. However, sounds at 25 dB SPL input will generally not be amplified so much as to be audible to a hearing impaired person using a hearing aid tuned according to standard fitting rules.

10 Other advantageous embodiments of the invention appear from the dependent claims.

Still other objects of the present invention will become apparent to those skilled in the art from the following description wherein the invention will be explained in greater detail. By way of example, there is shown and described a preferred embodiment of the invention. As will be realized, the invention is capable of other different embodiments, and its several details are capable of modification in various, obvious aspects all without departing from the invention.

#### BRIEF DESCRIPTION OF THE DRAWING

20 The invention will now be described in more detail in conjunction with several embodiments and the accompanying drawings, in which:

Fig. 1 shows a prior art compressor characteristic,

Fig. 2 shows a compressor characteristic according to the present invention,

Fig. 3 illustrates amplification of a sudden sound in a stationary sound environment by a hearing aid according to the present invention,

Fig. 4 shows a block diagram of a hearing aid according to the present invention, and

Fig. 5 is an enlarged view of a compressor characteristic according to the invention with illustration of the processing of a sound stimulus.

#### 30 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig.1 shows a plot of a prior art compressor characteristic, i.e. a plot of the compressor output level as a function of the input level, both in SPL. This

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characteristic may be for a general compressor or it may be for one among a bank of narrow-band compressors in a hearing aid signal processor. The particular characteristic may depend on the fitting to a particular user. The example in the figure assumes the hearing aid has been tuned to compensate a particular hearing deficiency, as partially illustrated by the hearing threshold line 8 at 70 dB. The fitting to other users may be suggested by those skilled in the art of hearing aid fitting.

The characteristic comprises two linear segments 5, 6, that are interconnected at a knee-point 10 (CT - Compression Threshold) typically positioned at 50 dB SPL input level. At sound levels below the knee point 10, as evidenced by the linear segment 5, there is substantially no compression, i.e. the gain is a constant gain, suitable for compensating the hearing loss at low input signal levels. In Fig. 1, this gain is 30 dB as illustrated at the line  $G_{15}$  at 15 dB input level and identically 30 dB as illustrated at the line  $G_{50}$  at 50 dB input level. Normal speech is about 50 dB input level. Above the knee point 10, as evidenced by the segment 6, there is a compression ratio above 1, typically 2:1, lowering the gain at high input levels as appropriate for compensating for recruitment. The compression ratio of a segment is equal to the reciprocal value of the slope of the segment. Given a low end gain of 30 dB and a hearing threshold of 70 dB, input levels below 40 dB will not be audible to this hearing aid user.

In order to be able to hear a faint sudden change in the sound environment, such as a sudden occurrence of a faint sound, the hearing aid user can increase the gain of the hearing aid thereby displacing the characteristic shown in Fig. 1 upwardly in the direction of the y-axis. In that case, however, other faint sounds in the stationary sound environment, such as the sound of a ventilator, traffic noise, etc, will also be amplified, possibly to a level above the hearing threshold causing an annoyance or an uncomfortable disturbance of the user.

Fig. 2 shows a compressor characteristic of a compressor according to the present invention. In Fig. 2, the segments 5, 6 correspond to the segments 5, 6 shown in Fig. 1. Preferably, segment 6 has a compression ratio that is greater than 1.4, and, more preferred, a compression ratio substantially equal to 2. Other values of the compression ratio may be used if appropriate. It is the gist of the present invention that the output level 9 at the knee-point or compression threshold is lower than the

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hearing threshold 8. In Fig. 2, the knee-point is situated at about 15 dB input level, i.e. in the low end of the range audible to people with normal hearing. The gain at the knee-point and below is about 40 dB as illustrated by  $G_{15}$ , drawn at 15 dB input level. Above the knee-point the gain rolls off governed by the compressor, reaching about 5 30 dB at 50 dB input level as illustrated by  $G_{50}$ . Thus, the gain at normal speech level is similar to that illustrated in Fig. 1. On the other hand the gain is substantially higher at low signal levels than for the prior art compressor.

The hearing aid according to the present invention may have a microphone that generates a low level of microphone noise. The hearing aid signal processor may 10 have a plurality of channels, preferably more than 6 channels, more preferred more than 8 channels, most preferred more than 10 channels, e.g. 15 channels. Since noise in each channel is substantially proportional to channel bandwidth, an increase in the number of channels leads to a reduction of the noise in each channel. Thus, in spite of the increased gain, the noise in a channel is still maintained below the hearing 15 threshold. In the present example, the knee point is situated at 15 dB SPL input level. Typically, the knee-level is situated below 25 dB SPL input level, more often below 20 dB SPL input level, for example below 15 dB SPL.

Fig. 3 illustrates amplification by a hearing aid according to the present invention of a sudden sound in an otherwise steady sound background 11. The 20 sudden sound is illustrated by a square wave pulse rising at 12 and disappearing at 13. The steady sound background is processed in the hearing aid to produce an output signal at the level A, below the hearing threshold. The compressor is provided with a slow attack time, such as 1 or 2 seconds. Transient signals are amplified linearly. When the sound pulse occurs at 12, the sound pulse is amplified with the 25 current large gain in order to produce initially an output sound signal at level B. In the example, B exceeds the hearing threshold 8, signifying that the signal is indeed audible to the hearing aid user.

If the sound pulse persists for a longer time than the attack time 16 of the compressor, the compressor will kick in to decrease the gain over time 18 to gradually 30 arrive at the output level C, below the threshold of hearing. Thus, depending on the magnitude of the signal, eventually the sudden sound may no longer be amplified above the hearing threshold 8. In the example, the sudden sound 13 can be heard

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by the hearing aid user for substantially the attack time 16 of the compressor which is a sufficient period for the user to be alerted by the sound. Disappearance of the square wave sound pulse at 13 produces a downward step taking the output level to the point D. The compressor recovers from this new lower level only slowly.

5 Gradually, according to the compressor release time, the gain grows to take the output level back to the initial level A.

Reference is also made to Fig. 5 for a plot of the points A, B, C and D in the input-output diagram. This plot illustrates the points A and C on the compressor curve, which represent steady state situations, whereas the points B and D, which  
10 represent transient states, are defined by a respective starting point and by a step height (up or down).

Generally, it is assumed that the human ear has a time constant for loudness perception in the order of 0.2 to 0.3 seconds. This is the minimum duration required by a human ear for a full perception of the loudness of the signal. Shorter signals  
15 may also be perceived, however the loudness of shorter signals tend to be underestimated.

Fig. 4 shows a schematic block diagram of a hearing aid 20 according to the present invention. It will be obvious for the person skilled in the art that the circuits indicated in Fig. 4 may be implemented using digital or analog circuitry or any  
20 combination thereof. In the present embodiment, digital signal processing is employed and thus, the processor 28 consists of a digital signal processing circuit. In the present embodiment, all the digital circuitry of the hearing aid 20 may be provided on a single digital signal processing chip or, the circuitry may be distributed on a plurality of integrated circuit chips in another way.

25 In the hearing aid 20, a microphone 22 is provided for reception of a sound signal and conversion of the sound signal into a corresponding electrical signal representing the received sound signal. The hearing aid 20 may comprise a plurality of input transducers with appropriate input stage processing for the purpose of added functionality, e.g. for providing a direction sensitive capability. The microphone 22  
30 converts the sound signal into an analog electric signal. The analog electric signal is sampled and digitized by an A/D converter 24 into a digital signal 26 for digital signal processing in the hearing aid 20. The digital signal 26 is fed to a digital signal

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processor 28 for amplification of the microphone output signal 26 according to a desired frequency characteristic and compressor function to provide an output signal 30 suitable for compensating the hearing deficiency of the user. The output signal 30 is fed to a D/A converter 32 and further to an output transducer 34, i.e. a receiver 5 34, that converts the output signal 30 into an acoustic output signal.

The signal processor 28 comprises a first filter bank 36 with bandpass filters  $36_i$  for dividing the electrical signal 26 into a set of bandpass filtered first electrical signal derivatives  $26_1, 26_2, \dots, 26_i$ . Further, the signal processor 28 comprises a set 38 of compressors and offset amplifiers  $38_1, 38_2, \dots, 38_i$  each of which is connected 10 to a different bandpass filter  $36_1, 36_2, \dots, 36_i$  for individual compression of the corresponding bandpass filtered signal derivatives  $26_1, 26_2, \dots, 26_i$ . Fig. 4 illustrates the compressor and offset amplifiers  $38_1, 38_2, \dots, 38_i$  in the respective frequency bands  $36_1, 36_2, \dots, 36_i$  having compressor characteristics in accordance with the present invention.

15 The illustrated compressor characteristics  $38_1$  and  $38_2$  correspond to the characteristic shown in Fig. 2. In the present example,  $36_1$  and  $36_2$  are low frequency bandpass filters, e.g. with passbands below 500 Hz.  $36_1$  may have a passband below 300 Hz and  $36_2$  may have a passband between 300 Hz and 500 Hz. For simplicity, compressors are not illustrated in every frequency band. Compressors with 20 characteristics in accordance with the present invention may be included in any appropriate frequency channel.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A multichannel hearing aid with a microphone, an output transducer and a signal processor, wherein the signal processor has at least one frequency channel having a compressor, wherein the compressor is provided with a compression threshold at an output level below the hearing threshold, with a knee point situated below 25 dB SPL input level, and with an attack time above 0.5 seconds, whereby hearing of a sudden sound in a stationary sound environment is facilitated.
2. The hearing aid according to claim 1, wherein the compressor has the knee point situated below 20 dB SPL input level.
3. The hearing aid according to claim 1 or 2, wherein the compressor has the attack time above 1 second.
4. The hearing aid according to any one of claims 1 to 3, wherein the compressor has the attack time above 2 seconds.
5. The hearing aid according to any one of claims 1 to 4, wherein the compressor has a release time above 5 seconds.
6. The hearing aid according to claim 5, wherein the compressor has the release time above 10 seconds.
7. The hearing aid according to any one of claims 1 to 6, wherein the compressor has a compression ratio above 1.4.
8. The hearing aid according to claim 7, wherein the compressor has the compression ratio of about 2.0.

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9. The hearing aid according to any one of claims 1 to 8, wherein the signal processor comprises a set of compressors and offset amplifiers, each of which is connected to a respective bandpass filter for individual compression of the corresponding bandpass filtered signal derivatives.
10. The hearing aid according to any one of claims 1 to 9, wherein the signal processor comprises a plurality of channels.
11. The hearing aid according to any one of claims 1 to 10, wherein the signal processor comprises more than 6 channels.
12. A method of processing a sound signal in a hearing aid, comprising the steps of  
converting an acoustic signal into an electric signal,  
processing the electric signal in a signal processor having in at least one frequency channel a compressor, and  
converting the processed signal into a sound signal, wherein  
the compressor has a compression threshold at an output level below the hearing threshold, a knee point situated below 25 dB SPL input level, and an attack time above 0.5 seconds.
13. The method according to claim 12, comprising compressing the signals above the knee point situated below 15 dB SPL.
14. The method according to claim 12 or 13, comprising compressing the signals upon the expiry of the attack time above 1 second.
15. The method according to any one of claims 12 to 14, comprising compressing the signals upon the expiry of the attack time above 2 seconds.

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16. The method according to any one of claims 12 to 15, comprising relinquishing compressing the signals upon the expiry of a release time above 5 seconds.
17. The method according to claim 16, comprising relinquishing compressing the signals upon the expiry of a release time above 20 seconds.
18. The method according to any one of claims 12 to 17 comprising compressing the signals to a compression ratio above 1.4.
19. The method according to claim 18, comprising compressing the signals to a compression ratio of about 2.0.
20. The method according to any one of claims 12 to 19, comprising processing the electric signals in a signal processor having a set of compressors and offset amplifiers, each of which is connected to a respective bandpass filter for individual compression of the corresponding bandpass filtered signal derivatives.
21. The method according to any one of claims 12 to 20, comprising processing the electric signals in a signal processor having a plurality of channels.
22. The method according to claim 21, comprising processing the electric signals in a signal processor having more than 8 channels.
23. A method of processing a sound signal in a hearing aid, comprising the steps of:
- converting an acoustic signal into an electric signal,
  - compressing the electric signal in a signal processor in at least one frequency channel according to a compression characteristic with an attack time above 0.5 seconds and a first and a second segment, said first and second segment being interconnected at a knee point at an output level below the hearing threshold, said first segment being situated below said knee point and having substantially no

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compression and said second segment being situated above said knee point and having a compression ratio greater than 1.4 to produce a compressed signal,

processing said compressed signal in said signal processor in order to produce a processor output signal suitable for compensating a users hearing deficiency,

converting the processor output signal into a sound signal and relinquishing compressing the signals upon the expiry of a release time above 5 seconds.

24. The method according to claim 23, comprising compressing the signals above a knee point situated below 25 dB SPL input level.

25. The method according to claim 23 or 24, comprising compressing the signals above a knee point situated below 20 dB SPL input level.

26. The method according to any one of claims 23 to 25, comprising compressing the signals above a knee point situated below 15 dB SPL.

27. The method according to any one of claims 23 to 26, comprising compressing the signals upon the expiry of an attack time above 1 second.

28. The method according to any one of claims 23 to 27, comprising compressing the signals upon the expiry of an attack time above 2 seconds.

29. The method according to any one of claims 23 to 28, comprising relinquishing compressing the signals upon the expiry of a release time above 10 seconds.

30. The method according to any one of claims 23 to 29, comprising relinquishing compressing the signals upon the expiry of a release time above 20 seconds.

31. The method according to any one of claims 23 to 30, comprising compressing the signals to a compression ratio above 2.0.

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PRIOR ART

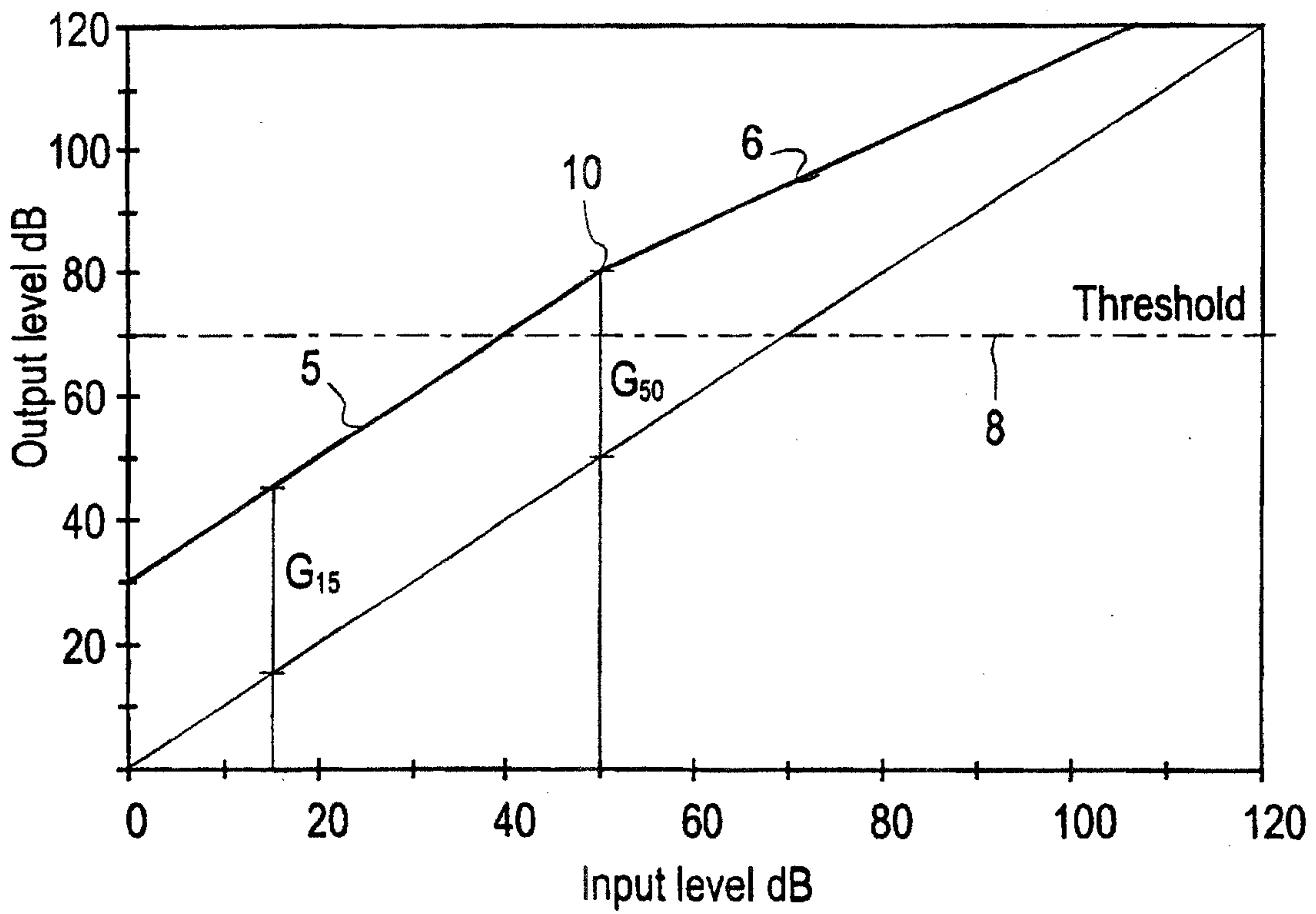
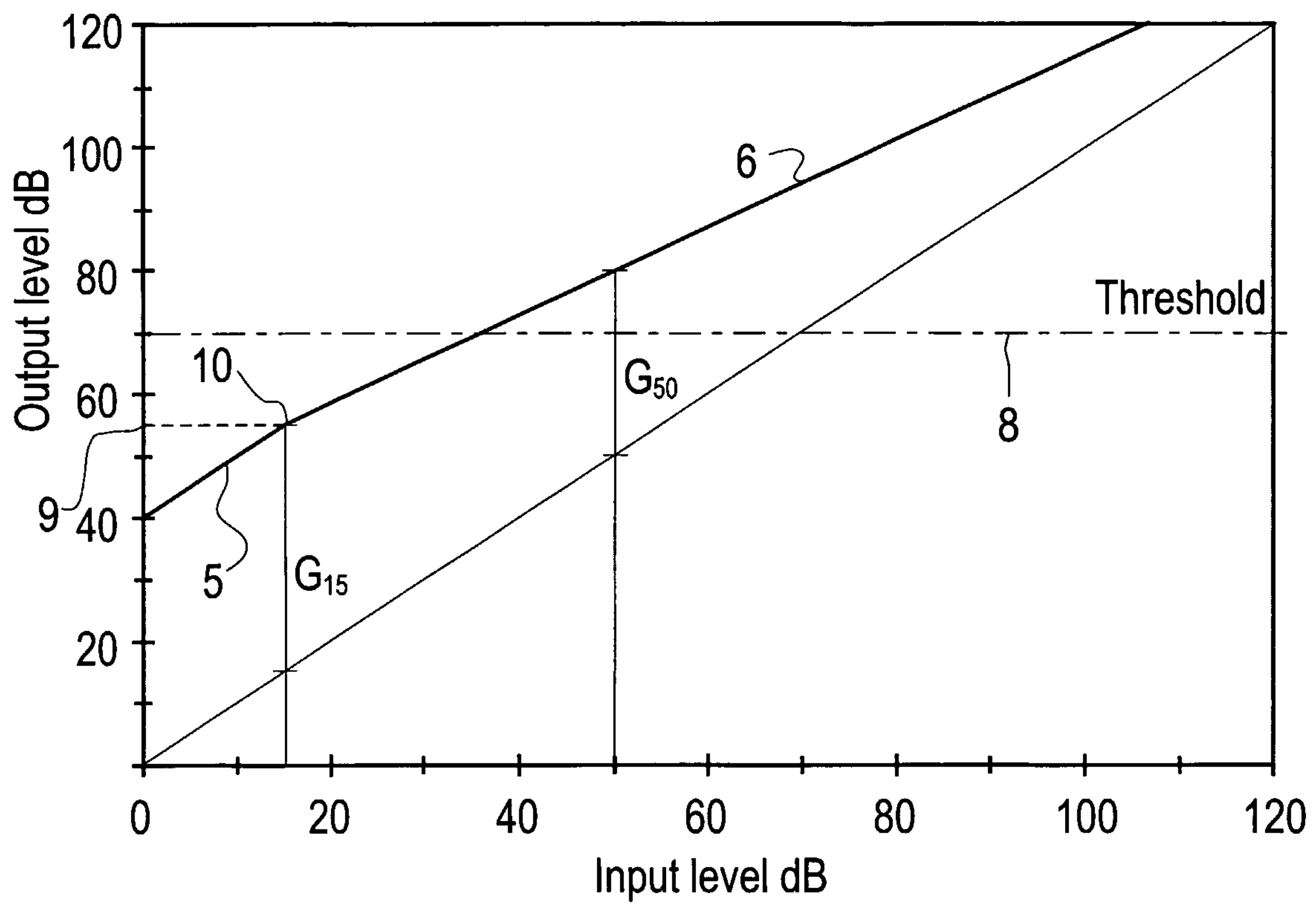
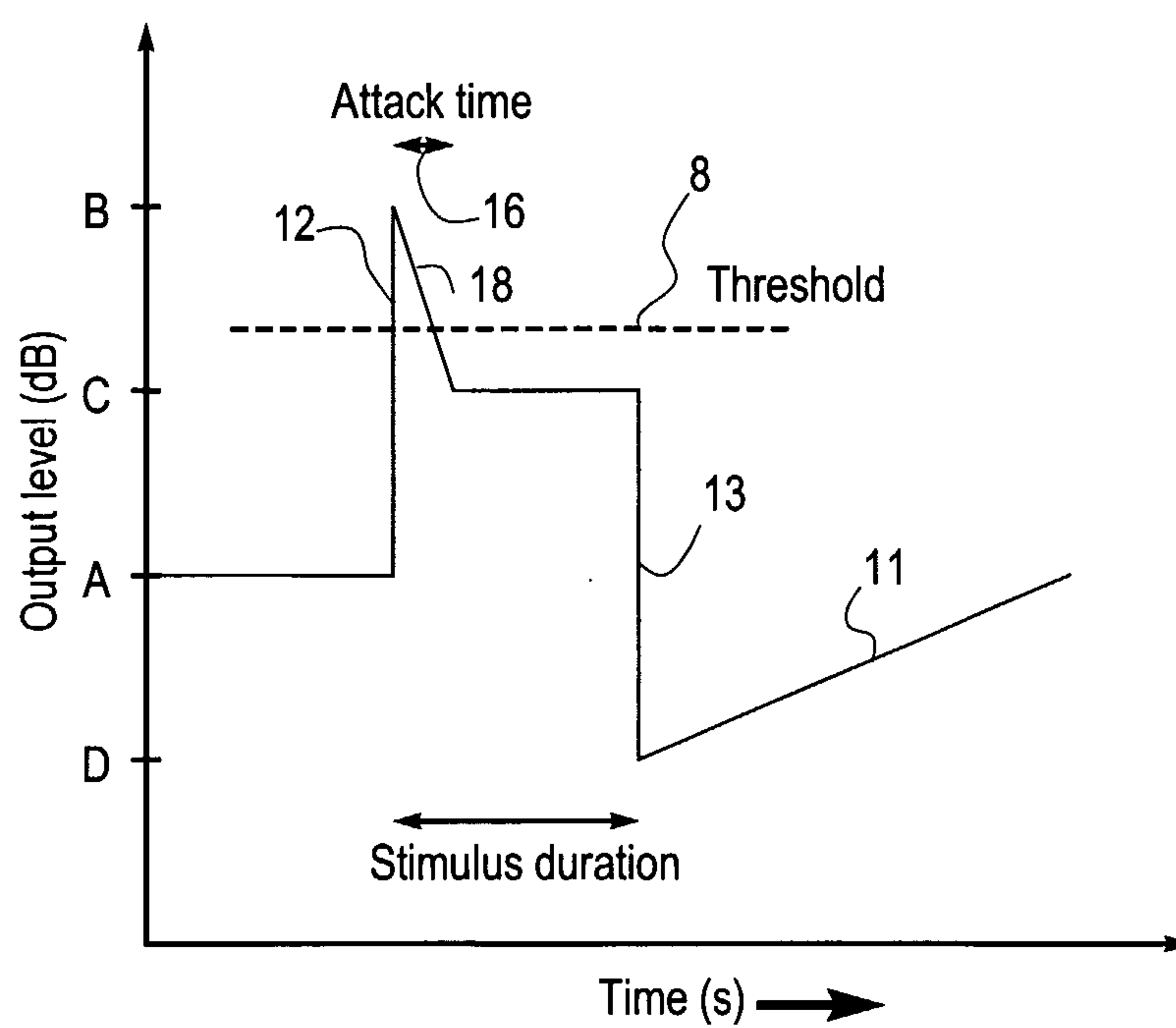


Fig. 1

**2/5****Fig. 2**

**3/5****Fig. 3**

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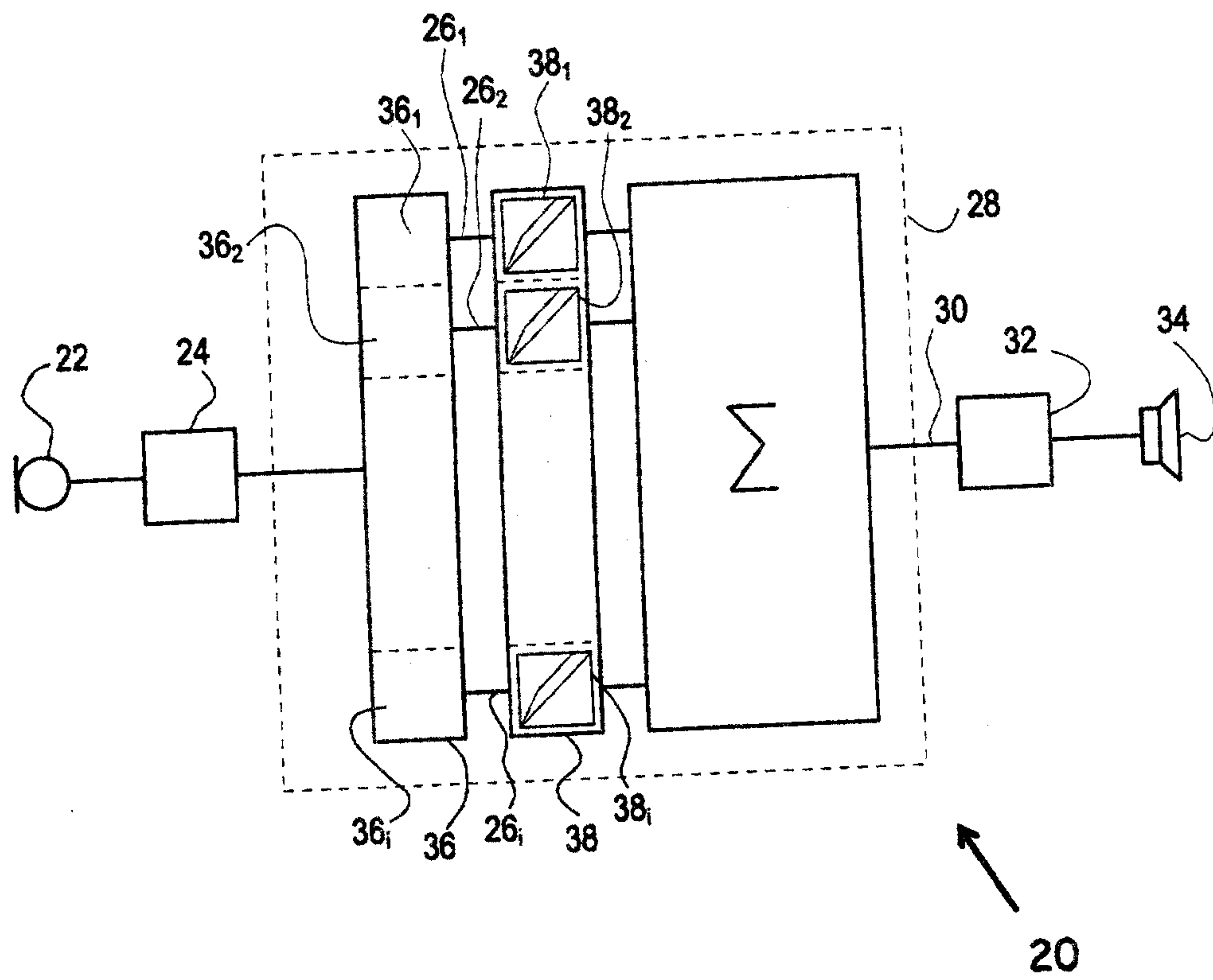


Fig. 4

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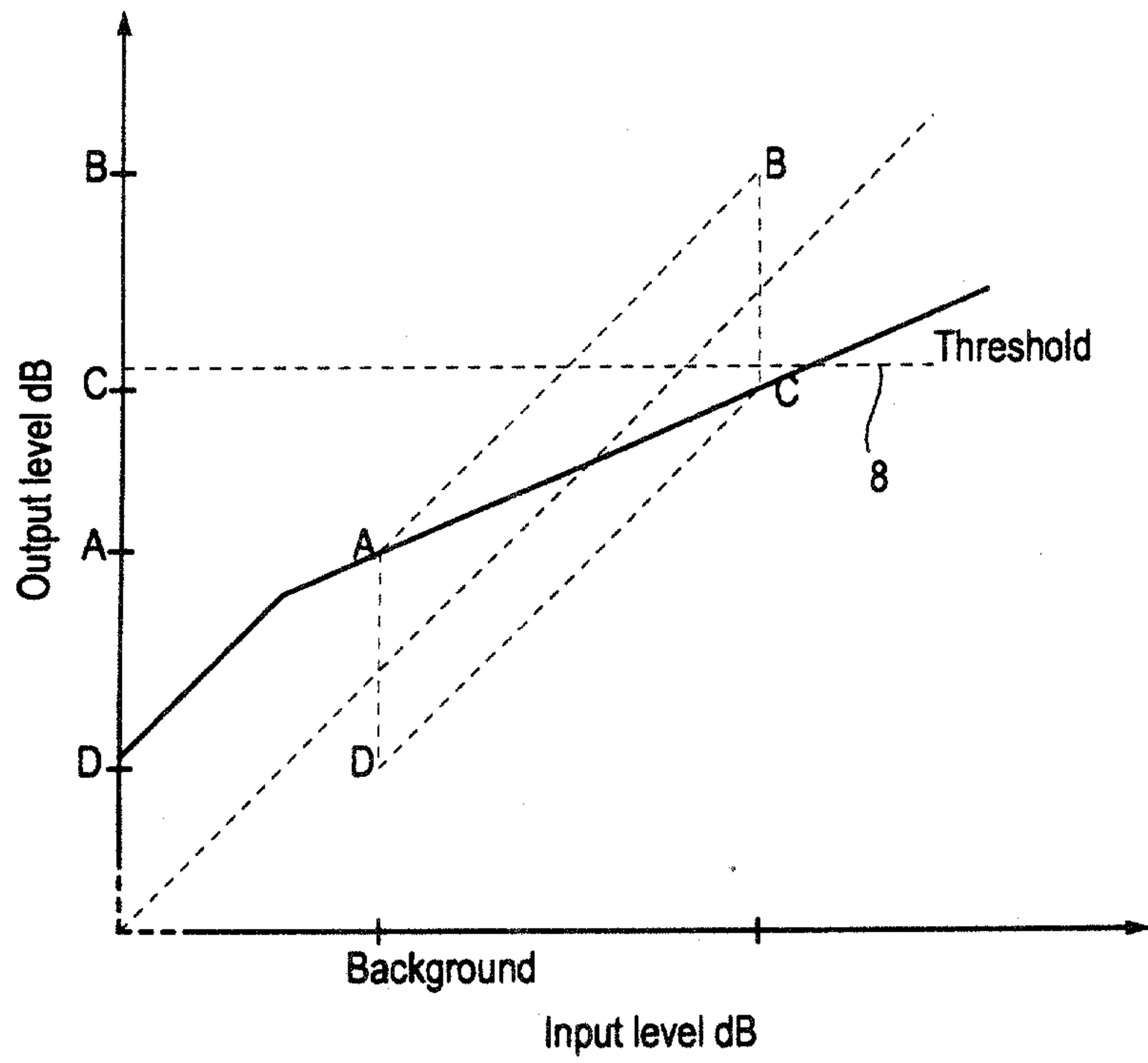


Fig. 5

