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(71) Applicant (for all designated States except US): SOUND ATTENUATORS LIMITED [GB/GB]; Eastgates, Colchester, Essex CO1 2TW (GB).

(72) Inventors: and

(75) Inventors/Applicants (for US only): CHAPLIN, George, Brian, Barrie [GB/GB]; Glebe House 31, Queens Road, Colchester (GB). SMITH, Roderick. Alan [GB/GB]; 10 The Glade, Colchester (GB). BRAMER, Terrence, Patrick, Conway [GB/GB]; 126 The Street, Capel St. Mary, Ipswich IP9 2EH, Suffolk (GB).


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(54) Title: METHOD AND APPARATUS FOR REDUCING REPETITIVE NOISE ENTERING THE EAR

(57) Abstract

Apparatus for improving the audibility of incident sound (4) to a person (3) operating in an environment where there is a substantial background noise field (2) coming from a source (1) of repetitive noise, comprises an adaptable waveform generator (7), a first electro-acoustic transducer (10) receiving a synthesised cancelling waveform from the generator (7) and generating a cancelling noise to at least partly null the background noise, a second electro-acoustic transducer (11) to sense the partially nulled background noise, and adaptive means (13) to modify the output of the generator (7) on the basis of the electrical output signal from the second transducer to minimise the nulled background noise, and means (5) to feed a triggering signal (6) derived from the source to the waveform generator. The electro-acoustic transducers (10, 11) can be mounted in a means (8) holding the transducers adjacent to an ear of said person without substantially impeding the arrival of said incident sound (4) to said ear.
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Method and apparatus for reducing repetitive noise entering the ear

Technical Field

This invention relates to an improved arrangement for the active cancellation of repetitive noise at the location of the ears of a person operating in an environment where there is at least a substantial background of such noise. The method and apparatus to which this invention relates has the advantage that because the cancellation only affects noise synchronised to the source (or sources) of the background noise, the bulk of the low frequency spectrum which is not synchronised remains unaffected, thus allowing good speech intelligibility, or improved audibility of sounds unsynchronised to the noise source, in the presence of low frequency machinery-induced noise. Thus warnings and sounds not related to the machinery will be substantially unaffected and their audibility can thus be enhanced by the method and apparatus described herein.

Background Art

British Patent Specification 1577322 discloses a method of reducing the amplitude of sound vibrations received at a selected location from a source of recurring noise which employs a waveform generator producing a synthesised waveform capable of being used to generate a cancelling sound in the location for the noise entering that location and uses a triggering signal, derived from the source, to accurately relate the generation of the cancelling sound to the noise it is wished to cancel. This prior specification (the entire disclosure of which is herein incorporated by reference) forms the basis for the present invention.

It is also known from Wheeler and Halliday's published representation (entitled "An active noise reduction
system for aircrew helmets - flight trials in strike aircraft") presented at Birkbeck College, London, on 16th February 1981, to mount an active noise reduction system in a passive ear defender to cancel the acoustic noise field detected inside an ear defender. However this known arrangement is incapable of distinguishing between components of the noise field and is thus of limited use and is not effective at all for improving the audibility of random signals appearing in a high background of repetitive noise signals.

**Brief Statements of Invention**

According to one aspect of the present invention there is provided a method of discriminating between a desired signal fed to an ear of a hearer and an interfering background noise in the hearer's ear, derived from a source of repetitive noise signals, which method comprises feeding a cancelling waveform to an acoustic transducer adjacent to the hearer's ear, and adjusting the cancelling waveform to optimise the efficiency of cancellation obtained in the hearer's ear, which method is characterised in that the noise-cancelling waveform is synchronised to the source of repetitive noise to selectively cancel that component of the sound reaching the hearer's ear which is derived from the said source.

In one embodiment, an open-backed headset is employed so that the repetitive background noise and the signal which the hearer wishes to hear are both airborne to the hearer's ear and the background noise is more strongly attenuated than the signal by an acoustic transducer carried in the headset. Normally of course separate acoustic transducers will be provided for each ear and suitably each transducer is fed with its own cancelling waveform derived from a separate waveform generator. The two generators can, however, receive common synchronising trigger signals from the noise source.
In a second embodiment, a closed-back headset is employed, the required signal being fed electrically to an acoustic transducer adjacent to the ear. Some background noise from the source of repetitive noise (particularly the lower frequency components) leaks around the seal between the headset and the wearer's head, but this can be selectively cancelled by feeding the appropriate noise cancelling waveform to the transducer with the required signal.

In a third embodiment, a headset is again employed, but here the noise signal is arriving with the required signal to the acoustic transducer in the headset. Once again an appropriate cancelling waveform synchronised with the noise is fed to the transducer to selectively eliminate the arriving noise signal and permit the hearer to more clearly discern the required non-synchronised signal.

Where there is more than one source of repetitive noise contributing to the background noise, a separate waveform generator can be synchronised respectively to each source, and the outputs from the separate generators can be fed to a common transducer for the or each ear.

According to a further aspect of the invention, apparatus for improving the audibility of incident sound to a person operating in an environment where there is a substantial background noise in the person's ear coming from a source of repetitive noise, comprises an adaptable waveform generator, a first electro-acoustic transducer receiving a synthesised cancelling waveform from the generator and generating a cancelling noise to at least partly null the background noise in the person's ear, a second electro-acoustic transducer to sense the partially nulled background noise, and adaptive means to modify the output of the generator on the basis of
the electrical output signal from the second transducer to minimise the nulled background noise, and means to feed a triggering signal derived from the source to the waveform generator, is characterised in that the electro-acoustic transducers are mounted in a means holding the transducers adjacent to an ear of said person without substantially impeding the audibility of said incident sound to said ear.

The head mounting means preferably includes two ear pieces, one for each ear of the wearer, each equipped with said first and second transducers.

The means to feed the triggering signal can be optical, ultra-sonic or electrical (e.g. by wire or inductive loop) and suitably the apparatus is portable by the person (e.g. it can be incorporated in the head-mounting means).

The waveform generator can be of the type described in the aforementioned British Patent Specification 1577322.

Brief Description of Drawings

The invention will now be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 schematically shows one form of apparatus according to the invention for reducing airborne background noise from a single source of repetitive noise in one ear of a hearer.

Figure 2 shows how the system of Figure 1 can be modified to cancel the noise from two sources of repetitive noise, and

Figure 3 shows an add-on feature to the apparatus.
of Figure 1 for improving speech transmission from a listener in an environment of high background repetitive noise.

Description of Specific Embodiments

Referring to Figure 1, a source 1 of recurring noise (e.g. an engine) generates a high background noise field 2 in an environment which includes a person 3 wishing to hear an incident sound 4 which is not related to the noise field 2.

A source of synchronising pulses 5 is associated with the source 1 and feeds triggering pulses 6 to an adaptive waveform generator 7. The source 5 can be, for example an electrical transducer associated with a toothed flywheel of an engine, and the pulses 6 can be transmitted by a wire, by an optical (e.g. infra-red) link, ultrasonically or via an inductive loop to the generator 7. The generator 7 can be of the kind described in British Patent Specification 1577322.

The person 3 wears a head-set 8 having an open earphone 9 over his right ear, which earphone 9 permits both the noise field 2 and the sound 4 to enter through it to the ear covered thereby. Within the earphone 9 is a speaker 10 and a closely adjacent microphone 11. A signal 12 from the microphone 11 is fed back to an adaptive means 13 forming a part of the generator 7. The arrangement of the components 7, 10, 11, 13 is such that the output from the generator 7 is adjusted from time-to-time to ensure that the output from the speaker 10 nulls the noise field 2 in the ear (i.e. the adaption algorithm is programmed to minimise the microphone signal from the vicinity of the earphone cavity). The means for achieving this are clearly described in the aforesaid specification and need not be further detailed here. Since the output from the generator 7 is related in time
in an appropriate way with the repetitive bursts of noise from the source 1, very high attenuation of the noise field 2 (e.g. 30 dB or better) is possible, but since the sound 4 is not so synchronised and will have a totally different frequency spectrum from the noise field 2, little attenuation of the sound 4 will normally arise with the active attenuation feedback loop 7, 10, 11, 13, so that the sound 4 passes substantially unaffected into the ear and can now be clearly heard, since the sound field 2 has been greatly reduced in the right ear of the person 3.

If only the right ear is provided with the loop 7, 10, 11, 13, the unit 14 covering the left ear can be a conventional passive ear defender which strongly attenuates both the field 2 and the sound 4. Normally however, better detection of the sound 4 is obtained if the unit 14 is also an open earphone also provided with a feedback loop like the loop 7, 10, 11, 13. The loop 7, 10, 11, 13 can be used for supplying cancelling signals to the left ear, but in practice since the sound field 2 is different in the two ears, better results are obtained with a separate feedback loop for each ear, although the two loops can be synchronised with the same trigger pulses 6.

Figure 2 illustrates a similar system to that shown in Figure 1 and similar reference numerals have been used to designate similar components. In Figure 2 a second source 1' contributes to the noise field and a second adaptive waveform generator 7' is provided triggered by pulses 6' from the source 1'. The waveforms from the generators 7 and 7' are here shown summed by an electronic summer 15 prior to being fed to the speaker 10 but an alternative method is to employ suitable software in the generator 7 and to connect the generator 7' directly to the generator 7.
In many cases it will be desirable for the person to be mobile and the active ear-defender can then be battery-powered, and mounted, for example, on a head-set or carried in a pocket. The synchronisation or triggering pulses can be transmitted to the heat-set in a variety of ways. The synchronisation system used can be common to a number of ear-defenders, e.g. in the case of a passenger-carrying vehicle or, as in the case of engine test cells, the transmission could be sufficiently localised so that the person's receiving unit would "lock on" at the most relevant local synchronisation signal.

In some cases, where the source of noise is particularly regular, it may be possible to generate the source of synchronisation by a phase-locking technique, from the acoustic or vibrational signal sensed in the acoustic or vibration field of the source of repetitive noise.

Modifications of the system shown in Figure 1 are possible. Many acoustic environments (such as a ship's engine-room) contain repetitive noise in the presence of a significant amplitude of high-frequency noise. This could be attenuated by conventional passive ear-defenders, used in conjunction with the system described herein, or with defenders which produce less pressure on the ears since the seal between the ear-defender and the head (essential for passive attenuation of low frequency) will be much less critical when augmented by an active system which is particularly effective at these lower frequencies. Alternatively, or in addition, a direct feedback method (c.f. Olsen's original work) could be combined with the system described herein, such that for example, the direct feed-back system attenuates the mid-band frequencies, the passive system operates at the highest audio frequencies, and the "repetitive" system here described operates at the lowest frequencies.
In another arrangement, an acoustic transducer in a headset may be being used to receive electrical signals which contain a desired signal superimposed on a background signal of a repetitive nature. Using the method of the invention, the background signal can be acted on by a cancelling electrical waveform so that the acoustic signal reaching the ear(s) of the headset wearer is substantially only the desired signal.

Figure 3 illustrates a further extension of the invention which would improve, for example, clear speech communication over a radio link (e.g. when using the active ear-defender shown in Figure 1 or Figure 2). Since the level of speech needed to communicate within, say the cockpit of an aircraft will be lower when the people therein are speaking to one another using the active ear-defenders, than it would be if they were not, the amplitude of the speech will be correspondingly lower, and the radio communication may be impaired because the signal 16 from a microphone 17 would be contaminated by the repetitive noise field. The signal 18 from an adaptive waveform generator 7" would then be added to the microphone signal 16, in a summer 19, the adaptive means 13" being programmed to adapt the generator 7" such that the two summed signals 16 and 18 produce a minimum of those parts of the summed signals which are synchronised to the source 1", but leave any unsynchronised (speech) signal unaffected. The output 20 from the summer 19 would then be fed to a communications system (not shown) for onward transmission.

The cancelling noise need not be generated by a conventional headphone but any transducer capable of producing sufficient power could be used. The transducer could be, for example, a loudspeaker mounted in a headrest or ducted to the vicinity of the head.
CLAIMS

1. A method of discriminating between a desired signal fed to an ear of a hearer and an interfering background noise in the hearer's ear, derived from a source of repetitive noise signals, which method comprises feeding a cancelling waveform to an acoustic transducer adjacent to the hearer's ear, and adjusting the cancelling waveform to optimise the efficiency of cancellation obtained in the hearer's ear, characterised in that the noise-cancelling waveform is synchronised to the source of repetitive noise to selectively cancel that component of the sound reaching the hearer's ear which is derived from the said source.

2. A method as claimed in claim 1, characterised in that separate acoustic transducers are provided for each ear and each transducer is fed with its own cancelling waveform derived from a separate waveform generator, the two generators receiving common synchronising trigger signals.

3. A method as claimed in claim 1 or claim 2, characterised in that the transducer is carried by a head-mounted member of the open-backed type.

4. A method as claimed in any preceding claim, characterised in that there is more than one source of repetitive noise contributing to the background noise, and a separate waveform generator synchronised respectively to each source is provided, the outputs from the separate generators being fed to a common acoustic transducer for the or each ear.

5. A method as claimed in claim 1 or claim 2, characterised in that the interfering background noise would appear as a component of the electrical signal
reaching the acoustic transducer, but is selectively nulled by said noise-cancelling waveform and therefore does not so significantly affect the output of the transducer as would otherwise be the case.

6. Apparatus for improving the audibility of incident sound to a person operating in an environment where there is a substantial background noise in the person's ear coming from a source of repetitive noise, comprising an adaptable waveform generator, a first electro-acoustic transducer receiving a synthesised cancelling waveform from the generator and generating a cancelling noise to at least partly null the background noise, a second electro-acoustic transducer to sense the partially nulled background noise in the person's ear, and adaptive means to modify the output of the generator on the basis of the electrical output signal from the second transducer to minimise the nulled background noise, and means to feed a triggering signal derived from the source to the waveform generator, characterised in that the electro-acoustic transducers are mounted in a means holding the transducers adjacent to an ear of said person without substantially impeding the audibility of said incident sound to said ear.

7. Apparatus as claimed in claim 6, characterised in that the mounting means includes two ear pieces, one for each ear of the wearer, each ear piece being equipped with said first and second transducers.

8. Apparatus as claimed in claim 6 or claim 7, characterised in that the apparatus is portable and the triggering signal is fed from the source to the apparatus by an optical, ultra-sonic or electrical link.

9. Apparatus as claimed in any of claims 6 to 8, characterised in that the waveform generator is of the
type described in British Patent 1577322.

10. Apparatus as claimed in any of claims 6 to 9, characterised in that a third electro-acoustic transducer is provided for picking up speech signals from the said person and generating an electrical output therefrom, the electrical output from said third electro-acoustic transducer being operated on by the output from said waveform generator to selectively reduce the effect of the repetitive noise coming from said source without significantly affecting the component of said output resulting from said speech signals.
INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 82/00176

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *
According to international Patent Classification (IPC) or to both National Classification and IPC

IPC**: G 01 K 11/16; A 61 F 11/02

II. FIELDS SEARCHED

Minimum Documentation Searched 4

Classification System Classification Symbols

IPC3 A 61 F; G 10 K; H 04 R

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched 4

III. DOCUMENTS CONSIDERED TO BE RELEVANT 14

Category 4 Citation of Document, 14 with indication, where appropriate, of the relevant passages 17 Relevant to Claim No. 16

X  DE, A, 2925134 (SENNHEISER ELECTRONIC KG) 8 January 1981 see page 4, last paragraph - page 7; figures 1-4 1-3,6-8

Y  FR, A, 2351466 (SOUND ATTENUATORS LIMITED) 9 December 1977 see page 5, line 1 - page 6, line 18; figures 1, 2 (cited in the application) & GB, A, 1577322 1,6,9

Y  VDI ZEITSCHRIFT, vol. 119, no. 7, April 1977 (Dusseldorf, DE) N. Hesselmann: "Aktive Lärmminderung durch Schallinterferenz im Rahmen des persönlichen Schallschutzes", pages 351-354, see page 352, left-hand column, last paragraph to the end of the article; figures 2,4,5 1-3,6-8

A  DE, A, 2401523 (HESSELMANN, NORBERT) 24 July 1975, see pages 1-3; figures 1-3 1-3,6-8

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IV. CERTIFICATION

Date of the Actual Completion of the International Search 3 5th August 1982

Date of Mailing of this International Search Report 3 23rd August 1982

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Signature of Authorized Officer 55

G.L.M. Korsenberg

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