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54 **Noise reduction device.**

57 An automatic gain active noise reduction arrangement for reducing the level of acoustic noise within the internal cavity or enclosure of an ear-defender or earphone structure, the arrangement comprises a noise pick-up microphone and a noise-cancelling transducer mounted within said cavity or enclosure, the noise pick-up microphone being adapted to produce an electrical signal output in response to an acoustic noise field within said cavity or enclosure, and phase inverter means, filtering means and amplifying means connected in a feedback control path extending between the noise pick-up microphone and the noise-cancelling transducer and effective in response to the generation of an electrical signal output by the noise pick-up microphone to produce a noise-cancelling signal output which is fed to the noise-cancelling transducer, in which the output from the noise pick-up microphone is also applied to signal processing and control means for producing an electrical output which is dependent upon the microphone output and a pre-determined non-linear control algorithm and which is applied to variable loop gain control means coupled

with the feedback control path for controlling the loop gain in accordance with a preselected parameter of the microphone output.

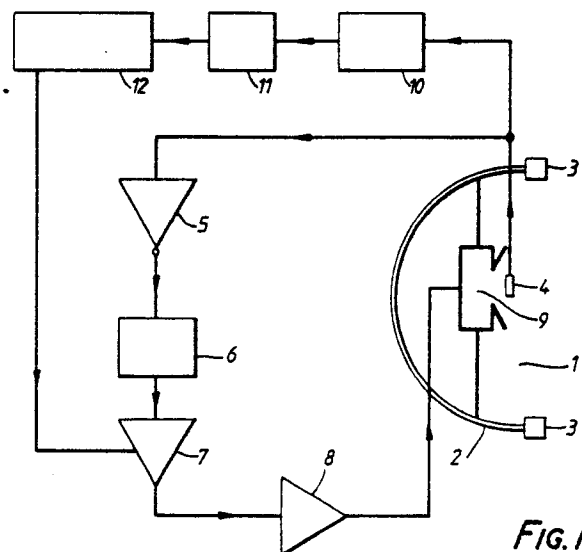


FIG. 1.

IMPROVEMENTS RELATING TO NOISE REDUCTION ARRANGEMENTS

This invention relates to arrangements for reducing the level of acoustic noise fields within the internal cavities or enclosures of so-called ear-defenders or earphone structures when being worn by personnel (e.g. pilots, vehicle drivers, industrial workers etc.) in high noise environments.

Known active noise reduction (ANR) arrangements for reducing the aforesaid acoustic noise field in ear-defenders comprise small noise pick-up microphones and noise-cancelling transducers mounted within the internal cavities or enclosures of the respective ear-defenders. The noise pick-up microphones produce electrical signal outputs in response to the acoustic noise fields within the aforesaid cavities and these signal outputs are phase inverted, filtered and amplified in a feedback loop arrangement for the production of noise-cancelling signals fed to the noise-cancelling transducers which accordingly produce noise-cancelling acoustic signals of substantially the same amplitude but of opposite phase to the acoustic noise field waveforms.

It will be appreciated that the noise pick-up microphones do not detect the incoming or ambient noise level but rather the reduced noise level within the cavities following acoustic noise reduction (ANR). It can be shown that such ANR arrangements produce a reduction in noise at a particular frequency given by:-

$(1 + 2 G \cos \theta + G^2)^{-\frac{1}{2}}$ where G is the total gain of the feedback loop arrangement and θ is the total loop phase change at the particular frequency concerned. From this expression it can readily be appreciated that the scale of noise reduction achieved is highly dependent upon the total loop gain. Due to the imperfect transfer functions of the noise pick-up microphones and noise-cancelling transducers the acoustic noise reduction arrangements will, at certain frequencies, be feeding in-phase (i.e. positive feedback) signals rather than anti-phase (i.e. negative feedback) signals to the noise-cancelling transducers. To prevent the ANR system becoming unstable the overall loop gain of the system must be kept at less than unity at the frequencies concerned otherwise the noise levels in the cavities of the earphone structures will actually be increased rather than reduced by the positive feedback signals fed to the noise-cancelling transducers. However, although the loop gain must be kept below unity at the aforesaid frequencies in order to maintain stability the loop gain of the ANR must be sufficiently high to provide the optimum acoustic noise reduction.

Fixed loop gain control techniques could be used but for changes that occur in the characteristics of components of the ANR system with the passage of time. Such fixed loop gain techniques would not provide the requisite compensation for changes in sensitivity of the noise-cancelling transducers resulting from changes in the volume of the earphone structure cavities which occur when the earphone structures are worn by different persons or from small changes in earphone structure position caused by normal movements of the wearer's head.

Automatic loop gain control techniques would be capable of providing the requisite aforesaid compensation but the conventional procedure has hitherto been to utilise only the output signal from the noise pick-up microphone of the ANR arrangement for linear feedback automatic gain control purposes.

Changes in the microphone output can result from a change in loop gain (e.g. due to earphone movement) which requires the automatic gain control arrangement to act to adjust the gain and from a change in external noise spectrum/level in which case the automatic gain control arrangement is not required to act. However, the cause of these changes in loop gain cannot be distinguished in an active noise reduction system utilising noise pick-up microphone outputs only for gain control purposes. Consequently, such simple linear feedback gain control systems are inherently unstable and cause the loop gain to oscillate continuously about the requisite value.

According to the present invention there is provided an automatic gain active noise reduction arrangement for reducing the level of acoustic noise within the internal cavity or enclosure of an ear-defender or earphone structure, the arrangement having improved stability and comprising a noise pick-up microphone and a noise-cancelling transducer mounted within said cavity or enclosure, the noise pick-up microphone being adapted to produce an electrical signal output in response to an acoustic noise field within said cavity or enclosure, and phase inverter means, filtering means and amplifying means connected in a feedback control path extending between the noise pick-up microphone and the noise-cancelling transducer and effective in response to the generation of an electrical signal output by the noise pick-up microphone to produce a noise-cancelling signal output which is fed to the noise-cancelling transducer, in which the output from the noise pick-up microphone is also applied to signal processing and control means for producing an electrical output

which is dependent upon the microphone output and a predetermined non-linear control algorithm and which is applied to variable loop gain control means coupled with the feedback control path for controlling the loop gain in accordance with a preselected parameter of the microphone output.

In carrying out the present invention which provides an active noise reduction arrangement that is stable in operation under all conditions, the control means may comprise a microprocessor which introduces a non-linear control algorithm into the loop gain in dependence upon the particular parameter of the microphone signal output that is being controlled. The choice of parameter will depend upon the intended working environment of the arrangement but in any event the control algorithm implemented by the microprocessor allows the parameter of the microphone output to vary over a finite range before any action is taken by the microprocessor to adjust the loop gain through the variable loop gain control means.

In this way stepwise (or iterative) loop gain control is provided. The signal processing means may be adapted to provide analogue processing - (e.g. filtering) of the microphone output signal followed by analogue-to-digital conversion prior to applying the digital signal to the microprocessor. Alternatively, the microprocessor itself may be arranged to perform the necessary processing of the microphone output signal.

By way of example the present invention will now be described with reference to the accompanying drawings in which:

Figure 1 shows a block schematic diagram of an earphone active noise reduction arrangement having automatic gain control according to the invention; and,

Figures 2 and 3 show, respectively, the controlling and controlled waveforms of a simple known linear feedback automatic gain control arrangement and of the non-linear automatic gain control arrangement included in Figure 1.

Referring to Figure 1 of the drawings, there is shown an earphone 1 comprising a cup-shaped housing 2 fitted around its rim with compliant material 3 which in use of the earphone cushions the housing 2 against the wearer's head. The earphone 1 is provided with an active noise reduction arrangement for reducing the overall level of noise within the earphone housing 2. This arrangement comprises a sub-miniature microphone 4 which detects the acoustic noise within the earphone housing 2 and provides an electrical output which is fed through an electrical phase inverter 5 and a filter 6 before being applied to a variable loop gain control device 7 and a power amplifier 8. The output from the power amplifier 8 is applied to a

suitably supported noise-cancelling transducer 9 - (e.g. moving-coil loudspeaker) within the earphone housing so that acoustic signals produced by the transducer 9 when the electrical output from the power amplifier 8 is applied thereto interferes destructively with the noise within the housing 2 thereby reducing substantially the level of noise within the latter. Ideally, the noise-cancelling transducer 9 produces acoustic signals of the same amplitude but of opposite phase to the acoustic noise field waveforms within the earphone housing 2.

The gain control arrangement extending from the noise detecting microphone 4 to the noise-cancelling transducer 9 but excluding the variable loop gain device 7 constitutes a close loop linear feedback automatic gain control active noise reduction arrangement.

As previously mentioned the loop gain in active noise reduction (ANR) arrangements needs to be high for the reduction of noise within the earphone cavity but should not be so high at certain frequencies at which the ANR arrangement would produce positive rather than negative feedback control signals and thereby add to the noise field within the earphone cavity.

For the purpose of providing automatic gain control of the feedback signal applied to the noise-cancelling transducer 9 the output from the microphone 4 is applied to an analogue processing device 10 (e.g. filter) the output from which is fed into an analogue-to-digital converter 11. The output from the converter 11 is then applied to a microprocessor 12 which is arranged to operate on the digital input thereto corresponding to a particular parameter of the microphone output so as to produce an output which is controlled in accordance with concerned is within a predetermined range of its desired value then no further change in the loop gain will be made unless the parameter again moves outside the desired range.

Referring to Figure 2 of the drawings, this shows two measured traces 13 and 14 which are derived from a known form of linear automatic gain control arrangement. The lower trace 13 represents a derived microphone output parameter which the control arrangement is monitoring and controlling. In the present instance the parameter concerned is the level of enhanced frequencies within the control loop. The upper trace 14 shows the loop gain. As can be seen, strong oscillation occurs in the loop gain as the control arrangement responds to changes in the parameter and vice versa thereby demonstrating the instability of the linear automatic gain control arrangement.

Referring now to figure 3, this demonstrates the action of the automatic gain control of the arrangement according to the present invention. The upper trace 15 shows the output from the control loop or the loop gain whereas the lower trace 16 shows the level of the parameter being controlled. After an initial period following activation of the control arrangement it can be seen that stable control of the control parameter is achieved. The random variation in the control parameter shown is due to the fact that the measurement was taken in the presence of external noise and on a longer time scale than in Figure 2.

Claims

1. An automatic gain active noise reduction arrangement for reducing the level of acoustic noise within the internal cavity or enclosure of an ear-defender or earphone structure, the arrangement comprising a noise pick-up microphone and a noise-cancelling transducer mounted within said cavity or enclosure, the noise pick-up microphone being adapted to produce an electrical signal output in response to an acoustic noise field within said cavity or enclosure, and phase inverter means, filtering means and amplifying means connected in a feedback control path extending between the

noise pick-up microphone and the noise-cancelling transducer and effective in response to the generation of an electrical signal output by the noise pick-up microphone to produce a noise-cancelling signal output which is fed to the noise-cancelling transducer, in which the output from the noise pick-up microphone is also applied to signal processing and control means for producing an electrical output which is dependent upon the microphone output and a predetermined non-linear control algorithm and which is applied to variable loop gain control means coupled with the feedback control path for controlling the loop gain in accordance with a preselected parameter of the microphone output.

2. An automatic gain active noise reduction arrangement as claimed in claim 1, in which the control means comprises a microprocessor which introduces a non-linear control algorithm into the loop gain in dependence upon the particular parameter of the microphone signal output that is being controlled.

3. An automatic gain active noise reduction arrangement as claimed in claim 2, in which the signal processing means is adapted to provide analogue processing (e.g. filtering) of the microphone output signal followed by analogue-to-digital conversion prior to applying the digital signal to the microprocessor.

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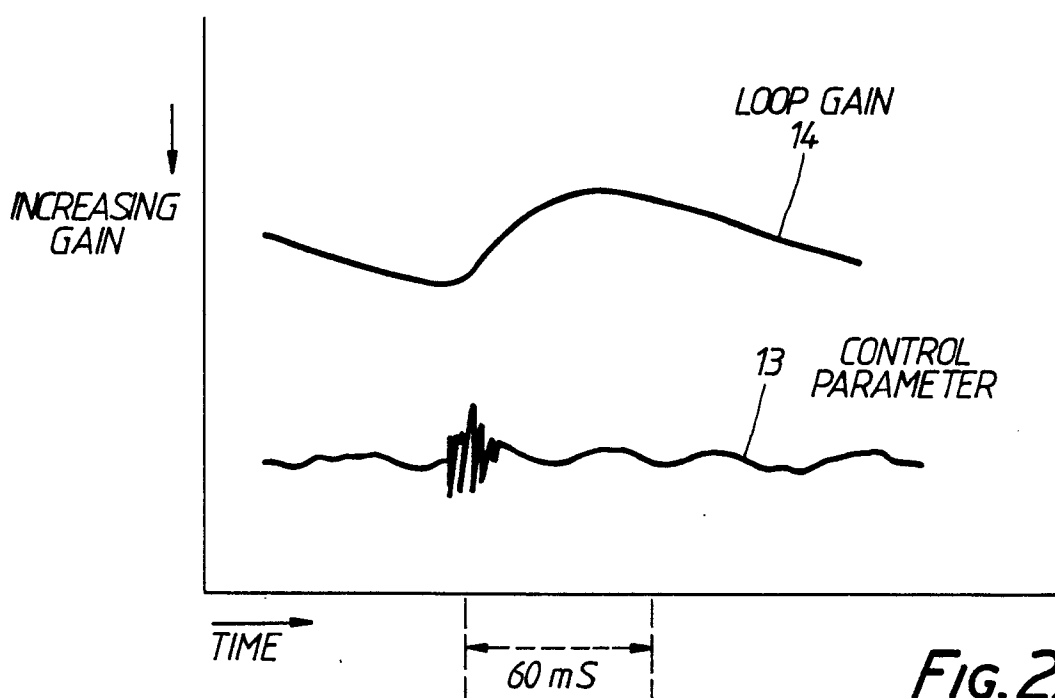
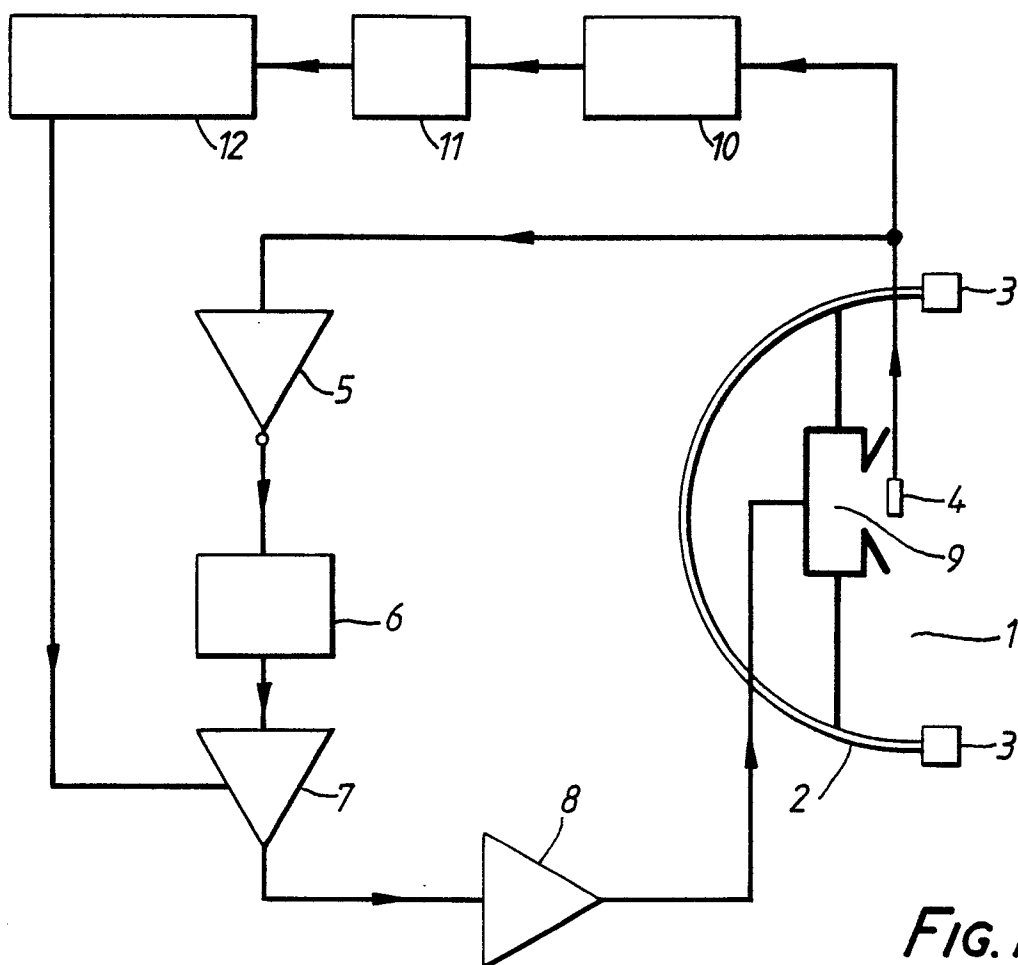
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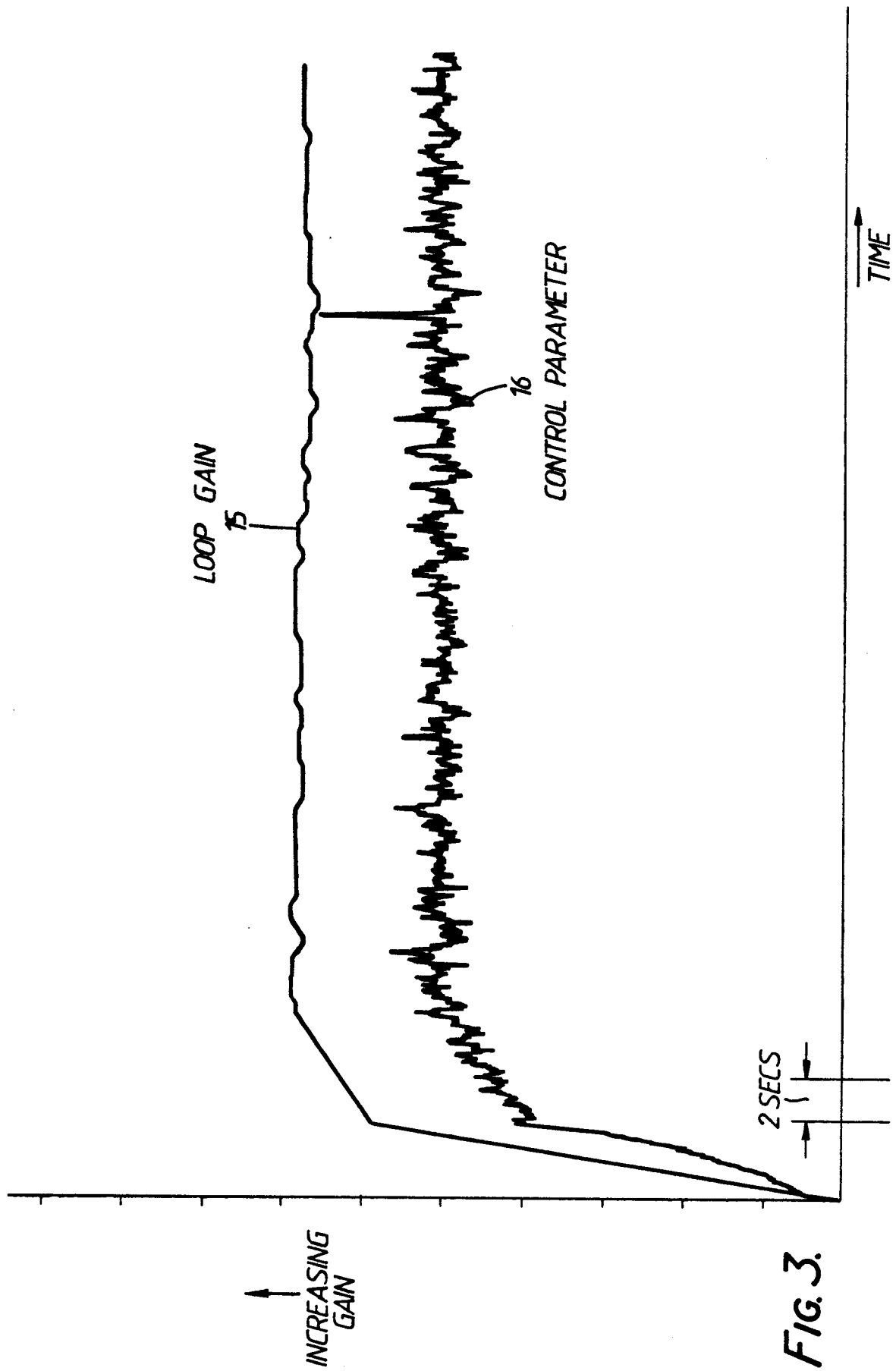


FIG. 3.