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ELECTRONIC CANCELLATION OF AMBIENT NOISE IN TELEPHONE RECEIVERS

BACKGROUND OF THE INVENTION

- Telephone receivers in headsets or handsets frequently must function in
- 5 locations where the ambient noise level is high enough to substantially reduce intelligibility of the incoming signal. To overcome the ambient noise, some prior art headsets incorporate a microphone which tracks the ambient noise signal and an active circuit which uses the microphone output to generate and deliver a noise cancelling signal to the receiver.
- 10 These circuits of the prior art usually are effective in reducing undesired acoustic energy in the frequency band from about 20 Hz to 700 Hz. This range of noise cancellation is not, however, wide enough to effectively cancel higher frequency unwanted noise, which in many noisy locations is the predominant cause of the loss of intelligibility.
- 15 Further, in known noise cancelling circuits of prior art sets, the incoming speech signal typically is fed directly to the noise cancellation circuit. The direct feed design can degrade the incoming signal, however, which defeats the objective of improving the incoming speech intelligibility. Additionally, many prior art ambient noise-reducing circuits have a tendency under some conditions to
- 20 oscillate, with the result that the set is momentarily disabled altogether.

SUMMARY OF THE INVENTION

The invention is a circuit design as described in claim 1.

BRIEF DESCRIPTION OF THE DRAWING

- FIG. 1 is a block diagram of the overall noise cancelling circuit;
- 25 FIG. 2 is a graph of a particular speaker-to-error microphone transfer function;
- FIG. 3 is a functional descriptive diagram of the compensation circuit;
- FIG. 4 is a graph of an exemplary handset compensation circuit
- response;
- 30 FIG. 5 is a graph of speaker-to-error microphone transfer function with compensation;

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FIG. 6 is a graph of active noise cancellation performance for a particular exemplary individual;

FIG. 7 is a graph illustrating headset speaker-to-error microphone transfer function;

5 FIG. 8 is a graph illustrating compensation circuit response for an exemplary headset;

FIG. 9 is a graph illustrating for the headset application a speaker-to-error microphone transfer function for a circuit with compensation;

10 FIG. 10 is a graph showing a CCITT-recommended telephone receiver frequency response;

FIG. 11 is a graph illustrating pre-conditioning circuit response for a handset;

FIG. 12 is a graph showing typical handset receive response for a circuit with pre-conditioning;

15 FIG. 13 is a graph illustrating pre-conditioning circuit response for a headset;

FIG. 14 is a graph showing typical headset receive response for a circuit with pre-conditioning; and

FIG. 15 is an oscillation prevention circuit block diagram.

20 DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

The noise cancellation circuit is shown in FIG. 1 connected to a speaker 11 of a handset or headset denoted 12 which contains an error microphone 13. Incoming voice signal from, for example, a telephone line is branched to voice pre-conditioning circuit 14 which provides a dual mode function controlled by switch 10. 25 When the noise cancellation is "off," the incoming voice signal is passed through pre-conditioning circuit 9 to speaker 11. With noise cancellation "on," the incoming voice is pre-conditioned in circuit 15 and passed to summer 16 where it is combined with the signal from error microphone 13 routed through gain circuit 17. Output from summer 16 is fed to compensation circuit 18. Output from circuit 18 is fed 30 through gain control 23 to speaker 11. A tap off the output of gain control 23 is connected to oscillation prevention circuit 19. Output of circuit 19 is a gain control signal to compensation circuit 18. The novel and advantageous features of the functions provided by the foregoing circuit configuration will now be discussed.

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FIG. 2 show an exemplary speaker-to-error microphone transfer function of a particular telephone hand set which does not have compensation. The transfer function illustrated in FIG. 2 presents several problems which the compensation circuit of the present invention overcomes by (1) flattening the transfer function gain in the 100 Hz to 1000 Hz frequency band thereby providing a more uniform cancellation response in this frequency range; (2) by providing attenuation at frequencies above 2 kHz, thereby increasing gain margin which results in stable operation under a wide range of conditions and reducing enhancement of noise in this frequency region; and (3) by adding positive phase in the 1000 Hz to 4000 Hz frequency band, thereby increasing phase margin in this region to allow for transfer function variations due to different users. The result is stable feedback operation over the relevant cancellation bandwidth.. High gain at low frequencies, attenuation at high frequencies and sufficient phase margin are combined to accommodate wide variations in the user characteristics.

These improvements may be obtained using the circuit of FIG. 3 which shows compensation circuit 18 in further functional detail as including a gain and phase equalization stage 20 and a high frequency rolloff and cancellation gain stage 21. The compensation circuit 18 may include a second order stage for low frequency gain and high frequency rolloff practices in the prior art. Additionally, however, stages are included to equalize the transfer function by increasing the gain at low frequencies and adding positive phase in the 1000 Hz to 4000 Hz band. This relationship is illustrated in FIG. 4.

Most troublesome ambient noise sources have predominant frequency content below 1000 Hz. These low frequency noises have a much greater effect on speech intelligibility than high frequency noise, due to an upward frequency masking phenomenon. The cancellation of noise in the 100 Hz to 1000 Hz band in accordance with the invention, illustrated in FIG. 6, eliminates the masking effect at higher frequencies.

Noise cancellation systems of the prior art that use feedback unfortunately tend to enhance noise at frequencies above the point where cancellation reduces to 0 dB. The increased phase margin at these frequencies, as illustrated by a comparison of FIGS. 2 and 5, reduces the level of noise enhancement.

A specific embodiment of the invention useful with telephone handsets may include a fifth order compensation circuit. By way of example, the frequency response of such a circuit is illustrated in FIG. 4. In the fifth order circuit, a third

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order stage may be used to equalize the transfer function and smooth the gain, and a second order stage may be used to apply low frequency gain and rolloff at high frequencies to the equalized transfer functions. The speaker-to-error transfer function with compensation is shown in FIG. 5. Comparison of FIG. 5 to the
5 uncompensated transfer function in FIG. 2 shows that the phase in the 1000 Hz to 1500 Hz region is more positive by 30 to 40 degrees for improved phase margin. In addition, the gain at higher frequencies is relatively less with the result that at frequencies above 2000 Hz the gain is at least 10 dB less than the gain at frequencies below 2000 Hz. The gain margin therefore will be greater than 10 dB for a noise
10 cancelling handset that provides cancellation at frequencies up to 1200 Hz. The cancellation performance for a typical handset with compensation is illustrated in FIG. 6.

A further specific embodiment of the compensation circuit useful with telephone headsets is next illustrated. An exemplary headset speaker-to-error
15 microphone transfer function without compensation is illustrated in FIG. 7. For the case of the headset, a sixth order compensation circuit advantageously may be used. The response of this latter circuit is illustrated in FIG. 8. In the sixth order circuit, a fourth order stage may also be used to provide gain smoothing and phase advance. A second order stage may also be used to provide the high frequency rolloff. The
20 speaker-to-error microphone transfer function with compensation is shown in FIG 9. A comparison of the uncompensated and compensated transfer functions show that the compensation circuit gain smoothing improves the gain below 300 Hz, thereby to increase cancellation. Further, the compensation circuit has provided high frequency rolloff and greater than 50 degrees of phase margin in the 1000 Hz to 1500 Hz
25 region, thereby to increase stability margin.

Voice intelligibility and quality may be improved if the incoming voice signal is pre-conditioned, or frequency shaped. Amplification of the incoming voice signal is effected over substantially the same frequency range within which the noise cancellation circuit operates. Referring again to FIG. 1, the incoming speech signal
30 is pre-conditioned by circuit 15 when noise cancellation is active and by circuit 9 when noise cancellation is not active. This shaping is compensated for by a pre-conditioning filter shown in FIG. 1. Specifically, the pre-conditioning produces a frequency response for the voice signal that approximates the ideal telephone receiver characteristics specified by the accepted CCITT standard shown in FIG. 10.

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The pre-conditioning responses advantageous for a noise cancellation handset are shown in FIG. 11. The transfer function from speech input to the entrance of a user's ear canal, with pre-conditioning, is shown in FIG. 12 for noise cancellation for the active and inactive cases. It is seen that both curves approximate
5 the desired telephone receiver ideal response of FIG. 10.

The pre-conditioning responses advantageous for a noise cancellation headset are shown in FIG. 13. The transfer function from speech input to the entrance of a user's ear canal with pre-conditioning is shown in FIG. 14 for noise cancellation for the active and inactive cases. Again, both curves approximate the
10 desired telephone receiver ideal response shown in FIG. 10.

The result is an improvement over prior art noise cancellation circuits in which the voice signal is merely added to the cancellation signal and filtered to produce a flat frequency response. With the new method, the voice quality is improved to telephonic applications as evidenced by the closeness of the receive
15 response to the ideal CCITT receiver characteristics.

Instabilities in a noise cancelling circuit used with a telephone handset, or that arise because of the wide range of different positions the earpiece might be placed in relation to the ear, may be substantially reduced. Some positions of the instrument on a user's ear will change overall feedback gain in the circuit of FIG. 1
20 and cause oscillations at frequencies where the phase produces positive feedback. An oscillation-prevention diagram is shown in FIG. 15 wherein functions performed and numerical callouts correspond to those of FIG. 1. Gain control 23 is fixed for purposes of providing normal noise cancellation. High-pass filter 24 passes energy of the speaker 11 input circuit at the frequencies where oscillation can occur. An
25 energy measuring circuit 22 continuously measures the output of filter 24. Summer 25 compares this output to a preset threshold value for the particular receiver.

When the detected energy exceeds the threshold, the gain control 23 located in the control feedback signal path to speaker 11 is reduced for a duration of about 1-2 seconds. Thereafter, the gain in gain control 23 is returned to its set value.
30 The oscillation prevention circuit provides for fast reduction of the feedback loop gain during transient unstable conditions, and automatic restoration of the feedback loop gain when the condition passes. The circuit is useful in both noise cancelling headset and handset applications.

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Claims:

1. An ambient noise reducing electronic receiving instrument comprising a speaker receiver(11,)an incoming signal path to said receiver, an error microphone (13)disposed at said receiver for generating an ambient noise signal, and a noise
5 cancelling circuit for inverting said ambient noise signal and feeding same into said incoming signal path, characterized in that:
said noise cancelling circuit comprises a circuit(18)for compensating the speaker-to-microphone transfer function comprising means for flattening the gain of said transfer function in a frequency band of substantially from 100 Hz to 1000 Hz,
10 thereby to increase substantially the cancellation response in said named frequency range.
2. Apparatus in accordance with claim 1 wherein said compensating circuit(18)further comprises:
means for attenuating said gain at frequencies above substantially 2
15 kHz, thereby to increase gain margin.
3. Apparatus in accordance with claim 2 wherein said compensating circuit further comprises means for equalizing the phase of said speaker-to-microphone transfer function in the 1000 Hz to 4000 Hz frequency band, said equalizing means comprising:
20 means for adding positive phase; and
means for increasing phase margin.
4. Apparatus in accordance with claims 1, 2, or 3 further comprising;
an incoming signal pre-conditioning circuit(14)comprising means in the circuit path to said speaker for frequency shaping said incoming signal over
25 substantially the same frequency range within whcih said noise cancellation circuit operates.
5. Apparatus in accordance with claim 4 further comprising an oscillation prevention circuit(19)comprising:
threshold circuit means(24, 22)for measuring energy level input to said
30 speaker in a selected frequency range against a preselected threshold; and

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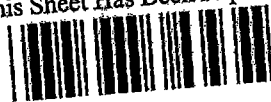


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means(25, 23)responsive to the reaching of said threshold value for momentarily reducing gain of said noise cancellation feedback circuit and thereafter for restoring said gain.

6. Apparatus in accordance with claim 5, wherein said compensation
- 5 circuit(18)further comprises:
- a gain and phase equalization stage(20) and
 - a high frequency rolloff and cancellation gain stage(21.)

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