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Graupe et al.

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[54] METHOD AND MEANS FOR ADAPTIVELY FILTERING NEAR-STATIONARY NOISE FROM AN INFORMATION BEARING SIGNAL

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[21] Appl. No.: **866,938**

[22] Filed: **Jan. 4, 1978**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 707,569, Jul. 21, 1976, abandoned, which is a continuation-in-part of Ser. No. 683,234, May 4, 1976, Pat. No. 4,025,721.

[51] **Int. Cl.**[2] **H04R 27/00**

[52] **U.S. Cl.** ..... **179/1 P**; 179/1 SC

[58] **Field of Search** ..... 179/1 P, 1 D

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,803,357	4/1974	Sachs	179/1 P
4,025,721	5/1977	Graupe et al.	179/1 P

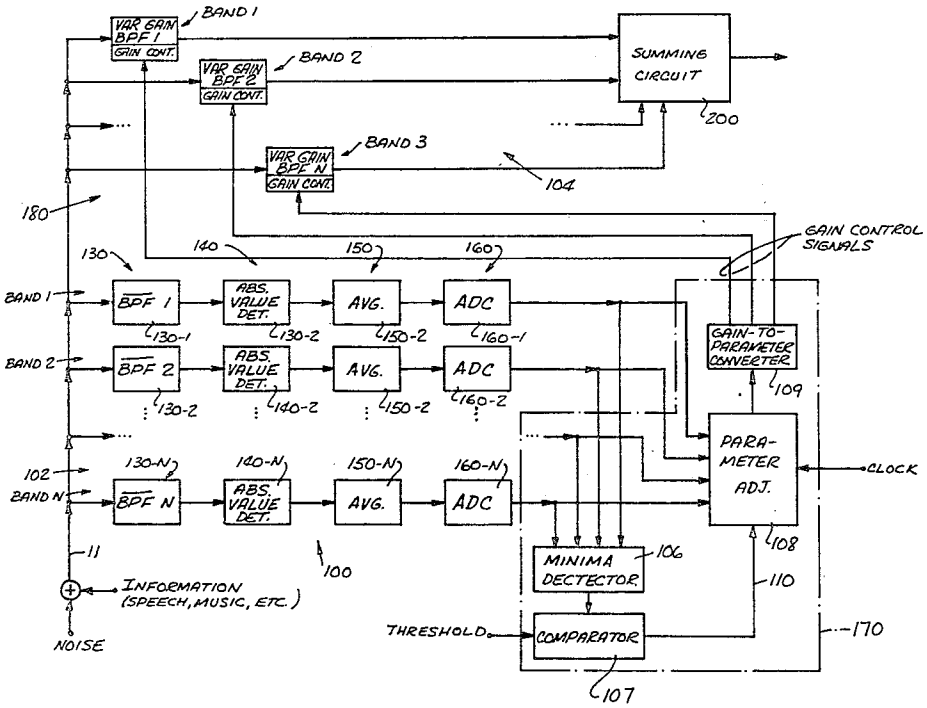
Primary Examiner—Kathleen H. Claffy
Assistant Examiner—E. S. Kemeny
Attorney, Agent, or Firm—Sandler & Greenblum

[57] **ABSTRACT**

An input signal containing information such as speech or music as well as near-stationary noise is applied in parallel to a noise-analysis circuit and a noise-reduction circuit, each of which comprises a plurality of bandpass filters covering the range of frequencies associated with the information. The absolute value, or a function thereof, of the output of each bandpass filter in the noise-analysis circuit is produced and smoothed. The presence of near-stationary noise in the input signal is determined by examining the nature of the smoothed signal in each band assuming noise has a frequency spectrum which does not vary with time or varies only within a narrow range over a predetermined period of time with respect to the spectral parameters of the information signal. If noise is detected, the noise-analysis circuit identifies spectral parameters of the information and/or noise in each band using the smoothed signal therein.

In the preferred embodiment of the invention, the bandpass filters of the noise-reduction circuit have gain elements that are adjusted in accordance with the identified parameters to minimize, under some continuous minimization criterion, the effect of the noise in the input signal thus enhancing intelligibility of the information therein. Minimization can be such that the gain-to-parameter relationships are similar to those in Weiner or Kalman filtering theory with a-priori knowledge of the noise, or of the noise and information, except that in this case, a-priori knowledge of the noise is acquired via identification and is not preassumed.

27 Claims, 8 Drawing Figures



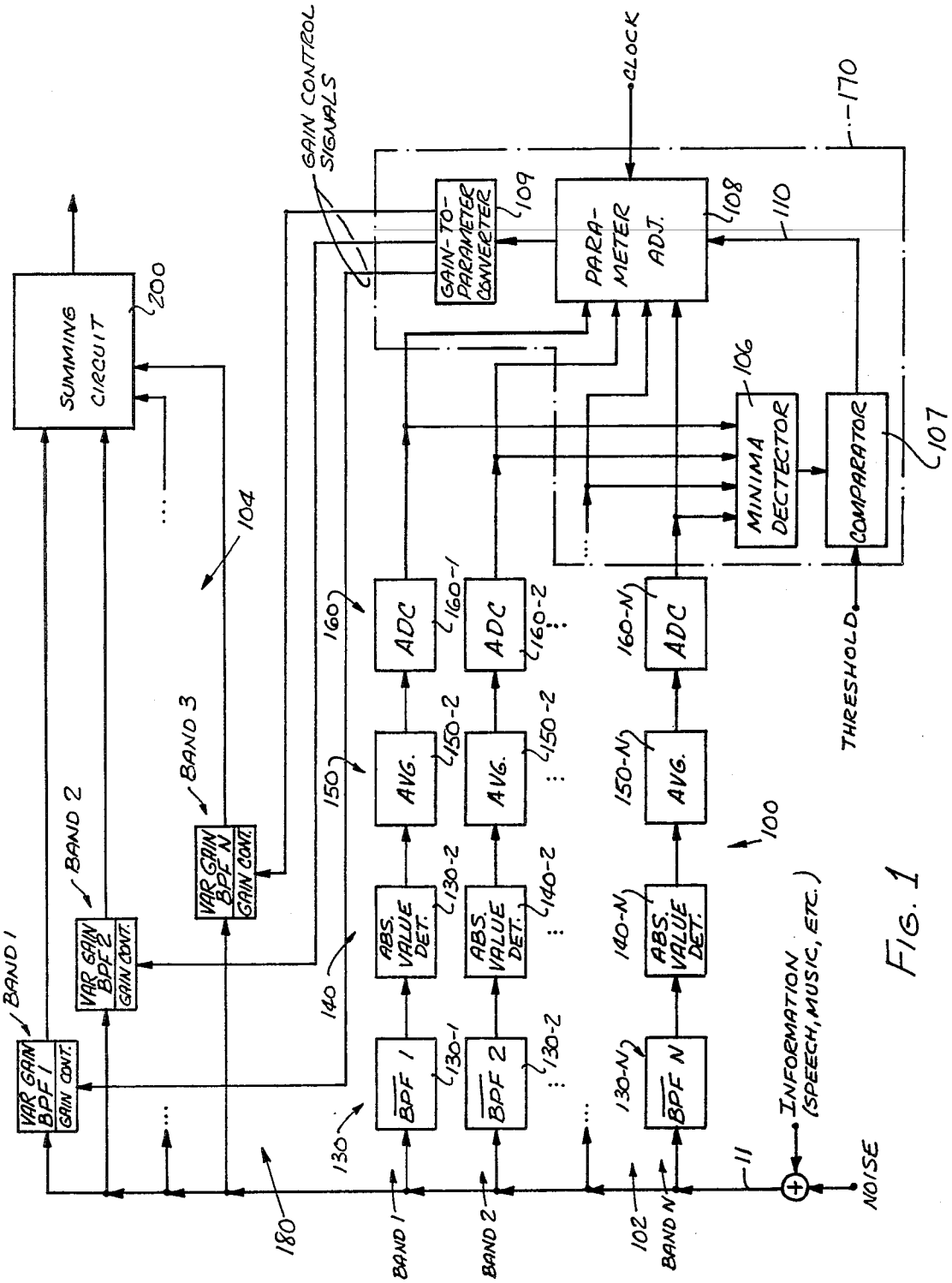


FIG. 1

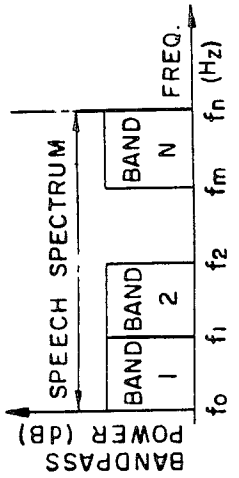


FIG. 2

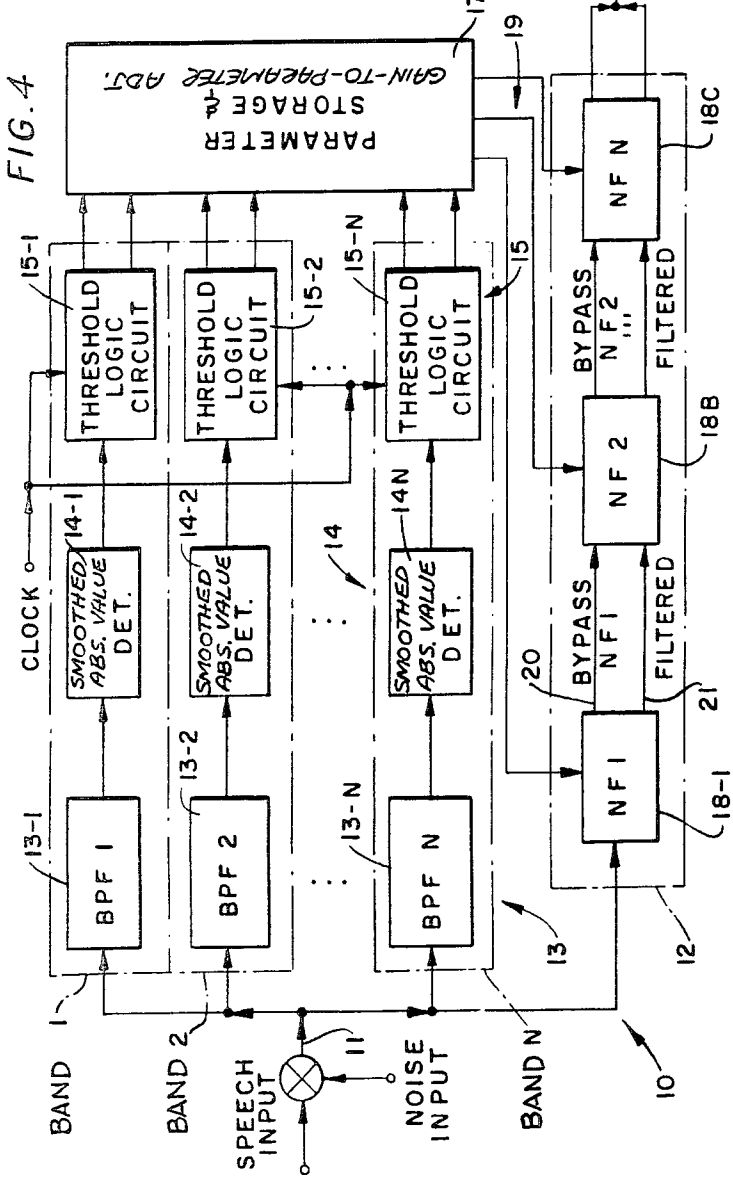


FIG. 4

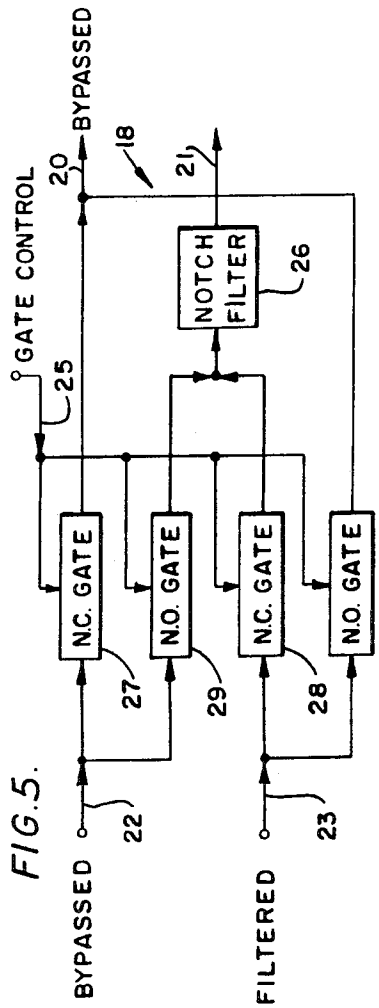


FIG. 5.

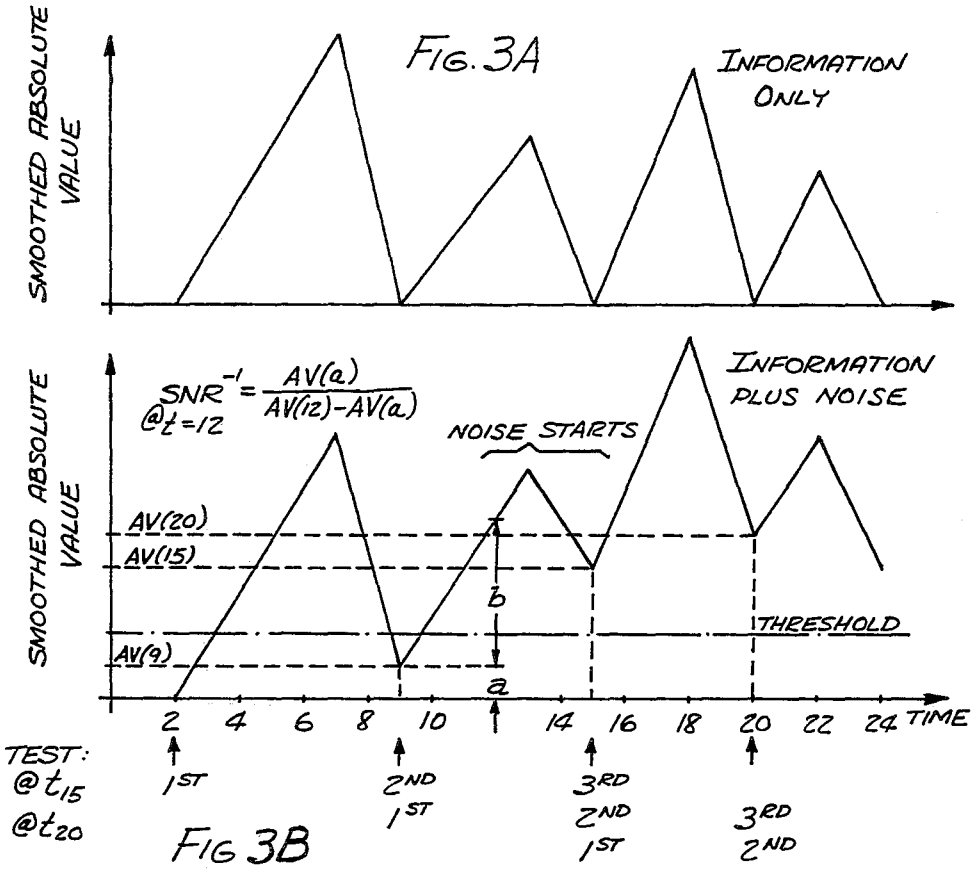


FIG 3A

FIG 3B

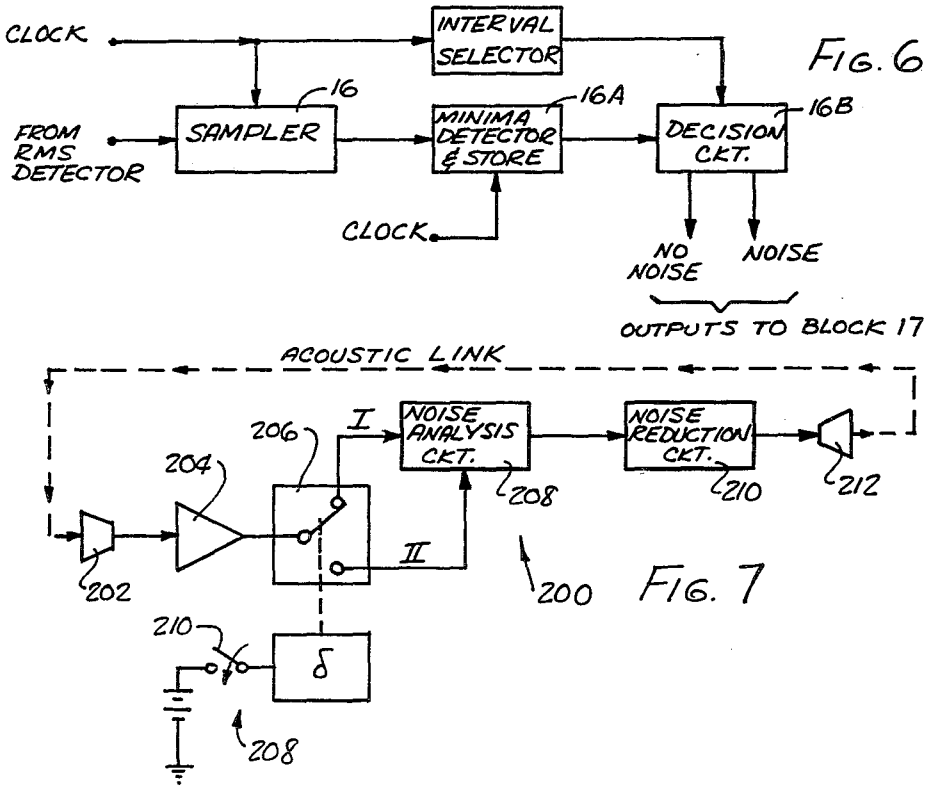


FIG. 6

FIG. 7

METHOD AND MEANS FOR ADAPTIVELY FILTERING NEAR-STATIONARY NOISE FROM AN INFORMATION BEARING SIGNAL

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of copending application Ser. No. 707,569, filed July 21, 1976, now abandoned, which application is hereby incorporated by reference. The last mentioned application is, itself, a continuation-in-part of application Ser. No. 683,234, filed May 4, 1976, now U.S. Pat. No. 4,025,721, which patent is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

The invention relates to a method of and means for filtering near-stationary, relatively long duration noise from an input signal containing information such as speech or music.

For the purpose of the present application, the term "near-stationary, relatively long duration noise", is hereinafter referred to as noise of the type described, and refers to noise whose frequency spectrum does not vary with time or varies only within a narrow range over a predetermined period of time particularly with respect to the spectral parameters of the information. Vehicular and machinery noises are examples of noise of the type described. The minimum duration of noise of the type described is thus considerably longer than periods over which the spectrum of normal speech remains nearly fixed, such periods being of the order of a second. In addition, the invention is described below as being applied to filtering noise of the type described from speech, but the invention is also applicable to other information bearing signals.

U.S. Pat. No. 4,025,721 discloses a method of and means for adaptively filtering noise of the type described from speech by recognizing the existence of such noise, identifying its parameters, adjusting the parameters of a filter so as to filter such noise, and applying an input signal containing such noise and speech to the filter. Termination of the noise of the type described is also recognized in order to cause the input signal to then bypass the filter.

Basic to the disclosure of the above identified patent is the necessity for recognition, in an input signal, of pauses between speech intervals. When a pause containing noise of the type described is recognized, the parameters of the noise within the pause are identified and used to adjust the parameters of the filter. Subsequently, the input signal is applied to the filter which is effective to filter the noise from subsequent speech intervals.

SUMMARY OF THE INVENTION

In the present invention, neither recognition of pauses between speech intervals, nor recognition of noise termination, is required; and the hardware for carrying out the present invention is extremely simple and fast. Briefly, identification is performed in the frequency domain alone allowing a spectral filter to be used to achieve the desired filtering of the noise of the type described.

An input signal containing noise of the type described and information, such as speech or music, is applied in parallel to a noise-analysis circuit that includes a plurality of bandpass filters covering the range of frequencies associated with the information. The absolute value, or a function thereof (e.g., the RMS value) of the signal in each band is obtained and smoothed, preferably by computing a running average of the absolute value in the band. In one technique, noise is assumed to be present in the input signal if a threshold is exceeded by all or by a predetermined percentage of successive minima of the smoothed signal in a band. Alternatively, the smoothed signal in each band can be sampled to enable the inverse signal-to-noise ratio (SNR^{-1}) to be computed, the presence of noise being assumed if an SNR^{-1} in a band exceeds a threshold. The SNR^{-1} in a sampling interval is computed by taking the ratio of the latest stored lowest minimum of the smoothed signal in a band to the difference between the sampled value of the smoothed signal and such minimum.

If the noise-analysis circuit detects the presence of noise in accordance with the above tests, spectral parameters of the noise, or of the noise and information are then identified by the circuit and used to control the operation of a noise-reduction circuit to which the input signal is also applied. The last mentioned circuit comprises a plurality of bandpass filters having a one-to-one correspondence with the bandpass filters of the noise-analysis circuit. Each of the bandpass filters of the noise-reduction circuit is responsive to a parameter identified from the smoothed signal in the corresponding band of the noise-analysis circuit for minimizing the effect of noise in the input signal on the output of the noise-reduction circuit, minimization occuring under some continuous minimization criterion.

The noise-analysis circuit can identify either noise parameters, or noise and information parameters in a band by utilizing the smoothed signal in the band. A parameter of the noise alone in a band can be in the form of a predetermined function of the lowest one of a predetermined number of successive minima of the smoothed signal in the band. Alternatively, the noise parameter can be in the form of a predetermined function of a more recent minimum of a succession of minima if such recent minimum does not exceed the previous lower minimum by more than a given percentage (e.g., 25%).

On the other hand, a parameter of the noise and information in a band can be in the form of a predetermined function of the signal-to-noise ratio (SNR) in the band. The SNR in a band is the difference between samples of the smoothed signal in the band and the most recently accepted noise-related minimum of a time-sequence of minima of the smoothed signal. The function's referred to above may be continuous functions of the variables to yield either spectral parameters or their time domain equivalents.

In the preferred form of the invention, the bandpass filters of the noise-reduction circuit have gain elements controlled by the parameters identified by the noise-analysis circuit. When noise parameters alone are identified, the gain-to-parameter relationship necessary to minimize noise may be similar to or approximate a Wiener filter with a-priori knowledge of noise as described in Chapter 8.6 of "Foundations of the Theory of Learning Systems" by Y. Tsypkin, Academic Press, New York (1973). In such case, a-priori knowledge of the noise is obtained via the identification process referred above and is not preassumed.

When both noise and information parameters are identified, the gain adjustment of a bandpass filter will be according to the signal-to-noise ratio in the bandpass

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