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(54) Title of the Invention: **Ambient noise-reduction system**
Abstract Title: **Noise reduction system for earphones controlled by incoming telephone calls**

(57) A noise reduction control system for ear-worn speaker-carrying devices such as earphones 11. The system senses ambient noise, preferably via microphone 10, and develops electrical signals which are used to reduce the amount of ambient noise audible to a wearer of the earphone 11. The noise cancellation signals may be merged with sounds intended for the listener's attention, such as music or speech. The system automatically responds to at least one controlling event to set the degree of noise reduction to one of a range of discrete setting levels. The controlling event is an incoming telephone call, and may be used to activate or deactivate the system for a prescribed period of time. Typically, the system employs active noise cancellation (ANC) techniques; this involves inverting and filtering the electrical signals relating to ambient noise and feeding the inverted and filtered signals to the speaker of the earphone 11 in time for the speaker to generate sounds capable of interfering destructively with the ambient noise.

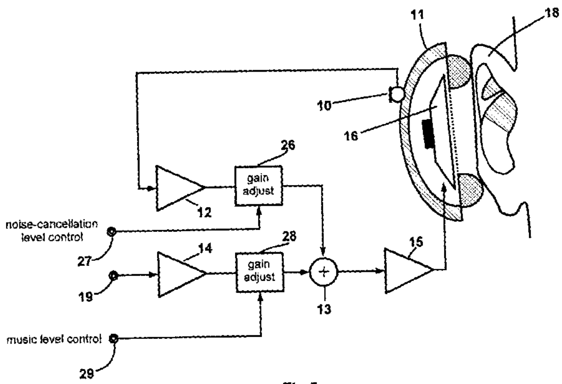

Fig 5

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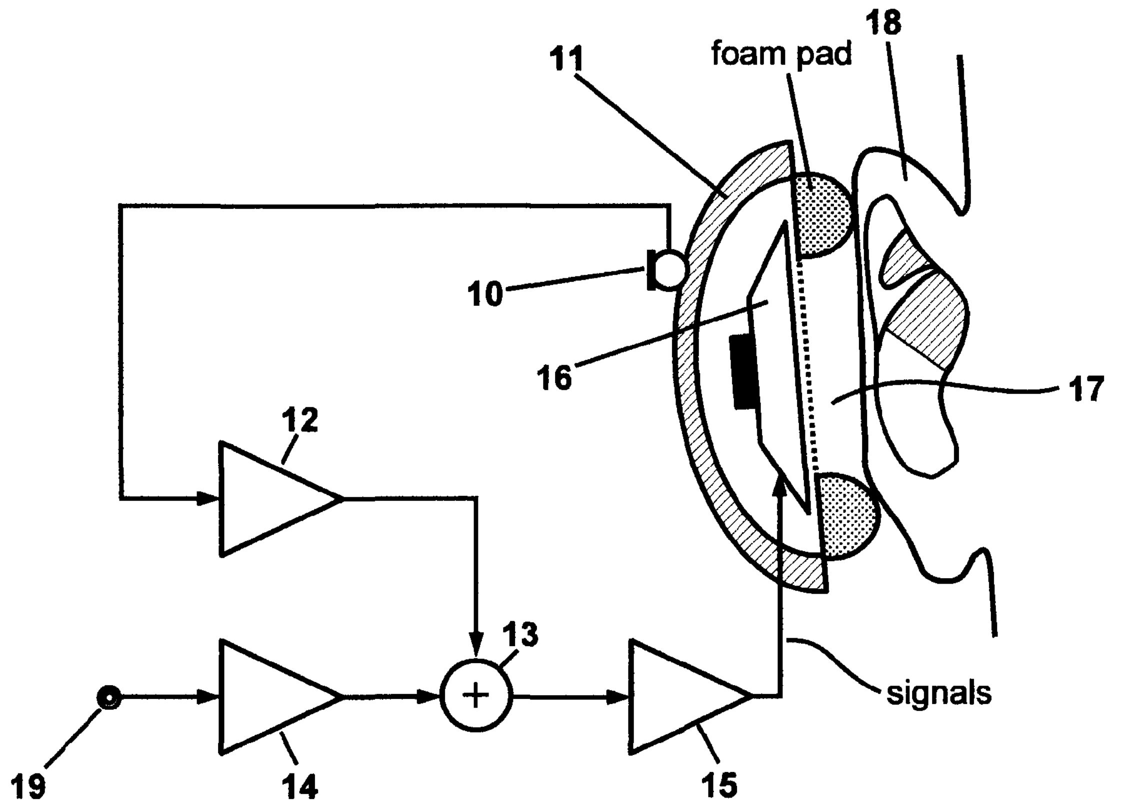


Fig 1

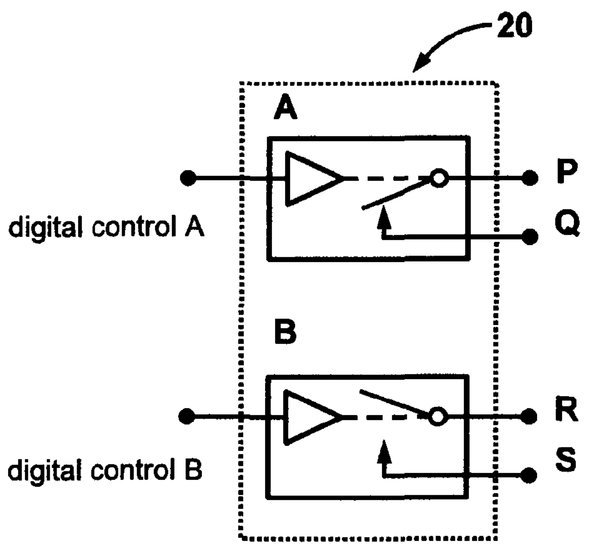


Fig 2a

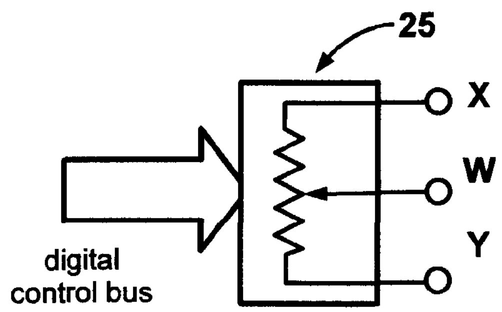


Fig 2b

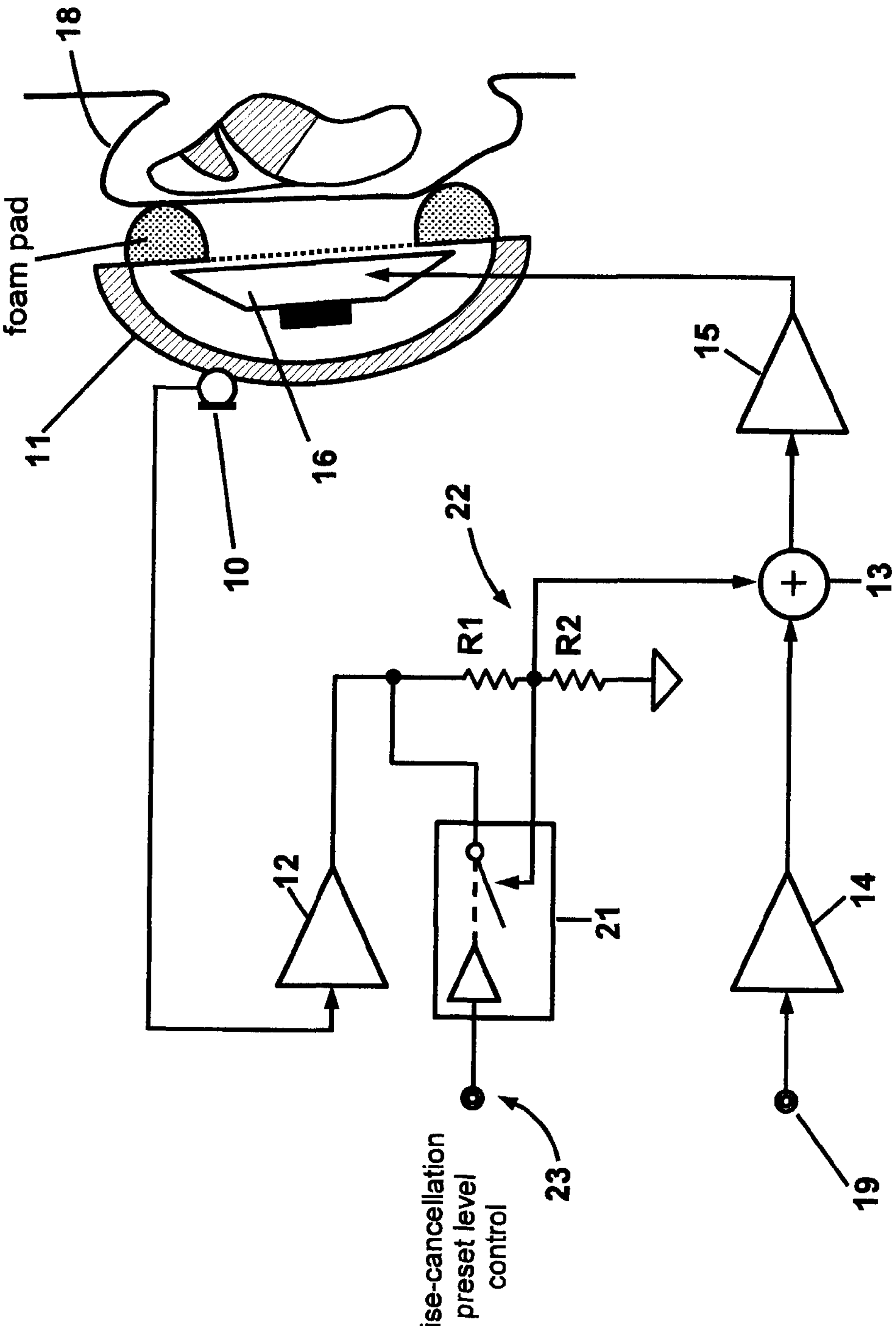

18
foam pad
11
16
10
22
R1
R2
13
15
12
21
14
23
noise-cancellation
preset level
control
19

Fig 3

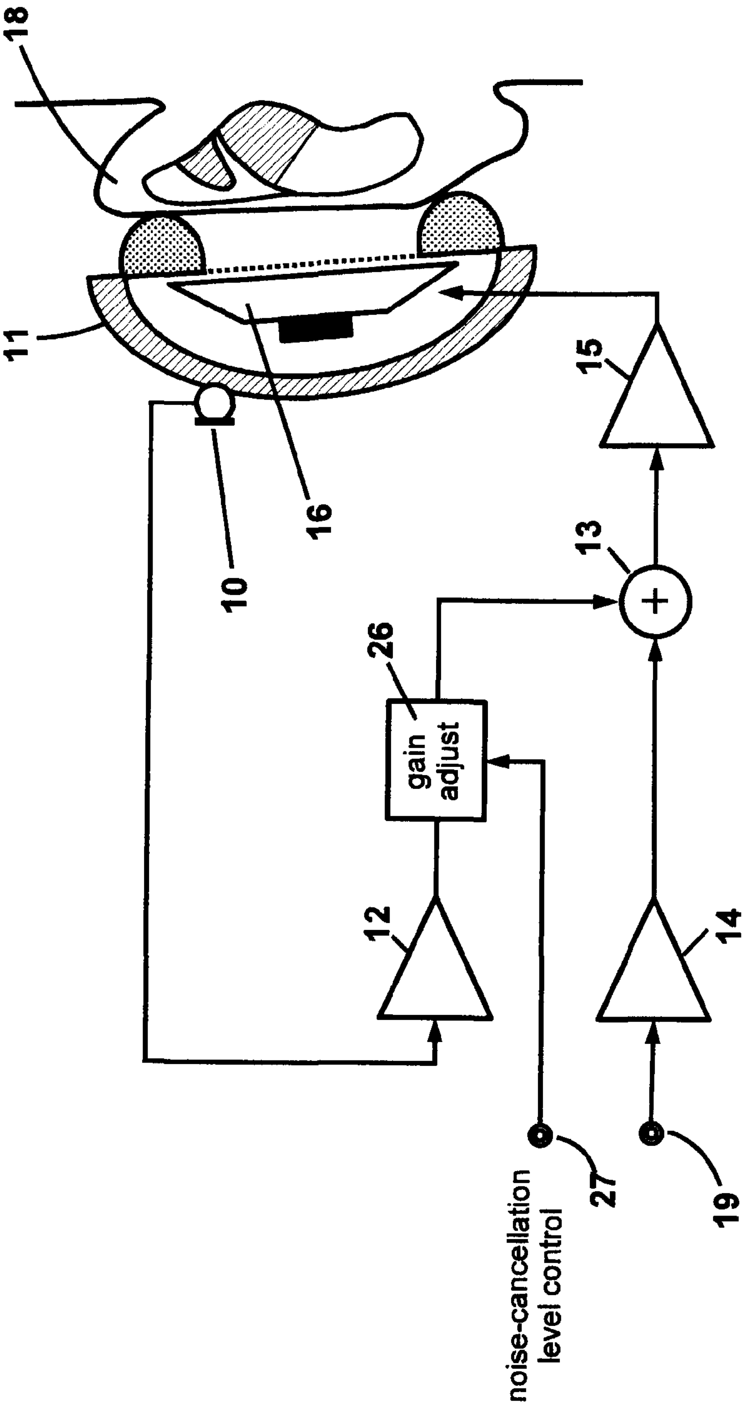

18
11
10
16
13
15
26
gain
adjust
12
14
27
19
noise-cancellation
level control

Fig 4

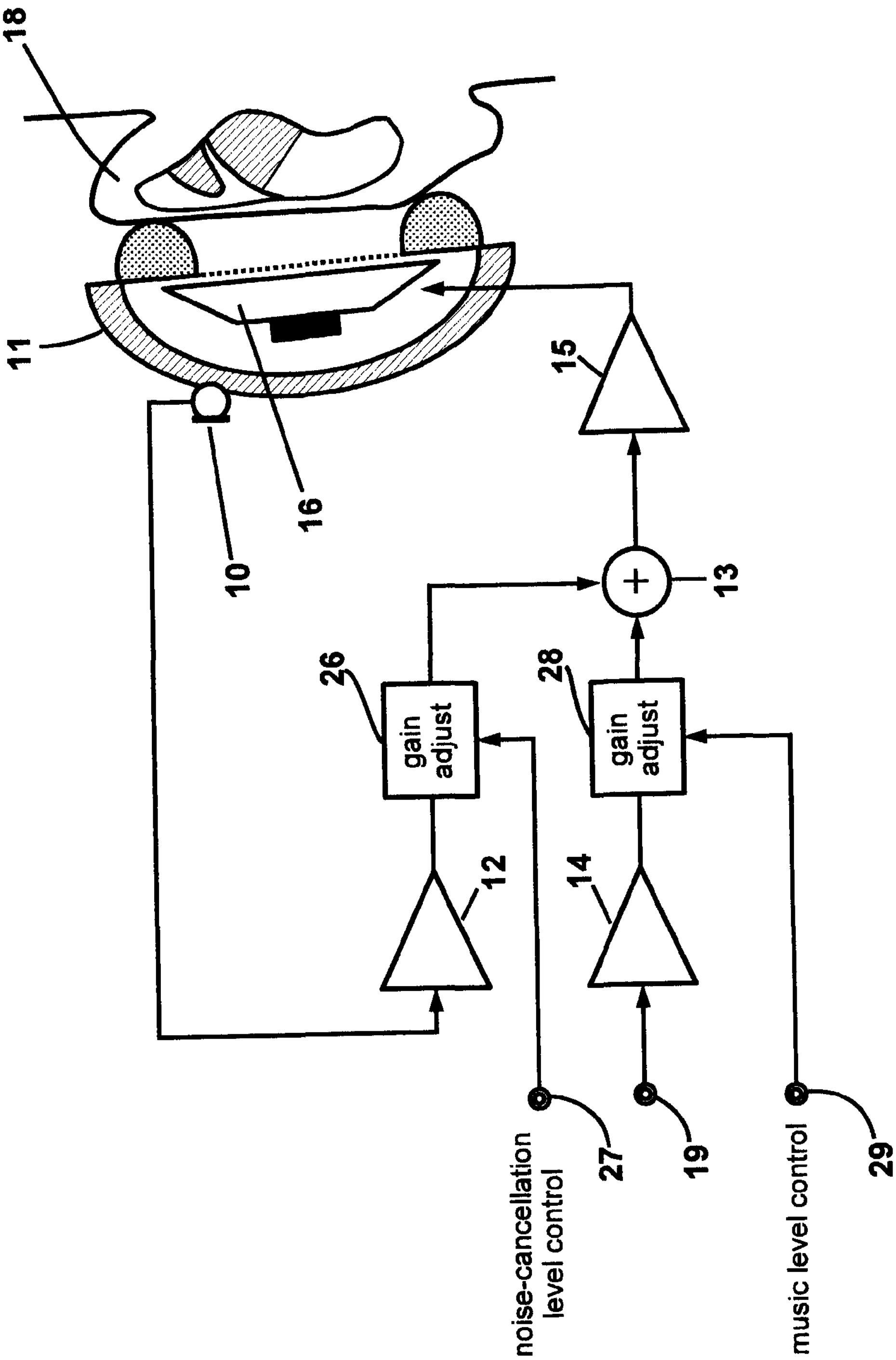

18
11
16
10
15
13
26
gain adjust
28
gain adjust
12
14
noise-cancellation level control
27
19
music level control
29

Fig 5

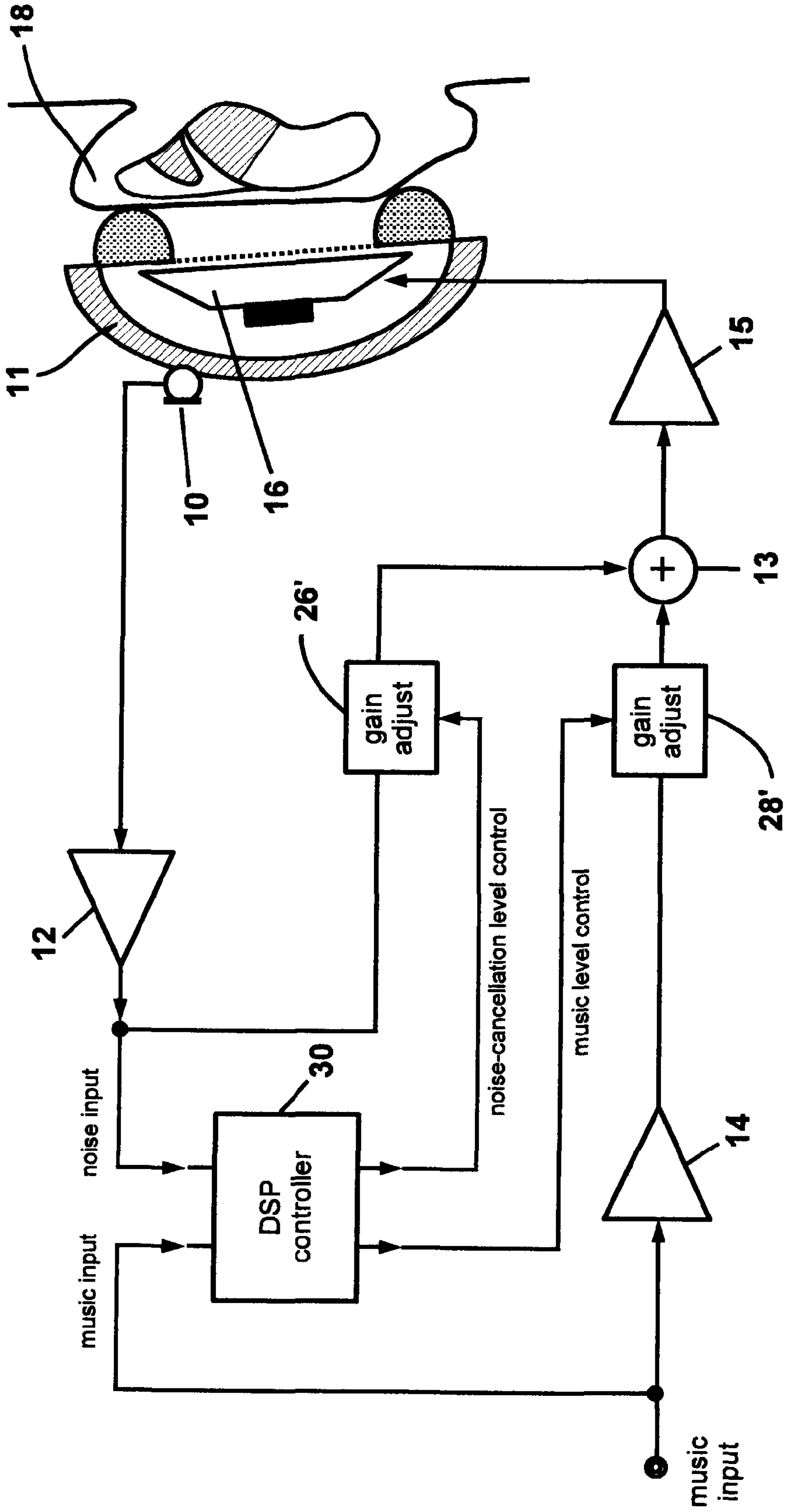

18
11
10
16
15
26'
13
gain adjust
gain adjust
28'
12
noise-cancellation level control
music level control
noise input
30
music input
DSP controller
14
music input

Fig 6

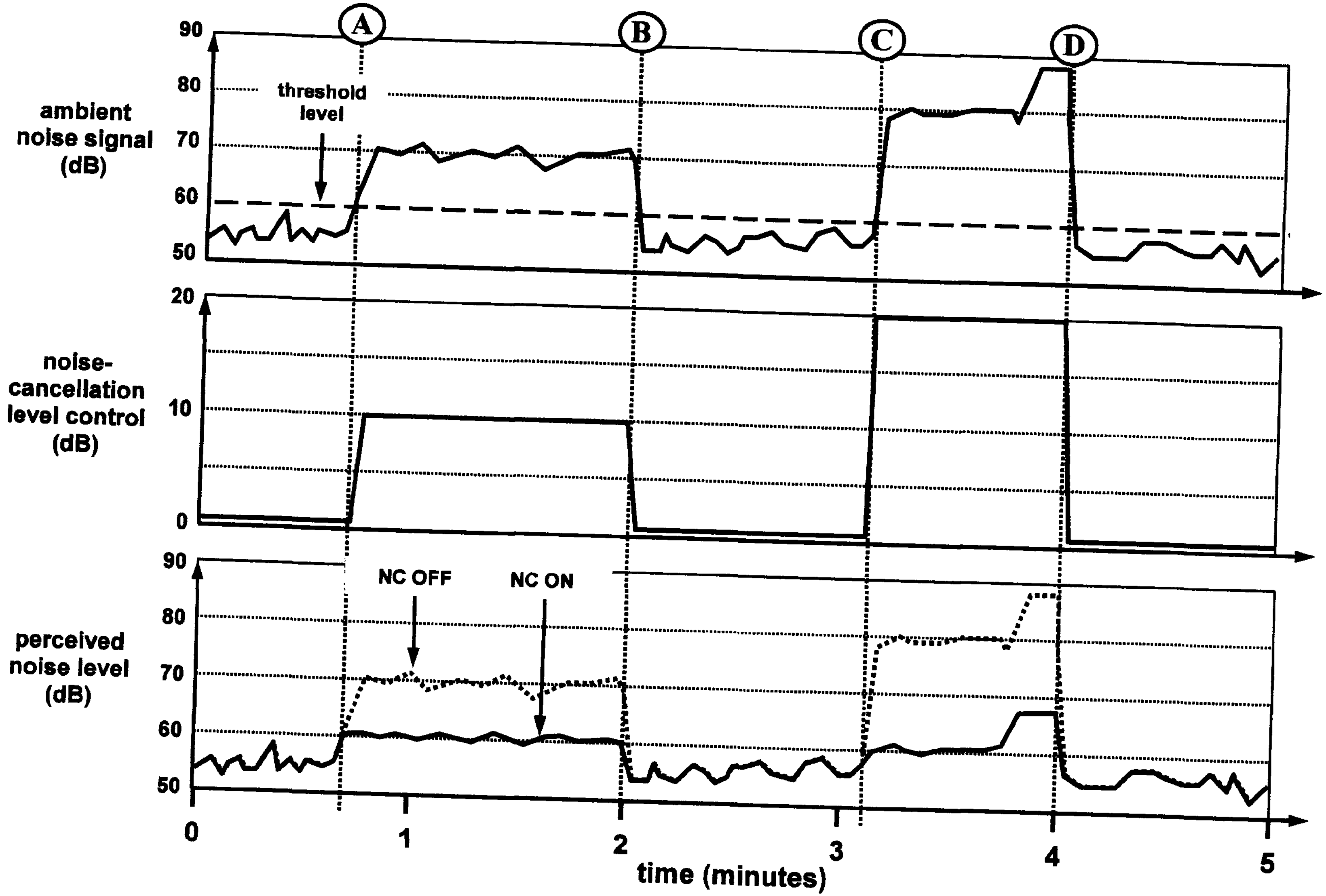

ambient noise signal (dB)
threshold level
noise-cancellation level control (dB)
perceived noise level (dB)
NC OFF
NC ON
A
B
C
D
90
80
70
60
50
20
10
0
0
1
2
3
4
5
time (minutes)

Fig 7

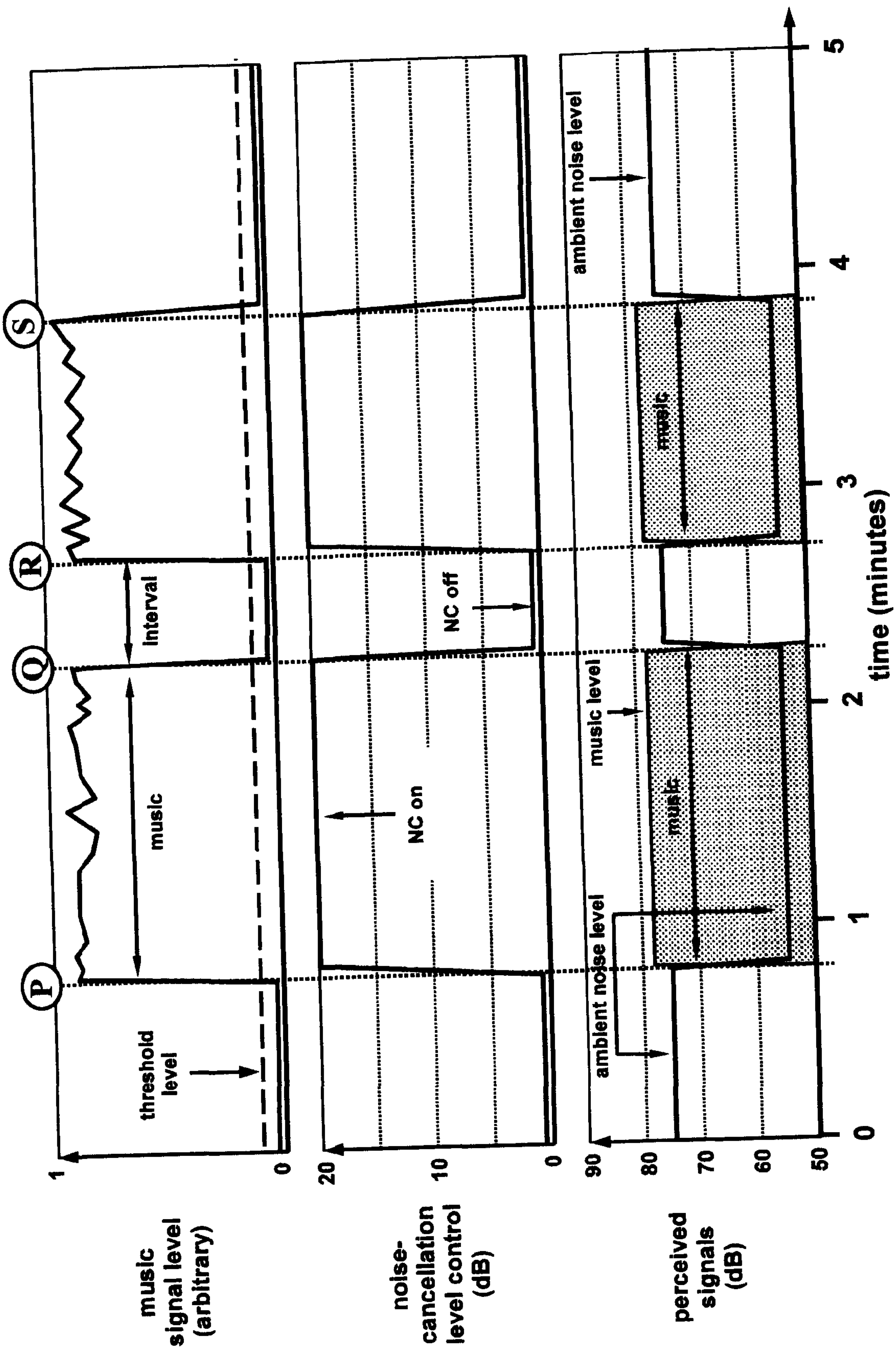
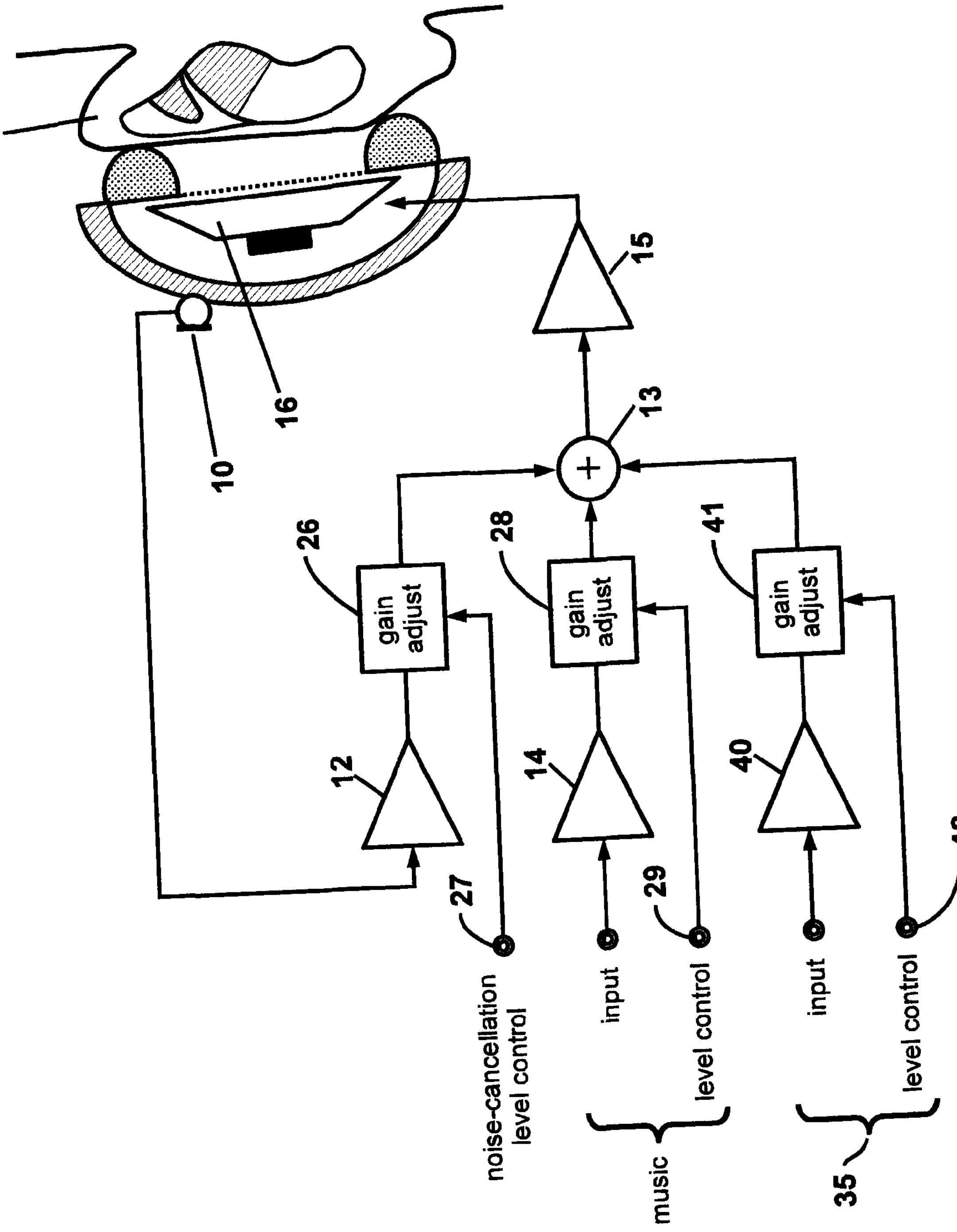

music signal level (arbitrary)
noise-cancellation level control (dB)
perceived signals (dB)
1
0
20
10
0
90
80
70
60
50
threshold level
music
interval
P
Q
R
S
NC on
NC off
ambient noise level
music level
music
music
ambient noise level
0
1
2
3
4
5
time (minutes)

Fig 8



18
10
16
15
13
26
28
41
gain adjust
gain adjust
gain adjust
12
14
40
27
29
42
noise-cancellation level control
input
level control
input
level control
music
35

Fig 9

Ambient noise-reduction control system

The present invention relates to ambient noise-reduction control systems, primarily for use with earphones and headphones (both of which are referred to hereinafter as "earphones" for convenience). The invention has especial, though not exclusive, application to earphones intended for use in conjunction with portable electronic devices, such as personal music players and cellular phones.

In this context, there are two different forms of ambient noise-reduction in present, widespread use; one relating to a so-called "talker", in which the ambient acoustic noise around a person who is speaking into a cell-phone microphone is detected by a secondary microphone and electronically subtracted from the signal generated by the cell-phone's microphone, such that ambient acoustic noise signal is removed or reduced from the signal transmitted by the cell-phone, thus improving the intelligibility of the speech content of the transmitted signal.

The other form of ambient noise-reduction relates to a so-called "listener", in which the ambient acoustic noise occurring around an individual who is listening to an earphone is detected by a microphone on (or inside) the earphone housing, electronically inverted and added to the earphone drive signal, so as to create an acoustic signal which, in principle, is substantially equal in magnitude, but substantially opposite in polarity, to the ambient acoustic noise. Consequently, destructive wave interference occurs between the ambient acoustic noise and its inverse, generated via the earphone, and so the level of the ambient acoustic noise, as perceived by the listener, is reduced. The present invention relates to this latter form; i.e. ambient acoustic noise-reduction for an earphone listener.

At present, some earphones are wired directly to their sound source via short leads and connectors, and some are connected via wireless links, such as the "Bluetooth" format, to a local sound generating device, such as a personal music player or cell-phone. The present invention can be used with both wired and wireless formats. There are several distinct types or families of earphones in use at the present time, both as single, one-ear devices, and also as stereophonic pairs, as described below.

1. In-ear type earphone (sealed), with ear canal sealing flange (termed "ear-bud").
2. In-ear type earphone (not sealed), with a relatively loose fit into the ear, and consequent acoustic leakage pathway around the device.
3. Pad-on-ear earphone, with foam disc pad which lies flat against the pinna (outer ear flap).
4. "Supra-aural" on-ear earphone with peripheral acoustic seal: as (3) but with a thicker peripheral acoustic seal around the rim so as to achieve some acoustic attenuation of the higher frequencies permeating into the ear from the outside world.
5. Circumaural: in which a larger earphone housing is used, slightly bigger than the pinna itself, such that when located in position against the side of the head, a large, cushion-type foam-rubber seal around the rim of the housing forms a substantial acoustic seal between the ambient and the inner cavity now existing between the ear and the inner surface of the earphone shell.

Types 1 and 5 both incorporate a form of acoustic seal in order to provide a degree of acoustic isolation for the listener, but many find that this leads to various types of discomfort.

For example, Type 1 earphones can be physically uncomfortable when lodged in the ear canal entrance for extended periods. Further, their acoustic isolating properties can be dangerous in terms of users' awareness of their physical surroundings. Also, because the ear canal is effectively sealed by the earphone, use of such earphones in aircraft can cause ear "popping" and discomfort in response to changes in cabin pressure. Furthermore, if the housing of the earphone is brushed against an object, such as a pillow or item of clothing, a very loud (and distracting) mechanical transmission of the friction sound directly into the ear canal frequently occurs. Additionally, if the user is eating, the chewing noises are transmitted into the ear-canal via the mastoid bone, again creating a large and unpleasant acoustic signal.

Type 5 earphones also strive to isolate the listener's ears from the ambient and, whilst their construction is such that a small cavity is formed around the outer ear, such that the ear canal is not directly sealed itself, the ear canal is nevertheless coupled acoustically to this cavity. This sealed cavity around the ear is not ventilated, and therefore can quickly become warm, humid and uncomfortable. Also, if there are small imbalances between the left and right channel signals at low frequencies, which might be caused, for example, by the two earphones not being seated perfectly symmetrically, than unpleasant acoustic effects can be introduced by the occurrence of non-natural left-right phase differences which have been variously described as "phasey", "sucking effect" and "ear-blocking".

The sound isolation provided by acoustically sealed systems is a fixed feature: it can neither be varied, nor switched off. If a user wishes to hear the outside world briefly, say for conversation or for crossing a road, it is necessary to physically remove the earphone from the ear, and then replace it again afterwards. This is a major disadvantage in everyday usage, and can lead to potentially dangerous situations should users leave the earphones in place continuously.

The present invention relates primarily to usage with earphone types (2), (3) and (4) in which there is some acoustic leakage present around the earphone itself, linking the user's ear to the ambient. Although this naturally makes electronic noise-reduction more difficult to achieve, the acoustic leakage affords a much more comfortable listening experience for the user, and this is a very important factor. The comfort factor of the pad-on-ear type of earphone is superior to the circumaural type in that (a) it is intrinsically relatively lightweight; (b) it allows natural air-flow and ventilation around the ears, thus avoiding sweatiness and irritation; and (c) it is not susceptible to artefacts associated with the actions of eating and chewing.

Another prime advantage of earphones with relatively large acoustic leakage is that most of the human directional hearing capabilities remain intact, so that users still possess spatial hearing ability with the earphones in place on the ears. Consequently, in the absence of loud music or noise-reduction signals, users can hear the world in a reasonably natural way. This is a safe default situation, unlike an acoustically sealed system that isolates a listener from the physical environment.

It is further important to note that existing ambient noise-reduction systems for earphones are based on either one of two entirely different principles, namely the "feedback" method, and the "feedforward" method.

The feedback method, described for example in US 4,455,675, is based upon a closed-back, circumaural-type earphone. Inside the cavity that is formed between the ear and the inside of the earphone shell, a miniature microphone is placed directly in front of the earphone loudspeaker, and it is coupled back to the loudspeaker via a negative feedback loop (an inverting amplifier), such that it forms a simple servo system in which the loudspeaker is constantly attempting to create a null sound pressure level at the microphone. Although this principle is simple, its practical implementation presents certain difficulties.

One of these difficulties arises because the *intrinsic* phase response of the loudspeaker and the propagation delay between the speaker and microphone both introduce significant phase lags at higher frequencies. When the resultant phase lag becomes equal to, or greater than, one half of a wavelength, the feedback system is no longer negative but becomes positive, thus creating instability which results in continuous, massive oscillation. Accordingly, high-frequency (HF) filtering must be introduced into the feedback loop, imposing severe restrictions upon the upper frequency of operation and typically limiting its effectiveness to frequencies of about 1 kHz or below. It is thus further necessary to provide effective passive acoustic attenuation to prevent the ingress of ambient noise above this upper frequency limit, and this is typically done by ensuring that the ear-enclosing circumaural seal blocks these frequencies.

Another of the aforementioned difficulties in implementing feedback systems arises because, if music or speech is to be fed to the user's earphone, provision must be made to avoid these particular signals themselves being cancelled out by the feedback system. This process can introduce undesirable spectral troughs and peaks ("colouration") in the music signal.

Another difficulty arises because a feedback system of this type requires the operating cavity to be substantially isolated from the ambient, which precludes its use with pad-on-ear earphones because of their intrinsic acoustic leakage.

Accordingly, although a pad-on-ear feedback device was disclosed in US Patent 4,644,581 as long ago as 1985, it appears that no earphones of this type are yet commercially available. Feedback systems are susceptible to go into "howl around" oscillation at switch on or when operating conditions change.

The feedforward method is disclosed, for example, in US 5,138,664 and is depicted in basic form in Figure 1. It can be employed with all of the different types of earphone described above. In contrast to the feedback system, however, a microphone 10 is placed on the exterior of the headphone shell 11 in order to detect the ambient noise signal on its way into and around the earphone. The detected signal is pre-amplified and inverted in a suitable inverting amplifier 12 and added at 13 to the earphone drive signal, supplied to the combining circuit 13 by way of a buffer amplifier 14, which is fed by way of a drive amplifier 15 to an earphone loudspeaker 16, thus creating a composite signal S containing a music component and a noise reduction signal component. As a consequence, destructive wave reduction occurs between the noise reduction signal component of the composite signal S and the incoming ambient acoustic noise signal, adjacent to the outlet port of the loudspeaker 16, within a cavity 17 formed between the headphone shell 11 and the outer ear shown schematically at 18. For this to occur, the noise reduction component of the composite signal S must have a magnitude which is substantially equal to that of the incoming noise signal, and it must be of substantially opposed polarity (that is, inverted, or 180° shifted in phase with respect to the noise signal).

The basic feedforward method of ambient noise reduction is simple to implement, and a working system for use with ordinary earphones can be assembled at low cost using a simple electret microphone capsule and a pair of operational amplifiers to amplify and invert its analogue signal, prior to mixing, as at 13, with the earphone audio drive signal. This is done via an adjustable gain means (not shown), such as a potentiometer, in order to adjust the magnitude of the noise reduction component of the signal S to substantially equal that of the ambient noise. Some measure of noise reduction can be achieved with this method and, although current systems are far from perfect, this feedforward principle forms the basis of various commercially available noise-reducing earphones. However, in such systems, even when the noise reduction signal is optimally adjusted and balanced, there remains a considerable residual noise signal, and so it is common to observe that most commercial systems are only claimed to operate below about 1 kHz; i.e. with a bandwidth similar to that of the feedback method, and to provide relatively modest amounts of noise reduction.

Some currently available noise-reducing earphones allow the user to switch off the noise reduction function, whereupon the earphone loudspeaker connections are switched away from the output of the internal noise-reducing drive amplifier 15 directly to the audio input connections (shown schematically at 19), thus acting as a conventional earphone if the battery has expired, or in order to conserve battery energy.

The long-standing situation of poor noise reduction efficacy has been changed recently by the invention of a much more efficient feedforward noise reduction system based on the usage of accurately time-aligned signals and an associated microphone technology, described and claimed in UK Patent Application No. GB 0601536.6 which is assigned to the present applicant and incorporated herein in its entirety by reference. This system provides a greater degree of noise reduction, and is effective up to higher frequencies (e.g. in the order of 3.5 kHz) than prior-art systems.

It has now been determined by the inventor that there is considerable merit in providing for variation in the amount or degree of ambient noise reduction that is effected, according to the circumstances and user preferences, and hence the present invention aims to provide a noise reduction control system in which the ambient noise reduction level can be controlled by one or more external events, thus permitting various manual and automatic modes of operation to be implemented.

According to the invention there is provided a noise reduction control system for earphones, comprising means for sensing ambient noise, for developing electrical signals indicative of said noise and for utilising said signals to influence the amount of said ambient noise audible by a listener to the earphone, and control means comprising means for responding to at least one controlling event to set the degree of said influence to a preselected level in a range of setting levels.

Preferably said means for sensing ambient noise is adapted to sense ambient noise on its way past said earphone towards the ear of the listener, and the system further comprises means for inverting said electrical signals and for feeding said inverted signals to a loudspeaker means in said earphone in time for the loudspeaker to generate sounds capable of interfering destructively with said sensed ambient noise when it arrives in the vicinity of said loudspeaker means.

It is further preferred that the system also comprises a source of further electrical signals relating to sounds intended for the listener's attention, and means for merging the further electrical signals with the inverted signals to create a composite signal for application to said loudspeaker means.

In one preferred example of the invention, the sounds intended for the listener's attention comprise music. Alternatively, or in addition, the sounds may be speech or other sounds received over a telecommunications link.

In some preferred embodiments, the said controlling event comprises the direct or indirect actuation of a switch by the listener, thereby to selectively control said degree of influence. The response to such actuation may be instantaneous, delayed or subjected to a time profile such as a ramp function. The response may be effective to invoke one or more predetermined levels of influence or to effect an adjustment of said degree of influence over a number of levels within the range.

In some preferred embodiments, said control means is adapted to separately control the said inverted signals and the said further electrical signals relating to sounds intended for the listener's attention. In such circumstances it is particularly preferred that the control means comprise a digital signal processor.

It is further preferred in some embodiments to provide plural channels for respective electrical signals relating to sounds intended for the listener's attention, for said control means to separately control the said signals in at least a first and a second of said channels.

The invention may receive external signals for the attention of the listener by way of direct electrical connections and/or through wireless communication.

Where a wireless communication is employed, it is preferred that such communication conforms to Bluetooth protocols.

The invention may beneficially be employed in association with an audio system providing 3D-audio virtualisation.

The present invention thus provides a system for variable, controllable ambient noise-reduction for an earphone user. It is especially suited for use with the efficient time-alignment system described and claimed in the aforementioned UK Patent Application, that is effective to frequencies up to, and beyond, 3 kHz, in contrast to the sub-1 kHz limit of presently available commercial products. Included amongst advantages of the invention are that the associated earphone type is both comfortable in use (being lightweight, not rigidly clamped to the head, and affording some ventilation), and that the amount or degree of noise-reduction that is effected may be electronically controllable; both of these characteristics being particularly desirable for earphones intended for use with mobile electronic devices. The noise-reduction level can be controlled in a binary "on-off" mode, or it can be switched directly between different pre-determined levels in a range, or it can be subjected to a time profile, such as a ramp function, to provide adjustment between levels on a "continuously variable" basis, either smoothly or in discrete increments.

The continuously variable function enables smoothly faded transitions to be made between different levels of ambient noise reduction, as will be described. For example, when initially activated, the ambient noise reduction can be contrived to fade from its "off" value of reduction factor (RF) of 0%, to its maximum effect (RF = 100%) over a period of, say, one second; thereby affording the listener a smoothly achieved transition, free from audible clicks and other unpleasant switching artefacts.

Alternatively, or in addition to direct user control, the control of noise-reduction level can be exercised in response to the occurrence of selected events which themselves may be outside the listener's control, thus enabling various automatic functions to be implemented for enhanced user satisfaction and safety.

In addition to directly connected earphone applications, the invention is also applicable to telephony applications such as radio-linked (Bluetooth) earphone devices, where an incoming call can be used to trigger a pre-determined sequence of events, and where the cessation of the call can restore the original listening conditions for the user.

In practice, the amount of active noise reduction that can be achieved is limited by physical variables related to earphone placement and the like, and it varies with frequency over the range of operation. For the purpose of illustration it will be assumed, in the examples that follow, that a relatively efficient ambient noise reduction system is used, affording 20 dB of noise reduction at the eardrum of the listener, and hence the RF of 100% corresponds to 20 dB noise reduction.

The invention can be applied to both feedback and feedforward types of ambient noise reduction, although it is best-suited to feedforward systems, where there is intrinsic acoustic leakage from the ambient to the eardrum. For clarity of description, the examples herein relate to the feedforward method. Also, for simplicity in the accompanying Figures, a single microphone system has been depicted, but it should be noted that a time-aligned, multi-microphone arrangement (for example of the kind described and claimed in the aforementioned UK Patent Application) is preferred, because it is more effective in use.

In order that the invention may be clearly understood and readily carried into effect, certain embodiments thereof will now be described, by way of example only, with reference to the accompanying drawings, of which:

Figure 1 shows, in block diagrammatic form, a conventional feedforward circuit arrangement for ambient noise reduction;

Figures 2a and 2b show respectively electronic analogue switching and gain-adjustment devices suitable for use in systems according to examples of the invention;

Figure 3 shows a circuit arrangement for a system in accordance with a first embodiment of the invention;

Figure 4 shows a circuit arrangement for a system in accordance with a second embodiment of the invention;

Figure 5 shows a circuit arrangement for a system in accordance with a third embodiment of the invention;

Figure 6 shows a circuit arrangement for a system in accordance with a fourth embodiment of the invention;

Figure 7 shows graphs explanatory of the operation of a system according to an example of the invention configured as an ambient noise limiting system;

Figure 8 shows graphs explanatory of the operation of a system according to an example of the invention configured to implement music-dependent ambient noise control; and

Figure 9 shows a system in accordance with an example of the invention configured to implement electronic control over noise reduction, music and telecommunications signals.

Whilst the following examples and drawings relate to an analogue circuit implementation, ambient noise reduction signal processing can alternatively or additionally be carried out in the digital domain; the invention being equally applicable to analogue and/or digital processing routes.

Some preferred embodiments of the invention provide an ambient-noise reduction system having a variable degree of reduction that can be controlled by one or more external events. Each controlling event can initiate one or more actions that control the degree of ambient noise reduction, using one or more of several different operating modes. Some illustrative examples of these controlling events, actions and operating modes are listed below, followed by descriptions of various embodiments and two automatic operating modes afforded by the invention.

Examples of Controlling Events

E1. Direct user activation. The listener can manually switch the noise reduction level to different values, or invoke different operations, via a switch, such as a touch-switch on the earphone itself. The action can be "toggled" (e.g. one touch for ON; another touch for OFF), or can initiate a timed period of selected operation, as will be described in more detail below.

E2. Incoming call activation. An incoming telephone call triggers one or more actions, or a sequence of events, such as activating otherwise dormant noise reduction whilst the call is in progress, and then switching it off again when the call is terminated.

E3. Clock and timer control. A local electronic clock or timer is used to control the noise reduction level for a prescribed period of time. For example, a user travelling on an aircraft might wish to sleep in silence until a particular time, and then have the ambient noise restored to serve as a gentle wake-up alarm method. Alternatively, a traveller using full noise reduction might wish to have the ambient noise restored temporarily for, say 10 seconds, in order to have a brief conversation, after which full noise reduction is restored again.

E4. Detection of motion. A motion detector transducer is used to detect movement of the user's head. It activates the noise reduction system whilst the user is substantially motionless, which would be the case if they were asleep or listening to music, but when the user stirs and moves around, the noise reduction is switched off to restore the ambient sounds.

E5. Auto-Noise Mode. The ambient noise signal is monitored by a microprocessor and compared to a threshold value, such that when the ambient noise level around the user exceeds the threshold level, the noise reduction is activated. This is done in a proportional way such that the system acts as a "limiter", or automatic gain control (AGC) for real-world noise, as is described subsequently.

E6. Auto-Music Mode. The incoming audio/music signal is monitored by a microprocessor and compared to a threshold value, such that when music is playing, or when other audio signals are present, the noise reduction is activated. When the music stops, for example between tracks, or because it has been switched off or paused, the noise reduction is caused to be switched off, attenuated or faded down to restore the ambient sounds for the listener.

Examples of Actions

A1. On/Off-instant. The noise reduction is switched ON or OFF instantly.

A2. On/Off-faded. The noise reduction is smoothly faded ON or OFF over a predetermined or selected period.

A3. Safe level. The noise reduction level is switched or faded to a preset, mid-value for the user's safety, say for example –6 dB, such that ambient sounds can still be heard by the user, albeit at a reduced loudness level (50% for –6 dB), in order to maintain some awareness for alarms and the like.

A4. User pre-set level. There is a "Go To" function that allows the user to switch instantly to a pre-set level of ambient noise reduction (RF in the range 0% to 100%).

<u>Examples of Operating Modes</u>

M1. Toggle. An event triggers an action, and the same event - occurring again - restores the initial conditions.

M2. Monostable. An event triggers an action for a pre-determined period of time.

M3. Bistable. One event triggers an action, and another event restores the initial conditions.

M4. Automatic. Various "auto" modes: for example, Auto-Noise Mode (E5) and the Auto-Music Mode (E6), above.

Figure 1, to which reference has already been made, shows a block diagram of the fundamental components and structure of a feedforward-type ambient noise reduction system. The microphone 10 (or preferably an array of microphones) is placed on the headphone shell 11 to register incoming ambient noise, and generates electrical signals, indicative of said incoming noise, which are fed to a pre-amplifier and inverter stage 12, after which the signal is summed at 13 with signals relating to incoming audio (e.g. music) intended for the listener's attention (after they have been suitably buffered at 14), and the combined noise-reduction and music/audio signals are fed to a drive amplifier 15 that is capable of driving the earphone loudspeaker driver transducer 16. The overall system gain is chosen such that the resultant acoustic noise reduction signal at the eardrum has an amplitude substantially identical to the incoming ambient noise signal at the eardrum, thus ensuring maximum destructive reduction of the ambient noise. As described in the aforementioned UK patent application, great care must be also be taken to ensure that the phase of the two signals is matched at the eardrum, preferably by engineering a time-aligned system.

In order to vary and control the amount or degree of noise reduction which is carried out, the magnitude of the noise reduction signal must be switched or reduced from its maximum, optimal value, to some other value, such as zero. It will be appreciated that this could be done at several points in the circuit of Figure 1, and ideally at the output of the pre-amplifier/inverter stage 12, prior to signal summation. The gain reduction can be carried out using either a solid-state analogue switch 20 (Figure 2a), or an electronic potentiometer 25 (Figure 2b).

One example of a suitable analogue switch is MAX325CPA (manufactured by Maxim), which is a double-pole double-throw switch based on coupled MOSFET devices having low R_{on} values (~33 Ω). Figure 2a shows one half of this device, in which a digital control signal A opens the connection between terminals P and Q, and a digital control signal B closes the connection between terminals R and S. Examples of suitable electronic potentiometers include the AD8400 series (manufactured by Analog Devices), and also the AD5207, which comprises a 256-step, dual 10 kΩ potentiometer, with serial 8-bit digital input. These devices behave as analogue potentiometers, but with the "slider" position set by an 8-bit digital control word.

Figure 3 shows how the circuit of Figure 1 can be modified such that the noise reduction level can be switched from maximum to a pre-set level using an analogue switch device 21. Here, a potential divider 22, comprising two resistors R1 and R2, has been inserted between the pre-amplifier stage 12 and ground. Consequently, by turning the switch 21 OFF, the pre-amplifier output signal, X, is reduced to a value $X\left(\frac{R2}{R1+R2}\right)$ at the junction between the two. For example, if a value of 10 kΩ was chosen for both R1 and R2, then the signal X would be reduced in amplitude by 50% (-6 dB), thus reducing the magnitude of the noise reduction signal, and hence reducing the degree of noise reduction that is achieved.

If the analogue switch 21 in parallel with R1 is switched ON, as shown in Figure 3, the signal at the R1/R2 junction is restored to its original value of X, which enables full noise reduction to be effected. The condition of the switch 21 is controlled by user-application of a signal to control input 23 thereof. Such operation may require direct actuation of the switch 21 itself or the actuation of a subsidiary switch (not shown) used to apply an operating potential to the input 23.

A more sophisticated arrangement for switching between different levels of ambient noise reduction can be achieved by using an electronic potentiometer in place of the resistor-pair arrangement of Figure 3, and such an arrangement is depicted in block form in Figure 4. In this case, the gain of the noise signal can be controlled in a variable manner, typically in 256 increments of gain, by addressing the electronic potentiometer 26 with the required 8-bit digital number. Consequently, if it is required to activate the noise reduction signal from an OFF state (RF = 0%; digital "0") to a fully ON state (RF = 100%; digital "256"), then the potentiometer is addressed rapidly with incrementing numbers from 0 to 256 over a brief period, say one or two seconds, thereby causing the ambient noise reduction to fade smoothly into maximum effect. This is much more pleasing and comfortable for the listener than to hear a sudden transition.

A further degree of sophistication can be achieved by applying a similar, controllable, variable-gain stage 28 to the music stage, prior to its summation with the noise signal, as shown in Figure 5. This enables independent dual control of both the noise reduction level and the music level, which in turn allows various automatic modes of operation to be implemented, using the system of Figure 6.

Figure 6 is an extension of Figure 5, in which a digital signal processor (DSP) 30 has been incorporated to monitor both the music input and the ambient noise signal from the microphone, or either of these. It is wired to, and controls, the control buses of both the ambient noise gain control stage 26' and the music signal gain control stage 28', thus providing the ability to fade either signal, independently, between 0% and 100%, or between any intermediate values, as rapidly or as slowly as required.

Two automatic mode embodiments, already briefly referred to above as E5 (Auto-Noise Mode) and E6 (Auto-Music Mode) will now be described in more detail.

Auto-Noise Mode (E5):

The purpose of this mode of operation is to allow a user to hear all the low-level ambient sounds, but to limit excessively loud sounds. For example, if the user is walking through a town, it would be advantageous (and safer) to hear the sounds of cars approaching, people talking and the like, but, when walking past a very noisy construction site, or when a high-speed train passes at a railway station, it would be very desirable to reduce these brief occurrences of very loud noise to a more comfortable level.

This can be achieved using the circuit shown in Figure 6, in which the incoming ambient noise signal is monitored by the DSP 30 and compared to a pre-determined threshold value such that, when the ambient noise level around the user exceeds this threshold level, the noise reduction is activated. This is done in a proportional way such that the system acts as a "limiter", or automatic gain control (AGC) for real-world noise. If the maximum noise reduction capability of the system is, say, -20 dB, and the threshold level is set to 60 dB, Figure 7 depicts the time course of an example series of events in the course of an imaginary town traveller, over a five minute period, to illustrate this embodiment of the invention.

The uppermost graph of Figure 7 shows the ambient noise level, in dB units, as a function of time over a five minute period, with a threshold level indicated at 60 dB, and four event markers A, B, C and D. The central graph shows the noise reduction level control, and represents the amount of ambient noise reduction that is implemented by the DSP, in the range 0 dB to a maximum of 20 dB. The lowermost graph of Figure 7 indicates the resultant noise level that is perceived by the user after noise reduction has taken place. There are two plots on this graph: the dotted line represents the perceived noise level with the system switched OFF, and the solid line indicates the perceived noise level with the system switched ON.

Initially, the ambient noise level is quite low, at 55 dB, but at point A, a noisy truck parks besides the user, raising the ambient noise level to 70 dB. This exceeds the activation threshold, and so the DSP 30 adjusts the gain of the noise reduction stage to implement 10 dB of ambient noise reduction, thus reducing the perceived noise level at the listener's eardrums to 60 dB. At point B, the truck moves on, the ambient noise level reverts to its original 55 dB, thus falling below threshold, and the DSP 30 switches the noise reduction off again. At point C, the user passes a noisy construction suite which generates an ambient noise level of 80 dB, and so the DSP effects –20 dB noise reduction, bringing the perceived level by the listener to be only 60 dB once again. However, this –20 dB is the maximum degree of available noise reduction, and so a further rise in ambient noise level, just before marker D, causes the perceived noise level to increase linearly beyond the 60 dB target. The purpose of this latter is to illustrate the benign nature of the system, in that overloading beyond the maximum noise reduction capability does not cause detrimental artefacts.

Auto-Music Mode (E6):

The purpose of this mode of operation is to switch on maximum ambient noise reduction when the music is playing, and to switch it off when the music channel is silent, in order that the user can hear all ambient sounds when the music is not playing.

For example, if the user is travelling on a noisy underground train, it would be very desirable (and safer) to hear all of the local environmental sounds in between music tracks, or in the silent pauses during radio programmes. Additionally, if the user wished to alight from one train, and then catch another, it would be advantageous to pause the music track, at which point the ambient noise reduction would be caused to be switched off, thus allowing the user to hear normally whilst negotiating the transition between trains, and then when the music is switched on again, the noise reduction is also activated automatically to maximum effect.

This is easier than having to switch both the music and the noise reduction off and on separately, and it is safer for the user than leaving the ambient noise reduction switched on continuously.

This example is illustrated in Figure 8, which depicts the time course of an example series of events in the course of an imaginary underground train commuter over a five minute period.

The uppermost graph of Figure 8 shows the music signal level, in arbitrary units (0 to 1), as a function of time over a five minute period, with a threshold level indicated at about 5% of maximum, and four event markers P, Q, R and S. The central graph shows the noise reduction level control, and represents the amount of ambient noise reduction that is implemented by the DSP, in the range 0 dB to a maximum of 20 dB. Here, it is simply switching between OFF (0 dB) and ON (20 dB). The lowermost graph of Figure 8 indicates the combined music and ambient noise signals that are perceived by the user after noise reduction has taken place. There are two plots on this particular graph: one line represents the perceived noise level, to show the reduction of ambient noise when the music is playing (and the non-reduction when it is not), and the second shows the music level itself, to indicate track interval (Q-R) and music pause (S) events.

Initially, and up to point P, the music is switched off, and the music signal lies below the threshold level, causing the ambient noise reduction to be switched OFF. Consequently, the user hears the environmental ambient noise, at a level of about 75 dB. At point P, the user switches the music ON, which exceeds the threshold level, causing the noise reduction to be switched ON, thus reducing the perceived noise at the listener's eardrum from 75 dB to 55 dB. At point Q the first music track stops and there is a short interval before the following track; the music signal falls below threshold, causing the noise reduction to switch OFF, and hence the user hears the ambient environment as normal, between tracks. At point R, the second music track starts, thus causing the ambient noise reduction to be switched ON again.

It will be understood that, without the noise reduction, the music and noise would have similar sound pressure levels at the eardrum of the listener, making the music almost impossible to appreciate. At point S, the user wishes to leave the carriage and cross the platform to another train, and so the user pauses the music, causing the level to fall below threshold, thereby causing the DSP to switch off the noise reduction and allow the user to hear the ambient environment as normal, providing the safe default condition.

A further embodiment is depicted in Figure 9, comprising an extension of the system of Figure 5 by the addition of a third audio channel 35 with an electronically controllable gain stage 41, in addition to the ambient noise reduction channel and the music channel. The additional, third channel 35 represents a telecommunications channel, suitable for telephony, and is for relaying audio information to the listener's ears from a cellular phone or similar telephonic device, including internet-based telephony means. Such audio information includes both alerting means, such as ring-tones, and spoken word communications.

This arrangement permits implementation of a sophisticated audio management system on, for example, a wireless stereo earphone set networked to a cellular phone that is also equipped with a personal stereo (MP3) music player capability, as follows.

1. The user is listening to music via the Bluetooth earphones, and with the ambient noise reduction switched ON. The various gain levels of stages 26, 28 and 41 are respectively set as:
   Noise Reduction 100% ON; Music 100% ON; Telecomms 0% ON.

2. An incoming phone call is detected, which causes the following sequence of events to occur:
   (a) the music level is faded from 100% to 50% over a two second (say) period;
   (b) the noise reduction level is faded down from 100% to 50% over the same period;
   (c) the telecomms channel is faded up from 0% to 50% over a five second period.

This sequence gently reduces the music level and fades in a moderate amount of ambient noise to reach the user's ears, whilst at the same time gradually fading in the alerting ring-tone. This is less traumatic than a sudden, fully loud alert, and allows the user to become acclimatised to the immediate surroundings in order to assess the caller status and decide on whether to answer or refer the incoming call.

3. If the call is accepted, the following events occur.
   (a) the music level is faded from 50% to 0% over a two second (say) period;
   (b) the noise reduction level is faded back up again from 50% to 100% over the same period;
   (c) the telecomms channel is faded up to full almost immediately (0.2 s).

   This sequence reduces the music level to zero, invokes full ambient noise reduction and maximum telecom signal for optimum intelligibility during dialogue.

4. If the call is rejected, or at the end of the call, the initial listening conditions (1, above) are restored over a two second period.

This sequence of events allows smooth, automatic transitions between the multiple audio channels, and makes for a pleasant and comfortable user experience.

As regards all of the embodiments of the invention herein described, it will be appreciated that electronic components of the control system can be housed in the earphone, or in a separate housing or "pod" connected (directly or wirelessly) thereto, or may be distributed between the earphone and the pod, depending upon factors such as design choice and operational convenience.

Furthermore, any embodiment of the invention may be utilised in association with an audio system providing 3D-audio virtualisation.

Although the invention has been described with reference to certain specific embodiments, these embodiments have been provided, by way of example only, to illustrate the scope and advantages of the present invention, the scope of which is not intended to be restricted to the details of any such embodiment.

CLAIMS

1. A noise reduction control system for earphones for use with a telephone device, comprising:

means for sensing ambient noise, for developing electrical signals indicative of said noise and for utilising said signals to influence the amount of said ambient noise audible by a listener to the earphone, and

control means comprising means for responding to at least one controlling event to set the degree of said influence to a preselected level in a range of setting levels,

wherein the controlling event is an incoming telephone call.

2. A noise reduction control system as claimed in claim 1, wherein the control means comprises means for responding to the incoming telephone call by activation of the noise cancellation only when a telephone call is received

3. A noise reduction control system as claimed in claim 1, wherein the control means comprises means for responding to the incoming telephone call by fading down the amount of noise reduction when a telephone call is received.

4. A system according to claim 1, wherein said means for sensing ambient noise is adapted to sense ambient noise on its way past said earphone towards the ear of the listener, and the system further comprises means for inverting said electrical signals and for feeding said inverted signals to a loudspeaker means in said earphone in time for the loudspeaker to generate sounds capable of interfering destructively with said sensed ambient noise when it arrives in the vicinity of said loudspeaker means.

5. A system according to claim 4, comprising a source of further electrical signals relating to sounds intended for the listener's attention, and means for merging the further electrical signals with the inverted signals to create a composite signal for application to said loudspeaker means.

6. A system according to claim 5, wherein the sounds intended for the listener's attention comprise music.

7. A system according to claim 5 or claim 6, wherein the sounds intended for the listener's intention comprise speech or other sounds received over a telecommunications link.

8. A system according to any of claims 5 to 7, wherein said control means is adapted to separately control the said inverted signals and the said further electrical signals relating to sounds intended for the listener's attention.

9. A system according to any of claims 5 to 8 comprising plural channels for respective electrical signals relating to sounds intended for the listener's attention, and wherein said control means is adapted to separately control the said signals in at least a first and a second of said channels.

10. A system according to claim 8 or claim 9, wherein said control means includes a digital signal processor.

11. A system according to any of claims 5 to 10, adapted to receive said signals for the attention of the listener by way of direct electrical connections.

12. A system according to any of claims 5 to 10, adapted to receive said signals for the attention of the listener through wireless communication.

13. A system according to claim 12, wherein said wireless communication conforms to Bluetooth protocols.

14. A system according to any preceding claim adapted to receive audio signals from an audio system providing 3D-audio virtualisation.

15. A method of noise reduction control for earphones, the method comprising the steps of:

sensing ambient noise;

developing electrical signals indicative of said noise;

utilising said signals to influence the amount of said ambient noise audible by a listener to the earphone; and responding to at least one controlling event to set the degree of said influence to a preselected level in a range of setting levels,

wherein the controlling event is a function of detected changes in physical motion of the earphones, representative of movement of the head of a listener.

16. A method according to claim 15, further comprising the step of:

detecting changes in physical motion of the earphones.

17. A method according to claim 15 or claim 16, further comprising the step of:

responding to detected changes in physical motion of the earphones, by activating noise reduction when the head of the listener is substantially motionless, and switching off noise reduction when the head of the listener is moving.

18. A method according to claim 15, wherein the step of sensing ambient noise comprises sensing ambient noise on its way past said earphone towards the ear of the listener, and wherein the method further comprises the steps of:

inverting said electrical signals; and

feeding said inverted signals to a loudspeaker means in said earphone in time for the loudspeaker to generate sounds capable of interfering destructively with said sensed ambient noise when it arrives in the vicinity of said loudspeaker means.

19. A method according to any of claims 15 to 18, further comprising the step of:

receiving further electrical signals relating to sounds intended for the listener's attention; and

merging the further electrical signals with the inverted signals to create a composite signal for application to said loudspeaker means.

20. A method according to claim 19, wherein the sounds intended for the listener's attention comprise music.

21. A method according to claim 19 or claim 20, wherein the sounds intended for the listener's intention comprise speech or other sounds received over a telecommunications link.

22. A method according to any of claims 19 to 21, further comprising the step of:

separately controlling the said inverted signals and the said further electrical signals relating to sounds intended for the listener's attention.

23. A method according to any of claims 19 to 22, wherein the step of receiving said signals for the attention of the listener comprises receiving said signals by way of direct electrical connections.

24. A method according to any of claims 19 to 22, wherein the step of receiving said signals for the attention of the listener comprises receiving said signals through wireless communication.

25. A method according to claim 24, wherein said wireless communication conforms to Bluetooth protocols.

26. A method according to any of claims 15 to 25, wherein the method further comprises the step of:

receiving audio signals from an audio system providing 3D-audio virtualisation.

27. A noise reduction control system substantially as described herein with reference to any of the figures of the accompanying drawings.

Amended claims have been filed as follows:-

CLAIMS

1. A noise reduction control system for earphones for use with a telephone device, comprising:

means for sensing ambient noise, for developing electrical signals indicative of said noise and for utilising said signals to influence the amount of said ambient noise audible by a listener to the earphone, and

control means comprising means for responding to at least one controlling event to set the degree of said influence to a preselected level in a range of setting levels,

wherein the controlling event is an incoming telephone call.

2. A noise reduction control system as claimed in claim 1, wherein the control means comprises means for responding to the incoming telephone call by activation of the noise cancellation only when a telephone call is received.

3. A noise reduction control system as claimed in claim 1, wherein the control means comprises means for responding to the incoming telephone call by fading down the amount of noise reduction when a telephone call is received.

4. A system according to claim 1, wherein said means for sensing ambient noise is adapted to sense ambient noise on its way past said earphone towards the ear of the listener, and the system further comprises means for inverting said electrical signals and for feeding said inverted signals to a loudspeaker means in said earphone in time for the loudspeaker to generate sounds capable of interfering destructively with said sensed ambient noise when it arrives in the vicinity of said loudspeaker means.

5. A system according to claim 4, comprising a source of further electrical signals relating to sounds intended for the listener's attention, and means for merging the further electrical signals with the inverted signals to create a composite signal for application to said loudspeaker means.

6. A system according to claim 5, wherein the sounds intended for the listener's attention comprise music.

7. A system according to claim 5 or claim 6, wherein the sounds intended for the listener's intention comprise speech or other sounds received over a telecommunications link.

8. A system according to any of claims 5 to 7, wherein said control means is adapted to separately control the said inverted signals and the said further electrical signals relating to sounds intended for the listener's attention.

9. A system according to any of claims 5 to 8 comprising plural channels for respective electrical signals relating to sounds intended for the listener's attention, and wherein said control means is adapted to separately control the said signals in at least a first and a second of said channels.

10. A system according to claim 8 or claim 9, wherein said control means includes a digital signal processor.

11. A system according to any of claims 5 to 10, adapted to receive said signals for the attention of the listener by way of direct electrical connections.

12. A system according to any of claims 5 to 10, adapted to receive said signals for the attention of the listener through wireless communication.

13. A system according to any preceding claim adapted to receive audio signals from an audio system providing 3D-audio virtualisation.

14. A method of noise reduction control for earphones for use with a telephone device, the method comprising the steps of:

sensing ambient noise;

developing electrical signals indicative of said noise;

utilising said signals to influence the amount of said ambient noise audible by a listener to the earphone; and

responding to at least one controlling event to set the degree of said influence to a preselected level in a range of setting levels,

wherein the controlling event is an incoming telephone call.

15. A method according to claim 14, wherein the method further comprises the step of:

responding to the incoming telephone call by activation of the noise cancellation only when a telephone call is received.

16. A method according to claim 14, wherein the method further comprises the step of:

responding to the incoming telephone call by fading down the amount of noise reduction when a telephone call is received.

17. A method according to claim 14, wherein the step of sensing ambient noise comprises:

sensing ambient noise on its way past said earphone towards the ear of the listener, and

wherein the method further comprises the steps of:

inverting said electrical signals; and

feeding said inverted signals to a loudspeaker means in said earphone in time for the loudspeaker to generate sounds capable of interfering destructively with said sensed ambient noise when it arrives in the vicinity of said loudspeaker means.

18. A method according to claim 17, further comprising the step of merging further electrical signals relating to sounds intended for the listener's attention with the inverted signals to create a composite signal for application to said loudspeaker means.

19. A method according to claim 18, wherein the sounds intended for the listener's attention comprise music.

20. A method according to claim 18 or claim 19, wherein the sounds intended for the listener's attention comprise speech or other sounds received over a telecommunications link.

21. A method according to any of claims 18 to 20, further comprising the step of:

separately controlling the said inverted signals and the said further electrical signals relating to sounds intended for the listener's attention.

22. A method according to any of claims 18 to 21, further comprising the step of:

separately controlling the said signals in at least a first and a second of plural channels for respective electrical signals relating to sounds intended for the listener's attention.

23. A method according to any of claims 18 to 22, wherein the step of receiving said signals for the attention of the listener comprises receiving said signals by way of direct electrical connections.

24. A method according to any of claims 18 to 22, wherein the step of receiving said signals for the attention of the listener comprises receiving said signals through wireless communication.

25. A method according to any of claims 14 to 24, wherein the method further comprises the step of:

receiving audio signals from an audio system providing 3D-audio virtualisation.

Application No:	GB1112203.3	**Examiner:**	Rhiannon Jenkins
Claims searched:	1-14	**Date of search:**	12 August 2011

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-14	GB 2352377 A (SAGEM SA) - See the figures and pages 3 to 6

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

G10K; H04R

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
G10K	0011/178	01/01/2006
H04R	0001/10	01/01/2006