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(54) ACOUSTIC FEEDBACK SUPPRESSION

(71) We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Corporation established by Statute, of Kingsgate House, 66—74 Victoria Street, London, S.W.1, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to apparatus for acoustic feedback suppression in audio input-audio output systems particularly but not exclusively for application to hearing aids.

The phenomenon of acoustic feedback, or acoustic reaction, is familiar in the operation of public-address systems which provide an atmospheric feedback path between a loudspeaker and a microphone. At a particular instant a high level of output from the loudspeaker may be fed back along such a path so that the microphone is re-excited in the phase of the original input. The feedback path may be retraced repetitively with increasing sound intensity which prevents further communication. The same problem is encountered in the use of hearing-aids and in teaching equipment for the deaf, but is much more acute since an aid which is prone to feedback may generate dangerously high levels of sound. As a result either further injury may be caused to the ear or the aid may be discarded. The type of aid in which a moulded ear-piece is connected by flexible cable to a portable microphone/amplifier unit provides a high level of amplification for the very deaf person and is most susceptible to feedback when the moulded ear-piece becomes loose-fitting as will inevitably occur for a growing child. It is known to apply conventional automatic gain control (AGC) to such aids to maintain a uniform mean output level independent of input variation. Although the danger level is then avoided the feedback remains and communication is prevented. In the absence of feedback AGC provides an unrealistic uniformity of output which is disadvantageous in speech education for a deaf child.

In accordance with the invention there is provided apparatus for acoustic feedback suppression in an audio-input/audio output system comprising means responsive to an input signal to produce a correction signal related to the excess of the level of the input signal above a predetermined level and means operative on the output signal in response to the correction signal to cause the reinforcement of the input signal in the presence of external feedback to be reduced on the occurrence of such excess input level.

The means operative on the output signal may include means for limiting the gain of an amplifier in the system output as the excess input level increases.

Alternatively, or advantageously in combination with the preceding feature, the apparatus may include means for transposing the input signal to a higher frequency in the audio band, the means operative on the output signal comprising restoring means responsivle to the correction signal to restore the transposed signal at the output with a displacement in frequency which varies as the excess input level.

The displacement of frequency may be arranged for different conditions, to be above or below the frequency of the input signal.

The means for transposing the input signal to a higher frequency may comprise balanced modulation means, oscillator means to provide a reference frequency and filter means to isolate a sum frequency side band.

The restoring means may comprise balanced demodulation means, shift frequency oscillator means to provide a signal proportionate in frequency to the value of the correction signal and frequency mixing means to provide a reference signal to the demodulation means having a frequency equal to the sum or difference of the carrier frequency and the shift frequency.

A hearing aid may incorporate apparatus having the gain limiting and/or frequency displacement features of the invention.

It must be appreciated that the problem of acoustic feedback in hearing aids most commonly arises from severe disablement in which high levels of sound intensity at the ear-piece, probably exceeding 70 dB, must be provided. Almost inevitably conditions will then frequently arise which permit feedback to occur. Attempts have been made to limit feedback by the deliberate introduction of phase-shift between microphone and loudspeaker but it is not generally possible to take into account the natural variation in delay over a short air-path which varies with movement of the body. The approach adopted in conceiving the invention has been to allow the initial stages of feedback to occur but to suppress its development, the occurrence of an input level in excess of a predetermined value being taken as a warning that feedback may be present. In response to such a value of input two corrective actions are provided either singly or in combination.

In order to limit the output level to a safe value a first control function operates to reduce the gain of the output amplifier. Unlike the application of conventional AGC which responds to high and low level signals to give a uniform output, gain is in this case reduced in dependence on the excess of the input level above the predetermined value. The relationship may be linear or non-linear and will be chosen to give the required rate of recovery from high input levels. The control is thus inoperative when the input level shows no excess and produces a progressive reduction in gain as soon as an excess appears. Such a control function can be arranged to inhibit the build-up of oscillatory feedback but if sustained the resultant rapid changes over a wide range of amplitude may be disturbing to the user of the aid. A second control function can however be provided, normally for use with the gain control function but also capable of inhibiting feedback when used alone. The second function operates to shift the frequency of a signal at the output from that of the input, again in dependence on the excess of the input level above the predetermined value. When used with gain control the intended degree of shift is small, from 1 Hz or less for the smallest excess to a maximum of 20 or 30 Hz and the relationship can then conveniently be made linear. As a result of the frequency shift any portion of the output signal which returns via the air-path to the microphone cannot identically reinforce the original input waveform. The precise effect on a single tone signal at a given instant cannot be predicted but for a small shift there may be substantial reinforcement. For a band of frequencies however the addition of non-coincident waveforms must result in lower peak values than would otherwise have developed. If the new level still exceeds the predetermined value of input, gain control may again be applied but the required range of control will now be much less than before. It is considered that operation of the control functions is likely to be barely preceptible to the user since feedback will usually be initiated by some transitory event and the corrective action need be applied only momentarily. If sustained correction is necessary it is not expected that a shift in output frequency up to 30 Hz will interfere significantly with the quality or recognition of speech. Such a shift would however be more likely to cause perceptible distortion in much since harmonic relationships are not then preserved.

If frequency shift is used alone a range of 30 Hz is considered adequate when the signal is complex or, if a pure tone, is transient. In order to suppress a sustained pure tone a larger shift (up to say 100 Hz) should be introduced rapidly to avoid reinforcement and the shift response to the excess input level could then be made exponential.

An embodiment of the invention and its manner of operation will now be described with reference to the accompanying drawings in which:—

Figure 1 represents schematically a circuit for a hearing aid incorporating feedback control in accordance with the invention; and

Figure 2 represents schematically a circuit for the feedback control stage of Fig. 1.

Referring to Figure 1 a basic schematic circuit is shown for suppressing feedback. A microphone 2, preamplifier 4, output amplifier 6 and loudspeaker 8 are common elements of a hearing aid. The elements introduced to carry out the invention are a level sensor 10, and in series between amplifiers 4 and 6 a frequency shift unit 12 and a gain control unit 14. The unit 14 operates to control the gain of amplifier 6 and will normally be constructed integrally with it. When the level of the input signal, measured at the output of preamplifier 4, lies below a value which is predetermined for the hearing aid in use by the patient concerned no corrective response occurs. The unit 14 is inoperative and the shift unit 12 produces no net shift in output frequency although as will be described its operation depends on an internal frequency shift which is followed normally by an exactly compensating shift. As soon as the predetermined value is exceeded at the output of preamplifier 4 the level sensor 10 produces a voltage output which is proportional to the amount of the excess. The output from sensor 10 constitutes a correction signal which is applied to produce a response in gain control unit 14 and in frequency shift unit 12.

If, in a particular case, the predetermined value has been set at 80 dB and the gain of amplifier 6 is 40 dB, the maximum tolerable output level is 120 dB. When the 80 dB input level is exceeded by say 10 dB the correction signal from sensor 10 to gain control unit 14 will at some settings be insufficient to reduce the gain of amplifier 6 by a similar amount.

The tolerable output level is then temporarily exceeded until feedback is progressively reduced on successive circuits of the feedback loop. The proportionality constant which determines the magnitude of the correction signal may however be chosen so that the gain is reduced to a much lower level such that the output is immediately insufficient to cause feedback. As was indicated earlier in this specification, the tendency for large swings in amplitude to accompany feedback suppression by gain-control alone can be avoided by the use of frequency shift.

With reference to Fig. 2 an arrangement suitable for frequency shift unit 12 is shown. The signal received from preamplifier 4 is taken to a balanced modulator 20 which also receives a sinusoidal reference signal at a frequency *fr* from an audio oscillator 22. Considering a frequency component *f* of the input signal, the output from modulator 20 contains only the sum and difference frequencies fr±f and the difference term is then removed in a filter 24. Since the input signal will occupy a band of frequencies fo to fn, filter 24 provides a pass band (fr+fo) to (fr+fn) for the transposed input signal. From filter 24 the signal passes to a balanced demodulator 26, identical to modulator 20. Demodulator 26 also receives a reference signal from audio oscillator 22 via a mixer 28, and in the absence of any correction signal from level sensor 10 the transposed input signal is restored undistorted to its original frequency band at the output from demodulator 26. The signal then passes via the inoperative gain control unit 14 to the output stage. During this process mixer 28, conveniently made identical to modulator 20, receives only the input from oscillator 2. In the presence of a high input level a correction signal is supplied by level sensor 10 to a shift oscillator 30 which produces an oscillatory output at a frequency fs, the frequency varying in proportion to the correction signal voltage. The output from shift oscillator 30 now provides a second input to mixer 28 which is arranged so that the reference signal to demodulator 26 becomes the sum frequency fr+fs. The transposed signal is consequently not restored identically to its original frequency band but is displaced downwards by a frequency fs. If the resultant output signal continues to be fed back at a sufficiently high level to activate level sensor 10 then successive further downward shifts in frequency will occur until ultimately an increasing proportion of the feedback signal will fail to pass the filter 24. Rejection is assisted by the sharp lower cut-off of the filter 24 which is necessary to eliminate the unwanted components of the normal mixed signal. Feedback suppression entirely dependent on frequency shift would not however be a norml mode of operation, the combined effect of frequency shift with gain control being the preferred means.

It will be noted that the function of level sensor 10 is to produce a correction signal whenever a selected level of input signal is exceeded and that although the occurrence of an excess has been assumed in the preceding description to be symptomatic of feedback, an unusually high level of direct input will produce the same result. The level sensor can therefore be set to serve as a volume limiter in normal operation.

The choice of the frequency *fr* should also be considered in relation to the signal bandwidth fo to fn which for a hearing aid is unlikely to be broader than 10 Hz to 5 KHz. A lower limit is set by the need to separate the sidebands which, it can be shown, is satisfied if *fr* is made not less than half the sum of the bandwidth and the minimum spacing between sidebands. For the first sidebands this is simply $fr = \frac{1}{2}(fn + fo)$ or 2.55 KHz in the present example and for the highest quality audio system, *fr* need not exceed 7.5 KHz.

If frequency shift is used alone as the feedback suppression means it is advantageous, as described with reference to Fig. 2, that the shift should be downwards so that cut-off by filter 24 ultimately occurs. When gain control is used in combination with frequency shift suppression will usually be completed without resort to filtering and the direction of shift may equally suitably be upward. For this purpose the difference frequency fr−fs, instead of the sum frequency, would be derived from mixer 28.

The functions illustrated in Fig. 2 may be performed by any of the means well known in the art. However the restriction on the power supply in a compact hearing aid to a battery of 1.5 volts makes necessary the use of devices such as Schottky diodes in which the forward volt drop is likely to be less than 0.5 v. It is envisaged that on a production scale integrated circuit techniques would be employed to miniaturise either a complete hearing-air incorporating the feedback-control units or the feedback-control stage only in a form suitable for incorporation in existing aids.

The main problem to which the invention is directed is the occurrence of feedback in high gain for the severely deaf. For those of lesser disability using aids of lower gain the invention now makes available the possibility that the ear-piece need not be moulded but may be held near the ear without the normally attendant risk of oscillation. Similarly, feedback supporession can be applied to teaching aids for the deaf in which a feedback path may exist between the instructor's microphone and the student's earphone. Among applications which do not involve a hearing disability are conventional public-address systems and 'walkie-talkie' or field-radio links when used in the full duplex mode (i.e. with transmit-receive channels open simultaneously).

WHAT WE CLAIM IS:—

1. Apparatus for acoustic feedback suppression in an audio-input/audio-output system comprising means responsive to an input signal to produce a correction signal related to the excess of the level of the input signal above a predetermined level and means operative on the output signal in response to the correction signal to cause the reinforcement of the input signal in the presence of external feedback to be reduced on the occurrence of such excess input level.

2. Apparatus according to Claim 1 in which the means operative on the output signal includes means for limiting the gain of an amplifier in the system output.

3. Apparatus according to Claim 1 or Claim 2 including means for transposing the input signal to a higher frequency in the audio band, the means operative on the output signal comprising restoring means responsive to the correction signal to restore the transposed signal at the output with a displacement in frequency which varies as the excess input level.

4. Apparatus according to Claim 3 in which displacement of the frequency of the restored signal is caused to be below the frequency of the input signal.

5. Apparatus according to Claim 3 in which displacement of the frequency of the restored signal is caused to be above the frequency of the input signal.

6. Apparatus according to any of Claims 3 to 5 in which the response of the restoring means to the correction signal is such as to cause the displacement in frequency to vary linearly with the excess input level.

7. Apparatus according to any of Claims 3 to 5 in which the response of the restoring means to the correction signal is such as to cause the displacement in frequency to vary exponentially with the excess input level.

8. Apparatus according to any of Claims 3 to 7 in which the means for transposing the input signal comprises balanced modulator means, oscillator means to provide a first reference frequency for input to the modulator means and filter means to isolate a sum frequency side-band from the output of the modulator means.

9. Apparatus according to Claim 8 in which the restoring means comprises balanced demodulation means, oscillator means to provide a shift frequency related to the value of the correction signal and frequency mixing means to provide a second reference frequency for input to the demodulation means having a value equal to the sum or difference of the first reference frequency and the shift frequency.

10. Apparatus substantially as hereinbefore described with reference to and as shown in Figures 1 and 2 of the accompanying drawings.

11. A hearing aid incorporating apparatus according to any of Claims 1 to 10.

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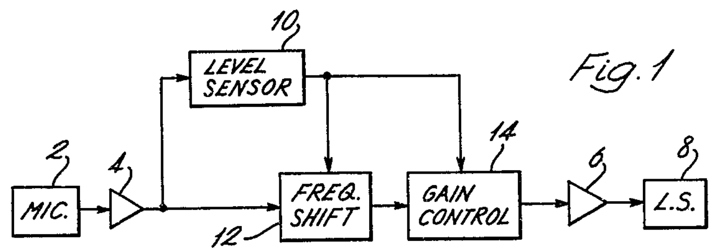
LEVEL SENSOR
10
MIC.
2
4
FREQ. SHIFT
12
GAIN CONTROL
14
6
L.S.
8

Fig. 1

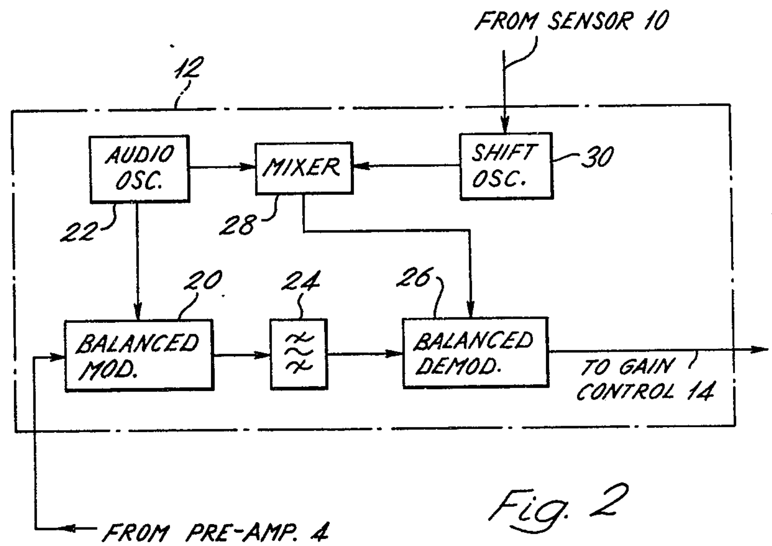
FROM SENSOR 10
12
AUDIO OSC.
22
MIXER
28
SHIFT OSC.
30
20
24
26
BALANCED MOD.
BALANCED DEMOD.
TO GAIN CONTROL 14
FROM PRE-AMP. 4

Fig. 2